Bulletin 42

Water Resources of Boulder County, Colorado

by Dennis C. Hall, Donald E. Hillier,
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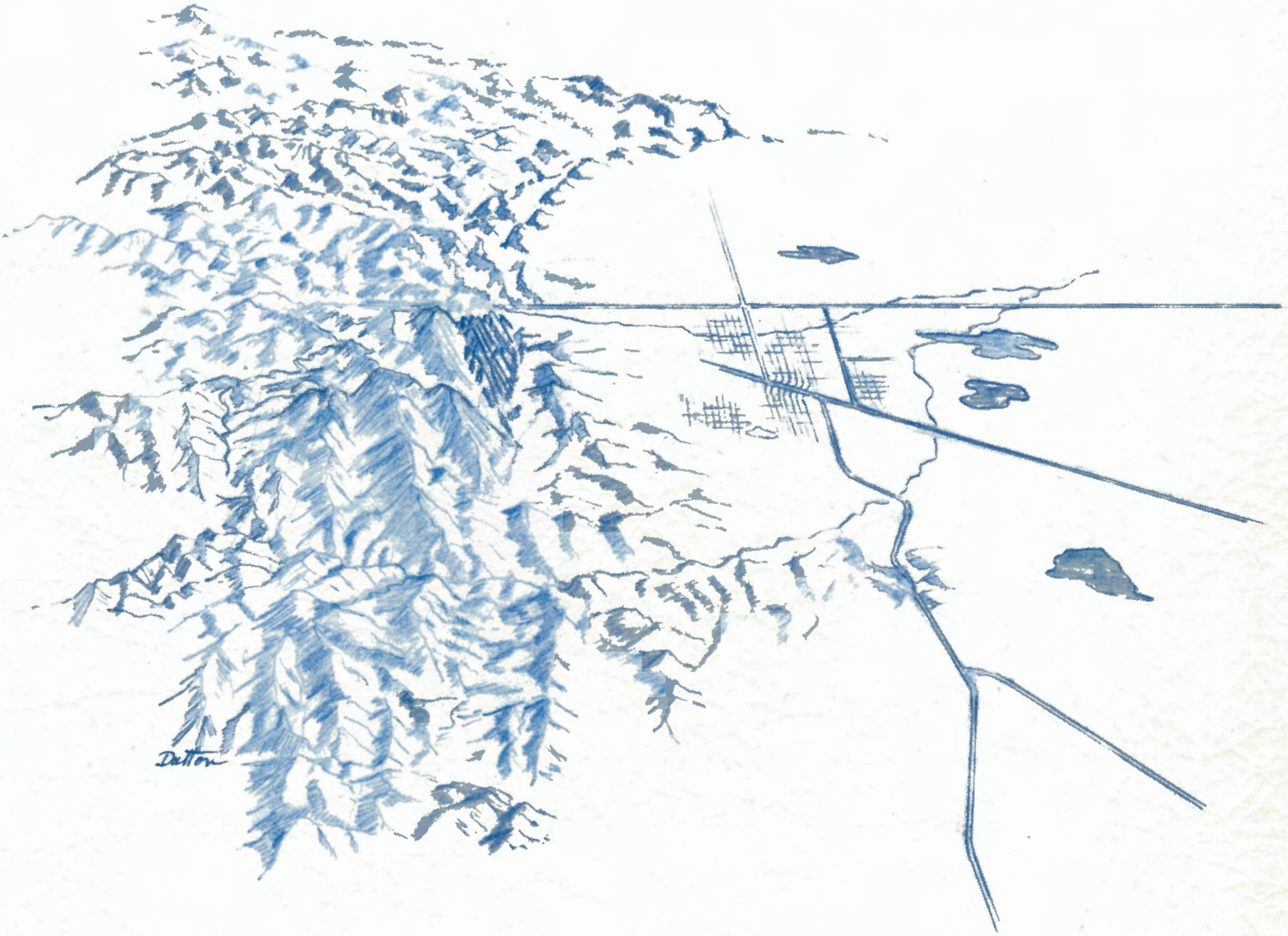

Colorado Geological Survey
Department of Natural Resources
Denver, Colorado / 1980

STATE OF COLORADO
1876

Cover illustration of Boulder County by X. W. Dutton, U.S. Geological Survey.

COLORADO GEOLOGICAL SURVEY

DEPARTMENT OF NATURAL RESOURCES

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STATE OF COLORADO

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METRIC CONVERSION FACTORS

To convert	*Multiply by*	*To obtain*
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
mile	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
gallon	3.785	liter
gallon per minute (gal/min)	0.06309	liter per second
cubic foot	0.02832	cubic meter
acre-foot (acre-ft)	1,233	cubic meter
foot per mile (ft/mi)	0.1894	meter per kilometer
foot per day	0.3048	meter per day
foot squared per day (ft^2/d)	0.0929	meter squared per day

To convert degrees Fahrenheit (°F) to degrees Celsius (°C), use the equation:

$$(°F-32)\times 5/9=°C.$$

To convert degrees Celsius (°C) to degrees Fahrenheit (°F), use the equation:

$$(9/5\times °C)+32=°F.$$

WATER RESOURCES OF BOULDER COUNTY, COLORADO

By Dennis C. Hall, Donald E. Hillier,
Doug Cain, and Elaine L. Boyd
U.S. Geological Survey

ABSTRACT

The mean annual precipitation of 18.6 inches over Boulder County produces 840,000 acre-feet of water--588,000 acre-feet in the mountains and 252,000 acre-feet in the plains. About 341,000 acre-feet of the precipitation that falls in the mountains is returned to the atmosphere by evapotranspiration each year and 247,000 acre-feet flows from the mountains to the plains. About 550,000 acre-feet of water enters the plains from precipitation (252,000 acre-feet), streamflow from the mountains (247,000 acre-feet), and transbasin diversions (51,000 acre-feet). About 154,000 acre-feet of water flows out of the plains each year. Most of the remaining 396,000 acre-feet of water is returned to the atmosphere by evapotranspiration.

Unconsolidated-rock (water-table) aquifers overlie sedimentary-rock aquifers in the eastern part of the county and overlie crystalline-rock aquifers in the western part of the county. Sedimentary-rock (water-table or artesian) aquifers occur only in the eastern part of the county. The Laramie-Fox Hills, an artesian aquifer, is the principal sedimentary-rock aquifer. The crystalline rocks function as water-table aquifers only in the mountains where the rocks have been fractured. The regional direction of water movement in the aquifers is principally to the east. Annual ground-water outflow from the county was estimated to be 6,900 acre-feet from the unconsolidated-rock aquifers, 350 acre-feet from the Laramie-Fox Hills aquifer, and negligible from the other aquifers. Water levels in 19 wells during 1976-77 generally were the same as in 1954-60.

All aquifers in the county yield sufficient quantities of water for domestic supplies (1 or more gallons per minute). Supplies sufficient for community water systems and commercial enterprises (15 or more gallons per minute) may be obtained from the flood-plain, terrace, glacial, Laramie-Fox Hills, Dakota, and Morrison-Ralston Creek-Lykins aquifers. Supplies sufficient for large-scale urban development and large-scale irrigation (100 or more gallons per minute) may be obtained from the flood-plain aquifer. Supplies sufficient for these purposes also may possibly be obtained in some localities from the terrace and the Laramie-Fox Hills aquifers. Increased withdrawal of ground water could cause a decrease in streamflow.

Streamflow in the county generally is suitable for municipal water supplies. Contamination by major ions, trace elements, and bacteria was limited. Streamflow in Little James and Rock Creeks is the least suitable for municipal water supplies. Manganese and fecal-coliform bacteria locally exceeded water-quality standards for agricultural use. Trace-element contamination with respect to aquatic-life standards was widespread, occurring in 12 of the 18 streams sampled.

Excessive concentrations of selected major ions and trace elements, bacteria, or radiochemicals limit the use of water for a drinking-water supply--at least locally in most aquifers. Generally, the quality of water from aquifers in the mountains is more suitable for a drinking-water supply. Water from the Pierre-Niobrara-Benton aquifer, with the exception of the Hygiene Sandstone Member of the Pierre Shale, is the least suitable for use as a drinking-water supply.

Residential development has increased significantly in selected areas of the county. Data indicate that all of the areas have at least some localized water-quality problems and many of the areas appear to have more widespread water-quality problems.

INTRODUCTION

Population growth and the increased use of the water resources in Boulder County (fig. 1) has resulted in a need by local and State agencies for an evaluation of the surface-water and ground-water resources of the county. Knowledge of the availability and quality of water and of factors affecting the quality of water will enable citizens, legislators, health officials, and planners to continue to manage the use of the water effectively. This report presents the results of a 2-year investigation begun in 1975 by the U.S. Geological Survey in cooperation with the Colorado Geological Survey and the Boulder County Health Department to evaluate the water resources of Boulder County.

Boulder County extends from the Continental Divide on the west to the Great Plains on the east. About 60 percent (450 mi^2) of the county consists of mountains and about 40 percent (300 mi^2) consists of plains. The county's population has increased from about 74,000 in 1960 to about 182,000 in 1977 (Boulder County Land Use Department, written commun., 1978). Only about 7,000 people reside in the mountainous part of the county. Most residents live in the eastern part of the county, which is included in the Colorado Front Range Urban Corridor[1], in the cities of Boulder (population about 95,000 in 1977), Longmont (population about 38,000 in 1977), and Broomfield (population about 15,000 in 1977).

The economy in the mountainous parts of the county is based principally on recreation and mining. Year-round outdoor recreation is popular in the Roosevelt National Forest, at the Rocky Mountain National Park, and at a ski resort near Eldora. Metal and fluorite mining in the Colorado Mineral Belt, while not as extensive as in the past, continues along Little James, James, Left Hand, Fourmile, and North Boulder Creeks. In the plains, agriculture, commercial development, electronics and research-type industrial development, and mining of coal and gravel are the principal economic activities.

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[1] Underscored words denote terms defined in Glossary at back of report.

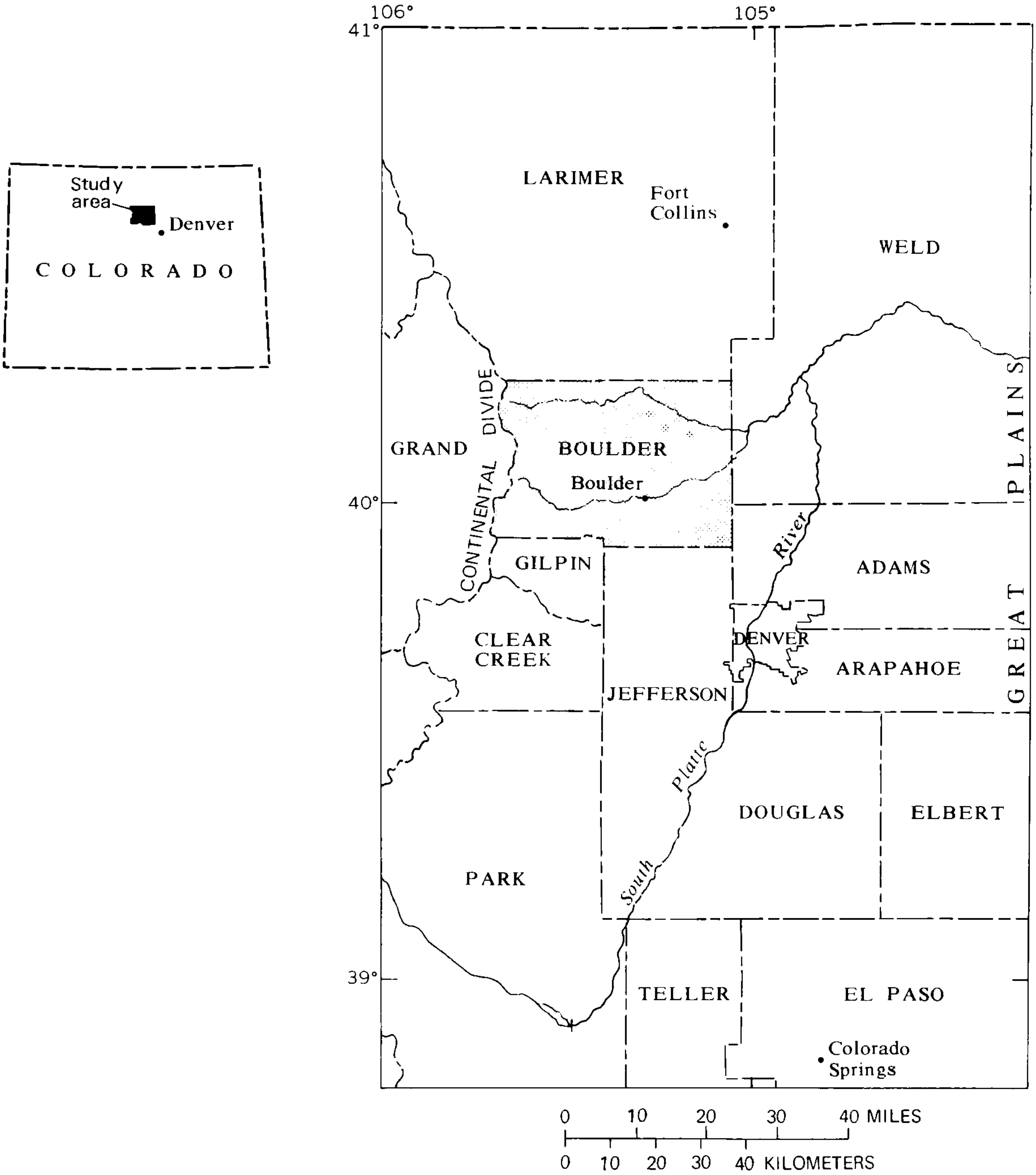


Figure 1.--Location of Boulder County.

Approach

Data on precipitation, streamflow, geology, water levels, well yields, aquifer characteristics, surface-water quality, and ground-water quality were needed to evaluate the water resources of Boulder County. The amount of precipitation occurring in Boulder County was calculated using data obtained from the U.S. Weather Bureau (1959, 1967). Volumes of streamflow were calculated using published and unpublished records of the U.S. Geological Survey. Published geologic maps by Colton (1978), Gable (1969, 1972), Gable and Madole (1976), Lovering and Goddard (1950), Madole (1969), and Tweto (1976), and an unpublished geologic map by D. E. Trimble and M. N. Machette (written commun., 1976) were used to prepare the generalized geologic maps presented in this report.

Water levels in wells were measured when possible or reported water levels were obtained from drillers' records on file with the Colorado Department of Natural Resources, Division of Water Resources, Office of the State Engineer. Water-table and potentiometric-surface maps were prepared using these data. Well-yield data were obtained from well owners or drillers' records. Aquifer-characteristics data were obtained from Wilson (1965).

Surface-water quality was determined from measurements of specific conductance and concentrations of major ions, trace elements, radiochemicals, and coliform, fecal-coliform, or fecal-streptococcal bacteria. Samples for water-quality analysis were collected from 37 sites on 18 streams. Results of the analyses are included in a report by Hall, Boyd, and Cain (1979). In order to determine water quality, sites for collection of surface-water samples were selected on the major streams from the headwaters in the mountains to where the streams leave the county in the plains. Sites also were located upstream from confluences with major tributaries to determine the effect of water quality in the tributaries on water quality in the streams. The general quality of surface water was determined from samples collected in late summer when most of the flow was base flow. Repeated measurements of specific conductance were made at 14 sites to assess seasonal variations due to agricultural return-flow and ground-water contributions.

Ground-water quality was determined from measurements of specific conductance and concentrations of major ions, trace elements, radiochemicals, and coliform and fecal-coliform bacteria. Samples for water-quality analysis were collected from 698 wells and 56 springs. Results of the analyses are included in a report by Hall, Boyd, and Cain (1979). Each aquifer was sampled throughout the area where it is used for water supply. Samples were collected according to methods described in Brown, Skougstad, and Fishman (1970). Samples collected for analysis of dissolved constituents were filtered at the well or spring site using a 0.45-micrometer filter. Water temperature and specific conductance were measured at the time samples were collected. Specific conductance also was determined in a laboratory for most samples to provide verification of the measurement made at the well or spring site.

Determinations of coliform, fecal-coliform, and fecal-streptococcal bacteria in both surface- and ground-water samples were made in field-laboratory vehicles using the membrane-filter technique described by Slack, Averett, Greeson, and Lipscomb (1973). Laboratory analyses of both surface- and ground-water samples were made at U.S. Geological Survey laboratories in Denver, Colo., Salt Lake City, Utah, and

Atlanta, Ga., using methods described in Brown, Skougstad, and Fishman (1970), Goerlitz and Brown (1972), Thatcher, Janzer, and Edwards (1977), and some newer unpublished methods. Information on detection limits and precision of all but the unpublished analytical techniques are discussed in these references.

Acknowledgments

The authors wish to thank the many residents of Boulder County who made possible the collection of samples and information by permitting access to their wells and springs and by patiently answering inquiries. The advice and assistance provided by personnel from the Colorado Geological Survey, the Boulder County Health Department, the Boulder County Planning Department, the Boulder City Engineering Division, the Northern Colorado Conservancy District, and Anne White of the League of Women Voters is appreciated.

WATER AVAILABILITY

Precipitation

Mean annual precipitation in Boulder County varies with altitude from less than 16 in. in the plains to more than 40 in. in the higher mountains along the Continental Divide (fig. 2). The mean annual precipitation of 18.6 in. over the county produces about 840,000 acre-ft of water. About 70 percent of the total precipitation (588,000 acre-ft) falls in the mountains and about 30 percent (252,000 acre-ft) falls in the plains.

Surface Water and Evapotranspiration

Most streams draining Boulder County originate in the county and all are tributaries of the South Platte River. The three major streams are, from north to south, St. Vrain, Boulder, and Coal Creeks. The St. Vrain Creek basin occupies almost the entire northern one-half of the county; tributaries of the Big Thompson River drain small areas along the northern edge of the county. All but a few square miles of the headwaters area of St. Vrain Creek are within the county. The Boulder Creek basin occupies most of the southern one-half of the county. All headwaters areas except the headwaters area of South Boulder Creek are within the county. Coal Creek, which originates outside the county, drains a small area along the southern edge and most of the southeastern part of the county; tributaries of Big Dry Creek drain the southeasternmost corner of the county. The stream system within the county is complex because of diversions from creek to creek within the county and transbasin diversions into and out of the county.

The flow in the streams varies considerably with the time of year, usually reaching a maximum in June due to runoff from snowmelt. The flow normally decreases throughout the remainder of the year as snowmelt runoff diminishes. During this time, ground-water seepage and spring flow contribute an increasing proportion of the water flowing in the streams.

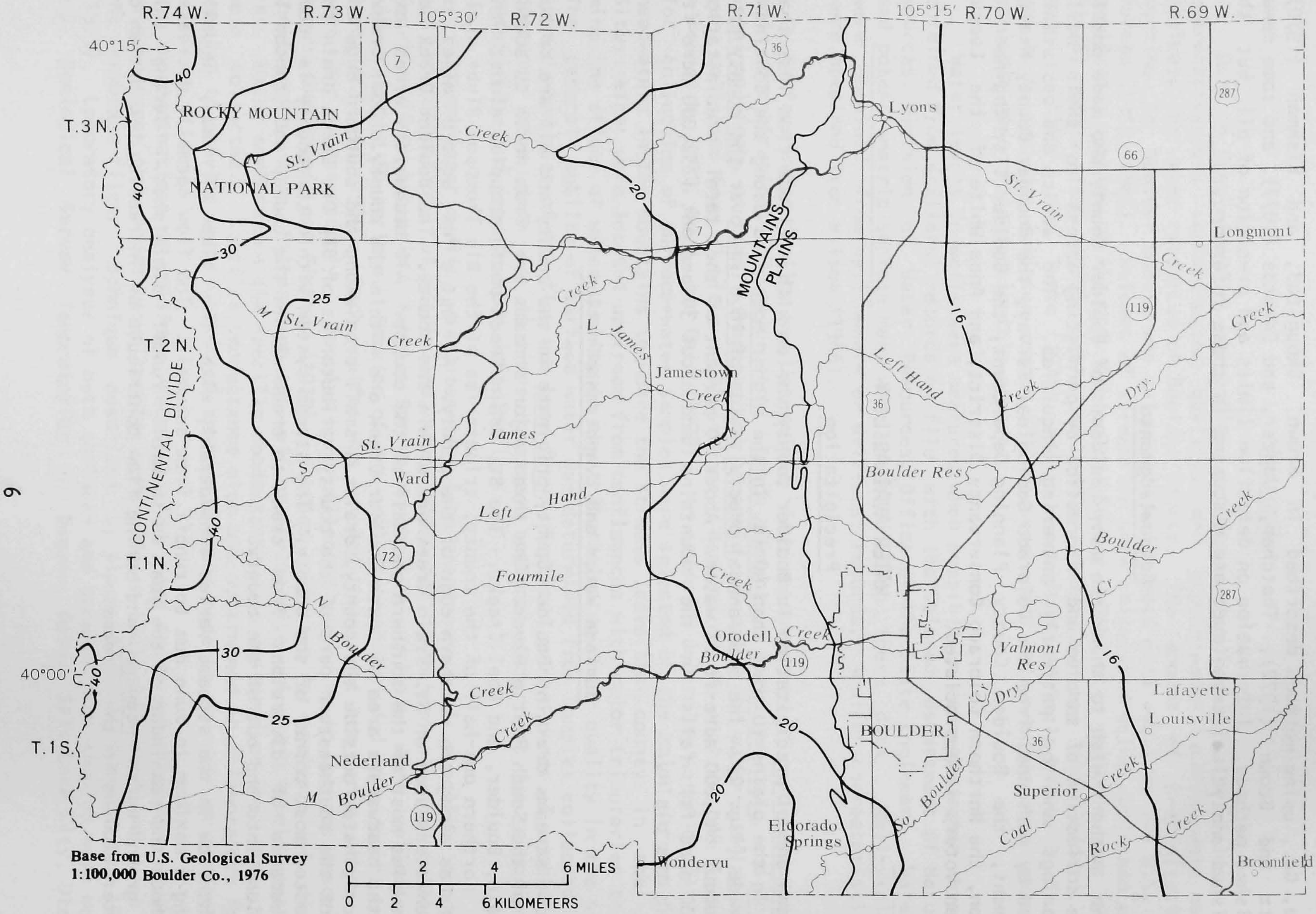


Figure 2. -- Mean-annual precipitation, in inches, 1931-60. (From U.S. Weather Bureau, 1967).

Based on historical streamflow records for subbasins in the mountains, an estimated 247,000 acre-ft of water flows from the mountains to the plains each year. Because of the limited storage capacity of the rocks and the few surface-water reservoirs in the mountains, most of the remaining 341,000 acre-ft that falls as precipitation in the mountains is returned to the atmosphere by evapotranspiration. This represents a loss of about 55 percent.

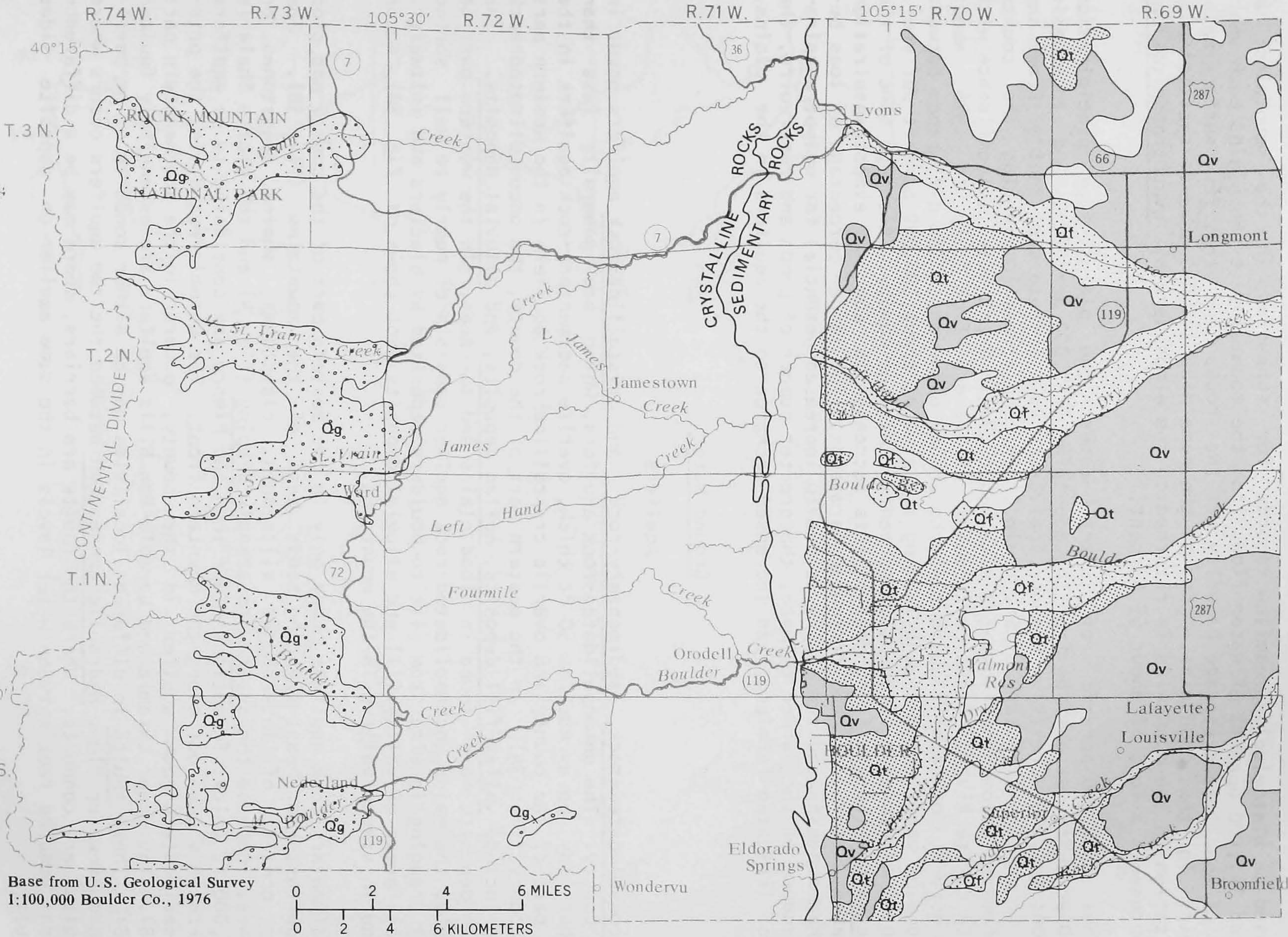
About 550,000 acre-ft of water enters the plains from precipitation (252,000 acre-ft), streamflow from the mountains (247,000 acre-ft), and transbasin diversions (51,000 acre-ft). Because Coal Creek is a tributary of Boulder Creek and Boulder Creek is a tributary of St. Vrain Creek, the streamflow leaving the county was estimated from the flow at a site on St. Vrain Creek near its confluence with the South Platte River. Based on 24 years of record from 1953 to 1976, about 154,000 acre-ft of water flows out of the county each year. The difference between the volume of water entering and leaving the plains, about 396,000 acre-ft per year, represents a decrease of about 70 percent within the county. Although some of the water recharges the aquifers, most of this decrease is due to evapotranspiration from lakes, reservoirs, and irrigated farmlands. The larger percentage of loss between the mountains and the plains is due to increased potential for evapotranspiration because of the warmer climate, the greater number of ponds and reservoirs, the amount of irrigated farmland, and increased recharge to the aquifers in the plains.

Ground Water

Aquifers

Unconsolidated-rock, sedimentary-rock, and crystalline-rock aquifers occur in Boulder County. The unconsolidated-rock aquifers, which are generally less than 30 ft but may be as much as 50 ft thick, overlie sedimentary-rock aquifers in the eastern part of the county and overlie crystalline-rock aquifers in the western part of the county (fig. 3A). In the eastern part of the county, the unconsolidated-rock aquifers include valley-fill deposits, eolian deposits, and alluvial deposits. The alluvial deposits are found in flood plains and terraces. In the western part of the county, the major unconsolidated-rock aquifer consists of poorly to well sorted material ranging in size from silt to boulders deposited by glaciers and meltwater. Some small areas of valley-fill and alluvial deposits (not shown on fig. 3A) occur along and in stream valleys in the mountains.

Sedimentary-rock aquifers occur only in the eastern part of the county and crop out in north-to-northeast trending bands east of the mountains (fig. 3B). The aquifers consist of interbedded siltstones, claystones, shales, sandstones, or limestones. Because the strata are steeply dipping (fig. 4) and the Pierre Shale is about 8,000 ft thick, formations older than the Pierre are considered to be aquifers only where they crop out along the mountain front. The Laramie-Fox Hills, the principal sedimentary-rock aquifer in the county, occurs in the southeastern part (fig. 3B). The upper Laramie and Laramie-Fox Hills aquifers are extensively faulted (fig. 3B). These faults in different localities may be either conduits of or barriers to ground-water flow. Hydraulic connection between the two aquifers occurs where the faults are conduits. Where the faults are barriers, there may be a difference of several hundred feet between water levels in the same aquifer on opposite sides of a fault.



Base from U.S. Geological Survey 1:100,000 Boulder Co., 1976

Figure 3A. -- Location of unconsolidated-rock aquifers.

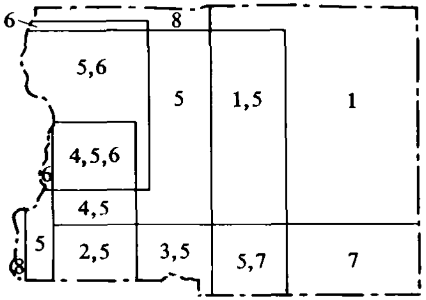
EXPLANATION

	UNCONSOLIDATED ROCK UNIT		Physical description	Approximate thickness (feet)	Aquifer unit	Well yields[1]
QUATERNARY	Qv	Valley-fill deposits, and eolian, undivided	Valley fill--Crudely bedded, poorly sorted material deposited on slopes and valley bottoms primarily by sheet wash	0-35	Valley fill	Small to inadequate
			Eolian--Wind-deposited fine sand and silt	0-25	Eolian	Small
	Qf	Flood-plain deposits	Stream-deposited boulders, gravel, and sand, with some clay and silt. These deposits are within the flood plain of streams	0-30	Flood Plain	Medium to large in plains, medium to small in mountains
	Qt	Terrace deposits	Stream-deposited boulders, gravel, and sand, with some clay and silt. These deposits are above the flood plain of streams	0-30	Terrace	Medium
	Qg	Glacial deposits	Material of all sizes from boulders to silt. Deposited by glaciers and outwash	0-50	Glacial	Medium to small

——— CONTACT

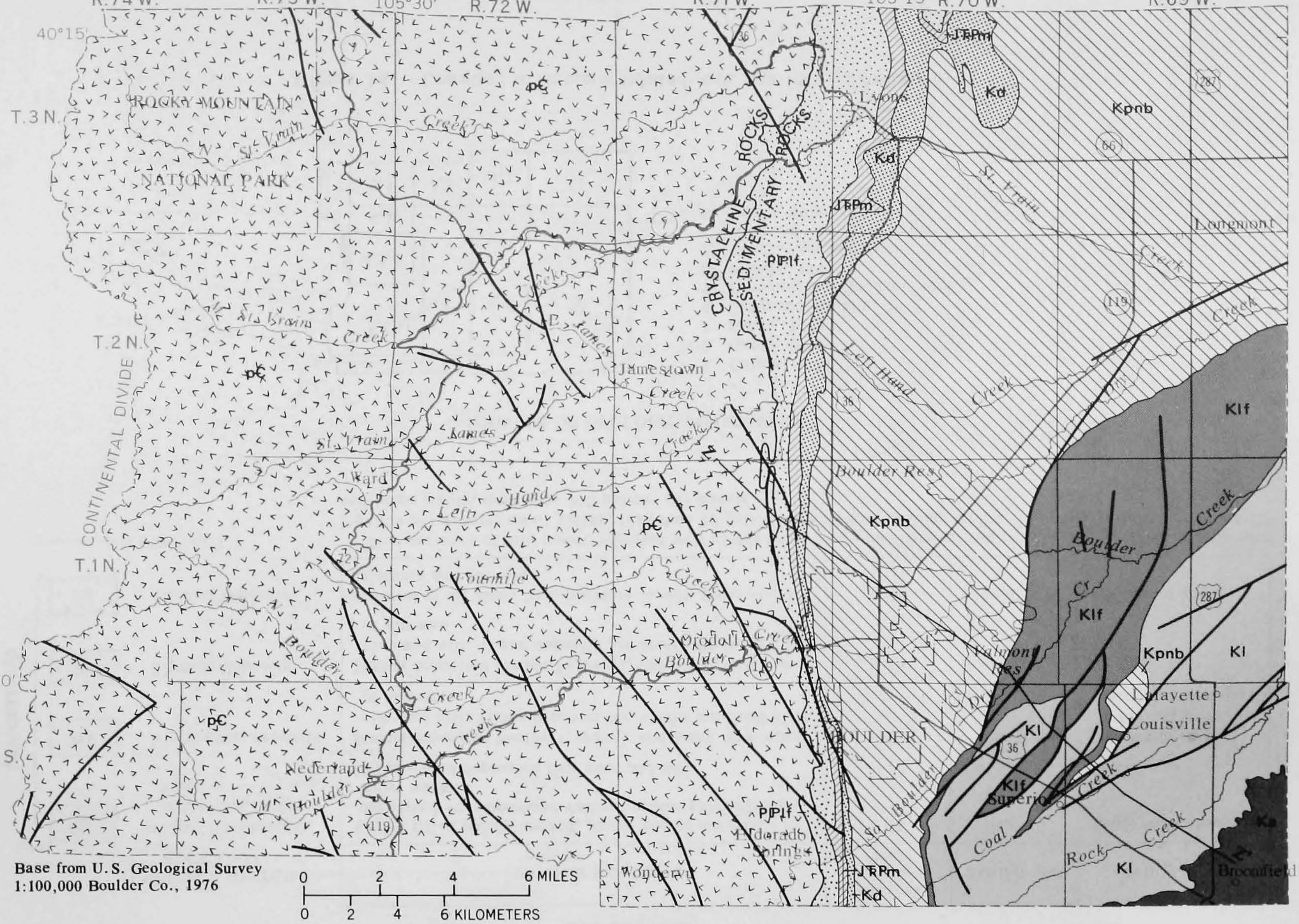
[1] For purposes of this report, reported well yields have been classified as follows: Inadequate yields, less than 1 gallon per minute; small yields, less than 15 gallons per minute; medium yields, 15 to 100 gallons per minute; and large yields, more than 100 gallons per minute

SOURCES OF GEOLOGIC INFORMATION



1. Colton, 1978
2. Gable, 1969
3. Gable, 1972
4. Gable and Madole, 1976
5. Lovering and Goddard, 1950
6. Madole, 1969
7. Trimble and Machette (written commun., 1976)
8. Tweto, 1976

Figure 3A.--Location of unconsolidated-rock aquifers--Continued.



