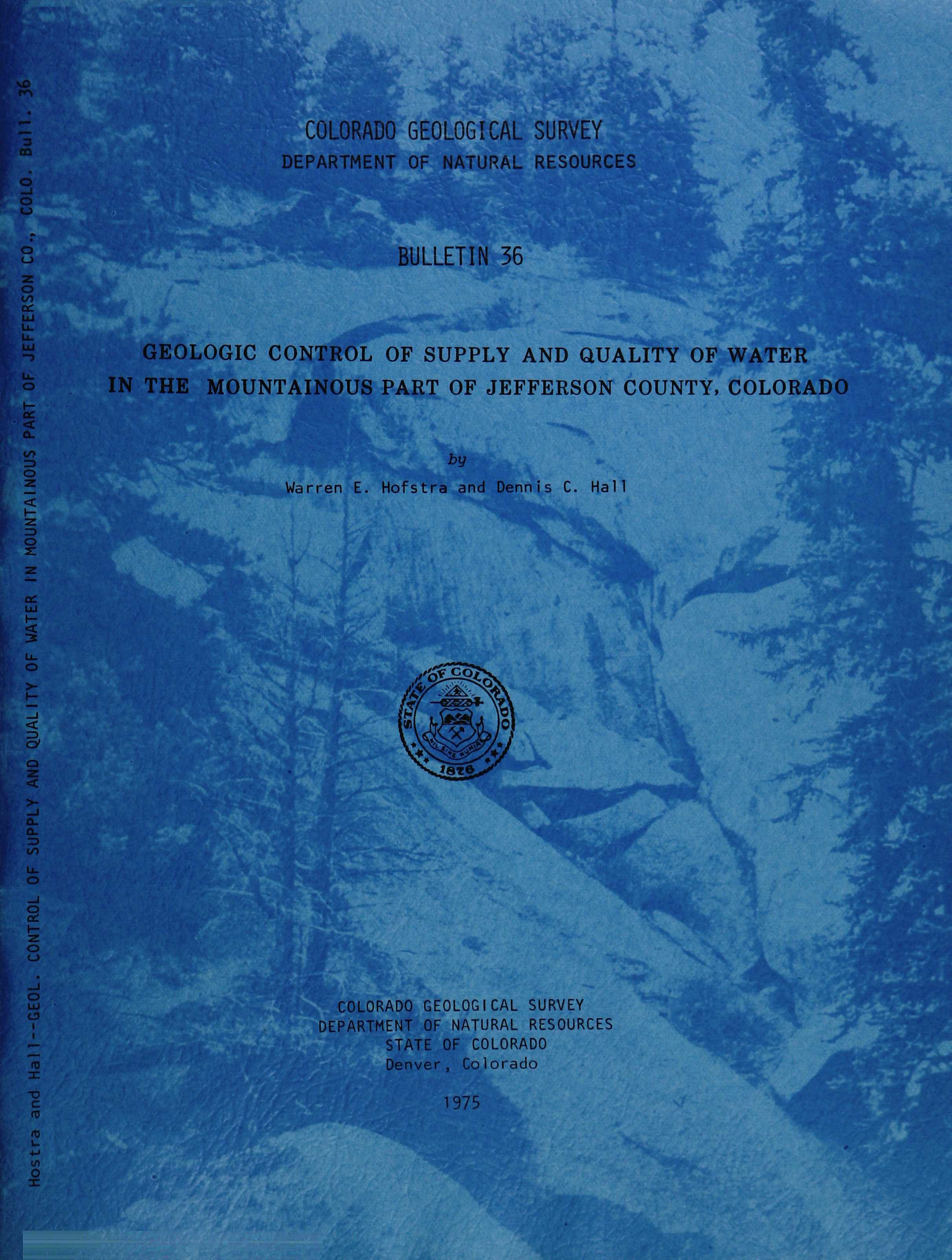

Hostra and Hall--GEOL. CONTROL OF SUPPLY AND QUALITY OF WATER IN MOUNTAINOUS PART OF JEFFERSON CO., COLO. Bull. 36

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES

BULLETIN 36

GEOLOGIC CONTROL OF SUPPLY AND QUALITY OF WATER IN THE MOUNTAINOUS PART OF JEFFERSON COUNTY, COLORADO

by

Warren E. Hofstra and Dennis C. Hall

1876

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
STATE OF COLORADO
Denver, Colorado

1975

STATE OF COLORADO
Richard D. Lamm, Governor

DEPARTMENT OF NATURAL RESOURCES
Harris D. Sherman,
Executive Director

COLORADO GEOLOGICAL SURVEY
John W. Rold, Director
and State Geologist

U.S. GEOLOGICAL SURVEY
James E. Biesecker, District Chief
In charge of cooperative water-resources investigations in Colorado

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MISSION OF THE COLORADO GEOLOGICAL SURVEY

The Colorado Geological Survey was legislatively re-established in February 1969 to meet the geologic needs of the citizens, governmental agencies, and mineral industries of Colorado. This modern legislation is aimed at applying geologic knowledge toward the solution of today's and tomorrow's problems of an expanding population, mounting environmental concern, and the growing demand for mineral resources.

SPECIFIC LEGISLATIVE CHARGES ARE:

"Assist, consult with and advise state and local governmental agencies on geologic problems."

"Promote economic development of mineral resources."

"Evaluate the physical features of Colorado with reference to present and potential human and animal use."

"Conduct studies to develop geological information."

"Inventory the State's mineral resources."

"Collect, preserve and distribute geologic information."

"Determine areas of geologic hazard that could affect the safety of or economic loss to the citizens of Colorado."

"Prepare, publish and distribute geologic reports, maps and bulletins."

"Evaluate the geologic factors affecting all new subdivisions in unincorporated areas of the State."

"Promulgate model geologic hazard area control regulation."

"Provide technical assistance to local governments concerning designation of and guidelines for matters of State interest in geologic hazard areas and the identification of mineral resource areas."

"To provide other governmental agencies with technical assistance regarding geothermal resources."

COLORADO GEOLOGICAL SURVEY

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U.S. Geological Survey

Prepared by the U.S. Geological Survey
in cooperation with the Colorado Geological Survey
and the County of Jefferson, a Body Politic and Corporate

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STATE OF COLORADO

RICHARD D. LAMM
Governor

JOHN W. ROLD
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LETTER OF TRANSMITTAL

Colorado Geological Survey
Bulletin #36

The Honorable Richard D. Lamm
Governor of Colorado

Dear Governor Lamm:

We are pleased to present to you Colorado Geological Survey Bulletin #36, "Geologic Control of Supply and Quality of Water in the Mountainous Part of Jefferson County, Colorado". This publication documents the occurrence of ground-water and the suitability of the environment for on-lot sewage treatment facilities in the approximate western one-half of Jefferson County. Due to the attractiveness of the area, in the past few years a large number of new subdivisions have been platted, which has resulted in a rapid population growth. Because of low density patterns in many of these new subdivisions, much of the new population is dependent upon ground-water supplies and on-lot facilities for sewage treatment. It has long been recognized that if on-lot sewage treatment facilities are not installed in a favorable geologic environment the effluent can cause pollution of surface and ground waters.

Recognizing the critical decisions facing the Jefferson County officials who must approve any proposed new development in the mountainous part of their county, and the people who wish to build there, the Colorado Geological Survey in cooperation with Jefferson County entered into an agreement with the U. S. Geological Survey to conduct a thorough appraisal of the geologic conditions governing the occurrence of ground-water and the suitability of the area for on-lot sewage treatment facilities. The U. S. Geological Survey has completed their investigation and Bulletin #36 reports their findings. County and State officials, and the general public should find this publication to be of considerable help and benefit when new developments are considered in the mountainous parts of Jefferson County.

COLORADO GEOLOGICAL SURVEY

John W. Rold

John W. Rold
Director and State Geologist

GEOLOGY
STORY OF THE PAST . . . KEY TO THE FUTUR

CONTENTS

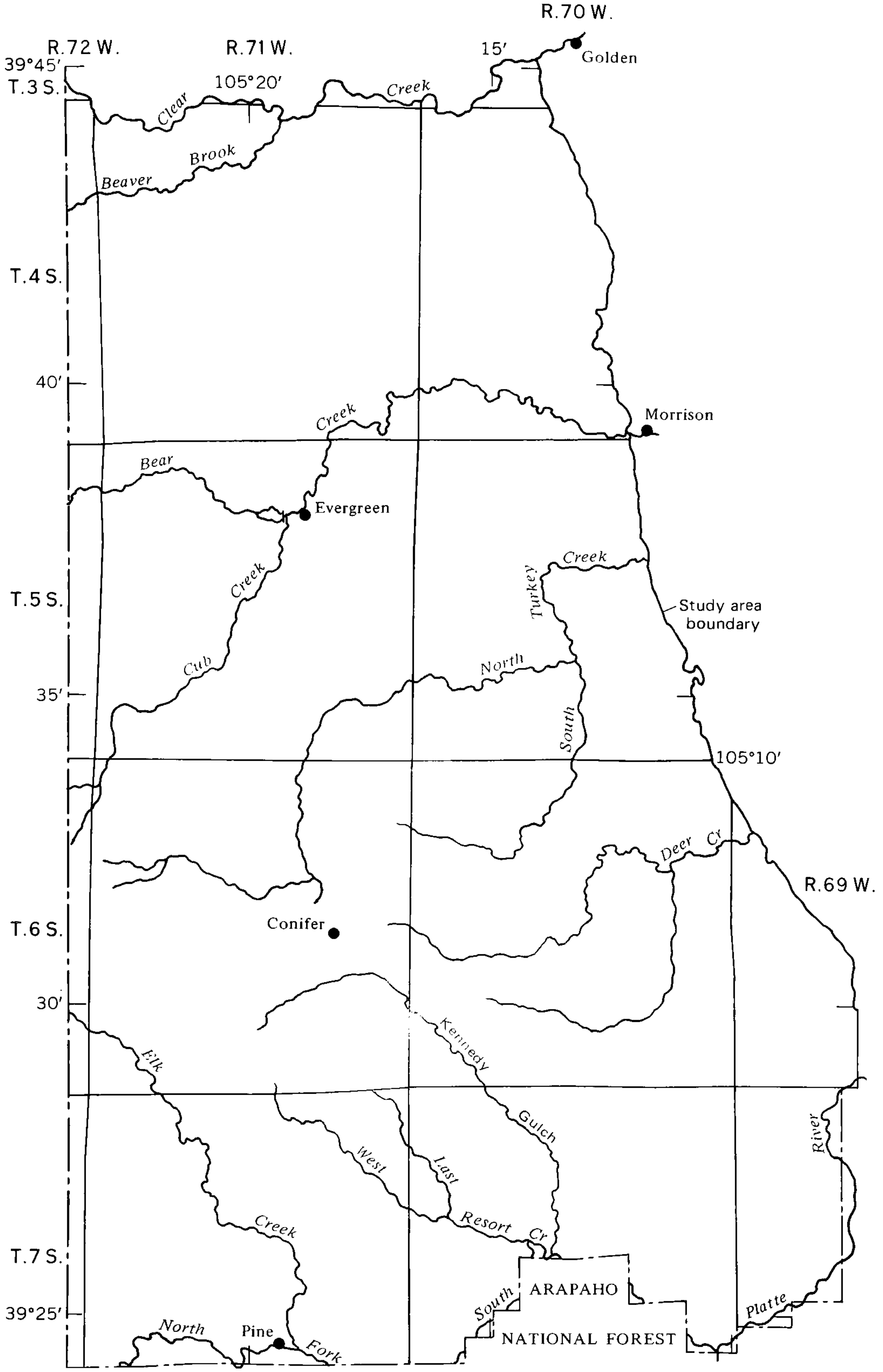
ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For those readers who prefer metric units rather than English units, conversion factors for the terms used in this report are listed below:

English unit	*Multiply by*	*Metric unit*
acres	0.4047	hectares (ha)
acre-feet (acre-ft)	.001233	cubic hectometres (hm^3)
cubic feet (ft^3)	28.32	litres (l)
	.02832	cubic metres (m^3)
cubic feet per acre (ft^3/acre)	.06998	cubic metres per hectare (m^3/ha)
feet (ft)	3.048	metres (m)
gallons (gal)	3.785	litres (l)
gallons per minute (gal/min)	.06309	litres per second (l/s)
inches (in)	25.40	millimetres (mm)
miles (mi)	1.609	kilometres (km)
square miles (mi^2)	2.590	square kilometres (km^2)



Base from U.S. Geological Survey
1:24,000 topographic quadrangles

Figure 1.--Index map of study area.

GEOLOGIC CONTROL OF SUPPLY AND QUALITY OF WATER IN THE MOUNTAINOUS PART OF JEFFERSON COUNTY, COLORADO

By Warren E. Hofstra and Dennis C. Hall
U.S. Geological Survey

ABSTRACT

Hydrologic investigations in a 300-square-mile (780-square-kilometre) area just west of Denver in the mountains of Jefferson County, Colo., indicate that the chemical and biological quality of the water is being degraded, especially in the more densely populated locales. The population has more than doubled since 1960, leading to increased use of the water resources. This study indicates that water-quality problems are related to the geology and hydrology of the mountain environment.

A water budget was calculated from precipitation and surface-water flow records and from information on subsurface fractures in the area. Precipitation was estimated to equal about 290,000 acre-feet (360 cubic hectometres) per year and ground water in storage was estimated to be about 21,000 acre-feet (26 cubic hectometres), roughly equal to the yearly runoff from the area (about 22,000 acre-feet or 27 cubic hectometres).

Chemical and bacteriological tests were performed on water samples collected from about 800 wells and springs; drinking-water standards recommended by the Colorado Department of Health were exceeded for coliform bacteria in 20 percent of the samples and for nitrate concentration in 5 percent of the samples. Twenty-five streams were tested seasonally; they almost always contained some coliform and fecal-coliform bacteria, but are seriously contaminated only locally.

Several possible approaches to the solution of water-supply and waste-disposal problems can be employed to provide potable water for residents. Alternatives are (1) to minimize degradation of the water by improving waste treatment, (2) to chlorinate or treat the water before use, or (3) to seek alternate sources of water, such as using a surface-water supply in place of a contaminated ground-water supply.

INTRODUCTION

Jefferson County's Problems and Needs

Rapid development of mountain land in the Jefferson County study area (fig. 1) creates serious problems for planners and residents of the area. From 1960 to 1970 the population in the mountains of Jefferson County increased by 5,900 people and from 1970 to 1974 the increase was 6,400 people (fig. 2). This is more than a 100-percent increase in population since 1960. Large mountainous tracts are being subdivided and sold, creating a suburban density of homes in many places. Two major problems confront residents--water supply and waste disposal. Rugged terrain, and a scarcity of ground water and surface water, create problems for urban community development. It is difficult to supervise development of mountain communities in such a way that sewage disposal systems do not degrade ground-water supplies.

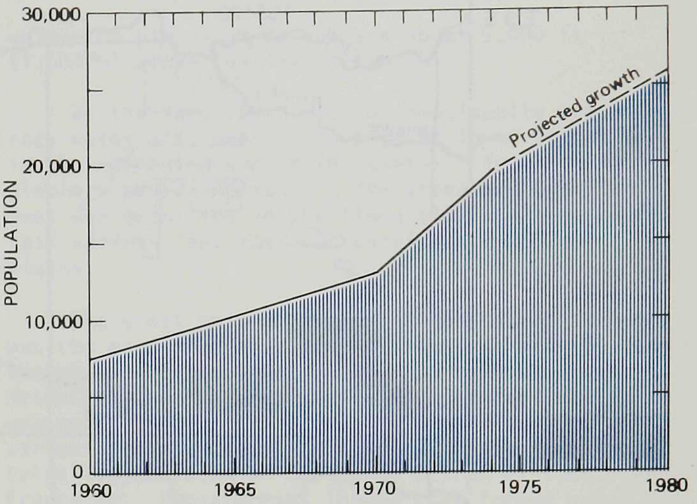
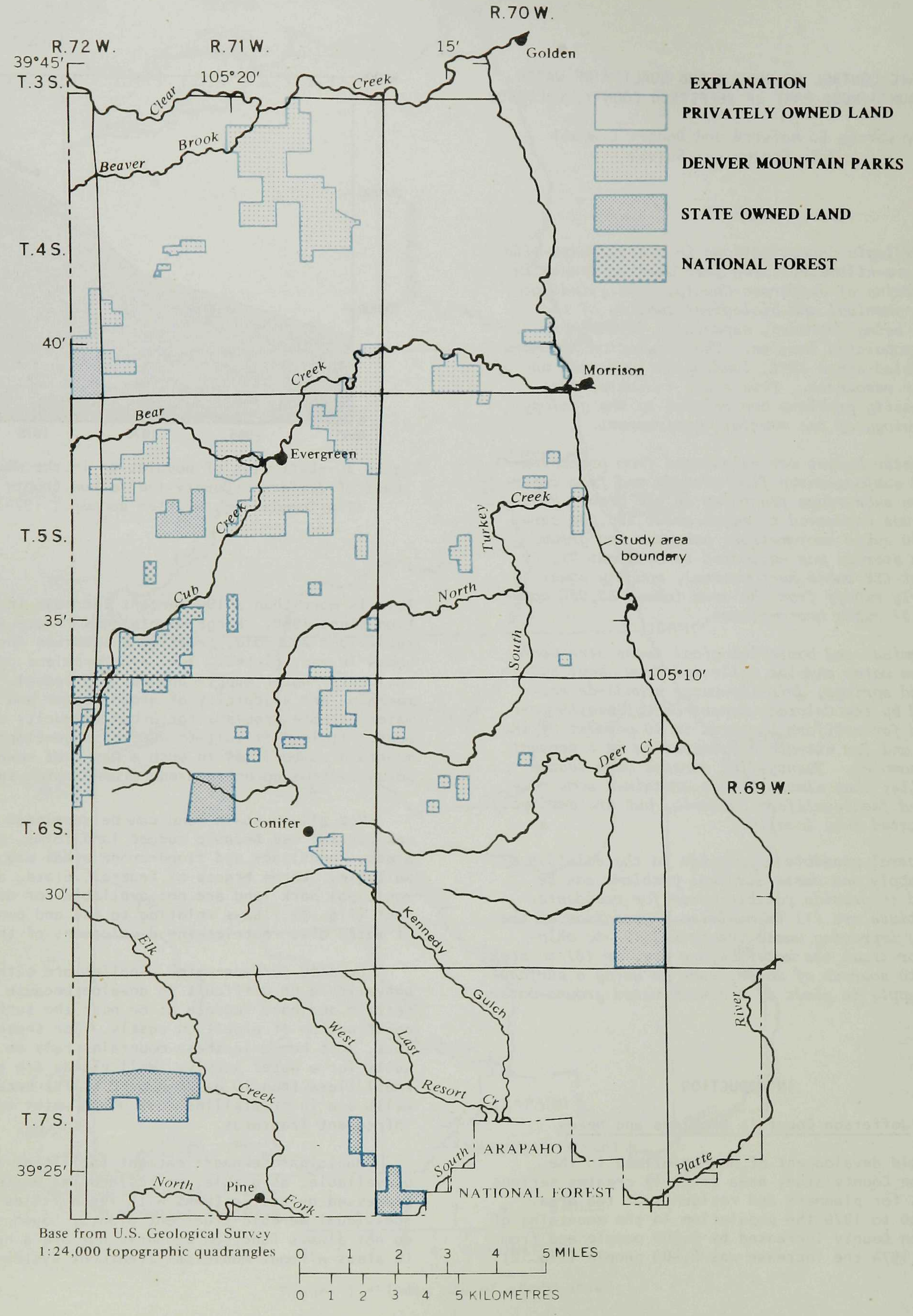


Figure 2.--Estimates of population in the mountainous part of Jefferson County (Jefferson County Planning Commission, written commun., 1974).

Not all mountain land can be developed for residential use because rugged land forms, alpine areas, landslide- and flood-prone areas are not suitable. Large tracts of Federal, State, and municipal park land are not available for development (fig. 3). Laws relating to use and ownership of water also restrict the development of the land.

Usually surface-water supplies are either unavailable or difficult to develop because rugged terrain and hard bedrock at or near the surface make construction of pipelines costly. For these reasons, most homes in these mountains rely on domestic wells for a water supply. Well yields are generally small (less than 10 gal/min or 0.6 l/s) because most wells are in crystalline rock where water occurs in infrequent fractures.

Municipal sewage-treatment facilities are also unavailable, as a rule, so residential wastes are processed by septic tanks with leach fields or by individual aerobic-treatment plants. Such systems do not always function properly but are a necessity in areas without municipal treatment systems.



Base from U.S. Geological Survey
1:24,000 topographic quadrangles

Figure 3.--Land ownership.

Purpose and Scope of Study

The aim of the present study was to investigate and describe the hydrology and geology of the mountainous part of Jefferson County, with emphasis on the effects of increased water use by residential developments on the quality of the water in this area. The information obtained will be useful in planning the future growth of the area. The U.S. Geological Survey conducted this 3-year investigation in cooperation with the Jefferson County Planning Commission and the Colorado Geological Survey.

Selection of Study Area

A study area typical of the mountain environment was selected, extending from Clear Creek on the north to the national forest boundary on the south. The study area (fig. 1) is about 300 mi^2 (780 km^2) of mountain land ranging from undeveloped land to urban communities.

The specific objectives of the study were: (1) to define existing water use and availability; (2) to determine the chemical and microbiological characteristics of ground- and surface-water supplies; (3) to determine the distribution of major rock units, fractures, and structures; (4) to describe the soil thickness and permeability and relate these factors to the suitability of sites for septic tank installation; and (5) to summarize the runoff characteristics of the principal watersheds.

Procedure of Investigation

First, all available hydrologic and geologic data were examined. Then field studies followed that included: systematic sampling of wells, springs, and streams for chemical and microbiological concentrations; describing many environmental and geologic factors at each sampling site; and testing and measuring hydrologic and geologic characteristics of test wells. Data collected for this study are published in a report by Hofstra and Hall (1975).

Acknowledgments

Consultation with planners, landowners, health officials, well drillers, engineers, and individuals in several county, State, and Federal agencies was most helpful and their assistance and cooperation are gratefully acknowledged.

PHYSICAL SETTING

Shape of the Land

In response to great mountain-building forces that began before the Ice Age, the Rocky Mountains have been thrust up above the adjacent plains. The altitude of the project area ranges from less than 6,000 ft (1,800 m) to more than 10,000 ft (3,000 m) while the plains at Denver are about 5,000 ft (1,500 m) above sea level (fig. 4).

