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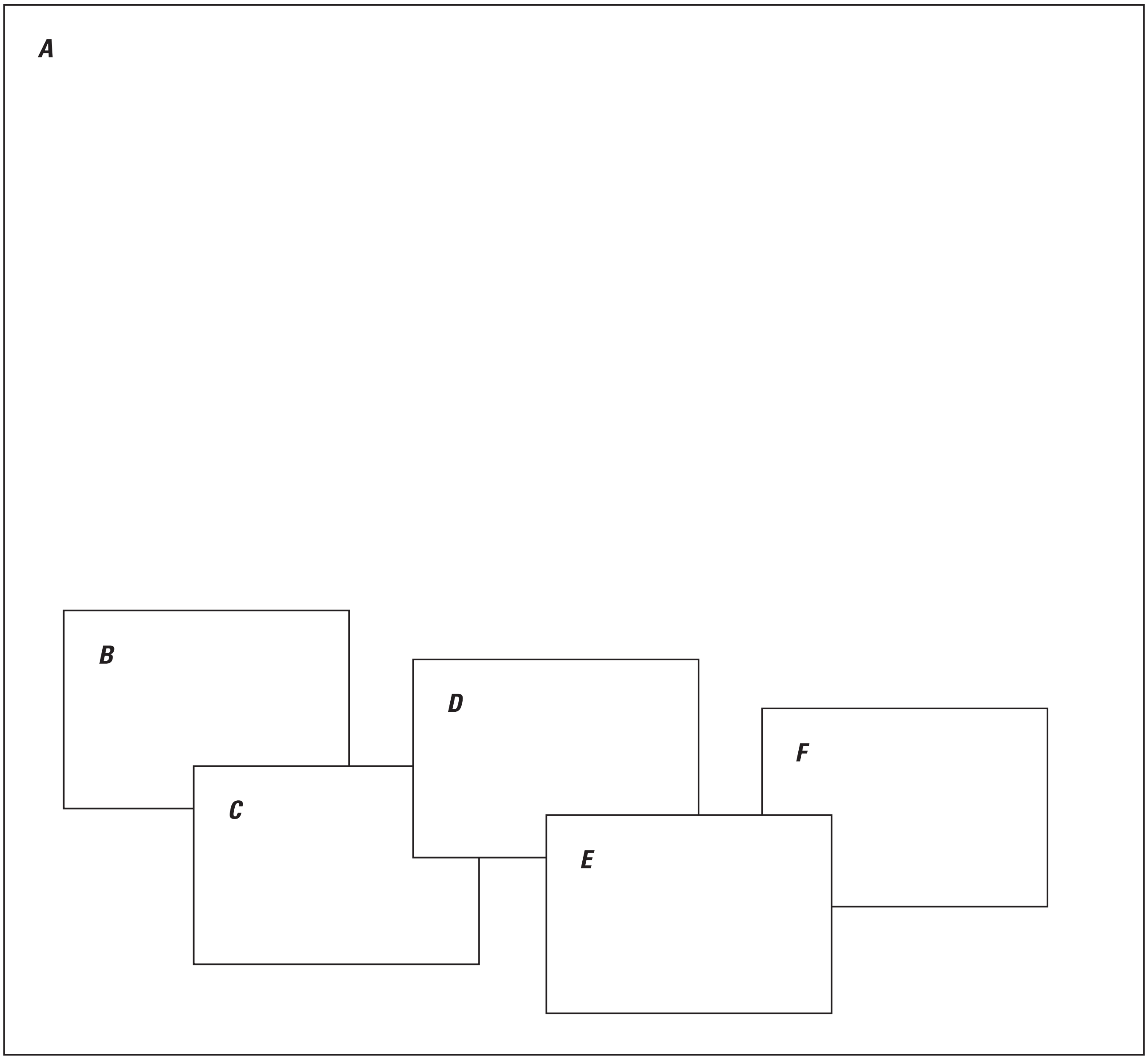
Availability, Sustainability, and Suitability of Ground Water, Rogers Mesa, Delta County, Colorado—Types of Analyses and Data for Use in Subdivision Water-Supply Reports

Scientific Investigations Report 2008–5020

U.S. Department of the Interior
U.S. Geological Survey



Front cover photographs: ***A***, East side of Rogers Mesa showing contact between Mancos Shale and alluvium; ***B***, Riverside Cemetary entrance with flowing springs on either side of gate; ***C***, wetlands; ***D***, irrigated field; ***E***, mule deer; and ***F***, pond. Photographs by Judith C. Thomas, U.S. Geological Survey.

Back cover photograph: Aerial photograph of Rogers Mesa, Colorado. Photograph courtesy of Dave Rice, Delta County Planning and Community Development.

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U.S. Geological Survey
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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
section (640 acres or 1 square mile)	259.0	square hectometer (hm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Specific capacity	
cubic foot per day per foot [(ft^3/d)/ft]	0.09290	cubic meter per day per meter [(m^3/d)/m]
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s)/m]
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per day (ft/d)	3.528	micrometer per second (µm/s)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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

$$°F=(1.8×°C)+32$$

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 the North American Vertical Datum of 1988 (NAVD 88).

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

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

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Availability, Sustainability, and Suitability of Ground Water, Rogers Mesa, Delta County, Colorado—Types of Analyses and Data for Use in Subdivision Water-Supply Reports

By Kenneth R. Watts

Abstract

The population of Delta County, Colorado, like that in much of the Western United States, is forecast to increase substantially in the next few decades. A substantial portion of the increased population likely will reside in rural subdivisions and use residential wells for domestic water supplies. In Colorado, a subdivision developer is required to submit a water-supply plan through the county for approval by the Colorado Division of Water Resources. If the water supply is to be provided by wells, the water-supply plan must include a water-supply report. The water-supply report demonstrates the availability, sustainability, and suitability of the water supply for the proposed subdivision. During 2006, the U.S. Geological Survey, in cooperation with Delta County, Colorado, began a study to develop criteria that the Delta County Land Use Department can use to evaluate water-supply reports for proposed subdivisions.

A table was prepared that lists the types of analyses and data that may be needed in a water-supply report for a water-supply plan that proposes the use of ground water. A preliminary analysis of the availability, sustainability, and suitability of the ground-water resources of Rogers Mesa, Delta County, Colorado, was prepared for a hypothetical subdivision to demonstrate hydrologic analyses and data that may be needed for water-supply reports for proposed subdivisions.

Rogers Mesa is a 12-square-mile upland mesa located along the north side of the North Fork Gunnison River about 15 miles east of Delta, Colorado. The principal land use on Rogers Mesa is irrigated agriculture, with about 5,651 acres of irrigated cropland, grass pasture, and orchards. The principal source of irrigation water is surface water diverted from the North Fork Gunnison River and Leroux Creek. The estimated area of platted subdivisions on or partially on Rogers Mesa in 2007 was about 4,792 acres of which about 2,756 acres was irrigated land in 2000.

The principal aquifer on Rogers Mesa consists of alluvial-fan deposits that overlie shale and, locally, sandstone. Maps of the base of the aquifer, the water table, and the saturated thickness of the aquifer were prepared from data from the well files of the Colorado Division of Water Resources. The base of the aquifer generally is topographically higher than the valleys of the North Fork Gunnison River and Leroux Creek, and direct hydraulic connection of the aquifer to North Fork Gunnison River and Leroux Creek is limited. The aquifer is recharged primarily by infiltration of surface water diverted for irrigation. Ground water discharges to seeps and springs and through slope deposits at the boundaries of the aquifer. Data from the well files also were used to estimate the specific capacity of wells and to estimate the transmissivity and hydraulic conductivity of the aquifer.

A water budget was used to estimate recharge to and discharge from the aquifer. Although storage within the aquifer likely varies seasonally and from year to year, it was assumed that there were no long-term changes in ground-water storage. Estimated average annual recharge to and discharge from the aquifer during November 1998 through October 2006 were about 30,767 acre-feet per year.

Although sufficient ground water is available on Rogers Mesa for additional domestic water supplies, conversion of irrigated land to residential land use likely would reduce recharge to the aquifer, affecting the sustainability of ground-water supplies on Rogers Mesa. Stream-depletion analyses indicate that the ground water in the aquifer likely would be considered tributary ground water and additional uses of ground water to supply new subdivisions likely would require implementation of augmentation plans.

Although the dissolved solids and dissolved sulfate concentrations in ground water from Rogers Mesa aquifer commonly exceeded the U.S. Environmental Protection Agency Secondary Maximum Contaminant Levels for drinking-water supplies, the quality of ground water from the aquifer generally is suitable for residential use. Concentrations of total nitrogen (nitrite plus nitrate, as nitrogen) in ground water ranged from 0.38 to 3.2 milligrams per liter and were less than the State of Colorado maximum contaminant level of 10 milligrams per liter. Concentrations of selenium from seeps and springs at the boundaries of the aquifer commonly

exceeded 50 micrograms per liter, the State of Colorado maximum contaminant level for drinking-water supplies.

This preliminary evaluation of ground-water supplies on Rogers Mesa could be improved with the collection of additional data including: additional mapping of hydrogeologic features; more accurate locations and altitudes of wells; accurate estimates of water-budget components; measurements of ground-water levels; and collection and analyses of ground-water samples. The use of numerical models of ground-water flow could improve evaluations of the potential effects of changes in land and water use on the water budget, aquifer storage, stream depletion, and well interference.

Introduction

The population of the Western United States is forecast to increase substantially during the next few decades. The population of Delta County, Colo. (fig. 1), is projected to increase by 79 to 105 percent, from about 28,000 in 2000 to between 50,200 and 57,500 in 2030 (Colorado Water Conservation Board, 2004; Colorado Department of Local Affairs, 2006). Much of the population increase in Delta County likely will be in rural subdivisions. Because new subdivisions may not have access to public water supplies and municipal sewage treatment systems, ground water from individual on-lot wells likely will be the source of domestic water, and individual sewage disposal systems (ISDS) likely will be used to treat and dispose of sanitary waste. The withdrawal of ground water and the discharge of sanitary waste from ISDS to the subsurface can have unanticipated and (or) undesirable effects on the availability, sustainability, and suitability of local ground-water supplies.

In Colorado, subdivision developers are required to submit subdivision plans, including a water-supply plan, for review and approval by the county and the Colorado Division of Water Resources (DWR). Generally, subdivision water-supply plans are prepared by consulting engineers, who specialize in water resources, and by attorneys, who specialize in water law. Water-supply plans for subdivisions that will use wells are required to include a water-supply report to provide adequate evidence that the proposed water supply is sufficient in terms of availability, sustainability, and suitability (Colorado Division of Water Resources, 2006).

In Colorado, the county reviews the water-supply plan and report for a proposed subdivision and submits them to the DWR for review and approval or modification. Because ground-water conditions in Colorado are highly variable and often are not defined by previous water-resources investigations, county land-use planners and subdivision developers need criteria to define the types of analyses and data that are needed in water-supply reports. The subdivision water-supply report also may provide information for future residents of a subdivision about the reliability and safety of the ground-water supply.

During 2006, the U.S. Geological Survey (USGS), in cooperation with Delta County, Colo., began a study to define the types of hydrologic analyses and data that may be needed in water-supply reports for proposed subdivisions. The Delta County Land Use Department can evaluate adequacy of water-supply reports on the basis of the inclusion or omission of the defined types of hydrologic analyses and data in the water-supply reports. As part of this study, a preliminary analysis of ground-water resources was prepared for a hypothetical subdivision as an example of the types of analyses and data that subdivision developers may use to prepare water-supply reports for proposed subdivisions.

Purpose and Scope

This report describes availability, sustainability, and suitability of ground water using preliminary analyses of example data for use in a water-supply report for a hypothetical subdivision on Rogers Mesa in Delta County, Colo. (fig. 1). Types of hydrogeologic data and analyses of those data that may be needed in subdivision water-supply reports to demonstrate the availability, sustainability, and suitability of the proposed water supply for residential use are described. Subdivision developers can use the information in this report and the types of hydrogeologic data and analyses as a guide to compile, collect, and analyze data for preparation of water-supply plans for proposed subdivisions. County officials can use this report as criteria to evaluate adequacy of water-supply plans for proposed subdivisions that plan the use of individual on-lot wells.

Data used in this report were compiled from publicly available sources, including the Colorado Decision Support System (CDSS), the DWR, the Colorado Water Conservation Board (CWCB), Delta County, the Natural Resources Conservation Service (NRCS), and the USGS. Data are available from the sources listed in table 1 for most of Delta County. Similar data generally are available for other areas in Colorado. The principal source of ground-water data used in this study was DWR well files. A field reconnaissance of Rogers Mesa was done in December 2006, primarily to better define the lateral extent of the surficial aquifer and to locate seeps and springs.

Data from DWR well files, from the field reconnaissance, and from other sources listed in table 1 were used to prepare hydrogeologic maps of Rogers Mesa. These maps show the approximate extent of the aquifer, the generalized configurations and altitudes of the base of the aquifer and the water table, the estimated saturated thickness of the aquifer, locations of water-supply wells, ground-water discharge areas, and other hydrologic features. Well yields and aquifer properties were estimated from drilling and pump-installation reports from the DWR well files. A preliminary water budget was prepared from available data to estimate ground-water recharge and discharge. A brief evaluation of the quality of ground water and its suitability for a domestic water supply

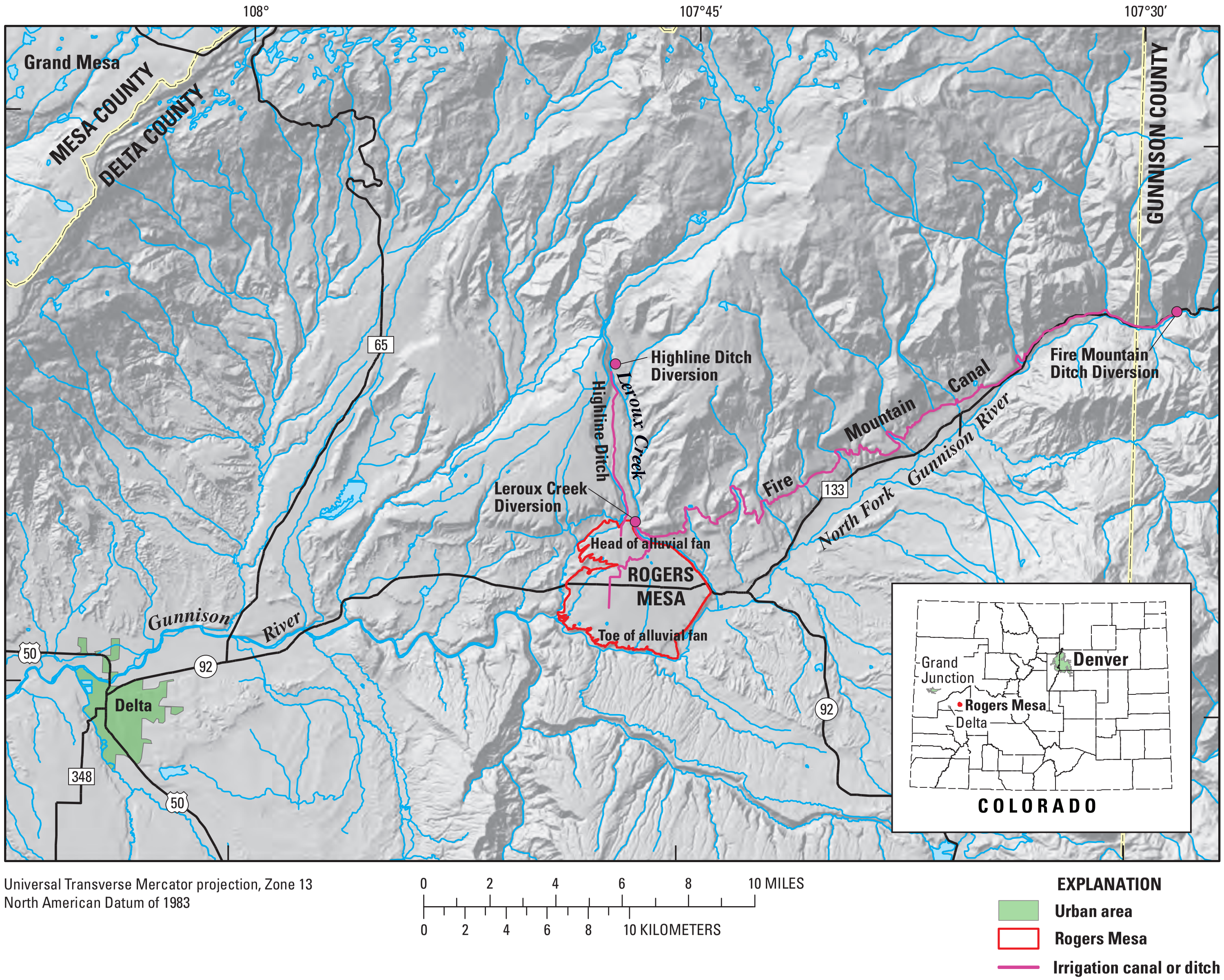


Figure 1. Location of Rogers Mesa, Delta County, Colorado.

was based on sparse data from the National Water Information System and from the Delta County Environmental Health Division and comparison with Federal and State drinking-water standards for public water supplies. Potential effects of ground-water withdrawals on discharge across the boundary of the aquifer were estimated for a range of distances from a hypothetical pumping center to the aquifer boundary. An analytical method was used to estimate potential effects of pumping wells for a hypothetical subdivision on discharge from the Rogers Mesa aquifer. Definitions of technical and regulatory terms are provided in the glossary at the back of this report.

Acknowledgments

The cooperation of landowners, who allowed access to their property during field reconnaissance, is gratefully acknowledged. Paul Healy, Coordinator of the Delta County Geographic Information section, provided geospatial data for water-provider service areas and platted subdivisions that were used in this study. Ken Nordstom, Director of the Delta County Environmental Health Division, provided water-quality data for selected sites on Rogers Mesa. Wayne Schieldt, Division Engineer for Water Division 4 (Gunnison River Basin) of the Colorado Division of Water Resources, and staff in Montrose, Colo., facilitated compilation of well data. Judith Thomas (USGS) compiled data from the DWR well files and conducted the field reconnaissance of Rogers Mesa.

Background and Review of Subdivision Water-Supply Plans and Reports

Preparation of a water-supply plan for a subdivision that proposes the use of ground water as the water supply requires consideration of hydrogeologic conditions in addition to the determination of the legal availability of the water. A water-supply report, prepared by an engineer, geologist, or hydrologist is an important component of the water-supply plan for a proposed subdivision. In some cases, where water will be provided by a municipality, water district, or public supply, a water-supply report may not be required. The water-supply report presents evidence that water of suitable quality will be available to provide a dependable (sustainable) water supply for the proposed subdivision when fully developed. This section of the report summarizes the legal definition of a

Table 1. Selected sources of hydrologic data for water-supply reports.

[Data sources: CDSS, Colorado Decision Support System; CDPHE, Colorado Department of Public Health and Environment; CGS, Colorado Geological Survey; CRS, Colorado Revised Statutes; DWR, Colorado Division of Water Resources; USDA, U.S. Department of Agriculture; USGS, U.S. Geological Survey]

Data source	Type of data	Data format	Website (hyperlink)	Access date
CDSS	Consumptive use and irrigated crop type and areas	Geospatial and tabular	*http://cdss.state.co.us/DNN/Gunnison/tabid/56/Default.aspx*	03/15/2007
CDPHE	Water-quality standards	Documents	*http://www.cdphe.state.co.us/*	03/15/2007
CGS	Geologic and water-resources maps and reports	Documents	*http://geosurvey.state.co.us/*	03/15/2007
CRS	Statutes	Document	*http://www2.michie.com/colorado/lpext.dll?f=templates&fn=fs-main.htm&2.0.*	03/15/2007
Delta County	Parcels and subdivisions	Geospatial	*http://www.deltacounty.com/index.asp?ID=70*	03/15/2007
DWR	Documents	Documents	*http://water.state.co.us/* *http://165.127.23.116/website/lttools/*	03/15/2007
DWR	Well data[1]	Tabular	*http://water.state.co.us/*	03/15/2007
DWR	Water-rights data	Tabular	*http://water.state.co.us/*	03/15/2007
USDA	Soils	Geospatial	*http://datagateway.nrcs.usda.gov/NextPage.aspx*	
USDA	Digital ortho photography	Geospatial	*http://165.221.201.14/NAIP.html*	03/15/2007
USGS	Land-surface altitude	Geospatial	*http://seamless.usgs.gov/*	09/11/2006
USGS	Geologic and water-resources maps and reports	Geospatial	*http://ngmdb.usgs.gov/ngmdb/* *http://infotrek.er.usgs.gov/pubs/*	09/29/2006 09/29/2006
USGS	Ground-water and water-quality data	Tabular	*http://waterdata.usgs.gov/co/nwis/*	03/15/2007

[1]Available for purchase from the Colorado Division of Water Resources. Limited well data may be accessed at the Colorado Division of Water Resources website at *http://water.state.co.us/* using an online map-based search engine.

subdivision; the administrative rules for submission, referral, and review of subdivision water-supply plans and reports; and types of well permits for domestic supplies.

Definition of a Subdivision

Colorado Revised Statutes (CRS) Section 30–128–10(10)(a) defines a subdivision or subdivided land as any parcel of land which is to be used for condominiums, apartments, or any other multiple-dwelling units or which is divided into two or more parcels. The DWR does not apply the subdivision rules to parcels that are 35 acres or more in extent. Subdivisions with parcels that are less than 35 acres in extent that were created after June 1, 1972, unless specifically exempted by the county, are subject to the subdivision rules.

Requirements of Subdivision Water-Supply Plans

The basic requirements for a subdivision water-supply plan, whether the proposed source is ground or surface water, are defined by CRS Section 30–28–133(3)(d). This statute requires that a water-supply plan provide evidence that a water supply is available (legally and physically) and is adequate in terms of quality, quantity, and sustainability for the proposed subdivision. The evidence must include but is not limited to the following items:

1. Evidence of ownership or right of acquisition or use of existing and proposed water rights;
2. Evidence of historic use and estimated yield of claimed water rights;
3. Evidence of amenability of existing water rights to a change in use;
4. Evidence that a willing public or private water supplier can and will supply water to the proposed subdivision, stating the amount of water available for use within the subdivision and the feasibility of extending service to that area; and
5. Evidence that the water supply is potable.

When the proposed water supply is ground water from individual on-lot wells, the wells must be permitted and are subject to administrative rules and policies of the DWR.

Administrative Rules for Subdivisions and Well Permits

The DWR has established administrative rules when the proposed water supply for a subdivision is ground water supplied by individual residential wells (Division of Water Resources, 2006). Criteria that determine the type of well permit that can be issued for individual wells in subdivisions include the date that the subdivision was created; other appropriations within the stream-aquifer system; the tributary status of the ground water; and, in some parts of Colorado, whether the wells are located in a designated basin (Colorado Division of Water Resources, 2005).

A designated basin is an area, established by the Colorado Ground Water Commission in accordance with CRS 37–90–106. A designated basin is an area in which ground water is not available to or required for fulfillment of decreed surface-water rights or that is not adjacent to a continuously flowing stream and in which ground-water withdrawals constituted the principal water usage for at least 15 years preceding the date of the first hearing on the proposed designation of the basin (Colorado Division of Water Resources, 2006). Currently (2007), all designated basins in Colorado are located in the eastern part of the state (Colorado Division of Water Resources, 2006).

The two different classes of well permits in Colorado are (1) permits for wells that are not administered under the priority system (exempt well permits) and (2) permits for wells that are administered under the priority system (nonexempt well permits). Water uses are limited by the conditions of approval stated on the well permit when it is issued. In most cases, permits for exempt wells limit the pumping rate to 15 gal/min or less and limit the annual appropriation, depending on the uses of the water. Generally, permits for domestic-and-livestock (domestic) and household-use-only (residential) wells require nonevaporative ISDS, such as standard septic tank and leach field systems. Water that infiltrates into the subsurface from an ISDS is assumed to return to the same stream drainage system in which the well is located. Except in a few cases, an exempt well permit is not issued where either a municipality or a water district can provide water to the property. In most cases, no more than one exempt well permit is issued for a single lot.

Several types of uses are allowed for exempt wells, including commercial-exempt, domestic, residential, and unregistered existing wells (Colorado Division of Water Resources, 2006). A permit for an exempt domestic well may be obtained for 35-acre or larger parcels, where the proposed well will be the only well on the tract. Parcels that are at least 35 acres in extent are not considered under the subdivision rules. A permit for an exempt domestic well may be obtained for tracts of land that are less than 35 acres if the surface drainage system is not overappropriated or if the well will produce from deep (nontributary) ground water. Depending on the provisions under which the well permit is issued, an exempt domestic well may be able to serve up to three single-family dwellings, irrigate 1 acre or less of lawn and garden, and provide water for an individual's domestic animals and livestock. A permit for an exempt household-use-only (residential) well may be obtained by the owner of a lot in a subdivision that was created prior to June 1, 1972, or if the parcel was created by an exemption to the subdivision laws by the local county planning authority.