Base from U.S. Geological Survey
1:100,000 Boulder Co., 1976

Figure 3B.--Location of sedimentary- and crystalline-rock aquifers.

EXPLANATION

Age	Map symbol	ROCK UNIT	Physical description	Approximate thickness (feet)	Aquifer unit	Well yields[1]
CRETACEOUS	[illegible]	Arapahoe Formation	Claystone and siltstone with lenses of sandstone	400	Arapahoe	No data
	Kl	Upper part of Laramie Formation	Claystone with some layers of sandstone and coal	600	Upper Laramie	Medium to inadequate
	Klf	Lower part of Laramie Formation and Fox Hills Sandstone, undivided	Sandstone with some thin beds of shale	250	Laramie-Fox Hills	Medium
	Kpnb	Pierre Shale, Niobrara Formation, and Benton Shale, undivided	Pierre--Shale with some sandstone beds in the middle and upper part, Hygiene Sandstone Member most prominent Niobrara and Benton--Shale with layers of limestone	8,000 600	Pierre-Niobrara-Benton	Inadequate
	Kd	Dakota Sandstone	Sandstone with layers of shale	300	Dakota	Medium to small
JURASSIC, TRIASSIC, AND PERMIAN	JTRPm	Morrison, Ralston Creek, and Lykins Formation, undivided	Siltstone with beds of sandstone and limestone. Deeply buried except near outcrop	900	Morrison-Ralston Creek-Lykins	Medium to small
PERMIAN AND PENNSYLVANIAN	PIPlf	Lyons Sandstone and Fountain Formation, undivided	Lyons--Sandstone. Deeply buried except near outcrop Fountain--Conglomeratic sandstone with lenses and layers of siltstone. Deeply buried except near outcrop	250 1,000	Lyons-Fountain	Small
PRECAMBRIAN	p€	Crystalline rocks	Fractured igneous and metamorphic rocks	-----	Crystalline rock	Small to inadequate

——— CONTACT

——— FAULT

Z-Z' LINE OF SECTION-Section shown on figure 4

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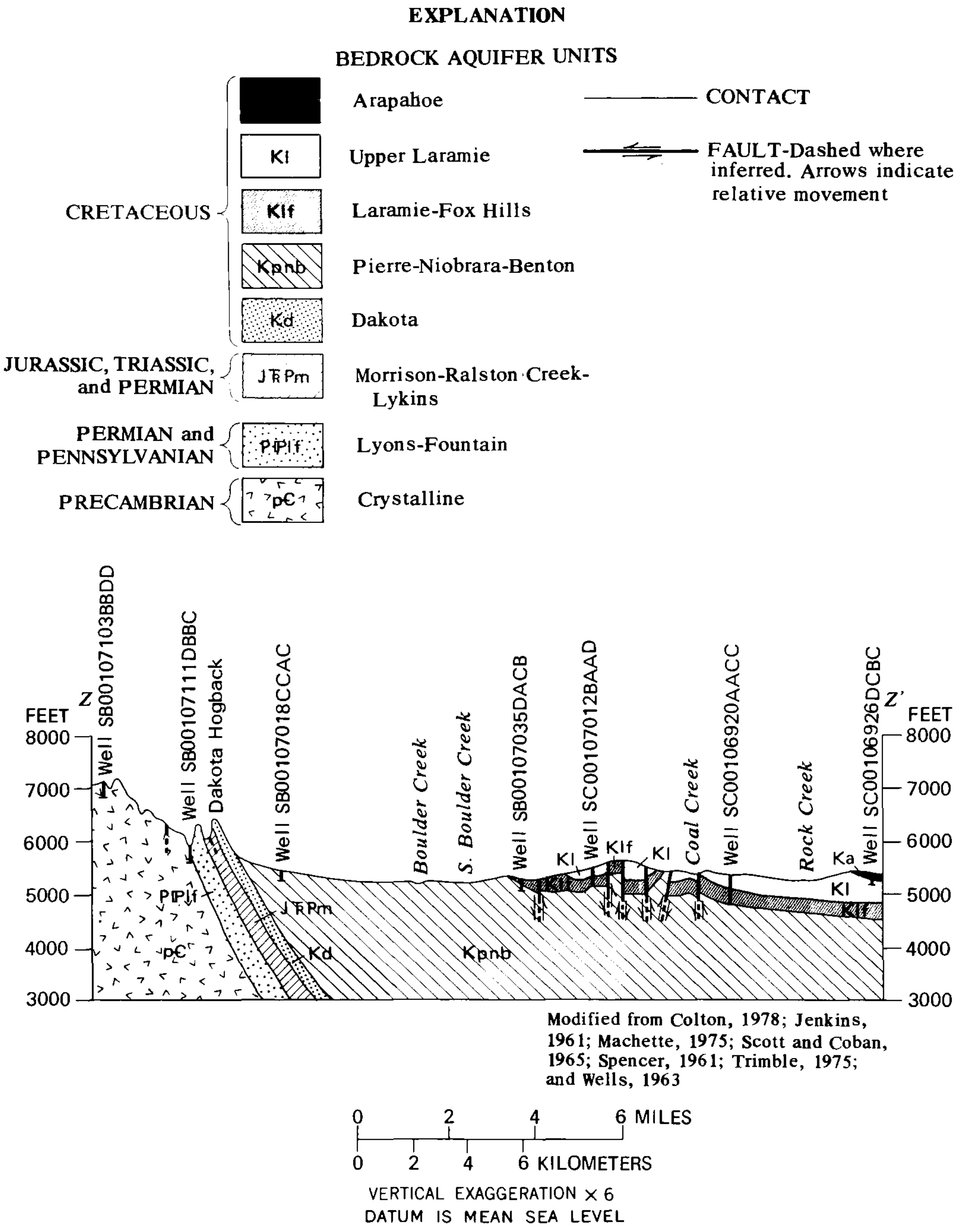
[1] For purposes of this report, reported well yields have been classified as follows: Inadequate yields, less than 1 gallon per minute; small yields, less than 15 gallons per minute; medium yields, 15 to 100 gallons per minute; and large yields, more than 100 gallons per minute

See figure 3A for sources of geologic information

Figure 3B.--Location of sedimentary- and crystalline-rock aquifers--Continued.



Modified from Colton, 1978; Jenkins, 1961; Machette, 1975; Scott and Coban, 1965; Spencer, 1961; Trimble, 1975; and Wells, 1963

Figure 4.--Generalized section of bedrock aquifer units (see figure 3B for trace of section).

Crystalline rocks, which consist of igneous and metamorphic rocks, occur below the sedimentary-rock aquifers, and function as an aquifer only in localities in the mountains where the rocks have been fractured. Fractures result from jointing or faulting of the rocks. Generally, the openings of the fractures decrease in size with increasing depth and chances of obtaining water generally decrease significantly below a depth of 300 ft. The occurrence of water in fault zones also may be limited by the presence of silt-size particles in the fractures that were formed as the rocks moved against each other when the faults were active.

Recharge and Discharge

Snowmelt and rainfall infiltration are the principal sources of recharge to the aquifers. Streamflow and infiltration from overlying aquifers are other sources of recharge. Recharge is generally greatest in the late spring and early summer during the snowmelt season. During the late summer and fall, intense rainstorms are sources of recharge. However, the relative amount of recharge from these storms is insignificant compared with the recharge from snowmelt. Streamflow, principally in the plains, generally is a source of recharge only during the snowmelt-runoff season. Later in the year, water usually flows back into the streams from the aquifers. Infiltration from overlying aquifers, which occurs principally in the plains, may occur throughout the year. The amount of recharge depends on the amount of water in the overlying aquifer and on the relative permeability of the aquifers.

Snowmelt and rainfall recharge all the aquifers and are virtually the only sources of recharge to most of the unconsolidated-rock aquifers, the sedimentary-rock aquifers older than the Pierre Shale, and the crystalline-rock aquifer. Streamflow recharges, to some extent, all the aquifers that underlie the stream valleys. Infiltration occurs principally from the unconsolidated-rock aquifers into the underlying sedimentary-rock and crystalline-rock aquifers. Infiltration between sedimentary-rock aquifers occurs principally in aquifers overlying the Pierre Shale.

Water is discharged from the aquifers by evapotranspiration; seepage into streams, swamps, ponds, lakes, and reservoirs; flow from springs; pumpage from wells; and flow between aquifers. Evapotranspiration is the most significant form of discharge. The combined volume of all other water discharged from the aquifers is minor compared with the volume of water discharged by evapotranspiration. Discharge by evapotranspiration is greatest during the summer and fall when evaporation rates and plant growth are greatest. Seepage into surface-water bodies also is greatest during the summer and fall. As water levels decline in the surface-water bodies, seepage occurs from the aquifers. The flow of springs generally decreases throughout the summer and fall as the amount of stored water in the aquifers decreases. Pumpage from wells occurs throughout the year; however, pumpage in agricultural areas generally increases during the summer and fall. Flow between aquifers also occurs throughout the year but may decrease or cease as the uppermost aquifers are drained.

Interpretation of available water-level data (p. 14), indicates that the ground-water system in the county is probably in a state of equilibrium. Recharge to the system equals discharge from the system.

System of Numbering Wells and Springs in Colorado

In this report, the locations of wells and springs are numbered using the U.S. Bureau of Land Management's system of land subdivision that locates a well or spring within a 2.5-acre tract; the system is explained in figure 5. The locations are described proceeding from the largest to the smallest land subdivision. This is in contrast to the legal description, which proceeds from the smallest to the largest land subdivision.

Water Levels

Measured or reported water-level data obtained for 498 wells are summarized by aquifer in table 1. Flowing wells indicate that artesian conditions existed in the aquifer or in a part of the aquifer in the vicinity of the well at the time of measurement.

Table 1.--*Depths to water in the aquifers*

[F=flowing well]

Aquifer	Number of wells	Measured or reported depth to water, in feet below land surface		
		Minimum	Median	Maximum
Valley fill and eolian, undifferentiated----------------	29	0	10	19
Flood plain-----------------------	111	0	8	41
Terrace--------------------------	56	F	8	29
Glacial--------------------------	12	4	13	30
Arapahoe-------------------------	0	--	----	---
Upper Laramie--------------------	6	10	24.5	98
Laramie-Fox Hills-----------------	71	F	80	360
Pierre-Niobrara-Benton------------	47	0	15	70
Dakota---------------------------	4	F	1.5	5
Morrison-Ralston Creek-Lykins-----	2	42	61.5	81
Lyons-Fountain-------------------	11	0	31	75
Crystalline-rock-----------------	149	F	27.5	201
Total------------------------	498			

Water levels measured in 19 wells during 1954-60 (Jenkins, 1961) were remeasured in 1976-77 to determine if water levels had changed significantly (table 2).

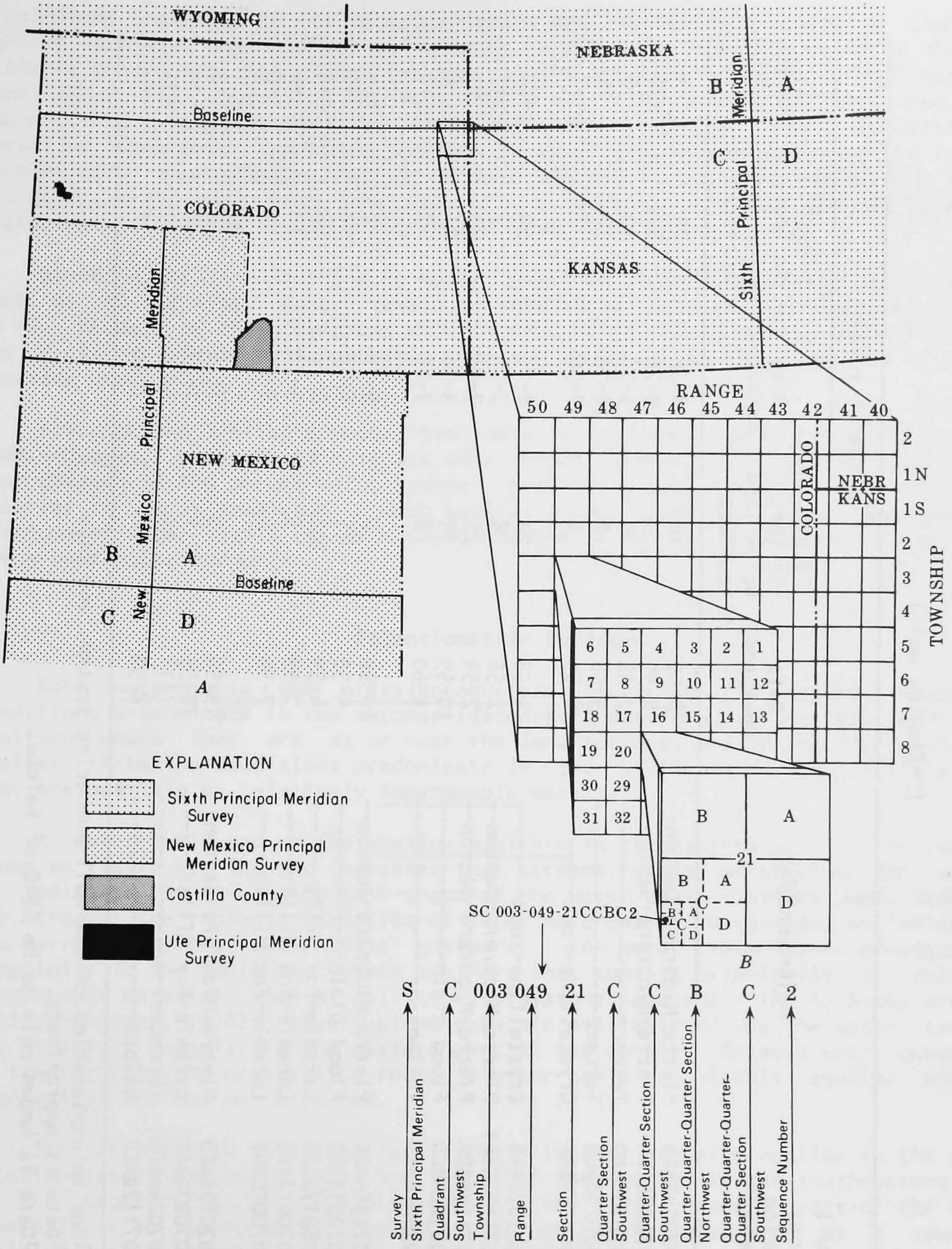


Figure 5. -- System of numbering wells and springs in Colorado.

Table 2.--*Comparison between depths to water measured in 1954-60 and in 1976-77*

[F=flowing well]

Well or spring number[1]	Major aquifer	Water levels				
		Date measured	Depth, in feet below land surface	Date measured	Depth, in feet below land surface	Change, in feet
SB00107004BDAD	Pierre-Niobrara-Benton--	8-59	16	8-76	20	-4
SB00107005BCDA	Pierre-Niobrara-Benton--	8-59	3	9-76	29	-26
SB00107018DBAD	Terrace------------------	7-58	5	3-76	10	-5
SB00107024DBCB	Terrace------------------	9-58	12	10-76	10	+2
SB00107105BDAA	Crystalline-rock--------	8-59	4	7-76	7	-3
SB00107107BAAB	Crystalline-rock--------	4-58	22	8-76	50	-28
SB00107113DABC1	Pierre-Niobrara-Benton--	2-56	8	7-76	7	+1
SB00107113DADA	Pierre-Niobrara-Benton--	2-54	22	7-76	23	-1
SB00206920DBCD	Flood plain-------------	10-59	13	3-76	21	-8
SB00207001DBCD	Eolian------------------	4-60	8	7-76	7	+1
SB00207136AADC	Pierre-Niobrara-Benton--	10-56	F	9-76	F	---
SB00307023BDBD	Flood plain-------------	4-59	15	6-76	13	+2
SC00106917BCAD	Laramie-Fox Hills-------	4-59	102	9-76	98	+4
SC00107001AABD	Laramie-Fox Hills-------	7-59	5	3-76	10	-5
SC00107001CAAB	Laramie-Fox Hills-------	7-59	6	9-76	11	-5
SC00107017AACD	Pierre-Niobrara-Benton--	[2]9-54	9	7-76	18	-9
SC00107027DBCD	Laramie-Fox Hills-------	8-59	F	1-77	F	---
SC00107024AADD2	Terrace------------------	(3)	46	8-76	11	+35
SC00107112DACD	Dakota------------------	8-59	F	7-76	F	---

[1] For an explanation of the well-numbering system, see page 14.

[2] Date is approximate.

[3] Date is known only to be 1960 or before.

Significant changes (±10 ft) in water levels are indicative of relative changes in aquifer storage and may reflect changes in water use near the wells or changes in climatic conditions that affect recharge to the aquifers. Climatic conditions have been about the same since the late 1950's until the drought of the middle 1970's. The wells were measured early in the drought before effects, if any, on water levels would be apparent; therefore, changes in water levels probably were the result of factors other than climate. A rise of more than 10 ft probably indicated a decrease in water withdrawal from the aquifer; a decline of more than 10 ft probably indicated an increase in water withdrawal from the aquifer.

Based on the data in table 2, water levels in 1976-77 generally were about the same as in 1954-60; water levels in only three wells rose or declined more than 10 ft. Because of the widespread distribution of the three wells, local factors in the vicinity of the wells probably were the cause of the large changes rather than areawide conditions.

Although the available water-level data in this instance do not indicate areawide changes, water-level data are usually one of the first indicators of significant changes in the ground-water system. Monitoring water levels in a network of observation wells completed in each aquifer to determine long-term trends and fluctuations of water levels can be a useful method of obtaining data needed to manage the ground-water resource.

Potentiometric Surfaces

Both water-table and artesian aquifers occur in the county. Water-table conditions predominate in the unconsolidated-rock aquifers, in the sedimentary-rock aquifers where they are at or near the land surface, and in the crystalline-rock aquifer. Artesian conditions predominate in the sedimentary-rock aquifers where they are overlain by relatively impermeable material.

A water-table map of the shallow aquifers in the eastern part of the county is shown on figure 6. The map indicates that streams receive water from the aquifers as indicated by the upstream V-shape of the water-table contours where they cross the streams; the regional direction of water movement is to the east as indicated by the arrows on the water-table contours. The water table may be discontinuous, especially in the sedimentary-rock aquifers that consist principally of relatively impermeable material, such as siltstone, claystone, and shale (P. A. Schneider, Jr., written commun., 1978). Insufficient data are available to map the water table in the glacial deposits in the western part of the county. Because water occurs only in fractures in the crystalline rocks, a water-table map of this aquifer would be meaningless and was not prepared.

The Laramie-Fox Hills aquifer is the principal artesian aquifer in the county. Artesian conditions exist in a 50-mi^2 part of the aquifer in the southeastern corner of the county (fig. 7). The direction of flow in the artesian part of the aquifer generally is to the northeast and east. The aquifer is being used as a source of municipal-water supplies in the Broomfield area. The potential use of the aquifer as a source of municipal-water supplies for the communities of Lafayette, Louisville, and Superior is being investigated (P. A. Schneider, Jr., oral commun., 1978).

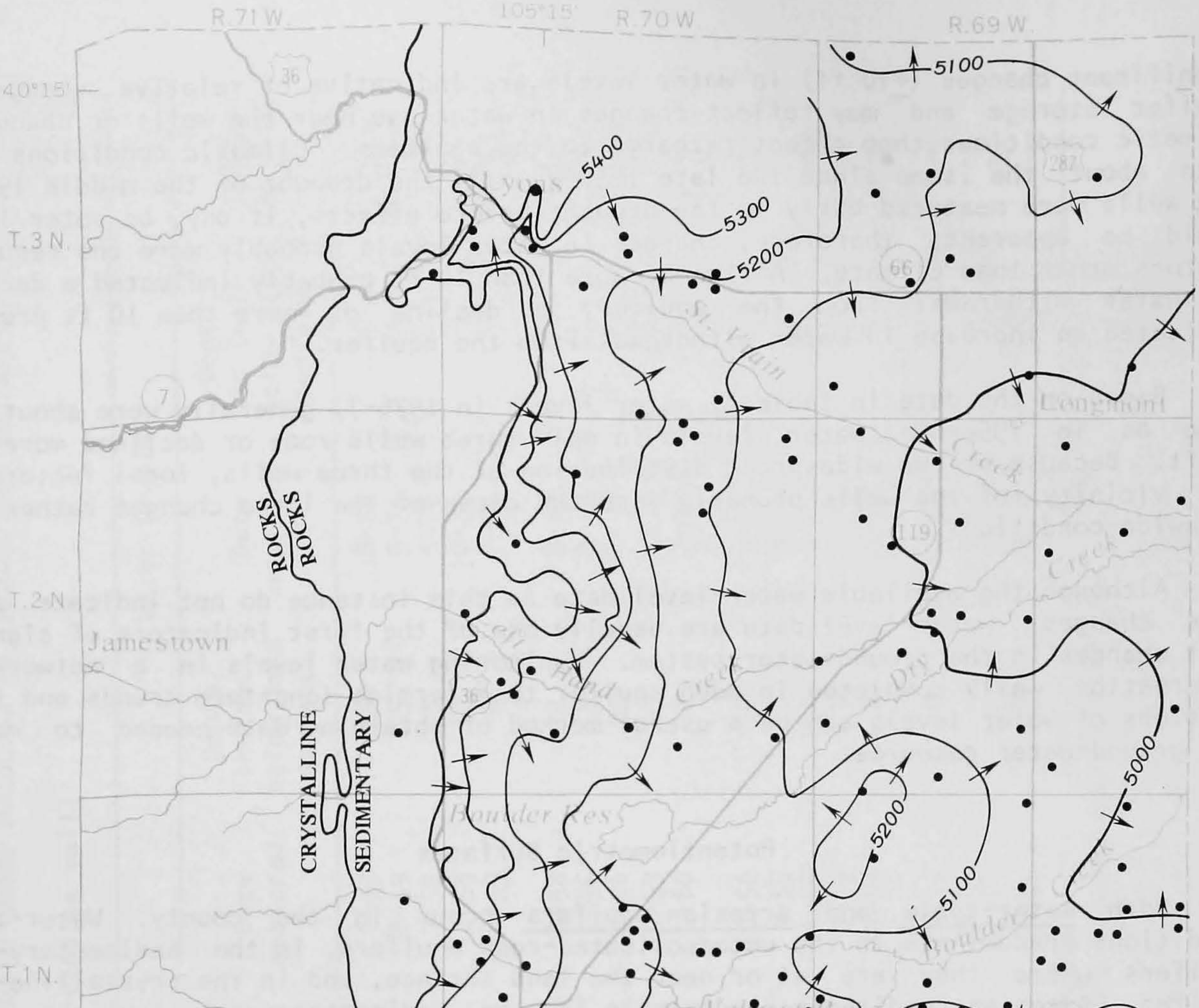


Figure 6.--Water table of shallow aquifers in eastern Boulder County.

EXPLANATION

•	DATA POINT
—*5200*—	WATER-TABLE CONTOUR – Shows altitude of the water table, 1976. Contour interval 100 feet. Datum is mean sea level
☐	AREAS WITH ANOMALOUS WATER-TABLE SURFACES THAT MAY BE EXPLAINED BY EXTENSIVE FAULTING OF THE SUBSTRATA
←	ARROW INDICATES RELATIVE DIRECTION OF WATER MOVEMENT

Supplies and Well Yields

Factors determining whether an aquifer will be used for a water supply are depth to water, magnitude and dependability of well yield, quality of water, intended use of the water, and availability of an alternative supply. Landowners who must depend on ground water for their water supply have few choices as to the source of supply unless their property is underlain by unconsolidated-rock aquifers. The presence of unconsolidated-rock aquifers enables landowners to choose between the unconsolidated-rock aquifer or the underlying consolidated-rock aquifer for their source of water supply.

All aquifers in the county will yield sufficient quantities of water for domestic supplies (1 or more gal/min) (table 3). Well yields sufficient for domestic supplies are most difficult to obtain from the crystalline-rock aquifer; those sedimentary-rock aquifers consisting principally of siltstone, claystone, or shale, such as the Arapahoe, upper Laramie, and Pierre-Niobrara-Benton aquifers; and valley-fill and eolian aquifers.

Supplies sufficient for community water-supply systems and commercial enterprises (15 or more gal/min) may be obtained from the flood-plain, terrace, glacial, Laramie-Fox Hills, Dakota, and Morrison-Ralston Creek-Lykins aquifers (table 3). Generally, the largest well yields will be obtained from the flood-plain aquifer.

Supplies sufficient for large-scale urban development and irrigation (100 or more gal/min) may be obtained from the flood-plain aquifer (table 3). Supplies sufficient for these purposes also may be obtainable from the terrace and Laramie-Fox Hills aquifers because the reported well yields from these aquifers, as well as from the flood-plain aquifer, may have been limited by the installed pump capacities. Yields of more than 100 gal/min could possibly be obtained from the terrace and Laramie-Fox Hills aquifers.

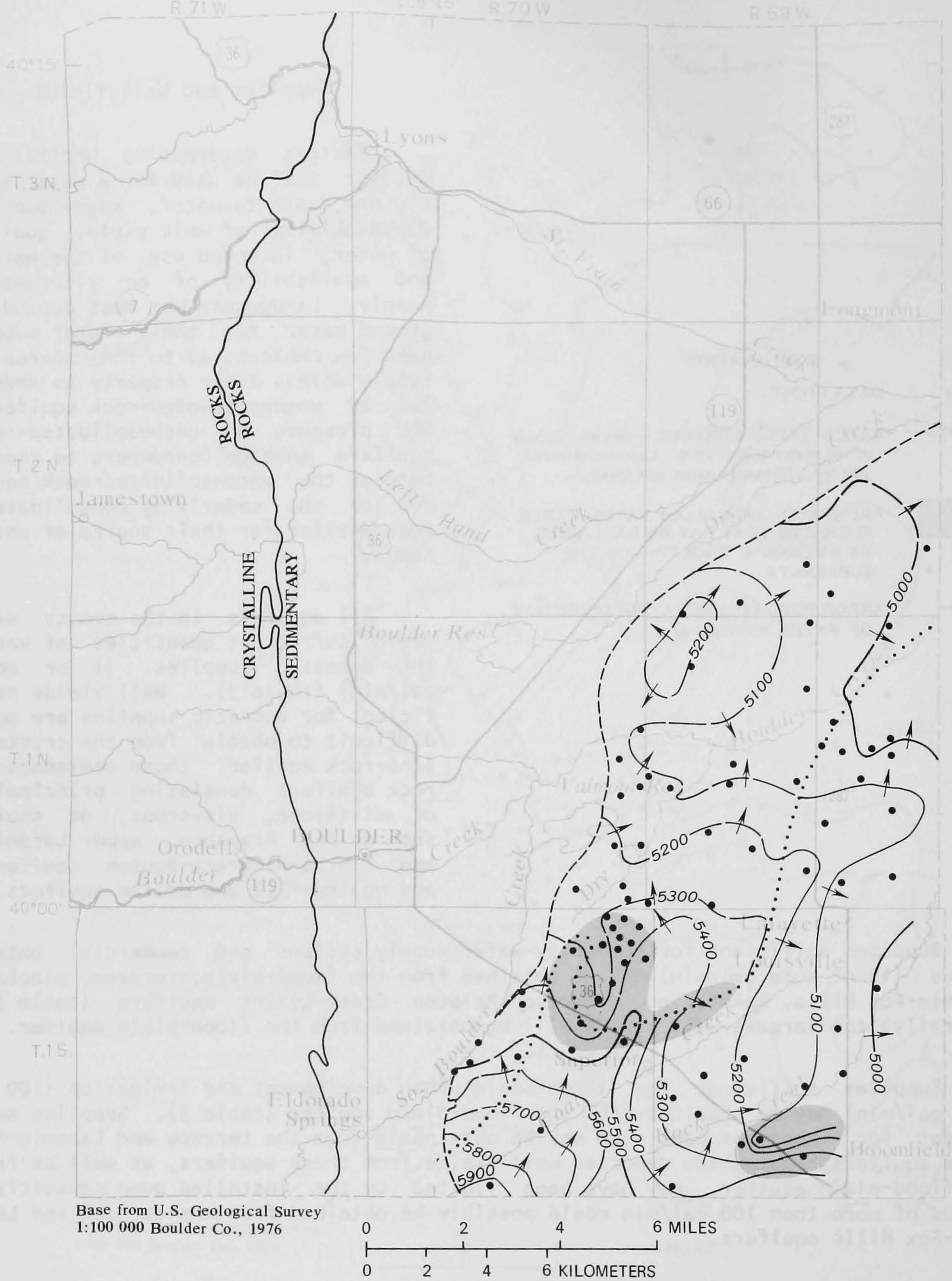


Figure 7.--Potentiometric surface of the Laramie-Fox Hills aquifer.

EXPLANATION

•	DATA POINT
---5200---	WATER-TABLE CONTOUR – Shows altitude of water table, 1976. Contour interval 100 feet. Datum is mean sea level.
——5400——	POTENTIOMETRIC CONTOUR – Shows altitude at which water level would have stood in tightly cased wells, 1976. Contour interval 100 feet. Datum is mean sea level.
....	APPROXIMATE BOUNDARY BETWEEN WATER-TABLE AND ARTESIAN CONDITIONS IN THE LARAMIE-FOX HILLS AQUIFER
---------	APPROXIMATE CONTACT BETWEEN THE PIERRE-NIOBRARA-BENTON AQUIFER AND THE LARAMIE-FOX HILLS AQUIFER
☐	AREAS WITH ANOMOLOUS WATER TABLE OR POTENTIOMETRIC SURFACES THAT MAY BE EXPLAINED BY EXTENSIVE FAULTING OF THE SUBSTRATA
←	ARROW INDICATES RELATIVE DIRECTION OF WATER MOVEMENT

Ground-Water Outflow from the County

Ground-water outflow from the county may be considered a form of discharge from the ground-water system because the water is no longer available for use in the county. Water flows out of the county from all the aquifers but principally from the unconsolidated-rock aquifers in stream valleys and from the Laramie-Fox Hills aquifer. Outflow from the crystalline-rock aquifer is probably insignificant because the water-bearing fractures generally are not interconnected sufficiently to transmit large volumes of water any appreciable distance. Outflow from sedimentary-rock aquifers, other than the Laramie-Fox Hills aquifer, was not determined either because the flow is relatively small due to the composition of the aquifers (principally siltstone, claystone, or shale for the Pierre-Niobrara-Benton and younger aquifers) or because the aquifers are economically developable only in the outcrop areas (aquifers older than the Pierre-Niobrara-Benton).

Outflow from the unconsolidated-rock and Laramie-Fox Hills aquifers was calculated using Darcy's Law. The amount of water flowing out of the county from the unconsolidated-rock aquifers was estimated to be 6,900 acre-ft per year based on an average transmissivity of 920 ft^2/d (Wilson, 1965) and an average hydraulic gradient of 50 ft/mi (water-table map, fig. 6).

The amount of water flowing out of the county from the Laramie-Fox Hills aquifer was estimated to be 350 acre-ft per year based on an average transmissivity of 23 ft^2/d (Wilson, 1965) and an average hydraulic gradient of 100 ft/mi (potentiometric-surface map, fig. 7). This volume is about 5 percent of the outflow from the unconsolidated-rock aquifers.