As the land rose, erosion continually cut away rock materials, depositing them at lower elevations in the mountains and in the plains. Then mountain glaciers added sediment to the streams. Some sediment was deposited in the flood plains of the mountain valleys, but most was carried out to the plains.

The great masses of granite that occur throughout the area generally are resistant to erosion, and therefore are prominent in the mountainous areas. Metamorphic rocks are usually more susceptible to weathering and are more readily eroded away by the streams. The tectonic forces that formed the mountains also created an extensive system of faults and fractures. These breaks in the rock formed well-defined zones of weakness that were attacked by the mountain streams (fig. 5).

All streams in the area flow generally eastward (fig. 6). Their courses are determined by variations in the resistance of the bedrock to erosion, which is influenced by the position of fault zones, major fracture patterns, and lithology. The headwaters of some of the larger streams are in glaciated valleys, but most of the valleys in this area are stream-cut. These narrow valleys sometimes contain deposits of alluvial sands and gravels but where slopes are steep, only boulders are present in the bedrock channel.

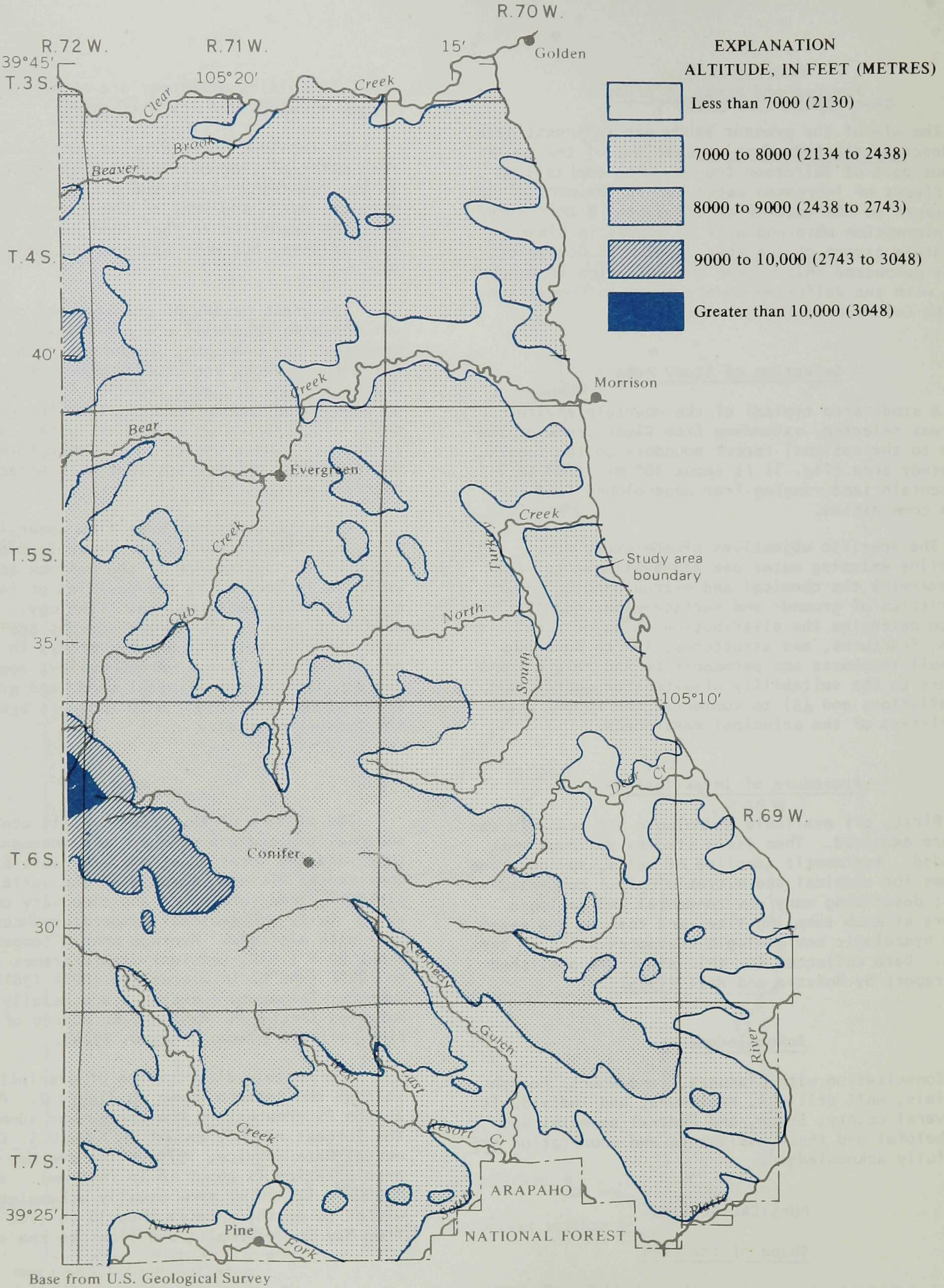
Climate

The climate of the study area is controlled by seasonal temperature changes, air movement, altitude, and the location of the area just east of the Continental Divide. Because of the variation in altitude, temperatures at any time vary considerably. Daily and seasonal temperatures correlate well with altitude. Average annual temperature is about 50°F (10°C, Celsius) with extremes of close to -40°F (-40°C) in winter and 100°F (38°C) in the summer. Temperature extremes are usually of short duration (Archie M. Kahan, U.S. Bureau of Reclamation, written commun., August 1974).

The monthly distribution of precipitation follows the pattern shown on figure 7. Precipitation is greatest in the spring and summer, with the largest monthly amount in May (U.S. Environmental Data Service, 1973). The average annual precipitation is about 18 in (460 mm). Above 8,000 ft (2,400 m) snow usually accumulates in winter to depths greater than 30 in (760 mm) and, from May to July, melts and flows to the streams.

Geology

The geologic conditions in the mountainous area of Jefferson County have great influence on man's use of the land. The position of great



Base from U.S. Geological Survey
1:24,000 topographic quadrangles

Figure 4.--Altitude zones.

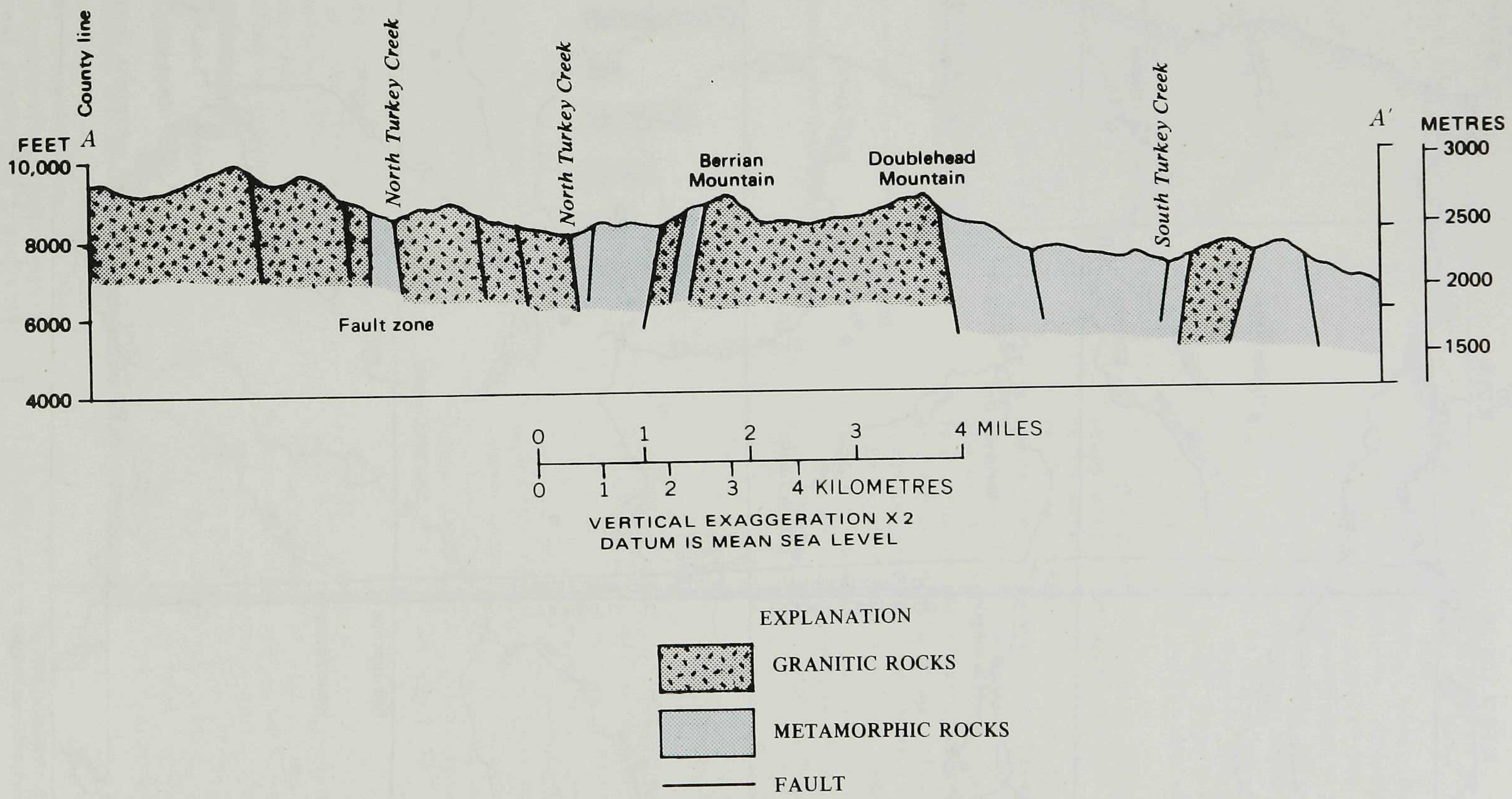
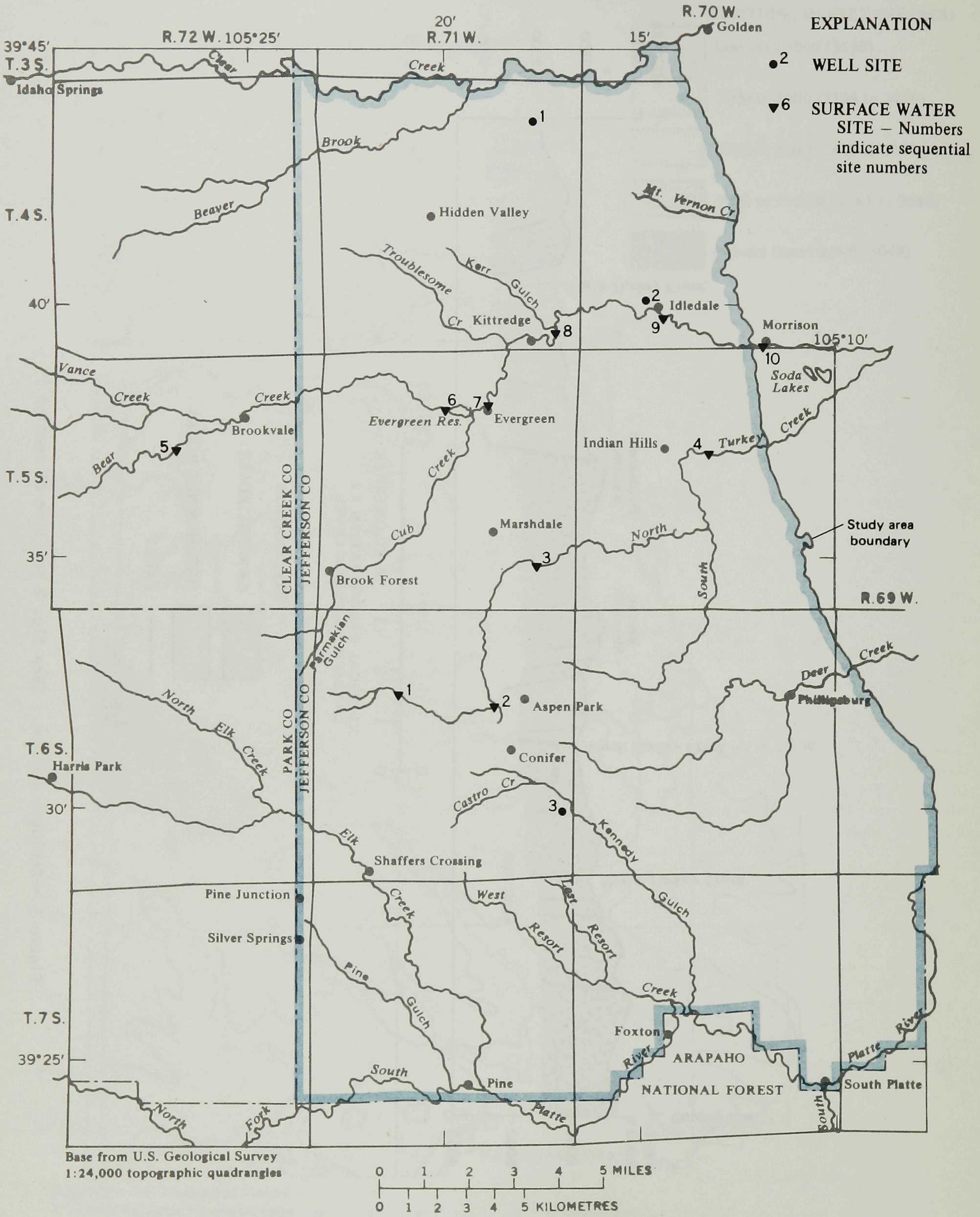


Figure 5.--Geologic section. (See fig. 8 for line of section.)



Base from U.S. Geological Survey
1:24,000 topographic quadrangles

Figure 6.--Drainage.

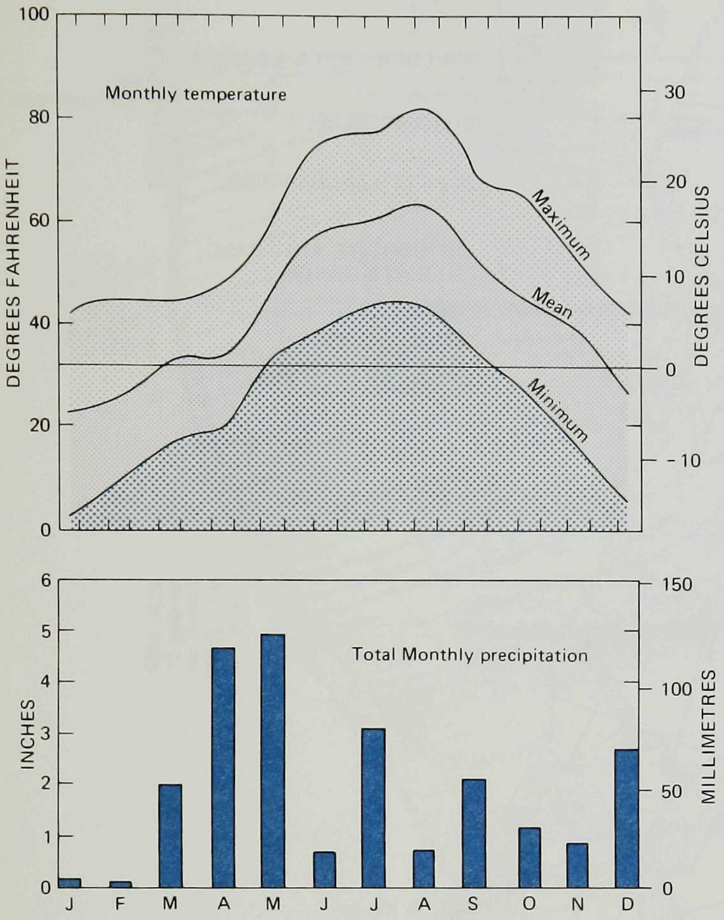


Figure 7.--Temperature and precipitation at Evergreen, 1973. (Altitude 6,997 feet or 2,133 metres; from U.S. Environmental Data Service, 1973.)

granite rock masses, faults, and other structures determine the topography and the drainage. Also, varying rock types and their modification by the natural processes of weathering, erosion, and soil movement determine what areas of mountain land are habitable.

Bedrock

Metamorphic rocks compose the bedrock in most of Jefferson County. These rocks were originally deposited as sediments and volcanic materials many millions of years ago. Subsequently, these materials were downfolded to great depths and transformed into metamorphic rocks by recrystallization due to heat, pressure, and intrusion of mineral-laden fluids. The metamorphosis of the original sedimentary and volcanic rocks was accompanied by magmatic intrusions that formed large granite masses. The general distribution of metamorphic and granitic rocks that form the bedrock in the study area is shown in figure 8.

Fractured bedrock constitutes the principal aquifer in the mountains. Fractures or joint systems in the study area parallel the major displacement features, which are northwest-trending faults and west-trending faults (fig. 8). Other major joint systems are at angles of about 90° to the fault systems. Depending on the area, either joint system may predominate. Usually the joints are high-angle features at 70° to 90° from a horizontal plane; locally lower-angle joints are common.

The general fracture pattern observed in the study area is an upper zone of abundant open fractures extending down from the land surface about 40 ft (12 m). Below this zone to about 200 ft (61 m) there are a few fractures capable of yielding water. Below 200 ft (61 m) water-bearing fractures are scarce, so that one might expect to intercept few fractures in the zone between 200 and 400 ft (61 and 122 m) in an average well. Most of the fractures observed in the mountains are not inclined greatly from the vertical, decreasing the probability of a well intersecting the fractures. The yields of wells are determined by the number and size of open water-bearing fractures intersected (fig. 9).

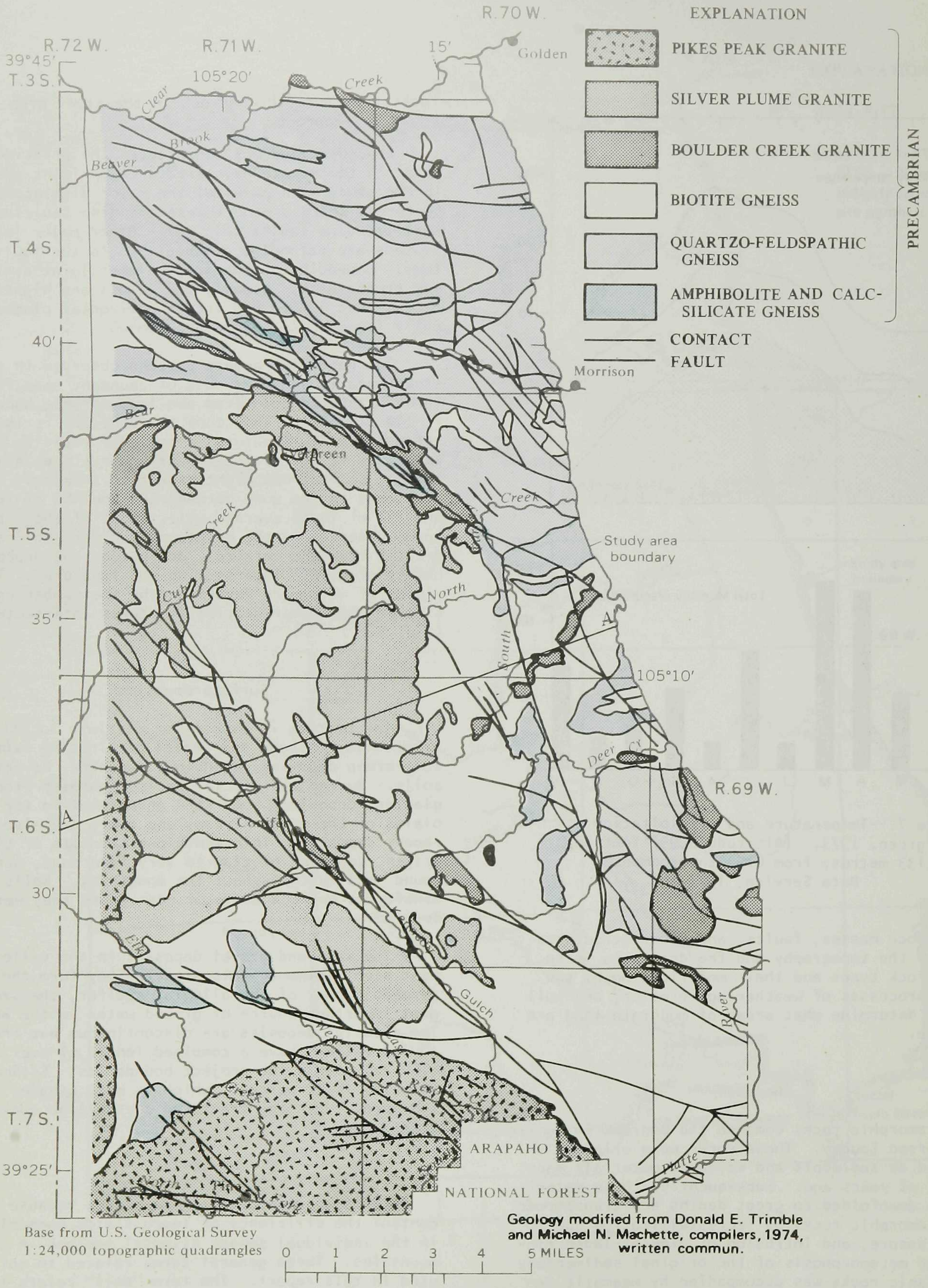
Surface deposits

The bedrock is exposed or overlain locally by unconsolidated sand and gravel originating from soil-creep deposits, windblown deposits, or residual soils. During the glacial period, outwash from glaciers deposited some sand and gravel in the flood plains of the major streams and there are also more recent deposits. Thin windblown deposits of glacial origin, composed of clay to very fine sand, are found locally throughout the mountains. Soils mantle the bedrock above or near where they were derived.

The sand and gravel deposits in the valleys are most significant in this study. They form the most permeable part of the alluvial aquifer, the second most important source of ground water in the area. The alluvial deposits are discontinuous but the alluvial valleys have a combined length of over 100 mi (160 km) within the project boundaries. Estimated porosity is 20 percent, which is much greater than the porosity in the fractured crystalline rocks.

Soils

Soils are important in this area because they control the efficiency of leach fields commonly used in the individual sewage disposal systems in the mountains. Three general terms related to soils are used in this report. The term "soil" refers to all of the weathered rock materials. "Top soil" refers to the uppermost part of the soil that is high in



Base from U.S. Geological Survey
1:24,000 topographic quadrangles

Geology modified from Donald E. Trimble and Michael N. Machette, compilers, 1974, written commun.