Residential wells that are located in subdivisions created after June 1, 1972, or those that are located in parcels that were not created by an exemption to the subdivision laws by the local county planning authority, generally are permitted as nonexempt residential wells. An augmentation plan may be required for nonexempt residential wells that are located in an overappropriated stream-aquifer system.

The purpose of an augmentation plan is to offset stream depletions caused by the withdrawal of tributary ground water by nonexempt wells. Ground water is considered tributary if its withdrawal will deplete the flow of a surface stream by one-tenth of one percent or more of the rate of withdrawal in 100 years. Ground water is considered nontributary to surface streams if its withdrawal will deplete the flow of a surface stream by less than one-tenth of one percent of the rate of withdrawal in 100 years. The intent of an augmentation plan is to prevent material injury to decreed water rights by replacing the consumptive use of water from nonexempt wells. New nonexempt wells in overappropriated areas of the State may be required to replace any out-of-priority stream depletions in time, place, amount, and quality by having augmentation water available. The augmentation plan must be approved before the DWR grants approval to the water-supply plan for a proposed subdivision. A plan for augmentation generally is not required in Colorado if the stream-aquifer system is not overappropriated. Development of an augmentation plan usually requires the services of a water-resource engineer and, possibly, a water attorney. More information about subdivision and well-permit rules, tributary ground water, and augmentation plans can be obtained from the DWR Web site at *http://water.state.co.us/*.

A stream-depletion analysis is done to determine if ground water is tributary to a stream and to calculate the potential stream depletion that would result from the proposed ground-water diversions for the subdivision. A computer program that calculates stream depletion that results from well pumping is available from the Integrated Decision Support Group at Colorado State University at *http://www.ids.colostate.edu/index.html?/projects/idsawas/*.

Administrative rules of the DWR (Colorado Division of Water Resources, 1986) and some counties in Colorado limit proposed ground-water appropriations of nontributary ground water from an aquifer by limiting the annual volume of diversions to a percentage of the estimated volume of ground water stored in the aquifer. Typically, the DWR limits the annual volume of appropriation of nontributary ground water to a maximum of 1 percent per year of ground water that is stored in the aquifer in which the well will be completed and that underlies the parcel of land in which the well will be located. This planned rate of depletion is referred to as the "100-year rule." If the volume of ground water stored in a nontributary aquifer is small, planned depletion effectively restricts the minimum size of parcels. For example, assuming that the annual appropriation needed for a residential well is 0.3 acre-ft and the available storage is 10 ft of water (per unit area) in a nontributary aquifer, a lot size of 3 acres would be required under the 100-year rule to provide 0.3 acre-ft/yr of water [0.3 acre-ft/yr / (10 ft X 0.01/yr) = 3 acres]. In some Colorado counties, the annual volume of pumping from nontributary aquifers is limited to an amount equal to 0.33 percent per year of nontributary ground water that is stored in the aquifer in which the well will be completed and that underlies the parcel of land in which the well will be located. This planned rate of storage depletion is referred to as the "300-year rule." Both the 100-year and 300-year rules assume that the rates of ground-water withdrawal from a nontributary aquifer are not sustainable. Neither rule considers changes in recharge to or discharge from the aquifer that may result from reductions in water levels in the aquifer. If ground-water withdrawals do not induce additional recharge or capture other discharge, the aquifer will be dewatered (mined) to a point at which water may no longer be available to wells. A water-supply plan based on ground water from a non-renewable aquifer also needs to incorporate alternative renewable water resources that provide a sustainable water supply for future generations (Colorado Division of Water Resources, 2005).

Referral and Review of Subdivision Water-Supply Plans

Colorado Revised Statutes Section 30–28–136 defines the referral and review process for subdivision water-supply plans. Initially, the county reviews the preliminary water-supply plan and submits it to the DWR. The DWR is required by CRS Section 30–28–136(2) to review and comment on the water-supply plan within 21 days of submission by the county commissioners. An extension to the 21-day period may be granted for review of a water-supply plan for certain circumstances and with agreement of the county and the applicant. The DWR provides an opinion to the Board of County Commissioners concerning (1) the potential injury to decreed water rights caused by diversions to supply the proposed subdivision and (2) the adequacy of the proposed water supply. Policies of the DWR about review of a water-supply plan are defined in a memorandum from the State Engineer (Colorado Division of Water Resources, 2005 [*http://water.state.co.us/pubs/policies/memo_subdivisions.pdf*]).

The preliminary water-supply plan includes the following components:

1. Expected water requirements (total demand and consumptive use) at full development of the subdivision for all anticipated water uses;

2. A water-supply report defining the legal and physical availability and sustainability of the water supply for the proposed subdivision;

3. Evidence of ownership or right of use of existing water rights;

4. Evaluation of potential material injury to all existing and proposed water rights that could result from proposed water use in the subdivision, which includes the cumulative effect of withdrawals of all on-lot wells at full development of the subdivision;

5. A completed water-supply information summary form listing the proposed uses; and
6. A 7.5-minute USGS topographic map with the boundaries of the proposed subdivision plotted as described by the metes and bounds description.

Subdivision Water-Supply Reports

A subdivision water-supply report defines both the legal and the physical characteristics of the water supply for a proposed subdivision. Definition of the legal availability of the water supply is based on compilation of existing water rights and is outside the scope of this report. A water lawyer generally prepares evidence of the legal availability of the water supply. A water-resources engineer generally prepares evidence of the physical availability and sustainability of the water supply. The Colorado Revised Statutes and administrative rules of the DWR do not explicitly define what evidence of the physical availability and sustainability of a water supply for a proposed subdivision is adequate.

For purposes of this report, ground-water availability means that a sufficient quantity of ground water of suitable quality can be obtained from wells or springs for the intended use of the water. Even if ground water is physically available in an aquifer, its use may be restricted to prevent injury to senior water rights. Ground-water use from nontributary aquifers also may be restricted to limit aquifer depletion and from tributary aquifers to prevent or mitigate stream depletion. Ground-water sustainability is defined as the development and use of ground water in a manner that can be maintained for an indefinite time without causing unacceptable consequences (Alley and others, 1999). Unacceptable consequences could include depletion of streamflow, depletion of aquifer storage, drying of springs and wetlands, and changes in water quality. Knowledge of the volume of ground-water storage and the water budget is needed to determine the sustainability of a ground-water supply. The sustainability of a ground-water supply can vary in response to short-term, seasonal, and long-term changes in recharge and discharge conditions. Development of a sustainable ground-water supply requires an understanding of the effects of development on long-term recharge and discharge conditions and the interaction of the aquifer with other parts of the hydrologic system.

The only three possible sources of water discharged by a well are ground-water storage, ground-water discharge, and additional recharge. Ground water cannot be withdrawn from an aquifer without affecting at least one of those three sources. The amount of ground water available for sustained use depends on more than the volume that can be extracted for use; it is a complex function of the aquifer's hydraulic and storage properties, boundary conditions, withdrawal rates, well locations, and the sources of ground water discharged by wells.

Availability, Sustainability, and Suitability of Ground Water on Rogers Mesa

This section of the report provides examples of hydrologic analyses and data that may be needed for a water-supply report for a proposed subdivision that plans the use of individual wells for its water supply. Types of analyses and data that can be used in subdivision water-supply reports are described in this section. An example of preliminary analyses and data for a water-supply report for a hypothetical subdivision on Rogers Mesa is then presented. The list of types of analyses and data can be used as a checklist in preparing and reviewing subdivision water-supply reports. The preliminary analysis includes a stream-depletion analysis of the proposed ground-water withdrawals for a hypothetical subdivision.

> "The foundation of any good ground-water analysis, including those analyses whose objective is to propose and evaluate alternative management strategies, is the availability of high-quality data" (Alley and others, 1999).

Because the analysis of ground-water conditions on Rogers Mesa presented in this report is based primarily on available data, which may not be of high quality, it should be considered preliminary. Suggestions for the collection of additional data and the analyses of data that would improve the understanding of ground-water conditions on Rogers Mesa also are included in this section.

Types of Analyses and Data for Use in Subdivision Water-Supply Reports

A water-supply report defines the availability, sustainability, and suitability of a proposed ground-water supply. A water-supply report may not be required in a water-supply plan if the water supply will be provided by an existing municipal or quasi-municipal water provider (Colorado Division of Water Resources, 2000). Determining the physical availability of a ground-water supply requires a hydrologic analysis to estimate the amount of water in ground-water storage and to determine if the aquifer will yield sufficient water to wells or springs for the intended use. Determining the sustainability of a proposed ground-water supply requires an understanding of how recharge to and discharge from the aquifer occur and how recharge and discharge may be affected by changes in land and water uses. The suitability of ground water for a residential supply depends primarily on the water's physical properties and chemical and biological characteristics. The determination of suitability should be based on analyses of water samples from the aquifer and from potential sources of recharge to the aquifer.

Subdivision regulations adopted by a board of county commissioners pursuant to CRS 30–28–133 require subdividers to submit data, surveys, analyses, studies, plans, and designs to the board of county commissioners. Although the requirements for a water-supply report are not defined explicitly, CRS 30–28–133(3)(d) states that adequate evidence that a water supply that is sufficient in terms of quality, quantity, and dependability will be available to ensure an adequate supply of water for the type of subdivision. The following analyses likely will be needed in a water-supply report for a proposed subdivision to meet the requirements of CRS 30–28–133(3)(d):

1. Evaluation of local ground- and surface-water resources on a system-wide basis to understand the potential effects of changes in ground-water use on the availability (quantity) and sustainability (dependability) of the water resources;

2. Evaluation of the potential material injury to decreed water rights that could be caused by pumping of the proposed wells at full development of the subdivision (Colorado Division of Water Resources, 2000); and

3. A hydrogeologic analysis of the ground-water/surface-water system, including

    a. a conceptual model of the hydrologic system,

    b. aquifer geometry, boundary conditions, and hydraulic and storage properties,

    c. a water budget, and

    d. water-quality characteristics.

If existing data are not adequate, data collection will be needed to define the availability, sustainability, and suitability of the proposed ground-water supply. This data collection could require installation of test and monitoring wells, aquifer tests, measurement of water levels, and collection of water samples to determine physical properties and chemical and biological characteristics of water in the aquifer.

The types of analyses and data that may be needed for a water-supply report for a subdivision that proposes the use of ground water from individual on-lot wells are listed in table 2 (modified from Alley and others, 1999, table 2). Table 2 can be used as a checklist by subdivision developers in preparation of water-supply reports and by land-use officials as criteria to evaluate subdivision water-supply reports. Not all types of data listed in table 2 may be needed for a subdivision water-supply report. For example, if ground water is not affected by infiltration from the surface or diversion of surface water for irrigation, water-budget components related to irrigation may be irrelevant. Data and analyses related to stream depletion and infiltration from the surface may not be necessary if ground water is nontributary.

A conceptual model describes geologic and hydrologic factors that control the occurrence and flow of ground water, including recharge and discharge conditions. For water-supply reports, the study area may be greater than the extent of the proposed subdivision. Where practical, the extent of the study area coincides with hydrologic boundaries, such as streams or other natural boundaries. For regionally extensive aquifers, the study area boundary encompasses those areas that may be affected directly by proposed ground-water diversions. The hydrogeologic setting is a part of the conceptual model that describes the climate, topography, surface and subsurface geologic and hydrologic conditions, and current and proposed land and water uses. Aquifer geometry, if not previously defined, is mapped to define the aquifer's lateral extent and thickness, and the aquifer's relation with other aquifers and confining units. Maps of the depths to or altitudes of the bottom and top of the aquifer and of water levels in the aquifer are needed. Aquifer boundary conditions define where and how water flows into or out of an aquifer. Where practical, the boundary conditions are defined at physical boundaries, such as geologic features or streams. Reilly (2001) provides a detailed discussion of conceptualization and mathematical treatment of boundary conditions. The hydraulic and storage properties define the ability of an aquifer or confining unit to transmit and store water. Knowledge of an aquifer's hydraulic and storage properties and their variability is needed to calculate flow and storage in the aquifer, to estimate potential well yields, to evaluate the effects of pumping or other changes in recharge and discharge conditions, and, if the aquifer is hydraulically connected to a stream, to calculate stream depletion. A water budget is an accounting of inflow, outflow, and storage changes of water for an aquifer. Because many of the components in a water budget are not measured routinely or cannot be measured directly, a water budget also includes the cumulative errors in the estimated components of the budget. A ground-water flow model may be needed to determine ground-water availability and sustainability and to predict potential effects of proposed pumping in complex systems. The water quality (physical, chemical, and biological) characteristics define the suitability of the ground water for domestic supply. Results from analyses of samples can be compared with drinking-water standards to establish the suitability of the water supply.

Example of Preliminary Analyses and Data for a Subdivision Water-Supply Report

A brief field reconnaissance and publicly accessible data (table 1) were used for this preliminary analysis of ground water on Rogers Mesa. If existing data are sparse, more intensive field investigations may be needed to prepare water-supply reports for subdivisions in other areas in Delta County. Detailed geologic mapping, drilling and installation of test wells, measurement of water levels and spring and well discharge, aquifer tests, and collection of water samples from springs and wells may be needed to define the availability, sustainability, and suitability of a ground-water supply for a proposed subdivision.

Table 2. Types of analyses and data that may be needed for subdivision water-supply reports [modified from Alley and others, 1999].

[--, may not be needed; X, may be needed]

Analysis	Data type	Confined aquifer	Unconfined aquifer
Hydrogeologic setting	Aquifers and confining units	X	X
	Land use	X	X
	Physiographic setting and topography	X	X
	Regional stratigraphy and geologic structure	X	X
	Stratigraphy and lithology	X	X
	Surface-water features, including irrigation canals and agricultural drains	X	X
Aquifer geometry and boundary conditions	Aquifer extent and boundary conditions	X	X
	Topography	X	X
	Depths to tops and bottoms of aquifers and confining units	X	X
	Well and spring locations	X	X
	Seeps and wetlands	X	X
	Water levels	X	X
	Saturated thickness	--	X
	Thickness of unsaturated zone	--	X
Hydraulic and storage properties	Hydraulic conductivity	--	X
	Transmissivity	X	--
	Specific yield	X	X
	Storage coefficient or specific storage	X	--
	Specific retention	X	X
	Specific capacity and yields of wells	X	X
Water budget	Surface inflow	--	X
	Surface outflow	--	X
	Subsurface inflow	X	X
	Subsurface outflow	X	X
	Recharge from losing streams	X	X
	Discharge to gaining streams	X	X
	Infiltration of irrigation return flow	--	X
	Infiltration from individual sewage disposal systems	--	X
	Infiltration of precipitation	--	X
	Surface-water application, irrigated areas	--	X
	Ground-water application, irrigated areas	--	X
	Consumptive use, irrigated areas by crops	--	X
	Consumptive use, nonirrigated areas	--	X
	Leakage to and from vertically adjacent units	X	X
	Discharge to agricultural drains and tail-water pits	--	X
	Discharge from wells	X	X
	Discharge to springs, seeps, and wetlands	X	X
Water quality	Physical properties and chemical and biological characteristics of surface water	X	X
	Physical properties and chemical and biological characteristics of ground water	X	X
Aquifer depletion	Pumping rate, saturated thickness, and specific yield	X	X
Stream depletion	Aquifer properties, pumping rate, and well and stream locations	X	X
Well interference	Aquifer properties, pumping rate, and well locations	X	X

Availability

The physical availability of ground water for subdivision water supply on Rogers Mesa is limited by the volume of water stored in the aquifer, the ability of wells to extract a sufficient quantity of ground water for residential use, and the effects that additional ground-water use will have on the subsurface and surface environment. The following section of the report is a preliminary analysis of ground-water availability on Rogers Mesa that was based on publicly available data. A more complete analysis of ground-water availability likely would require the collection of additional data.

Hydrogeologic Setting of Rogers Mesa

The study area, Rogers Mesa, is about 15 mi east of Delta, Colo. (fig. 1). The boundary of the study area (fig. 2) encompasses an area of 7, 641 acres or about 12 mi^2. The population of Rogers Mesa is estimated to be about 800 to 1,000 on the basis of the number of domestic and residential wells and active water taps. Irrigated agriculture is the principal land use on Rogers Mesa. About 5,651 acres of cropland, grass pasture, and orchards were irrigated in the study area during 2000 (Colorado Division of Water Resources and Colorado Water Conservation Board, 2007). The estimated area of platted subdivisions on or partially on Rogers Mesa (fig. 2) is about 4,792 acres (Paul Healy, Delta County, Colorado, electronic commun., 2007), of which about 2,756 acres also was identified as irrigated land in 2000.

Rogers Mesa is a relatively flat-topped upland that is covered with alluvial-fan deposits and underlain by sedimentary rocks. The altitude of the land surface at the head of the alluvial fan on Rogers Mesa is about 6,000 ft, and the altitude of the land surface atop the scarp at the toe of the alluvial fan is about 5,400 ft (fig. 1). The land surface of Rogers Mesa slopes southward toward the North Fork Gunnison River Valley at about 150 ft/mi (fig. 2). Local surface relief from the edge of Rogers Mesa to the North Fork Gunnison River Valley is about 150 to 200 ft and to the Leroux Creek Valley is about 100 to 150 ft (fig. 2).

The North Fork Gunnison River Valley to the south, Leroux Creek Valley to the east, and Big Gulch to the west of Rogers Mesa are cut into the northerly dipping sedimentary rocks, which are of Cretaceous-Jurassic age (fig. 3; modified from Day and others, 1999). South flowing streams deposited a Quaternary age alluvial fan on an erosional surface (angular unconformity) on top of the sedimentary rocks. Continued erosion by the streams removed some of the alluvial-fan deposits and cut narrow valleys into the underlying sedimentary rocks, forming the steep scarps between Rogers Mesa and the North Fork Gunnison River and Leroux Creek valleys. Generally, these steep scarps limit the contact and hydraulic connection of the alluvial-fan deposits with recent alluvium along these streams.

The alluvial-fan deposits consist of a heterogeneous mixture of unconsolidated sediments that includes clay, silt, sand, gravel, cobbles, and boulders (fig. 4). Thickness of the alluvial-fan deposits, as estimated from reported depths to shale or sandstone from drillers' logs, ranges from 32 to 255 ft. Many of the cobbles and boulders in the alluvial-fan deposits were eroded from basalt on Grand Mesa (fig. 1). Where saturated, the alluvial-fan deposits are referred to in this report as the "Rogers Mesa aquifer." The Rogers Mesa aquifer is an unconfined aquifer.

The Cretaceous-age Mancos Shale, which underlies most of Rogers Mesa, is a relatively impermeable regional confining unit with an estimated hydraulic conductivity of about $3x10^{-4}$ ft/d (Lazear, 2006) to 1.4 ft/d (Weigel, 1987). The Mancos Shale is exposed or thinly covered by slope deposits at the edge of Rogers Mesa. Weathered Mancos Shale is exposed along Big Gulch to the west and northwest of Rogers Mesa. The Mancos Shale, where not removed by erosion, separates the alluvial-fan deposits from the Cretaceous-age Dakota Sandstone and Burro Canyon Formation. Near the southwestern part of Rogers Mesa, the Mancos Shale thins and the alluvial-fan deposits may directly overlie the Dakota Sandstone and Burro Canyon Formation. Locally, the Dakota Sandstone and Burro Canyon Formation are important aquifers in western Colorado (Topper and others, 2003) but reportedly yield only small quantities of water to wells near Rogers Mesa. Additional field investigations are needed to determine the lateral extent of the Mancos Shale in the southwestern part of Rogers Mesa, where the Dakota Sandstone and Burro Canyon Formation may directly underlie the base of the Rogers Mesa aquifer. The Morrison and Wanakah Formations and the Entrada Sandstone (Jurassic-age sedimentary rocks) crop out in the North Fork Gunnison River Valley south of Rogers Mesa (Day and others, 1999) and likely are not in contact with the alluvial-fan deposits on Rogers Mesa (fig. 3).

Climate

The climate of the Rogers Mesa area is semiarid with the potential for evaporation and transpiration (evapotranspiration) to exceed precipitation in every month of the year (fig. 5). A meteorological station (HOT01; fig. 6), which is part of the Colorado Agricultural Meteorological (COAGMET) network, is located on Rogers Mesa at the Colorado State University Experiment Station. The COAGMET network is operated by the Colorado Climate Center at Colorado State University and is used to estimate local reference evapotranspiration (consumptive use) by crops. Consumptive use is the amount of water evaporated from soil and transpired by plants. Reference evapotranspiration is the hypothetical evapotranspiration or consumptive use of water by a well-watered crop of alfalfa. Reference evapotranspiration is calculated using an energy balance equation, the 1982 Kimberly Penman equation for alfalfa (Wright, 1982), and local measurements of relative humidity, precipitation, solar radiation, wind speed, and air and soil temperatures. Data from the COAGMET network can be accessed at *http://ccc.atmos.colostate.edu/%7Ecoagmet/*. Average annual precipitation during

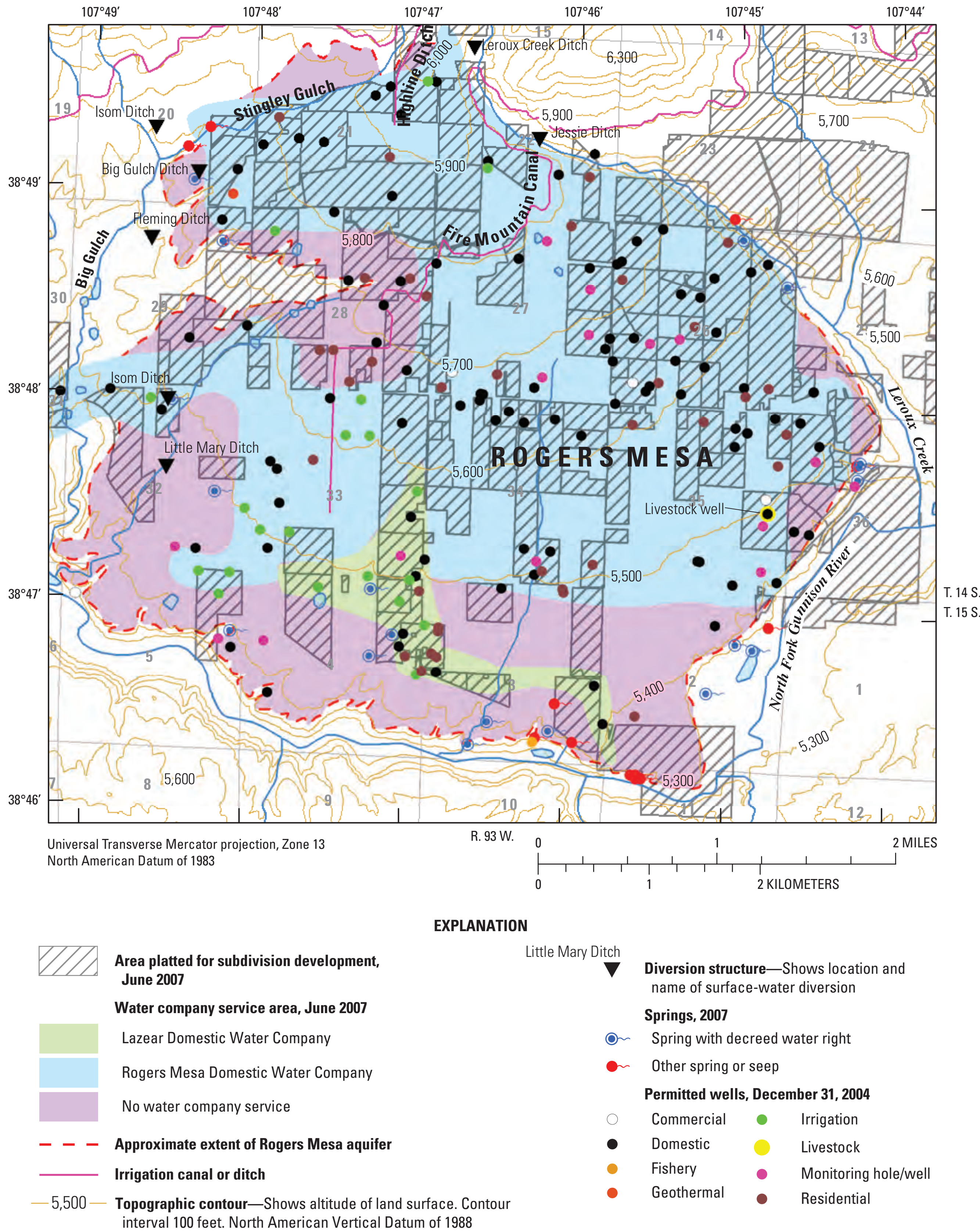


Figure 2. Generalized topography, subdivisions, water company service areas, springs, and wells, Rogers Mesa, Delta County, Colorado.