Table 3.--*Reported well yields from the aquifers*

Aquifer	Number of wells	Well yields, in gallons per minute		
		Minimum	Median	Maximum
Valley fill and eolian, undifferentiated	5	2	6	8
Flood plain	33	3	15	210
Terrace	23	1	25	65
Glacial	3	1	2	15
Arapahoe	0	-	----	---
Upper Laramie	5	3	7	[1]910
Laramie-Fox Hills	59	2	15	50
Pierre-Niobrara-Benton	22	1	5	27
Dakota	2	1	25.5	50
Morrison-Ralston Creek-Lykins	2	2	51	100
Lyons-Fountain	8	1	3.5	10
Crystalline-rock	54	1	3	20
Total	216			

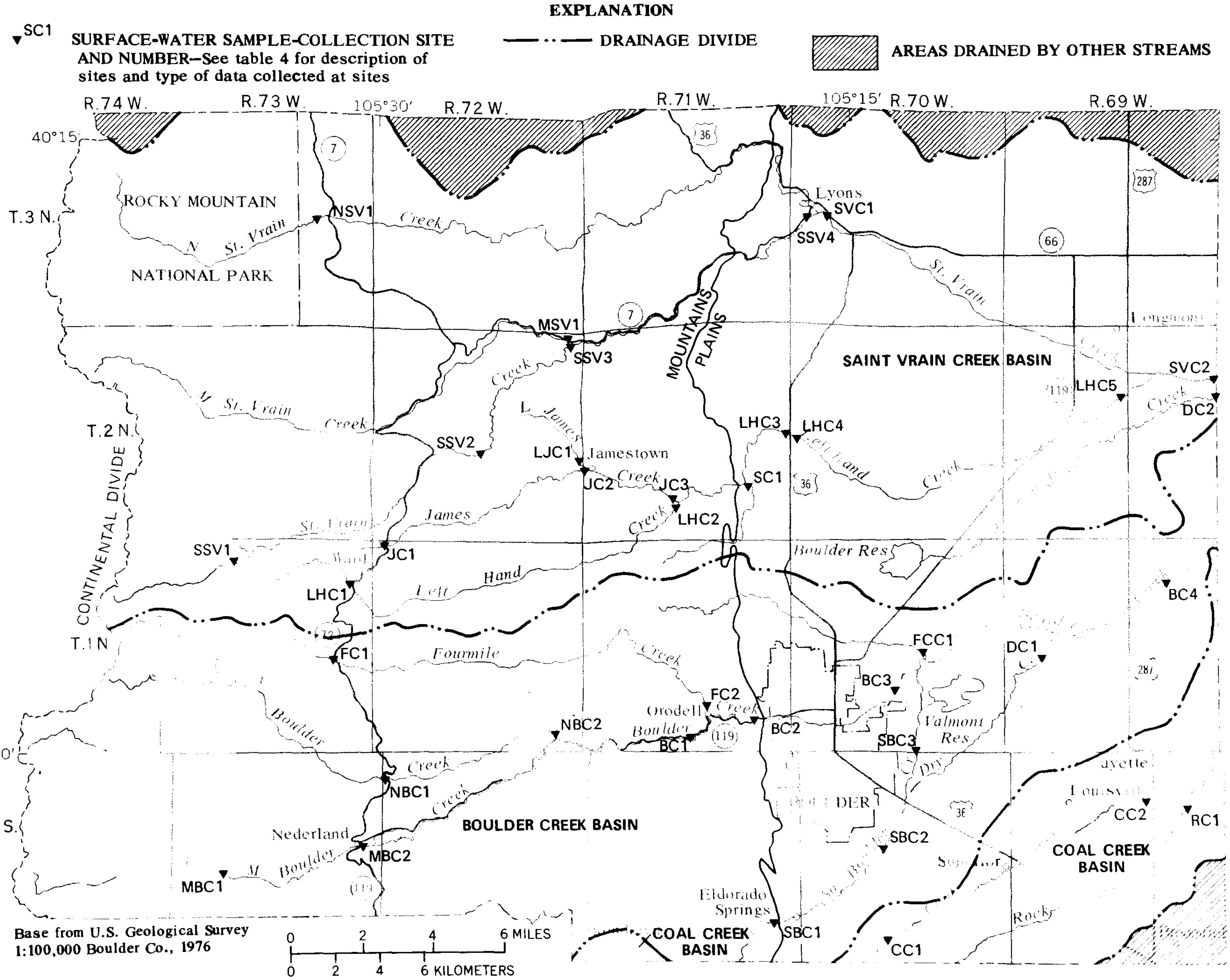
[1] Water obtained from an abandoned coal mine.

SURFACE-WATER QUALITY

Location of Water-Sample-Collection Sites and Types of Water-Quality Data

Samples for water-quality analyses were collected from 34 sites on 18 streams (fig. 8 and table 4). Samples were collected once at 32 sites in late September or early October 1975 for analysis of major ions, trace elements, bacteria, and radiochemicals. At site SSV4, one sample was collected for analysis of major ions, trace elements, bacteria, and radiochemicals. Samples also were collected monthly for 14 months at sites SSV4 and LHC3 for analysis of major ions. The monthly samples were collected as part of the National Water-Quality Monitoring program of the U.S. Geological Survey.

In addition, second samples for analysis of radiochemicals were collected at six sites (table 4). Specific conductance and water temperature were measured weekly at six sites and monthly at eight sites (table 4) to determine seasonal variations in water quality. All water-quality analyses and measurements are included in a report by Hall, Boyd, and Cain (1979).



Base from U.S. Geological Survey
1:100,000 Boulder Co., 1976

Figure 8. --Location of surface-water sample-collection sites.

Table 4.--*Summary of types of water-quality data*

Site number on fig. 8	Location
	ST. VRAIN CREEK BASIN--Mountains
NSV1	North St. Vrain Creek at State Highway 7, near Meeker Park
SSV1	South St. Vrain Creek above Brainard Lake
SSV2	South St. Vrain Creek near Jamestown
SSV3	South St. Vrain Creek at County Highway 84, below Raymond
MSV1	Middle St. Vrain Creek at mouth, below Raymond
LHC1	Left Hand Creek at State Highway 72, at Ward
LHC2	Left Hand Creek above James Creek, near Jamestown
JC1	James Creek at State Highway 72, near Ward
JC2	James Creek at Canyon Drive, at Jamestown
LJC1	Little James Creek at mouth, at Jamestown
JC3	James Creek at mouth, below Jamestown
	ST. VRAIN CREEK BASIN--Plains
SSV4	South St. Vrain Creek above Lyons
SVC1	St. Vrain Creek at Lyons
SC1	Sixmile Creek at mouth, below Jamestown
LHC3	Left Hand Creek at Altona
LHC4	Left Hand Creek at U.S. Highway 36, below Altona
LHC5	Left Hand Creek at U.S. Highway 287, at Longmont
SVC2	St. Vrain Creek at East County Line Road, at Longmont
DC2	Dry Creek at East County Line Road, near Longmont
	BOULDER CREEK BASIN--Mountains
MBC1	Middle Boulder Creek above Eldora
MBC2	Middle Boulder Creek at Nederland
NBC1	North Boulder Creek at State Highway 72, near Ward
NBC2	North Boulder Creek at mouth, below Nederland
BC1	Boulder Creek near Orodell
FC1	Fourmile Creek at State Highway 72, near Ward
FC2	Fourmile Creek at mouth, at Orodell
BC2	Boulder Creek above Boulder
	BOULDER CREEK BASIN--Plains
BC3	Boulder Creek at North 55th Street, below Boulder
SBC1	South Boulder Creek near Eldorado Springs
SBC2	South Boulder Creek at State Highway 93, near Eldorado Springs
SBC3	South Boulder Creek at Baseline Road, near Boulder
FCC1	Fourmile Canyon Creek at North 61st Street, below Boulder
DC1	Dry Creek at Valmont Drive, below Boulder
BC4	Boulder Creek at Kenosha Road, near Erie
	COAL CREEK BASIN--Plains
CC1	Coal Creek at State Highway 128, above Superior
CC2	Coal Creek at U.S. Highway 287, at Lafayette
RC1	Rock Creek at 120th Street, near Lafayette

obtained at streamflow sites

Major ions, trace elements, bacteria, and radiochemicals (1 analysis)	Major ions (monthly, 14 analyses)	Radiochemicals (1 analysis)	Specific-conductance and water-temperature measurements	
			Weekly	Monthly
		ST. VRAIN CREEK BASIN--Mountains		
X	-	-	-	-
X	-	-	-	-
-	-	-	-	X
X	-	-	-	-
X	-	-	-	-
X	-	-	X	-
X	-	-	X	-
X	-	-	-	-
X	-	-	-	-
X	-	-	-	-
X	-	-	X	-
		ST. VRAIN CREEK BASIN--Plains		
X	X	-	-	X
X	-	-	-	-
X	-	-	-	-
-	X	-	-	X
X	-	-	X	-
X	-	X	X	-
X	-	-	X	-
X	-	X	-	-
		BOULDER CREEK BASIN--Mountains		
X	-	-	-	-
X	-	-	-	-
X	-	-	-	-
X	-	-	-	-
X	-	-	-	-
X	-	-	-	-
X	-	-	-	X
-	-	-	-	X
		BOULDER CREEK BASIN--Plains		
X	-	-	-	X
X	-	-	-	-
-	-	-	-	X
X	-	-	-	-
X	-	-	-	-
X	-	X	-	-
X	-	X	-	-
		COAL CREEK BASIN--Plains		
X	-	X	-	-
X	-	-	-	X
X	-	X	-	-

General Water Quality Indicated by Specific Conductance

Specific conductance is an indicator of general water quality because it is directly related to the concentration of dissolved solids (mineral matter) in the water. As specific conductance increases, dissolved-solids increase, and, in most instances, the concentrations of the individual constituents comprising the dissolved solids increase correspondingly. Specific conductance in streamflow was measured at 37 sites during September-October 1975 to determine the relative magnitude of values throughout the county. Subsequently, specific conductance was measured weekly at six sites and monthly at eight sites for about 1 year to determine seasonal variations in general water quality (table 5).

During September-October 1975, the specific conductance of water in mountain streams ranged from 21 micromhos (micromhos per centimeter at 25° Celsius) in North St. Vrain Creek (site NSV1) to 607 micromhos in Little James Creek (site LJC1). As the streams flowed across the plains, specific conductance increased. Maximum specific-conductance values in the principal streams were measured at the most downstream sites: Left Hand Creek, 1,730 micromhos at site LHC5; St. Vrain Creek, 1,520 micromhos at site SVC2; Boulder Creek, 575 micromhos at site BC4; and Coal Creek, 800 micromhos at site CC2. The increase in specific-conductance values from west to east in the county is a naturally occurring process. As additional tributaries with their corresponding dissolved-solids constituents enter the streams, the overall specific conductance of the water may increase. However, relative volumes of flow in the streams affect the impact of tributary inflow on specific conductance in the main stream. For example, even though the specific conductance in Left Hand Creek at site LHC5 was 1,730 micromhos, the specific conductance in St. Vrain Creek at site SVC2 downstream from the confluence with Left Hand Creek was 1,520 micromhos. The decrease in specific conductance was due to the greater volume of flow in St. Vrain Creek containing fewer dissolved solids (specific conductance was 90 micromhos at site SVC1).

At all 14 sites where multiple measurements were made, specific conductance was smallest during the summer and early fall (June through September) and greatest during the late fall and early spring (November through April) (table 5). The specific conductance in streams generally is directly related to the source of the streamflow. Precipitation, which is the primary source of streamflow during the summer as a result of snowmelt and rainstorms, contains relatively small amounts of dissolved constituents. Ground water, which is the primary source of streamflow during the late fall and winter, contains relatively large amounts of dissolved constituents when compared to precipitation.

Table 5.--*Specific conductance of surface water, 1975-76*

Site number on fig. 8	Specific conductance September-October 75 (micromhos per centimeter at 25°C)	Frequency of measurement	Minimum specific conductance (micromhos per centimeter at 25°C)	Date of measurement (M-D-Y)	Maximum specific conductance (micromhos per centimeter at 25°C)	Date of measurement (M-D-Y)
		ST. VRAIN CREEK BASIN--Mountains				
NSV1	21	Once	---	-------	-----	--------
SSV1	32	Once	---	-------	-----	--------
SSV2	28	Monthly	28	9-02-75	68	2-03-76
SSV3	55	Once	---	-------	-----	--------
MSV1	39	Once	---	-------	-----	--------
LHC1	<50	Weekly	<25	9-22-75 9-30-75	72	4-20-76
LHC2	89	Weekly	58	9-02-75	260	11-04-75
JC1	27	Once	---	-------	-----	--------
JC2	44	Once	---	-------	-----	--------
LJC1	607	Once	---	-------	-----	--------
JC3	107	Weekly	27	7-19-76	209	2-24-76
		ST. VRAIN CREEK BASIN--Plains				
SSV4	51	Monthly	31	7-16-76	75	1-14-76, 2-11-76, 3-29-76
SVC1	90	Once	---	-------	-----	--------
SC1	85	Once	---	-------	-----	--------
LHC3	100	Monthly	31	9-13-76	230	2-11-76
LHC4	100	Weekly	35	7-13-76	450	4-06-76
LHC5	1,730	Weekly	662	9-16-75	2,400	4-06-76
SVC2	1,520	Weekly	700	6-01-76	2,400	12-08-75
DC2	1,780	Once	---	-------	-----	--------
		BOULDER CREEK BASIN--Mountains				
MBC1	<50	Once	---	-------	-----	--------
MBC2	60	Once	---	-------	-----	--------
NBC1	40	Once	---	-------	-----	--------
NBC2	90	Once	---	-------	-----	--------
BC1	65	Once	---	-------	-----	--------
FC1	50	Once	---	-------	-----	--------
FC2	391	Monthly	101	6-01-76	377	11-04-75
BC2	48	Monthly	31	8-03-76	356	11-04-75
		BOULDER CREEK BASIN--Plains				
BC3	160	Monthly	43	8-03-76	300	2-03-76
SBC1	40	Monthly	42	8-03-76	204	1-05-76
SBC2	49	Once	---	-------	-----	--------
SBC3	92	Once	---	-------	-----	--------
FCC1	263	Once	---	-------	-----	--------
DC1	858	Once	---	-------	-----	--------
BC4	575	Once	---	-------	-----	--------
		COAL CREEK BASIN--Plains				
CC1	400	Once	---	-------	-----	--------
CC2	800	Monthly	810	6-01-76	2,400	12-08-75
RC1	1,890	Once	---	-------	-----	--------

Activities such as mining, farming, and ranching, and disposal of municipal and industrial wastes usually increase the specific conductance in streams if degraded water resulting from these activities either flows overland to, or is discharged directly into streams. The anomolous value of 607 micromhos measured in Little James Creek (site LJC1) probably was due to runoff from spoils piles and discharge from mines in the area. Increases in specific conductance resulting from agricultural activities and waste-disposal facilities are greatest in the eastern part of the county where agricultural activities and population densities are greatest. The relative impact of overland runoff or discharge on general water quality in streams can be approximated by a series of specific-conductance measurements made upstream and downstream from the site of inflow.

Water-Quality Evaluation

Water-quality data were evaluated with respect to water-quality-protection standards established by the Colorado Department of Health (1978) for raw water used for municipal supplies, agricultural use, and aquatic life (table 6). The standards for major ions, trace elements, and radiochemicals in table 6 are for total (dissolved plus suspended) concentrations, except for iron and manganese in raw water used for municipal supplies where the established standards are for dissolved concentrations only. The water samples collected for this study were analyzed only for dissolved concentrations; therefore, the dissolved concentrations are either equal to or less than the total concentrations in the water.

Table 6.--*Water-quality-protection standards for surface water*

[From Colorado Department of Health, 1978; mg/L=milligram per liter; µg/L=microgram per liter; mL=milliliter; pCi/L=picocurie per liter]

Constituent	Water-quality standards		
	Raw water used for municipal supplies[1]	Agricultural use	Aquatic life
MAJOR IONS:			
Chloride (mg/L)	250	-----	---------
Fluoride (mg/L)	[2]2.0	-----	---------
Magnesium (mg/L)	125	-----	---------
Nitrite (mg/L, as nitrogen)	1	10	[3]0.05-0.5
Nitrate (mg/L, as nitrogen)	10	100	---------
Sulfate (mg/L)	250	-----	---------
TRACE ELEMENTS:			
Arsenic (µg/L)	50	100	50
Barium (µg/L)	1,000	-----	---------
Cadmium (µg/L)	10	10	[4]0.4-15
Copper (µg/L)	1,000	200	[4]10-40
Iron (µg/L)	[5]300	-----	1,000
Lead (µg/L)	50	100	[4]4-150
Manganese (µg/L)	[5]50	200	1,000
Mercury (µg/L)	2	-----	0.05
Selenium (µg/L)	10	20	50
Zinc (µg/L)	5,000	2,000	[4]50-600
BACTERIA:			
Fecal coliform per 100 mL (geometric mean	1,000	1,000	---------
RADIOCHEMICALS:			
Gross alpha radiation greater than background concentrations excluding uranium and radon (pCi/L)	15	15	15
Gross beta radiation greater than background concentrations excluding strontium-90 (pCi/L)	50	50	50
Radium-226 plus radium-228 greater than background concentrations (pCi/L)	5	5	5
Uranium (mg/L)	5	5	[4]0.03-0.6

---

[1] These water supplies normally receive coagulation, sedimentation, filtration, and disinfection treatments prior to use in a municipal system.

[2] Based on 56-year average of mean annual maximum air temperature at Boulder, Colo.--63.4°F or 17.4°C (U.S. Weather Bureau, 1959).

[3] Standard depends on water temperature.

[4] Standard depends on water hardness.

[5] Dissolved concentration.

Major Ions and Trace Elements

Concentrations of major ions and trace elements in surface water that exceeded water-quality standards during September and October 1975 are summarized in table 7. Of the major ions, only fluoride and sulfate exceeded the standards. The excessive fluoride concentration in Little James Creek may have been due to drainage from a fluorite mine and associated spoils piles in the vicinity of Jamestown. Excessive concentrations of sulfate probably were due to weathering of sulfate and sulfide minerals, such as gypsum, chalcopyrite, and pyrite, that are common in the unconsolidated and sedimentary rocks.

Cadmium, copper, iron, lead, manganese, mercury, selenium, and zinc exceeded the trace-element standards, principally for aquatic life. Excessive cadmium occurred in 10 of the 18 streams sampled. Excessive concentrations of trace elements in many of the mountain streams probably were due to weathering of ore deposits and spoils piles or drainage from mines. Runoff from urban areas commonly contains excessive concentrations of lead and cadmium, which are also components of automobile exhaust (S. R. Ellis, written commun., 1978).

Bacteria

Fecal-coliform bacteria occur most commonly in human and animal wastes or in soils contaminated by animal wastes; their presence in water is an indication of contamination by human and animal wastes. The presence of fecal-streptococcal bacteria, which are characteristic of fecal contamination and rarely occur in soils or on vegetation not subject to continual fecal contamination, verifies that most of the fecal-coliform bacteria originated from human and animal wastes. Fecal-coliform bacteria are considered a health hazard because pathogenic bacteria and viruses may be associated with these bacteria (McKee and Wolf, 1971).

During September-October 1975, concentrations of fecal-coliform bacteria in streams ranged from about 1 to 34,000 and concentrations of fecal-streptococcal bacteria ranged from about 1 to greater than 10,000 (table 8). Generally the bacterial concentrations were less in the mountain streams and increased as the streams flowed across the plains. The increases in bacterial concentrations in streams as they flow across the county indicate contamination resulting from waste-disposal discharges and livestock. Fecal-coliform bacteria in Boulder and Fourmile Canyon Creeks exceeded water-quality standards for raw water used for municipal supplies and for agricultural use (table 8).

Radiochemicals

Gross alpha and gross beta radiation were determined in streamflow at 33 sites during 1975-76 (table 9). Gross alpha radiation was corrected for uranium (eight sites) after multiplying the dissolved-uranium concentrations in milligrams per liter by 0.68 to obtain concentrations in picocuries per liter (Thatcher and others,

Table 7.--*Sites at which concentrations of major ions and trace elements in surface water exceeded water-quality-protection standards, September-October 1975*
[mg/L=milligram per liter; µg/L=microgram per liter]

Site number on fig. 8	Raw water used for municipal supplies					Agricultural use	Aquatic life						
	Fluoride (2.0 mg/L)	Sulfate (250 mg/L)	Iron (300 µg/L)	Manganese (50 µg/L)	Selenium (10 µg/L)	Manganese (50 µg/L)	Cadmium (µg/L)	Copper (µg/L)[1]	Iron (1,000 µg/L)	Lead (µg/L)[1]	Mercury (0.05 µg/L)	Zinc (µg/L)[1]	Hardness (mg/L)
ST. VRAIN CREEK BASIN--Mountains													
SSV1	---	---	-----	-----	--	-----	[2]1	---	-----	---	0.2	----	9
SSV3	---	---	-----	-----	--	-----	[2]1	---	-----	---	---	----	23
LHC1	---	---	-----	-----	--	-----	[3]3	---	-----	---	---	----	10
LHC2	---	---	-----	-----	--	-----	[3]4	[4]17	-----	[2]11	---	[3]60	32
JC1	---	---	390	-----	--	-----	---	---	-----	---	---	----	--
JC2	---	---	380	-----	--	-----	[2]1	---	-----	---	---	----	19
LJC1	5.2	---	1,600	1,000	--	1,000	[3]2	---	-----	---	---	[6]60	40
JC3	---	---	-----	-----	--	-----	---	[5]26	1,600	---	---	[6]260	220
ST. VRAIN CREEK BASIN--Plains													
SC1	---	---	-----	-----	--	-----	[3]2	---	-----	---	---	----	36
LHC4	---	---	-----	-----	--	-----	[3]4	---	-----	---	.1	[3]60	49
LHC5	---	660	-----	110	--	-----	---	---	-----	---	---	----	---
SVC2	---	570	-----	320	--	320	---	---	-----	---	.1	----	---
DC2	---	750	-----	-----	--	-----	---	---	-----	---	---	----	---
BOULDER CREEK BASIN--Mountains													
MBC2	---	---	-----	-----	--	-----	[3]2	---	-----	---	---	----	25
NBC1	---	---	-----	-----	--	-----	[3]3	---	-----	[2]12	---	----	17
BOULDER CREEK BASIN--Plains													
BC3	---	---	-----	-----	--	-----	---	---	-----	[2]6	.1	----	73
SBC1	---	---	-----	-----	--	-----	[3]3	---	-----	---	---	----	18
SBC3	---	---	-----	-----	--	-----	[3]5	---	-----	[2]6	---	----	37
FCC1	---	---	-----	-----	--	-----	[4]10	---	-----	[4]84	---	----	96
DC1	---	270	-----	-----	--	-----	---	---	-----	---	---	----	---
BC4	---	---	-----	-----	--	-----	---	[6]11	-----	---	---	----	240
COAL CREEK BASIN--Plains													
CC1	---	---	-----	-----	--	-----	[7]2	---	-----	---	---	----	180
RC1	2.9	430	-----	70	35	-----	---	---	-----	---	---	----	---

---

[1] Standard depends on water hardness.

[2] Value exceeds standard when hardness=0 to 100 mg/L.

[3] Value exceeds standard when hardness=0 to 100 mg/L and 100 to 200 mg/L.

[4] Value exceeds standard when hardness=0 to 100 mg/L, 100 to 200 mg/L, and 200 to 300 mg/L.

[5] Value exceeds standard when hardness=200 to 300 mg/L and 300 to 400 mg/L.

[6] Value exceeds standard when hardness=200 to 300 mg/L.

[7] Value exceeds standard when hardness=100 to 200 mg/L.

Table 8.--*Fecal-coliform and fecal-streptococcal bacteria in surface water, September-October 1975*

Site number on figure 8	Fecal-coliform bacteria per 100 milliliters of water	Fecal-streptococcal bacteria per 100 milliliters of water
	ST. VRAIN CREEK BASIN--Mountains	
NSV1	<1	1
SSV1	<1	3
SSV2	-------	-------
SSV3	<1	8
MSV1	<1	16
LHC1	<1	13
LHC2	<1	165
JC1	<1	5
JC2	2	100
LJC1	27	120
JC3	3	17
	ST. VRAIN CREEK BASIN--Plains	
SSV4	<1	10
SVC1	10	54
SC1	6	220
LHC3	-------	-------
LHC4	10	290
LHC5	220	280
SVC2	540	380
DC2	390	395
	BOULDER CREEK BASIN--Mountains	
MBC1	1	<1
MBC2	160	150
NBC1	<1	18
NBC2	3	280
BC1	[1]>1,000	7,500
FC1	<1	<1
FC2	250	760
BC2	-------	-------
	BOULDER CREEK BASIN--Plains	
BC3	[1]4,700	>10,000
SBC1	46	7
SBC2	-------	-------
SBC3	11	78
FCC1	[1]34,000	>10,000
DC1	280	250
BC4	73	280
	COAL CREEK BASIN--Plains	
CC1	17	17
CC2	39	77
RC1	360	260

---

[1] Exceeded standard of 1,000 per 100 milliliters both for raw water used for municipal supplies and for agricultural use.

Table 9.--*Radiochemicals in surface water, 1975-76*

[pCi/L=picocurie per liter; mg/L=milligram per liter]

Site number on figure 8	Gross alpha radiation (pCi/L)	Gross beta radiation (pCi/L)	Radium-226 (pCi/L)	Uranium (mg/L)
	ST. VRAIN CREEK BASIN--Mountains			
NSV1	1.6	2.2	-----	------
SSV1	.8	3.2	-----	------
SSV2	-------	----	-----	------
SSV3	3.2	3.7	-----	------
MSV1	2.1	3.8	-----	------
LHC1	2.8	3.3	-----	------
LHC2	1.7	2.6	-----	------
JC1	.7	1.5	-----	------
JC2	7.1	4.7	-----	------
LJC1	[1,2]73	27	0.30	0.042
JC3	5.5	4.2	-----	------
	ST. VRAIN CREEK BASIN--Plains			
SSV4	4.7	4.3	-----	------
SVC1	2.7	2.7	-----	------
SC1	4.7	4.2	-----	------
LHC3	-------	----	-----	------
LHC4	6.2	3.8	-----	------
LHC5	[1,2]78	21	.1	.029
SVC2	[1,2]60	14	<.1	.026
DC2	[1,2]62	11	.1	.021
	BOULDER CREEK BASIN--Mountains			
MBC1	1.9	3.3	-----	------
MBC2	1.5	2.0	-----	------
NBC1	<.5	1.6	-----	------
NBC2	3.2	3.3	-----	------
BC1	1.5	2.5	-----	------
FC1	1.5	2.1	-----	------
FC2	6.0	4.8	-----	------
BC2	-------	----	-----	------
	BOULDER CREEK BASIN--Plains			
BC3	6.2	5.2	-----	------
SBC1	1.3	2.4	-----	------
SBC2	-------	----	-----	------
SBC3	1.7	2.4	-----	------
FCC1	6.0	5.9	-----	------
DC1	[1]<13	22	<.1	.0077
BC4	[1]12	29	<.1	.0047
	COAL CREEK BASIN--Plains			
CC1	[1]13	13	<.1	.0099
CC2	[2]21	14	-----	------
RC1	[1]7.2	4.4	<.1	.0017

---

[1] Corrected for uranium.

[2] May have exceeded standard of 15 pCi/L for municipal supplies, agricultural use, and aquatic life.

1977). Radon and strontium-90 were not determined; therefore, the radiation concentrations were not corrected for these constituents. Because the concentrations of gross alpha and gross beta radiation were not fully corrected, a complete evaluation with respect to water-quality standards could not be made.

Radium-226 was determined in streamflow at eight sites (table 9). Only when concentrations of radium-226 are greater than 3 pCi/L (picocuries per liter) is it recommended that radium-228 be determined (U.S. Environmental Protection Agency, 1977). Because the maximum concentration of radium-226 in the water was 0.3 pCi/L, the concentration of radium-228 was not determined. The standard of 5 pCi/L for radium-226 plus radium-228 probably was not exceeded because the concentration of radium-228 generally is less than the concentration of radium-226 (U.S. Environmental Protection Agency, 1977).

Uranium was determined in streamflow at eight sites (table 9). The maximum concentration of 0.042 mg/L (milligram per liter) in Little James Creek (site LJC1) did not exceed the standard for aquatic life based on the hardness of the water.

Suitability of Surface Water for Various Uses

Based on the water-quality analyses, streamflow in the county generally is suitable for municipal water supplies. Contamination by major ions (fluoride or sulfate) occurred in Little James Creek and in the easternmost reaches of Left Hand Creek, St. Vrain Creek, Dry Creek (St. Vrain Creek basin), Dry Creek (Boulder Creek basin), and Rock Creek. Contamination by trace elements (iron, manganese, or selenium) occurred in James and Little James Creeks and in the easternmost reaches of Left Hand, St. Vrain, and Rock Creeks. Bacterial contamination was limited to Boulder and Fourmile Canyon Creeks. Gross alpha radiation may have been excessive in Little James Creek and in the easternmost reaches of Left Hand Creek, St. Vrain Creek, Dry Creek (St. Vrain Creek basin), and Coal Creek. Streamflow in Little James and Rock Creeks is the least suitable for municipal water supplies.

Manganese in Little James Creek was the only constituent that exceeded water-quality standards for agricultural use. Concentrations of fecal-coliform bacteria exceeded the standard in Boulder and Fourmile Canyon Creeks. Gross alpha radiation may have been excessive in Little James Creek, and in the easternmost reaches of Left Hand Creek, St. Vrain Creek, Dry Creek (St. Vrain Creek basin), and Coal Creek.

Trace-element contamination with respect to aquatic-life standards was widespread, occurring in 12 of the 18 streams sampled. Contamination by cadmium occurred in 10 streams, by copper in 3 streams, by iron in 1 stream, by lead in 5 streams, by mercury in 4 streams, and by zinc in 3 streams. Gross alpha radiation may have been excessive in Little James Creek and in the easternmost reaches of Left Hand Creek, St. Vrain Creek, Dry Creek (St. Vrain Creek basin), and Coal Creek.

Ranges and median values for specific conductance, dissolved solids, hardness, and 16 selected constituents used in evaluation of streamflow quality for streams in the mountains and in the plains are summarized in figure 9. Based on these data, streamflow in the mountains was more suitable for use than streamflow in the plains.

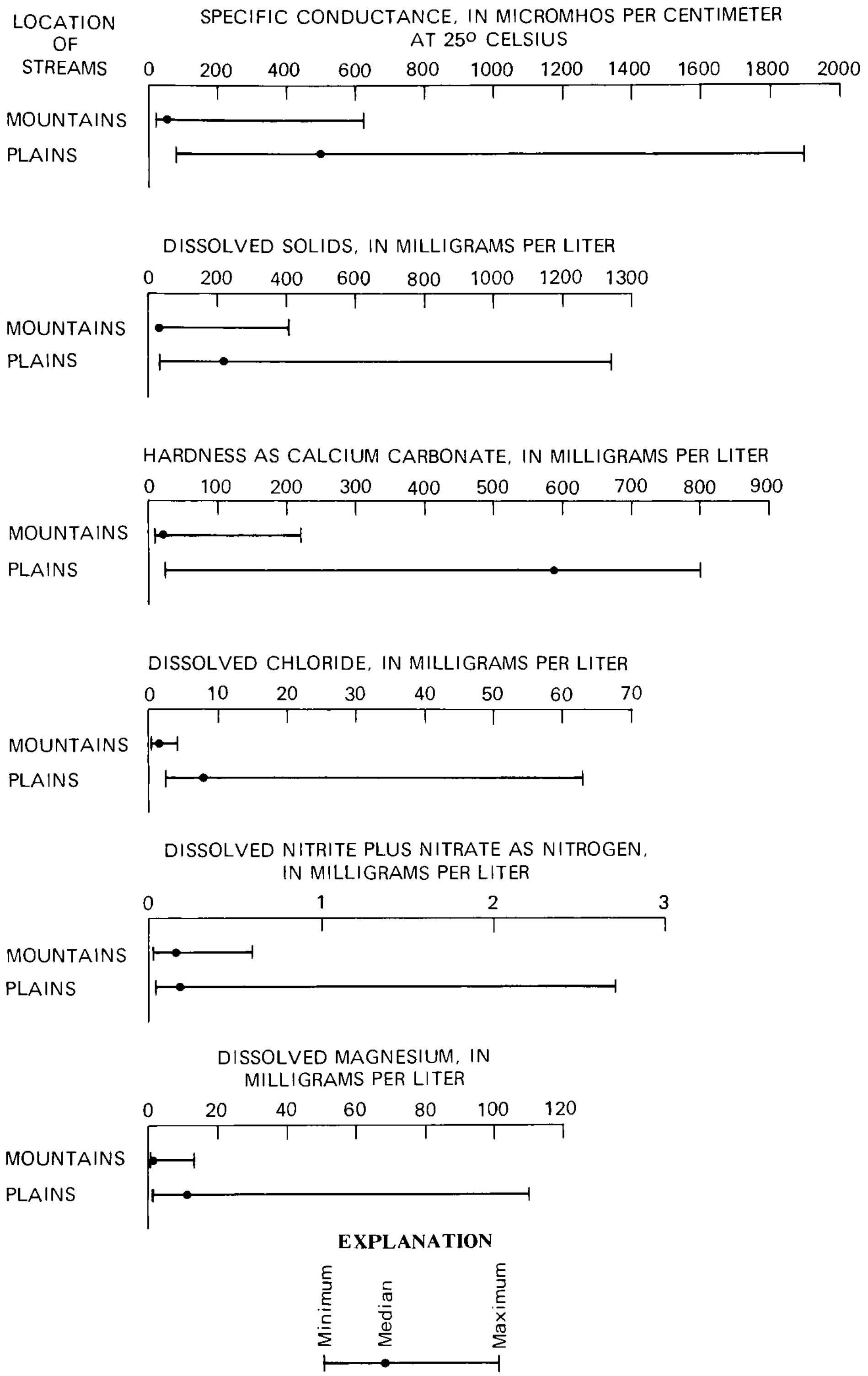


Figure 9.--Ranges and median values of selected constituents in water from streams in the mountains and plains, September–October 1975.