Figure 8.--Generalized geologic map. (see fig. 5 for Geologic Section)

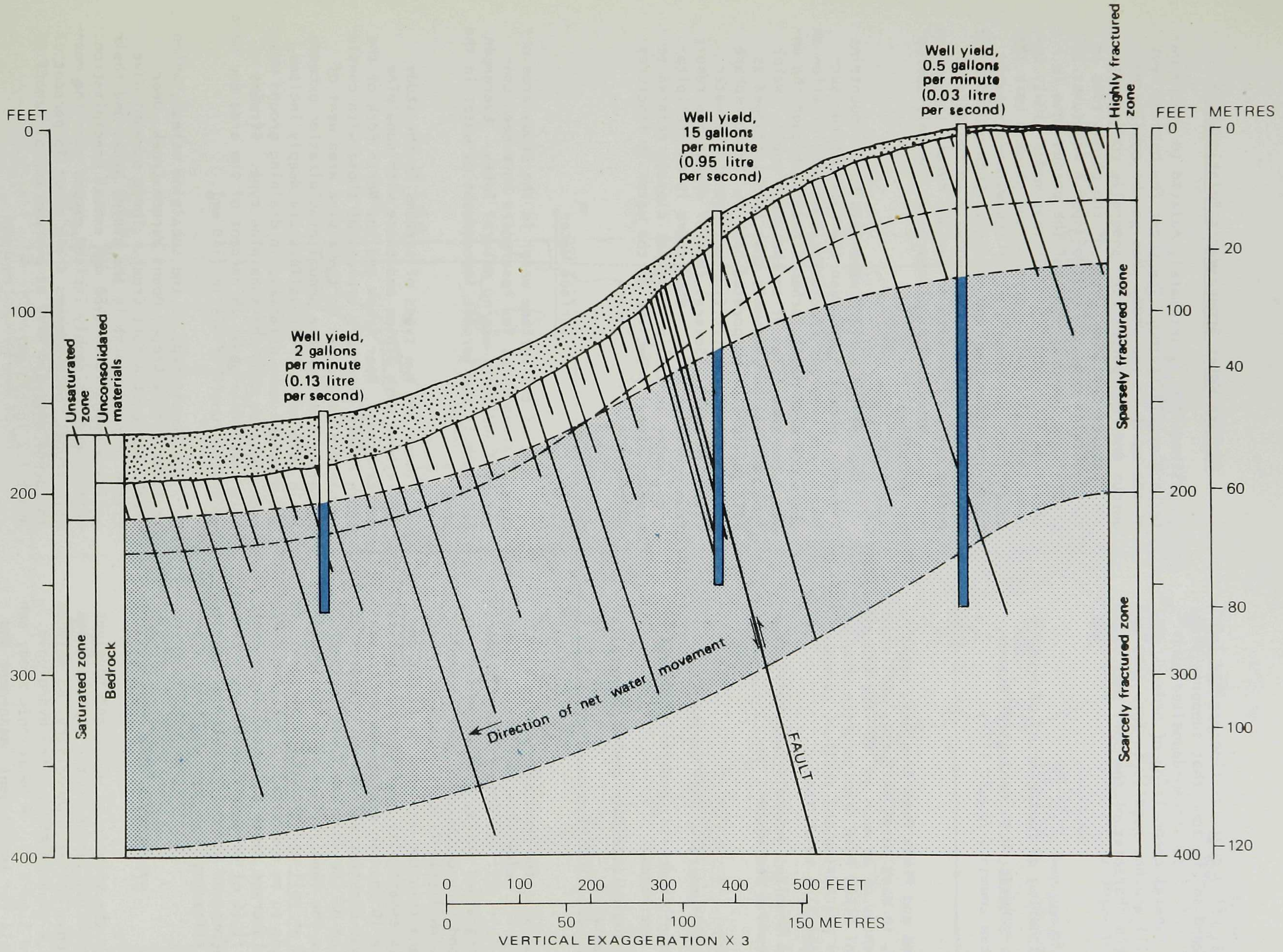


Figure 9.--Idealized one-joint fracture system and relation to ground-water yield.

organic materials, often contains fine-grained inorganic materials, and is the zone that supports plant life. "Alluvium" refers to stream-deposited sand and gravel. The mineral composition of bedrock determines if it will weather readily to form soil and also determines the character of the soil that is formed (table 1).

Table 1.--*Weathering characteristics of rocks*

[After Paul W. Schmidt, U.S. Geological Survey, written commun., August 1974]

Igneous rocks	
	Boulder Creek and Pikes Peak Granites, variably weathered, in many cases uniformly well weathered to depths of as much as 100 feet (30 m). Outcrops of Pikes Peak Granite often show spheroidal weathering and shallow, curved jointing parallel to surface.
	Silver Plume Granite, generally weathered to a depth of only a few inches.
Metamorphic rocks	
	Biotite gneiss, generally well weathered.
	Quartzofeldspathic gneiss, generally moderately to poorly weathered.
	Amphibolite and calcsilicate gneiss, generally poorly weathered.

Most top soils in the mountains are so thin that leach fields are below this zone in the underlying soil materials that are most frequently coarse grained. Coarse-grained soils, with the exception of some valley and terrace deposits, are commonly very permeable with little filtering capacity. In situations where a thin top soil has developed on bedrock, there is essentially no filtering capacity. The map in figure 10 showing average depths to consolidated rock was constructed from well records on file in the office of the Colorado State Engineer. The interval from the land surface to consolidated rock is composed of soil and decomposed bedrock. Special care needs to be exercised in locating leach fields where the average depth to consolidated rock is less than 20 ft (6 m) because much of the interval may be partly decomposed bedrock--a material unsuited for leach field filtering.

HYDROLOGY

Hydrology is the science of water and involves the study of streamflow, ground-water movement, precipitation, geology, and water chemistry, as well as related topics. A diagram showing the hydrologic cycle is shown in figure 11. A hydrologic study can establish the basis for intelligent management and conservation of this valuable resource.

Surface Water-Ground Water Relationships

Streamflow is intimately related to ground water and precipitation. The upper few hundred feet of the earth in the study area can be considered porous and this porous zone generally conforms to the shape of the land. Most of the porous zone in the mountains consists only of sparse fractures in crystalline bedrock. Part of the porous zone is saturated with water (fig. 9) that moves slowly toward lower altitudes. Springs and streams mark the level where the upper part of the water-saturated zone intersects the land surface. Such ground-water discharge contributes continuously to the streams. During dry periods with no surface runoff (base-flow periods), ground-water discharge is the only source of streamflow.

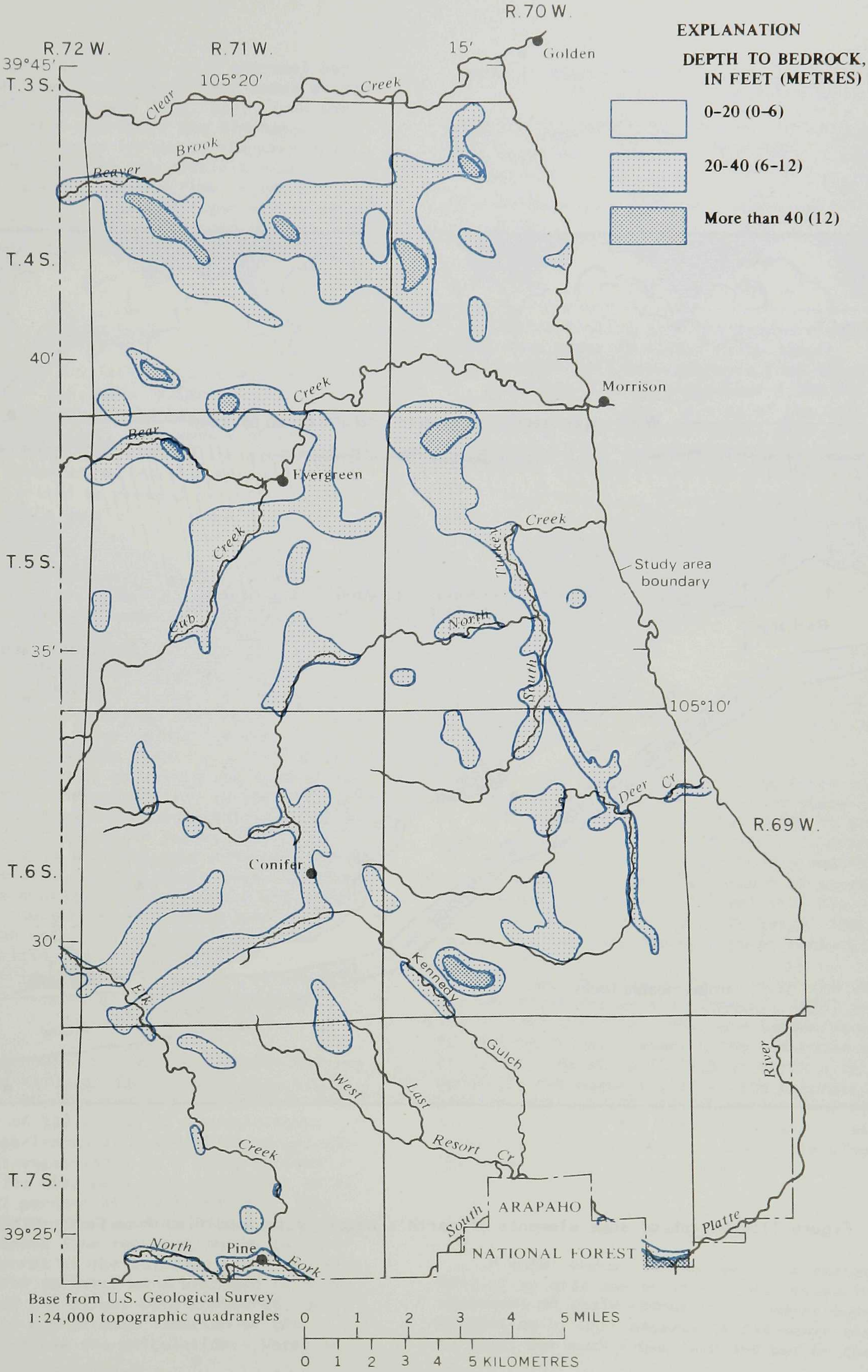
Because the surface materials in the mountains are very permeable and even the rock outcrop surfaces have numerous fractures, some precipitation on the study area moves rather directly through the unsaturated zone (fig. 9) to the water table. Water from rainfall and snowmelt that is not trapped as soil moisture or evaporated back to the atmosphere causes rather dramatic fluctuations of the water levels in wells. Several feet of change can result from one large storm. When there is no precipitation, water levels in wells not closely related to streams steadily decline as the water in fractures moves downslope.

Surface Water

Most of the surface water in the study area occurs in streams, as few reservoirs have been constructed and there are no natural lakes. Evergreen Reservoir is the largest impoundment of water in the area.

There are two types of streams in the study area--those with alpine and those with subalpine source areas. Bear Creek and the North Fork of the South Platte River are typical of those with considerable drainage areas in the alpine area west of Jefferson County where annual precipitation exceeds 20 in (510 mm). Their valleys are deeply incised, and they are more effective in draining ground water from the area than the subalpine type. Streams of this type drain about 25 percent of the area and have an annual runoff of 4.4 in (110 mm).

The second type is the subalpine stream, which includes Turkey Creek, Mount Vernon Creek, Deer Creek, and Last Resort Creek. These streams have little or no drainage in the alpine area, and their basins average 18 in (460 mm) annual precipitation. Valleys are not deeply incised except near the mountain front. Such streams drain about 75 percent of the study area and have an average annual runoff of about 1.2 in (30 mm).



Base from U.S. Geological Survey
1:24,000 topographic quadrangles

Figure 10.--Average depths to bedrock (from records of the State Engineer).

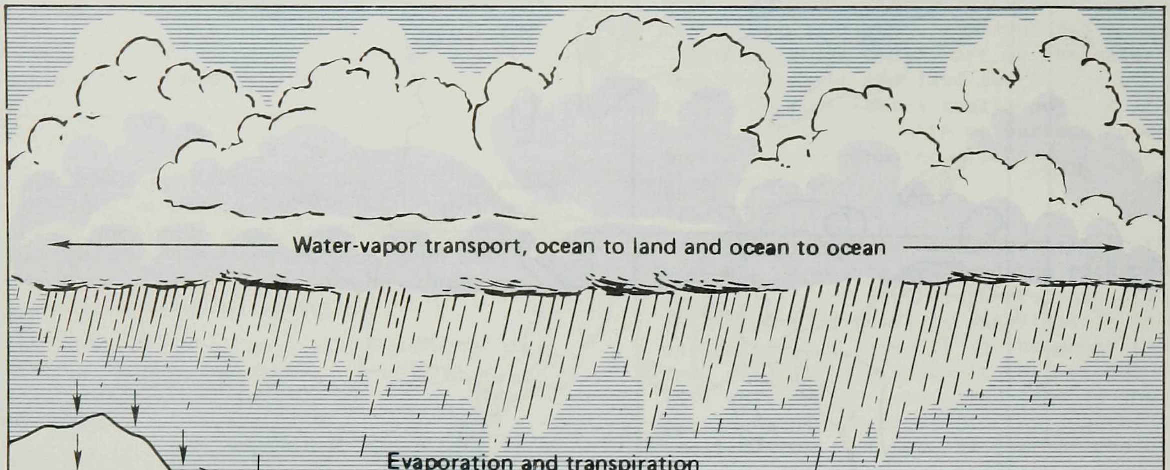


Figure 11.--Sketch of some elements of earth's water cycle (modified from Feth, 1973).

Streamflow generally varies on a seasonal basis, as illustrated by the discharge of Bear Creek at Morrison for the 1973 water year (fig. 12). From the first of October until mid-April the discharge is small because ground-water inflow is the principal source of water and much of the precipitation is locked in the snowpack. Maximum flow in May is caused by a combination of snowmelt and spring storms. The gradual decline from May to the end of September is probably less pronounced than usual because of July precipitation.

Ground Water

The quality and availability of ground water may affect man's use of the land. Water found underground is constantly moving and may be considered as being in transient storage. The source of this water is precipitation that percolates to the water table and then slowly moves downgradient. Not all of the water in an aquifer can be removed by wells so the specific yield of the aquifer is always less than the water in storage.

Two types of ground-water reservoirs or aquifers occur in the study area. The most common type is the fractured bedrock and this water source is characterized by small storage capacity, generally small yields to wells, and rather large water-level fluctuations when recharged by precipitation (fig. 13). These large fluctuations are caused by filling and draining the void spaces of the fractures and do not necessarily indicate a large volume of recharge or discharge. The static water level in wells tapping water-bearing fractures is usually a few tens of feet below land surface. The second type is the alluvial aquifer composed of sand and gravel that is found in small discontinuous deposits in valleys along the streams. The alluvial aquifers have a higher storage capacity and more stable water levels than the other type because they contain more void space and are supported both by surface runoff and ground-water discharge from the water-bearing fractures. The static water level in the alluvial aquifers is usually a few feet below land surface. The alluvial aquifers are usually adequate for domestic water supplies.

The amount of water stored in the water-bearing fractures and the alluvial aquifer have been evaluated separately. Storage in the water-bearing fractures to a depth of 300 ft (91 m) was calculated utilizing the logarithmic decrease of porosity relative to depth as established in a study by Snow (1968). Porosities used were 0.04 percent at 30 ft (9.1 m) and 0.002 percent at 300 ft (91 m). (See table 2.) Average depths to water in the study area (fig. 14) were mapped from reported depths to water from the well records of the Colorado State Engineer. The reported depths to water were averaged in 0.25 mi^2 (0.65 km^2) and the values were contoured, using topography and approximate location of the wells to further refine the calculation. Water is present in major fractures and faults below 300 ft (91 m) but such occurrences are local in nature and difficult to predict.

Table 2.--*Ground-water storage in the water-bearing fractures for a 300-foot well*

Depth to water zone shown on figure 14 (ft)	Average depth to water (ft)	Saturated thickness (ft)	Ground water stored[1] to depth of 300 ft (ft^3/acre)
0-40	20	280	4,500
40-80	60	240	3,500
[2]80-300	140	160	2,030

[1] Extrapolating from the fracture model (Snow, 1968) some water is stored below 300 ft. If our hypothetical well were deepened from 300 ft to 1,000 ft, there would be an additional 3,560 ft^3 of stored water per acre in the vicinity of the well. However, because the fracture spacing and size of fracture openings both decrease markedly with depth, so does the amount of available water decrease with depth.

[2] From well logs (State Engineer), no depths to water in producing wells were greater than 200 ft. Dry holes deeper than 200 ft were reported. If a water-filled fracture had been intersected below 200 ft in such a hole, the water level would have risen in the well until it reached the water level in the intersected fracture.

Assuming the average depth to water in the water-bearing fractures for the whole study area is 40 ft (12 m), the storage is about 4,000 ft^3/acre (280 m^3/ha) or 30,000 gal (110,000 l). If one-half of this water were recoverable by wells and if consumptive household use were 10 percent of an estimated average daily pumpage of 165 gal (625 l), 1 acre (0.4 ha) would provide about 2½ years' supply for a residence, not considering natural recharge or reuse.

The mapped alluvial deposits of the area (Trimble and Machette, written commun., 1974) are about 105 mi (169 km) long. They are seldom more than 15 ft (4.6 m) thick. Assuming the saturated part is 300 ft (91 m) wide and 5 ft (1.5 m) thick with 20 percent porosity, the water stored in the saturated alluvial aquifer is about 170 million ft^3 (4.7 million m^3). About 770 million ft^3 (22 million m^3) is stored in water-bearing fractures in a zone extending 300 ft (91 m) below the land surface.

Water Budget

A water budget can be used in planning development of an area and by others interested in the environment of their community. A water budget is an accounting of what happens to the water that falls on an area; how much flows into and out of the area,

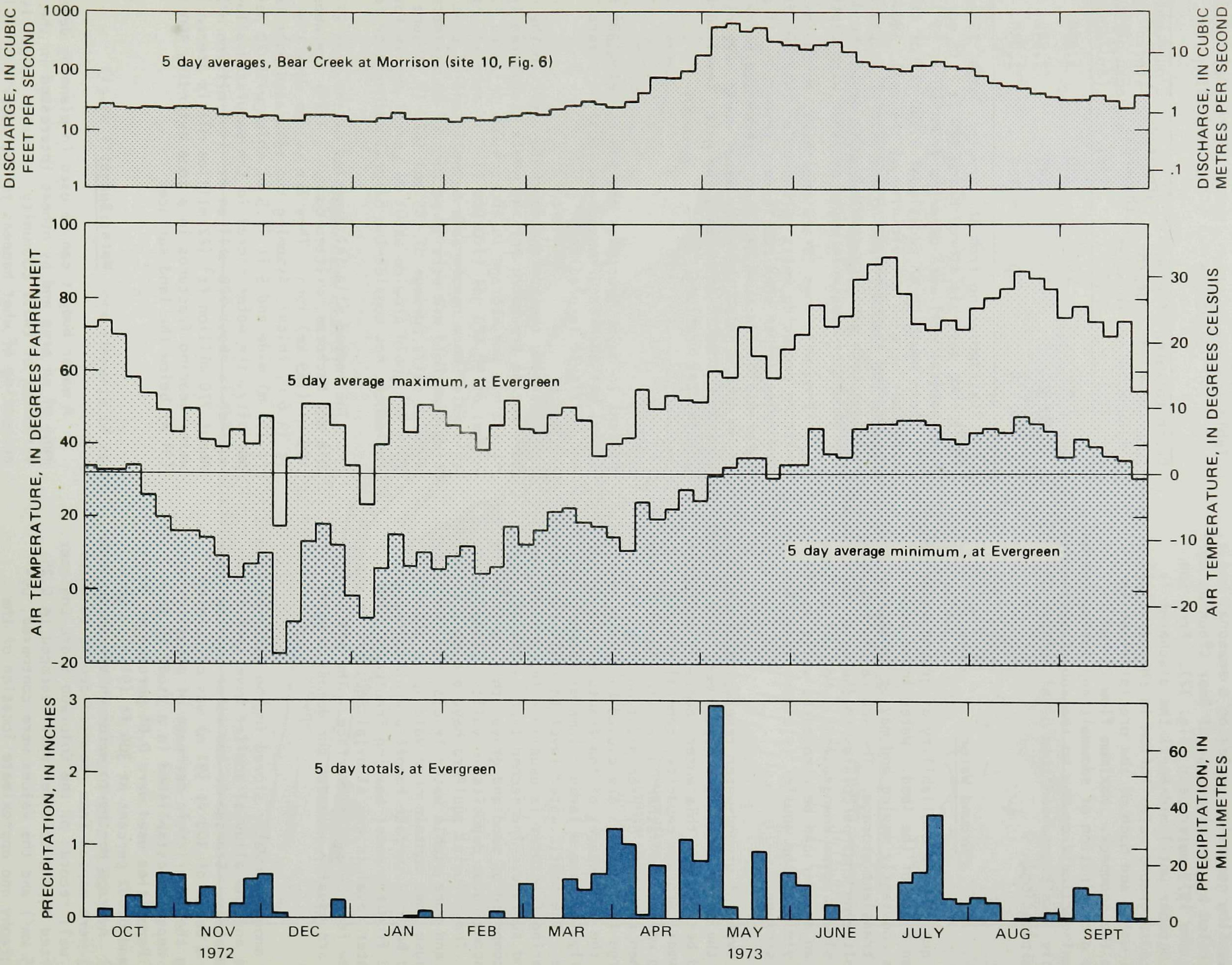


Figure 12.--Flow of Bear Creek at Morrison, and temperature and precipitation at Evergreen, for the 1973 water year. (Climatological data from the U.S. Environmental Data Service, 1972-73.)