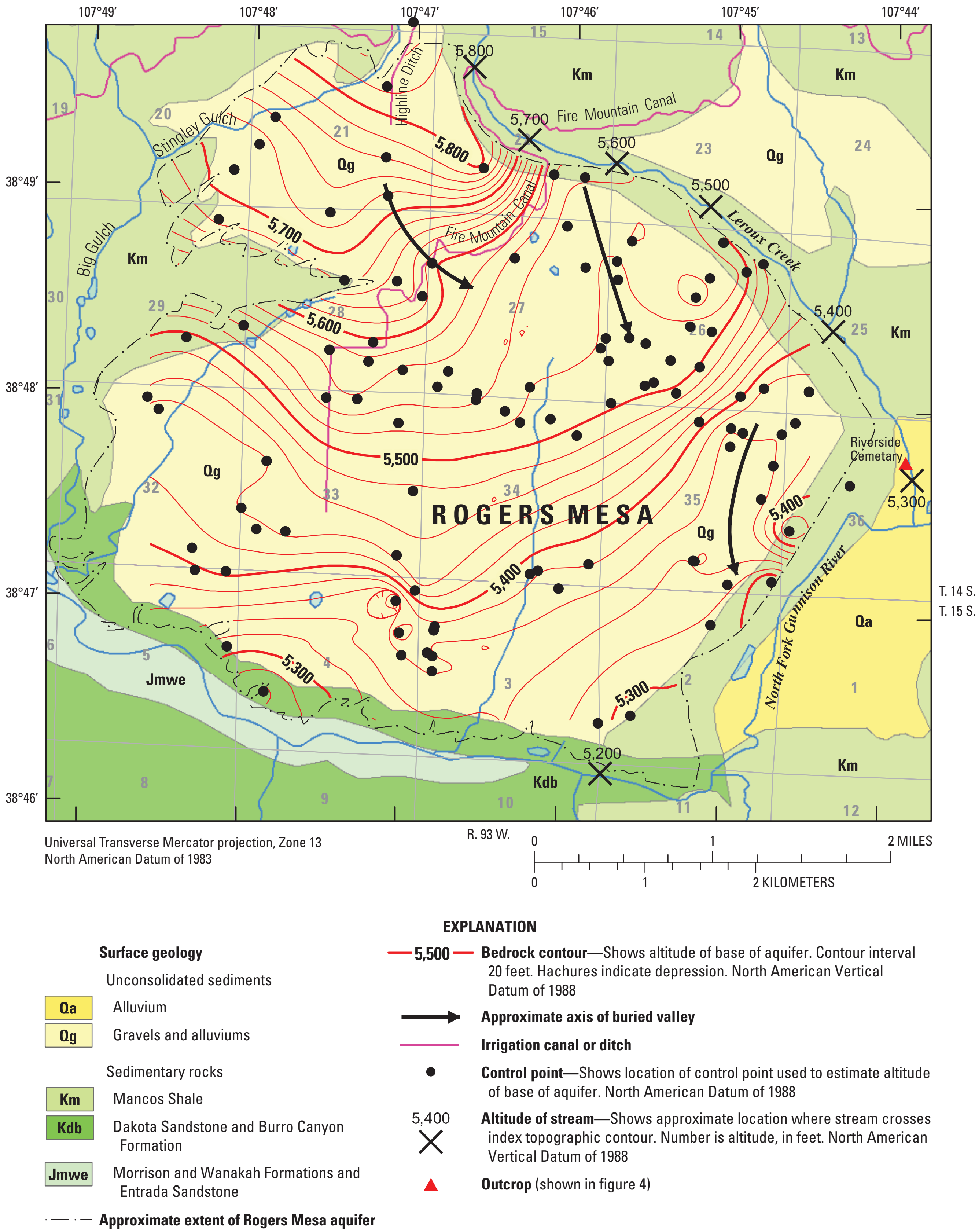


Figure 3. Generalized surface geology and configuration of the base of the aquifer (the contact of alluvial-fan deposits with shale or sandstone) on Rogers Mesa, Delta County, Colorado.

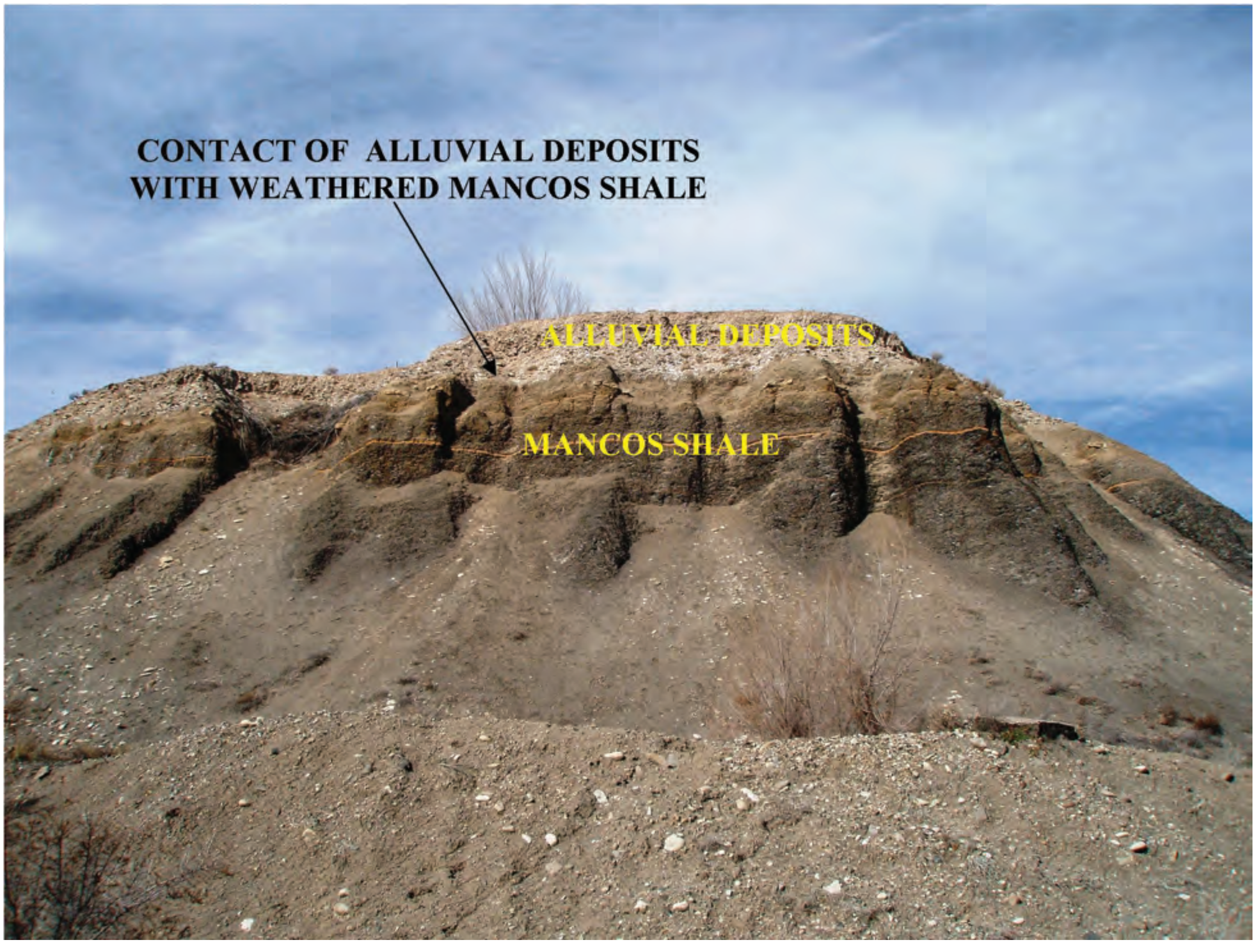


Figure 4. Contact of alluvial deposits with weathered Mancos Shale near Riverside Cemetery, Rogers Mesa, Delta County, Colorado. Riverside Cemetary is at top of hill and Leroux Creek is at base of slope. Approximate location shown in figure 3. Photograph by Judith Thomas, U.S. Geological Survey.

irrigation years 1999–2006 at station HOT01 was about 0.87 ft and ranged from about 0.6 ft in irrigation year 2003 to about 1 ft in irrigation year 2005. (An irrigation year begins November 1 of the previous calendar year and ends October 31 of the calendar year.) Average annual reference evapotranspiration during irrigation years 1999–2006 was about 4.7 ft and ranged from about 4.2 ft during irrigation year 2006 to 5.2 ft during irrigation year 2000. The difference between average annual precipitation and average annual reference evapotranspiration during irrigation years 1999–2006 was a deficit of about 3.8 ft. This deficit represents the minimum amount of irrigation water that would be needed by a well-watered crop of alfalfa. The annual deficit between precipitation and reference evapotranspiration ranged from 3.2 ft in irrigation year 2005 to 4.5 ft in irrigation year 2000.

Soils

Soils on Rogers Mesa are developed on the alluvial-fan deposits and are moderately permeable (fig. 6). The saturated vertical hydraulic conductivity of soils at depths of 3 to 5 ft on Rogers Mesa generally ranges from 4.23 to 14.11 micrometers per second (μm/s), which is equivalent to about 1.2 to 4 ft/d (U.S. Department of Agriculture, Natural Resources Conservation Service, 2007a). Because the hydraulic conductivity of soils is measured or estimated perpendicular to the land surface, it is an estimate of the vertical hydraulic conductivity of the soil. The available water capacity of the soils at depths of 3 to 5 ft on Rogers Mesa is variable and averages about 8 percent (U.S. Department of Agriculture, Natural Resources Conservation Service, 2007a). Available water capacity is the difference between the soil water content at field capacity and the wilting point (U.S. Department of Agriculture, Natural Resources Conservation Service, 2007b). Field capacity is the amount of moisture that remains in a soil after free water in the pores has drained into the underlying unsaturated soil. Field capacity is measured as the ratio of the weight of water in the soil to the oven-dry weight of the soil. For permeable soils of medium texture, the time required for drainage to field capacity is about 2 or 3 days after a substantial rain or irrigation. The wilting point is the moisture content (the ratio of the weight of water in the soil to the oven-dry weight of the

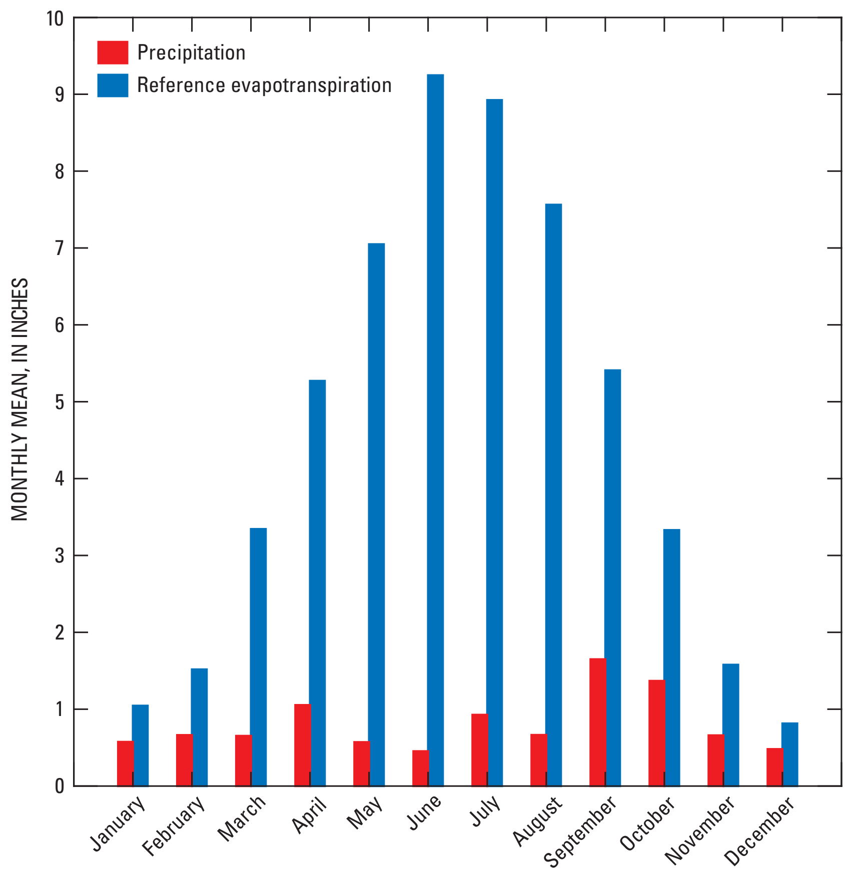


Figure 5. Mean monthly precipitation and estimated reference evapotranspiration at meteorological station HOT01, Rogers Mesa, Delta County, Colorado, May 21, 1998, through December 31, 2006.

soil) at which plants cannot extract water from the soil (U.S. Department of Agriculture, Natural Resources Conservation Service, 2007c). The available water capacity commonly is expressed as a fraction of an inch of water per inch (or per foot) of soil but also can be expressed as a dimensionless ratio. The available water capacity is approximately equivalent to the specific retention (fig. 6) of the porous media (Lohman and others, 1972).

The estimated clay content of soils on Rogers Mesa, at depths of 3 to 5 ft, ranges from 18 to 28 percent by volume (U.S. Department of Agriculture, Natural Resources Conservation Service, 2007a). Assuming the clay content in the soil at 3 to 5 ft is similar to that in the underlying alluvial-fan deposits, the alluvial-fan deposits would be described as a clayey sand and gravel. The infiltration of precipitation and irrigation water applied to the land surface likely is inhibited by clay within the soil and the unsaturated zone overlying the water table. As water infiltrates through the unsaturated zone, clay provides sites for ion exchange that may affect the chemical composition of the water as it percolates to the water table.

Irrigation

Irrigated agriculture is the principal land use on Rogers Mesa. Surface water is diverted from the North Fork Gunnison River by the Fire Mountain Canal, from Leroux Creek by the Highline Ditch and Leroux Creek Ditch, and by several smaller ditches to irrigate about 5,572 acres on Rogers Mesa (Colorado Division of Water Resources and Colorado Water Conservation Board, 2007). The Fire Mountain Diversion Dam and Canal were built primarily from 1949 to 1953. The diversion for the Fire Mountain Canal is located on the North Fork Gunnison River about 17 mi upstream from Rogers Mesa (fig. 1). The Fire Mountain Canal ranges from 4 ft wide, where it is concrete lined, to 10 ft wide, where it is clay lined. Maximum capacity of the Fire Mountain Canal is about 100 ft^3/s where it crosses Leroux Creek onto Rogers Mesa (Bureau of Reclamation, 2006). The Highline Ditch diverts water from Leroux Creek about 6 mi north of Rogers Mesa (fig. 1). Locations of diversion structures for Big Gulch Ditch, Fleming Ditch, Isom Ditch, Jessie Ditch, Leroux Creek Ditch, and Little Mary Ditch are shown in figure 7. Ground water

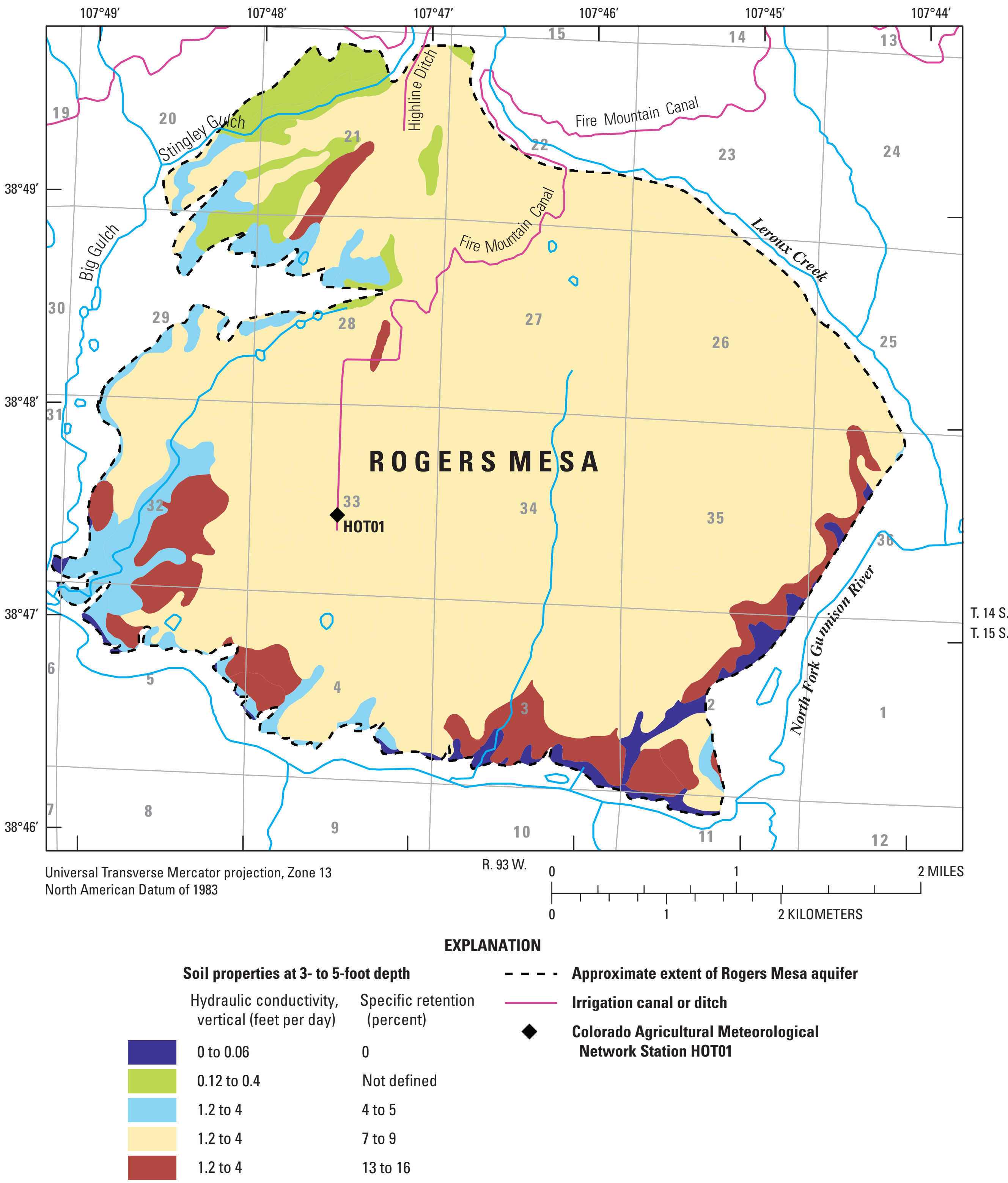


Figure 6. Estimated vertical hydraulic conductivity and specific retention of soils derived from alluvial-fan deposits, Rogers Mesa, Delta County, Colorado. [Data modifed from U.S. Department of Agriculture, Natural Resources Conservation Service, 2007.]

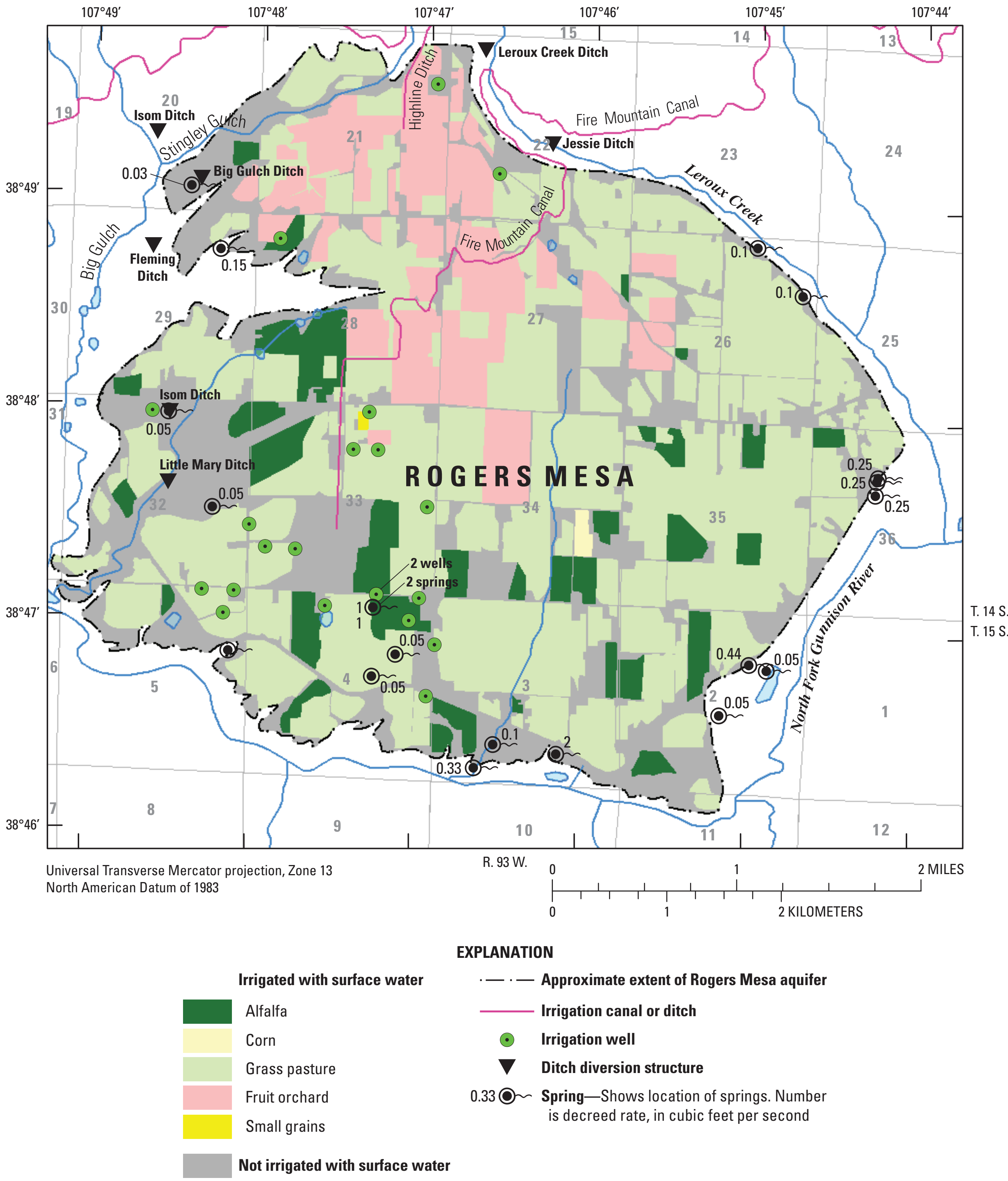


Figure 7. Irrigated cropland, pasture, and orchards, and locations of canals, ditches, diversion structures, irrigation wells, and selected springs on Rogers Mesa, Delta County, Colorado, 2000.

from wells also may be used to irrigate an estimated 723 acres on Rogers Mesa; however, no records of diversion by irrigation wells on Rogers Mesa are available. As of December 2004, only 21 wells in the DWR well file had a primary or secondary use for irrigation on Rogers Mesa (fig. 7).

In 2000, the principal crops irrigated on Rogers Mesa included about 3,991 acres of grass pasture, about 931 acres of fruit orchards, about 633 acres of alfalfa, about 14 acres of corn, and about 3.4 acres of small grains (fig. 7; Colorado Division of Water Resources and Colorado Water Conservation Board, 2007). The estimated area of lawns and gardens irrigated with ground water from domestic wells is about 78 acres.

Residential Water Supplies

Lazear Domestic Water Company and Rogers Mesa Domestic Water Company (fig. 2) have a combined 430 active water taps and annually import a total of 32.9 Mgal or about 101 acre-ft of water for use on Rogers Mesa. The source of water for the Lazear Domestic Water Company is ground water from the aquifer along the North Fork Gunnison River (Colorado Department of Health and Environment, 2004) and for the Rogers Mesa Domestic Water Company is surface water from Leroux Creek (U.S. Environmental Protection Agency, 2007a). In 2004, there were 98 domestic and 40 residential (household use only) wells with permits on Rogers Mesa (fig. 2). There also were permits for 21 irrigation wells, 3 commercial wells, and 1 stock well. In addition, 20 springs on Rogers Mesa have decreed water rights (fig. 7).