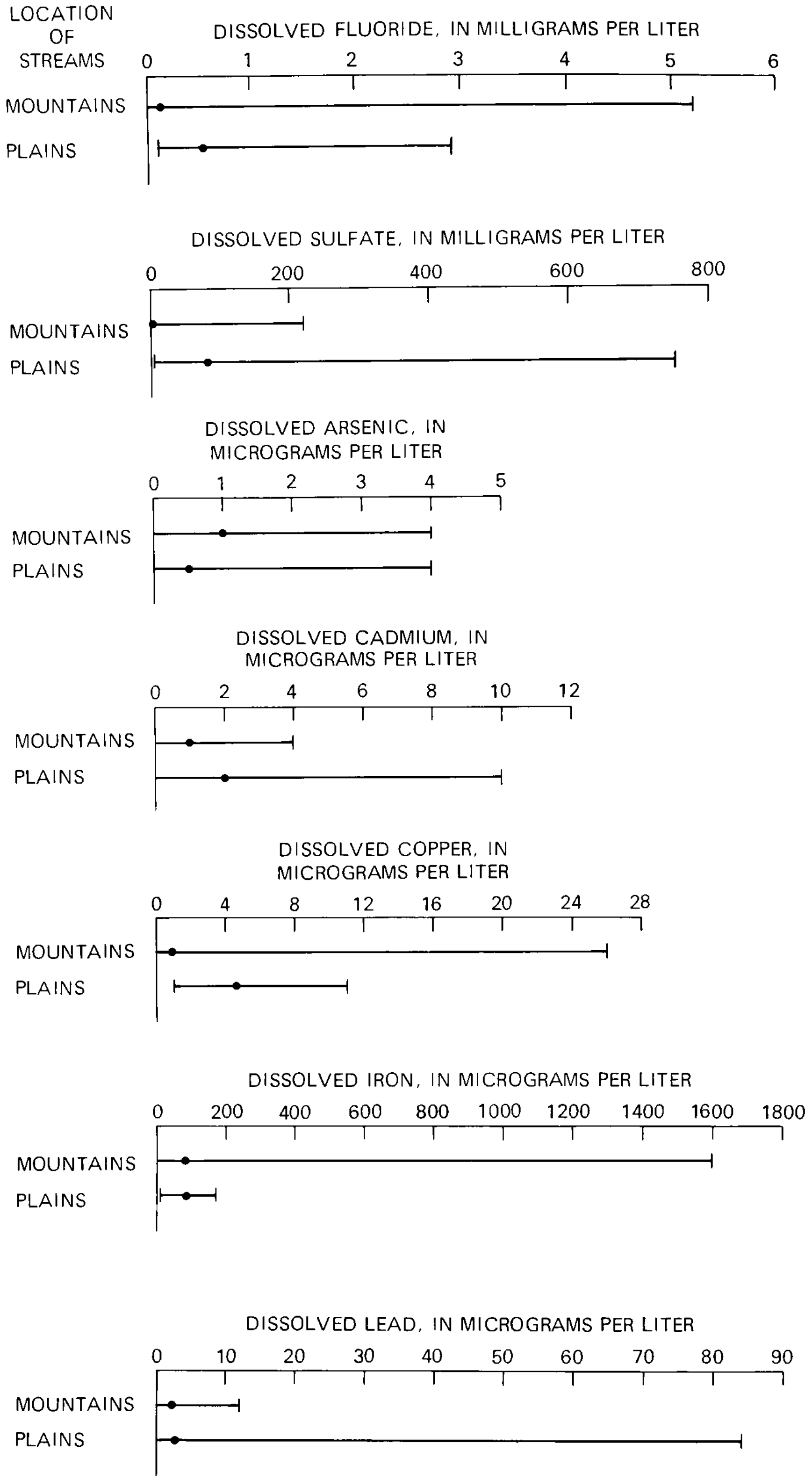


Figure 9.--Ranges and median values of selected constituents in water from streams in the mountains and plains, September–October 1975--Continued.

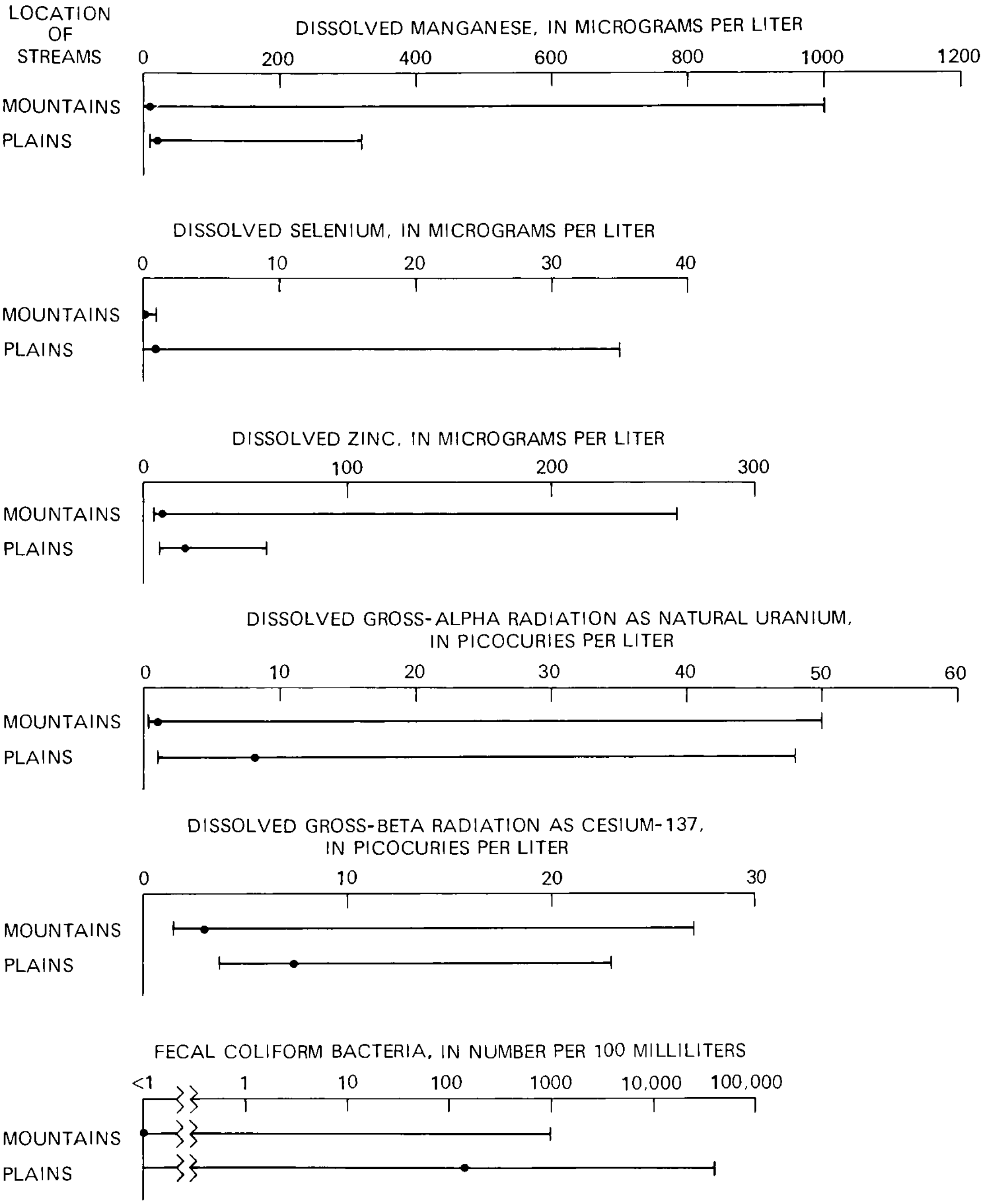


Figure 9.--Ranges and median values of selected constituents in water from streams in the mountains and plains, September—October 1975--Continued.

RELATION BETWEEN SURFACE- AND GROUND-WATER QUALITY

A relation between surface- and ground-water quality occurs because of the hydraulic connection between streams and aquifers. Movement of water between streams and aquifers continues throughout the year. During the snowmelt-runoff period in the late spring and early summer, streamflow moves into the aquifers adjacent to streams, diluting the water in the aquifers. As streamflow subsides throughout the summer and early fall, water from the aquifers moves back into the streams in increasing amounts and with increasing concentrations of dissolved solids. By late fall and winter, streamflow is being sustained by ground-water seepage. At this time, some of the water moving through the unconsolidated-rock aquifers into the streams may have originated in the sedimentary- or crystalline-rock aquifers.

The relation between water quality in streams and aquifers is illustrated in figure 10, using Boulder Creek as an example. Specific conductance measured during September-October 1975 at seven sites on Boulder Creek from the headwaters in the western part of the county to the Weld County line was plotted by site location. Specific conductance of water from wells completed in unconsolidated-rock aquifers adjacent to Boulder Creek also was plotted by well location along the creek. The sharp increase in specific conductance in Boulder Creek downstream from the city of Boulder reflects, to a large degree, the increased dissolved-solids concentrations in water moving into the creek from the aquifers. The trend of the water-table contours shown on figure 6 verifies the large degree of hydraulic connection between the creek and the aquifers in the reach from Boulder to the Weld County line.

GROUND-WATER QUALITY

Selection of Water-Sample-Collection Sites

Locations of water-sample-collection sites were selected to provide representative geographic coverage of Boulder County. Where possible, one ground-water sample was collected in each section (1 mi^2) of a township. In selected areas where population increases have been significant in recent years, more than one sample per section was collected. Sites also were selected to provide water-quality information for all of the major aquifers in the county. Generally, each well or spring was sampled once.

Types of Analyses

Two types of water-quality analyses were made. The first type of analysis is referred to in this report as a "complete analysis" that consisted of a specific-conductance measurement made at the well or spring site; a laboratory analysis of major ions, trace elements, and radiochemicals; and a field-laboratory determination of coliform and fecal-coliform bacteria. Complete analyses were made for samples from 98 sites (sites C01 to C99 on pl. 1). Results of the chemical and bacteriological analyses for these samples are included in a report by Hall, Boyd, and Cain (1979).

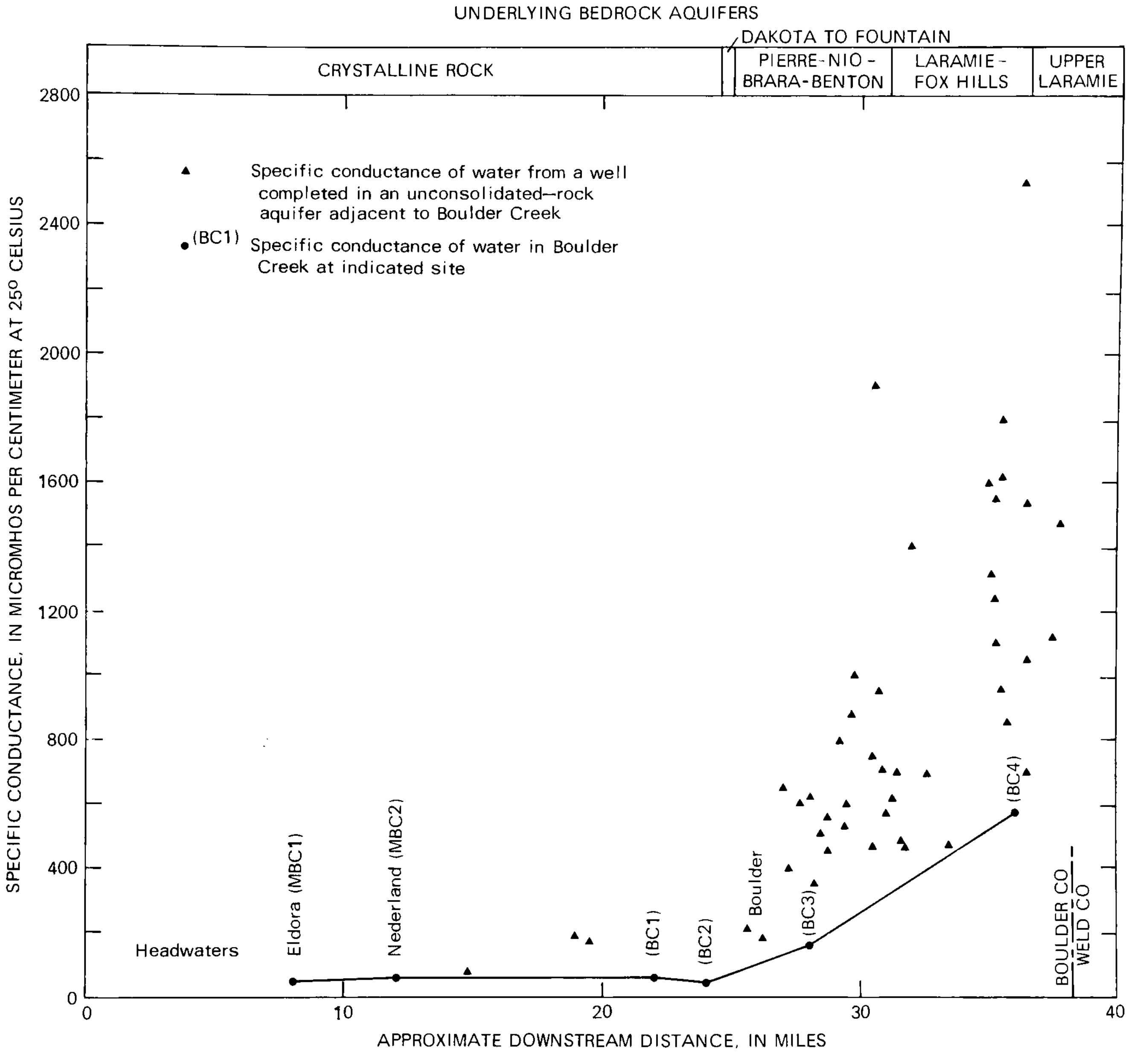


Figure 10.--Specific conductance in Boulder Creek and in water in adjacent unconsolidated–rock aquifers from the headwaters to the Weld County line.

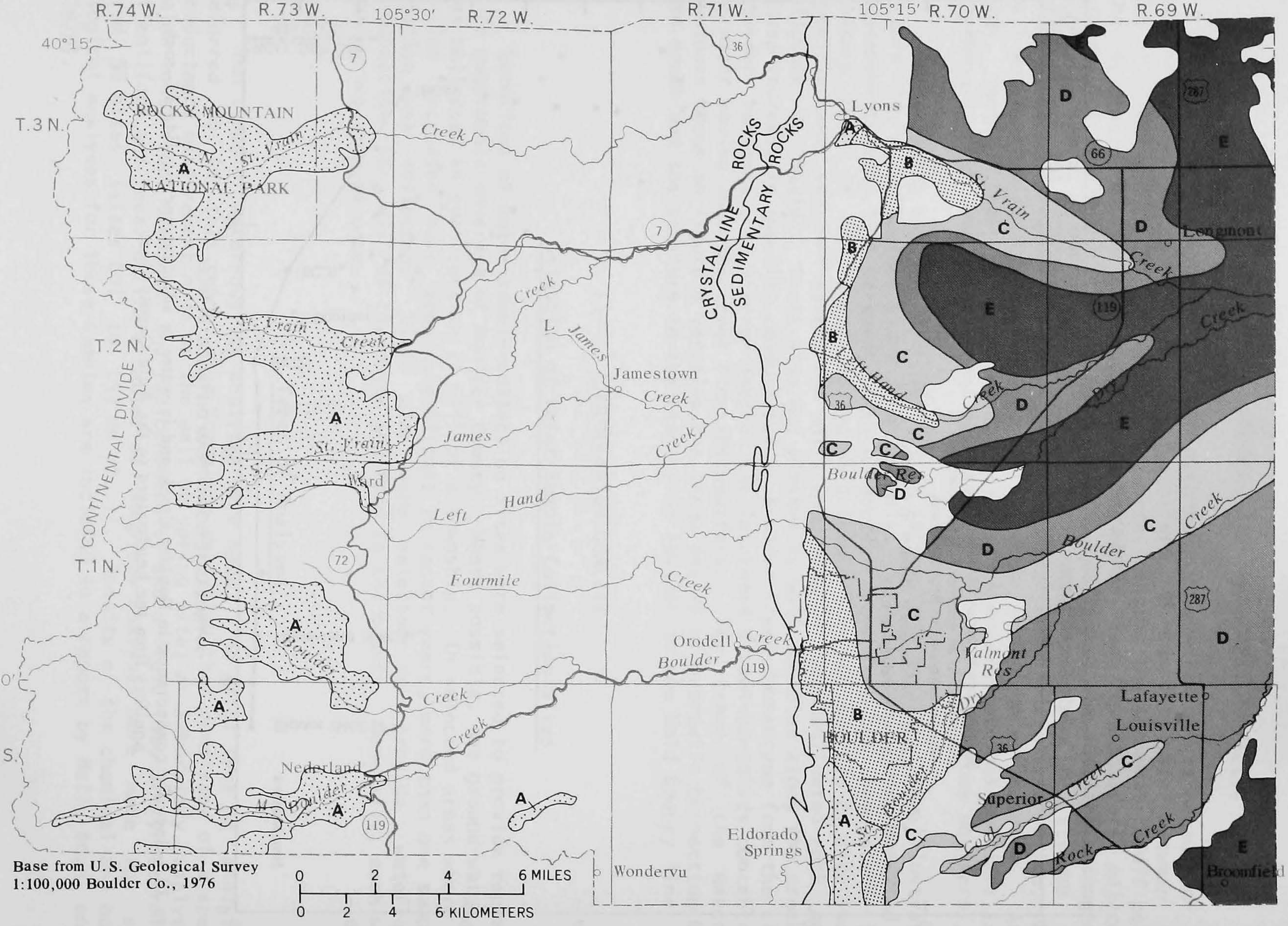


Figure 11A.--Predominant specific conductance of water from unconsolidated-rock aquifers.

EXPLANATION

SPECIFIC CONDUCTANCE, IN MICROMHOS PER CENTIMETER AT 25°CELSIUS

A	Less than 250
B	250 to 500
C	500 to 1000
D	1000 to 2000
■	2000 to 4000

Note: Predominant specific conductance was generally less than 250 micromhos in unconsolidated-rock aquifers that are too small to show on the map in the mountains

The second type of analysis is referred to in this report as an "indicator analysis" that consisted of a specific-conductance measurement made at the well or spring site, a laboratory analysis of dissolved chloride and dissolved nitrite plus nitrate, and a field-laboratory determination of coliform and fecal-coliform bacteria. Indicator analyses, designed to give an indication of overall water quality and the degree of water-quality degradation, were made for 550 ground-water samples (sites 001 to 674 on pl. 1). Results of the indicator analyses are included in a report by Hall, Boyd, and Cain (1979).

General Water Quality Indicated by Specific Conductance

The specific conductance of water from 648 wells and springs was mapped to obtain a countywide appraisal of the general quality of ground water. As with surface water, increasing specific conductance in ground water indicates increasing dissolved-solids concentrations. The predominant specific conductance of water from the unconsolidated-rock aquifers is shown on figure 11A and from the crystalline- and sedimentary-rock aquifers on figure 11B. Because some localized areas with significant variations in water quality were too small to show on the maps, only predominant specific conductance is shown.

Specific conductance of water in the unconsolidated-rock aquifers increases from west to east (fig. 11A). In the mountains, specific conductance generally is less than 500 micromhos. In the plains, specific conductance generally ranges from 500 to 4,000 micromhos, is less in aquifers occurring in stream valleys, and increases with distance from the streams. Specific conductance generally increases downgradient in the stream valleys. Specific-conductance data for the various unconsolidated-rock aquifers are summarized in figure 12. With the exception of valley-fill aquifers, specific conductance is less variable in the mountains than in the plains. Because ranges of specific conductance tend to increase as the sample size is increased, caution must be used when comparing this type of data.

Specific conductance in water from the major sedimentary-rock aquifers (Pierre-Niobrara-Benton, Laramie-Fox Hills, and upper Laramie) generally increases toward the northeast (fig. 11B). Specific conductance increases from less than 500 micromhos south of Boulder to more than 4,000 micromhos north of Longmont. The variations in specific conductance found between Boulder and Louisville probably result from effects on movement of water by faults in the area (fig. 3B). Specific-conductance data for those sedimentary-rock aquifers for which five or more measurements were made are summarized in figure 12. Specific conductance is most variable in the Pierre-Niobrara-Benton and Laramie-Fox Hills aquifers.

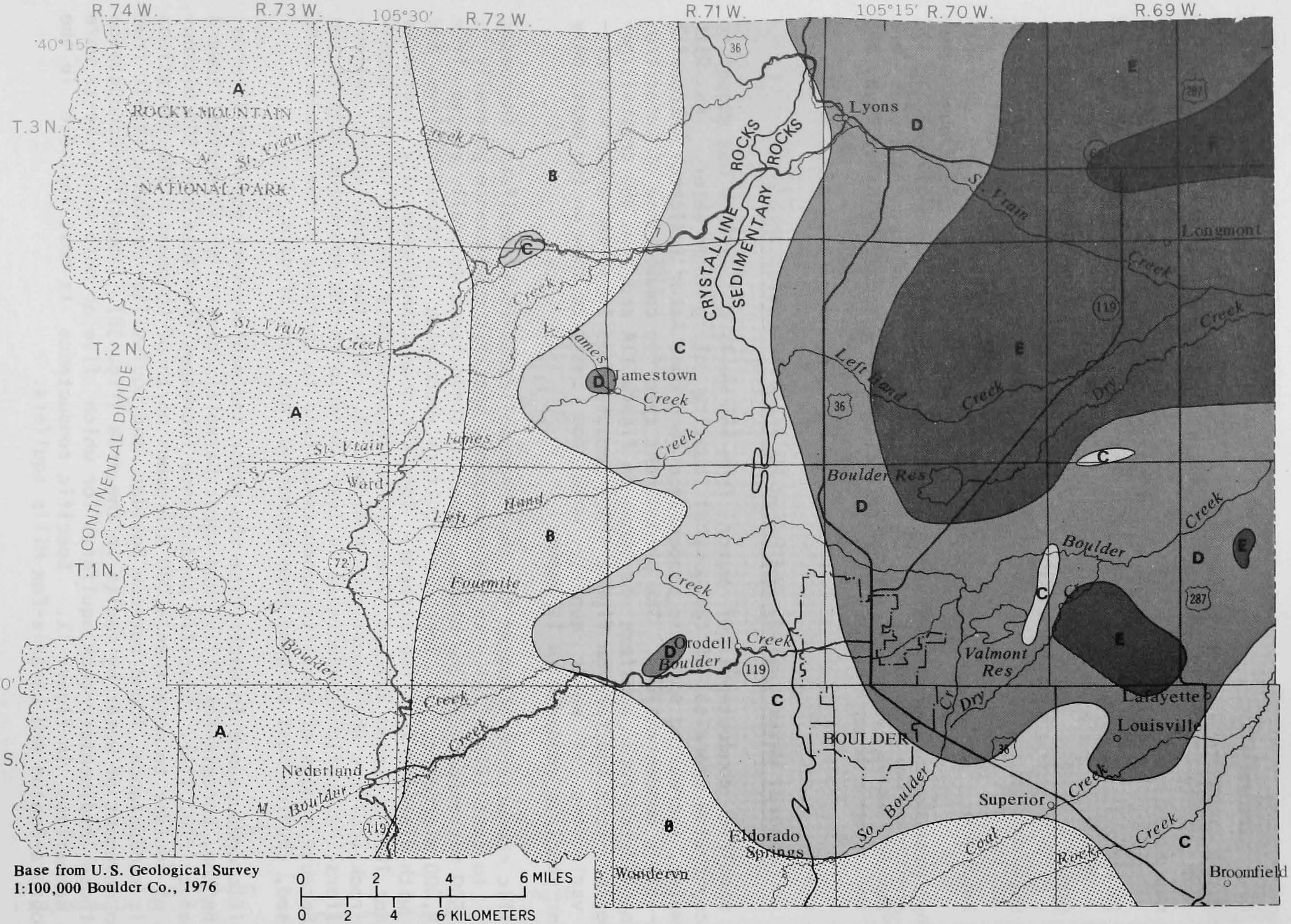


Figure 11B.--Predominant specific conductance of water from sedimentary- and crystalline-rock aquifers.

EXPLANATION

SPECIFIC CONDUCTANCE, IN MICROMHOS PER CENTIMETER AT 25° CELSIUS

A	Less than 250
B	250 to 500
C	500 to 1000
D	1000 to 2000
■	2000 to 4000
■	Greater than 4000

Generally, specific conductance in water from the crystalline-rock aquifer also increases from west to east with the greatest values, usually less than 1,000 micromhos, occurring along the mountain front (fig. 11B). Localized areas of greater specific conductance shown on figure 11B are the result of mining near the communities of Jamestown and Orodell and residential development in the vicinity of Riverside. Specific-conductance data for the crystalline-rock aquifer are summarized in figure 12.

Large variations in specific conductance occur in water from most of the aquifers. These variations may be due to local variations in the chemical or physical characteristics of the aquifer materials or to localized water-quality degradation. The causes of variation in water quality indicated by specific conductance are discussed in more detail later in the report in the section on "Factors Affecting Ground-Water Quality."

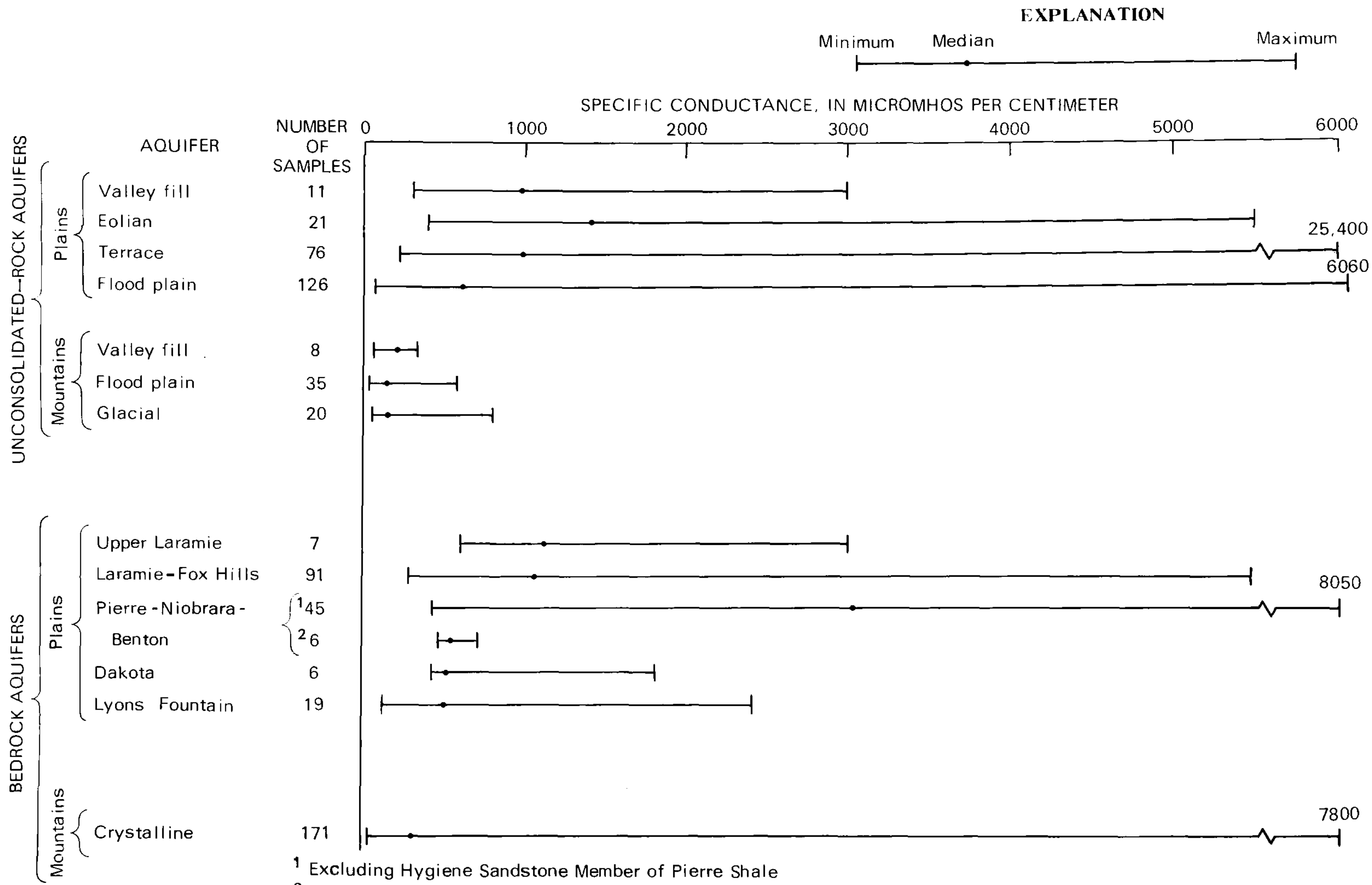
Use of Specific Conductance to Estimate Concentrations of Constituents

Water-quality data from the 98 complete analyses were examined to determine if correlations existed between specific conductance and individual constituents. Correlations were developed between specific conductance and concentrations of dissolved solids, magnesium, sulfate, and hardness in ground water in the county. Estimates of the concentrations of these constituents in ground water can be made from specific-conductance measurements using the following equations:

$$SC \times 0.68 = DS; \quad (1)$$
$$SC \times 0.05 = Mg; \quad (2)$$
$$SC \times 0.30 = SO_4, \text{ when SC is less than 2,000}; \quad (3)$$
$$SC \times 0.49 = SO_4, \text{ when SC is greater than 2,000; and} \quad (4)$$
$$SC \times 0.48 = H; \quad (5)$$

where:

SC =specific conductance, in micromhos per centimeter at 25° Celsius;
DS =dissolved solids, in milligrams per liter;
Mg =magnesium, in milligrams per liter;
SO_4=sulfate, in milligrams per liter; and
H =hardness, as calcium carbonate, in milligrams per liter.



[1] Excluding Hygiene Sandstone Member of Pierre Shale

[2] Hygiene Sandstone Member of Pierre Shale

Figure 12.--Ranges and median values of specific conductance in water from selected aquifers.

Applying these equations to the recommended drinking-water standards for dissolved solids and sulfate, the standard of 500 mg/L for dissolved solids probably will be exceeded when specific conductance is greater than 735 micromhos; the standard of 250 mg/L for sulfate probably will be exceeded when specific conductance is greater than 840 micromhos. The former drinking-water standard of 125 mg/L for magnesium probably will be exceeded when specific conductance is greater than 2,500 micromhos. Based on the hardness classification used by the U.S. Geological Survey (see complete discussion of hardness beginning on p. 55), water containing hardness concentrations greater than 180 mg/L is classified as very hard. Water will probably be very hard when specific conductance is greater than 375 micromhos.

The above relationships were checked using data from the 98 complete analyses to determine the reliability of the relationships so that they could be used in evaluating the 550 indicator analyses. The relationship for dissolved solids was valid in 92 percent of the 36 samples from unconsolidated-rock aquifers, in 93 percent of the 42 samples from sedimentary-rock aquifers, and in 100 percent of the 20 samples from the crystalline-rock aquifer. The relationship for magnesium was valid in 95 percent of the samples from each aquifer type. The relationship for sulfate was valid in 81 percent of the samples from unconsolidated-rock aquifers, in 88 percent of the samples from sedimentary-rock aquifers, and in 95 percent of the samples from the crystalline-rock aquifer. The relationship for sulfate in water was valid only in 70 percent of the 23 samples from eolian and flood-plain aquifers, but the relationship was valid in 100 percent of the 13 samples from valley-fill, glacial, and terrace aquifers. The relationship for hardness was valid in 97 percent of the samples from unconsolidated-rock aquifers, in 79 percent of the samples from sedimentary-rock aquifers, and in 100 percent of the samples from the crystalline-rock aquifer. The relationship for hardness in water from the Laramie-Fox Hills aquifer was valid only in 69 percent of the 13 samples.

Relation to Drinking-Water Standards

The ground-water quality was evaluated in terms of drinking-water standards because most of the ground water sampled was being used as a source of drinking water. The Colorado Department of Health (1977) has established mandatory (primary) standards and the U.S. Environmental Protection Agency (1977) has proposed recommended (secondary) standards for the quality of drinking water, as presented in table 10. Mandatory standards should not be exceeded and are usually established for health reasons; recommended standards may be exceeded if another supply is not available. Recommended standards are usually established for esthetic or other nonhealth reasons, such as objectionable taste. A summary of ground-water quality in relation to these standards also is included in table 10. Sites where concentrations of one or more analyzed constituents exceeded the standards are shown on plate 1.