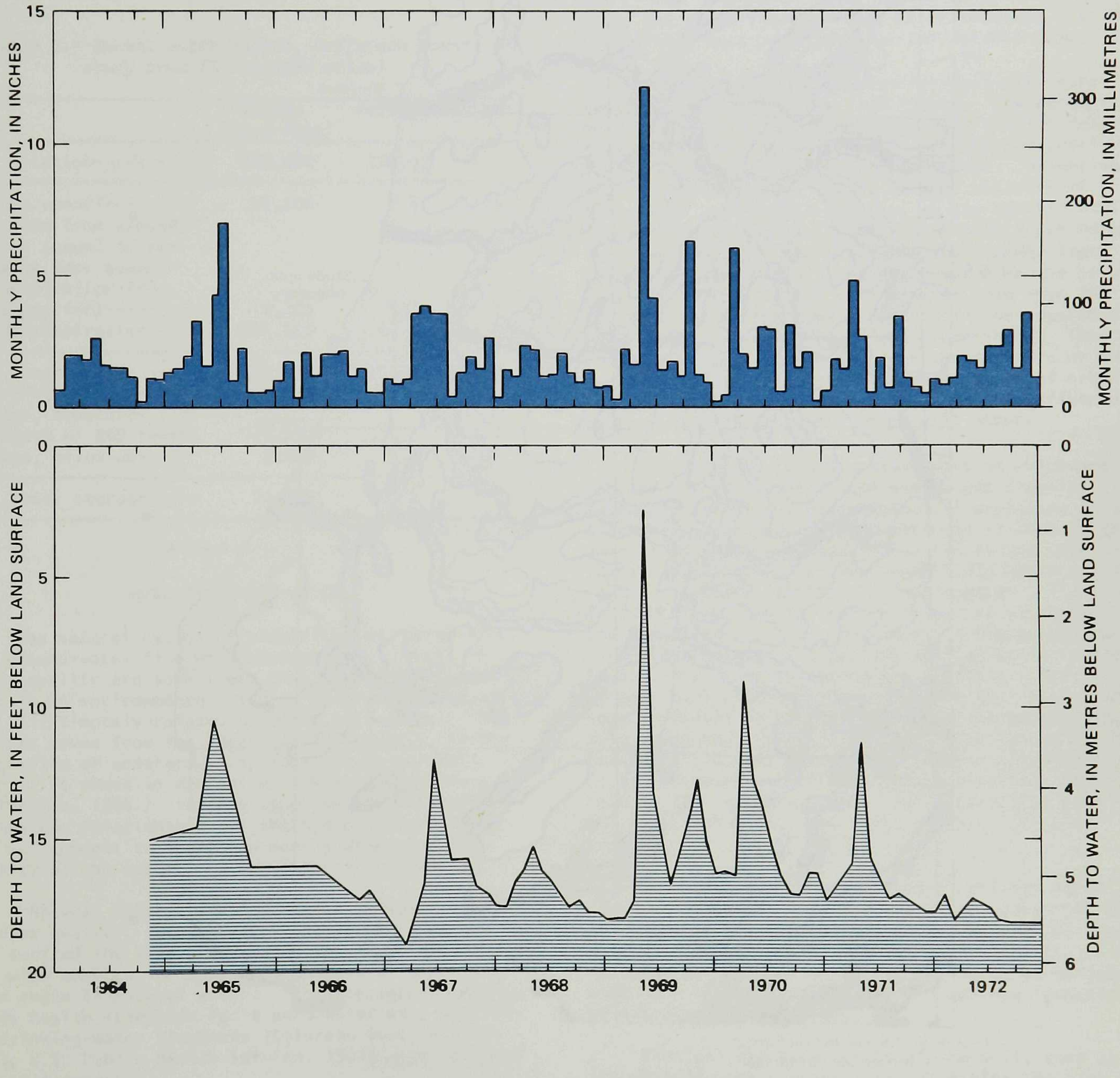


Figure 13.--Monthly precipitation and water-level measurements at well site 1 (fig. 6). (Depths to water and precipitation measurements by Bruce Bryant, written commun., 1972.)

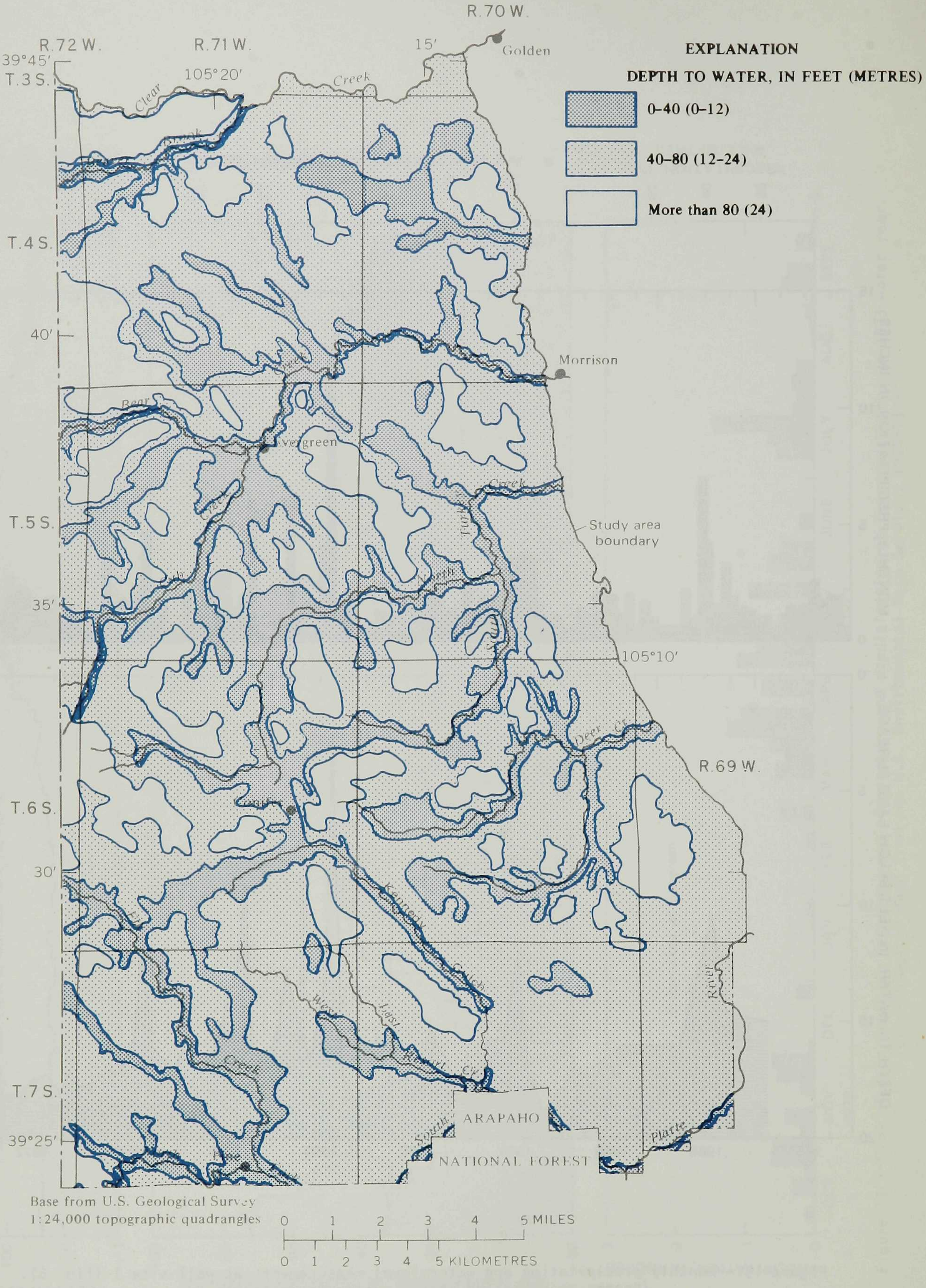


Figure 14.--Average reported depths to water (from records of the State Engineer).

both on the surface and underground; how much is evaporated or transpired by plants; and how much goes into transient storage in the earth. An analysis of precipitation, streamflow, and the areas of each drainage basin are necessary to make this type of calculation (table 3).

Table 3.--*Annual water budget, Jefferson County study area (300 square miles)*

	Volume (acre-feet)	Percent	Inches
Precipitation---------	288,000	100.0	18.0
Surface runoff---------	22,200	7.8	1.4
Base flow from ground water (equal to recharge less evapotranspiration from the aquifer)---------	9,200	3.2	.6
Evapotranspiration-----	256,600	89.0	16.0
Totals-----------	288,000	100.0	18.0
Storage, fractures (to a depth of 300 feet)-	17,600	6.1	1.1
Storage, alluvium------	3,800	1.3	.2
Total storage-----	21,400	7.4	1.3

QUALITY OF THE WATER

The natural cycles of precipitation, streamflow, and ground-water flow with accompanying changes in water quality are some items that should be considered in an environmental study. Environmental quality is intimately related to man's activities. "As a river moves from its inception in snowmelt, in the outpouring of underground springs, or in rainfall runoff, it comes in contact with many environments." (Geldreich, 1966.) In this study we are investigating the relationships of the hydrologic cycle in the environment to learn how man is affecting the quality of the water in a mountain environment.

"Natural water," ideally, would be water of untainted quality, such as was found in the area before man settled the area. "Degraded water" refers to water with chemical or bacterial concentrations higher than those in natural water. "Polluted water" exceeds health standards for a particular use; published drinking-water standards (Colorado Dept. Health, 1971; U.S. Public Health Service, 1962) were followed for this report.

Waste Disposal in the Hydrologic System

Concentrations of chemical constituents and bacteria in ground water are the main pollution problems in the study area. These contaminants mostly come from sewage and household wastes. Man introduces waste water into the hydrologic system, most often using a septic tank with a leach field. County regulations specify that leach field tiles will be 18 in (460 mm) below the land surface with 4 ft (1.2 m) of soil with certain infiltration characteristics below the tiles. The leach field must also be 4 ft (1.2 m) above the water table. Thus, it is required that the leach field must be in soil in the aerobic zone.

Aerobic and anaerobic environments are represented in the subsurface flow system. The aerobic environment consists of the soil zone and the fractured rock zone where the pores are not completely filled with water and oxygen is present. Oxidation reactions predominate in the aerobic environment. Biological activity is greatest in the aerobic environment and this activity decreases with depth below the land surface. The anaerobic environment lies below the water table. The water table may be at or near the surface in the soil zone or more than 100 ft (30 m) below the land surface. In the anaerobic environment, reducing reactions predominate. The environment controls which organisms (aerobic or anaerobic types) will survive, and the types of organisms which are metabolizing have a marked influence on the chemical reactions which will occur.

Septic tanks retain solids, part of which are settled out as sludge as the wastes are digested by various chemical and bacteriological processes in an anaerobic environment. Some nitrogen is removed as ammonia in these processes. The fluids and some solids are discharged into the leach field where aerobic reactions occur. Biological and chemical activity further break down any remaining solids and many of the dissolved chemical compounds. A biological mat, consisting mostly of organisms such as bacteria and fungi, assists by filtering the effluent. The mineral particles and humic matter of the soil also remove some chemicals by adsorption. Bacteria are continually dying and, in addition, are filtered out of the leachate. In this aerobic environment nitrogen tends to be converted to nitrates that are soluble and remain in the leachate. This fluid percolates down to the water-saturated zone where nitrate formation ceases.

Depending upon the hydrologic setting, leachfield effluent may make a short trip through the aerobic zone to the water table with a minimum of available nitrogen compounds converted to nitrates, or the percolating effluent may trickle through an aerobic zone many tens of feet thick with maximum formation of nitrate compounds.

Physical characteristics of the soil, such as its porosity and permeability, determine the size and efficiency of the biological filter mat in a leach field. If permeability is too high, most effluent will percolate downward below the zone of biological activity near the surface in a short distance and filtration of solids and bacteria will be minimal. If permeability is low enough to spread effluent through the leach field, the biological mat will reach maximum size and efficiency. If permeability is too low--a situation that seldom occurs in the mountains with a new and properly constructed system--effluent will move up to the land surface. Leach fields do have a finite life expectancy, determined mostly by the amount of solid materials that escape from the septic tank and plug up the leach field. Because of the occurrence of highly permeable soils, leach fields last longer in the mountains than in many other parts of the country, but eventually all leach fields become ineffective.

When we add a properly functioning septic tank-leach field system of one household to the hydrologic system, what processes take place? Septic tank effluent from an average household with an estimated daily volume of about 150 gal (570 l) percolates down to the water table. It contains chemicals derived from human wastes, unused food products, cleansers, solvents, and other materials. The septic tank leach field reduces bacterial concentrations to insignificant levels. The concentrations of chemicals exceed those in the ground water. When the leach-field effluent reaches the water table, degradation of the ground-water quality takes place (fig. 15). If the septic tank-leach field system is not functioning properly, the effluent will reach the water table rapidly and with less treatment and the degradation will be greater. This degraded water begins to move downslope in the upper part of the saturated zone. Very little water is contained in the fractures, so initially, contamination of the ground water is large. The degraded water begins to mix slowly with the native ground water by molecular diffusion and hydrodynamic dispersion. As the water in the fracture system spreads and moves to lower levels, the chemical concentration eventually is reduced to concentrations approaching health standard limits. It then consists of a fan or plume of degraded ground water in which contamination decreases with distance from the leach field.

A water well, withdrawing water for the household, changes the direction of water movement near the well. As the fracture aquifer contains a small amount of ground water, the withdrawal may dewater many tens of feet of fractures in the vicinity of the well bore. This creates a hydraulic gradient much greater than the natural one and may cause the flow of degraded water to the well and, consequently, back to the household for reuse.

There are other sources of ground-water degradation, although leach fields are the most important. Livestock often pollute wells situated in or near corrals or water tanks. Virtually all of the mountain streams contain some coliform bacteria, as do shallow wells in flood-plain deposits. During floods, many wells are under water and receive contaminated water directly. Sheet wash during rainstorms or during the spring runoff can contaminate wells if they are not properly grouted.

Quality of Surface Water

Water quality of streams in the study area varies seasonally and has different patterns in subalpine and alpine streams. Both types of streams throughout the year have water with low dissolved solids (below 250 mg/l), although in the spring much suspended sediment is in the water. The principal dissolved chemical constituents in the streams of the area are, as a rule, calcium, sodium, and magnesium bicarbonates.

In streams of the subalpine type, the dissolved-solids concentration is lowest during spring runoff and gradually increases to a maximum at times of low flow (figs. 16*A*, 17). At low flow the dissolved-solids concentration equals or sometimes exceeds the average concentration in the ground water (220 mg/l).

Evapotranspiration from the ground water affects the quality of the surface water. Specific conductance--a measure of charged particles in the water sample and closely related to dissolved solids--in ground water lying below a few feet of soil at the upper edge of a sloped meadow had low conductance (in June 1973), whereas the conductance of the ground water where it surfaced out in the meadow was several times higher. The increase in conductance where the water table was at the surface was probably due to greater evapotranspiration. In summer, surveys showed that the water in short tributaries to all the streams had higher salinities than the main streams. This is attributed to the heightened effect of evapotranspiration when the volume of flow is very small.

In the deeply incised major streams of the alpine type, the dissolved-solids concentration is somewhat higher during spring runoff, although the opposite is true for the subalpine streams (figs. 16*B*, 18). Even at base flow when virtually all of the flow is from ground water, the dissolved-solids concentration is low in these streams, about one-half that of the average for ground water in the study area. Apparently, during periods of low flow, most of the water in alpine-type streams originates outside of the study area from ground water low in dissolved solids.

The natural waters of mountain streams are low in nutrients required for growth by plants and animals. When sewage is added to a stream the increase in nutrients may allow abundant growth of blue-green algae and other opportunistic plants and animals. This condition is then termed "eutrophication." Dilution of polluted streams by tributary and ground-water inflow and oxygenation of the water as it flows downstream gradually helps to remedy the eutrophication. In spite of dilution, the introduction of sewage effluent causes a higher concentration of dissolved solids in downstream reaches.

In the mountains, the problems with sewage effluent in streams are not as severe as in the slow-moving streams in the flatlands. Studies of Bear Creek in 1972 and 1973 (fig. 18) show a remarkable recovery from sewage contamination in short distances. The water is affected for only a short distance below the major sewage outfalls at Evergreen and Kittredge. The appearance and smell of

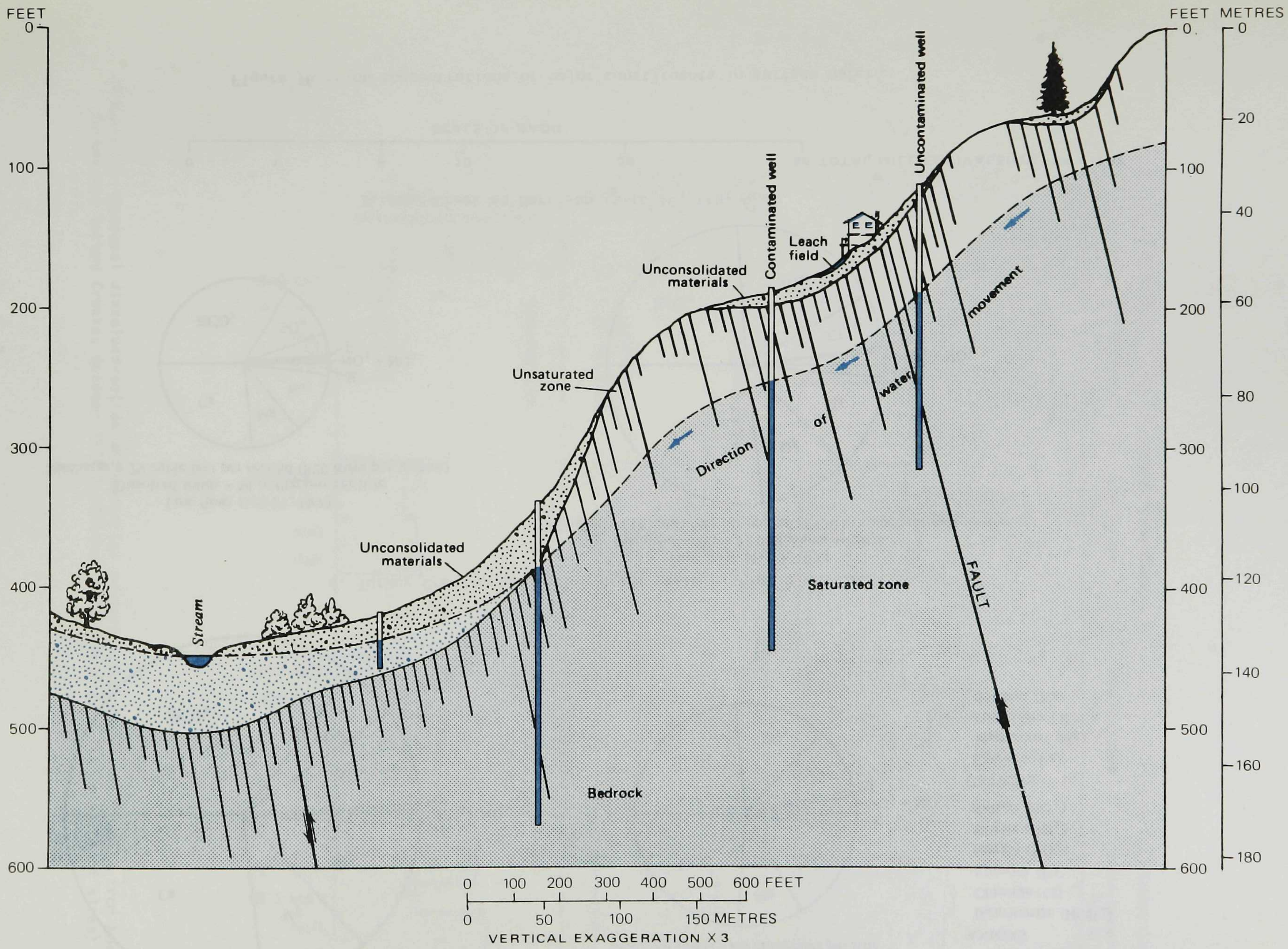
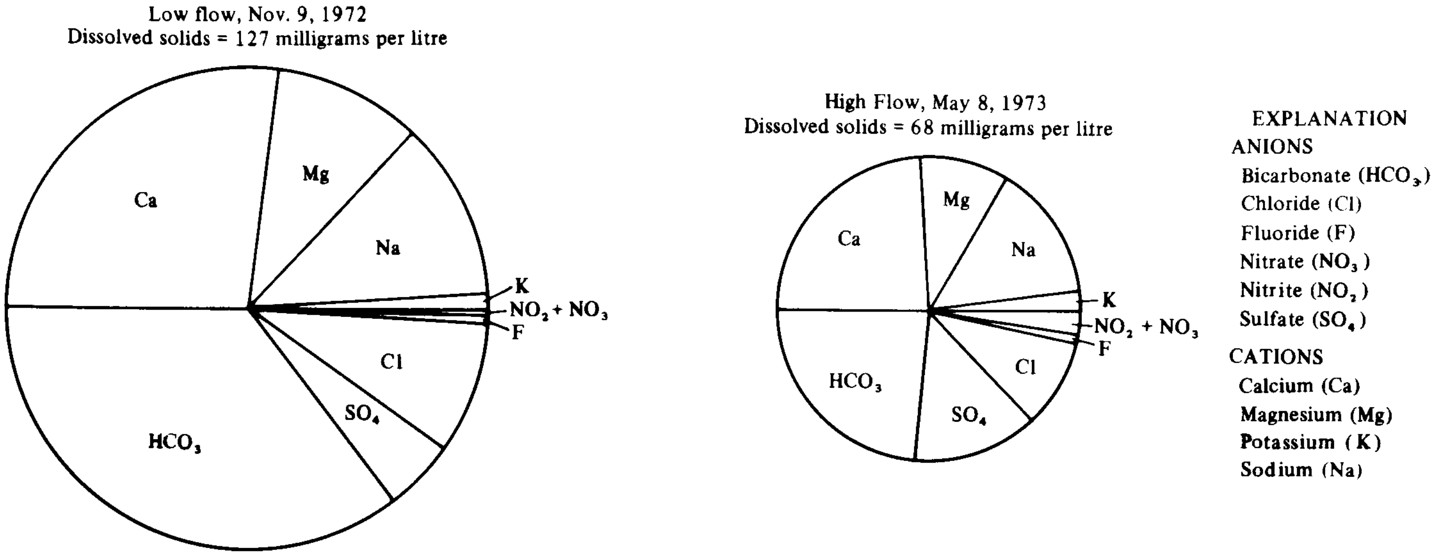
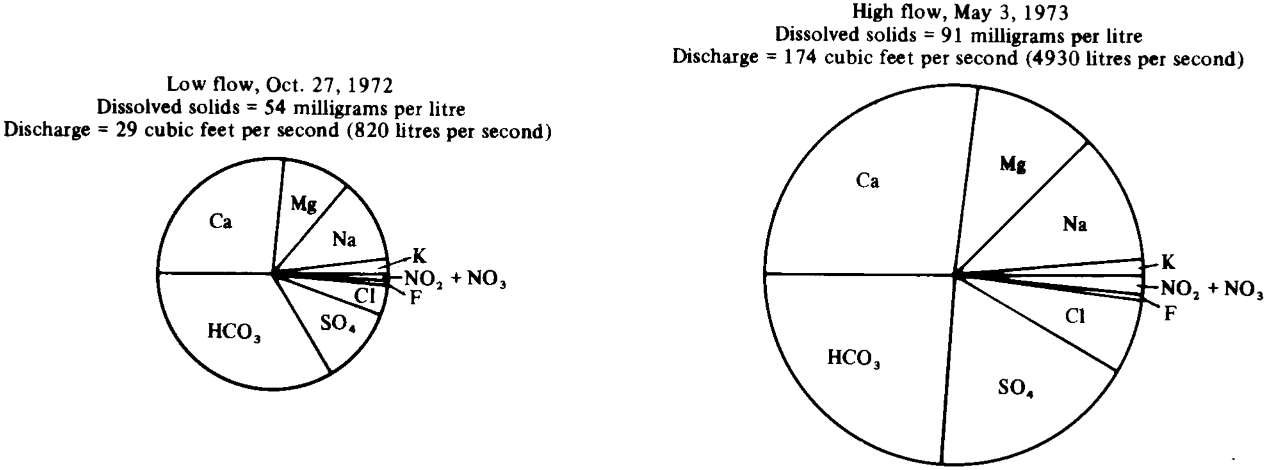


Figure 15.--Degradation of ground water resulting from leach-field effluent.