Because the study area does not have a centralized sewage treatment system, sanitary wastes are treated and disposed of by using ISDS. Assuming that the 430 active water taps and the 98 domestic, 40 residential, and the 3 commercial wells dispose of wastewater by using ISDS, an estimated 571 ISDS are located on Rogers Mesa. Nonconsumptive water use from 571 systems is assumed to return to the aquifer (to recharge the aquifer) by infiltration from the leach fields of the ISDS. No quantitative studies of consumptive use of residential water have been done in the Rogers Mesa area; however, nonconsumptive use of water by Colorado residences using ISDS is estimated to range from 84 to 93 percent (Ralf Topper, Colorado Geological Survey, written commun., 2007; *http://dnr.state.co.us/NR/rdonlyres/C9D61BC3-26A6-418B-A179-4856C941B03D/0/TopperMemoWaterUsebyIndividualSewageSystems5707.doc).* Nonconsumptive use of residential water supplies on Rogers Mesa was assumed to be 90 percent of in-house water use.

Aquifer Boundary Conditions

Boundary conditions for Rogers Mesa aquifer are relatively simple. The lower boundary, the base of the aquifer, which is the contact of the alluvial-fan deposits with the Mancos Shale, Dakota Sandstone, or Burro Canyon Formation, is a no-flow (specified flow of zero) boundary. The upper boundary, the water table, is a specified flow boundary across which the aquifer is recharged by downward infiltration of water through the unsaturated zone. The lateral boundaries of the aquifer generally are specified head (head-dependent flow) boundaries across which flow is variable, depending on the transmissivity of the aquifer and the hydraulic gradient at the boundary. Locally, flows across the lateral boundaries of the aquifer are concentrated at lows in the basal surface of the aquifer, where ground water discharges to the surface at springs and seeps. In some areas along the lateral boundaries, the aquifer grades into soil and slope deposits and ground water discharges through the soil and slope deposits. Ground-water discharge areas along the lateral boundary of the aquifer commonly are indicated by the occurrence of water-loving plants, such as cattails and willows, or by salt encrustation on the land surface.

Lower Boundary—Base of the Aquifer

The generalized configuration of the base of the aquifer, the lower no-flow boundary of the aquifer, is shown in figure 3. The map of the base of the aquifer (fig. 3) was prepared using drillers' logs for 105 wells from the DWR well database. Although about 30 percent of the drillers' logs did not report a depth to shale or sandstone, it was assumed that all wells were drilled to shale or sandstone. The altitudes of the land surface at the control points for the bedrock surface were estimated from a national elevation dataset (U.S. Geological Survey, 2007). The altitudes of the base of the aquifer (the bedrock surface) at the control points were calculated by subtracting the reported depth to shale, sandstone, or, if the depth to shale or sandstone was not reported, the total well depth from the estimated altitude of the land surface at the well. Kriging, a geostatistical interpolation method, as implemented in Environmental Systems Research Inc. (1999–2005) ESRI ArcMap 9.1, was used to estimate the altitude of the bedrock surface (the base of the aquifer) between control points and to estimate the standard error of the estimated surface. Kriging was used to contour the generalized configuration of the base of the aquifer rather than manual contouring because of errors in point values that result from the accuracy of well locations. Manual contouring methods require that contour lines honor all data values; thus, contour lines must pass between points that are larger than the contour value and points that are smaller. Kriging, as implemented in ESRI ArcMap, interpolates a grid surface from the point values. When two or more point values fall within a grid cell, the mean value of the point values in the grid cell is used. Use of a mean value in kriging can result in contour lines that appear not to honor all data points. Because the locations of wells in the DWR well files generally were reported by 40-acre tracts within sections, two or more wells may have the same reported location even though they actually could be separated by more than 1,800 ft.

The bedrock surface (fig. 3) generally slopes to the south toward the North Fork Gunnison River. Upslope deflections in the contour lines indicate the presence of buried channels in several locations. Generally, the altitude of the base of the aquifer is greater than the altitude of the land surface in adjacent valleys; thus, the Rogers Mesa aquifer essentially is a perched aquifer. However, the altitude of the base of the aquifer in the southwest quarter, sec. 23, T. 14 S., R. 93 W., may be lower than the altitude of Leroux Creek to the east, which implies that locally the Rogers Mesa aquifer is hydraulically connected with Leroux Creek.

Upper Boundary—Water Table

The upper boundary of the aquifer, the water table, receives recharge through the unsaturated zone and is a specified flow boundary. The water table will fluctuate with changes in the rates of infiltration of recharge and pumping of nearby wells. The altitude of the water table (fig. 8) was estimated from the reported depth to water for 115 wells from the DWR well database. The altitudes of the water table at the wells were calculated by subtracting the reported depth to water from the estimated altitude of the land surface from the national elevation dataset (U.S. Geological Survey, 2007). Kriging also was used to estimate the altitude of the water table between control points and to estimate the standard error of the estimated surface. Because the reported depths to water that were used to estimate the altitude of the water table are from a wide range of dates (October 13, 1964, through February 28, 2006), figure 8 should be considered only an approximation of the water-table surface. Undoubtedly, variations of recharge and discharge during 1964–2006 would have caused the water table to fluctuate. Ideally, water levels used to prepare a map of the water table would be contemporaneous measurements.

Lateral Boundaries—Aquifer Extent

The lateral extent of the Rogers Mesa aquifer initially was assumed to coincide with the extent of “older alluviums and gravels” as mapped by Day and others (1999; fig. 3). The lateral extent of the aquifer (fig. 8) was modified on the basis of drillers’ logs, field reconnaissance, and topographic expression. Detailed field mapping of the contact of the alluvial-fan deposits with the sedimentary rocks could improve definition of the aquifer’s lateral extent and the altitude of the base of the aquifer.

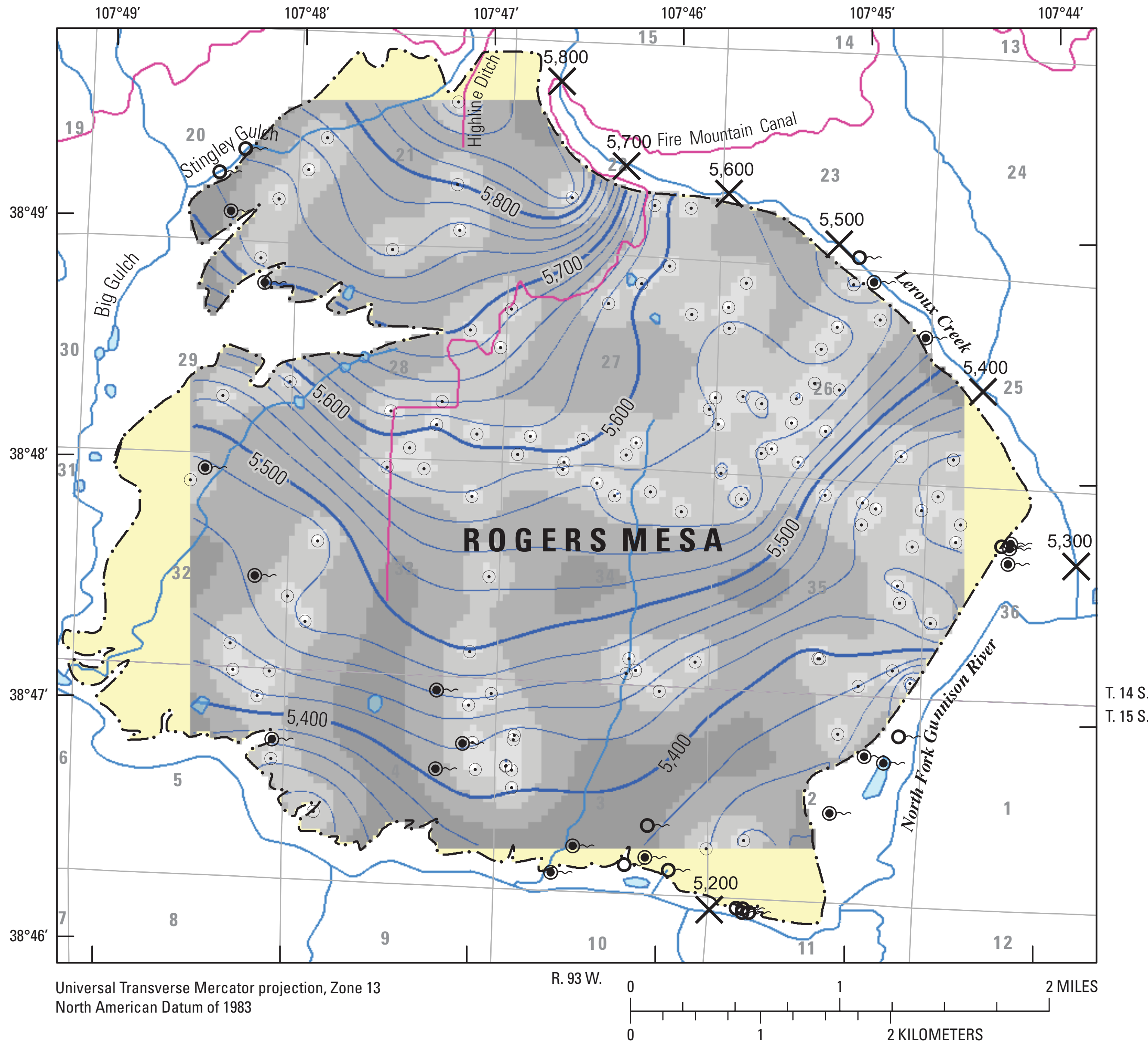
Where water-table contours (fig. 8) are perpendicular to the lateral boundaries of an isotropic aquifer, the hydraulic gradient across the boundary is zero and there is no flow across the boundary. For practical purposes, where water-table contours are perpendicular to an aquifer boundary, the boundary can be considered a specified no-flow boundary. Because the predominant slope of the base of the Rogers Mesa aquifer is toward the south, no-flow boundaries occur locally on the southern sides of gullies that are eroded through the alluvial-fan deposits. Where water-table contours (fig. 8) are not perpendicular to the lateral boundary of the aquifer, ground water is flowing across the boundary and the boundary is a specified head boundary. The water table in the Rogers Mesa aquifer adjacent to Leroux Creek Valley generally slopes easterly, indicating a potential for subsurface flow towards Leroux Creek. The water table in the southwest quarter of sec. 23, T. 14 S., R. 93 W., slopes away from Leroux Creek Valley toward the aquifer, indicating that this reach of Leroux Creek may be losing water to the Rogers Mesa aquifer. Confirmation of a hydraulic connection between Leroux Creek and the Rogers Mesa aquifer would require more detailed field mapping and test drilling.

Hydraulic and Storage Properties

Ideally, the hydraulic and storage properties of an aquifer are determined by controlled tests, referred to as “aquifer tests.” In the absence of aquifer tests, however, the hydraulic and storage properties of an aquifer often are estimated using available data from drillers’ pumping tests, pump-installation tests, and lithologic logs. Drillers’ pumping tests and pump-installation tests can be used to estimate the specific capacity of wells and the relative hydraulic properties of an aquifer. When results from aquifer tests and laboratory tests of cores are not available, the storage properties of an aquifer can be estimated from lithology of the deposits or rocks. The storage properties (porosity, specific yield, and specific retention) of the Rogers Mesa aquifer were estimated on the basis of lithologic descriptions from drillers’ logs and specific yield and specific retention values for similar geologic materials (Robson, 1993).

The specific capacity of a well is the ratio of the pumping rate and the drawdown caused by pumping. Drawdown is the water-level change, the difference between the static water level prior to pumping and the water level at some time after pumping began. The specific capacity of a well can be used to estimate aquifer transmissivity. However, aquifer transmissivity generally is underestimated by the specific capacity of a well because specific capacity of a well may be substantially affected by well construction and development, the pumping rate, and duration of the test. Drillers’ pumping tests and pump-installation tests often are used to estimate the specific capacity of wells but are subject to large errors. The principal sources of error in drillers’ pumping tests and pump-installation tests likely are inaccurate measurements of well discharge, static water level, and pumping water level. If the wells in an area have similar construction characteristics, however, analyses of drillers’ pumping tests and pump-installation tests may provide an estimate of the relative hydraulic characteristics of the aquifer.

Data were available from drillers’ pumping tests of 99 wells and from pump-installation tests for 67 wells completed in the Rogers Mesa aquifer; 60 of the wells had both drillers’ pumping and pump-installation tests. The estimated specific capacity of the wells was calculated by dividing the reported pumping rate by the difference between the reported static and pumping water levels. The statistical distributions of estimated specific capacity for two classes of wells, small-capacity wells with reported pumping rates of



EXPLANATION

Standard error of estimated altitude (feet)

- No data
- Less than 10
- 10 to 20
- 20 to 30
- 30 to 40
- 40 to 50

Approximate extent of Rogers Mesa aquifer

5,500 **Water table**—Shows line of equal altitude of water table. Contour interval 20 feet. North American Vertical Datum of 1988

Irrigation canal or ditch

Spring with decreed water right

Other spring or seep—Shows location of spring or seep from the U.S. Geological Survey National Water Information System

Control point—Shows location of control point used to estimate altitude of water table, in feet. North American Vertical Datum of 1988

5,200 **Altitude of stream**—Shows approximate location where stream crosses index topographic contour. Number is altitude, in feet. North American Vertical Datum of 1988

Figure 8. Generalized configuration and altitude of the water table, and locations of springs, Rogers Mesa, Delta County, Colorado.

less than 50 gal/min and large-capacity wells with reported pumping rates of 50 gal/min or greater, are shown in figure 9. The common reporting unit for specific capacity of gallons per minute per foot (gal/min/ft) of drawdown was converted to consistent units of cubic feet per day per foot of drawdown [(ft^3/d)/ft]. The consistent units of cubic feet per day per foot [(ft^3/d)/ft] is dimensionally equivalent to units of square feet per day (ft^2/d).

For small-capacity wells, obvious differences exist between specific-capacity values estimated on the basis of drillers' pumping tests and those estimated on the basis of pump-installation tests (fig. 9). The median estimated specific-capacity value from pump-installation tests of small capacity wells of 361 (ft^3/d)/ft (1.88 (gal/min)/ft) was about 4 times greater than the median value from drillers' pumping tests of 96 (ft^3/d)/ft (0.5 (gal/min)/ft). The difference in the estimated values may result from additional well development, differences in pumping methods, and differences in measurement of pumping rates and static and pumping water levels. Drillers' pumping tests commonly are done as the well is being developed by the use of a bailer. Pump-installation tests generally are done after well development and by the use of a well pump.

The estimated specific-capacity values from six tests of large-capacity wells ranged from about 500 to 21,700 (ft^3/d)/ft (about 2.7 to 113 (gal/min)/ft) and had a median value of about 3,200 ft^3/d/ft (about 16.6 (gal/min)/ft). The estimated specific-capacity values from drillers' pumping tests and pump-installation tests of large-capacity wells were nearly identical. The ninefold difference between the median estimated specific capacity values from pump-installation tests of small- and large-capacity wells (fig. 9) may result from differences in well construction and development. Although a specific-capacity test is done to test the capacity of a well to yield water, the specific capacities of wells often are used to estimate aquifer transmissivity when aquifer-test results are not available (Theis, 1963; Lohman, 1979; Driscoll, 1986). Because specific-capacity tests are affected by test conditions, well construction, and well development, they often underestimate the transmissivity of the aquifer.

The transmissivity of an aquifer is a measure of the ability of an aquifer to transmit water through a unit width of an aquifer under a unit hydraulic gradient (Lohman and others, 1972). Though spoken of as a property of the aquifer, it also embodies the saturated thickness of the aquifer and the density and viscosity of the ground water. The transmissivity of the Rogers Mesa aquifer has not been determined by aquifer test. On the basis of the estimated specific capacity of wells completed in the aquifer, the estimated transmissivity of the Rogers Mesa aquifer ranges from a few hundred to 20,000 or more ft^2/d. Because transmissivity is the product of the saturated thickness and the hydraulic conductivity of the aquifer, variations in hydraulic conductivity and in saturated thickness can result in large variability of aquifer transmissivity.

Hydraulic conductivity is defined as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow (Lohman and others, 1972). Although hydraulic conductivity can vary with direction of measurement, in this report the hydraulic conductivity of the aquifer is assumed isotropic in the horizontal plane. The horizontal hydraulic conductivity of the Rogers Mesa aquifer was estimated by dividing the estimated aquifer transmissivity, which was estimated on the basis of drillers' pumping and pump-installation tests, by the saturated thickness of the aquifer. The saturated thickness of the aquifer was estimated by subtracting the reported static water level from the reported depth to shale, sandstone, or, if the depth to shale or sandstone was not reported, the reported total well depth. Estimated horizontal hydraulic conductivity values ranged from less than 1 to about 350 ft/d and had a median of about 6 ft/d. A horizontal hydraulic conductivity of 6 ft/d is near the low range of hydraulic conductivity for fine-grained or silty sand (Freeze and Cherry, 1979, table 2.2, p. 29) and likely is smaller than the hydraulic conductivity typical for the silty sand and gravel (alluvial-fan deposits) on Rogers Mesa. The horizontal hydraulic conductivity values of the Rogers Mesa aquifer likely are greater than the values estimated from the drillers' pumping and pump-installation tests. The range of hydraulic conductivity for silty sand and gravel is approximately 0.1 to 500 ft/d (Freeze and Cherry, 1979, table 2.2, p. 29). On the basis of the water-budget analysis (discussed later in this report) and the lithology of the alluvial-fan deposits, the median horizontal hydraulic conductivity of the Rogers Mesa aquifer likely is nearer to the upper range of hydraulic conductivity values for silty sand and gravel and is underestimated by drillers' pumping and pump-installation tests.

The vertical hydraulic conductivity of the Rogers Mesa aquifer, as estimated from the hydraulic conductivity of soils at 3- to 5-ft depths (U.S. Department of Agriculture, Natural Resources Conservation Service, 2007a), is about 1.2 to 4 ft/d. The large difference between the estimated horizontal and vertical hydraulic conductivities of the Rogers Mesa aquifer is typical of alluvial deposits. The heterogeneity and bedded nature of alluvial deposits, including alluvial-fan deposits, imparts a strong anisotropy to average properties of large volumes of an aquifer (Freeze and Cherry, 1979, p. 148). Aquifer tests and laboratory tests of core samples from the alluvial-fan deposits are needed to better define the transmissivity, hydraulic conductivity, and storage properties of the aquifer but are relatively expensive to conduct and often difficult to interpret.

For the most part, lithologic descriptions of subsurface materials from driller's logs are subjective and too general to be useful in estimating vertical variations in grain size of the alluvial-fan deposits. The alluvial-fan deposits consist of a mixture of particles of various sizes that range in diameter from less than 0.02 millimeter (clay and silt) to greater than 1 meter (boulders). Slichter (1899; as cited in Lohman, 1979)

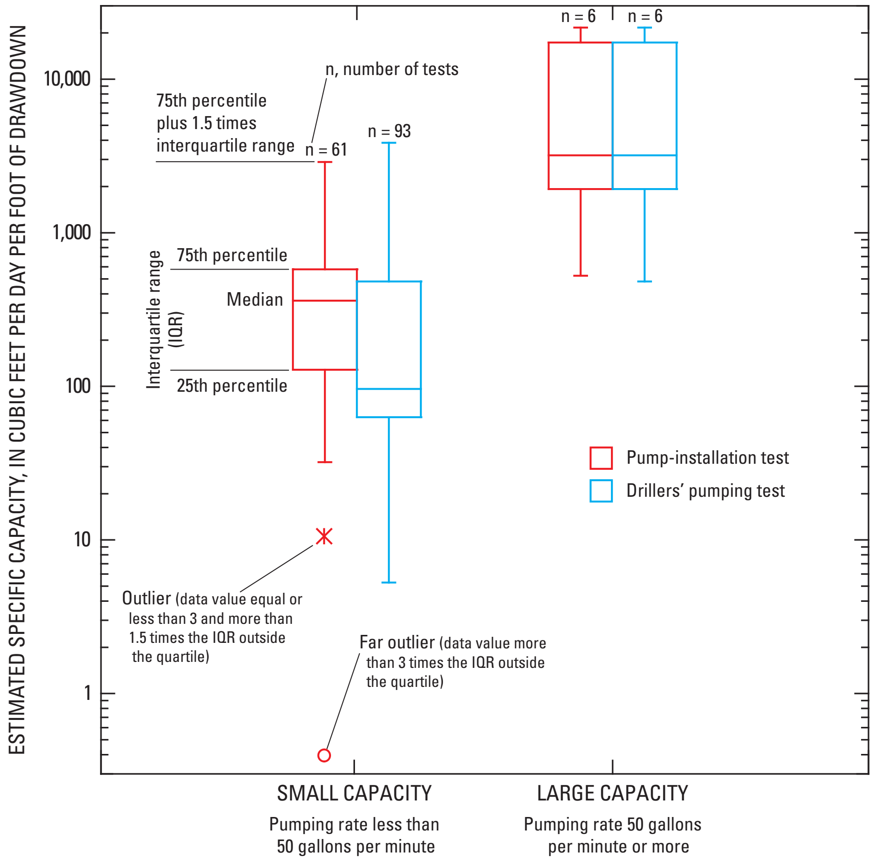


Figure 9. Estimated specific capacity for small- and large-capacity wells, Rogers Mesa, Delta County, Colorado.

demonstrated that the range of porosity for spherical particles of equal size ranges from about 0.26 to 0.48. Because alluvial-fan deposits are heterogeneous mixtures of different sized particles, the porosity of the alluvial-fan deposits likely is near the lower end of the range of porosity for equal-sized spheres and is assumed to be 0.3. With respect to water, the porosity of an aquifer consists of two parts: pores that will drain by gravity (specific yield) and those that will not drain by gravity (specific retention). The specific yield of an aquifer is the ratio of the volume of water in an aquifer that will drain by gravity to the total volume of the aquifer (Lohman and others, 1972). The specific retention of an aquifer is the ratio of the volume of water that is retained in the aquifer against the force of gravity to the total volume of the aquifer (Lohman and others, 1972). Assuming a porosity of 0.3 and that specific retention equals 0.08 (the available water capacity of soils on Rogers Mesa at 3- to 5-ft depths; U.S. Department of Agriculture, Natural Resources Conservation Service, 2007a), the specific yield of the Rogers Mesa aquifer is an estimated 0.22 (0.3–0.08 = 0.22). Aquifer tests and laboratory tests of core samples could better define the storage properties of the aquifer.

Saturated Thickness and Aquifer Storage

Saturated thickness of the Rogers Mesa aquifer (fig. 10) was estimated as the difference between the altitude of the water table (fig. 8) and the altitude of the base of the aquifer (fig. 3). Saturated thickness was not estimated for about 10 percent of the areal extent of the aquifer, primarily near the edges of the aquifer, because there were too few well data to define the water table and the bedrock surfaces. The estimated saturated thickness ranged from a minimum of about 18 ft to a maximum of about 130 ft. In some areas on Rogers Mesa, the aquifer is saturated near the contact of the alluvial-fan deposits with the underlying sedimentary rock, as indicated by the occurrence of seeps and springs, but in some areas, the alluvial-fan deposits are unsaturated at the contact with the underlying sedimentary rock (fig. 4).

The volume of saturated aquifer was estimated by subtracting the altitude of the base of the aquifer (fig. 3) from the altitude of the water table (fig. 8) and multiplying by the area of the aquifer. The area of the aquifer was determined by dividing the areal extent of the aquifer into blocks or cells, each about 164 ft by 164 ft, then summing the saturated volumes of all grid cells within the areal extent of the aquifer. The estimated volume of saturated aquifer is about 1.52 $x10^{10}$ ft^3 (15.2 billion cubic feet). The volume of water in storage in the aquifer equals the product of the volume of saturated aquifer and the estimated porosity (0.3) of the aquifer. The estimated volume of water in storage in the aquifer is about 4.56 $x10^9$ ft^3 (1.52 $x10^{10}$ ft^3 * 0.3 = 4.56 $x10^9$ ft^3) or about 104,700 acre-ft. Assuming a specific yield of about 0.22 and a specific retention of about 0.08, about 76,800 acre-ft of water could drain from the Rogers Mesa aquifer by gravity and about 27,900 acre-ft would be held (retained) against the force of gravity.

The volume of unsaturated aquifer above the water table, including the soil zone, was estimated by subtracting the altitude of the water table (fig. 8) from the altitude of the land surface. The estimated volume of unsaturated alluvial-fan deposits and soils on Rogers Mesa is about 1.89 $x10^{10}$ ft^3. Assuming a specific retention of 0.08, a minimum of about 1.51 $x10^9$ ft^3 (1.89 $x10^{10}$ ft^3 * 0.08 = 1.51 $x10^9$ ft^3) or about 34,700 acre-ft of water is retained between the land surface and the water table. Assuming a specific yield of 0.22, the amount of unsaturated pore space between the land surface and the water table is about 4.16 $x10^9$ ft^3 (1.89 $x10^{10}$ ft^3 * 0.22 = 4.16 $x10^9$ ft^3) or about 95,450 acre-ft.