Table 10.--*Drinking-water standards*

[mg/L=milligram per liter; µmho=micromho per centimeter at 25° Celsius;

Water-quality parameter	Drinking-water standard
MAJOR IONS:	
Dissolved solids, sum of constituents (mg/L)	[2]500
Specific conductance (µmho)	(3)
Total hardness as $CaCO_3$ (mg/L)	(3)
Chloride (mg/L)	[2]250
Fluoride (mg/L)	[4]2.0
Magnesium (mg/L)	[2]125
Nitrite plus nitrate (mg/L, as nitrogen)	[4]10
Nitrite (mg/L, as nitrogen)	(3)
Sulfate (mg/L)	[2]250
Detergent (mg/L)	[2].5
TRACE ELEMENTS:	
Arsenic (µg/L)	[4]50
Barium (µg/L)	[4]1,000
Cadmium (µg/L)	[4]10
Copper (µg/L)	[2]1,000
Iron (µg/L)	[2]300
Lead (µg/L)	[4]50
Manganese (µg/L)	[2]50
Mercury (µg/L)	[4]2
Selenium (µg/L)	[4]10
Zinc (µg/L)	[2]5,000
BACTERIA:	
Coliform per 100 mL	(3)
Fecal coliform per 100 mL	(3)
RADIOCHEMICALS:	
Gross alpha radiation, uncorrected (pCi/L)	(5)
Gross alpha radiation, corrected for uranium (pCi/L)	(5)
Gross beta radiation, as cesium-137 (pCi/L)	(3)
Radium-226 (pCi/L)	(3)
Uranium (µg/L)	(3)

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[1] The U.S. Geological Survey defines "dissolved" as material that will pass through a 0.45-micrometer filter (Brown and others, 1970, p. 37).

[2] Recommended (secondary) standard (U.S. Environmental Protection Agency, 1977) for water supplied to public. Recommended standard for magnesium from former State regulations (Colorado Department of Health, 1967).

[3] No standard. See text for discussion.

and summary of ground-water quality

µg/L=microgram per liter; pCi/L=picocurie per liter; mL=milliliter]

Number of sites sampled	Value or concentration			Samples where standard was exceeded	
	Minimum	Median	Maximum	Number	Percentage
98	23	440	4,050	45	46
648	25	570	25,400	--	--
98	7	260	2,400	--	--
645	.2	5.9	1,100	6	1
98	.1	.59	43	10	10
98	.4	21	310	10	10
646	0	.58	85	41	6
83	0	0	.29	--	--
98	2.1	79	2,400	29	30
88	0	0	3.0	10	11
98	0	0	35	0	0
97	0	0	300	0	0
97	0	2	7	0	0
94	0	9	1,400	1	1
98	0	50	16,000	12	12
97	0	3	32	0	0
98	0	10	2,700	20	20
97	0	0	5.3	2	2
96	0	1	160	8	8
97	0	100	8,300	1	1
643	0	0	>320	--	--
641	0	0	>120	--	--
98	.7	12	156	--	--
29	4.1	13.6	120	--	--
98	.8	7.5	100	--	--
44	.01	.15	12	1	2
39	.2	14	94	--	--

[4] Mandatory (primary) standard (Colorado Department of Health, 1977). Standard for nitrite plus nitrate is for nitrate only; see text for discussion. Standard for fluoride is based on 56-year average of mean annual maximum air temperature at Boulder--63.4°F or 17.4°C (U.S. Weather Bureau, 1959).

[5] Standard of 15 pCi/L for gross alpha radiation is after correction for radon and uranium. Radiation corrected only for uranium because radon was not determined. To convert uranium in µg/L to pCi/L, multiply by 0.68 (Thatcher and others, 1977).

Water-Quality Evaluation

Dissolved Solids

Excessive concentrations of dissolved solids may impart an unpleasant taste to the water (McKee and Wolf, 1971). Concentrations of major ions, such as chloride, magnesium, and sulfate, as well as hardness, generally increase as concentrations of dissolved solids increase. Concentrations of major ions, such as fluoride and nitrate, detergents, trace elements, bacteria, and radiochemicals, are not well correlated with dissolved-solids concentrations. Concentrations of these constituents may or may not increase as dissolved solids increase. The number of samples where the recommended standard of 500 mg/L for dissolved solids was or may have been exceeded are summarized by aquifer in table 11.

Table 11.--*Aquifer sources of samples that contained dissolved solids in excess of recommended standard of 500 milligrams per liter for drinking water*

Aquifer	Number of samples: Complete analyses	Where standard was exceeded		Indicator analyses	Where standard was estimated to have been exceeded	
		Mountains	Plains		Mountains	Plains
UNCONSOLIDATED ROCKS:						
Valley fill---------	2	-	2	17	0	6
Eolian--------------	3	-	3	18	--	16
Flood plain---------	20	0	10	140	0	39
Terrace-------------	9	-	2	67	--	44
Glacial-------------	2	0	--	18	1	--
SEDIMENTARY ROCKS:						
Arapahoe and upper Laramie-----	2	-	2	6	--	5
Laramie-Fox Hills---	13	-	6	78	--	38
Pierre-Niobrara-Benton------------	17	-	12	36	--	28
Dakota--------------	3	-	2	3	--	0
Morrison-Ralston Creek-Lykins------	1	-	0	2	--	0
Lyons-Fountain------	6	-	2	14	--	3
CRYSTALLINE-ROCK------	20	4	--	151	21	--

Magnesium

Excessive concentrations of magnesium may have a laxative effect on new users of the water and may impart an unpleasant taste to the water (McKee and Wolf, 1971). Those samples where the concentration of magnesium exceeded or may have exceeded 125 mg/L, the former recommended standard for drinking water, are summarized by aquifer in table 12.

Table 12.--*Aquifer sources of samples that contained magnesium in excess of 125 milligrams per liter*

Aquifer	Number of samples: Complete analyses	Where standard was exceeded		Indicator analyses	Where standard was estimated to have been exceeded	
		Mountains	Plains		Mountains	Plains
UNCONSOLIDATED ROCKS:						
Valley fill---------	2	-	0	17	0	2
Eolian--------------	3	-	0	18	-	3
Flood plain---------	20	0	1	140	0	3
Terrace-------------	9	-	2	67	-	9
Glacial-------------	2	0	-	18	0	--
SEDIMENTARY ROCKS:						
Arapahoe and upper Laramie-----	2	-	0	6	-	1
Laramie-Fox Hills---	13	-	1	78	-	8
Pierre-Niobrara-Benton------------	17	-	6	36	-	22
Dakota--------------	3	-	0	3	-	0
Morrison-Ralston Creek-Lykins------	1	-	0	2	-	0
Lyons-Fountain------	6	-	0	14	-	0
CRYSTALLINE-ROCK------	20	0	-	151	1	--

Sulfate

Excessive concentrations of sulfate, as for magnesium, may have a laxative effect on new users of the water and may impart an unpleasant taste to the water (McKee and Wolf, 1971). Those samples where the recommended standard of 250 mg/L was or may have been exceeded are summarized by aquifer in table 13.

Table 13.--*Aquifer sources of samples that contained sulfate in excess of recommended standard of 250 milligrams per liter for drinking water*

Aquifer	Number of samples					
	Complete analyses	Where standard was exceeded		Indicator analyses	Where standard was estimated to have been exceeded	
		Mountains	Plains		Mountains	Plains
UNCONSOLIDATED ROCKS:						
Valley fill---------	2	-	1	17	0	6
Eolian--------------	3	-	1	18	--	9
Flood plain---------	20	0	5	140	0	32
Terrace-------------	9	-	2	67	--	38
Glacial-------------	2	0	--	18	0	--
SEDIMENTARY ROCKS:						
Arapahoe and upper Laramie-----	2	-	1	6	--	2
Laramie-Fox Hills---	13	-	5	78	--	31
Pierre-Niobrara-Benton------------	17	-	10	36	--	27
Dakota--------------	3	-	1	3	--	0
Morrison-Ralston Creek-Lykins------	1	-	0	2	--	0
Lyons-Fountain------	6	-	1	14	--	3
CRYSTALLINE-ROCK------	20	2	--	151	14	--

Fluoride

While fluoride in drinking water may reduce the incidence of dental caries (cavities), excessive concentrations may cause mottling of teeth, especially in children (McKee and Wolf, 1971). The mandatory standard of 2.0 mg/L for drinking water is based on the air temperature at Boulder and is related to the amount of water a person drinks. The assumption is that the warmer the climate, the more water a person would normally drink. Because of the varying climatic conditions in the county, the mandatory standard could be slightly greater than 2.0 mg/L in the mountains or slightly less than 2.0 mg/L in the easternmost plains.

Concentrations of fluoride were determined only as part of the 98 complete analyses. Fluoride exceeded 2.0 mg/L in 10 samples. Three samples were from the crystalline-rock aquifer. The seven samples from aquifers in the plains were from seven different aquifers: Eolian, flood plain, terrace, upper Laramie, Laramie-Fox Hills, Pierre-Niobrara-Benton, and Dakota.

Chloride and Nitrate

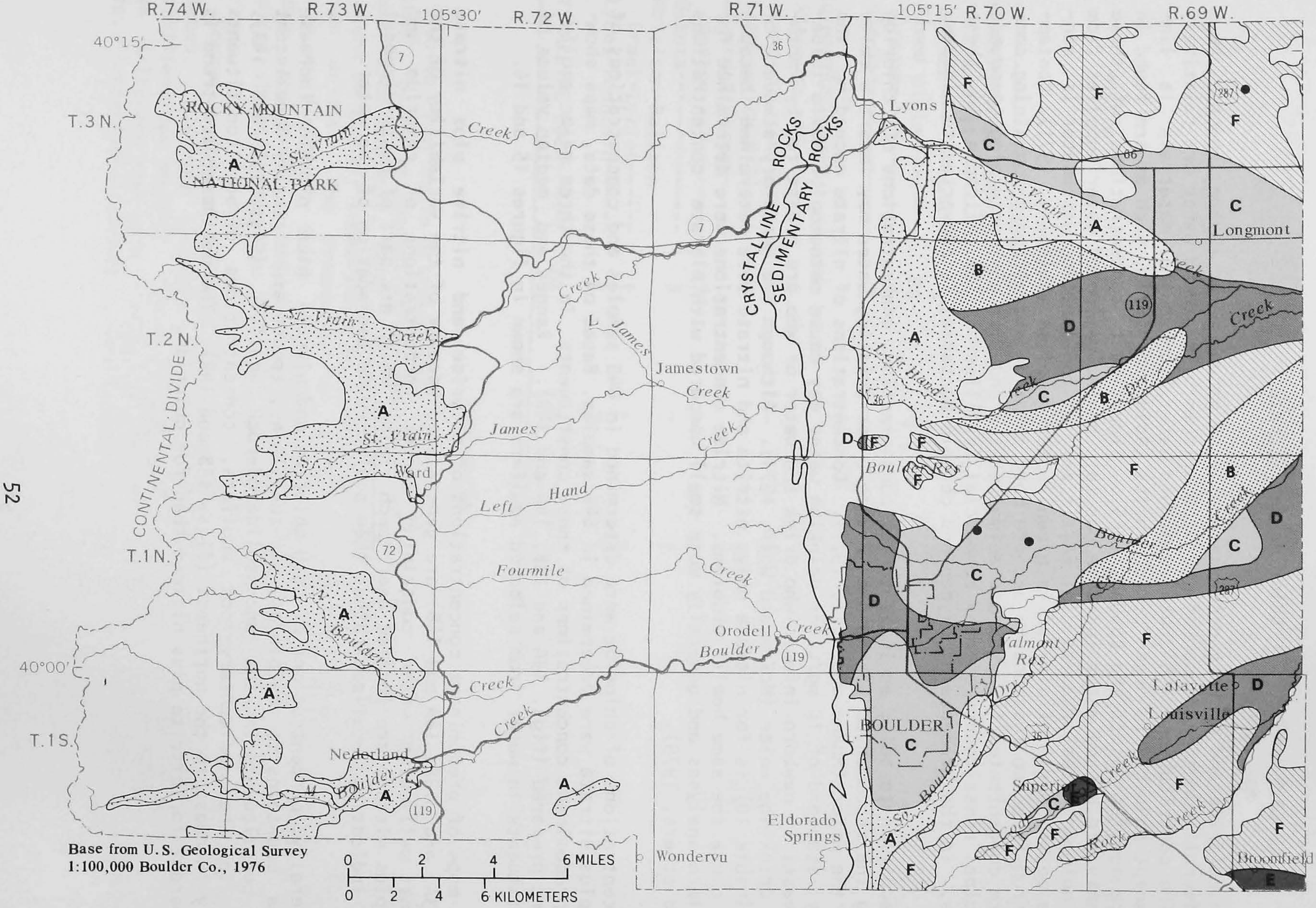
Both chloride and nitrate occur naturally in ground water in the county; however, natural concentrations of both constituents in ground water are relatively small. The contribution of nitrate to ground water from aquifer materials is limited, except possibly in organic-rich shales (Goldberg, 1971), such as are found in the Pierre aquifer (Scott and Cobban, 1965). Significant concentrations of these constituents in ground water indicate possible contamination of water supplies from human or animal wastes or commercial fertilizer, as infiltrating wastewater is considered a major source of nitrate in ground-water supplies (Goldberg, 1971). Contamination from these sources occurs because both chloride and nitrogen-containing compounds are concentrated in human and animal wastes and nitrogen-containing compounds are principal constituents of many commercial fertilizers. The nitrogen in these compounds, in the presence of oxygen and certain bacteria, is converted to nitrate.

In addition to being an indicator of contamination, concentrations of chloride exceeding the recommended standard of 250 mg/L for drinking water may impart a salty taste to the water (McKee and Wolf, 1971). Concentrations of nitrate exceeding the mandatory standard of 10 mg/L for drinking water may cause methemoglobinemia (blue-baby disease) in newborn infants who drink the water or who are breast fed by mothers who drink the water (McKee and Wolf, 1971). Although the mandatory standard of 10 mg/L (table 10) is for nitrate only, nitrite and nitrate were determined because both can cause the same health problems. Nitrite concentrations were determined for the complete analyses and generally were small compared with nitrate concentrations (Hall and others, 1979).

Concentrations of chloride were determined in 645 samples and concentrations of nitrite plus nitrate were determined in 646 samples. Based on these data, maps showing the predominant concentrations of these constituents in the three major aquifer types were prepared (figs. 13A and 13B; 14A and 14B). Ranges and median values of the constituents in water from selected aquifers are shown in figures 15 and 16.

The maps of predominant concentrations of chloride and nitrite plus nitrate (figs. 13A and 13B; 14A and 14B) are generalized because of the variability of the data. Most wells with water containing larger concentrations of chloride and nitrite plus nitrate are located near leach fields, which are part of waste-disposal systems, indicating localized rather than aquifer-wide degradation of the water.

Generally, concentrations of both chloride and nitrite plus nitrate increase from the mountains to the plains. In the plains, trends are virtually nonexistent for both constituents in the unconsolidated-rock aquifers (figs. 13A and 14A). However, in the sedimentary-rock aquifers, concentrations of both constituents generally increase to the northeast (figs. 13B and 14B). The northeastward trend is more apparent for nitrite plus nitrate than for chloride.



Base from U.S. Geological Survey 1:100,000 Boulder Co., 1976

Figure 13A.--Predominant concentrations of dissolved chloride in water from unconsolidated-rock aquifers.

EXPLANATION

CONCENTRATION OF DISSOLVED CHLORIDE, IN MILLIGRAMS PER LITER

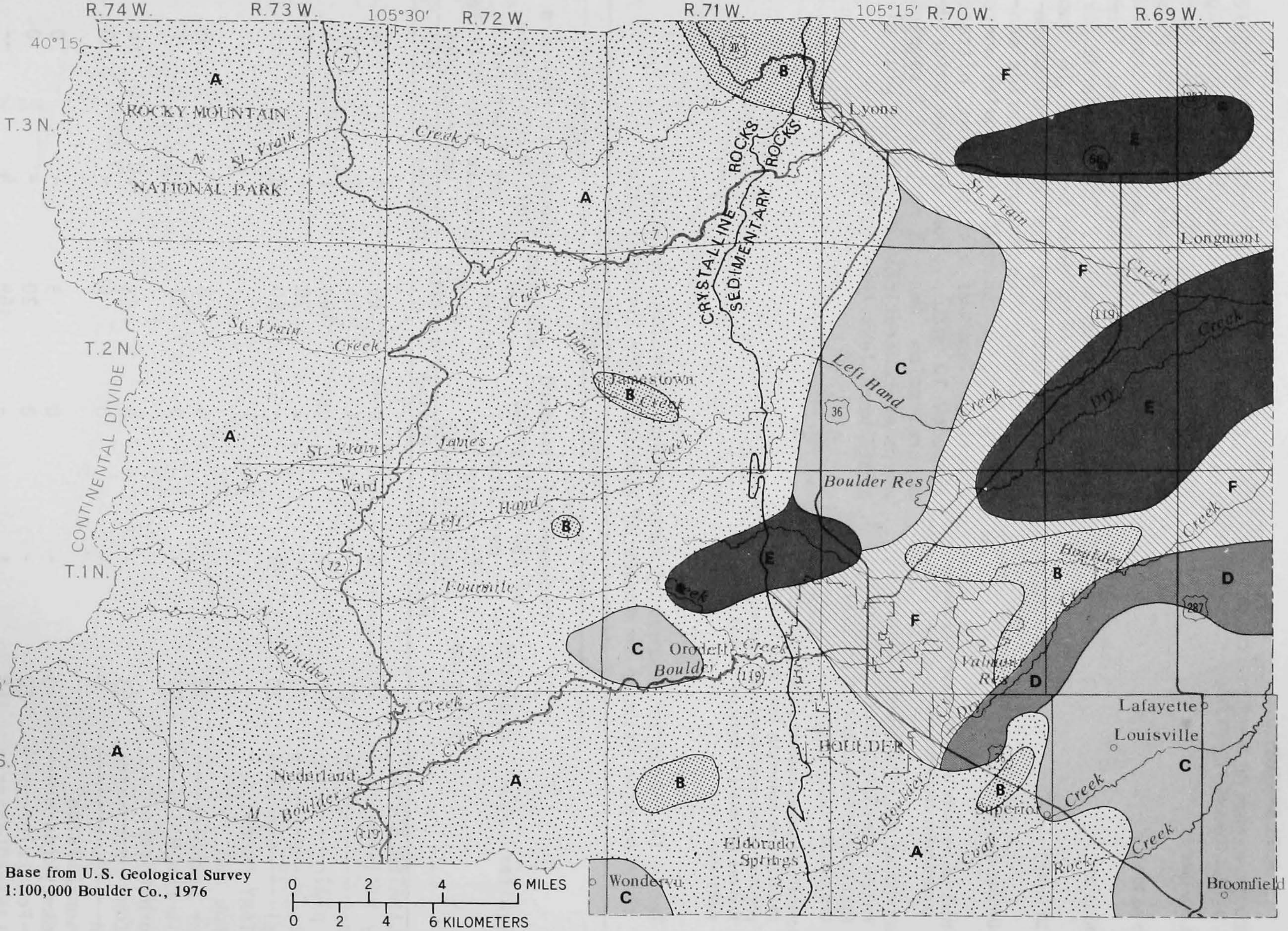
A	Less than 5
B	5 to 10
C	10 to 20
D	20 to 40
E	Greater than 40
F	Data too variable or insufficient to determine predominant concentration
●	INDIVIDUAL WELL OR SPRING WHERE WATER CONTAINED MORE THAN 250 MILLIGRAMS PER LITER OF DISSOLVED CHLORIDE

Note: Predominant concentration of dissolved chloride was gennerally less than 5 milligrams per liter in unconsolidated-rock aquifers that are too small to show on the map in the mountains

Concentrations of chloride exceeded the recommended standard for drinking water in 6 samples from 4 aquifers (table 14); concentrations of nitrite plus nitrate exceeded the mandatory standard for drinking water in 41 samples from 6 aquifers (table 14). The standards for both constituents were exceeded in two samples, both from the Pierre-Niobrara-Benton aquifer. The average chloride concentration was 58 mg/L in samples where concentrations of nitrite plus nitrate exceeded 10 mg/L. The average chloride concentration was 18 mg/L in samples where concentrations of nitrite plus nitrate were less than 10 mg/L.

Table 14.--*Aquifer sources of samples that contained chloride or nitrite plus nitrate in excess of standards for drinking water*

Aquifer	Number of samples					
	Analyzed for chloride	Where recommended standard of 250 milligrams per liter for chloride was exceeded		Analyzed for nitrite plus nitrate	Where mandatory standard of 10 milligrams per liter for nitrite plus nitrate was exceeded	
		Mountains	Plains		Mountains	Plains
UNCONSOLIDATED ROCKS:						
Valley fill---------	19	0	0	19	0	0
Eolian--------------	21	-	1	21	-	2
Flood plain---------	160	0	0	160	1	4
Terrace-------------	76	-	2	76	-	11
Glacial-------------	20	0	-	20	0	--
SEDIMENTARY ROCKS:						
Arapahoe and upper Laramie-----	8	-	0	8	-	0
Laramie-Fox Hills---	91	-	0	91	-	5
Pierre-Niobrara-Benton------------	53	-	2	53	-	14
Dakota--------------	6	-	0	6	-	0
Morrison-Ralston Creek-Lykins------	3	-	0	3	-	0
Lyons-Fountain------	20	-	0	20	-	0
CRYSTALLINE-ROCK------	168	1	-	169	4	--



Base from U.S. Geological Survey
1:100,000 Boulder Co., 1976

Figure 13B.--Predominant concentrations of dissolved chloride in water from sedimentary- and crystalline-rock aquifers.

EXPLANATION

CONCENTRATION OF DISSOLVED CHLORIDE, IN MILLIGRAMS PER LITER

A	Less than 5
B	5 to 10
C	10 to 20
D	20 to 40
E	Greater than 40
F	Data too variable or insufficient to determine predominant concentration
●	INDIVIDUAL WELL OR SPRING WHERE WATER CONTAINED MORE THAN 250 MILLIGRAMS PER LITER OF DISSOLVED CHLORIDE

Detergents

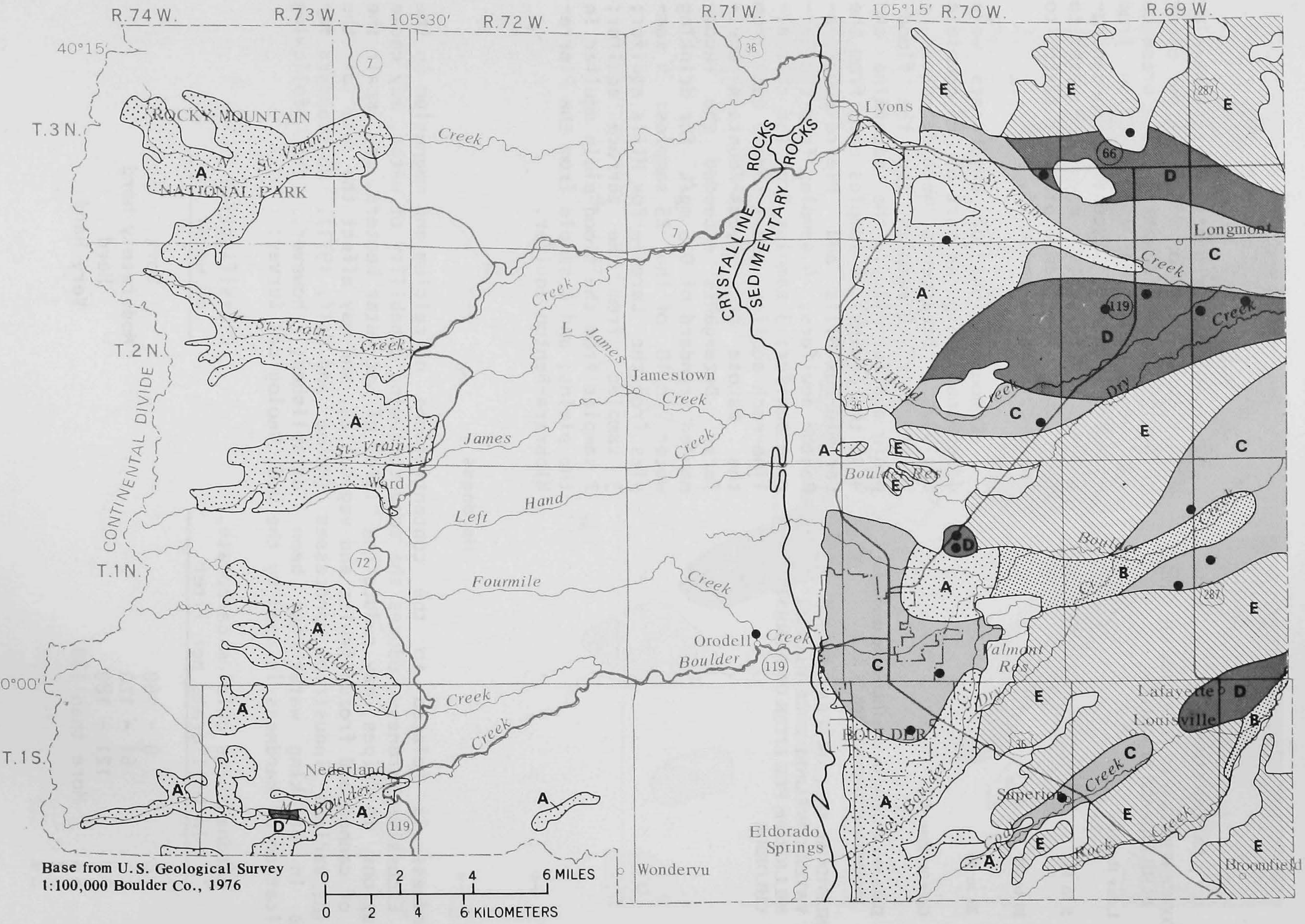
Because detergents (methylene-blue active substances or MBAS) do not occur naturally in ground water, their presence indicates positive contamination from domestic wastes. Excessive concentrations of detergents may cause water to foam and impart an unpleasant taste to the water (McKee and Wolf, 1971).

Concentrations of detergents were determined only as part of 88 complete analyses. Detergents were detected in 25 samples: 6 samples from the flood-plain aquifer (2 in the mountains and 4 in the plains); 4 samples each from the Laramie-Fox Hills and Pierre-Niobrara-Benton aquifers; 4 samples from the terrace aquifer; 3 samples from the crystalline-rock aquifer, and 1 sample each from the Dakota and Lyons-Fountain aquifers. Detergents exceeded the recommended standard of 0.5 mg/L for drinking water in 10 of the 25 samples: 4 samples from the Laramie-Fox Hills aquifer; 3 samples from the terrace aquifer; 2 samples from the flood-plain aquifer in the plains; and 1 sample from the Pierre-Niobrara-Benton aquifer.

Hardness

Hardness is related to the concentrations of calcium and magnesium in the water. Excessive hardness reduces the soap-consuming capability of water, may cause incrustations in pipes, may reduce the "life" of hot-water heaters, may impair the quality of canned and frozen fruits and vegetables, and may affect the use of the water in various industrial processes (McKee and Wolf, 1971). No standard for hardness in drinking water has been established; however, the following classification of hardness is used by the U.S. Geological Survey:

Hardness, as calcium carbonate, in milligrams per liter	Classification of water
0 - 60	Soft
61 - 120	Moderately hard
121 - 180	Hard
More than 180	Very hard



Base from U. S. Geological Survey
1:100,000 Boulder Co., 1976

Figure 14A.--Predominant concentrations of dissolved nitrite plus nitrate in water from unconsolidated-rock aquifers.

EXPLANATION

CONCENTRATION OF DISSOLVED NITRITE PLUS NITRATE, IN MILLIGRAMS PER LITER AS NITROGEN

A	Less than 1
B	1 to 2
C	2 to 5
D	Greater than 5
E	Data too variable or insufficient to determine predominant concentration
●	INDIVIDUAL WELL OR SPRING WHERE WATER CONTAINED MORE THAN 10 MILLIGRAMS PER LITER OF DISSOLVED NITRITE PLUS NITRATE AS NITROGEN

Note: Predominant concentration of dissolved nitrite plus nitrate as nitrogen was generally less than 1 milligram per liter in unconsolidated-rock aquifers that are too small to show on the map in the mountains

Comparing this classification with the results of the 98 complete analyses, soft water occurred in 20 samples, moderately hard water occurred in 5 samples, hard water occurred in 9 samples, and very hard water occurred in 64 samples (table 15).

The hardness of water in the 550 indicator analyses was estimated using specific-conductance measurements. The estimation was limited to determining the number of samples in which hardness may have been less than or more than 180 mg/L. Results of the estimation are shown in table 16.

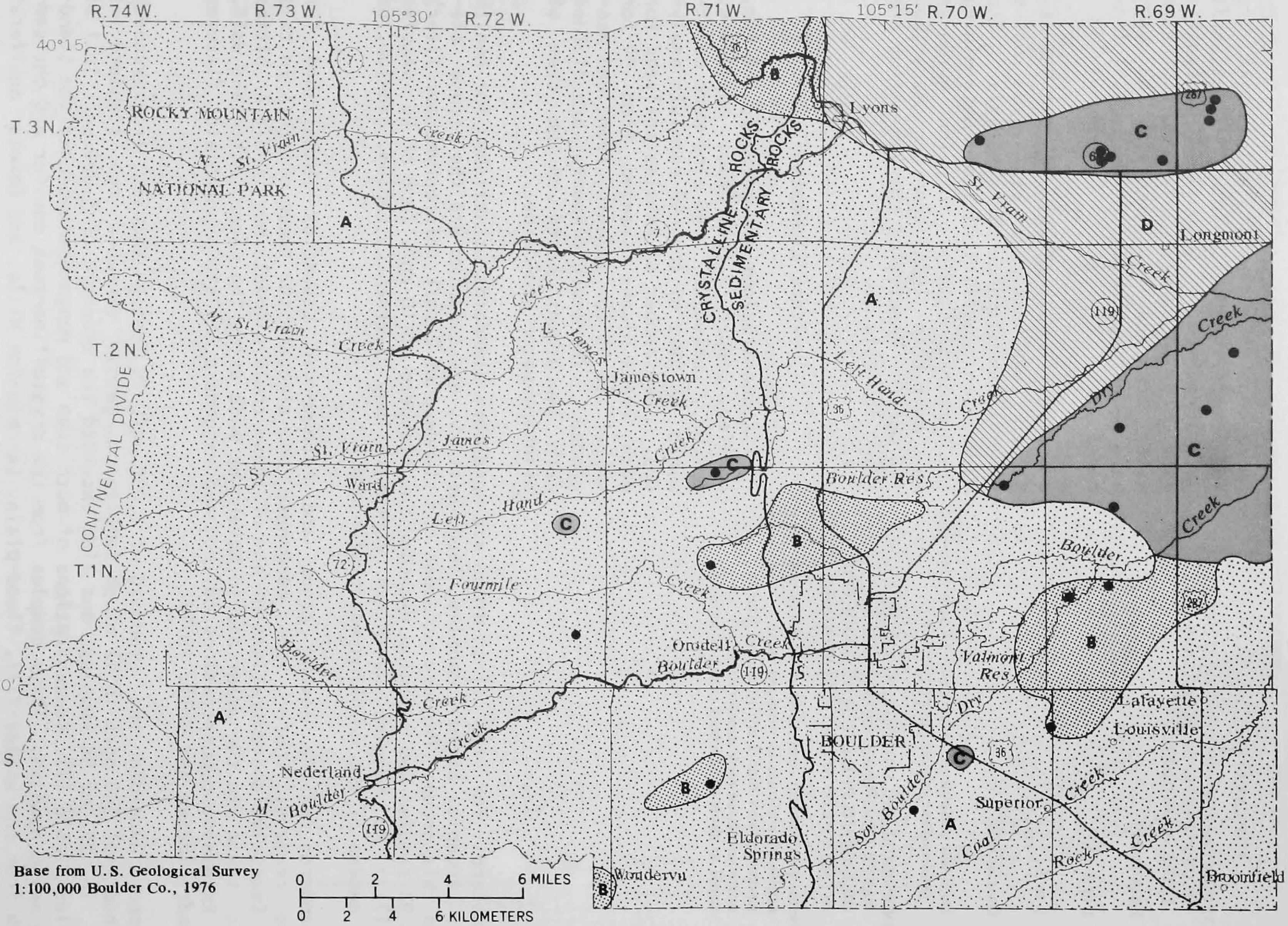
Trace Elements

Concentrations of arsenic, barium, cadmium, copper, iron, lead, manganese, mercury, selenium, and zinc were determined as part of the 98 complete analyses. The number of samples analyzed for each trace element ranged from 94 for copper to 98 for arsenic, iron, and manganese. The trace elements are divided into two groups based on the type of drinking-water standards.

Standards for the first group are mandatory standards established for health reasons. Arsenic, barium, cadmium, lead, mercury, and selenium are the trace elements in this group. Mercury exceeded the standard of 2 μg/L (micrograms per liter) in 2 of 97 samples and selenium exceeded the standard of 10 μg/L in 8 of 96 samples (table 17). No samples contained concentrations of arsenic, barium, cadmium, or lead in excess of the drinking-water standard.