A. Turkey Creek below Indian Hills (site 4, fig. 6).



B. Bear Creek at Morrison (site 10, fig. 6).

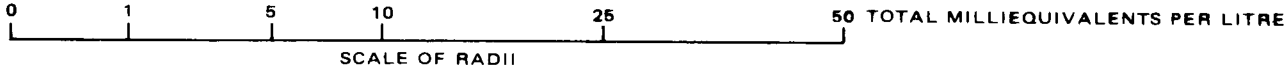


Figure 16.--Ion concentrations of major constituents in surface water.

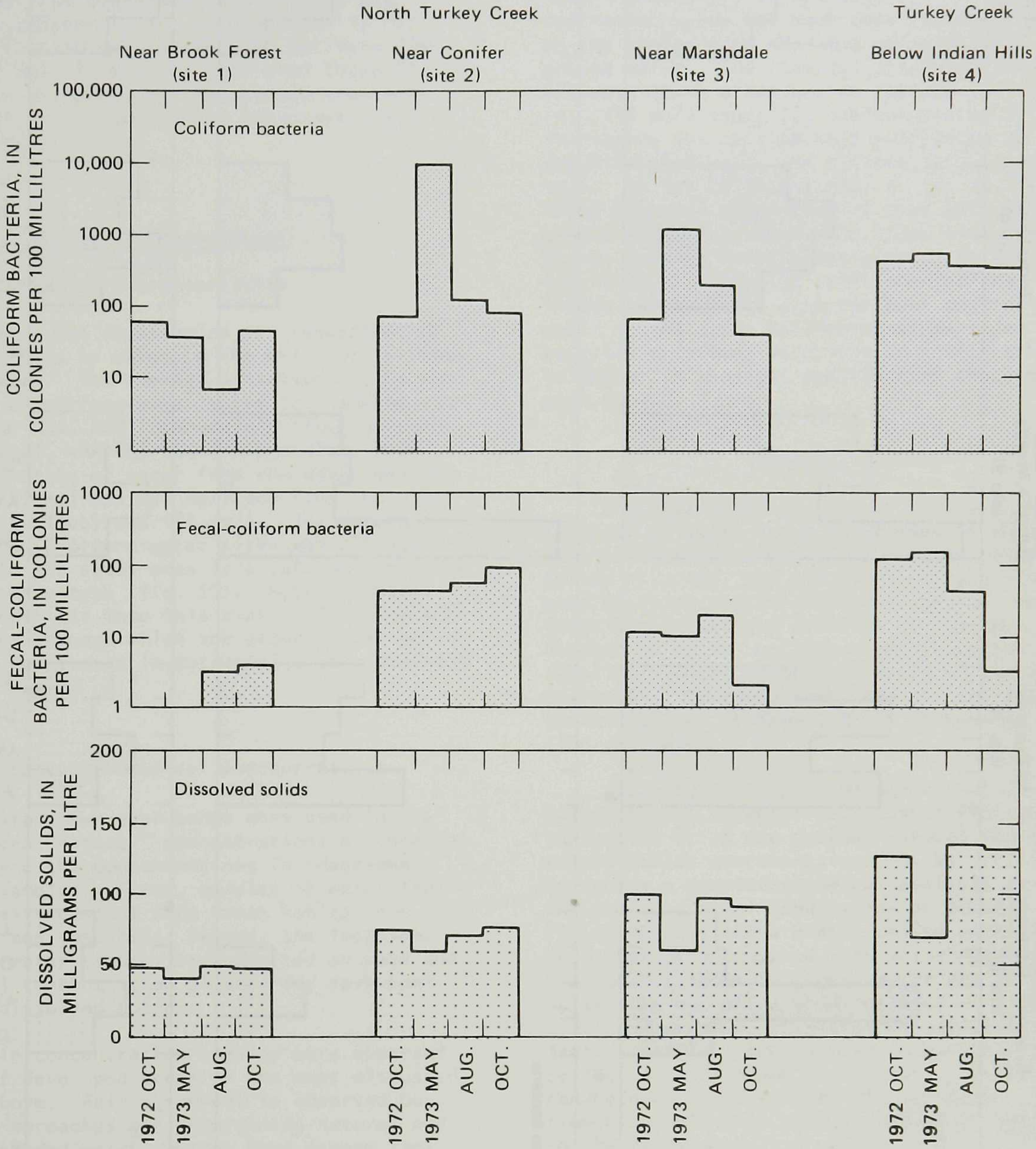


Figure 17.--Seasonal dissolved-solids and bacterial concentrations for water samples from North Turkey and Turkey Creeks, October 1972 to October 1973 (see fig. 6 for location of sites).

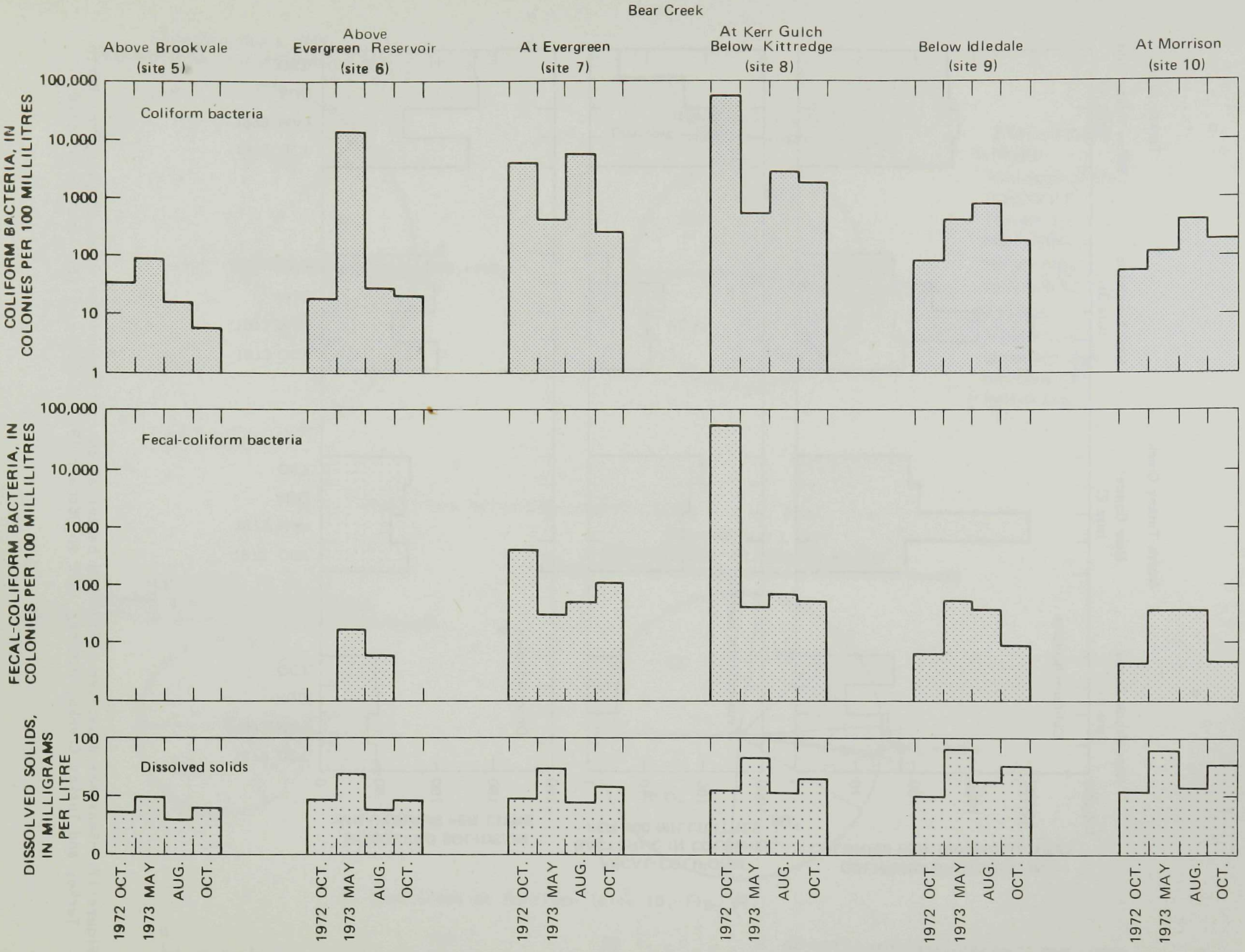


Figure 18.--Seasonal dissolved solids and bacterial concentrations for water samples from Bear Creek, October 1972 to October 1973 (see fig. 6 for location of sites).

the stream indicate sewage effluent in this reach, but the stream quality improves in downstream reaches. The total-coliform bacteria concentration usually returns to near-normal levels by the time the water flows from Evergreen to Morrison, but fecal-coliform content is not as dramatically reduced. Exceptions to this pattern of coliform die-off occur at times of very low flow when there is little dilution or aeration. New sewage-treatment facilities have been installed at Evergreen since the time of this study.

Quality of Ground Water

Chemical Characteristics

Ground water has about twice the concentration of dissolved solids as water in the principal streams of the study area. The average dissolved-solids concentration of 24 surface-water sites for samples collected at high, low, and intermediate flows at each site was 108 mg/l, whereas the average dissolved-solids concentration of water from the water-bearing fractures (42 sites) was 227 mg/l and from the alluvial aquifer (8 sites) was 181 mg/l. The combined average for the 50 ground-water sites was 220 mg/l. Ground water in the study area is a calcium magnesium sodium bicarbonate type (fig. 19). Natural and degraded water both fit into this class. The mineralogy of the rocks through which the ground water percolates plays a large part in determining the chemistry of the ground water.

Significance of Chemical Concentrations

In this study two approaches were used to distinguish between "natural" concentrations of chemical constituents and the concentrations in "degraded" ground-water samples. First, samples of water from streams and wells distant from human habitations were analyzed and compared. Second, the locations of all ground-water samples were plotted on maps and lines of equal concentration plotted for each constituent and dissolved solids.

Changes in concentration areally were observed at the edge of developed areas on the maps discussed immediately above. Fair agreement is observed between the two aproaches for determining natural and chemically degraded water, except that stream samples even during base flow have lower chemical content than most ground-water samples.

The chemical-concentration mapping method makes use of both measured chemical concentration and housing density. Waste disposal at private dwellings is the most probable source of ground-water degradation. The sample sites are posted on a map showing the home sites, with the concentration of the chemical constituent under consideration marked at each sample site. Most samples from isolated sites have concentrations in a lower range than those from communities. When concentrations in samples from developed communities are contoured, a distinct pattern of diminishing concentrations outward from the developed area is observed. Working first in areas with the highest sampling density, it was possible to establish a concentration value for each constituent that best marked the change from degraded to relatively unaffected ground water. The chemical concentrations used to separate these areas are as follows: dissolved solids, 155 mg/l (specific conductance of 250 μmhos/cm [micromhos per centimetre]) multiplied by 0.62); chloride, 4.0 mg/l; and nitrate as nitrogen, 0.20 mg/l. On the following maps (figs. 20, 21, 22), the lines of equal concentration that best delineate degraded water are shown. In areas with sparse sampling, housing density was used as an aid in contouring, thus transferring relationships that were established in the areas with the best control. Ground water in the areas delineated as degraded is not necessarily polluted, according to health standards, but is poorer in chemical quality than that in the adjacent areas.

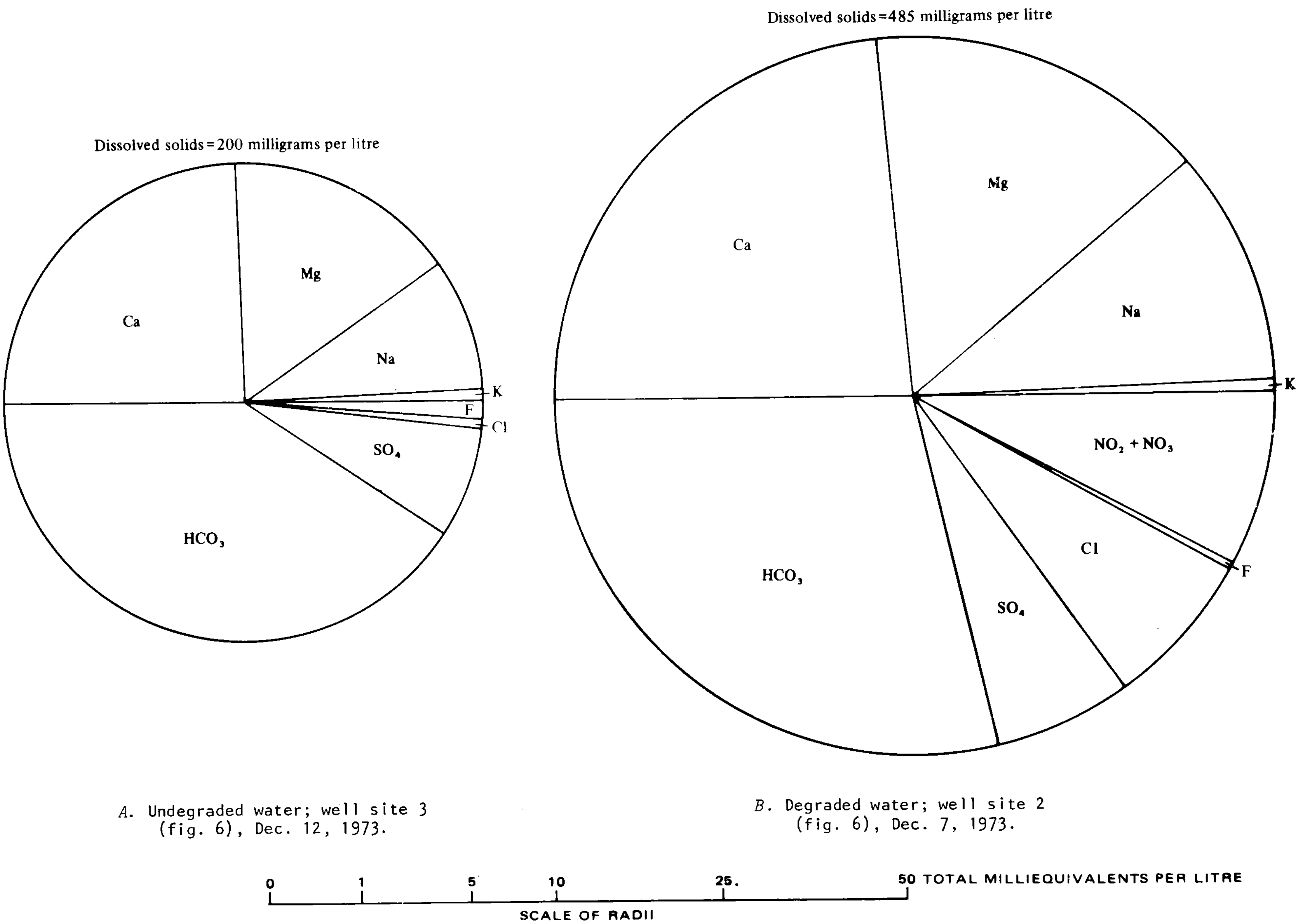
Chemical Quality

The interrelationships of the five chemical indicators of water degradation used in the study are simple. Dissolved solids, dissolved potassium, dissolved chloride, and dissolved nitrate plus nitrite have positive statistical correlations, meaning that their concentrations increase or decrease together. Changes in total phosphorus concentration do not parallel changes in concentration of the other constituents. As conductance and nitrite-plus-nitrate concentrations increase, total phosphorus concentration decreases.

Dissolved solids.--The concentration of dissolved solids in water is a useful indicator of contamination or of any unusual natural source. Dissolved-solids concentrations may be estimated either by making a complete chemical analysis or by measuring the electrical conductance of a water sample. The electrical measurement, called specific conductance, has been compared with dissolved-solids concentration for about 50 ground-water and 50 surface-water samples, and a good correlation is seen. Specific conductance, in micromhos per centimetre at 25 degrees Celsius, can be used to estimate dissolved solids, in milligrams per litre, by multiplying the conductance value by 0.62 (62 percent). The relationship applies to either surface or ground water in the study area.

Specific-conductance values ranged from 25 to 2,400 μmhos/cm at 25°C, with a modal range of from 250 to 275 μmhos/cm at 25°C (fig. 23). The modal range is the interval that contains the highest frequency of samples.

Mapping of variations in dissolved-solids concentration is useful for locating areas where water degradation is taking place. The apparent break between natural and degraded water is 155 mg/l (fig. 20).



A. Undegraded water; well site 3 (fig. 6), Dec. 12, 1973.

B. Degraded water; well site 2 (fig. 6), Dec. 7, 1973.

Figure 19.--Ion concentrations of major constituents in ground water.