Well Yields

The reported yields (pumping rates) of wells on Rogers Mesa range from less than 1 to 500 gal/min (fig. 11) and generally are adequate for residential supplies. The median reported yield for commercial and residential (small-capacity) wells was 15 gal/min (fig. 11). However, results from drillers' pumping tests and pump-installation tests (fig. 10) indicate that many of the small-capacity wells on Rogers Mesa cannot maintain pumping rates of 15 gal/min for long periods. The typical volume of water permitted for self-supplied in-house use in Colorado is 0.3 acre-ft/yr (Colorado Division of Water Resources, 2006). A well capable of producing 15 gal/min could withdraw 0.3 acre-ft/yr while pumping less than 20 minutes per day. Pumping rates for domestic and residential wells of only a few gallons per minute also can yield an adequate supply for in-house use. An estimated 76,800 acre-ft of ground water is physically available for withdrawal within the boundaries of the Rogers Mesa aquifer and well yields generally are adequate to supply in-house water use. However, increased ground-water pumping may not be sustainable and ultimately could decrease the volume of ground water discharged to seeps, springs, and streams, and could decrease the saturated thickness at and yields of existing wells.

Sustainability

For a subdivision's water supply to be sustainable, the rate of withdrawal cannot exceed the capture of additional recharge and other discharge from the aquifer. Recharge and discharge conditions of the aquifer must be quantified so the potential effects of increased pumping by new wells can be anticipated. A water budget is an accounting of the flow in and out and the change in storage of water in a hydrologic system. A water budget provides a preliminary means of evaluating the relative importance of recharge and discharge processes. However, a water budget is only a preliminary evaluation and cannot be used to predict when and where the effects of additional ground-water withdrawals will occur. A numerical ground-water flow model may be needed to evaluate the sustainability of a ground-water supply and the potential effects of additional pumping on the hydrologic system.

Water Budget

A water budget is based on the principle of conservation of mass—inflow minus outflow equals change in storage. The inflow and outflow components of a water budget often are estimated because much of the data needed to prepare a water budget are not readily available. Although a water budget is an estimate and has unknown error, the development of a water budget helps focus attention on the interconnectedness of a hydrologic system and the relative contribution of the various components of the system. A hydrologic system, as used in this report, includes both surface and subsurface water and the processes by which water is exchanged between the atmosphere, surface, and subsurface.

A quasi-steady-state water budget was prepared for Rogers Mesa as part of the evaluation of the sustainability of the aquifer. A quasi-steady-state condition means that inflow approximately equals outflow and there is no substantial change in ground-water storage. Although inflow, outflow, and ground-water storage of Rogers Mesa vary seasonally, the average water budget for Rogers Mesa for periods greater than a few years in duration likely approximates a quasi-steady-state condition. Surface water diverted from the North Fork Gunnison River and Leroux Creek for irrigation on Rogers Mesa is the principal source of recharge to the aquifer and was relatively constant during irrigation years 1999–2006. Although the use of ground water for irrigation is not measured, it is relatively small in comparison to the use of surface water for irrigation. However, few long-term water-level data or records of spring discharge from the Rogers Mesa aquifer are available to confirm the assumption of quasi-steady-state conditions.

The estimated annual water budget for Rogers Mesa (table 3) was prepared for average annual conditions during irrigation years 1999–2006. The period 1999–2006 was selected for estimating the water budget from Rogers Mesa because meteorological data were available to estimate consumptive use (evapotranspiration) from irrigated land. The irrigation year was used in the water budget because surface-water diversions in Colorado are reported on that basis. The water budget for Rogers Mesa includes estimates of inflows to and outflows from the land surface and the aquifer. The water budget was used to estimate recharge to the aquifer from the surface and to estimate discharge at the aquifer boundaries.

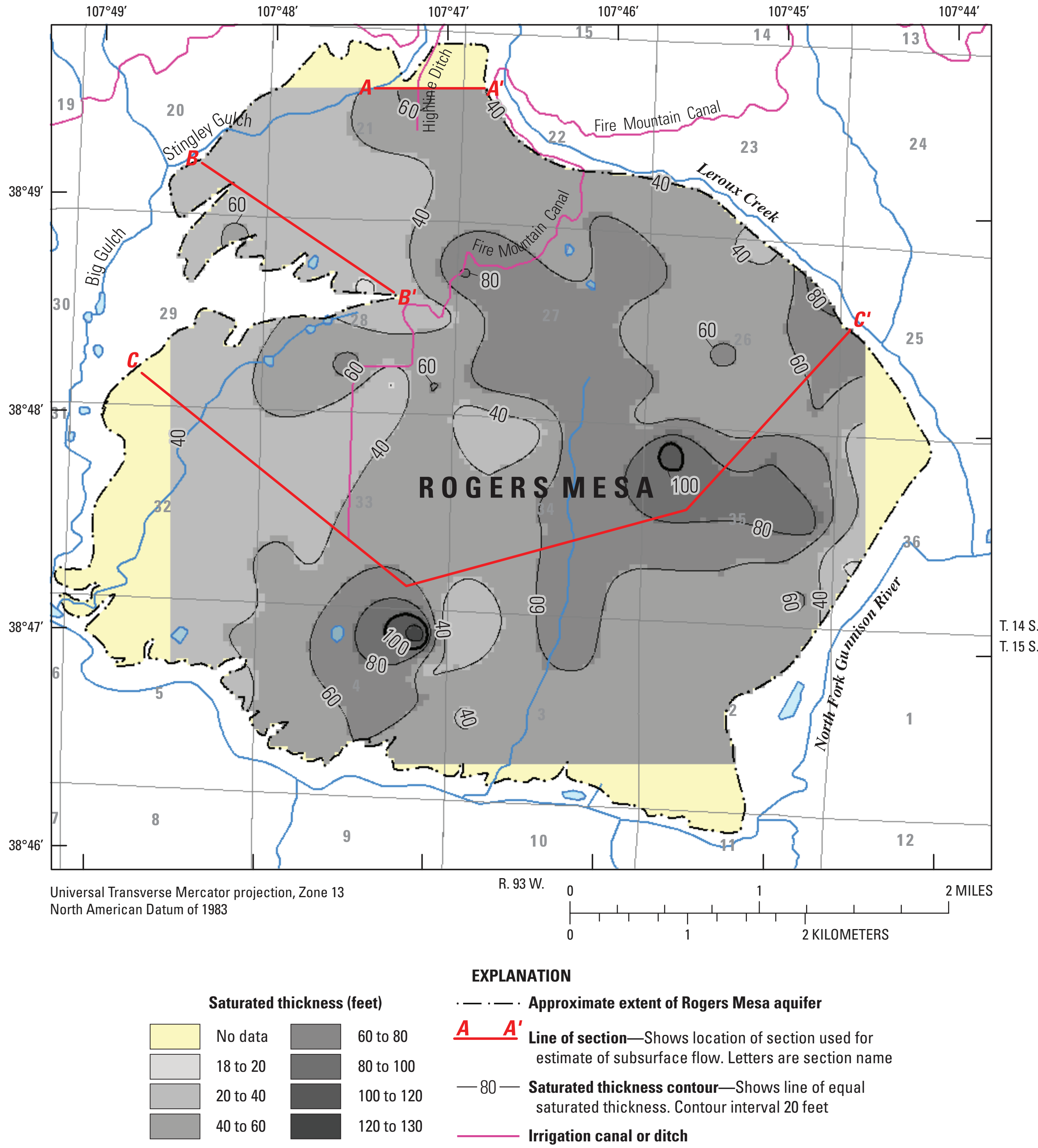


Figure 10. Generalized saturated thickness of the Rogers Mesa aquifer, Delta County, Colorado.

The water-budget estimates of recharge to and discharge from the aquifer were used with Darcy's law (Lohman and others, 1972, eq. 2) to estimate the average hydraulic conductivity of the aquifer.

Surface Inflow

The principal sources of inflow to the surface on Rogers Mesa are surface-water diversions from the North Fork Gunnison River and Leroux Creek for irrigation of crops (alfalfa, corn, and small grains), grass pasture, and orchards. Irrigation with ground water and precipitation also are sources of inflow to the surface. Because the amounts of surface-water diversions are reported to the DWR at the points of diversion, the reported amounts of diversions can include water used upstream from Rogers Mesa and conveyance losses that occur between the points of diversion and Rogers Mesa. Conveyance loss refers to the water that is lost by evaporation, evapotranspiration, seepage, and spillage, as irrigation water travels from its source to the irrigated field (Price, 1995). Reported amounts of monthly diversions to Fire Mountain Canal and Highline Ditch were decreased on the basis of the proportion of the area on Rogers Mesa irrigated with water from each system to the total irrigated area for each system. The estimated amount of diversions by Fire Mountain Canal and Highline Ditch to Rogers Mesa also were decreased for conveyance losses that occur upstream from Rogers Mesa. Published estimates of conveyance losses from irrigation canals and ditches are not available for the study area. The estimated amounts of diversions that were delivered by Fire Mountain Canal to Rogers Mesa were decreased by 25 percent for upstream conveyance losses; similarly, the estimated amounts of surface-water diversions that were delivered by Highline Ditch to Rogers Mesa were decreased by 10 percent for upstream conveyance losses. Conveyance losses were not estimated for the other ditches (table 3) that divert water for irrigation on Rogers Mesa. The mean (average) of the estimated annual diversions for irrigation on Rogers Mesa during irrigation years 1999–2006 was about 34,311 acre-ft (table 3). Variability in estimated annual diversions to Rogers Mesa during 1999–2006 was relatively small, as indicated by the standard deviation for estimated annual surface-water diversions of about 6,162 acre-ft. The minimum of estimated annual diversions for irrigation on Rogers Mesa during irrigation years 1999–2006 was 21,153 acre-ft, during irrigation year 2002, and the maximum was 40,190 acre-ft, during irrigation year 2005. Fire Mountain Canal, Highline Ditch, and Leroux Creek Ditch (fig. 1) are estimated to have supplied, on average, about 89 percent of the surface water diverted to Rogers Mesa (table 3).

An estimated 976 acre-ft/yr of ground water may be used to irrigate an estimated 723 acres of cropland and pasture on Rogers Mesa, and an estimated 294 acre-ft/yr of ground water may be used to irrigate an estimated 78 acres of lawn and garden on Rogers Mesa. However, ground-water use for irrigation on Rogers Mesa generally is not measured or reported and field investigations are needed to corroborate estimated ground-water use for irrigation.

Average annual precipitation during irrigation years 1999–2006 at station HOT01 was about 0.87 ft (10.4 in.). Assuming uniform precipitation on the 7,641-acre study area, the volume of precipitation averages about 6,647 acre-ft/yr. About 4,916 acre-ft of the annual precipitation occurs on irrigated cropland and pasture and the remainder, 1,731 acre-ft, occurs on nonirrigated land.

Surface Outflow

The largest components of outflow from the surface in the water budget for Rogers Mesa are infiltration of irrigation water and precipitation through the soil and unsaturated zone to the water table and the consumptive use (evapotranspiration) of water by irrigated crops, grass pasture, and orchards (table 3). Other minor outflows from the surface include consumptive use from lawns and gardens; and evapotranspiration from non-irrigated land, riparian areas, and ponds. Because infiltration of irrigation water and precipitation is not measured, it was estimated as the difference between inflow to and other outflows from the surface.

Monthly consumptive use of water by crops, grass pasture, and orchards during irrigation years 1999–2006 was estimated for irrigated areas on Rogers Mesa (Colorado Division of Water Resources, and Colorado Water Conservation Board, 2007) from the following information:

1. Daily reference evapotranspiration rates from measurements at COAGMET meteorological station HOT01 (location shown in figure 6) were available online at *http://ccc.atmos.colostate.edu/~coagmet/*;
2. Seasonal crop coefficients (Broner, 1993, table 4); and
3. Geographic information system (geospatial) data for irrigated areas in 2000 from the Colorado Decision Support Systems website (*http://cdss.state.co.us/DNN/GIS/tabid/67/Default.aspx*).

Daily consumptive use was calculated for each crop type as the product of daily reference evapotranspiration rate and the seasonal crop coefficient. Monthly consumptive use of water was calculated by summing the daily values by month. The estimates of monthly consumptive use for each crop type were summed for each irrigation year from 1999 through 2006. The annual rates of consumptive use were multiplied by the estimated acreage for each crop to estimate average annual consumptive use during irrigation years 1999 through 2006 (table 3). Estimates that are more precise might be achieved by calculating consumptive use on a daily basis and incorporating soil-moisture conditions to estimate daily infiltration below the root zone.

Evapotranspiration was estimated to consume about 92 percent of precipitation on non-irrigated land. During the growing season, April through October, rates of evapotranspiration greatly exceed rates of precipitation (fig. 5) and there is

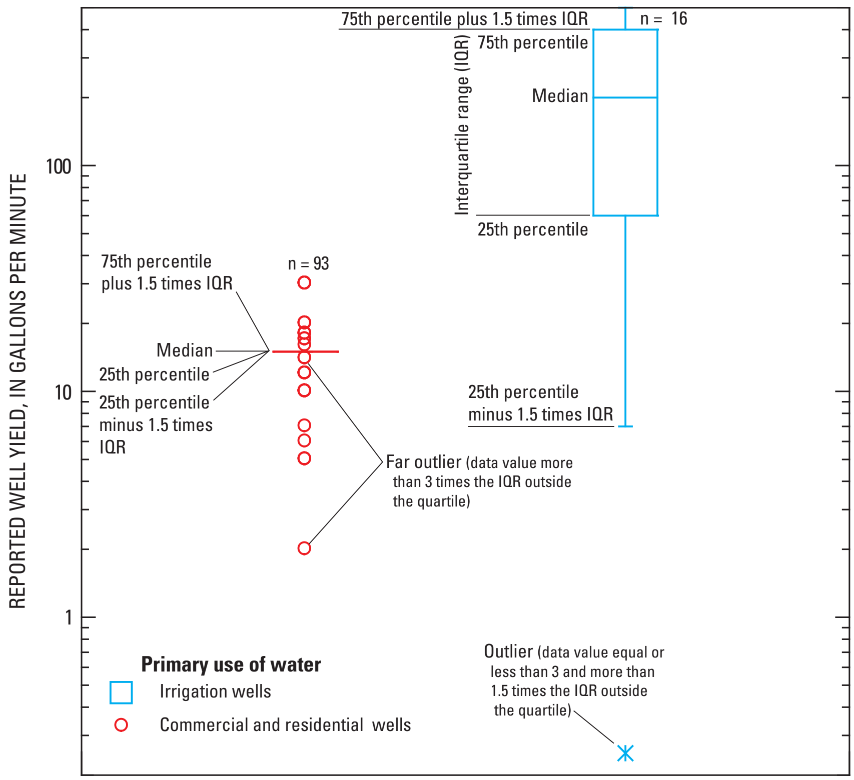


Figure 11. Reported yields of wells, Rogers Mesa, Delta County, Colorado.

little potential for recharge from infiltration of precipitation. Published estimates of ground-water recharge from precipitation are not available for the study area. Precipitation during November through March averaged about 0.25 ft (3 inches). Although monthly evapotranspiration during November through March of irrigation years 1999–2006 generally exceeded precipitation, it was assumed that part of the precipitation during November through March infiltrates below the soil zone and recharges the aquifer. Recharge from infiltration of precipitation is an assumed 0.07 ft/yr or about 8 percent of annual precipitation.

Evapotranspiration by vegetation in riparian areas and evaporation from ponds was estimated. Riparian (vegetated) area along surface drainages was estimated from a geographic information system coverage of hydrologic features and a digital image of Rogers Mesa from the National Agricultural Imagery Project (U.S. Department of Agriculture, Farm Service Agency, 2007) to be about 10 acres. Areas of ponds were estimated from the geographic information system coverage of hydrologic features to be about 10.5 acres. The difference between average annual reference evapotranspiration and precipitation of 3.8 ft/yr was assumed to equal the evapotranspiration rate from riparian vegetation and ponds. Annual evapotranspiration from riparian areas and evaporation from ponds was estimated as the product of area and the assumed evapotranspiration rate.

Infiltration of water from the surface to the water table was estimated as the difference between the volume of water applied naturally by precipitation and artificially by irrigation to the surface and the volume consumed by evapotranspiration. The combined volume of surface water and ground water for irrigation and precipitation on irrigated and nonirrigated land, ponds, and riparian areas during irrigation years 1999–2006 averaged 42,228 acre-ft/yr (table 3). The combined volume of estimated consumptive use from the land surface, including consumptive use from irrigated land and evapotranspiration from nonirrigated land, riparian areas, and ponds, averaged 11,461 acre-ft/yr during that same period (table 3). The difference between the volume of water applied to the surface (surface inflow) and that consumed by evapotranspiration (surface outflow) averaged 30,767 acre-ft/yr during irrigation years 1999–2006 and is assumed to equal ground-water recharge from the surface.

Ground-Water Inflow

Ground-water inflow to the Rogers Mesa aquifer consists of infiltration from the surface (30,767 acre-ft/yr), infiltration in the subsurface from ISDS, and subsurface inflow. Infiltration from the surface was an estimated 30,767 acre-ft/yr during irrigation years 1999–2006. Infiltration in the subsurface from ISDS was assumed to equal 90 percent of in-house

Table 3. Estimated average annual water budget for Rogers Mesa, Delta County, Colorado, November 1998 through October 2006.

[--, not applicable; <, less than]

Water-budget components	Number of sites	Estimated area (acres)	Average annual rate (feet per year)	Average annual volume (acre-feet)
Surface inflow				
Surface-water diversions (structure number)				
Big Gulch Ditch (4000915)	--	144	7.7	1,109
Fire Mountain Canal (4001133)	--	3,489	7.9	20,573
Fleming Ditch (4000922)	--	29	16.9	490
Highline Ditch (4000923)[1]	--	857	7.9	6,072
Isom Ditch (4000925)	--	61	8.5	521
Jessie Ditch (4000929)	--	252	4.7	1,176
Leroux Creek Ditch (4000926)	--	685	5.9	4,014
Little Mary Ditch (4000927)	--	56	6.4	356
Ground-water irrigation				
Cropland	21	723	1.35	976
Lawn and garden	80	78	3.8	294
Precipitation, irrigated land, and lawn and garden	--	5,651	.87	4,916
Precipitation, nonirrigated land	--	1,990	.87	1,731
			Subtotal	42,228
Surface outflow				
Streamflow (assumed)				0
Consumptive use, irrigated land				
Alfalfa	--	633.6	–2.3	–1,451
Corn	--	13.9	–2.2	–30
Grass pasture	--	3,991.4	–1.6	–6,346
Orchard	--	930.9	–2.0	–1,834
Small grains	--	3.4	–1.9	–6
Consumptive use, lawn and garden	--	78	–1.6	–124
Evapotranspiration, non-irrigated land	--	1,990	–0.8	–1,592
Evapotranspiration from riparian areas	--	10	–3.8	–38
Evapotranspiration from ponds	--	10.5	–3.8	–40
			Subtotal	–11,461
Surface inflow minus surface outflow				**30,767**

Table 3. Estimated average annual water budget for Rogers Mesa, Delta County, Colorado, November 1998 through October 2006.—Continued

[--, not applicable; <, less than]

Water-budget components	Number of sites	Estimated area (acres)	Average annual rate (feet per year)	Average annual volume (acre-feet)
Ground-water inflow				
Infiltration from the surface[2]				30,767
Infiltration, individual sewage disposal systems	571	--	0.27	119
Subsurface inflow from north	--	--	--	4,491
Subsurface inflow from Leroux Creek	--	--	--	533
			Subtotal	35,910
Ground-water outflow				
Estimated pumpage				
Commercial wells	3	--	–.3	–1
Domestic wells including 78 acres of irrigated lawn and garden	98	--	–3.0	–298
Residential wells	40	--	–.3	–12
Irrigation wells[3]	21	723	–1.35	–976
Livestock well	1	--	--	1
Subsurface outflow (excluding discharge of springs with decreed rates)	--	--	--	–27,822
Springs with decreed rates	20	--	--	–6,800
			Subtotal	–35,910
Change in ground-water storage (ground-water inflow minus ground-water outflow)				**0**

[1]Reported diversions by the Fire Mountain Canal and Highline Ditch were reduced for upstream water use and conveyance loss.

[2]Infiltration from the surface was estimated as the difference between surface inflow and surface outflow.

[3]The average annual volume of water pumped by irrigation wells was estimated from decreed rates of diversion.

water use for 3 commercial, 98 domestic, and 40 residential wells, and for the 430 active water taps. Estimated infiltration from ISDS in the subsurface was about 119 acre-ft/yr. Although the volume of recharge from ISDS is relatively small in comparison with other water-budget components, infiltration of effluent from ISDS could affect the quality of ground water.

Subsurface flow equals the product of aquifer width (perpendicular to flow), saturated thickness, hydraulic conductivity, hydraulic gradient, and time. Subsurface inflow into the Rogers Mesa aquifer from the north (fig. 10, Section *A–A'*) was estimated for steady flow as the product of saturated cross-sectional area, an assumed average hydraulic conductivity of 107 ft/d, hydraulic gradient, and the cosine of the estimated angle between the water-table contours and section *A–A'*. The assumed average hydraulic conductivity value for the Rogers Mesa aquifer (107 ft/d) was the value needed to balance subsurface flow in the water budget. The cosine of the angle between the water-table contours and segments of section *A–A'* was included in the computation because section *A–A'* is not parallel to the water table contours (fig. 8). By definition, the hydraulic gradient is in the direction of maximum decrease in head (Lohman and others, 1972), which is perpendicular to water table contours in an isotropic aquifer. Estimated subsurface flow across section *A–A'* was 535,925 ft^3/d or about 4,491 acre-ft/yr.

Leroux Creek, North Fork Gunnison River, and Big Gulch have cut through the alluvial-fan deposits into sedimentary rocks and as a result, their valley floors generally are topographically lower than the base of the Rogers Mesa aquifer. Therefore, the boundary of the Rogers Mesa aquifer generally is a discharge boundary at which ground water discharges at seeps and springs or into slope deposits. However, in the southwest quarter of sec. 23, T. 14 S, R. 93 W., the base of the aquifer likely is at a lower altitude than Leroux Creek (fig. 3), and Leroux Creek may be losing water to the aquifer. The water-table surface (fig. 8) in that area also indicates a potential for flow from Leroux Creek into the aquifer along a 1,350-ft long stream reach. Streamflow loss from Leroux Creek to the aquifer was estimated as the product of an estimated 1,350-ft long stream reach, a saturated aquifer thickness of 40 ft (fig. 10), an assumed average hydraulic conductivity of 107 ft/d, and a hydraulic gradient of 0.011, to be about 63,610 ft^3/d or 533 acre-ft/yr. However, the accuracies of the altitudes of the base of the aquifer (fig. 3) and of the water table (fig. 8) are inadequate to confirm a direct hydraulic connection between the stream and aquifer. Additional field investigations are needed to confirm streamflow loss from Leroux Creek to the aquifer. Streamflow loss to the aquifer of this magnitude possibly could be measured for low streamflow rates.

Ground-Water Outflow

Ground water pumped by wells represents a relatively small portion of total ground-water outflow from Rogers Mesa aquifer. Ground-water outflow from the Rogers Mesa aquifer is primarily subsurface outflow at the aquifer boundary and discharge to springs and seeps.

In 2004, 98 domestic wells, 40 residential wells, 21 irrigation wells, 3 commercial wells, and 1 livestock well had permits to pump water from the Rogers Mesa aquifer. Ground-water withdrawals are not routinely monitored or reported. Estimated ground-water withdrawal by permitted wells from Rogers Mesa aquifer was about 1,290 acre/ft/yr (table 3).

Assuming that there was no long-term change in ground-water storage during irrigation years 1999–2006, subsurface flow toward the downgradient boundaries of the aquifer equals the average infiltration to the water table plus subsurface inflow from the north (fig. 10, section *A–A'*) and from Leroux Creek minus ground-water withdrawals by wells. Using this assumption, subsurface flow toward the downgradient boundaries of the aquifer and including estimated discharge to springs is an estimated 34,622 acre-ft/yr (about 48 ft^3/s).