Standards for the second group are recommended standards established for esthetic reasons. Copper, iron, manganese, and zinc are the trace elements in this group. Excessive concentrations of any of these trace elements may impart a bitter metallic taste to the water and to beverages made using the water (McKee and Wolf, 1971). Excessive concentrations of iron and manganese may stain porcelain fixtures and laundry (McKee and Wolf, 1971).

Copper exceeded the standard of 1,000 μg/L in 1 of 94 samples; iron exceeded the standard of 300 μg/L in 12 of 98 samples; manganese exceeded the standard of 50 μg/L in 22 of 98 samples; and zinc exceeded the standard of 5,000 μg/L in 1 of 97 samples (table 17). Concentrations of both iron and manganese exceeded the standards in seven samples: Three samples from the crystalline-rock aquifer and one sample each from the valley-fill, flood-plain, Laramie-Fox Hills, and Dakota aquifers.



Base from U.S. Geological Survey 1:100,000 Boulder Co., 1976

Figure 14B.--Predominant concentrations of dissolved nitrite plus nitrate in water from sedimentary- and crystalline-rock aquifers.

EXPLANATION

CONCENTRATION OF DISSOLVED NITRITE PLUS NITRATE, IN MILLIGRAMS PER LITER AS NITROGEN

A	Less than 1
B	1 to 5
C	Greater than 5
D	Data too variable or insufficient to determine predominant concentration
●	INDIVIDUAL WELL OR SPRING WHERE WATER CONTAINED MORE THAN 10 MILLIGRAMS PER LITER OF DISSOLVED NITRITE PLUS NITRATE AS NITROGEN

Bacteria

With respect to health, the implications of the presence of bacteria in ground water are the same as were discussed in the section on "Surface-Water Quality" (p. 22). The presence of coliform bacteria in the absence of fecal-coliform bacteria indicates less recent or nonfecal contamination, while the presence of fecal-coliform bacteria indicates recent and possibly dangerous contamination. Bacterial contamination of a water supply obtained from a well commonly indicates a defect in the well installation. Overland runoff may enter a well if a sanitary seal has not been installed, if the seal has been installed improperly, or if the seal has deteriorated. Bacterial contamination of a water supply obtained from a spring generally indicates a lack of adequate protection from overland runoff or from contamination by domestic or wild animals at the spring site.

Concentrations of coliform bacteria were determined in 643 samples and concentrations of fecal-coliform bacteria were determined in 641 samples. There are no drinking-water standards for bacteria concentrations in a single sample. However, the presence of more than 1 coliform bacterium or 1 or more fecal-coliform bacteria per 100 mL of water is cause for concern and remedial action, such as disinfection of the water supply (Boulder County Health Department, oral commun., 1978). More than 1 coliform bacterium was present in 170 samples and 1 or more fecal-coliform bacteria were present in 52 samples (table 18).

Countywide, 26 percent (170 of 643) of the samples contained excessive concentrations of coliform bacteria and 8 percent (52 of 641) of the samples contained excessive concentrations of fecal-coliform bacteria. The valley-fill, eolian, floodplain, and terrace aquifers in the plains had a greater percentage of samples containing bacteria than the countywide average of 26 percent (table 18). This is due to the fact that most waste-treatment systems discharge into these aquifers because they are the surficial aquifers in most of the plains. The percentage of samples containing bacteria in the most widely used bedrock aquifers was less than 26 percent for samples from the Laramie-Fox Hills and the crystalline-rock aquifers and was about 26 percent for samples from the Pierre-Niobrara-Benton aquifer (table 18).

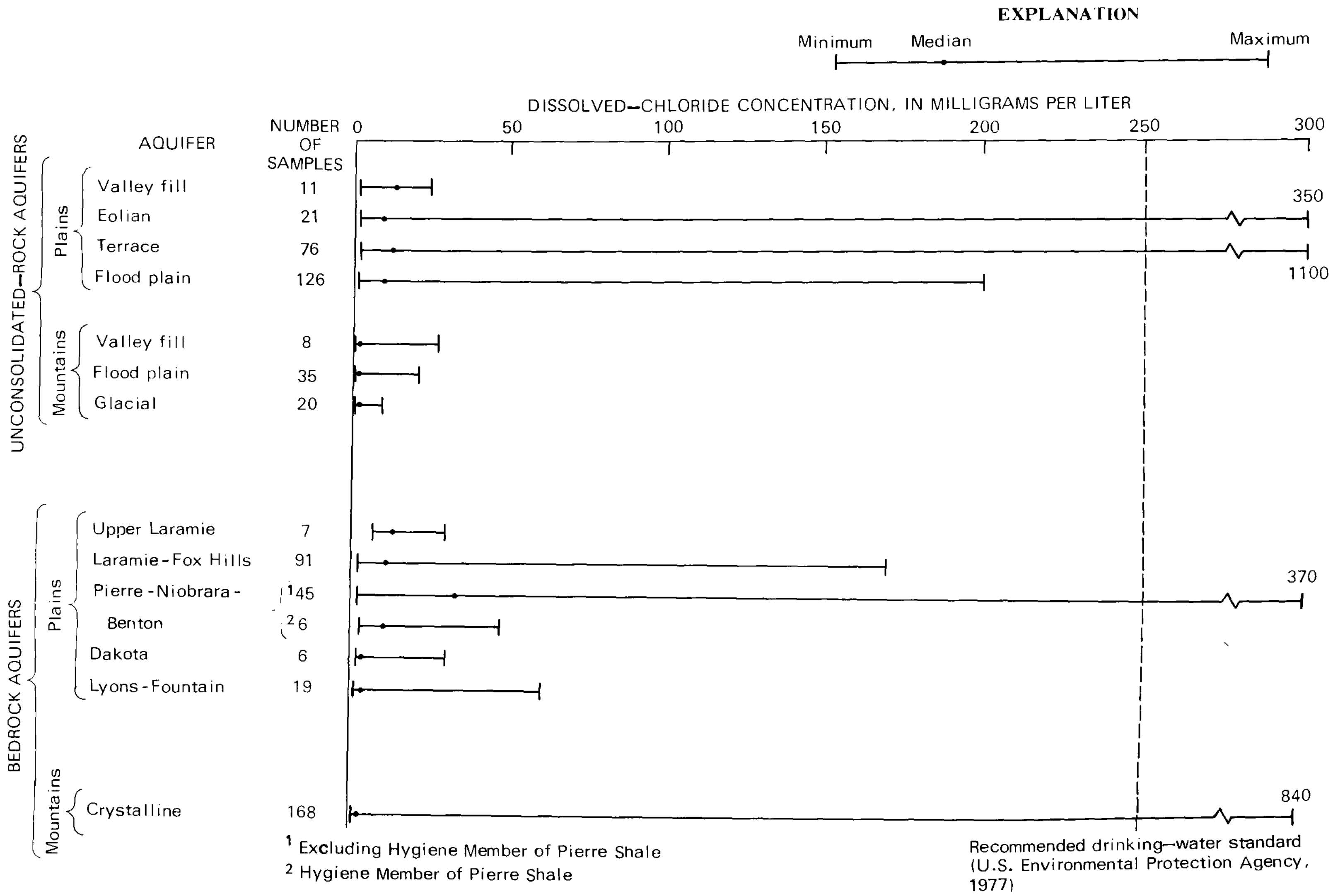


Figure 15.--Ranges and median values of dissolved chloride in water from selected aquifers.

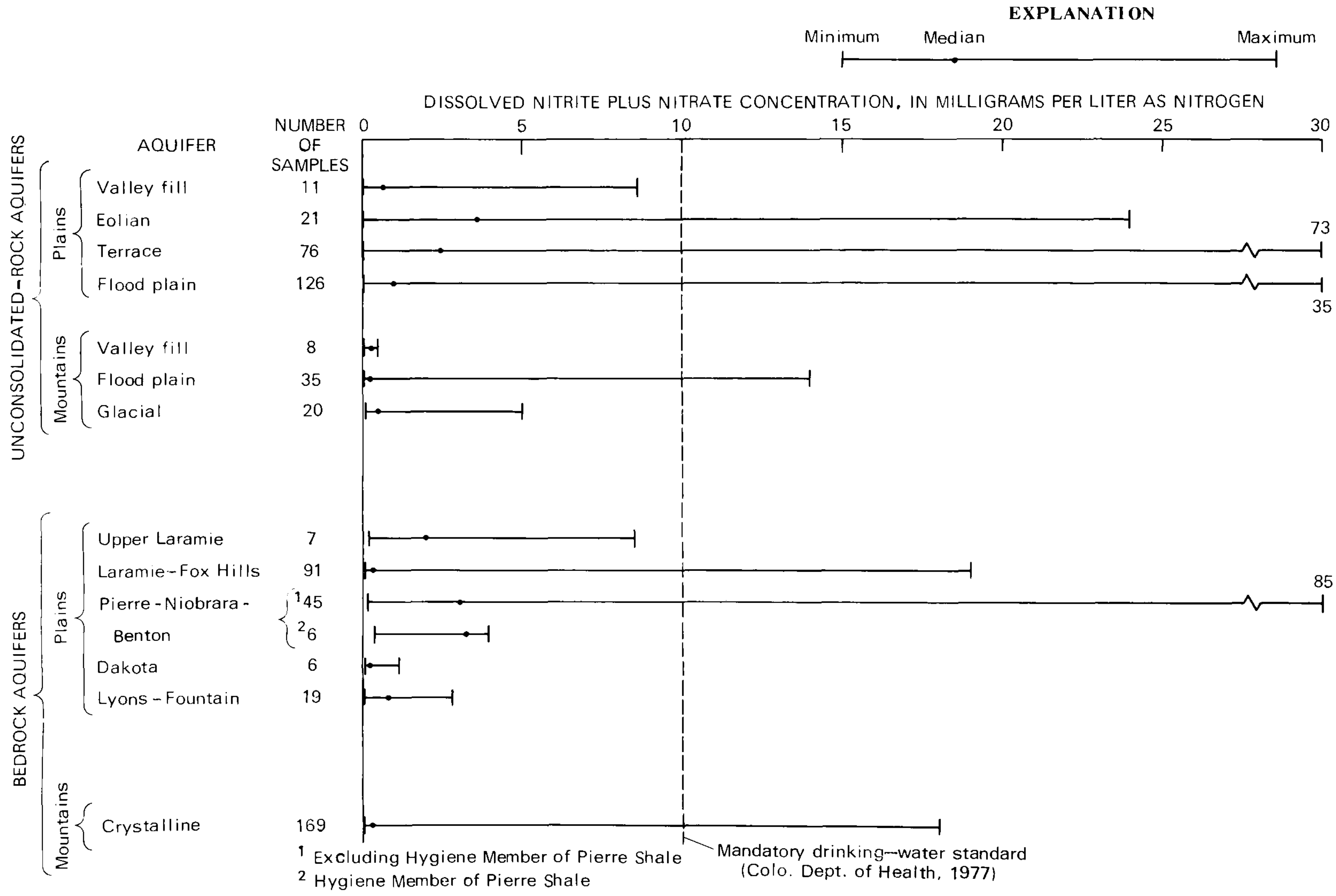


Figure 16.--Ranges and median values of dissolved nitrite plus nitrate in water from selected aquifers.

Table 15.--*Aquifer sources of samples within various hardness classifications*

Aquifer	Number of complete analyses	Number of samples in classification group based on hardness, as calcium carbonate, in milligrams per liter indicated in parentheses			
		Soft water (0-60)	Moderately hard water (61-120)	Hard water (121-180)	Very hard water (more than 180)
UNCONSOLIDATED ROCKS:					
Valley fill (plains)	2	0	0	0	2
Eolian	3	0	0	0	3
Flood plain (mountains)	3	1	1	0	1
Flood plain (plains)	17	2	0	0	15
Terrace	9	0	0	0	9
Glacial	2	1	1	0	0
SEDIMENTARY ROCKS:					
Upper Laramie	2	0	0	0	2
Laramie-Fox Hills	13	2	0	3	8
Pierre-Niobrara-Benton	17	2	1	2	12
Dakota	3	1	0	0	2
Morrison-Ralston Creek-Lykins	1	0	0	0	1
Lyons-Fountain	6	2	0	1	3
CRYSTALLINE-ROCK	20	9	2	3	6

Radiochemicals

Gross alpha and gross beta radiation were determined for 93 of the 98 complete analyses. If gross alpha radiation were greater than 10 pCi/L, radium-226 and uranium generally were determined--radium-226 in 44 samples and uranium in 38 samples. The drinking-water standard for gross alpha radiation specifies correction for radon and uranium. Because radon was not determined and because only 38 values were corrected for uranium, a complete evaluation with respect to the drinking-water standard of 15 pCi/L could not be made. Gross alpha radiation, corrected for uranium, exceeded 15 pCi/L in 13 of the 38 samples: 6 samples from the flood-plain aquifer in the plains; 3 samples from the Pierre-Niobrara-Benton aquifer; and 2 samples each from the terrace and crystalline-rock aquifers.

The drinking-water standard for radium is for radiation from both radium-226 and radium-228. Because radium-228 was not determined, a complete evaluation with respect to the drinking-water standard of 5 pCi/L could not be made. However, the radium-226 concentration in one sample from the crystalline-rock aquifer was 12 pCi/L, which exceeded the drinking-water standard. The radium-226 concentration in another sample from the crystalline-rock aquifer was 4.6 pCi/L, which may have exceeded the standard. The radium-226 concentrations in the remaining 42 samples

Table 16.--*Aquifer sources of samples that were estimated to contain less than or more than 180 milligrams per liter of hardness*

Aquifer	Number of indicator analyses	Number of samples where hardness was estimated to have been	
		Less than 180 milligrams per liter	More than 180 milligrams per liter
UNCONSOLIDATED ROCKS:			
Valley fill (mountains)	8	8	0
Valley fill (plains)	9	2	7
Eolian	18	0	18
Flood plain (mountains)	32	32	0
Flood plain (plains)	108	36	72
Terrace	67	3	64
Glacial	18	17	1
SEDIMENTARY ROCKS:			
Arapahoe and upper Laramie	6	0	6
Laramie-Fox Hills	78	23	55
Pierre-Niobrara-Benton	36	8	28
Dakota	3	0	3
Morrison-Ralston Creek-Lykins	2	1	1
Lyons-Fountain	14	4	10
CRYSTALLINE-ROCK	151	88	63

were less than 3 pCi/L. The standard of 5 pCi/L for radium-226 plus radium-228 probably was not exceeded in these samples because the concentration of radium-228 generally is less than the concentration of radium-226 (U.S. Environmental Protection Agency, 1977).

No drinking-water standard has been established for gross beta radiation. However, State regulations (Colorado Department of Health, 1977) specify that when gross beta radiation exceeds 50 pCi/L, the water should be analyzed to identify the major radioactive constituents present. Gross beta radiation exceeded 50 pCi/L in 2 of the 93 samples: 1 sample each from the terrace and crystalline-rock aquifers.

The most excessive radiation occurred in water from a spring (SB00207129DABA) in the crystalline-rock aquifer. Gross alpha radiation, corrected for uranium, was 227 pCi/L; radium-226 radiation was 12 pCi/L; and gross beta radiation was 68 pCi/L. Excessive radiation also occurred in water from a well (SB00207224DACA1) in the crystalline-rock aquifer about 2 mi from the spring. Gross alpha radiation, uncorrected, was 120 pCi/L; radium-226 radiation was 4.6 pCi/L; and gross beta radiation was 32 pCi/L.

Table 17.--*Aquifer sources of samples that contained trace elements in excess of standards for drinking water*

[µg/L=microgram per liter]

Aquifer	Number of samples analyzed	Number of samples where standard was exceeded									
		Mandatory standards						Recommended standards			
		Arsenic (50 µg/L)	Barium (1,000 µg/L)	Cadmium (10 µg/L)	Lead (50 µg/L)	Mercury (0.2 µg/L)	Selenium (10 µg/L)	Copper (1,000 µg/L)	Iron (300 µg/L)	Manganese (50 µg/L)	Zinc (5,000 µg/L)
UNCONSOLIDATED ROCKS:											
Valley fill (plains)-----	2	0	0	0	0	0	0	0	1	1	0
Eolian------------------	3	0	0	0	0	0	0	0	0	0	0
Flood plain (mountains)--	3	0	0	0	0	0	0	0	0	0	0
Flood plain (plains)-----	[1]17	0	0	0	0	0	3	1	2	2	0
Terrace-----------------	9	0	0	0	0	0	0	0	0	1	0
Glacial-----------------	2	0	0	0	0	0	0	0	0	0	0
SEDIMENTARY ROCKS:											
Arapahoe and upper Laramie----------------	2	0	0	0	0	0	0	0	0	0	0
Laramie-Fox Hills--------	[2]13	0	0	0	0	0	3	0	1	3	0
Pierre-Niobrara-Benton---	[3]17	0	0	0	0	0	2	0	2	6	0
Dakota------------------	3	0	0	0	0	0	0	0	2	1	0
Morrison-Ralston Creek-Lykins----------------	1	0	0	0	0	0	0	0	0	0	0
Lyons-Fountain----------	[4]6	0	0	0	0	0	0	0	0	0	0
CRYSTALLINE-ROCK----------	20	0	0	0	0	2	0	0	4	8	1

[1] 16 samples for barium, lead, mercury, and zinc; 15 samples for copper.

[2] 12 samples for copper.

[3] 16 samples for selenium and copper.

[4] 5 samples for selenium.

Table 18.--*Number and percentage of samples that contained bacteria, by aquifer source*

Aquifer	Number of samples analyzed for bacteria	Number and percentage of samples: That contained more than 1 coliform bacterium per 100 milliliters of water		That contained more than 1 coliform bacterium and 1 or more fecal-coliform bacteria per 100 milliliters of water	
		Number	Percent	Number	Percent
UNCONSOLIDATED ROCKS:					
Valley fill (mountains)--	8	2	25	0	0
Valley fill (plains)-----	11	5	45	1	9
Eolian-------------------	21	8	38	4	19
Flood plain (mountains)--	34	7	21	3	9
Flood plain (plains)-----	121	41	34	11	9
Terrace------------------	[1]76	36	47	13	17
Glacial------------------	20	1	5	1	5
SEDIMENTARY ROCKS:					
Arapahoe and upper Laramie----------------	8	2	25	1	13
Laramie-Fox HIlls--------	91	16	18	1	1
Pierre-Niobrara-Benton---	[2]53	12	23	4	8
Dakota-------------------	6	3	50	2	33
Morrison-Ralston Creek-Lykins-----------------	3	0	0	0	0
Lyons-Fountain-----------	20	4	20	2	10
CRYSTALLINE-ROCK-----------	171	33	19	9	5

[1] 75 samples analyzed for fecal-coliform bacteria.

[2] 52 samples analyzed for fecal-coliform bacteria.

Suitability of Ground Water for Use as a Drinking-Water Supply

An evaluation of the suitability of water from the various aquifers for use as a drinking-water supply was made using the results of the complete and indicator analyses, and estimated concentrations of dissolved solids, magnesium, sulfate, and hardness. The estimated concentrations were based on the relationships between specific conductance and the individual constituents. In each of the aquifer summaries, the results of the analyses are presented first, followed by the estimated results, when both are available.

Valley-Fill Aquifer--Mountains

Based on eight indicator analyses, water in the valley-fill aquifer in the mountains probably is suitable for use as a drinking-water supply although bacterial contamination is a problem locally. Water-quality characteristics are summarized below:

Dissolved solids: Estimated not to have exceeded 500 mg/L in eight samples.
Magnesium: Estimated not to have exceeded 125 mg/L in eight samples.
Sulfate: Estimated not to have exceeded 250 mg/L in eight samples.
Fluoride: Not determined.
Chloride: Determined in eight samples; did not exceed 250 mg/L.
Nitrite plus nitrate: Determined in eight samples; did not exceed 10 mg/L as nitrogen.
Detergents: Not determined.
Hardness: Estimated not to have exceeded 180 mg/L in eight samples.
Trace elements: Not determined.
Bacteria: Determined in eight samples; more than one coliform bacterium was present in two samples.
Radiochemicals: Not determined.

Valley-Fill Aquifer--Plains

Based on two complete and nine indicator analyses, water in the valley-fill aquifer in the plains generally is not suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids, sulfate, and hardness are problems. Excessive concentrations of trace elements and bacteria are problems locally. Water-quality characteristics are summarized below:

Dissolved solids: Exceeded 500 mg/L in two samples; estimated to have exceeded 500 mg/L in six of nine samples.
Magnesium: Did not exceed 125 mg/L in two samples; estimated not to have exceeded 125 mg/L in seven of nine samples.
Sulfate: Exceeded 250 mg/L in one of two samples; estimated to have exceeded 250 mg/L in six of nine samples.
Fluoride: Determined in two samples; did not exceed 2.0 mg/L.
Chloride: Determined in 11 samples; did not exceed 250 mg/L.
Nitrite plus nitrate: Determined in 11 samples; did not exceed 10 mg/L as nitrogen.
Detergents: Determined in one sample; not detected.
Hardness: Exceeded 180 mg/L in two samples; estimated to have exceeded 180 mg/L in seven of nine samples.
Trace elements: Determined in two samples; iron exceeded 300 µg/L and manganese exceeded 50 µg/L in one sample.
Bacteria: Determined in 11 samples; more than 1 coliform bacterium was present in 5 samples; 1 or more fecal-coliform bacteria were present in 1 of the 5 samples.
Radiochemicals: Determined in two samples; not excessive.

Eolian Aquifer

Based on 3 complete and 18 indicator analyses, water in the eolian aquifer generally is not suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids, sulfate, and hardness are problems. Bacterial contamination is a problem locally. Water-quality characteristics are summarized below:

Dissolved solids: Exceeded 500 mg/L in 3 samples; estimated to have exceeded 500 mg/L in 16 of 18 samples.
Magnesium: Did not exceed 125 mg/L in 3 samples; estimated not to have exceeded 125 mg/L in 15 of 18 samples.
Sulfate: Did not exceed 250 mg/L in 2 of 3 samples; estimated not to have exceeded 250 mg/L in 9 of 18 samples.
Fluoride: Determined in three samples; did not exceed 2.0 mg/L in two samples.
Chloride: Determined in 21 samples; did not exceed 250 mg/L in 20 samples.
Nitrite plus nitrate: Determined in 21 samples; did not exceed 10 mg/L as nitrogen in 19 samples.
Detergents: Determined in three samples; not detected.
Hardness: Exceeded 180 mg/L in 3 samples; estimated to have exceeded 180 mg/L in 18 samples.
Trace elements: Determined in three samples; not excessive.
Bacteria: Determined in 21 samples; more than 1 coliform bacterium was present in 8 samples; 1 or more fecal-coliform bacteria were present in 4 of the 8 samples.
Radiochemicals: Determined in three samples; not excessive.

Flood-Plain Aquifer--Mountains

Based on 3 complete and 32 indicator analyses, water in the flood-plain aquifer in the mountains generally is suitable for use as a drinking-water supply, although bacterial contamination is a problem locally. Water-quality characteristics are summarized below:

Dissolved solids: Did not exceed 500 mg/L in 3 samples; estimated not to have exceeded 500 mg/L in 32 samples.
Magnesium: Did not exceed 125 mg/L in 3 samples; estimated not to have exceeded 125 mg/L in 32 samples.
Sulfate: Did not exceed 250 mg/L in 3 samples; estimated not to have exceeded 250 mg/L in 32 samples.
Fluoride: Determined in three samples; did not exceed 2.0 mg/L.
Chloride: Determined in 35 samples; did not exceed 250 mg/L.
Nitrite plus nitrate: Determined in 35 samples; did not exceed 10 mg/L as nitrogen in 34 samples.
Detergents: Determined in three samples; detected in two samples.
Hardness: Did not exceed 180 mg/L in 2 of 3 samples; estimated not to have exceeded 180 mg/L in 32 samples.
Trace elements: Determined in three samples; not excessive.
Bacteria: Determined in 34 samples; more than 1 coliform bacterium was present in 7 samples; 1 or more fecal-coliform bacteria were present in 3 of the 7 samples.
Radiochemicals: Determined in three samples; not excessive.

Flood-Plain Aquifer--Plains

Based on 17 complete and 108 indicator analyses, water in the flood-plain aquifer in the plains generally is suitable for use as a drinking-water supply in areas just east of the mountain front. Suitability generally decreases toward the east and water in the flood-plain aquifer along the eastern edge of the county generally is not suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids, sulfate, hardness, trace elements, bacteria, and radiochemicals are problems locally. Water-quality characteristics are summarized below:

Dissolved solids: Exceeded 500 mg/L in 10 of 17 samples; estimated not to have exceeded 500 mg/L in 69 of 108 samples.
Magnesium: Did not exceed 125 mg/L in 16 of 17 samples; estimated not to have exceeded 125 mg/L in 105 of 108 samples.
Sulfate: Did not exceed 250 mg/L in 12 of 17 samples; estimated not to have exceeded 250 mg/L in 76 of 108 samples.
Fluoride: Determined in 17 samples; did not exceed 2.0 mg/L in 16 samples.
Chloride: Determined in 125 samples; did not exceed 250 mg/L.
Nitrite plus nitrate: Determined in 125 samples; did not exceed 10 mg/L as nitrogen in 121 samples.
Detergents: Determined in 15 samples; detected in 4 samples; exceeded 0.5 mg/L in 2 of the 4 samples.
Hardness: Exceeded 180 mg/L in 15 of 17 samples; estimated to have exceeded 180 mg/L in 72 of 108 samples.
Trace elements: Determined in 17 samples; copper exceeded 1,000 μg/L in 1 sample; iron exceeded 300 μg/L in 1 sample; manganese exceeded 50 μg/L in 1 sample; selenium exceeded 10 μg/L in 3 samples. Standards for both iron and manganese were exceeded in 1 sample.
Bacteria: Determined in 121 samples; more than 1 coliform bacterium was present in 41 samples; 1 or more fecal-coliform bacteria were present in 11 of the 41 samples.
Radiochemicals: Determined in 17 samples; gross alpha radiation was excessive in 6 samples.

Terrace Aquifer

Based on 9 complete and 67 indicator analyses, water in the terrace aquifer generally is not suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids, sulfate, and hardness are problems. Excessive concentrations of magnesium, nitrite plus nitrate, bacteria, and radiochemicals are problems locally. Water-quality characteristics are summarized below:

Dissolved solids: Did not exceed 500 mg/L in 7 of 9 samples; estimated to have exceeded 500 mg/L in 44 of 67 samples.
Magnesium: Did not exceed 500 mg/L in 7 of 9 samples; estimated not to have exceeded 125 mg/L in 58 of 67 samples.
Sulfate: Did not exceed 250 mg/L in 7 of 9 samples; estimated to have exceeded 250 mg/L in 38 of 67 samples.
Fluoride: Determined in nine samples; did not exceed 2.0 mg/L in eight samples.

Chloride: Determined in 76 samples; did not exceed 250 mg/L in 74 samples.
Nitrite plus nitrate: Determined in 76 samples; did not exceed 10 mg/L as nitrogen in 65 samples.
Detergents: Determined in eight samples; detected in four samples; exceeded 0.5 mg/L in three of the four samples.
Hardness: Exceeded 180 mg/L in 9 samples; estimated to have exceeded 180 mg/L in 64 of 67 samples.
Trace elements: Determined in nine samples; manganese exceeded 50 µg/L in one sample.
Bacteria: Coliform bacteria determined in 76 samples; fecal-coliform bacteria determined in 75 samples. More than 1 coliform bacterium was present in 36 samples; 1 or more fecal-coliform bacteria were present in 13 of the 36 samples.
Radiochemicals: Determined in nine samples; gross alpha radiation was excessive in two samples; gross beta radiation was excessive in one sample.

Glacial Aquifer

Based on 2 complete and 18 indicator analyses, water in the glacial aquifer generally is suitable for use as a drinking-water supply, although bacterial contamination is a problem locally. Water-quality characteristics are summarized below:

Dissolved solids: Did not exceed 500 mg/L in 2 samples; estimated not to have exceeded 500 mg/L in 17 of 18 samples.
Magnesium: Did not exceed 125 mg/L in 2 samples; estimated not to have exceeded 125 mg/L in 18 samples.
Sulfate: Did not exceed 250 mg/L in 2 samples; estimated not to have exceeded 250 mg/L in 18 samples.
Fluoride: Determined in two samples; did not exceed 2.0 mg/L.
Chloride: Determined in 20 samples; did not exceed 250 mg/L.
Nitrite plus nitrate: Determined in 20 samples; did not exceed 10 mg/L as nitrogen.
Detergents: Determined in one sample; not detected.
Hardness: Did not exceed 180 mg/L in 2 samples; estimated not to have exceeded 180 mg/L in 17 of 18 samples.
Trace elements: Determined in two samples; not excessive.
Bacteria: Determined in 20 samples; more than 1 coliform bacterium and 1 or more fecal-coliform bacteria were present in 1 sample.
Radiochemicals: Determined in two samples; not excessive.

Arapahoe Aquifer

Insufficient data (one indicator analysis) are available to evaluate the suitability of water from the Arapahoe aquifer for use as a drinking-water supply. The results of the indicator analysis summarized below may not be representative of the water quality in the aquifer:

Dissolved solids: Estimated to have exceeded 500 mg/L.
Magnesium: Estimated not to have exceeded 125 mg/L.
Sulfate: Estimated to have exceeded 250 mg/L.
Fluoride: Not determined.
Chloride: Did not exceed 250 mg/L.
Nitrite plus nitrate: Did not exceed 10 mg/L as nitrogen.
Detergents: Not determined.
Hardness: Estimated to have exceeded 180 mg/L.
Trace elements: Not determined.
Bacteria: More than 1 coliform bacterium present.
Radiochemicals: Not determined.

Upper Laramie Aquifer

Based on two complete and five indicator analyses, water in the upper Laramie aquifer generally is not suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids and hardness are problems. Bacterial contamination is a problem locally. Water-quality characteristics are summarized below:

Dissolved solids: Exceeded 500 mg/L in two samples; estimated to have exceeded 500 mg/L in four of five samples.
Magnesium: Did not exceed 125 mg/L in two samples; estimated not to have exceeded 125 mg/L in four of five samples.
Sulfate: Did not exceed 250 mg/L in one of two samples; estimated not to have exceeded 250 mg/L in four of five samples.
Fluoride: Determined in two samples; exceeded 2.0 mg/L in one sample.
Chloride: Determined in seven samples; did not exceed 250 mg/L.
Nitrite plus nitrate: Determined in seven samples; did not exceed 10 mg/L as nitrogen.
Detergents: Determined in two samples; not detected.
Hardness: Exceeded 180 mg/L in two samples; estimated to have exceeded 180 mg/L in five samples.
Trace elements: Determined in two samples; not excessive.
Bacteria: Determined in seven samples; more than 1 coliform bacterium and 1 or more fecal-coliform bacteria were present in one sample.
Radiochemicals: Determined in two samples; not excessive.

Laramie-Fox Hills Aquifer

Based on 13 complete and 78 indicator analyses, water in the Laramie-Fox Hills aquifer generally is suitable for use as a drinking-water supply in the southern and western parts of the area where recharge is significant. In other parts of the area, water in the aquifer generally is less suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids and hardness are problems. Excessive concentrations of magnesium, sulfate, trace elements, and bacteria are problems locally. Water-quality characteristics are summarized below:

Dissolved solids: Did not exceed 500 mg/L in 7 of 13 samples; estimated not to have exceeded 500 mg/L in 40 of 78 samples.

Magnesium: Did not exceed 125 mg/L in 12 of 13 samples; estimated not to have exceeded 125 mg/L in 70 of 78 samples.
Sulfate: Did not exceed 250 mg/L in 8 of 13 samples; estimated not to have exceeded 250 mg/L in 47 of 78 samples.
Fluoride: Determined in 13 samples; did not exceed 2.0 mg/L in 12 samples.
Chloride: Determined in 91 samples; did not exceed 250 mg/L.
Nitrite plus nitrate: Determined in 91 samples; did not exceed 10 mg/L as nitrogen in 86 samples.
Detergents: Determined in 13 samples; detected in 5 samples; exceeded 0.5 mg/L in 4 of the 5 samples.
Hardness: Exceeded 180 mg/L in 8 of 13 samples; estimated to have exceeded 180 mg/L in 55 of 78 samples.
Trace elements: Determined in 13 samples; manganese exceeded 50 µg/L in 2 samples; selenium exceeded 10 µg/L in 3 samples. Standards for both iron (300 µg/L) and manganese were exceeded in 1 sample.
Bacteria: Determined in 91 samples; more than 1 coliform bacterium was present in 16 samples; 1 or more fecal-coliform bacteria were present in 1 of the 16 samples.
Radiochemicals: Determined in 13 samples; not excessive.