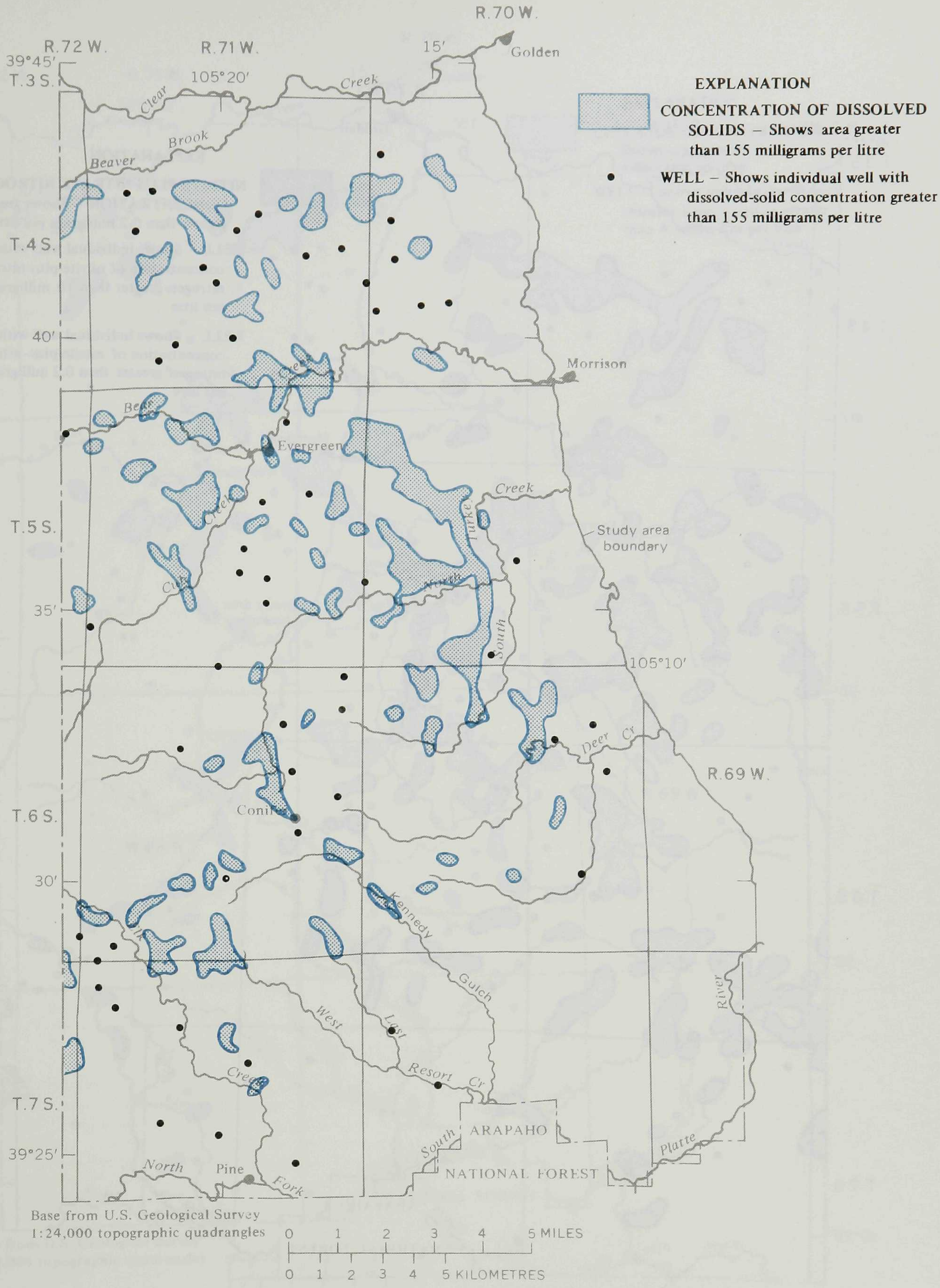
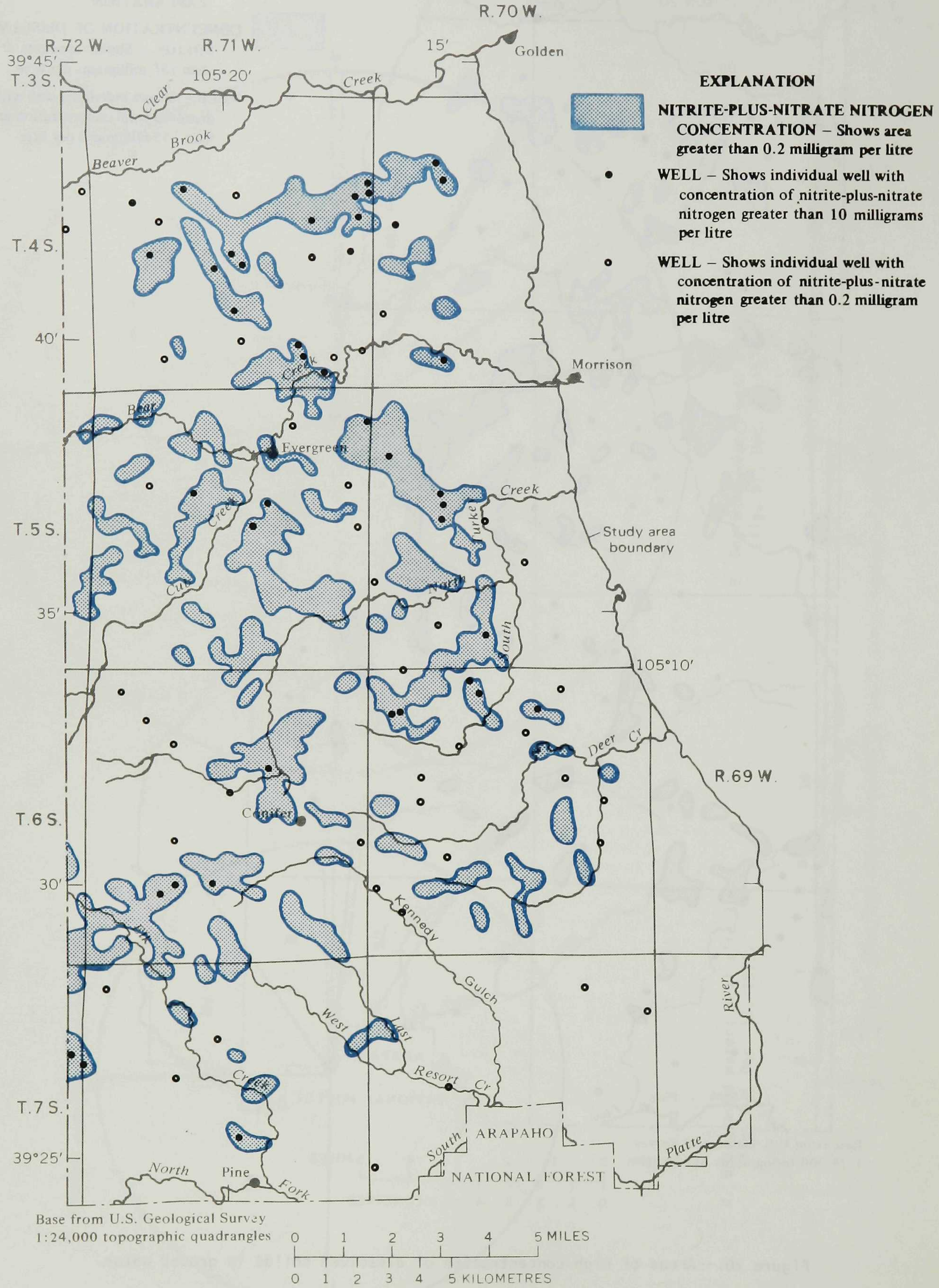
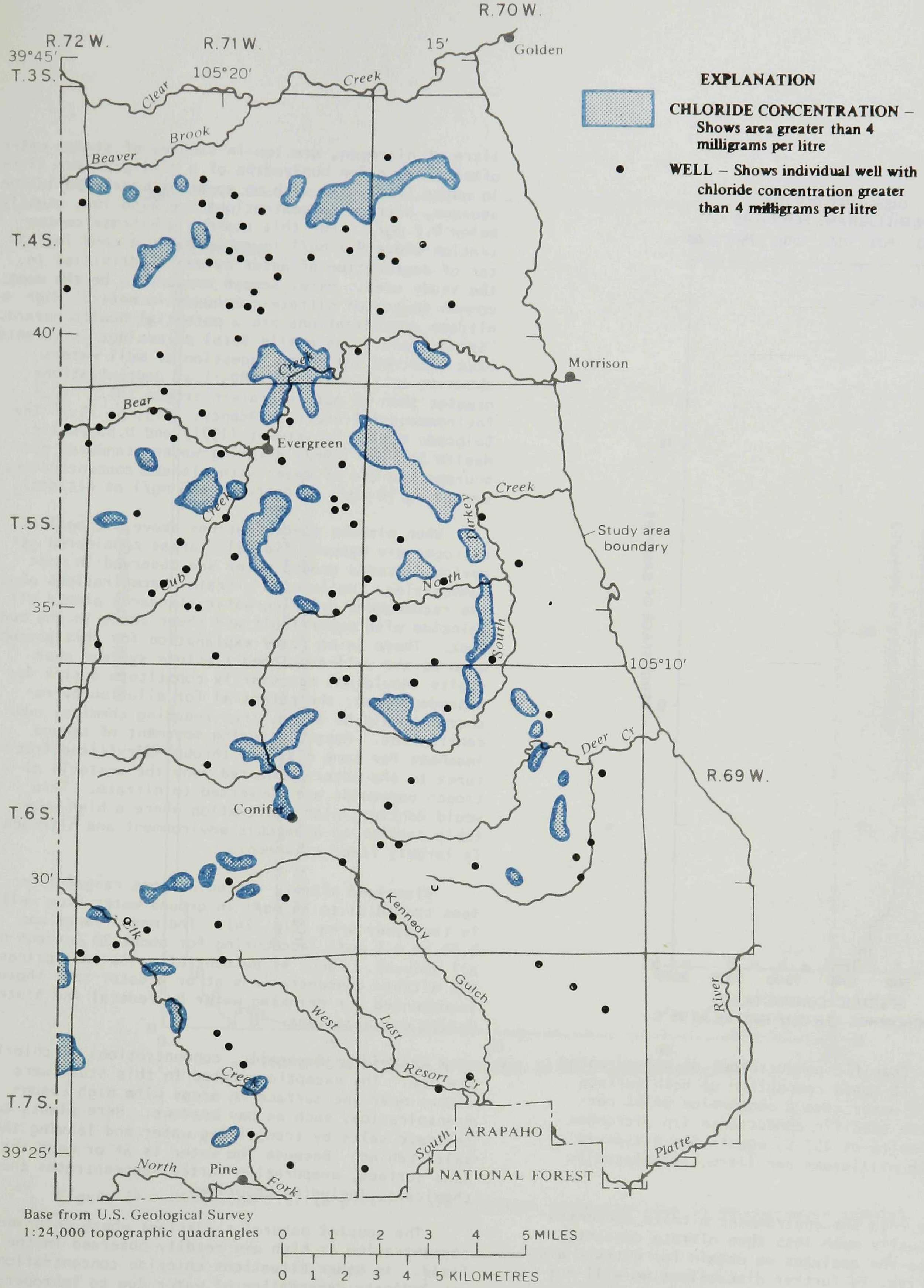


Figure 20.--Areas of high concentration of dissolved solids in ground water.



Base from U.S. Geological Survey
1:24,000 topographic quadrangles

Figure 21.--Areas of high concentration of dissolved nitrite-plus-nitrate nitrogen in ground water.



Base from U.S. Geological Survey
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Figure 22.--Areas of high concentration of dissolved chloride in ground water.

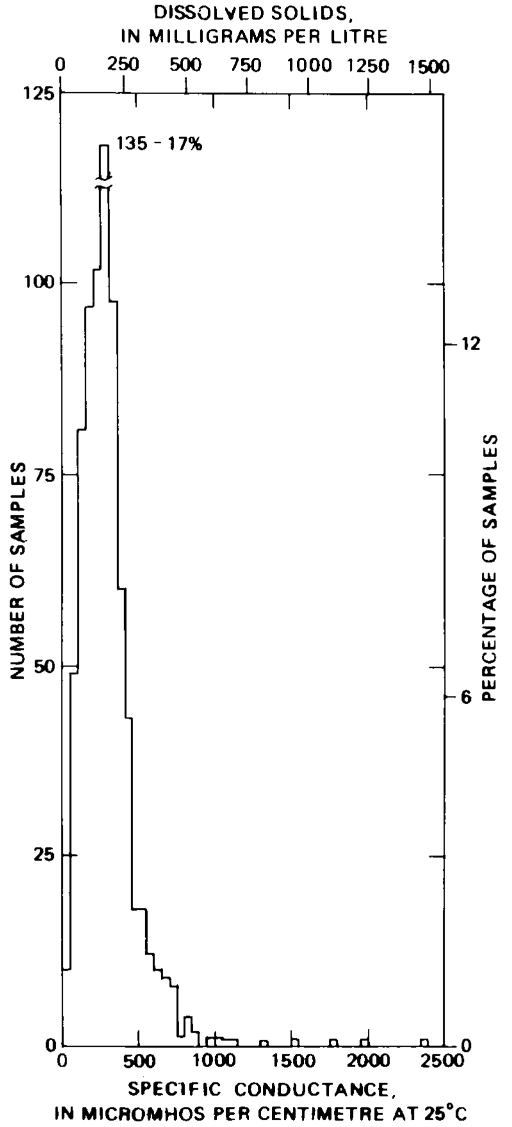


Figure 23.--Specific conductances of ground-water samples. (Graphic comparison of both surface and ground water gave a conversion of 62 percent of the specific conductance [in micromhos per centimetre at 25° C] equals the dissolved solids [in milligrams per litre, calculated]).

Nitrate.--In the environment nitrite concentrations are usually much less than nitrate concentrations. Since the analyses we obtain for nitrate also include nitrite, in further discussions we will not differentiate between nitrate, and nitrate-plus-nitrite nitrogen concentrations.

Nitrate compounds are not naturally abundant in water in the mountain environment. For instance, nitrate concentrations, expressed in milligrams per litre of nitrogen, are low in samples of stream water, often being a few hundredths of a milligram per litre. In water from wells with no apparent nearby pollution sources, nitrate concentrations are also low, usually below 0.2 mg/l. For this reason, a nitrate concentration above 0.2 mg/l is regarded as a good indicator of degradation of water by man's activities in the study area. Here, sewage appears to be the most common source of nitrate compounds in water. High nitrate concentrations are a potential health hazard. "Serious and occasionally fatal poisonings in infants have occurred following ingestion of well waters shown to contain nitrate (NO_3-) at concentrations greater than 10 mg/l nitrate-nitrogen (N)." (U.S. Environmental Protection Agency, 1973, p. 73.) The Colorado Health Department (1971) and U.S. Public Health Service (1962) drinking-water standards discourage the use of water with nitrate concentrations exceeding 10 mg/l as nitrogen (45 mg/l as nitrate).

When nitrate concentrations above 0.2 mg/l of nitrogen are mapped (fig. 21), areas considered as having degraded ground water are observed in most communities. Wells with nitrate concentrations above the recommended drinking-water standards almost all coincide with major fault and shear zones in the bedrock. There is no ready explanation for this phenomenon as the well-developed fracture systems near faults should not necessarily constitute a sink for degraded water; the potential for dilution by recharge should be large, thus reducing chemical concentrations. Possibly during movement of sewage leachate for some distance through air-filled fractures to the water-saturated zone the unstable nitrogen compounds are converted to nitrate. This would contrast with a situation where a high water table creates an anaerobic environment and nitrogen is largely freed as ammonia.

Dissolved nitrate concentrations ranged from less than 0.01 to 54 mg/l in ground water from wells in the study area (fig. 24). The modal range was 0.00 to 0.1 mg/l (accounting for about 20 percent of all values). About 4½ percent of wells and springs had nitrate concentrations at or greater than those recommended for drinking water by Federal and State health organizations.

Chloride.--Generally, concentrations of chloride are low. The exceptions noted in this study were waters near the surface in areas with high evapotranspiration, such as hay meadows. Here plants concentrate salts by transpiring water and leaving the salts behind. Because the water is at or near the land surface, evaporation further concentrates the chemicals, including chlorides.

The special natural situations where chloride concentration is high are readily observed in the field. In other situations chloride concentration may indicate degradation of water due to improper waste-disposal practices and recycling of a limited amount of ground water from a well through the leach field and back to the aquifer (fig. 22). A minimum value of 4.0 mg/l chloride was used in mapping areas with degraded water.

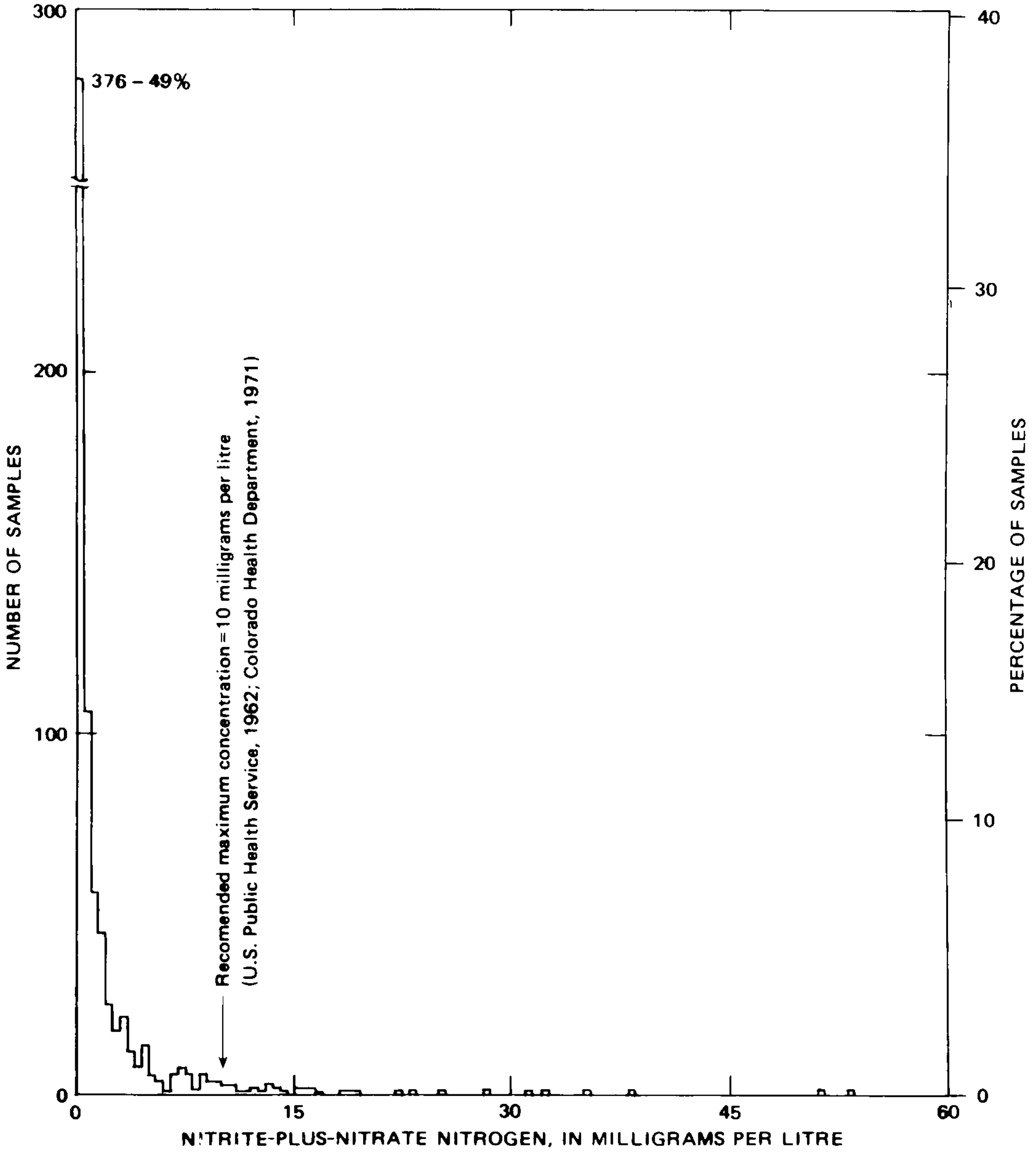


Figure 24.--Dissolved nitrite-plus-nitrate nitrogen concentrations in ground-water samples.

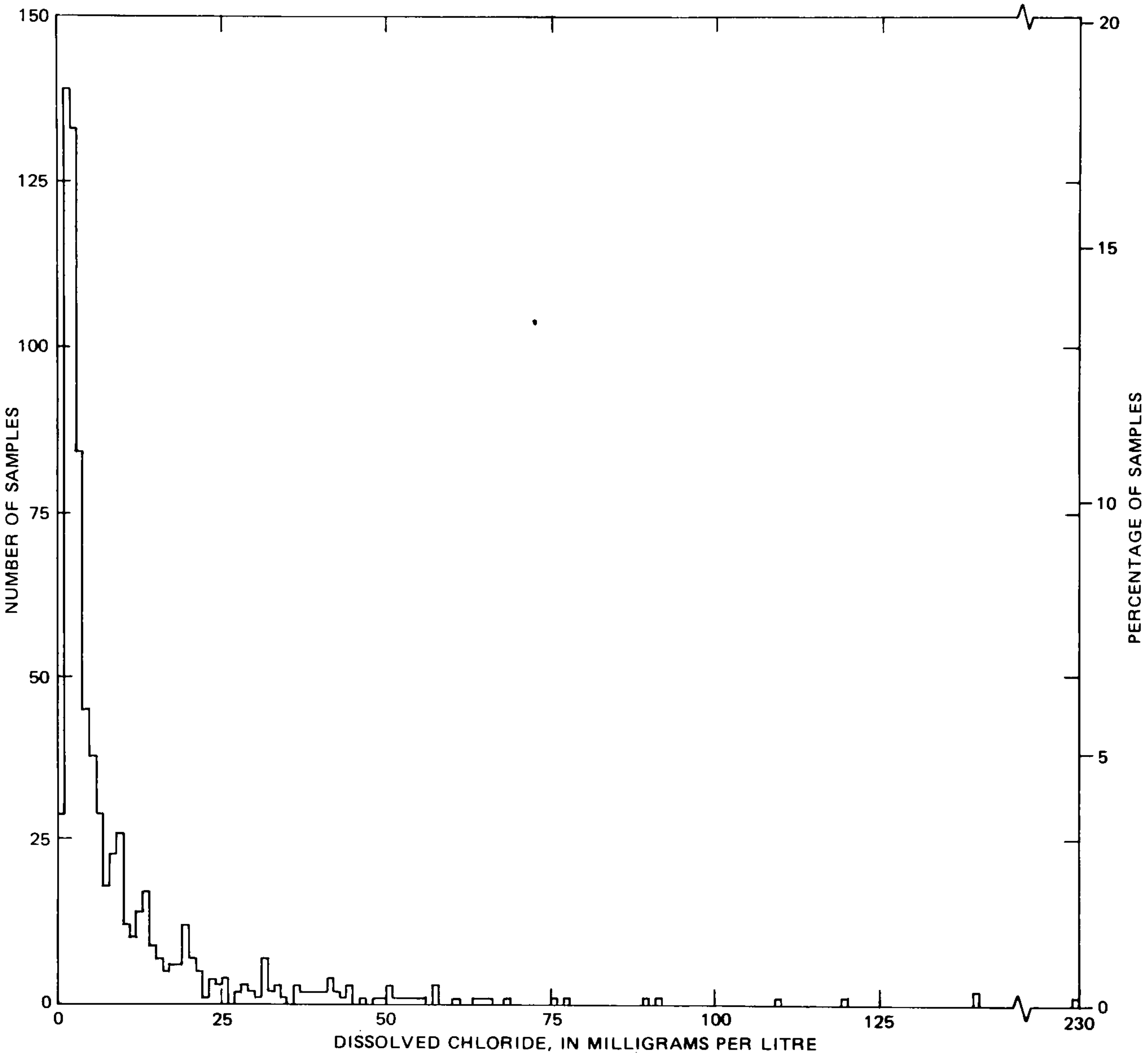


Figure 25.--Dissolved chloride concentrations in ground-water samples.

The range for dissolved chloride concentrations was from 0.3 to 230 mg/l, and the modal range of concentrations was from 1 to 2 mg/l (fig. 25).

Potassium.--The concentration of this element parallels that of dissolved solids and chloride. However, quantities of potassium present are variable because potassium is adsorbed by some fine-textured minerals. Since the other indicator chemicals are much more responsive and correlate generally with potassium concentration, they are used in this study in preference to potassium as indicators of pollution.

Dissolved potassium concentrations ranged from less than 0.1 to 9 mg/l. The modal range was from 1 to 1.5 mg/l (fig. 26).

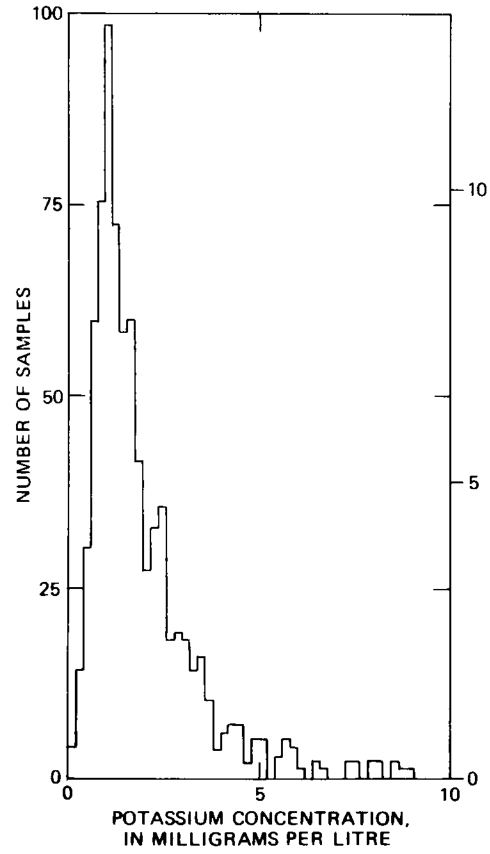


Figure 26.--Dissolved potassium concentrations in ground-water samples.

Phosphorus.--Phosphorus concentrations were low in water samples. It is an essential nutrient for plant growth. This element is commonly found in sewage effluent as phosphate, but is very quickly adsorbed to soil materials and, for this reason, seldom travels far from the leach field where it is sequestered and separated from the nitrate-bearing leachate that percolates down to the water-saturated zone. Phosphorus concentrations in ground water proved so low regardless of the pollution sources that phosphorus analyses are not very useful in pollution studies of this type.