Subsurface flow through sections *B–B'* and *C–C'* (fig. 10) toward the downgradient boundaries of the aquifer was estimated as the product of saturated cross-sectional areas, hydraulic gradients, and hydraulic conductivity. The saturated cross-sectional areas (the product of aquifer width and saturated thickness) of sections *B–B'* and *C–C'* were about 195,000 and 1,089,000 ft^2, respectively; the average hydraulic gradients perpendicular to sections *B–B'* and *C–C'* were 0.02 and 0.018, respectively; and the average hydraulic conductivity was an assumed 107 ft/d. Combined subsurface flow through sections *B–B'* and *C–C'* was an estimated 21,800 acre-ft/yr. The estimated flow through sections *B–B'* and *C–C'* is less than the estimated 34,622 acre-ft/yr of subsurface outflow from the aquifer because net recharge (infiltration from the surface minus well discharge) downgradient from sections *B–B'* and *C–C'* is about 12,822 acre-ft/yr.

The assumed hydraulic conductivity of 107 ft/d that was used to estimate subsurface flow for the Rogers Mesa aquifer is substantially larger than the median hydraulic conductivity of 6 ft/d that was estimated from drillers' pumping tests and pump-installation tests but is within the range of plausible values for unconsolidated sand and gravel (Freeze and Cherry, 1979, table 2.2, p. 29). Aquifer tests are needed to determine the hydraulic properties of the Rogers Mesa aquifer. The average hydraulic conductivity value of 107 ft/d is a relative value; if the components of the water budget, especially infiltration from the surface, can be estimated more precisely, the average hydraulic conductivity value for the aquifer also can be estimated more precisely.

Ground-Water Storage

Although the volume of water stored in the Rogers Mesa aquifer likely varies seasonally with changes in recharge and discharge, seasonal changes in storage could not be evaluated because no long-term water-level data are available for the aquifer. The estimated volume of ground water stored in the saturated part of the aquifer is about 107,000 acre-ft, but only part of that water could be withdrawn by wells. An estimated 37,000 acre-ft of water also is retained in the unsaturated zone by capillary forces.

Water-Budget Errors

Errors in the individual components of the water budget for Rogers Mesa (table 3) likely are large and increase uncertainty in the evaluation of the availability and sustainability of ground water on Rogers Mesa. Because errors in individual components of a budget are additive, they are propagated through the budget when it is used to estimate other components, such as ground-water recharge and discharge. The largest errors in the ground-water budget for Rogers Mesa result primarily from errors in the estimated volume of irrigation water applied to the land surface and in estimates of consumptive use of water by irrigated crops, grass pasture, and orchards.

Uncertainty in estimated recharge to the aquifer can be decreased if errors in the other components of the budget can be decreased. Although diversions by Fire Mountain Canal, Highline Ditch, and Leroux Creek Ditch are measured at their points of diversion, actual deliveries of surface-water diversions to Rogers Mesa are not reported. When the diversion point is distant from the place of water application, estimates of conveyance loss and use of water outside the study area introduce unknown errors in the estimated amount of water delivered to Rogers Mesa.

Suitability

The suitability of ground water from individual residential wells for domestic use in a subdivision is a function of the physical, chemical, and biological characteristics of the water. Data from numerous sites in the Rogers Mesa area are available from the National Water Information System (NWIS); however, results are limited principally to measurements of physical properties of water and selenium concentrations. Analytical results in the NWIS for physical properties and concentrations of major ions, nutrients, and selected trace constituents were available for only six ground-water wells on Rogers Mesa (table 4). Analytical results for another four ground-water wells (domestic or residential wells) on Rogers Mesa (table 4) were available from the Delta County Environmental Health Division. Data from the NWIS are available at *http://waterdata.usgs.gov/co/nwis/*. Values of physical properties and concentrations of selected chemical constituents in ground water from Rogers Mesa aquifer are included in a reconnaissance report on the ground-water resources in North Fork Gunnison River Basin (Ackerman and Brooks, 1986).

Collection of ground-water samples by the USGS for biological analyses is not routine, and few data are available for the study area in published reports or publicly accessible databases. The Delta County Environmental Health Division reviews subdivision proposals for adequacy of private drinking-water supplies. Testing is required to prove that the water is a safe potable supply (Delta County Environmental Health Division, 2007). The Colorado Department of Public Health and Environment (2002) provides information about the safety of drinking water from wells and a list of certified laboratories that can test water samples. Bacteriologic sample containers are available at the Delta County Environmental Health Division office to sample water for contamination.

Values of physical properties and concentrations of selenium in surface-water samples are included in table 4 because those results represent the quality of water diverted from streams for irrigation and, in some areas, the quality of ground water discharged from the aquifer to surface drainages. Specific conductance of water is a function of the concentration and types of dissolved ions in the water and is an indicator of the salinity or dissolved-solids content of water (Hem, 1985). The variability of specific conductance of surface-water samples in the Rogers Mesa vicinity is large. Specific conductance values of surface-water samples range from 135 µS/cm (Fire Mountain Canal at Leroux Creek) to 2,650 µS/cm (Big Gulch at Highway 92; table 4). Concentrations of dissolved solids in ground water discharged from the Rogers Mesa aquifer towards Big Gulch likely are increased by evapotranspiration of water from the soils and by dissolution of minerals the water contacts in the subsurface, as indicated by the presence of salt crusts and saline soils along Big Gulch. Studies by the Bureau of Reclamation indicate that salt loading occurs when seepage from irrigation conveyance systems and irrigation return flow passes through highly saline soils and the underlying Mancos Shale (Bureau of Reclamation, 2007).

Results for ground-water samples from Rogers Mesa (table 4) were compared with Colorado's drinking-water standards (Colorado Department of Public Health and Environment, 2005) for selected physical properties and chemical constituents. On the basis of these few comparisons, ground water from Rogers Mesa aquifer is considered suitable for domestic use with a few exceptions. The pH of a sample from Doughty Springs (table 4, site-identification number 384611107453000) was 6.3 standard units, which is below the acceptable range of 6.5 to 8.5 standard units. Concentrations of dissolved solids exceed the U.S. Environmental Protection Agency Secondary Maximum Contaminant Level (SMCL) of 500 mg/L (Colorado Department of Public Health and Environment, 2005, table 3–1) for 11 of 12 ground-water samples from Rogers Mesa aquifer (table 4). SMCLs are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water (U.S. Environmental Protection Agency, 2007b). Concentrations of dissolved sulfate exceed the SMCL of 250 mg/L for 3 of 12 ground-water samples (table 4). Without treatment, the large concentrations of dissolved solids, as much as 1,250 mg/L, and sulfate, as much as 633 mg/L, may limit the use of ground water from Rogers Mesa for drinking-water supplies.

Table 4. Values of physical properties and concentrations of selected chemical constituents in ground and surface water from Rogers Mesa and vicinity, Delta County, Colorado.

[The local names are modified from local names in the U.S. Geological Survey National Water Information System. µS/cm, microsiemens per centimeter; °C, degree Celsius; mg/L, milligrams per liter; NWIS, National Water Information System; GW, ground water; --, no value; DCEHD, Delta County Environmental Health Department; SW, surface water; µg/L, micrograms per liter; <, less than; yellow shading indicates that value exceeds secondary drinking-water standard; pink shading indicates that value exceeds primary drinking-water standard; BD, less than method detection limit. Drinking-water standards are available online at *http://www.cdphe.state.co.us/regulations/waterqualitycontroldivision/100301primarydrinkingwater.pdf*]

Site identification number or station name	Local name	Latitude (decimal degrees)	Longitude (decimal degrees)	Site type	Source of data	Sample date	pH (standard units)	Specific conductance (µS/cm)	Temperature, water (°C)	Hardness, as calcium carbonate (mg/L)	Dissolved solids, sum of constituents (mg/L)
					Ground water						
384611107453000	Doughty Springs	38.76970669	107.75894817	Spring	NWIS	19800626	6.3	4,700	14	--	--
384620107455001	Tommy Dowell Spring	38.77220664	107.76450390	Spring	NWIS	19770818	7.6	910	13	320	612
384621107455601	SC01509303DDB1	38.77248440	107.76617062	Spring	NWIS	19780330	8	825	14	350	636
384632107460300	SC01509303DBD1	38.77553991	107.76811513	Spring	NWIS	19780609	--	949	13	340	628
384656107444401	Seep near Delta Fish Hatchery	38.78220666	107.74617013	Seep	NWIS	19981014	8.1	748	13.7	--	--
384707107455201	SC01509303AAA1	38.78526201	107.76505951	Well	NWIS	19790323	--	680	13.5	--	--
384735107470501	SC01409333ADC1	38.79303960	107.78533794	Well	NWIS	19770818	7.6	910	13	360	647
384744107441301	SC01409336BAC1	38.79554002	107.73755896	Spring	NWIS	19790323	7.5	875	13.5	420	772
384753107435601	Seep area in draw below Highway 92	38.79804010	107.73283669	Seep	NWIS	20001205	8.2	851	7.9	--	--
384800107442201	SC01409325CCD1	38.79998435	107.74005900	Well	NWIS	19790323	7.6	875	9	--	--
384801107454201	SC01409326CCC1	38.80026182	107.76228170	Well	NWIS	19780415	7.5	860	14.5	310	683
384809107464501	SC01409327CCC1	38.80248394	107.77978225	Well	NWIS	19790323	7.8	900	9	--	--
384842107444201	T14SR93W026ADD Well near 3300 Road	38.81165072	107.74561465	Well	NWIS	20000620	7.5	1,710	14.1	770	1,250
384854107474501	SC01409328BBA1	38.81498369	107.79894956	Well	NWIS	19780331	7.5	535	13	280	381
384855107450101	Seep along Leroux Creek above Duke Ditch	38.81526167	107.75089250	Seep	NWIS	20000620	8	1,400	12.4	--	--
384912107482601	Lower seep area along Stingley Gulch	38.81987248	107.80769985	Seep	NWIS	20001206	7.8	883	3.2	--	--
384918107481801	Seep on right bank of Stingley Gulch	38.82151136	107.80547756	Seep	NWIS	20001206	7.7	2,190	2.9	--	--

Table 4. Values of physical properties and concentrations of selected chemical constituents in ground and surface water from Rogers Mesa and vicinity, Delta County, Colorado.—Continued

[The local names are modified from local names in the U.S. Geological Survey National Water Information System. µS/cm, microsiemens per centimeter; °C, degree Celsius; mg/L, milligrams per liter; NWIS, National Water Information System; GW, ground water; --, no value; DCEHD, Delta County Environmental Health Department; SW, surface water; µg/L, micrograms per liter; <, less than; yellow shading indicates that value exceeds secondary drinking-water standard; pink shading indicates that value exceeds primary drinking-water standard; BD, less than method detection limit. Drinking-water standards are available online at *http://www.cdphe.state.co.us/regulations/waterqualitycontroldivision/100301primarydrinkingwater.pdf*]

Site identification number or station name	Local name	Latitude (decimal degrees)	Longitude (decimal degrees)	Site type	Source of data	Sample date	pH (standard units)	Specific conductance (µS/cm)	Temperature, water (°C)	Hardness, as calcium carbonate (mg/L)	Dissolved solids, sum of constituents (mg/L)
					Ground water—Continued						
AG1	3176 L Road	38.814889	107.768860	Well	DCEHD	--	7.8	720	--	318	535
JTH1	3144 Highway 92	38.800153	107.770896	Well	DCEHD	--	7.9	831	--	297	624
LCA1	1096 3250 Road	38.813052	107.753332	Well	DCEHD	--	7.28	700	--	195	678
LF1	1125 3080 Road	38.820951	107.786510	Well	DCEHD	--	7.49	1,120	--	--	784
					Surface water						
384756107490801	Big Gulch at Highway 92	38.79887271	107.81950568	Stream	NWIS	19990512	7.7	2,650	14.5	--	--
384756107490801	Big Gulch at Highway 92	38.79887271	107.81950568	Stream	NWIS	19990831	7.8	2,140	15.8	--	--
384756107490801	Big Gulch at Highway 92	38.79887271	107.81950568	Stream	NWIS	19991109	8.2	1,320	8.3	--	--
384756107490801	Big Gulch at Highway 92	38.79887271	107.81950568	Stream	NWIS	20000314	8.6	1,140	7.3	--	--
384842107443901	Leroux Creek at 3300 Road	38.81165074	107.74478131	Stream	NWIS	20000314	8.6	1,010	10.6	--	--
384842107443901	Leroux Creek at 3300 Road	38.81165074	107.74478131	Stream	NWIS	20000620	8.4	1,210	17.5	--	--
384853107451201	Jessie Ditch at 3250 and L Roads	38.81470611	107.75394815	Diversion	NWIS	20000725	8.2	626	15.8	--	--
384854107450201	Leroux Creek above Duke Ditch Diversion	38.81498389	107.75117029	Stream	NWIS	20000328	8.5	933	13.9	--	--
384854107450201	Leroux Creek above Duke Ditch Diversion	38.81498389	107.75117029	Stream	NWIS	20000620	8.4	1,010	17	--	--
384910107482701	Stingley Gulch above Big Gulch	38.81953915	107.80800541	Stream	NWIS	20001206	8.3	1,250	5.2	--	--

Table 4. Values of physical properties and concentrations of selected chemical constituents in ground and surface water from Rogers Mesa and vicinity, Delta County, Colorado.—Continued

[The local names are modified from local names in the U.S. Geological Survey National Water Information System. µS/cm, microsiemens per centimeter; °C, degree Celsius; mg/L, milligrams per liter; NWIS, National Water Information System; GW, ground water; --, no value; DCEHD, Delta County Environmental Health Department; SW, surface water; µg/L, micrograms per liter; <, less than; yellow shading indicates that value exceeds secondary drinking-water standard; pink shading indicates that value exceeds primary drinking-water standard; BD, less than method detection limit. Drinking-water standards are available online at *http://www.cdphe.state.co.us/regulations/waterqualitycontroldivision/100301primarydrinkingwater.pdf*]

Site identification number or station name	Local name	Latitude (decimal degrees)	Longitude (decimal degrees)	Site type	Source of data	Sample date	pH (standard units)	Specific conductance (µS/cm)	Temperature, water (°C)	Hardness, as calcium carbonate (mg/L)	Dissolved solids, sum of constituents (mg/L)
Surface water—Continued											
384914107460601	Jessie Ditch Diversion, Leroux Creek	38.82053930	107.76894864	Diversion	NWIS	20000328	8.3	1,860	10.1	--	--
384915107460801	Leroux Creek above Jessie Ditch Diversion	38.82081707	107.76950421	Stream	NWIS	20000620	8	2,570	14.7	--	--
384919107481601	Stingley Gulch at West Draw	38.82192802	107.80492199	Stream	NWIS	20001206	8	1,410	7.1	--	--
384937107463801	Leroux Creek below Fire Mountain Canal	38.82692806	107.77783783	Stream	NWIS	20000620	8.3	2,020	16.6	--	--
384938107463601	Fire Mountain Canal at Leroux Creek	38.82720584	107.77728226	Diversion	NWIS	20000620	8.1	135	13.7	--	--
384942107463701	Leroux Creek Diversion at Fire Mountain Canal	38.82831694	107.77756005	Diversion	NWIS	20000328	8.6	1,340	11.2	--	--
384944107463601	Leroux Creek above Fire Mountain Canal	38.82887248	107.77728226	Stream	NWIS	20000620	8.5	1,320	13.1	--	--

Table 4. Values of physical properties and concentrations of selected chemical constituents in ground and surface water from Rogers Mesa and vicinity, Delta County, Colorado.—Continued

[The local names are modified from local names in the U.S. Geological Survey National Water Information System. µS/cm, microsiemens per centimeter; °C, degree Celsius; mg/L, milligrams per liter; NWIS, National Water Information System; GW, ground water; --, no value; DCEHD, Delta County Environmental Health Department; SW, surface water; µg/L, micrograms per liter; <, less than; yellow shading indicates that value exceeds secondary drinking-water standard; pink shading indicates that value exceeds primary drinking-water standard; BD, less than method detection limit. Drinking-water standards are available online at *http://www.cdphe.state.co.us/regulations/waterqualitycontroldivision/100301primarydrinkingwater.pdf*]

Site identification number or station name	Local name	Sample date	Calcium (mg/L)	Mag-nesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Acid neutral-izing capac-ity, as calcium carbonate (mg/L)	Alkalinity, as calcium carbonate (mg/L)	Bicar-bonate (mg/L)	Car-bonate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Sulfate (mg/L)
Ground water														
384611107453000	Doughty Springs	19800626	--	--	--	--	--	--	--	--	--	--	--	--
384620107455001	Tommy Dowell Spring	19770818	59	41	16.0	78	340	--	420	0	5	0.70	36.0	160
384621107455601	SC01509303DDB1	19780330	60	48	17.0	85	350	--	430	0	6.3	.60	39.0	160
384632107460300	SC01509303DBD1	19780609	61	45	16.0	85	340	--	420	0	5.9	.90	40.0	160
384656107444401	Seep near Delta Fish Hatchery	19981014	--	--	--	--	--	--	--	--	--	--	--	--
384707107455201	SC01509303AAA1	19790323	--	--	--	--	--	--	--	--	--	--	--	--
384735107470501	SC01409333ADC1	19770818	47	59	19.0	77	340	--	420	0	7.9	.60	35.0	190
384744107441301	SC01409336BAC1	19790323	86	50	13.0	92	340	--	--	--	13	50	38.0	260
384753107435601	Seep area in draw below Highway 92	20001205	--	--	--	--	--	--	--	--	--	--	--	--
384800107442201	SC01409325CCD1	19790323	--	--	--	--	--	--	--	--	--	--	--	--
384801107454201	SC01409326CCC1	19780415	64	37	12.0	110	340	--	410	0	6.4	.50	35.0	210
384809107464501	SC01409327CCC1	19790323	--	--	--	--	--	--	--	--	--	--	--	--
384842107444201	T14SR93W026ADD Well near 3300 Road	20000620	110	120	11.1	104	--	348	--	--	9.62	0.76	41.5	633
384854107474501	SC01409328BBA1	19780331	56	34	7.7	19	250	--	310	0	2.1	1.10	35.0	71
384855107450101	Seep along Leroux Creek above Duke Ditch	20000620	--	--	--	--	--	--	--	--	--	--	--	--

Table 4. Values of physical properties and concentrations of selected chemical constituents in ground and surface water from Rogers Mesa and vicinity, Delta County, Colorado.—Continued

[The local names are modified from local names in the U.S. Geological Survey National Water Information System. µS/cm, microsiemens per centimeter; °C, degree Celsius; mg/L, milligrams per liter; NWIS, National Water Information System; GW, ground water; --, no value; DCEHD, Delta County Environmental Health Department; SW, surface water; µg/L, micrograms per liter; <, less than; yellow shading indicates that value exceeds secondary drinking-water standard; pink shading indicates that value exceeds primary drinking-water standard; BD, less than method detection limit. Drinking-water standards are available online at *http://www.cdphe.state.co.us/regulations/waterqualitycontroldivision/100301primarydrinkingwater.pdf*]

Site identification number or station name	Local name	Sample date	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Acid neutralizing capacity, as calcium carbonate (mg/L)	Alkalinity, as calcium carbonate (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Sulfate (mg/L)
						Ground water—Continued								
384912107482601	Lower seep area along Stingley Gulch	20001206	--	--	--	--	--	--	--	--	--	--	--	--
384918107481801	Seep on right bank of Stingley Gulch	20001206	--	--	--	--	--	--	--	--	--	--	--	--
AG1	3176 L Road	--	50	47	16.3	44	--	347	--	--	--	0.095	--	78
JTH1	3144 Highway 92	--	28	55	14	52	--	328	--	--	--	--	--	98
LCA1	1096 3250 Road	--	--	--	32	294	--	410	--	--	--	.088	--	148
LF1	1125 3080 Road	--	--	--	--	--	--	BD	--	--	--	--	--	500
						Surface water								
384756107490801	Big Gulch at Highway 92	19990512	--	--	--	--	--	--	--	--	--	--	--	--
384756107490801	Big Gulch at Highway 92	19990831	--	--	--	--	--	--	--	--	--	--	--	--
384756107490801	Big Gulch at Highway 92	19991109	--	--	--	--	--	--	--	--	--	--	--	--
384756107490801	Big Gulch at Highway 92	20000314	--	--	--	--	--	--	--	--	--	--	--	--
384842107443901	Leroux Creek at 3300 Road	20000314	--	--	--	--	--	--	--	--	--	--	--	--
384842107443901	Leroux Creek at 3300 Road	20000620	--	--	--	--	--	--	--	--	--	--	--	--
384853107451201	Jessie Ditch at 3250 And L Roads	20000725	--	--	--	--	--	--	--	--	--	--	--	--

Table 4. Values of physical properties and concentrations of selected chemical constituents in ground and surface water from Rogers Mesa and vicinity, Delta County, Colorado.—Continued

[The local names are modified from local names in the U.S. Geological Survey National Water Information System. µS/cm, microsiemens per centimeter; °C, degree Celsius; mg/L, milligrams per liter; NWIS, National Water Information System; GW, ground water; --, no value; DCEHD, Delta County Environmental Health Department; SW, surface water; µg/L, micrograms per liter; <, less than; yellow shading indicates that value exceeds secondary drinking-water standard; pink shading indicates that value exceeds primary drinking-water standard; BD, less than method detection limit. Drinking-water standards are available online at *http://www.cdphe.state.co.us/regulations/waterqualitycontroldivision/100301primarydrinkingwater.pdf*]

Site identification number or station name	Local name	Sample date	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Acid neutralizing capacity, as calcium carbonate (mg/L)	Alkalinity, as calcium carbonate (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Sulfate (mg/L)
Surface water—Continued														
384854107450201	Leroux Creek above Duke Ditch Diversion	20000328	--	--	--	--	--	--	--	--	--	--	--	--
384854107450201	Leroux Creek above Duke Ditch Diversion	20000620	--	--	--	--	--	--	--	--	--	--	--	--
384910107482701	Stingley Gulch above Big Gulch	20001206	--	--	--	--	--	--	--	--	--	--	--	--
384914107460601	Jessie Ditch Diversion, Leroux Creek	20000328	--	--	--	--	--	--	--	--	--	--	--	--
384915107460801	Leroux Creek above Jessie Ditch Diversion	20000620	--	--	--	--	--	--	--	--	--	--	--	--
384919107481601	Stingley Gulch at West Draw	20001206	--	--	--	--	--	--	--	--	--	--	--	--
384937107463801	Leroux Creek below Fire Mountain Canal	20000620	--	--	--	--	--	--	--	--	--	--	--	--
384938107463601	Fire Mountain Canal at Leroux Creek	20000620	--	--	--	--	--	--	--	--	--	--	--	--
384942107463701	Leroux Creek Diversion at Fire Mountain Canal	20000328	--	--	--	--	--	--	--	--	--	--	--	--
384944107463601	Leroux Creek above Fire Mountain Canal	20000620	--	--	--	--	--	--	--	--	--	--	--	--

Table 4. Values of physical properties and concentrations of selected chemical constituents in ground and surface water from Rogers Mesa and vicinity, Delta County, Colorado.—Continued

[The local names are modified from local names in the U.S. Geological Survey National Water Information System. µS/cm, microsiemens per centimeter; °C, degree Celsius; mg/L, milligrams per liter; NWIS, National Water Information System; GW, ground water; --, no value; DCEHD, Delta County Environmental Health Department; SW, surface water; µg/L, micrograms per liter; <, less than; yellow shading indicates that value exceeds secondary drinking-water standard; pink shading indicates that value exceeds primary drinking-water standard; BD, less than method detection limit. Drinking-water standards are available online at *http://www.cdphe.state.co.us/regulations/waterqualitycontroldivision/100301primarydrinkingwater.pdf*]

Station or site identification number or name	Local name	Sample date	Nitrite plus nitrate, as nitrogen (mg/L)	Orthophosphate, as phosphorus (mg/L)	Orthophosphate (mg/L)	Phosphorus (µg/L)	Iron (µg/L)	Manganese (µg/L)	Selenium (µg/L)
Ground water									
384611107453000	Doughty Springs	19800626	--	--	--	--	--	--	0
384620107455001	Tommy Dowell Spring	19770818	2.10	10	0.06	--	<10	<10	--
384621107455601	SC01509303DDB1	19780330	1.50	20	.06	--	20	<10	6
384632107460300	SC01509303DBD1	19780609	1.60	80	.06	--	80	<10	--
384656107444401	Seep near Delta Fish Hatchery	19981014	--	--	--	--	--	--	1
384707107455201	SC01509303AAA1	19790323	--	--	--	--	--	--	--
384735107470501	SC01409333ADC1	19770818	1.00	10	.12	--	<10	<10	--
384744107441301	SC01409336BAC1	19790323	3.20	20	.12	0.030	20	<10	6
384753107435601	Seep area in draw below Highway 92	20001205	--	--	--	--	--	--	2.4
384800107442201	SC01409325CCD1	19790323	--	--	--	--	--	--	--
384801107454201	SC01409326CCC1	19780415	1.10	40	.06	--	40	<10	2
384809107464501	SC01409327CCC1	19790323	--	--	--	--	--	--	--
384842107444201	T14SR93W026ADD Well near 3300 Road	20000620	1.63	--	--	--	--	<1.0	20.1
384854107474501	SC01409328BBA1	19780331	.38	20	.03	--	20	<10	4
384855107450101	Seep along Leroux Creek above Duke Ditch	20000620	--	--	--	--	--	--	9.4
384912107482601	Lower seep area along Stingley Gulch	20001206	--	--	--	--	--	--	3
384918107481801	Seep on right bank of Stingley Gulch	20001206	--	--	--	--	--	--	73.2