Pierre-Niobrara-Benton Aquifer

Based on 17 complete and 36 indicator analyses, water in the Pierre-Niobrara-Benton aquifer, with the exception of water in the Hygiene Sandstone Member of the Pierre Shale, generally is not suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids, magnesium, sulfate, and hardness are problems. Excessive concentrations of nitrite plus nitrate, trace elements, bacteria, and radiochemicals are problems locally. Water-quality characteristics are summarized below:

Dissolved solids (excluding Hygiene): Exceeded 500 mg/L in 12 of 14 samples; estimated to have exceeded 500 mg/L in 28 of 33 samples.
Dissolved solids (Hygiene): Did not exceed 500 mg/L in three samples; estimated not to have exceeded 500 mg/L in three samples.
Magnesium (excluding Hygiene): Did not exceed 125 mg/L in 8 of 14 samples; estimated to have exceeded 125 mg/L in 22 of 33 samples.
Magnesium (Hygiene): Did not exceed 125 mg/L in three samples; estimated not to have exceeded 125 mg/L in three samples.
Sulfate (excluding Hygiene): Exceeded 250 mg/L in 10 of 14 samples; estimated to have exceeded 250 mg/L in 27 of 33 samples.
Sulfate (Hygiene): Did not exceed 250 mg/L in three samples; estimated not to have exceeded 250 mg/L in three samples.
Fluoride (excluding Hygiene): Determined in 14 samples; did not exceed 2.0 mg/L in 13 samples.
Fluoride (Hygiene): Determined in three samples; did not exceed 2.0 mg/L.
Chloride (excluding Hygiene): Determined in 47 samples; did not exceed 250 mg/L in 45 samples.
Chloride (Hygiene): Determined in six samples; did not exceed 250 mg/L.
Nitrite plus nitrate (excluding Hygiene): Determined in 47 samples; did not exceed 10 mg/L as nitrogen in 33 samples.

Nitrite plus nitrate (Hygiene): Determined in six samples; did not exceed 10 mg/L as nitrogen.
Detergents (excluding Hygiene): Determined in 12 samples; detected in 4 samples; exceeded 0.5 mg/L in 1 of the 4 samples.
Detergents (Hygiene): Determined in three samples; detected in one sample.
Hardness (excluding Hygiene): Exceeded 180 mg/L in 10 of 14 samples; estimated to have exceeded 180 mg/L in 25 of 33 samples.
Hardness (Hygiene): Exceeded 180 mg/L in two of three samples; estimated to have exceeded 180 mg/L in three samples.
Trace elements (excluding Hygiene): Determined in 14 samples; iron exceeded 300 µg/L in 2 samples; manganese exceeded 50 µg/L in 5 samples; selenium exceeded 10 µg/L in 2 samples.
Trace elements (Hygiene): Determined in three samples; manganese exceeded 50 µg/L in one sample.
Bacteria (excluding Hygiene): Determined in 47 samples; more than 1 coliform bacterium was present in 11 samples; 1 or more fecal-coliform bacteria were present in 3 of the 11 samples.
Bacteria (Hygiene): Determined in six samples; more than 1 coliform bacterium and 1 or more fecal-coliform bacteria were present in one sample.
Radiochemicals (excluding Hygiene): Determined in 13 samples; gross alpha radiation was excessive in 3 samples.
Radiochemicals (Hygiene): Determined in three samples; not excessive.

Dakota Aquifer

Based on three complete and three indicator analyses, water in the Dakota aquifer generally is suitable for use as a water supply, although excessive concentrations of hardness are a problem. Excessive concentrations of dissolved solids, trace elements, and bacteria are problems locally. Water-quality characteristics are summarized below:

Dissolved solids: Exceeded 500 mg/L in two of three samples; estimated not to have exceeded 500 mg/L in three samples.
Magnesium: Did not exceed 125 mg/L in three samples; estimated not to have exceeded 125 mg/L in three samples.
Sulfate: Did not exceed 250 mg/L in two of three samples; estimated not to have exceeded 250 mg/L in three samples.
Fluoride: Determined in three samples; exceeded 2.0 mg/L in one sample.
Chloride: Determined in six samples; did not exceed 250 mg/L.
Nitrite plus nitrate: Determined in six samples; did not exceed 10 mg/L as nitrogen.
Detergents: Determined in three samples; detected in one sample.
Hardness: Exceeded 180 mg/L in two of three samples; estimated to have exceeded 180 mg/L in three samples.
Trace elements: Determined in three samples; iron exceeded 300 µg/L in one sample; iron exceeded 300 µg/L and manganese exceeded 50 µg/L in one sample.
Bacteria: Determined in six samples; more than 1 coliform bacterium was present in three samples; 1 or more fecal-coliform bacteria were present in two of the three samples.
Radiochemicals; determined in three samples; not excessive.

Morrison-Ralston Creek-Lykins Aquifer

Based on one complete and two indicator analyses, water in the Morrison-Ralston Creek-Lykins aquifer probably is suitable for use as a drinking-water supply, although excessive concentrations of hardness may be a problem locally. Water-quality characteristics are summarized below:

Dissolved solids: Did not exceed 500 mg/L in one sample; estimated not to have exceeded 500 mg/L in two samples.
Magnesium: Did not exceed 125 mg/L in one sample; estimated not to have exceeded 125 mg/L in two samples.
Sulfate: Did not exceed 250 mg/L in one sample; estimated not to have exceeded 250 mg/L in two samples.
Fluoride: Determined in one sample; did not exceed 2.0 mg/L.
Chloride: Determined in three samples; did not exceed 250 mg/L.
Nitrite plus nitrate: Determined in three samples; did not exceed 10 mg/L as nitrogen.
Detergents: Determined in one sample; not detected.
Hardness: Exceeded 180 mg/L in one sample; estimated to have exceeded 180 mg/L in one of two samples.
Trace elements: Determined in one sample; not excessive.
Bacteria: Determined in three samples; not excessive.
Radiochemicals: Determined in one sample; not excessive.

Lyons-Fountain Aquifer

Based on 6 complete and 14 indicator analyses, water in the Lyons-Fountain aquifer generally is suitable for use as a drinking-water supply, although excessive concentrations of hardness are a problem. Excessive concentrations of dissolved solids, sulfate, and bacteria are problems locally. Water-quality characteristics are summarized below:

Dissolved solids: Did not exceed 500 mg/L in 4 of 6 samples; estimated not to have exceeded 500 mg/L in 11 of 14 samples.
Magnesium: Did not exceed 125 mg/L in 6 samples; estimated not to have exceeded 125 mg/L in 14 samples.
Sulfate: Did not exceed 250 mg/L in 5 of 6 samples; estimated not to have exceeded 250 mg/L in 11 of 14 samples.
Fluoride: Determined in six samples; did not exceed 2.0 mg/L.
Chloride: Determined in 20 samples; did not exceed 250 mg/L.
Nitrite plus nitrate: Determined in 20 samples; did not exceed 10 mg/L as nitrogen.
Detergents: Determined in six samples; detected in one sample.
Hardness: Exceeded 180 mg/L in 3 of 6 samples; estimated to have exceeded 180 mg/L in 10 of 14 samples.

Trace elements: Determined in six samples; not excessive.

Bacteria: Determined in 20 samples; more than 1 coliform bacterium was present in 4 samples; 1 or more fecal-coliform bacteria were present in 2 of the 4 samples.

Radiochemicals: Determined in six samples; not excessive.

Crystalline-Rock Aquifer

Based on 20 complete and 151 indicator analyses, water in the crystalline-rock aquifer generally is suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids, sulfate, hardness, trace elements, bacteria, and radiochemicals are problems locally. Water-quality characteristics are summarized below:

Dissolved solids: Did not exceed 500 mg/L in 16 of 20 samples; estimated not to have exceeded 500 mg/L in 130 of 151 samples.

Magnesium: Did not exceed 125 mg/L in 20 samples; estimated not to have exceeded 125 mg/L in 150 of 151 samples.

Sulfate: Did not exceed 250 mg/L in 18 of 20 samples; estimated not to have exceeded 250 mg/L in 137 of 151 samples.

Fluoride: Determined in 20 samples; did not exceed 2.0 mg/L in 17 samples.

Chloride: Determined in 168 samples; did not exceed 250 mg/L in 167 samples.

Nitrite plus nitrate: Determined in 169 samples; did not exceed 10 mg/L as nitrogen in 165 samples.

Detergents: Determined in 17 samples; detected in 3 samples.

Hardness: Did not exceed 180 mg/L in 14 of 20 samples; estimated not to have exceeded 180 mg/L in 88 of 151 samples.

Trace elements: Determined in 20 samples; iron exceeded 300 µg/L in 1 sample; manganese exceeded 50 µg/L in 5 samples; mercury exceeded 0.2 µg/L in two samples; zinc exceeded 5,000 µg/L in 1 sample. Standards for both iron and manganese were exceeded in three samples.

Bacteria: Determined in 171 samples; more than 1 coliform bacterium was present in 33 samples; 1 or more fecal-coliform bacteria were present in 9 of the 33 samples.

Radiochemicals: Determined in 18 samples; gross alpha radiation was excessive in 2 samples; radium-226 was excessive in 1 sample; gross beta radiation was excessive in 1 sample.

Factors Affecting Ground-Water Quality

The quality of ground water in Boulder County varies widely as indicated in table 10. Much of this variation is due to the physical and chemical properties of the different aquifers. The quality of water in the aquifers may be degraded as a result of the activities of man. The inadequate treatment of sewage by individual sewage-treatment systems is a potential cause of degradation in ground-water quality. The quality of water pumped from the aquifers can be further affected as a result of well location, construction, and maintenance.

Aquifer Characteristics

The three types of aquifers (unconsolidated-rock, sedimentary-rock, and the crystalline-rock) have been previously described in this report in terms of physical properties that relate to the capability of each aquifer to yield water to wells, to store water, and to transmit water. Many of these properties also relate to the quality of water produced from these aquifers and to the degree of natural protection from degradation that they may receive. The minerals present in the aquifers also will affect the quality of water produced.

Water-table aquifers (such as the unconsolidated-rock, the crystalline-rock, the weathered Pierre-Niobrara-Benton, and part of the Laramie-Fox Hills) are generally recharged through direct infiltration of precipitation from land surface to the water table, or through direct contact with streamflow. The quality of the recharging water will have a direct impact on the ground-water quality. If recharge water is degraded, an adverse impact on the aquifer may result. The water in these aquifers will generally move from west to east. The rate of water movement will be controlled by aquifer properties such as grain size, degree of grain-size uniformity, and number and size of fractures. Water may move more slowly where the grain size is small, as in eolian deposits, and where the grain size is highly variable, as in glacial and valley-fill deposits. Water may move more rapidly through the fractures that occur in crystalline rocks, and through material of larger and more uniform grain size, as in flood-plain and terrace aquifers. The water may chemically interact with the aquifers during such movement, depending on both the chemical characteristics of the water and the aquifer materials. Soluble minerals in the aquifer may be dissolved and other chemical reactions may occur. If the water moves slowly, larger concentrations of the soluble minerals may be dissolved because of the longer reaction time. The crystalline rocks appear to contribute the smallest amounts of dissolved solids to ground water, while the Pierre-Niobrara-Benton aquifer contributes the largest amount.

The Laramie-Fox Hills is the only artesian aquifer that is extensively used in Boulder County. As shown previously (fig. 7), only part of the area of use of this aquifer is under artesian pressure. In this area, recharge does not occur locally, but to the south and west in the area of outcrop. The relatively impermeable layer between the land surface and the aquifer affords some local protection from effluent from individual sewage-treatment systems.

These varying physical and chemical properties contribute to water-quality differences among the aquifers. These differences are apparent in all the constituents analyzed as part of the indicator analysis and in many of the constituents analyzed as part of the complete analyses.

Individual Sewage-Treatment Systems

Many areas of Boulder County do not have municipal sewage-treatment facilities. Where such municipal treatment is not available, some form of individual waste treatment and disposal is used. Information about waste disposal was collected at each well and spring site (Hall and others, 1979). At about 5 percent of the sites, wastes were disposed of through municipal sewer systems. At about 95 percent of those sites with individual sewage treatment, septic tanks and leach fields were used for sewage treatment and disposal; privies, aerobic-treatment systems, or chemical or electric toilets were used at the other 5 percent of the sites.

Under ideal conditions, septic systems can be a viable method of sewage treatment and disposal. Waste material flows into the septic tank, where heavier solids settle out, and fatty substances rise to the surface. Bacteria slowly digest the wastes and convert the wastes to simple chemical compounds. Sludge and scum are retained in the septic tank as the effluent flows out and into the leach field. Digestion of organic pollutants by bacteria continues in the leach field, where, in the presence of oxygen, protozoa prey on the bacteria, keeping the soil pores open. With the soil pores open, the effluent filters down through the unsaturated soil with removal of bacteria occurring in the first few feet. By the time the effluent reaches the water table, removal of the bacteria and digestion of complex organic material should be complete, so only simple chemical compounds--such as nitrate and chloride--remain, which are diluted by the ground water.

Several factors can interfere with proper functioning of the septic-tank leach-field systems, resulting in ground-water-quality degradation. They are: Density of sewage-treatment systems, inadequate soil thickness and permeability, shallow water table, and improper use and maintenance.

Density of Sewage-Treatment Systems

The septic-tank leach-field systems were originally designed for use at isolated rural homes (McGauhey, 1975). However, today these systems are used in areas with greater housing densities, as in small towns without municipal sewage-treatment facilities and in some suburban subdivisions. Where the density of systems is great, ground-water degradation may occur, as the result of the larger quantity of digested waste that the ground water may not dilute to satisfactory levels even if each individual system is operating properly. This type of degradation would generally affect an area larger than the immediate vicinity of an individual leach field. Chloride and nitrate are two constituents that can be used to monitor this effect, because they usually occur in leach-field effluent in greater concentrations than in the ground water itself. In areas where the well and the septic system use different aquifers which are separated from each other by a relatively impermeable layer, density of septic systems should be unrelated to well-water quality, assuming proper well construction.

Because of the complexity of the hydrology, no simple relation was determined between ground-water quality and density of individual sewage-treatment systems. Estimates of the density of individual sewage-treatment systems that will not cause degradation of ground-water quality need to be made on a case-by-case basis with full consideration of hydrologic, geologic, soil, and water-quality conditions. The chloride and nitrate maps presented in this report (figs. 13A and 13B; 14A and 14B) may be used as a starting point for this type of evaluation.

Inadequate Soil Thickness and Permeability

For adequate treatment of septic-tank effluent, the soil should be thick enough to allow complete filtration and digestion of the wastes by bacteria before bedrock or the water table is encountered. In addition, the soil must be permeable enough to allow the effluent to pass through, but not so permeable that wastes pass through without complete treatment. Moreland and Moreland (1975) have mapped the soils of Boulder County and have tabulated soil limitations for use as leach fields. This information, along with percolation tests, should aid in deciding the suitability of any soil to treat effluent from septic tanks.

Shallow Water Table

A shallow water table can interfere with proper functioning of a leach field by causing anaerobic conditions, in which bacteria may clog the soil pores, resulting in failure of the system. Problems also may occur if the water table is just below the bottom of the leach field. In this instance, no unsaturated soil exists below the leach field and little or no removal of bacteria will occur. The bacteria are then introduced directly into the saturated ground-water zone, where they are much more mobile than in the unsaturated zone. Franks (1972) states that in saturated coarse-textured soils, coliform bacteria can move more than 200 ft before being reduced to acceptable levels.

The relation between depth to water and occurrence of coliform bacteria in well water is shown in figure 17. Coliform bacteria were present in water from less than 15 percent of the wells where the depth to water was 40 ft or more. Coliform bacteria were present in water from about 25 to 45 percent of the wells where the depth to water was 10 ft or less. Depth to the water table generally is 10 ft or less in about one-third of the plains (fig. 18). Such areas are the most susceptible to bacterial contamination from individual waste-treatment systems that are functioning improperly.

Because the water-level measurements used to construct figure 17 were made at different times of the year, they may not accurately show the seasonal high water table. In irrigated areas the seasonal high water table may occur during the irrigation season. The seasonal high water table is a critical factor in the proper design and siting of leach fields. Moreland and Moreland (1975) mapped the seasonal high water table from soil profiles. Their data, although more detailed, show the same general areas of shallow water table as shown in figure 18.

Improper Use and Maintenance

Septic-tank leach-field systems will fail if they are improperly used or maintained. A major cause of failure is overloading of the system. During overloading,

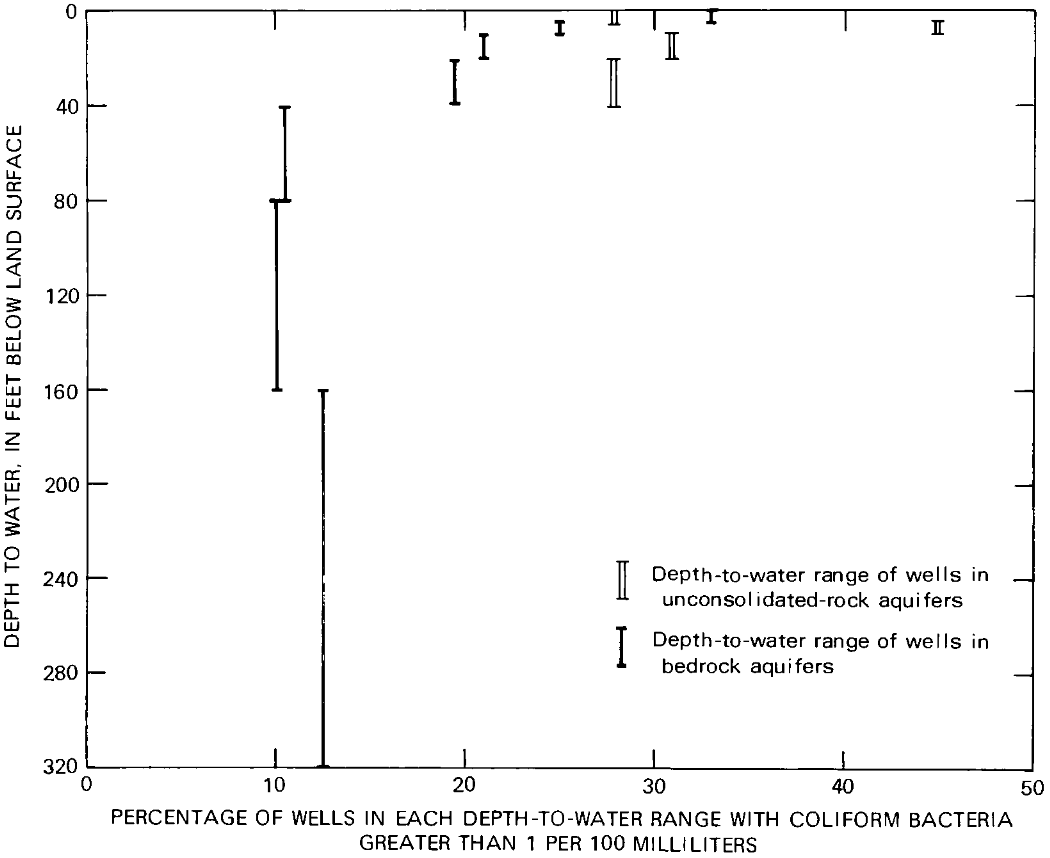


Figure 17.--Relation between depth to water and occurrence of coliform bacteria in well water.

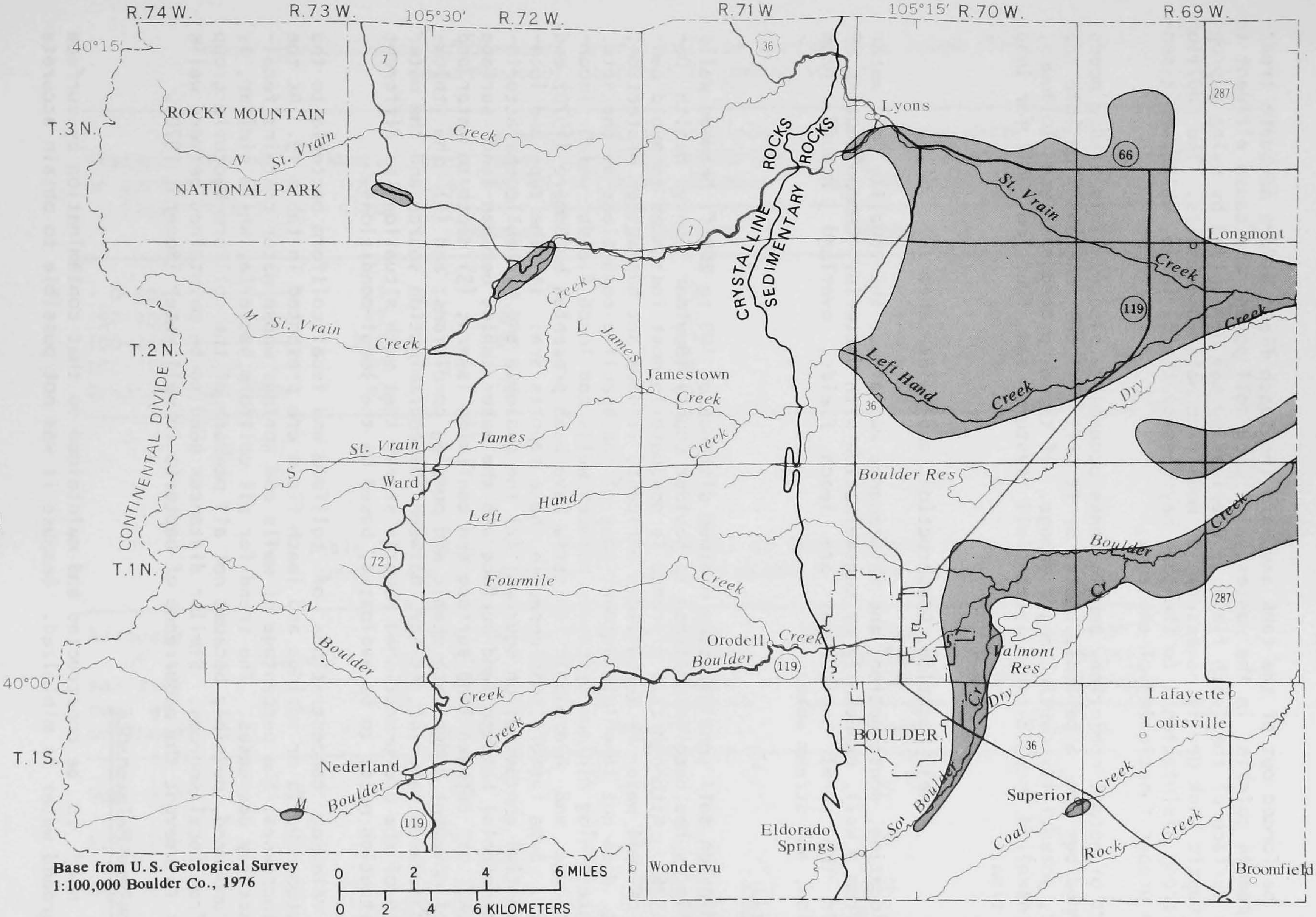


Figure 18.--Areas of shallow water table where depth to water is 10 feet or less below land surface (shaded). (Smaller areas of shallow ground water may occur along stream valleys).

wastes will be forced out of the tank and into the leach field before adequate treatment. Suspended material in the wastes will clog soil pores and cause effluent to rise to the surface of the leach field. Overloading may be avoided by using a properly sized septic tank or, if necessary, by modifying water-use habits. The addition of lye or strong disinfectants to the tank may destroy the bacteria, which are essential to the proper functioning of the tank.

As part of normal operation, septic tanks accumulate sludge. This sludge needs to be pumped out on a periodic basis, or it will fill the tank and flow into the leach field, potentially causing major damage. If these procedures are followed, properly installed septic-tank leach-field systems can function well for long periods of time.

Well Location, Construction, and Maintenance

Well location, construction, and maintenance may affect the quality of water produced from a well, especially by contamination with bacteria. Common sources of bacteria in the rural environment are leach fields, overland runoff from precipitation, and stream water.

Well Location

Depending on soil conditions, a minimum distance of 100 to 200 ft between wells and leach fields has been established in Boulder County (Boulder County Health Department, 1976). Although this distance is adequate in most instances to avoid contamination of well water by leach-field effluent, it does not guarantee protection, because it does not take into account many of the specific conditions at the site. Ways for determining minimum distances between wells and leach fields which incorporate geologic and hydrologic criteria have been presented by Romero (1970) and Waltz (1972). Some factors considered in these reports are: (1) The type and location of potential contamination sources; (2) the geologic and hydraulic characteristics of the material between land surface and the water table, between land surface and bedrock, or between land surface and confining layers; (3) depth to water and direction of movement under both static and pumping conditions; and (4) the thickness of unsaturated material, if any, between the contamination source and the water table. Both of the above-mentioned reports stress that each situation is different and each situation needs to be evaluated, based on the local conditions.

Data relating concentrations of coliform and fecal-coliform bacteria to the distance between wells or springs and leach field are presented in table 19. As the distance increases, the percentage of wells and springs whose water contains fecal-coliform bacteria decreases. The trend for all coliform bacteria, while similar, is not as pronounced, possibly because not all members of the coliform-bacteria group originate from fecal sources. Similar distances need to be maintained between wells and streams to prevent the occurrence of bacteria in well water (Romero, 1970).

Construction and Maintenance

Wells need to be constructed and maintained so that contamination by surface runoff or ground water is minimized. Because it was not possible to obtain accurate

Table 19.--*Relation of distance from a well or spring to a leach field and occurrence of bacteria in ground water*

Distance from well or spring to leach field (feet)	Number of sites	Sites where water contained more than 1 coliform bacterium per 100 milliliters of water		Sites where water contained 1 or more fecal-coliform bacteria per 100 milliliters of water	
		Number	Percent	Number	Percent
0-50------------	21	6	29	3	14
50-100-----------	47	14	30	6	13
100-200-----------	222	69	31	20	9
200-300-----------	60	13	22	1	2
Greater than 300--	49	6	12	2	4

Table 20.--*Relation of sanitary seal at the wellhead to occurrence of bacteria in water produced from the well*

Adequacy of sanitary seal at wellhead[1]	Number of sites	Sites where water contained more than 1 coliform bacterium per 100 milliliters of water		Sites where water contained 1 or more fecal-coliform bacteria per 100 milliliters of water	
		Number	Percent	Number	Percent
Good-----	265	49	18	15	6
Poor-----	89	41	46	10	11
None-----	47	22	47	11	23

[1] See text for discussion.

data from wellowners on well-construction practices, such as drilling method, casing, and grouting, no data are presented here regarding the effect of these factors on water quality in Boulder County. However, Whitsell and Hutchinson (1973) summarized information from studies in three other States with the following conclusions: Jetted, driven, and drilled wells are easier to protect from bacterial contamination than dug wells; a water-tight casing and a grout seal between the casing and the wall of the drill hole decrease the likelihood of bacterial contamination.

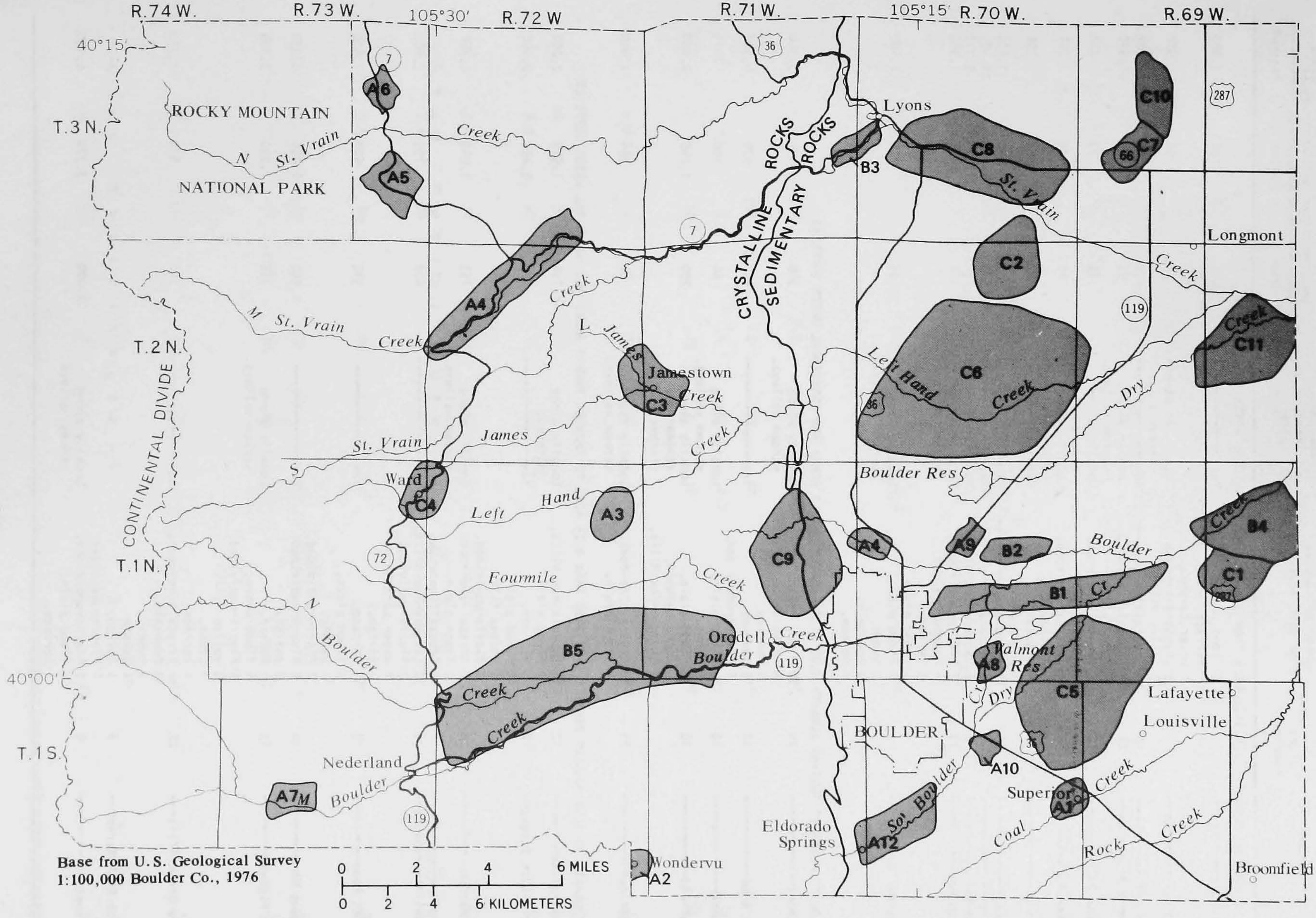
Surface runoff may be directed away from the well by installing a grout seal between the casing and the wall of the drill hole, extending the well casing above ground level, contouring the well site so that water drains away from the well in all directions, and sealing the top of the well casing to exclude any contaminants. The condition of the seal at the top of wells sampled in Boulder County was noted at the time of sample collection (Hall and others, 1979). The seal was categorized as follows: "Good," the seal was adequate in all respects; "poor," an inadequate seal was in place; and "none," the top of the well was open. The data in table 20 illustrate the effectiveness of the seal in preventing bacterial contamination.

Ground-Water Quality of Selected Areas

Residential development has increased significantly in selected areas of the county (fig. 19). To determine if the increased development has affected ground-water quality in the areas, additional samples for water-quality analysis were collected. Results of the water-quality analyses are summarized in table 21 by areas, categorized according to housing density and source of drinking-water supply. These data indicate that all of the areas have at least some water-quality problems and many of the areas appear to have widespread water-quality problems. The areas with widespread water-quality problems are tabulated in table 22 and the problem or problems in each area are indicated.

Long-Term Trends in Ground-Water Quality

During the current study, 34 of the wells and springs in the southeastern part of the county sampled during 1956-60 (Jenkins, 1961) were resampled to determine if long-term changes in ground-water quality had occurred. Resampled wells and springs and specific-conductance data for the two samplings are listed in table 23. Specific conductance increased by more than 20 percent in 10 wells and 1 spring, indicating a deterioration in water quality since 1960 (wells C44, C69, 359, 362, and C89 completed in the Laramie-Fox Hills aquifer; wells C73 and C84 completed in the terrace aquifer; wells 116 and 156 completed in the crystalline-rock aquifer; well C81 completed in the Pierre-Niobrara-Benton aquifer (Hygiene Sandstone Member); and spring C63 flowing from the Pierre-Niobrara-Benton aquifer). However, the data do not indicate that the deterioration in water quality is widespread, involving entire aquifers or geographic areas. Specific conductance decreased by more than 20 percent in water samples from 6 wells (wells C77, 446, C68, and 656 completed in the flood-plain aquifer; well C90 completed in the eolian aquifer; and well C75 completed in the Laramie-Fox Hills aquifer). Data for other constituents may be found in tables 3, 4, and 5 of the report by Jenkins (1961) and in Hall, Boyd, and Cain (1979).



Base from U.S. Geological Survey
1:100,000 Boulder Co., 1976

Figure 19.--Location of selected areas that were intensively sampled to determine ground-water quality (see table 21 for names of the areas).