Total phosphorus concentrations ranged from less than 0.01 to about 1 mg/l. The modal range was from 0.00 to 0.01 mg/l. More than 60 percent of the concentrations were 0.02 mg/l or less (fig. 27).

Bacteriological Quality

"The objective of using the coliform group as an indicator of the sanitary quality of water is to determine that the water is free from pathogenic entities." (Geldreich, 1966, p. 42.) It has been established that when coliforms are present in water, there is a high probability that disease-causing bacteria and viruses are also present (Geldreich, 1966). The coliform group of bacteria lives principally in the digestive tracts of warm-blooded animals. They are abundant in sewage and animal feces. Their presence in ground water indicates probable contamination from nearby sewage sources or corrals. Coliforms do not survive long in streams and especially in ground water because life-sustaining nutrients are scarce and the bacteria are removed from their natural environment.

Membrane filtration tests for coliform bacteria in the study area indicate wide variations in the occurrence of the coliform group of organisms. In some communities about 50 percent of the wells tested contained these bacteria. In other areas there were few positive tests. Water samples from wells in the alluvial aquifer contained one or more colonies per 100 ml in 44 percent of the samples. The close association with bacteria-carrying streams seems to be the cause. In water from wells in biotite gneiss--a common aquifer--about one-half as many occurrences of total-coliform bacteria as the average for the study area were noted. The biotite gneiss weathers readily, and the detritus layer formed is thicker and apparently has better filtration characteristics than that formed from other rock types in the study area.

High density of waste-treatment units combined with adverse geologic conditions, such as thin permeable detritus and highly fractured bedrock, causes some ground-water pollution by total-coliform bacteria. Water from beneath a few of the old, densely populated communities in the study area was slightly contaminated, but water from beneath new developments where houses are located on large lots was seldom contaminated. Those few of the latter that were found to be contaminated indicate adverse geologic factors such as fractures connecting well and leach field.

The apparent controls for the occurrence of total-coliform bacteria in wells are: location (in flood plain or not), housing density, suitability of surface materials for leach-field operation, well

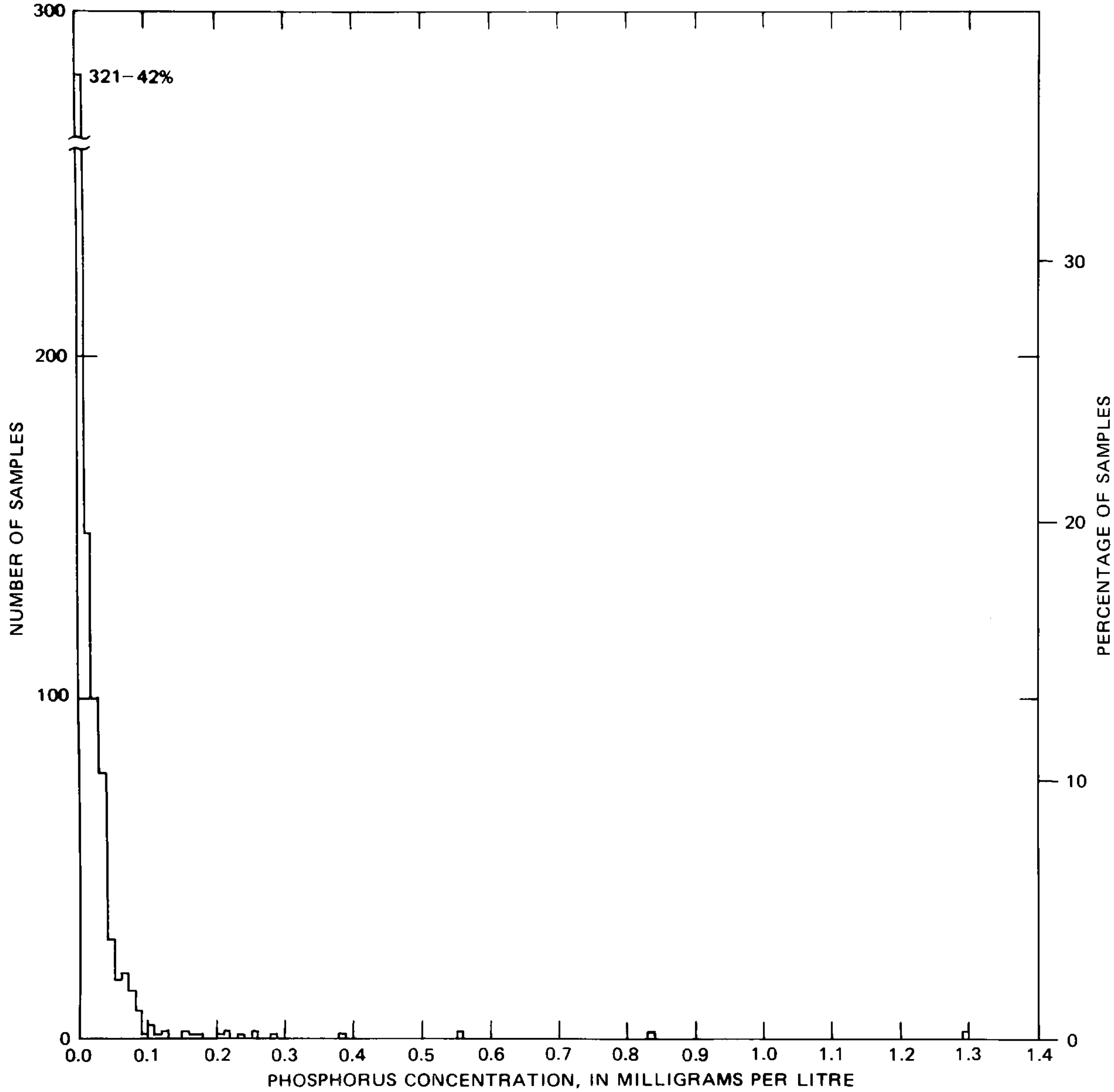


Figure 27.--Total phosphorus concentrations in ground-water samples.

construction, septic-tank design and maintenance, and the abundance of sources of surface contaminants, such as corrals. The significance of these factors is discussed later in the report.

Bacterial concentrations ranged from 0 to 1,400 total-coliform bacteria per 100 ml. The mode was zero and included over 70 percent of the samples. Nineteen percent of the ground-water sites sampled had two or more total-coliform bacteria per 100 ml (fig. 28). Total-coliform concentrations did not significantly correlate with any of the other factors, except that aquifers in certain rock types had markedly higher occurrences of coliform bacteria (see discussion in following sections).

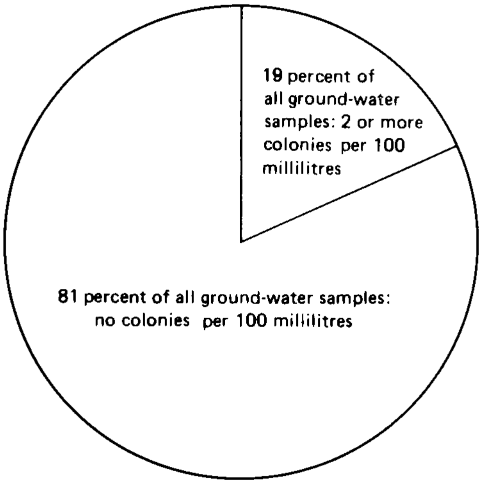


Figure 28.--Total-coliform bacterial concentrations in ground-water samples.

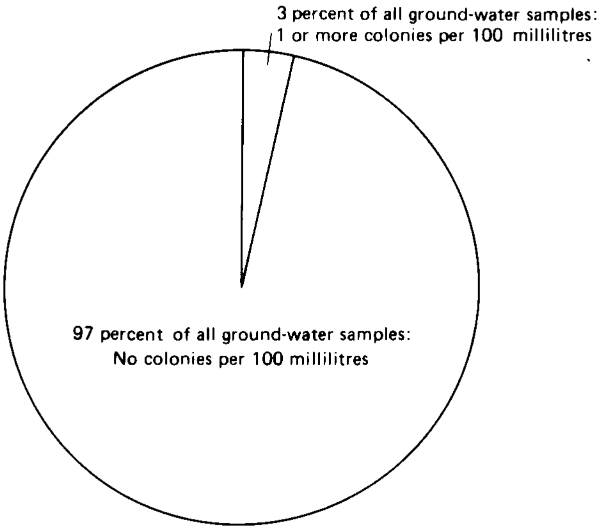


Figure 29.--Fecal-coliform bacterial concentrations in ground-water samples.

Fecal-coliform bacteria concentrations ranged from 0 to 46 per 100 ml. Values were zero in 97.4 percent of the cases (fig. 29). No correlations were found with any of the other variables except aquifer type.

Water Quality and Health Standards

Because soluble minerals occur in the geologic formations of the area, some natural water contains dissolved minerals in amounts that render the water unsuitable for many purposes. Table 4 shows the drinking-water standards of the Colorado Health Department and the number of samples taken from the study area that exceed these standards. Analyses

Table 4.--*Ground-water samples exceeding Colorado Health Department (1971) drinking-water standards*

[Values expressed in milligrams per litre unless otherwise specified]

Analysis	Recommended limit	Number of samples	Samples exceeding limit	Percent exceeding limit
Dissolved chloride-	250	50	0	0
Dissolved fluoride-	2	50	7	14
Dissolved iron-----	.3	50	4	8
Dissolved manganese--------	.05	50	9	18
Dissolved nitrite-plus-nitrate nitrogen---------	10	50	5	10
Dissolved sulfate--	250	50	1	2
Dissolved solids (sum of constituents)-------	500	50	1	2
Dissolved selenium-	.01	49	0	0
Coliform bacteria, in colonies per 100 millilitres--	2	49	0	0
Fecal-coliform bacteria, in colonies per 100 millilitres--	1	49	0	0
Dissolved gross-alpha radioactivity (presence of radium-226 unknown), in picocuries per litre-	3	11	9	82
Dissolved gross-beta radioactivity (presence of strontium-90 and alpha-emitters unknown), in picocuries per litre------------	10	11	1	9

were obtained for samples collected from 49 wells and 1 spring. Fluoride and radiochemical concentrations in ground water are discussed in more detail below.

The mineral fluorite is often associated with granitic intrusives. Several small fluorite deposits have been discovered in the study area. In view of these facts, it is not surprising that fluoride compounds in concentrations that exceed the Colorado Health Department standards (1971) for drinking water have been detected in some ground-water samples. Excessive fluoride in drinking water can harden and mottle children's teeth.

There are numerous small uranium prospects in part of the study area, indicating the presence of localized radioactive deposits. Water samples from 9 of 11 observation wells drilled by the U.S. Geological Survey had dissolved gross-alpha radioactivity in excess of 3 pCi/l (picocuries per litre), the upper limit for drinking water when the source of radiation is radium-226, according to Colorado Health Department standards (1971) and the U.S. Public Health Service (1962) recommended drinking-water standards. Radium-226 is concentrated in bones, thus exposing cells that produce red blood cells to radiation. The radiation may damage the cells and cause pernicious anemia. However, William Dunn, chief chemist for the Colorado Department of Health (oral commun., 1974), indicates that naturally occurring uranium compounds in the State account for much alpha radiation. Only when total alpha radioactivity exceeds 10 pCi/l, does the State routinely check for radium-226. Water from 4 of the 10 wells had dissolved alpha radiation above 10 pCi/l, indicating the possibility--though not necessarily the probability--that radioactivity from bone-seeking isotopes could be present in concentrations constituting a health hazard.

It is always prudent to have new ground-water supplies analyzed, especially if the well is in an undeveloped area or in the vicinity of known mineralization. Analyses should be made for toxic trace metals, dissolved minerals, radioactivity, and coliform bacteria.

GROUND-WATER SAMPLING

Because the study area was large and had to be sampled in a limited period of time, it was not feasible to sample all wells located in the study area. Ideally, samples should be spaced evenly over the entire region without concentrating too heavily in the more populated areas, but there should be a high enough overall sampling density so that localized trends could be detected. It was decided to sample two wells per quarter-section, and to select wells separated by at least 0.2 mi (0.3 km). This was not always attainable because the population of the area is not evenly distributed, some of the larger municipalities do not rely on private wells for supply of water, and in some areas it often was not possible to locate owners to get permission to take water samples.

All samples were analyzed according to the Standard Methods for the Examination of Water and Waste Water, 13th edition (American Public Health Association, 1971) and published methods of the U.S. Geological Survey (Brown and others, 1970; Goerlitz and Brown, 1972; and Slack and others, 1973; radiochemical analyses, V. J. Janzer and L. J. Schroder, written commun., 1975). Analyses for selected chemical constituents were made on samples of water from most wells and springs. Constituents determined were specific conductance, total phosphorous, dissolved potassium, dissolved chloride, and dissolved nitrite plus nitrate, all of which were specifically selected as possible indicators of contamination of the well water by sewage.

Selected chemical analyses were made for samples from 721 wells and 31 springs. Thirty-four of these wells and one spring were subsequently resampled. For these latter samples, the concentrations of the indicator constituents generally differed little from those in the samples collected earlier at the same site.

More extensive analyses were run on samples from 49 wells and one spring. Thirty-three of these sites had previously been sampled for a selected analysis. Availability of a State Engineer's registration form was another criterion used to select these wells, thereby increasing the amount of information on the well.

Based on our survey of 737 wells and 31 springs in the study area, most of the wells and springs are small-capacity (less than 10 gal/min or 0.63 l/s) and privately owned household water supplies (fig. 30). Most of the water supply in the area is from wells. A few of the towns have public water supplies, and some of these are supplied in part or totally by wells. A few wells are used only for irrigation or for stock supply.

Reported well and spring yields ranged from 0.1 to 291 gal/min (0.006 to 18.4 l/s). The most frequent range or modal interval was from 0 to 1 gal/min (0 to 0.06 l/s). Yields did not correlate significantly with any of the pollution-indicator variables. Most of the wells are 6 in (150 mm) in diameter, and have about 20 ft (6.1 m) of surface casing, grouted with clay or cement. They range in depth from a few feet to 700 ft (213 m) and average about 100 ft (30 m) deep, with a reported yield of around 1 gal/min or 0.06 l/s (fig. 31). Depths to bedrock range from 0 to about 150 ft (0 to 46 m) (fig. 32), with the most common depth (about 47 percent) being 10 ft (3.0 m) or less.

Water from deeper wells generally has higher specific conductance and lower phosphorus and chloride concentrations. Deeper wells generally have encountered bedrock nearer the surface and are on smaller lots than the shallow wells. Newer wells tend to be deeper than older wells.

The producing aquifer in 3 of every 4 wells was fractured crystalline Precambrian rock, with allu-

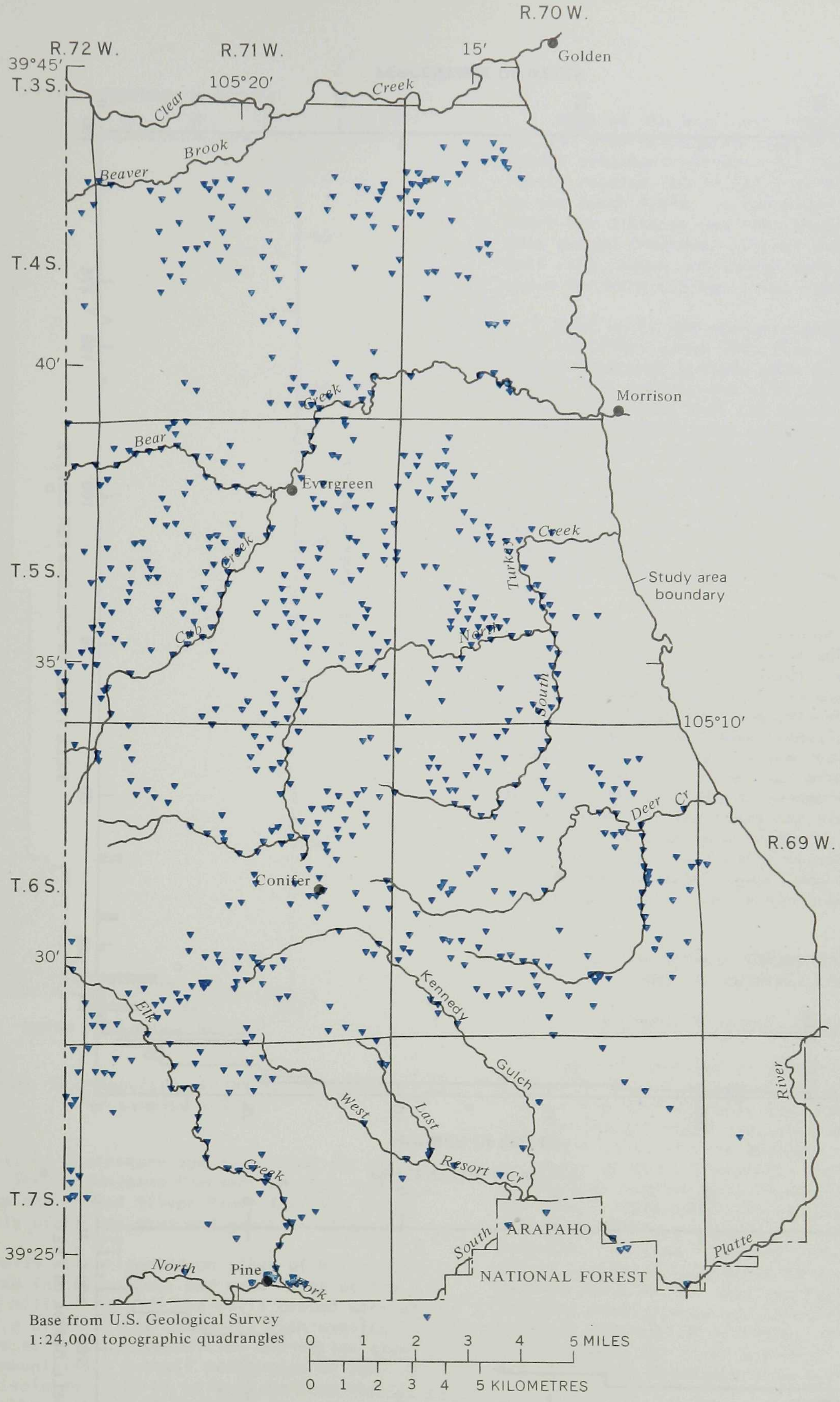


Figure 30.--Locations of ground-water sampling sites.

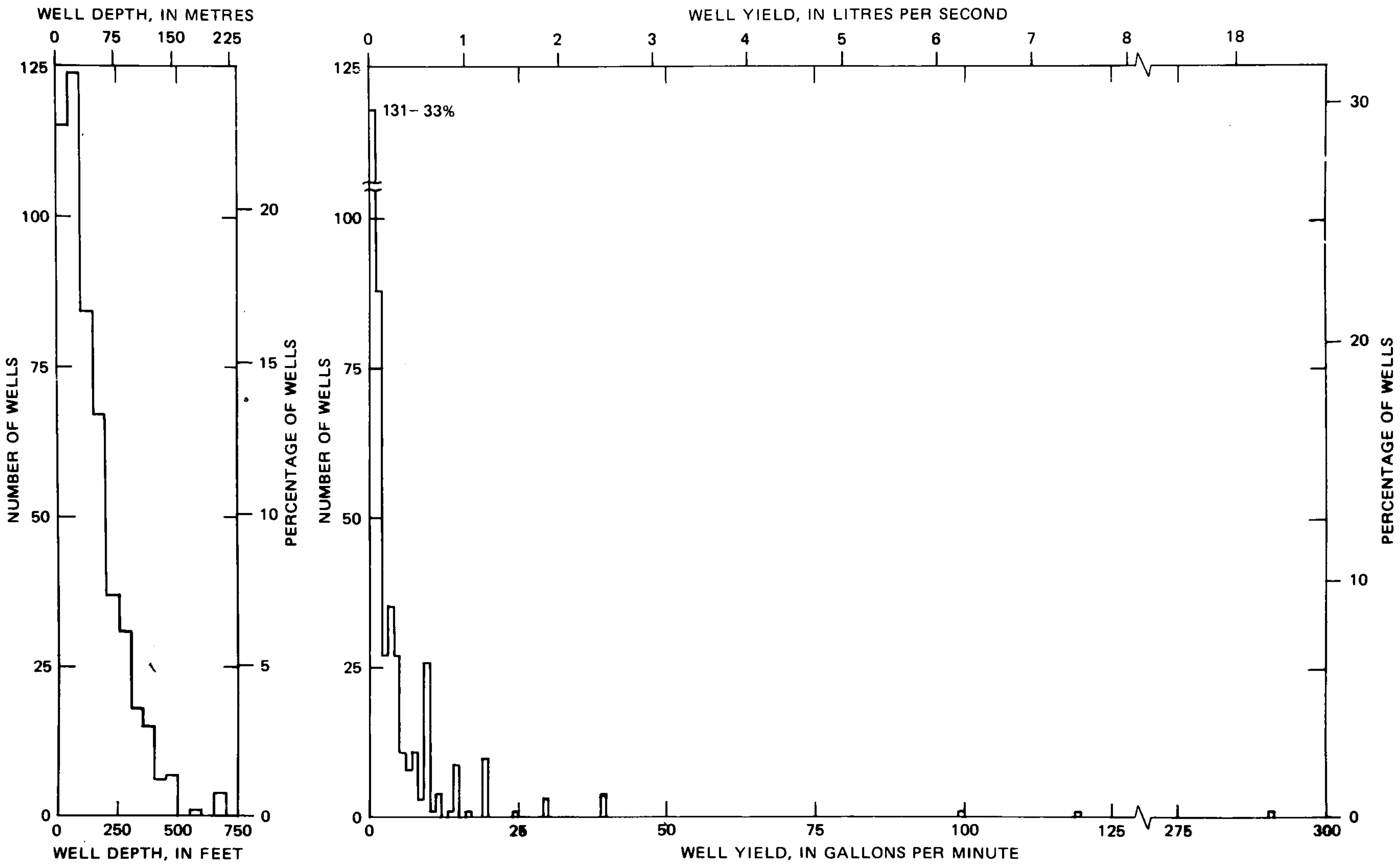


Figure 31.--Reported depths and yields for sampled wells.