Table 4. Values of physical properties and concentrations of selected chemical constituents in ground and surface water from Rogers Mesa and vicinity, Delta County, Colorado.—Continued

[The local names are modified from local names in the U.S. Geological Survey National Water Information System. µS/cm, microsiemens per centimeter; °C, degree Celsius; mg/L, milligrams per liter; NWIS, National Water Information System; GW, ground water; --, no value; DCEHD, Delta County Environmental Health Department; SW, surface water; µg/L, micrograms per liter; <, less than; yellow shading indicates that value exceeds secondary drinking-water standard; pink shading indicates that value exceeds primary drinking-water standard; BD, less than method detection limit. Drinking-water standards are available online at *http://www.cdphe.state.co.us/regulations/waterqualitycontroldivision/100301primarydrinkingwater.pdf*]

Station or site identification number or name	Local name	Sample date	Nitrite plus nitrate, as nitrogen (mg/L)	Orthophosphate, as phosphorus (mg/L)	Orthophosphate (mg/L)	Phosphorus (µg/L)	Iron (µg/L)	Manganese (µg/L)	Selenium (µg/L)
				Ground water—Continued					
AG1	3176 L Road	--	1.63	--	--	--	--	--	BD
JTH1	3144 Highway 92	--	--	--	--	--	--	--	--
LCA1	1096 3250 Road	--	1.11	--	--	--	--	--	BD
LF1	1125 3080 Road	--	--	--	--	--	--	--	--
				Surface water					
384756107490801	Big Gulch at Highway 92	19990512	--	--	--	--	--	--	9
384756107490801	Big Gulch at Highway 92	19990831	--	--	--	--	--	--	8
384756107490801	Big Gulch at Highway 92	19991109	--	--	--	--	--	--	7
384756107490801	Big Gulch at Highway 92	20000314	--	--	--	--	--	--	7
384842107443901	Leroux Creek at 3300 Road	20000314	--	--	--	--	--	--	4.5
384842107443901	Leroux Creek at 3300 Road	20000620	--	--	--	--	--	--	13.7
384853107451201	Jessie Ditch at 3250 and L Roads	20000725	--	--	--	--	--	--	10.4
384854107450201	Leroux Creek above Duke Ditch Diversion	20000328	--	--	--	--	--	--	3.5
384854107450201	Leroux Creek above Duke Ditch Diversion	20000620	--	--	--	--	--	--	7.9

Table 4. Values of physical properties and concentrations of selected chemical constituents in ground and surface water from Rogers Mesa and vicinity, Delta County, Colorado.—Continued

[The local names are modified from local names in the U.S. Geological Survey National Water Information System. µS/cm, microsiemens per centimeter; °C, degree Celsius; mg/L, milligrams per liter; NWIS, National Water Information System; GW, ground water; --, no value; DCEHD, Delta County Environmental Health Department; SW, surface water; µg/L, micrograms per liter; <, less than; yellow shading indicates that value exceeds secondary drinking-water standard; pink shading indicates that value exceeds primary drinking-water standard; BD, less than method detection limit. Drinking-water standards are available online at *http://www.cdphe.state.co.us/regulations/waterqualitycontroldivision/100301primarydrinkingwater.pdf*]

Station or site identification number or name	Local name	Sample date	Nitrite plus nitrate, as nitrogen (mg/L)	Orthophosphate, as phosphorus (mg/L)	Orthophosphate (mg/L)	Phosphorus (µg/L)	Iron (µg/L)	Manganese (µg/L)	Selenium (µg/L)
				Surface water—Continued					
384910107482701	Stingley Gulch above Big Gulch	20001206	--	--	--	--	--	--	6.9
384914107460601	Jessie Ditch Diversion, Leroux Creek	20000328	--	--	--	--	--	--	89.4
384915107460801	Leroux Creek above Jessie Ditch Diversion	20000620	--	--	--	--	--	--	53.2
384919107481601	Stingley Gulch at West Draw	20001206	--	--	--	--	--	--	4.9
384937107463801	Leroux Creek below Fire Mountain Canal	20000620	--	--	--	--	--	--	140
384938107463601	Fire Mountain Canal at Leroux Creek	20000620	--	--	--	--	--	--	<.7
384942107463701	Leroux Creek Diversion at Fire Mountain Canal	20000328	--	--	--	--	--	--	8
384944107463601	Leroux Creek above Fire Mountain Canal	20000620	--	--	--	--	--	--	7.2

The concentration of selenium in a ground-water sample from a seep along Stingley Gulch, in the northwestern part of Rogers Mesa, was 73.2 µg/L (table 4, site identification number 384918107481801) and exceeds the State of Colorado maximum contaminant level of 50 µg/L (Colorado Department of Public Health and Environment, 2005, table 2–3).

Concentrations of dissolved total nitrogen (nitrite plus nitrate, as nitrogen) ranged from 0.38 to 3.2 mg/L and were less than the maximum contaminant level of 10 mg/L for total nitrogen (Colorado Department of Public Health and Environment, 2005, table 2–3) in all ground-water samples (table 4). Excessive concentrations of total nitrogen in ground water can indicate contamination from surface sources, such as animal wastes, chemical fertilizers, and effluent from ISDS (Hem, 1985, p. 125). Background concentrations of nitrite plus nitrate, as nitrogen, in ground water that is unaffected by surface sources typically are less than 2 mg/L (Nolan and others, 1998).

Hardness, as calcium carbonate, ranged from 195 to 770 mg/L for ground-water samples from Rogers Mesa aquifer (table 4). Water that has hardness (as calcium carbonate) concentrations greater than 180 mg/L is classified as “very hard” water (Hem, 1985). Water softeners commonly are used to decrease hardness to acceptable levels (less than 80 mg/L of hardness).

The maximum contaminant levels are enforceable standards, and the SMCLs are nonenforceable guidelines for public water supplies. Neither maximum contaminant levels nor SMCLs apply to individual domestic supplies (Colorado Department of Public Health and Environment, 2005). The use of drinking-water standards in this report is merely for comparison. It is the responsibility of the well owner or user to ensure that their drinking-water supply is safe. Drinking-water regulations, including drinking-water standards, are available at *http://www.cdphe.state.co.us/regulations/waterqualitycontroldivision/100301primarydrinkingwater.pdf*. Information about water supplies for private well owners and users is available from the Colorado Department of Public Health and Environment at *http://www.cdphe.state.co.us/wq/drinkingwater/PrivateWellInformation.html*.

Because many of the ground-water samples from Rogers Mesa were collected from seeps and springs near discharge areas for the aquifer, concentrations of dissolved solids and sulfate likely are greater than is expected in ground water from areas near sources of recharge. Concentrations of some dissolved constituents tend to increase as water flows though an aquifer because of geochemical reactions and the long contact time of the water with geologic materials. Because many of the ground-water samples that were used in this study were collected during the 1970s and 1980s, additional ground-water samples are needed to confirm the suitability of ground water for subdivision water supplies.

Potential Hydrologic Effects of Ground-Water Use for Hypothetical Subdivisions

As subdivisions are developed on Rogers Mesa, the change in land use from irrigated agriculture to residential use could have unanticipated effects. Additional pumping for subdivision water supplies will decrease ground-water storage and discharge to seeps, springs, and subsurface flow at the lateral boundaries of the aquifer but likely will not increase recharge. If the 2,756 acres of irrigated land on Rogers Mesa that currently (2007) also is platted for subdivision development (fig. 2) were developed as 1-acre residential lots with no outside water use, recharge of the Rogers Mesa aquifer could decrease by an estimated 14,000 acre-ft/yr. If the water that has been used to irrigate that 2,756 acres is not used to recharge the aquifer, ground-water storage will decrease and, eventually, discharge from the aquifer to seeps, springs, and subsurface flow will decrease by about 14,000 acre-ft/yr.

For purposes of demonstration, the potential hydrologic effects of ground-water use for a hypothetical subdivision on Rogers Mesa were approximated using analytical equations. The potential effects of pumping on nearby wells (well interference), depletion of ground-water storage, and capture of ground-water discharge were considered for an idealized aquifer. Analyses that incorporated the spatial variability of an aquifer’s transmissivity, specific yield, boundaries, and recharge and discharge conditions were beyond the scope of this study and likely would require the use of a numerical model of ground-water flow.

The following conditions were assumed for the analyses of the potential effects of pumping wells in a hypothetical subdivision:

1. The hypothetical subdivision included 100 contiguous 1-acre lots with water supplied by individual residential wells;

2. Individual wells were assumed to be pumped at a rate of 35.8 ft^3/d (about 268 gal/d or 0.186 gal/min) to supply 0.3 acre-ft/yr for each lot;

3. Pumping of the 100 wells was continuous and simultaneous;

4. The consumptive-use rate for in-house use of water was assumed to be 10 percent of the pumping rate with 90 percent of pumpage returned to the aquifer through infiltration of ISDS effluent;

5. The idealized aquifer was unconfined, homogeneous, isotropic, and infinite in extent;

6. Saturated thickness of the aquifer was 46 ft;

7. Transmissivity of the aquifer was 4,922 ft^2/d;
8. Specific yield of the aquifer was 0.22;
9. Wells were fully penetrating the aquifer;
10. Infiltration of recharge from the surface was unaffected by pumping of wells; and
11. The lateral boundary of the aquifer represented a fully penetrating stream.

Effects of Pumping on Nearby Wells

A concern of planners in evaluating subdivision plans is the effect that lot size may have on the sustainability of individual wells. When wells are closely spaced (lot sizes are small), pumping of nearby wells could decrease (interfere with) the supply of water available to other nearby wells. Well interference may decrease the saturated thickness and transmissivity of the aquifer at nearby wells. Water levels decrease (drawdown) in an aquifer as a well is pumped, with the drawdown greatest near the pumped well. The amount of drawdown is a function of the pumping rate, the duration of pumping, the distance from the pumped well, and the transmissivity and storage properties of the aquifer.

Theis (1935) developed an equation for analysis of the time-dependent response of a ground-water system to a pumping well in a confined aquifer. The Theis equation generally is used to analyze aquifer-test data (in an analytical mode) to determine the hydraulic and storage properties of confined aquifers. The Theis equation also can be used to predict drawdown due to pumping (in a predictive mode) when the aquifer transmissivity and storage coefficient are known.

The Theis equation cannot be integrated directly but its value is given by the following equation (Lohman, 1979, eq. 44, p. 15):

$$s = Q/4\pi T\,[-0.577216 - \log_e u + u - u^2/(2\text{x}2!) + u^3/(3\text{x}3!) - \cdots], \qquad (1)$$

where

$$u = r^2S\,/\,(4Tt) \qquad (2)$$

and the drawdown (s) at some radial distance (r) is caused by constant withdrawal (Q) of ground water by a fully penetrating well of infinitesimal diameter for a period of duration (t) from a homogeneous and isotropic confined aquifer with a transmissivity (T) and a storage coefficient (S). The value of the series in the brackets on the right-hand side of equation 1, $[-0.577216 - \log_e u + u - u^2/(2\text{x}2!) + u^3/(3\text{x}3!) - \cdots]$, commonly is referred to as "the well function or W(u)." Values of W(u) for values of u (eq. 2) from 10^{-15} to 9.9 are given by Lohman (1979, table 4, p. 16) or can be approximated using a computer spreadsheet as described by Halford and Kuniansky (2002).

Although the Theis equation is strictly valid only for confined aquifers, it also can be used for analysis of aquifer tests of unconfined aquifers. The storage coefficient (S) in equation 2 is assumed to equal the specific yield (Sy) when ground water is unconfined. If the measured drawdown during an aquifer test of an unconfined aquifer is a substantial portion of its initial saturated thickness, the measured drawdown should be corrected for the decrease in transmissivity that is caused by drawdown. The correction to measured drawdown, when ground water is unconfined, is given by the following equation (Jacob, 1963):

$$s' = s - (s^2/2b), \qquad (3)$$

where
- s' is the corrected drawdown (the equivalent drawdown for confined conditions),
- s is the measured drawdown for unconfined conditions, and
- b is the initial saturated thickness of the unconfined aquifer.

The drawdown predicted with equation 1 is the drawdown that would occur in a confined aquifer, an aquifer with constant transmissivity. The predicted drawdown is less than the actual drawdown that would occur in an unconfined aquifer. When drawdown in an unconfined aquifer is predicted using equation 1, it should be corrected with the following equation:

$$s'' = b - (b^2 - 2bs')^{0.5}, \qquad (4)$$

where
- s'' is the predicted drawdown in an unconfined aquifer and
- s' is the predicted drawdown in a confined aquifer.

Equation 4 is only valid when s'/b is less than 0.5.

Drawdown predicted for a single well pumping from an aquifer with a transmissivity of 4,922 ft^2/d, a specific yield of 0.22, and an initial saturated thickness of 46 ft, and at a rate of 35.8 ft^3/d is relatively small at distances of more than a few feet from the pumped well. The theoretical drawdown of water levels in the aquifer at distances of 1 to 25,000 ft was calculated for a constant pumping rate of 3,580 ft^3/d for pumping periods of 1, 10, and 100 years (fig. 12). The pumping rate of 3,580 ft^3/d used in the example is equivalent to the combined discharge of 100 residential wells, each pumping at a rate of 35.8 ft^3/d. Note that the x-axis in figure 12 is a logarithmic scale and that the y-axis is inverted. Theoretical drawdown at a distance of 209 feet from a pumped well after 100 years of constant pumping at a rate of 3,580 ft^3/d is about 0.62 ft. (The distance between wells at the center of adjacent 1-acre lots is approximately 209 ft.) Because drawdown is proportional to pumping rate, the drawdown at a distance of 209 feet from a well pumped at a constant rate of 35.8 ft^3/d for 100 years, is about 0.0062 ft. For the hypothetical conditions assumed for this analysis, the pumping of individual residential wells is not likely to cause significant drawdown in nearby wells. However, if the transmissivity and specific yield of the Rogers Mesa aquifer are substantially different from the values used in this analysis, drawdown could be larger or smaller than were predicted for the idealized aquifer.

Analytical equations can be used in simple situations that involve only a few wells and simple boundary conditions to predict the effects that pumping a well will have on ground-water levels. The effects of pumping in complex situations that involve many pumping wells with variable pumping rates, long periods of time, and complex aquifer and boundary conditions can be predicted more readily using numerical models of ground-water flow.

Depletion of Ground-Water Storage

Because of the small rates of withdrawal by residential wells, depletion of ground-water storage in an unconfined aquifer with a specific yield of 0.22 would be relatively small. Assuming residential use of ground-water withdrawal is 0.3 acre-ft/yr per 1-acre lot, and consumptive use of that water is 10 percent and infiltration of effluent from ISDS is 90 percent of in-house use, the net withdrawal will be only 0.03 acre-ft/yr. Assuming a specific yield of 0.22, the change in water level at the lot associated with the net withdrawal of 0.03 acre-ft/yr per 1-acre lot is about 0.14 ft/yr [0.03 acre-ft/yr ÷ 1 acre ÷ 0.22 ≈ 0.14 ft/yr].

The potential effects to ground-water storage from changes in historic land and water use may be of greater

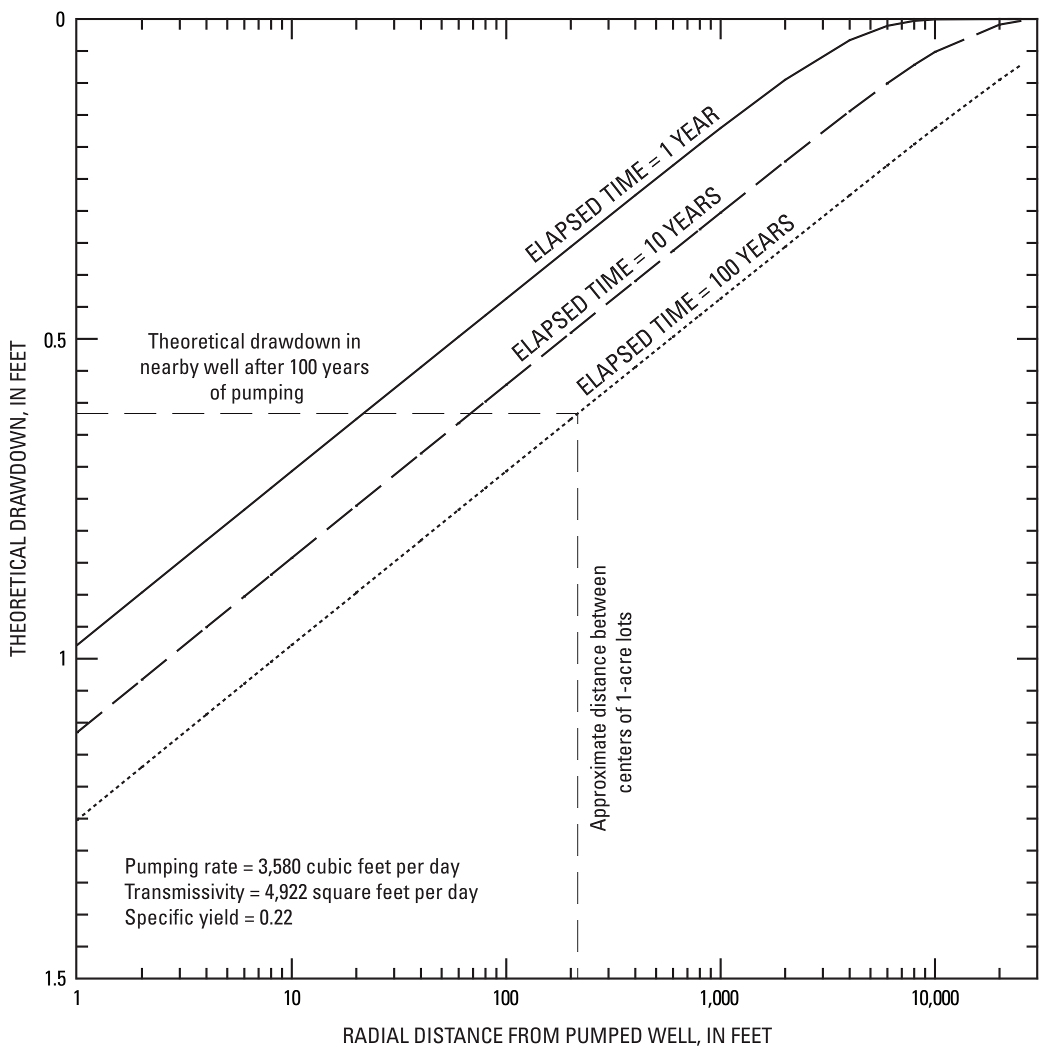


Figure 12. Relation between theoretical drawdown and radial distance in an idealized unconfined aquifer for a constant pumping rate and elapsed times of 1, 10, and 100 years.

concern than the small withdrawals of ground water by residential wells if the changes in land use decrease infiltration from the surface. If a subdivision is created from land that was formerly irrigated and that land is not irrigated after the subdivision is built, infiltration from the surface on that land will decrease substantially and likely result in substantial decreases in water levels, affecting both ground-water storage and discharge from the aquifer. Changes in irrigation practices that result in decreased infiltration (recharge) also can result in depletion of ground-water storage and, eventually, discharge from the aquifer.

Capture of Ground-Water Discharge

When streams and aquifers are hydraulically connected, withdrawal of ground water will deplete flow of surface streams, either by capture of surface water from streams or by capture of ground water that would discharge to streams. In Colorado, ground water is considered tributary to a stream if withdrawal of ground water by a well will deplete the flow of a surface stream by 0.1 percent or more of the withdrawal rate in 100 years (CRS 37–90–103, available online at *http://www2.michie.com/colorado/lpext.dll?f=templates&fn=fs-main.htm&2.0*). The direct hydraulic connection of the Rogers Mesa aquifer to streams is limited because the North Fork Gunnison River and Leroux Creek generally are topographically lower than the base of the Rogers Mesa aquifer (fig. 3). However, subsurface discharge of ground water across the boundaries of the Rogers Mesa aquifer and discharge of ground water to seeps and springs likely reach surface streams. Thus, ground water in the Rogers Mesa aquifer could be considered tributary water. Direct capture of streamflow from Leroux Creek by pumping from the Rogers Mesa aquifer possibly could occur in the southwest quarter of sec. 23, T. 14 S., R. 93 W., where the base of the Rogers Mesa aquifer may be lower in altitude than Leroux Creek (fig. 3).

Except for the segment of the aquifer boundary along Leroux Creek Valley, where the base of the Rogers Mesa aquifer may be lower in altitude than Leroux Creek, the lateral boundaries of Rogers Mesa aquifer are drains. A drain is a head-dependent flow boundary that only discharges water from an aquifer, such as a spring. Where the aquifer boundary is a head-dependent flow boundary, ground-water withdrawals from the aquifer eventually will decrease saturated thickness and hydraulic gradient at the boundary and, consequently, ground-water discharge across the boundary of the aquifer. Where the Rogers Mesa aquifer is hydraulically connected to alluvium along Leroux Creek, ground-water withdrawals from the aquifer may either decrease flow from Rogers Mesa aquifer to the alluvium or induce flow from the alluvium and stream to the aquifer. If sufficient ground-water discharge across the boundary is captured and additional flow of water from outside the boundary cannot physically be captured, the aquifer may become unsaturated at the boundary and flow across that part of the boundary will cease. In either case, ground-water withdrawals from the Rogers Mesa aquifer eventually will reduce streamflow.

The amount and timing of stream depletion depend upon the integrated effects of irregular impermeable boundaries, stream meanders, aquifer properties and their areal variation, distance from the stream, and imperfect hydraulic connection between the aquifer and the stream (Jenkins, 1968). The DWR has adopted the Alluvial Water Accounting System (AWAS) to calculate stream depletion resulting from ground-water withdrawals. The AWAS software was developed by the Integrated Decision Support Group at Colorado State University, Fort Collins, Colo., and is available for download at *http://www.ids.colostate.edu/projects/idsawas*. This computer program calculates stream depletions by using either the stream-depletion-factor method (Jenkins, 1968) or an analytical stream-depletion method developed by DWR (Schroeder, 1987). The latter method uses analytical equations described by Glover (1977). AWAS can be used to analyze historic stream depletion and to forecast future stream depletion. Stream depletion can be calculated by using either daily or monthly time steps for an idealized aquifer. The analytical equation solved by AWAS (Schroeder, 1987) is based on the following assumptions:

1. The aquifer is isotropic, homogeneous, of uniform thickness, and infinite in extent;
2. Drawdown is negligible when compared to the aquifer thickness and the transmissivity does not change with time;
3. The water table is initially flat;
4. Water temperatures are constant;
5. Water is released instantaneously from storage;
6. The stream is straight, infinite in length, and fully penetrates the aquifer;
7. The pumping rate is constant for any pumping period; and
8. The diameter of the well is negligible.

Other analytical models (Barlow and Moench, 1999; Butler and Tsu, 2001; Butler and others, 2001; Hunt, 1999 and 2003) have been developed to estimate aquifer parameters from pumping tests when stream depletion occurs. The AWAS model was selected as the DWR standard after a detailed analysis and review (Ray Bennett, Colorado Water Conservation Board, written commun., 2006, accessed March 13, 2007, at *http://water.state.co.us/pubs/presentations/rbennett_handout_090606.pdf*).

Sophocleous and others (1995) compared results of analytical solutions of stream depletion with results from numerical models of ground-water flow (MODFLOW, McDonald and Harbaugh, 1988) and concluded that the three most important assumptions affecting analyses of stream depletion were streambed conductance, partial penetration of streams, and aquifer heterogeneity. They noted that analytical models of stream depletion consistently overestimated stream depletion when conditions did not meet assumptions of the analytical solutions. The most important differences between the Rogers Mesa aquifer and the idealized aquifer are that the Rogers Mesa aquifer is anisotropic, heterogeneous, and variable in thickness, and that the boundary of the aquifer is not linear. The anisotropy, heterogeneity, and variable thickness may cause substantial differences between actual and predicted stream depletion, particularly if the variability in properties is spatially correlated. The boundary of Rogers Mesa aquifer is a drain and reasonably represents a fully penetrating boundary. However, stream depletion at that boundary of Rogers Mesa aquifer principally would consist of the capture of ground-water discharge to the surface and not the capture of streamflow. Because the boundary of Rogers Mesa aquifer is not a straight line, as assumed by the stream-depletion model, the effects of a pumping well could impinge on the aquifer boundary at multiple points and in all directions; thus, stream depletion could be greater than that predicted by the stream-depletion model.