Table 21.--*Summary of hydrologic and ground-water-quality*

Area number on fig. 19	Area name	Number of sites sampled	Number of samples from each aquifer	Shallow water table	Specific conductance (micromhos per centimeter at 25°C)		
					Minimum	Median	Maximum
AREAS WITH HIGH HOUSING DENSITY (LOT SIZE LESS THAN 1 ACRE) AND INDIVIDUAL WATER SUPPLIES							
A1	Superior-----------	11	9 Flood plain, 1 terrace, 1 upper Laramie.	Yes--------------	440	760	3,590
A2	Wondervu-----------	5	3 Crystalline-rock, 2 valley fill.	Locally in stream valleys.	54	195	510
A3	Gold Hill----------	10	10 Crystalline-rock---	No---------------	150	243	285
A4	Raymond-Riverside--	21	17 Crystalline-rock, 4 flood plain.	Locally along stream valleys.	33	80	1,510
A5	Allens Park--------	12	8 Crystalline-rock, 4 flood plain.	Locally along stream valleys.	25	73	328
A6	Meeker Park--------	5	4 Crystalline-rock, 1 glacial.	Locally along stream valleys.	60	180	254
A7	Eldora-------------	15	14 Glacial, 1 flood plain.	Yes--------------	52	157	795
A8	Gapter-------------	13	13 Flood plain--------	Yes--------------	207	480	1,000
A9	Juhls--------------	8	8 Terrace------------	Yes--------------	540	1,220	25,400
A10	Mesa-Valley--------	6	6 Laramie-Fox Hills--	No---------------	1,250	1,715	3,270
A11	North Boulder------	13	5 Pierre-undivided, 4 Pierre-Hygiene, 3 terrace, 1 flood plain.	Locally along stream valleys.	480	640	1,550
A12	Eldorado Springs---	13	7 Flood plain, 3 Lyons, 2 Fountain, 1 Dakota.	Locally along stream valleys.	105	225	2,400
AREAS WITH LOW TO MODERATE HOUSING DENSITY (LOT SIZE GREATER THAN 1 ACRE) AND INDIVIDUAL WATER SUPPLIES							
B1	Valmont------------	26	20 Flood plain, 5 Laramie-Fox Hills, 1 terrace.	Locally along stream valleys.	340	694	3,360
B2	Jay Road-----------	10	9 Terrace, 1 Pierre-undivided.	Yes--------------	487	970	4,500
B3	Lyons--------------	16	13 Flood plain, 3 Lyons.	Locally along stream valleys.	66	100	415
B4	Canfield-----------	18	13 Flood plain, 3 upper Laramie, 1 Laramie-Fox Hills, 1 terrace.	Locally along streams and ditches.	700	1,265	2,800
B5	Sugarloaf----------	24	20 Crystalline-rock, 4 flood plain.	Locally along stream valleys.	80	368	1,440
AREAS WITH MODERATE TO HIGH HOUSING DENSITY (LOT SIZE FROM 0.25 ACRE TO GREATER THAN 1 ACRE) AND MUNICIPAL WATER SUPPLIES							
C1	Brownsville--------	12	10 Laramie-Fox Hills, 2 flood plain.	Locally along ditches.	794	1,575	2,200
C2	North 65th Street--	10	5 Terrace, 2 flood plain, 1 valley fill, 2 Pierre-undivided.	Yes--------------	800	3,150	6,060
C3	Jamestown----------	6	4 Crystalline-rock, 2 flood plain.	Locally along stream valleys.	153	1,040	1,350
C4	Ward---------------	2	2 Crystalline-rock,	---INSUFFICIENT DATA---			
C5	Baseline-Arapahoe--	36	32 Laramie-Fox Hills, 2 Pierre-undivided, 1 upper Laramie, 1 eolian.	No---------------	400	795	3,500
C6	Niwot Road---------	18	13 Terrace, 3 flood plain, 1 Dakota, 1 Pierre-undivided.	Yes-------------	318	650	7,800
C7	Anhawa Manor-------	10	8 Pierre-undivided, 2 eolian.	Yes-------------	1,400	6,050	8,050
C8	Ute Highway--------	15	4 Eolian, 4 flood plain, 3 Pierre-undivided, 2 valley fill, 1 Lyons, 1 terrace.	Locally along stream valleys.	185	1,290	3,800
C9	Pine Brook Hills---	22	16 Crystalline-rock, 3 Fountain, 2 Lyons, 1 Dakota.	No---------------	160	610	1,730
C10	North 95th Street--	2	1 Eolian, 1 Pierre-undivided.	---INSUFFICIENT DATA---			
C11	Prospect-----------	4	2 Pierre-undivided, 1 flood plain, 1 terrace.	Locally along stream valleys.	2,000	3,370	6,100

data for selected developed areas

Dissolved chloride (milligrams per liter)			Dissolved nitrite plus nitrate (milligrams per liter)			Percentage of samples containing	
Minimum	Median	Maximum	Minimum	Median	Maximum	More than 1 coliform bacterium per 100 milliliters of water	1 or more fecal-coliform bacteria per 100 milliliters of water
7.0	17	200	0.13	1.2	13	60	10
.8	16	110	.13	2.6	5.0	20	0
1.8	12	15	.07	4.4	9.6	30	20
.6	2.0	25	.00	.07	3.1	24	0
.4	.95	12	.01	.10	1.7	25	17
1.2	2.8	11	.00	.04	4.6	20	0
.3	1.7	36	.17	.75	5.0	7	7
2.6	11	54	.01	1.4	6.3	46	15
7.2	27	1,100	.08	22	73	63	25
5.3	8.7	170	.32	1.1	9.1	17	0
5.3	25	97	.20	3.1	4.6	31	15
.8	3.0	61	.18	.66	6.3	38	15
3.4	11.5	67	0.9	0.94	17	54	8
3.0	9.1	390	.2	.39	42	60	20
1.1	2.2	6.2	.4	.37	6.7	19	0
6.3	13	50	.19	2.3	18	18	12
1.0	4.0	39	.01	.38	13	13	4
8.0	16	37	0.12	1.3	11	45	0
2.6	8.2	47	.12	.73	15	30	10
.2	5.8	11	.00	.07	7.5	33	17
----INSUFFICIENT DATA----							
3.0	7.4	84	.1	.47	11	11	0
1.7	3.5	89	.06	1.6	16	22	22
1.4	42	260	.98	18	85	0	0
1.9	7.8	73	.00	.82	23	13	7
1.5	6.5	200	.01	.92	14	14	5
----INSUFFICIENT DATA----							
20	29	93	2.9	19	35	25	25

Table 22.--*Summary of ground-water-quality problems in selected developed areas*

Area number on fig. 19	Area name	Excessive values of specific conductance	Excessive concentrations of dissolved chloride	Excessive concentrations of dissolved nitrite plus nitrate	Large percentage of wells with	
					More than 1 coliform bacterium per 100 milliliters of water	1 or more fecal-coliform bacteria per 100 milliliters of water
A1	Superior----------	-	X	X	X	-
A2	Wondervu----------	-	X	X	-	-
A3	Gold Hill---------	-	X	X	-	X
A5	Allens Park--------	-	-	-	-	X
A7	Eldora------------	-	-	X	-	-
A8	Gapter------------	-	-	X	X	X
A9	Juhls-------------	-	X	X	X	X
A10	Mesa Valley--------	-	-	X	-	-
A11	North Boulder------	-	X	X	-	X
A12	Eldorado Springs---	-	-	-	X	X
B1	Valmont-----------	-	-	X	X	-
B2	Jay Road----------	-	-	-	X	X
B4	Canfield----------	-	-	X	-	-
C1	Brownsville--------	-	-	X	X	-
C2	North 65th Street--	X	-	-	-	-
C3	Jamestown---------	-	-	-	-	X
C6	Niwot Road---------	-	-	X	-	X
C7	Anhawa Manor-------	X	X	X	-	-
C9	Pine Brook Hills---	-	-	X	-	-
C11	Prospect----------	X	X	X	-	X

Table 23.--*Comparison between specific conductance measured during 1956-60 and during this study*

Site number on plate 1	Local well number	First measurement		Second measurement	
		Date (M-Y)	Specific conductance (micromhos per centimeter at 25°C)	Date (M-Y)	Specific conductance (micromhos per centimeter at 25°C)
C44	SB00106907AAAA---	11-59	909	2-76	1,300
C77	SB00106916BCBC---	6-59	753	4-76	460
403	SB00106919DABB---	9-59	3,000	9-76	3,360
458	SB00107005BCDA---	8-59	500	9-76	520
C73	SB00107018DBAD---	-----	624	3-76	779
446	SB00107022DBDD---	9-59	700	9-76	580
C68	SB00107024BAAC---	9-59	933	3-76	700
480	SB00107024DBCB---	9-58	600	10-76	620
C67	SB00107028DCAD---	-----	893	3-76	950
439	SB00107028DCCD---	8-59	750	9-76	850
506	SB00107034DCDC---	-----	220	10-76	207
116	SB00107105BDAA---	8-59	210	7-76	310
157	SB00107107BAAB---	4-58	375	8-76	400
C15	SB00107113DABC---	-----	525	7-76	550
156	SB00107115CBCA---	8-59	310	8-76	495
C81	SB00107124ADBA---	12-56	340	5-76	460
C74	SB00206920DBCD---	10-59	1,100	3-76	975
C90	SB00207001DBCD---	4-60	2,000	7-76	1,400
C91	SB00207007BABA[a]--	5-60	1,100	7-76	1,310
C84	SB00207008CDCB---	-----	290	7-76	552
656	SB00207019BACA---	7-59	500	10-76	279
C80	SB00207129DABA[a]--	8-59	3,840	5-76	3,910
C63	SB00207136AADC[a]--	10-56	1,100	3-76	1,525
C65	SC00106917BCAD---	4-59	1,200	7-76	1,120
C69	SC00107001AABD---	7-59	625	3-76	1,050
381	SC00107001CAAB---	7-59	925	9-76	1,100
359	SC00107002CDCD---	7-59	900	8-76	1,300
362	SC00107010DCBC---	-----	800	8-76	1,430
C75	SC00107012AADA---	7-59	1,160	3-76	790
C76	SC00107012ABAA---	6-59	431	3-76	435
C70	SC00107012ACCC---	11-59	619	3-76	500
C89	SC00107021BDAB---	8-59	220	7-76	690
339	SC00107027DBCD[a]--	8-59	350	8-76	320
C83	SC00107112DACD[a]--	8-59	534	7-76	490

[a] Spring or flowing well.

SUMMARY

Mean annual precipitation in Boulder County varies from less than 16 in. in the plains to more than 40 in. in the mountains. The mean annual precipitation of 18.6 in. produces about 840,000 acre-ft of water--about 252,000 acre-ft in the plains and about 588,000 acre-ft in the mountains. An estimated 247,000 acre-ft of water flows from the mountains to the plains. Most of the remaining 341,000 acre-ft that falls as precipitation in the mountains is returned to the atmosphere by evapotranspiration. About 550,000 acre-ft of water enters the plains from precipitation, streamflow from the mountains, and transbasin diversions. About 154,000 acre-ft of water flows out of the county each year. Most of the difference, about 396,000 acre-ft per year, is returned to the atmosphere by evapotranspiration.

Unconsolidated-rock, sedimentary-rock, and crystalline-rock aquifers occur in the county. The unconsolidated-rock aquifers, which are generally less than 30 ft but may be as much as 50 ft thick, overlie sedimentary-rock aquifers in the eastern part of the county and overlie crystalline-rock aquifers in the western part of the county. In the eastern part of the county, the unconsolidated-rock aquifers include valley-fill, eolian, and alluvial deposits. In the western part of the county, the unconsolidated-rock aquifers include glacial deposits and some valley-fill and alluvial deposits.

Sedimentary-rock aquifers, which occur only in the eastern part of the county and crop out in north-to-northeast trending bands, consist of interbedded siltstones, claystones, shales, sandstones, or limestones. Because the strata are steeply dipping and the Pierre Shale is about 8,000 ft thick, formations older than the Pierre are considered to be aquifers only where they crop out along the mountain front. The Laramie-Fox Hills, the principal sedimentary-rock aquifer, occurs in the southeastern part of the county.

The crystalline-rocks function as an aquifer only in the mountains where the rocks have been fractured. Generally, the openings of the fractures (joints and faults) decrease in size with increasing depth, and chances of obtaining water generally decrease significantly below a depth of 300 ft.

Water levels measured in 19 wells during 1954-60 were remeasured in 1976-77 to determine any changes. Water levels in 1976-77 generally were about the same as in 1954-60. The ground-water system in the county is probably in a state of equilibrium; recharge to the system equals discharge from the system.

In the county, water-table conditions predominate in the unconsolidated-rock aquifers, in the sedimentary-rock aquifers where they are at or near the land surface, and in the crystalline-rock aquifer. Artesian conditions predominate in the sedimentary-rock aquifers in localities where they are overlain by relatively impermeable material.

A water-table map of the shallow aquifers in the eastern part of the county indicates that streams receive water from the aquifers and that the regional direction of water movement is to the east.

The Laramie-Fox Hills aquifer is the principal artesian aquifer in the county. Artesian conditions exist in a 50-mi^2 part of the aquifer in the southeastern corner of the county. The direction of flow in the artesian part of the aquifer generally is to the northeast and east.

All aquifers in the county will yield sufficient quantities of water for domestic supplies (1 or more gal/min). Yields sufficient for domestic supplies are most difficult to obtain from the crystalline-rock aquifer; those sedimentary-rock aquifers consisting principally of siltstone, claystone, or shale, such as the Arapahoe, upper Laramie, and Pierre-Niobrara-Benton aquifers; and valley-fill and eolian aquifers.

Supplies sufficient for community water systems and commercial enterprises (15 or more gal/min) may be obtained from the flood-plain, terrace, glacial, Laramie-Fox Hills, Dakota, and Morrison-Ralston Creek-Lykins aquifers. Generally, the largest yields will be obtained from the flood-plain, terrace, and Laramie-Fox Hills aquifers.

Supplies sufficient for large-scale urban development and irrigation (100 or more gal/min) may be obtained from the flood-plain aquifer. Supplies sufficient for these purposes also may be obtainable from the terrace and Laramie-Fox Hills aquifers. Increased withdrawal of water from the aquifers could result in decreased streamflow.

The amount of water flowing out of the county from the unconsolidated-rock aquifers was estimated to be 6,900 acre-ft per year. The amount of water flowing out of the county from the Laramie-Fox Hills aquifer was estimated to be 350 acre-ft per year.

The quality of streamflow in the county generally is suitable for municipal water supplies. Contamination by major ions (fluoride or sulfate) occurred in Little James Creek and in the easternmost reaches of Left Hand Creek, St. Vrain Creek, Dry Creek (St. Vrain Creek basin), Dry Creek (Boulder Creek basin), and Rock Creek. Contamination by trace elements (iron, manganese, or selenium) occurred in James and Little James Creeks and in the easternmost reaches of Left Hand, St. Vrain, and Rock Creeks. Bacterial contamination was limited to Boulder and Fourmile Canyon Creeks. Gross alpha radiation may have been excessive in Little James Creek and in the easternmost reaches of Left Hand Creek, St. Vrain Creek, Dry Creek (St. Vrain Creek basin) and Coal Creek. Streamflow in Little James and Rock Creeks is the least suitable for municipal water supplies.

Manganese in Little James Creek was the only chemical constituent that exceeded water-quality standards for agricultural use. Concentrations of fecal-coliform bacteria exceeded the standard in Boulder and Fourmile Canyon Creeks. Gross alpha radiation may have been excessive in Little James Creek, and in the easternmost reaches of Left Hand Creek, St. Vrain Creek, Dry Creek (St. Vrain Creek basin), and Coal Creek.

Trace-element contamination with respect to aquatic-life standards was widespread, occurring in 12 of the 18 streams sampled. Contamination occurred by cadmium in 10 streams, by copper in 3 streams, by iron in 1 stream, by lead in 5 streams, by mercury in 4 streams, and by zinc in 3 streams. Gross alpha radiation may have been excessive in Little James Creek and in the easternmost reaches of Left Hand Creek, St. Vrain Creek, Dry Creek (St. Vrain Creek basin), and Coal Creek.

Water in the valley-fill aquifer in the mountains probably is suitable for use as a drinking-water supply although bacterial contamination is a problem locally. Water in the valley-fill aquifer in the plains generally is not suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids, sulfate, and hardness are problems. Excessive concentrations of trace elements and bacteria are problems locally.

Water in the eolian aquifer generally is not suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids, sulfate, and hardness are problems. Bacterial contamination is a problem locally.

Water in the flood-plain aquifer in the mountains generally is suitable for use as a drinking-water supply although bacterial contamination is a problem locally.

Water in the flood-plain aquifer in the plains generally is suitable for use as a drinking-water supply in areas just east of the mountain front. Suitability generally decreases toward the east. Water in the flood-plain aquifer along the eastern edge of the county generally is not suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids, sulfate, hardness, trace elements, bacteria, and radiochemicals are problems locally.

Water in the terrace aquifer generally is not suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids, sulfate, and hardness are problems. Excessive concentrations of magnesium, nitrite plus nitrate, bacteria, and radiochemicals are problems locally.

Water in the glacial aquifer generally is suitable for use as a drinking-water supply. Bacterial contamination is a problem locally.

Water in the Arapahoe and upper Laramie aquifers generally is not suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids and hardness are problems. Bacterial contamination is a problem locally.

Water in the Laramie-Fox Hills aquifer generally is suitable for use as a drinking-water supply in the southern and western parts of the area where recharge is significant. In other parts of the area, water in the aquifer generally is less suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids and hardness are problems. Excessive concentrations of magnesium, sulfate, trace elements, and bacteria are problems locally.

Water in the Pierre-Niobrara-Benton aquifer, with the exception of water in the Hygiene Sandstone Member of the Pierre, generally is not suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids, magnesium, sulfate, and hardness are problems. Excessive concentrations of nitrite plus nitrate, trace elements, bacteria, and radiochemicals are problems locally.

Water in the Dakota aquifer generally is suitable for use as a water supply although excessive concentrations of hardness are a problem. Excessive concentrations of dissolved solids, trace elements, and bacteria are problems locally.

Water in the Morrison-Ralston Creek-Lykins aquifer probably is suitable for use as a drinking-water supply. Excessive concentrations of hardness may be a problem locally.

Water in the Lyons-Fountain aquifer generally is suitable for use as a drinking-water supply although excessive concentrations of hardness are a problem. Excessive concentrations of dissolved solids, sulfate, and bacteria are problems locally.

Water in the crystalline-rock aquifer generally is suitable for use as a drinking-water supply. Excessive concentrations of dissolved solids, sulfate, hardness, trace elements, bacteria, and radiochemicals are problems locally.

The quality of ground water in Boulder County varies widely due to the physical and chemical properties of the different aquifers and the activities of man. Inadequate treatment of sewage by individual sewage-treatment systems also has caused ground-water degradation. The quality of water pumped from the aquifers may be affected by well location, construction, and maintenance.

Residential development has increased significantly in selected areas of the county. All areas have at least some water-quality problems and many areas appear to have widespread water-quality problems.

During the current study, 34 wells and springs in the southeastern part of the county sampled during 1956-60 were resampled to determine if long-term changes in ground-water quality had occurred. Specific conductance increased by more than 20 percent in 10 wells and 1 spring, indicating a deterioration in water quality since 1960. However, the data do not indicate that the deterioration in water quality is widespread, involving entire aquifers or geographic areas. Specific conductance decreased by more than 20 percent in water samples from six wells.

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GLOSSARY

Terms defined in the GLOSSARY are underscored when first used in the report.

aerobic.--Characterized by the presence of oxygen.

alluvial deposits.--Unconsolidated material consisting of moderately to well-sorted sand, gravel, and boulders with some silt and clay, deposited in valleys by streams, including flood-plain and terrace aquifers.

anaerobic.--Characterized by a lack of free oxygen.

aquifer.--A 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.

artesian aquifer.--An aquifer where the water level in a tightly cased well completed in the aquifer rises above the top of the aquifer. The water may or may not flow at the land surface. Also called a confined aquifer.

base flow.--The streamflow that occurs without direct contribution from precipitation. Also called sustained flow or fair-weather runoff.

coliform bacteria.--A group of bacteria whose presence in water may be an indicator of contamination by sewage.

Colorado Front Range Urban Corridor.--The urbanized area along the eastern slope of the Front Range. The cities of Colorado Springs, Denver, Boulder, Broomfield, Fort Collins, and Greeley are located in this urban corridor. The eastern one-half of Boulder County is in this urban corridor.

Colorado Mineral Belt.--An area extending diagonally across the State from near the southwest corner to the Front Range near Boulder, in which metal mining in Colorado generally has been concentrated. Most of the mountainous part of Boulder County is included in the mineral belt (Lovering and Goddard, 1950).

crystalline rocks.--Igneous and metamorphic rocks.

Darcy's Law.--The velocity of water movement in an aquifer is equal to the hydraulic gradient times the hydraulic conductivity.

dip.--The angle a stratum is inclined from the horizontal.

effluent.--Liquid discharge.

eolian deposits.--Windblown silt and fine sand deposited on uplands between stream valleys.

evapotranspiration.--The part of precipitation that returns to the atmosphere by direct evaporation and by transpiration of vegetation.

faults.--Fractures in the crust of the earth accompanied by displacement of one side relative to the other in a direction parallel to the fault.

fecal-coliform bacteria.--That part of the coliform group of bacteria that is present in the gut or feces of warm-blooded animals; they are indicators of contamination by sewage.

fecal-streptococcal bacteria.--A group of noncoliform bacteria that is present in the gut of warm-blooded animals; their presence in natural waters is considered to verify fecal contamination.

gross alpha radiation.--The alpha radiation contributed by all the dissolved constituents in a water sample, without regard to the specific nuclide producing the radiation.

gross beta radiation.--The beta radiation contributed by all the dissolved constituents in a water sample, without regard to the specific nuclide producing the radiation.

ground-water outflow.--The discharge from an area that occurs as ground water.

hydraulic connection.--A means by which water may move from one water body to another.

hydraulic gradient.--The change in hydraulic head per unit length of flow path.

hydraulic head.--The height above a standard reference point that a column of water can be supported by the static (equilibrium) pressure.

igneous rocks.--Rocks formed by the cooling and solidification of molten material.

impermeable.--Not permitting passage of fluids (water).

infiltration.--The flow of a fluid into a substance through pores or small openings, such as the infiltration of water into the soil or an aquifer.

ion.--An atom or group of atoms with a net negative or positive charge.

joints.--Fractures or cracks in rock without dislocation along the fractures.

leach field.--A subsurface permeable layer, preferably above the water table, into which effluent from septic tanks is discharged for continued digestion and filtration of wastes and percolation of the resultant fluid to the water table.

major ions.--Those ions that commonly occur in natural waters in relative abundance (greater than 1 milligram per liter).

mean.--The arithmetic average of a group of numbers. Calculated by adding the numbers and dividing by their total number.

median.--The middle value in a group of numbers. Half the numbers are greater, and half are less than the median value.

metamorphic rocks.--Rocks that have formed in the solid state from pre-existing rocks in response to pronounced changes of temperature, pressure, and chemical environment at depth in the Earth's crust.

outcrop.--That part of a stratum that is exposed at the land surface.

pathogenic.--Capable of causing disease.

permeability.--An indication of the ease with which a porous medium can transmit a fluid (water).

potentiometric surface.--The surface for a given aquifer to which water would rise in a tightly cased well.

radiochemicals.--Nuclides that disintegrate by emission of radiation.

recharge.--The process by which water is added to an aquifer.

sedimentary rocks.--Rocks formed from consolidation of loose sediment that characteristically accumulates in layers.

seepage.--The percolation of a fluid through a porous material, such as seepage of water from an aquifer.

shallow aquifers.--Aquifers located close to the land surface. For this report, a shallow aquifer was considered to be unconfined and less than 100 ft below the land surface.

shallow water table.--A water table located close to land surface. Arbitrarily defined for this report as a water table within 10 feet of land surface.

soluble.--Capable of dissolving into solution with a fluid (water).

specific conductance.--A measure of the ability of water to conduct an electric current. Specific conductance is closely related to the concentration of ions dissolved in the water.

strata.--Sedimentary-rock beds or layers.

trace elements.--Those elements that commonly occur in natural waters in relatively small concentrations--usually less than 1 milligram per liter.

transmissivity.--The rate at which water may be transmitted through a unit width of aquifer under a unit hydraulic gradient.

unconsolidated rocks.--Loose material that has not been cemented or otherwise solidified into larger units.

valley-fill deposits.--Poorly sorted silt, clay, sand, gravel, and rock fragments, deposited on slopes and in valley bottoms by sheet wash.

water table.--The level at which water stands in an aquifer that is not confined above by an impermeable layer of material.

water-table aquifer.--An aquifer that has a water table. Also called an unconfined aquifer.

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DEPARTMENT OF NATURAL RESOURCES
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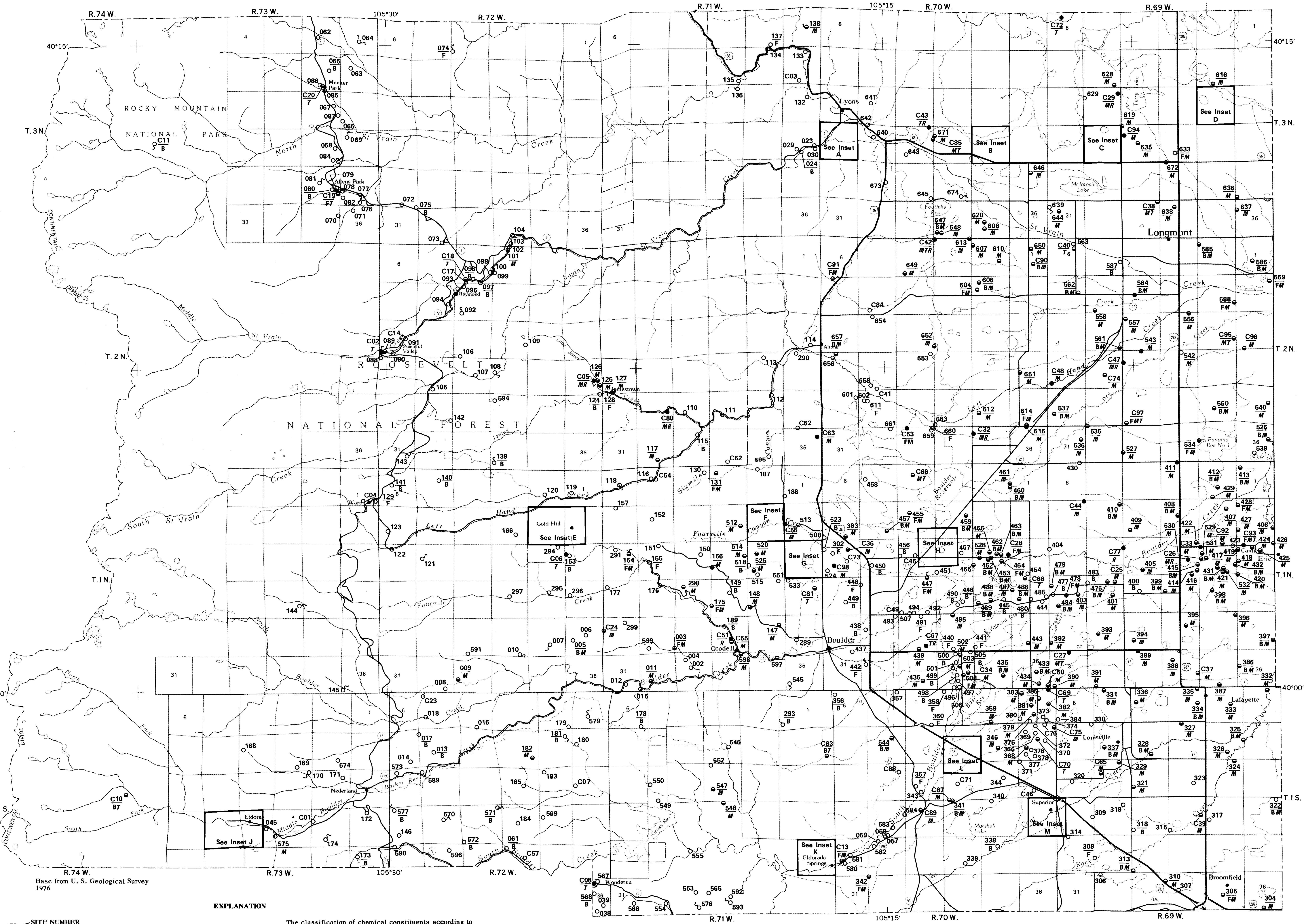
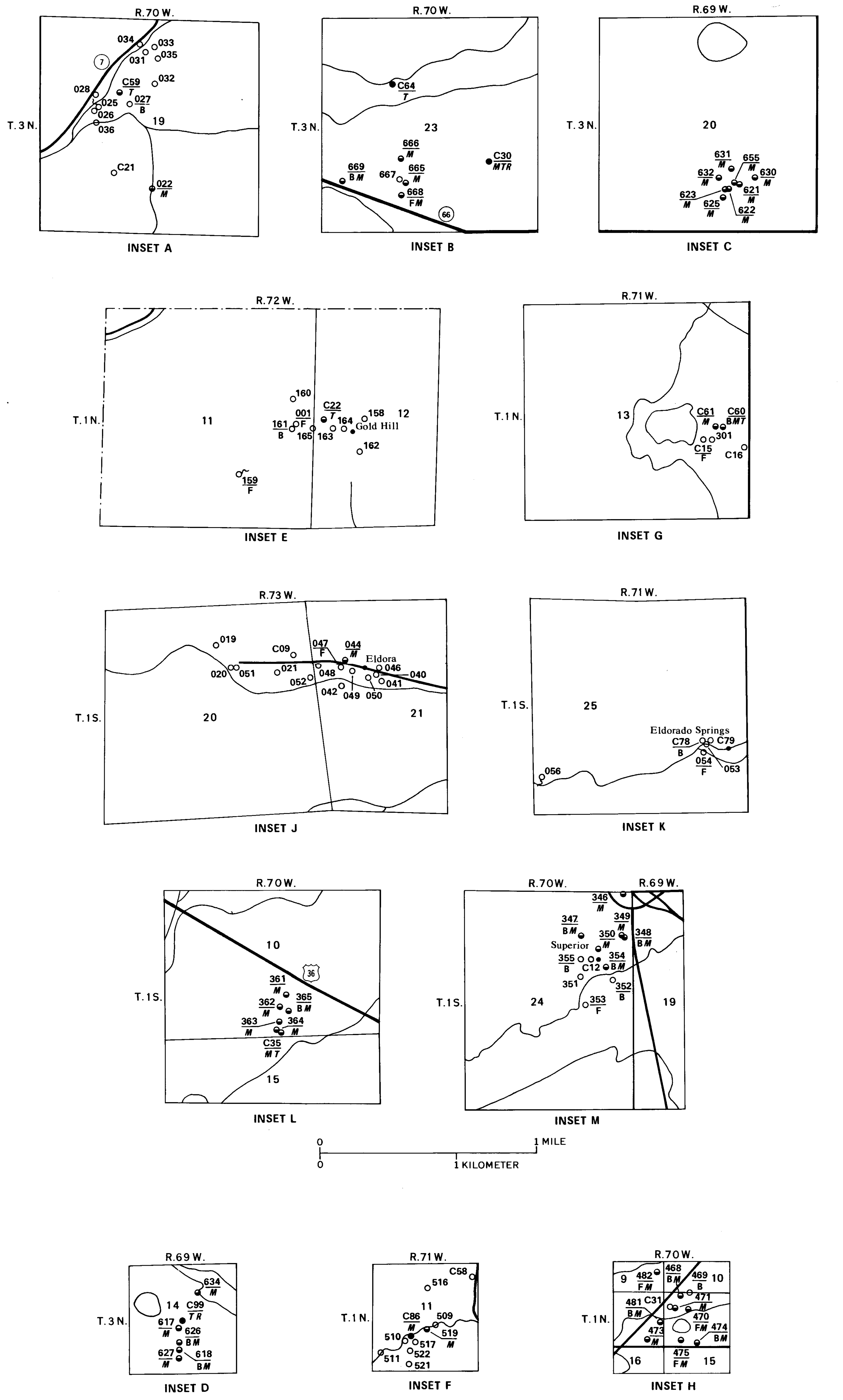
BULLETIN 42
PLATE 1





Base from U. S. Geological Survey
1976

EXPLANATION

C78 — SITE NUMBER

B — LETTERS INDICATE WATER SAMPLE CONTAINED BACTERIA

B More than 1 coliform bacterium was present

F More than 1 coliform bacterium and 1 or more fecal coliform bacteria were present

C36 — SITE NUMBER

M — LETTERS INDICATE THE TYPE OF CHEMICAL CONSTITUENT THAT WAS CONTAINED IN A WATER SAMPLE AT A CONCENTRATION GREATER THAN A MANDATORY DRINKING-WATER STANDARD (COLORADO DEPARTMENT OF HEALTH, 1977) OR A RECOMMENDED STANDARD (U.S. ENVIRONMENTAL PROTECTION AGENCY,1977)

M Standard for one or more major chemical constituents was exceeded

T Standard for one or more trace elements was exceeded

R Standard for one or more radiochemical constituents was exceeded

Letters refer only to the type of standard indicated by the symbol

The classification of chemical constituents according to major, trace, and radiochemical are contained in table 10 with drinking-water standards for all parameters

SAMPLING SITES

● Well or spring where water contained one or more analysed chemical constituents at a concentration greater than a mandatory standard for drinking water

◓ Well or spring where water contained one or more analysed chemical constituents at a concentration greater than a recommended standard for drinking water

○ Well or spring where water contained no analysed chemical constituents at concentrations greater than drinking-water standards

MAP SHOWING LOCATION OF WELLS AND SPRINGS FOR WHICH WATER-QUALITY DATA ARE AVAILABLE AND RELATIVE SUITABILITY OF GROUND WATER FOR DRINKING, BOULDER COUNTY, COLORADO