The AWAS model requires the specification of a stream-depletion factor. The stream-depletion factor (sdf) is equivalent to the time, in days, at which stream depletion equals 28 percent of the pumping rate. The stream-depletion factor (Jenkins, 1968) is calculated from the distance of the well from the stream and the transmissivity and specific yield of the aquifer, as follows:

$$\mathrm{sdf} = a^2 \cdot Sy/T, \tag{5}$$

where

- a is the distance of the well from the stream,
- Sy is the specific yield, and
- T is the transmissivity.

The stream-depletion analytical model (AWAS) was used to evaluate the potential effects of ground-water pumping from the Rogers Mesa aquifer on discharge across the aquifer boundaries. Transmissivity of the aquifer was assumed to be 4,922 ft^2/d and specific yield was assumed to be 0.22. The stream-depletion factor was calculated for various distances from a well to a boundary. The volume of stream depletion is calculated by AWAS for each time step of a user-specified prediction period. A monthly time step and a prediction period of 100 yrs were used for this analysis. Because the rate of stream depletion is proportional to the specified rate of withdrawal by the well, stream depletion may be expressed as a ratio of the stream-depletion rate and pumping rate. This ratio is independent of the rate of withdrawal and is dependent only on the distance of the well from the stream and the transmissivity and specific yield of the aquifer. For ease of data input, a pumping rate of 1 acre-ft per month was assumed for this analysis. Assuming a consumptive use of 10 percent of in-house water use, a monthly withdrawal of 1 acre-ft is approximately the monthly consumptive use by 400 residential wells, each pumping at a rate of 35.8 ft^3/d.

Stream depletion (flow-boundary depletion) was calculated for hypothetical pumping wells at distances of 1,000, 3,000, 7,500, 15,000, and 25,000 ft from a flow boundary. The distance of 25,000 ft is the approximate maximum distance across the Rogers Mesa aquifer. The ratios of the annual volume of flow-boundary depletion to the annual volume of ground-water withdrawal for these distances during the 100-yr prediction period are shown as a series of curves in figure 13. Note that the x-axis in figure 13 is on a logarithmic scale. For the assumed aquifer specific yield and transmissivity, the proportion of ground-water withdrawal that is captured boundary flow would exceed 0.1 percent of the pumping rate within about 4 yrs of the onset of pumping (fig. 13) by a well anywhere within the boundary of the Rogers Mesa aquifer. Thus, water in the Rogers Mesa aquifer likely would be considered tributary ground water. Therefore, new subdivisions on Rogers Mesa that propose the use of nonexempt wells completed in the Rogers Mesa aquifer likely would require an augmentation plan (Colorado Division of Water Resources, 2006). Although analytical models of stream depletion provide a preliminary evaluation of the potential effects of ground-water withdrawals on streamflows, a numerical model of ground-water flow may provide better estimates of stream depletion caused by pumping. Numerical models of ground-water flow could be designed to incorporate aquifer anisotropy and heterogeneity, multiple pumping wells, and boundary conditions that are more realistic.

Suggestions for Collection and Analyses of Additional Data

This preliminary analysis of availability, sustainability, and suitability of ground water on Rogers Mesa primarily used publicly available data. The evaluation could be improved with the collection of additional data and the development of a numerical model of ground-water flow. The following list of data-collection and analyses activities, if implemented, could substantially improve the analyses of availability, sustainability, and suitability of ground water on Rogers Mesa for subdivision water supplies:

1. Detailed field mapping is needed to define the lateral boundaries of the aquifer, to identify ground-water discharge areas, and to determine accurate horizontal and vertical coordinates of existing springs and wells, and could decrease errors in hydrogeologic maps;

2. Measurement of conveyance losses and ground- and surface-water application to irrigated areas, determination of local crop coefficients, and the use of soil-moisture conditions could decrease errors in the water budget and improve estimates of recharge to and the hydraulic and storage properties of Rogers Mesa aquifer;

3. Water-level measurements are needed to define seasonal variability of ground-water storage and to improve maps of the water table:
4. Aquifer tests and specific-capacity tests of wells are needed to decrease uncertainty in estimates of aquifer properties;
5. Determination of the physical properties (pH, specific conductance, and temperature) and chemical characteristics of ground water in recharge and discharge areas and of surface water diverted into the area could improve evaluation of the suitability of the water for residential use; and
6. Numerical models of ground-water flow could improve evaluations of the potential effects of changes in land and water use on the water budget, aquifer storage, stream depletion, and well interference.

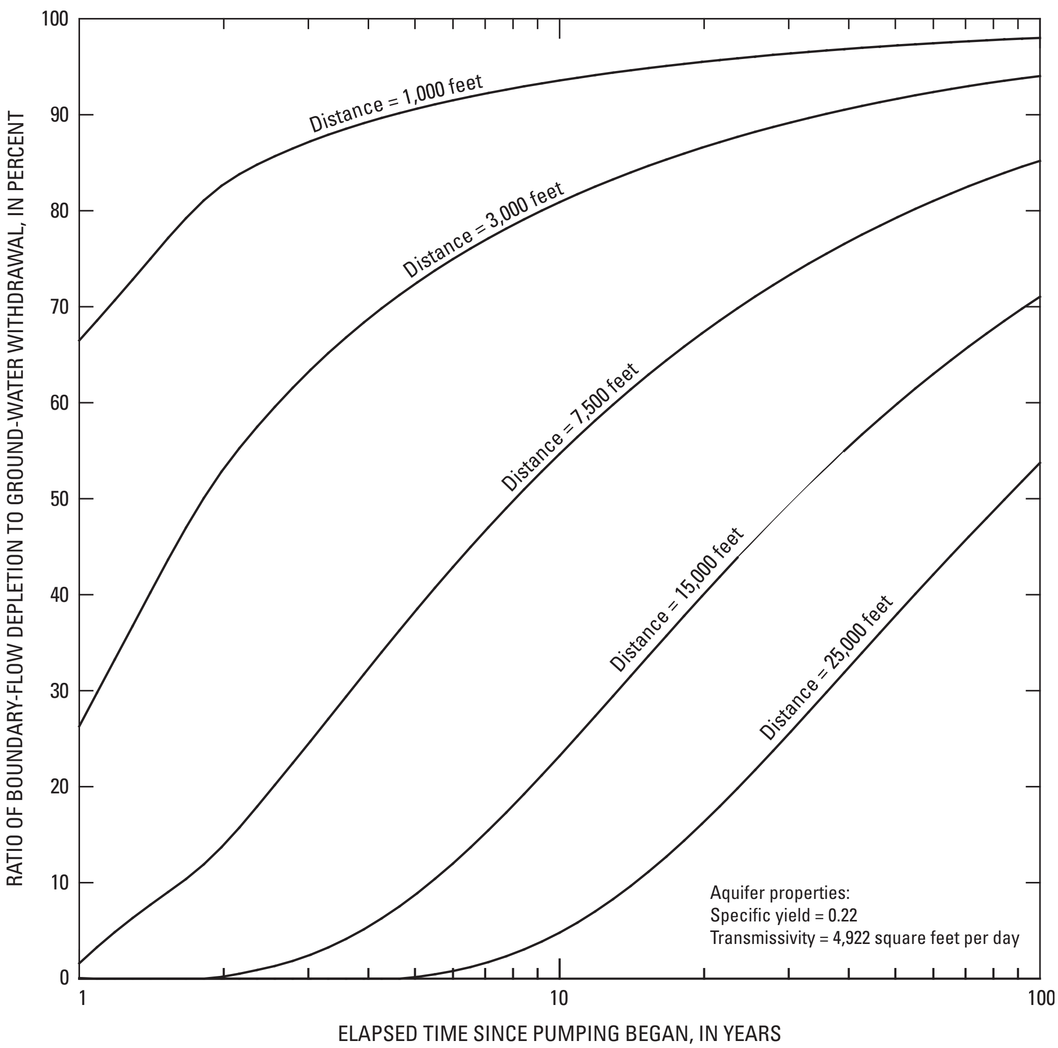


Figure 13. Relation between depletion of boundary flow to ground-water withdrawal, distance of pumped well from flow boundary, and elapsed time since pumping began in an idealized aquifer.

Summary

The population of the Western United States is forecast to increase substantially during the next few decades. The population of Delta County, Colo. (fig. 1), is projected to increase by 79 to 105 percent, from about 28,000 in 2000 to between 50,200 to 57,500 in 2030. A substantial portion of that increase in population likely will reside in subdivisions that rely on residential wells for water supply. In Colorado, water-supply plans for new subdivisions must demonstrate the availability, sustainability, and suitability of the water supply. Because ground-water conditions in Colorado are highly variable and often are not well defined, developers and approving agencies need criteria to define and evaluate what data and analyses are needed to define the availability, sustainability, and suitability of ground water as the water supply for a proposed subdivision. A preliminary analysis of the ground-water resources of Rogers Mesa, Delta County, Colorado, was done by the U.S. Geological Survey, in cooperation with Delta County, to demonstrate the use of available data to define the availability, sustainability, and suitability of ground water for a hypothetical subdivision.

A list is provided of the types of analyses and data needed for preparation of a water-supply report for a proposed subdivision, when ground water is the proposed supply. These analyses and data provide a minimum level of detail needed to demonstrate the physical availability, sustainability, and suitability of ground water for a proposed subdivision's water supply. The legal availability of a proposed water supply is not addressed in this report.

Publicly available data from the Colorado Division of Water Resources, the Colorado Decision Support System, the Colorado Agricultural Meteorological Network, Delta County, the U.S. Geological Survey, and other sources were used to prepare a preliminary evaluation of ground-water resources for Rogers Mesa. Maps of the altitude of the base of the aquifer, the water table, and the saturated thickness of the Rogers Mesa aquifer were prepared from data from the well files of the Division of Water Resources. A field reconnaissance was done to better define the lateral extent of the aquifer and to locate potential ground-water discharge areas.

Hydraulic properties of the aquifer were estimated from drillers' pumping tests and pump-installation tests. Estimated transmissivity of the aquifer ranges from a few hundred to more than 20,000 square feet per day. Estimated specific yield and specific retention of the aquifer are 0.22 and 0.08, respectively. Horizontal hydraulic conductivity of the aquifer, as estimated from drillers' pumping tests and pump-installation tests, ranged from less than 1 foot per day to about 350 feet per day. Average horizontal hydraulic conductivity, as estimated from the water budget, was 107 feet per day.

Ground-water storage in the aquifer was estimated to be about 107,000 acre-feet. A preliminary water budget for the aquifer was used to estimate recharge to the aquifer. During November 1998 through October 2006, infiltration of precipitation and irrigation water to the aquifer averaged 30,767 acre-feet per year. Although ground water is physically available in the Rogers Mesa aquifer to supply additional residential wells, its use may be limited by administrative rules of the Colorado Division of Water Resources.

On the basis of an evaluation of sparse water-quality data, relatively large concentrations of dissolved solids and sulfate and hardness may limit use of ground water for residential supplies. The U.S. Environmental Protection Agency Secondary Maximum Contaminant Level (SMCL) for dissolved solids of 500 milligrams per liter was exceeded in 11 of 12 samples and the SMCL for dissolved sulfate of 250 milligrams per liter was exceeded in 3 of 12 samples. The maximum concentration of total nitrogen (nitrite plus nitrate, as nitrogen) in ground water was 3.2 milligrams per liter. Concentrations of total nitrogen typically were less than the background concentration, which is less than 2 milligrams per liter, and do not indicate substantial contamination from potential surface sources of nitrogen.

A preliminary stream-depletion analysis indicates that ground water in Rogers Mesa aquifer is tributary water. Thus, augmentation plans likely would be required for the development of ground water from nonexempt wells for proposed subdivisions on Rogers Mesa. The potential effects to ground-water recharge and storage from changes in historic land and water use from irrigated agriculture to residential land use may be of greater concern than the small withdrawals of ground water by residential wells.

Uncertainty in the water budget and the hydraulic and storage properties of the aquifer could be decreased with the collection of additional data, including accurate locations and altitudes of wells. Better estimates of surface-water deliveries for irrigation and crop-consumptive use could improve estimates of ground-water recharge. Better estimates of aquifer transmissivity and specific yield are needed for use in water-budget and stream-depletion analyses of Rogers Mesa. Numerical models of ground-water flow could improve evaluations of the potential effects of changes in land and water use on the water budget, aquifer storage, stream depletion, and well interference.

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Glossary

A

alluvial fan A low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream (especially in a semiarid region) at the place where it issues from a narrow mountain valley upon a plain or broad valley, or where a tributary stream is near or at its junction with the main stream, or wherever a constriction in a valley abruptly ceases or the gradient of the stream suddenly decreases; it is steepest near the mouth of the valley where its apex points upstream, and it slopes gently and convexly outward with gradually decreasing gradient (Bates and Jackson, 1980, p. 16).

alluvium (alluvial deposit) Clay, silt, sand, and gravel, or other rock materials transported by water and deposited in comparatively recent geologic time as sorted or semi-sorted sediments in riverbeds, estuaries, and flood plains, and in fans deposited by running water at the bases of mountain slopes (Thrush, 1968).

anisotropic A condition in which a property varies with the direction of measurement at a point.

aquifer A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs (Lohman and others, 1972).

aquifer test A controlled field test designed to determine the hydraulic or storage properties or both of an aquifer, associated confining units, or both (modified from U.S. Geological Survey, 1989).

augmentation plan In Colorado, a plan approved by the water court to protect senior water rights from the depletion of streamflow caused by new diversions. An augmentation plan may involve (1) storing junior water when in priority and releasing that water when a river call comes on; (2) purchasing stored water from federal entities or others for release when a river call comes on; or (3) purchasing senior irrigation water rights and changing the use of those rights to offset the injury to the stream from new uses (Colorado Division of Water Resources, 2007).

available water capacity (soil) The volume of water that should be available to plants if the soil, inclusive of fragments, was at field capacity. Available water capacity is approximately equal to specific retention. It commonly is estimated as the amount of water held between field capacity and the wilting point, with corrections for salinity, fragments, and rooting depth (U.S. Department of Agriculture, Natural Resources Conservation Service, 2007b).

C

capture The decrease in discharge plus the increase in recharge that results from a change in ground-water discharge to wells. Capture may occur as decreases in ground-water discharge to surface-water bodies (stream depletion), springs and seeps, or the component of evapotranspiration derived from the saturated zone, or as increases in infiltration from surface-water bodies (Lohman and others, 1972).

cone of depression A depression of the potentiometric surface in the shape of an inverted convex cone that develops around a well that is being pumped (U.S. Geological Survey, 1989).

confining unit (bed or zone) A geologic formation, group of formations, or part of a formation of impermeable or distinctly less permeable material bounding one or more aquifers; a general term that replaces the terms aquitard, aquifuge, and aquiclude (Lohman and others, 1972, p. 5).

consumptive use That part of water that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment. Also referred to as water consumption or water consumed (Templin and others, 2007).

conveyance loss Water that is lost as it is conveyed from its source to the irrigated field. The factors that lead to conveyance loss include evaporation, evapotranspiration, seepage, and spillage (Price, 1995).

D

drainable ground water The volume of drainable water in an aquifer equals the product of volume of saturated aquifer and the specific yield of the aquifer (Gutentag and others, 1984). Generally, not all the drainable water in an aquifer can be recovered for use. The volume that can be recovered is dependent on site-specific hydrogeologic conditions, well construction, costs of recovery, and water quality considerations.

E

exempt well In Colorado, an exempt well is a well from which the use of water is not subject to the administrative rules of prior appropriation (Colorado Division of Water Resources, 2006). For additional information, see sections 37-92-602 and 37-90-105 of the Colorado Revised Statutes at *http://www.state.co.us/gov_dir/leg_dir/olls/colorado_revised_statutes.htm*.

F

field capacity (soil) The soil moisture content just after the soil has drained following a period of rain and humid weather, after a spring thaw, or after heavy irrigation, expressed as the ratio of the weight of water to the weight of the soil plus the weight of the water. An approximation of soil moisture content at field capacity commonly is made in the laboratory using 1/3-bar moisture percentage for clayey and loamy soil materials and 1/10-bar for sandy materials (U.S. Department of Agriculture Natural Resources Conservation Service, 2007b).

G

ground water, confined Ground water that is under pressure significantly greater than atmospheric, its upper limit is the bottom of a bed of distinctly lower hydraulic conductivity than that of the material in which the confined water occurs (Lohman and others, 1972).

ground water, perched Ground water that is unconfined but that is separated from an underlying body of ground water by an unsaturated zone. Its water table is a perched water table. It is held up by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the intervening unsaturated zone above atmospheric pressure (Lohman and others, 1972).

ground water, unconfined Ground water in an aquifer that has a water table (Lohman and others, 1972).

ground-water availability The amount of ground water that is available for use, which does not cause unacceptable changes in the subsurface and surface environment. Estimation of the amount of ground water that is available for use requires (1) an evaluation of ground and surface water on a systemwide basis, including the amounts of water available from changes in ground-water recharge, from changes in ground-water discharge, and from changes in storage for different levels of water consumption; and (2) an evaluation of the effects that changes in ground-water use will have on the subsurface and surface environments (Alley and others, 1999).

ground-water suitability The suitability of ground water for specific uses may be limited by the physical properties and chemical and bacteriological characteristics of the water. The Colorado Department of Public Health and Environment (2005) and U.S. Environmental Protection Agency (2007b) have established standards for drinking water from public supplies. The suitability of water from individual private wells is not subject to these drinking-water standards.

ground-water sustainability Ground-water sustainability is defined as the development and use of ground water in a manner that can be maintained for an indefinite time without causing unacceptable consequences (Alley and others, 1999). Ultimately, the public should determine the tradeoff between ground-water use and changes to the environment.

H

head, static The height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point (Lohman and others, 1972).

heterogeneous A condition in which the properties of a geologic formation or an aquifer are not uniform in structure or composition. Heterogeneity primarily is a function of the geologic environments under which the rock was formed and under which it has been altered.

homogeneous A condition in which the properties of a geologic formation or an aquifer are uniform in structure or composition.

hydraulic conductivity The volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow (Lohman and others, 1972, p. 4). Hydraulic conductivity is not only a property of the porous media but includes the properties of the fluid (kinematic viscosity) and the acceleration due to gravity. The standard unit for hydraulic conductivity is cubic foot per day per square foot. In this report, the mathematically reduced form, foot per day, is used for convenience. If hydraulic conductivity is independent of the direction of measurement, the porous medium is isotropic, but if it varies with direction of measurement, the porous medium is anisotropic. In most alluvial sediments, hydraulic conductivity is generally greatest parallel to bedding and least perpendicular to bedding.

hydraulic gradient The change in static head per unit of distance in a given direction. If not specified, the direction generally is understood to be that of the maximum rate of decrease in head (Lohman and others, 1972, p. 8).

I

irrigation year The irrigation year begins November 1 of one calendar year and ends on October 31 of the following calendar year. The irrigation year is used for purposes of reporting and recording annual diversions of water for irrigation (Waskom and Neibauer, 2004).

isotropic A condition in which a property is independent of the direction of measurement at a point (Lohman and others, 1972, p. 9).

N

nonexempt well In Colorado, a nonexempt well is a well from which the use of water is subject to the administrative rules of prior appropriation (Colorado Division of Water Resources, 2006). For additional information see sections 37–92–602 and 37–90–105 0f the Colorado Revised Statutes at *http://www.state.co.us/gov_dir/leg_dir/olls/colorado_revised_statutes.htm*.

nontributary ground water (aquifer) Ground water is considered nontributary if it is outside the boundaries of any designated ground-water basins in existence on January 1, 1985, and its withdrawal will not deplete the flow of a natural stream at an annual rate greater than one-tenth of one percent of the annual rate of withdrawal within one hundred years. The determination of whether ground water is nontributary or tributary shall be based on aquifer conditions existing at the time of permit application (Colorado Revised Statute 37–90–103, available online at *http://www2.michie.com/colorado/lpext.dll?f=templates&fn=fs-main.htm&2.0*).

O

out of priority Diversion of water is governed by the priority system in which the priority is based on both the initial appropriation date and the adjudication date of a water right, as confirmed by the water court. The senior water rights holder has the right to divert water from a common source before a junior water rights holder. When a junior water rights holder diverts water from the common source before the senior water rights holder that diversion is ”out of priority” (Colorado Division of Water Resources, 2006).

P

porosity A property of a rock or soil containing interstices or voids. Porosity is expressed as the ratio of the volume of voids to the volume of the rock or soil, as either a decimal fraction or a percentage. A related term is effective porosity, which refers to the amount of interconnected pore space available for fluid transmission (Lohman and others, 1972, p. 10).

potentiometric surface A surface that represents the static head and that is defined by the levels to which water will rise in tightly cased wells. Where head varies appreciably with depth, a potentiometric surface is meaningful only if it defines the static head along a specified surface or stratum in the aquifer. More than one potentiometric surface may be required to define the three-dimensional distribution of head in an aquifer. The water table is a particular potentiometric surface (Lohman and others, 1972, p. 11).

R

reference evapotranspiration Reference evapotranspiration is the estimated consumptive use of water by well-watered alfalfa under local weather conditions. The reference evapotranspiration value that is provided by the Colorado Agricultural Meteorological network is computed using local meteorological measurements and a reference equation for alfalfa (Wright, 1982). Reference evapotranspiration values for other crops are adjusted using a crop coefficient. Reference evapotranspiration values are for conditions during which soil moisture is greater than 50 percent of field capacity. If soil moisture is less than 50 percent of field capacity, a soil coefficient value can be applied in addition to the crop coefficient (Colorado Climate Center, 2007).

S

saturated hydraulic conductivity (soil) Saturated hydraulic conductivity is the amount of water that would move vertically through a unit area of saturated soil in unit time under unit hydraulic gradient (U.S. Department of Agriculture Natural Resource Conservation Service, 2007b).

specific retention The ratio of (1) the volume of water which a rock or soil, after being saturated, will retain against the pull of gravity to (2) the volume of the rock or soil (Lohman and others, 1972).

specific storage The ratio of volume of water released from or taken into storage per unit surface area per unit change in head in a compressible ground-water body (Lohman and others, 1972).

specific yield The ratio of (1) the volume of water which a rock or soil, after being saturated, will yield by gravity to (2) the volume of the rock or soil (Lohman and others, 1972).

storage coefficient The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In a confined aquifer, the water derived from storage with decline in head comes from expansion of the water and compression of the aquifer; similarly, water added to storage with a rise in head is accommodated by compression of the water and expansion of the aquifer. In an unconfined aquifer, the storage coefficient is virtually equal to specific yield (Lohman and others, 1972).

stream depletion The capture by a well of surface water from a stream or subsurface water that normally would discharge to a stream. Stream depletion means either direct depletion of stream flow or reduction of ground-water flow to the stream (Jenkins, 1968).

subdivision Any parcel of land in Colorado, which is to be used for condominiums, apartments, or any other multiple-dwelling units, or which is divided into two or more parcels, separate interests, or in common, unless exempted (Colorado Division of Water Resources, 2007).

system of prior appropriation The use of water in Colorado is governed by what is known as the prior appropriation system. This system of water allocation controls who uses how much water, the types of uses allowed, and when those waters can be used. A simplified way to explain this system is often referred to as the priority system or "first in time, first in right." The first person to appropriate water and apply that water to use has the first right to use that water within a particular stream system. This person, after receiving a court decree verifying their priority status, then becomes the senior water right holder and that water right must be satisfied before any other water rights are filled (Colorado Division of Water Resources, 2006).

T

transmissivity The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient (Lohman and others, 1972, p. 13). Though spoken of as a property of the aquifer, it also embodies the saturated thickness of the aquifer and the properties of the contained liquid.

tributary water Water that is connected to a natural stream system by either surface or underground flows (Colorado Division of Water Resources, 2006). Ground water located outside the boundaries of any designated ground-water basins in existence on January 1, 1985, the withdrawal of which will within one hundred years, deplete the flow of a natural stream at an annual rate of one-tenth of one percent or more of the annual rate of withdrawal is considered tributary. The determination of whether ground water is non-tributary or tributary shall be based on aquifer conditions existing at the time of permit application (Colorado Revised Statute 37-90-103, available online at *http://www2.michie.com/colorado/lpext.dll?f=templates&fn=fs-main.htm&2.0*).

W

water table The potentiometric surface in an unconfined aquifer at which the pressure is atmospheric (Lohman and others, 1972).

wilting point (soil) The amount of water held too tightly in soil for commonly grown crops to extract (U.S. Department of Agriculture, Natural Resources Conservation Service, 2007c).

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