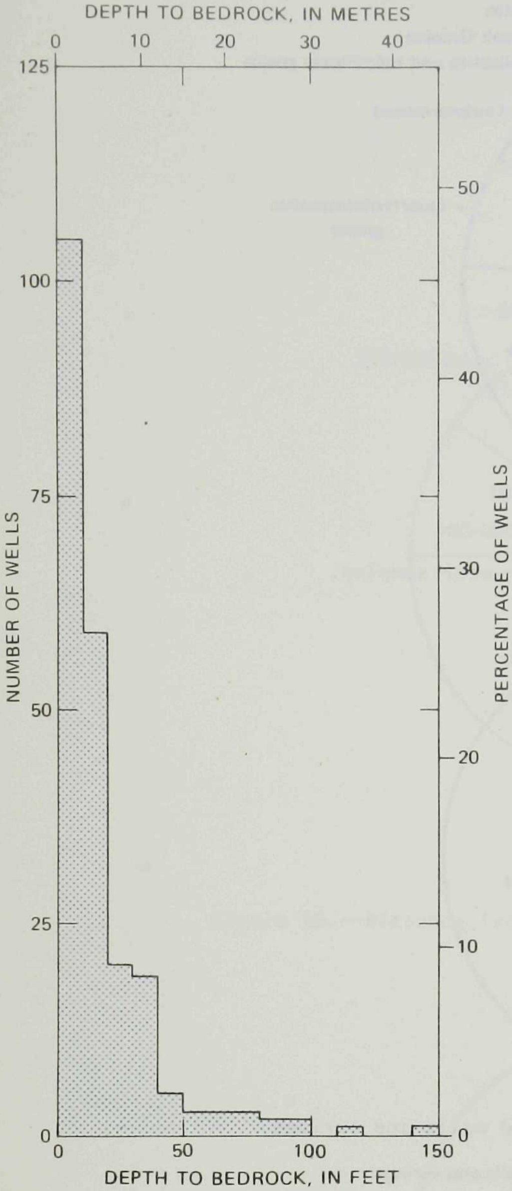


Figure 32.--Reported depths to bedrock for sampled wells.

vial deposits of Quaternary age accounting for the remainder. The predominant Precambrian rock types were biotite gneiss and Silver Plume Granite, and less commonly other gneisses and granites (fig. 33).

Most wells were situated on sides of hills with fewer located in the valleys and even fewer at the tops of the hills. Most of the wells tested were at the edge of a cluster-type community with smaller numbers from strip-type communities and inside cluster-type communities. A small percentage of the wells were isolated (0.25 mi or 0.40 km from the nearest neighbor) (figs. 34 and 35).

Most of the wells are from 50 to 150 ft (15.2 to 45.7 m) from the nearest part of the leach field or sewage treatment system. The county regulations currently require 100 ft (30.4 m) or more from the well to the leach field. A few older systems were found where the distance was less than 50 ft (15.2 m). Most sewage-treatment systems were downslope from the well site, about one-fourth were at the same level, and a few were upslope (figs. 36 and 37).

Most wells and sewage-treatment systems have been installed since 1960 (fig. 38), and most of the sewage-treatment systems were septic tanks with leach fields. In discussions with owners of these systems, it became evident that the septic tanks are seldom cleaned. The remaining sewage-treatment systems account for about one-eighth of the total and include such systems as septic tanks with no leach fields, aeration systems with leach fields, and combination septic tanks and aeration tanks. Over one-half of the wells or springs were located on lots less than 5 acres (2.0 ha) in size. About one-tenth of the lots were over 100 acres (40.5 ha) in size (figs. 39 and 40).

In addition to collection of water samples from existing wells, 11 observation wells were drilled at locations throughout the study area and were sampled. They are located near existing communities or on sites where future developments are scheduled to occur. Water-level measurements are made monthly in these wells, and complete chemical and coliform bacteria analyses were done soon after the wells were drilled. The well depths ranged from 70 to 230 ft (21 to 70 m) and the sustained yields of water ranged from 0.1 to 6.8 gal/min (0.006 to 0.43 l/s). These wells are part of a planned network for continuing surveillance of water levels and water quality in the mountainous area of Jefferson County.

RELATION BETWEEN GROUND-WATER QUALITY AND ENVIRONMENTAL FACTORS

Distance from Well to Leach Field

Plots of chemical or bacterial concentration in well water as a function of the distance of the leach field from the well show considerable scatter, but the overall trend indicates decreasing concentration with increasing distance. The scatter, particularly at small distances, would be expected since water samples were taken from sites with much variation: different with respect to aquifers, hydraulic gradients, topography, and geologic fracture patterns. Figures 41 and 42 show plots of nitrate and of total-coliform bacteria versus distance from well to leach field. Similar scatter was observed for data when nitrate and total coliform were plotted as a function of lot size. This was expected because, when lot sizes are small, distances between well and leach field are also small.

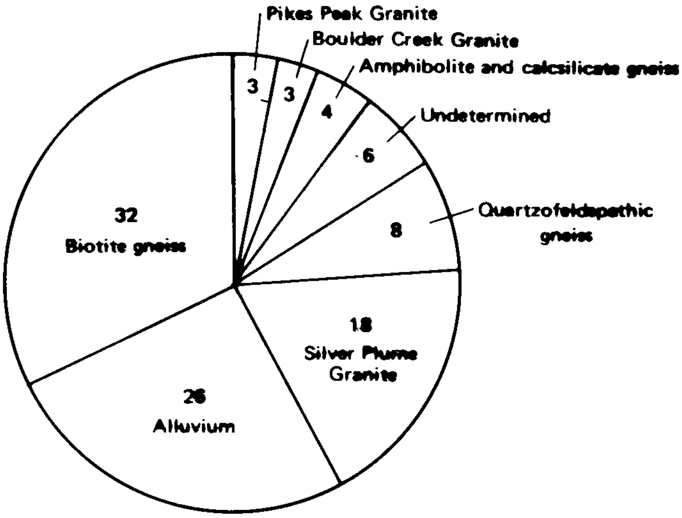


Figure 33.--Geologic source of ground-water samples.

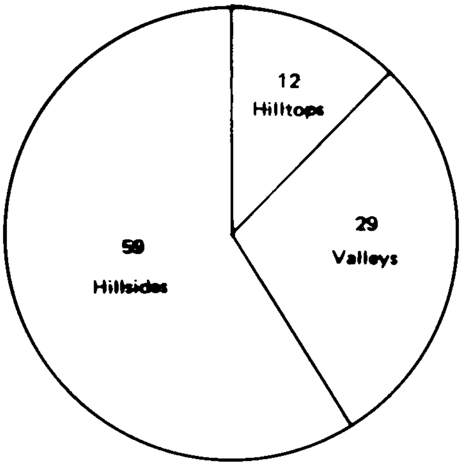
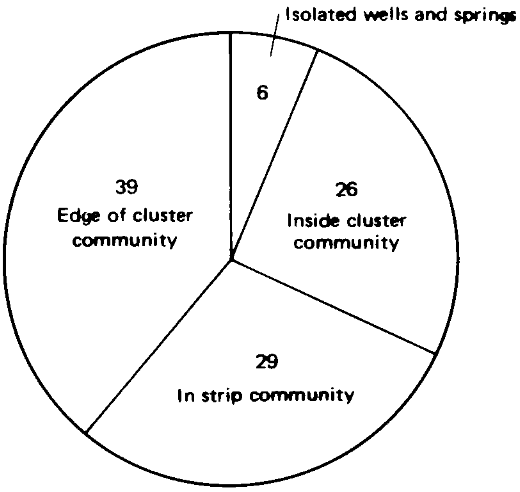


Figure 34.--Topographic position of sampled wells and springs.



Values in percent

Figure 35.--Position of sampled wells and springs relative to populated areas.

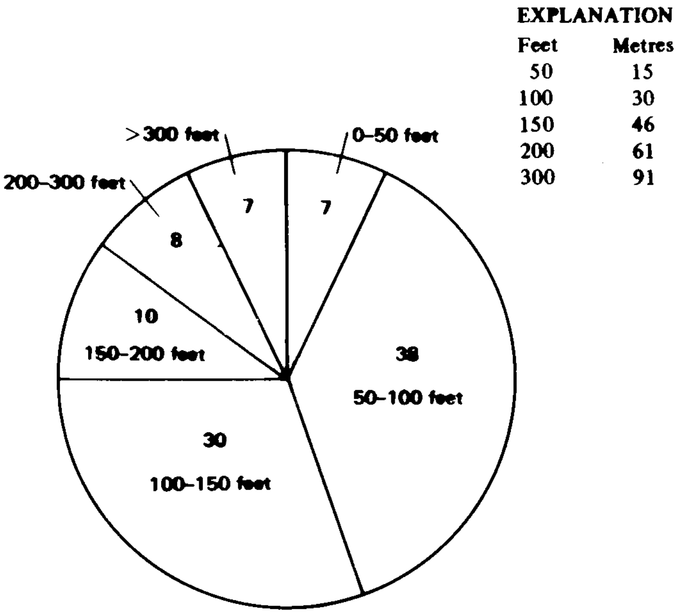
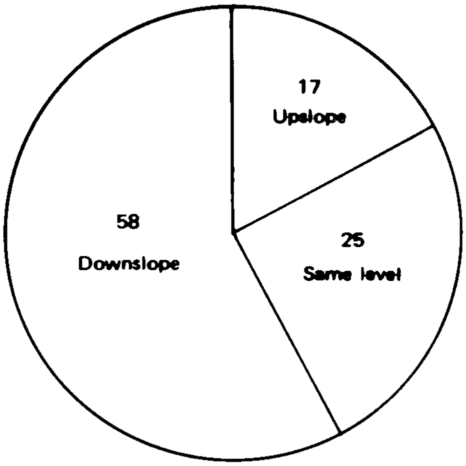


Figure 36.--Distance from sampled well or spring site to leach field.



Values in percent

Figure 37.--Location of the sampled well or spring site relative to the leach field.

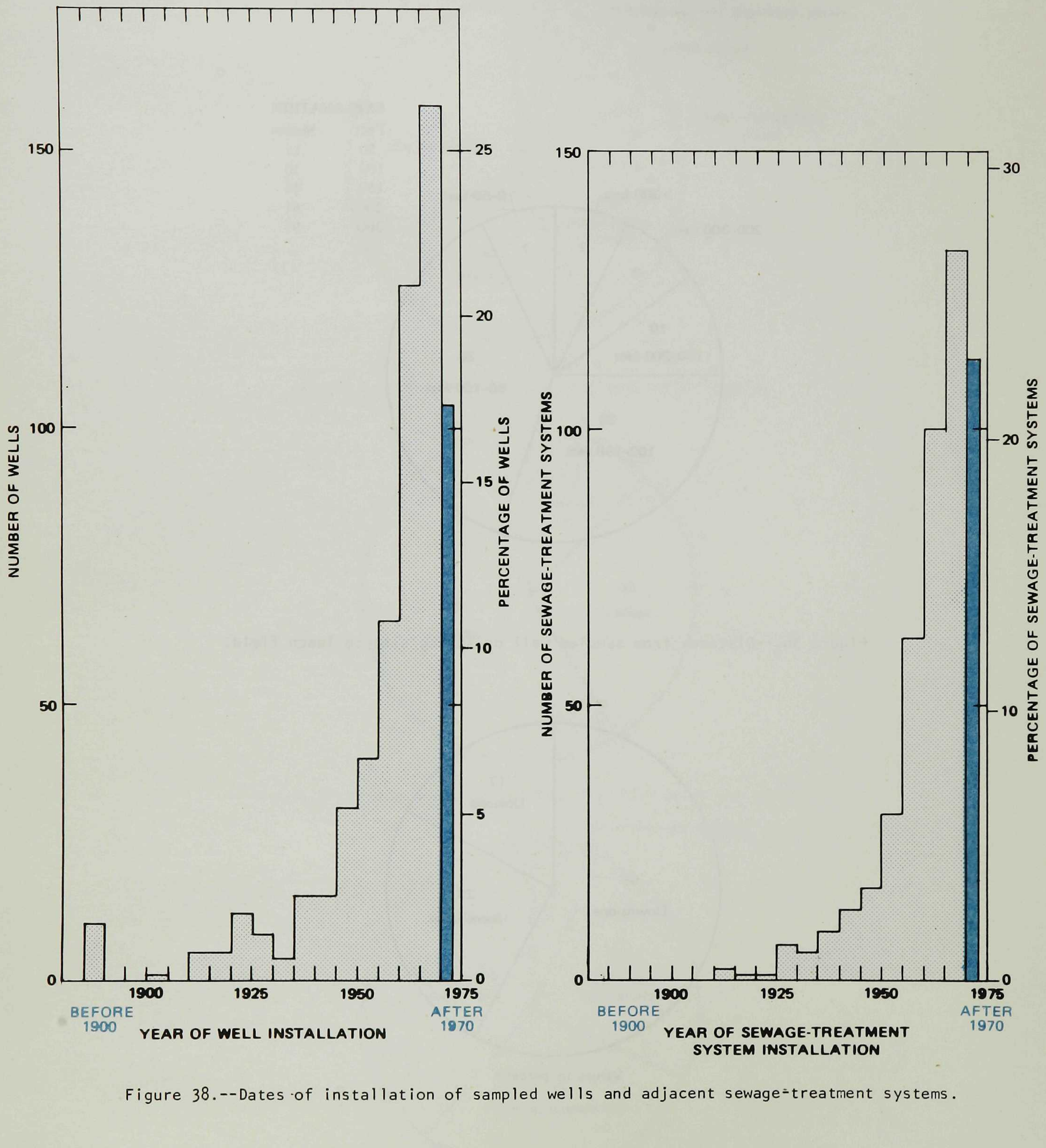


Figure 38.--Dates of installation of sampled wells and adjacent sewage-treatment systems.

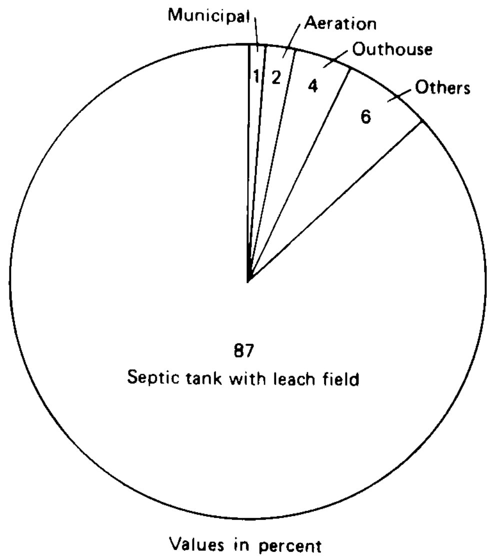
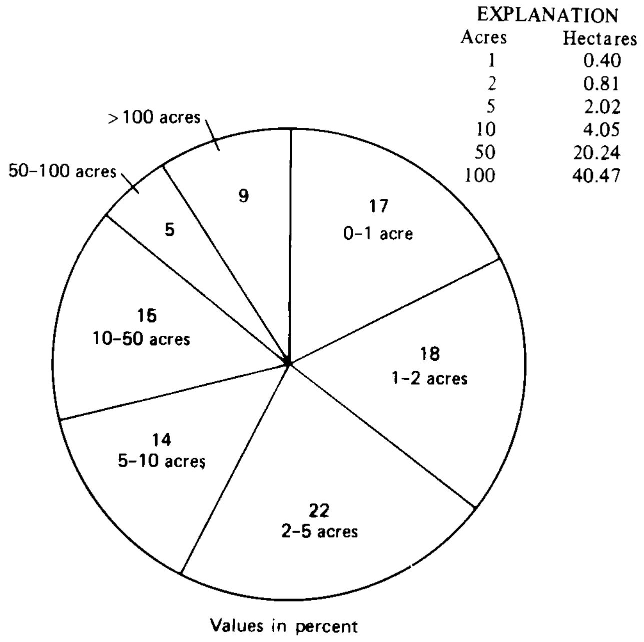


Figure 39.--Type of sewage-treatment system adjacent to sampled well or spring.



EXPLANATION

Acres	Hectares
1	0.40
2	0.81
5	2.02
10	4.05
50	20.24
100	40.47

Figure 40.--Lot-size distribution of properties where wells and springs were sampled.

Figure 41 shows that nitrite-plus-nitrate nitrogen concentrations equal to or above the 10 mg/l health limit are clustered in the wells not more than 300 ft (101 m) from the nearest leach field. At distances greater than 300 ft (101 m), only 2 wells out of 41 wells sampled had concentrations of 10 mg/l or more.

Coliform bacteria at concentrations of more than 11 per 100 ml of water are clustered entirely in wells 500 ft (169 m) or less from the nearest leach field. For 20 samples from the wells more than 500 ft (169 m) from the nearest leach field, only two wells contained two or more coliform bacteria per 100 ml.

Specific conductance or chloride values plotted versus distance from well to leach field (not shown), shows a scatter that resembles that for nitrate and coliform bacteria versus well to leach-field distance. That is, there is more variation in concentration at shorter distances and lower concentrations at greater distances. The variation in concentration at the longer distances, for chloride and especially for specific conductance, is greater than for nitrate and coliform bacteria. This is not surprising because chloride and most of the constituents responsible for specific conductance are stable in the environment; that is, they persist and are not readily changed to new forms. Nitrate and coliform bacteria are not stable; that is, the nitrate is readily altered chemically and the coliform bacteria die. Also, the background levels of specific conductance and chloride in ground water are higher and more variable than nitrate and coliform bacteria.

Aquifer Types

Water in the different aquifers varies in chemical and bacterial quality (table 5). Three aquifer types were sources of most of the water samples and these will be emphasized: alluvium, biotite gneiss, and Silver Plume Granite. The crystalline rocks of the area are not readily dissolved by the water. As a result, the rock type of the aquifer is not important in chemically regulating the quality of ground water. The weathering of the bedrock is important in ground-water quality, since filtration or lack of it determines what materials are carried down from the surface. The different types of bedrock weather at different rates and to different depths as discussed earlier (see table 1).

The alluvium includes weathered material. Water from this aquifer is low in specific conductance but high in chloride. Alluvium is high for extremes (see table 5 for definition of "extremes") in specific conductance, and total- and fecal-coliform bacteria, and low in extremes of nitrate. Biotite gneiss is weathered extensively. Water from the biotite gneiss aquifer was low in extremes for specific conductance, chloride, nitrate, and both types of coliform bacteria. Silver Plume Granite is resistant to weathering so one might expect to find little filtration and, therefore, increased degradation of the ground water. This hypothesis was not supported because modal ranges were not shifted and percentages in the extreme groups were decreased for all indicators except fecal-coliform bacteria which was close to the norm. Part of the explanation for this apparent low degradation of the water is that dwelling density is usually low in the area where Silver Plume Granite is found. In contrast, most of our water samples from the Boulder Creek Granite aquifer were taken from a single, densely populated, older community, and had increased percentages of extremes for all indicators except total-coliform bacteria.

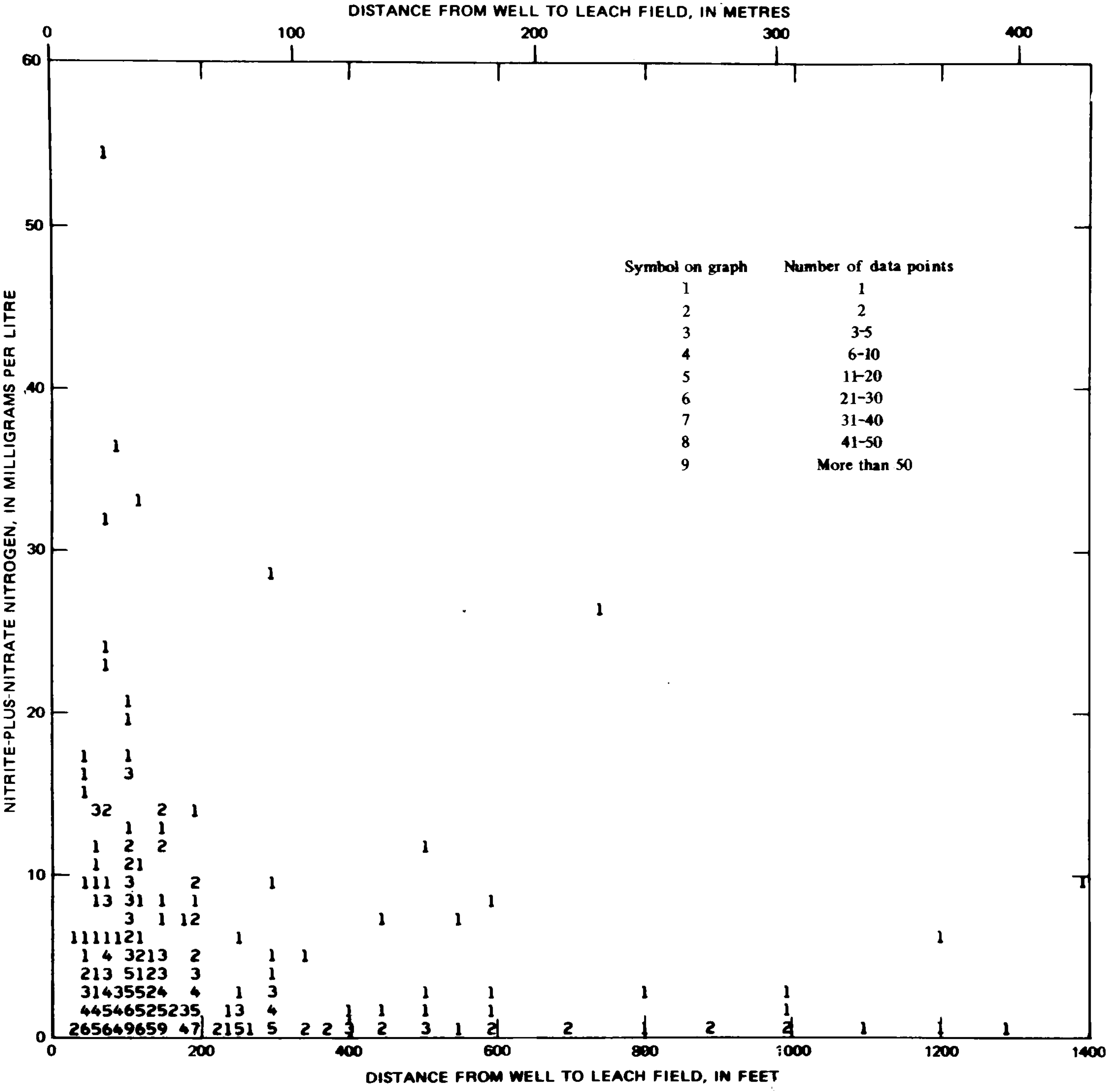


Figure 41.--Relation between nitrate concentration and distance from well to leach field.

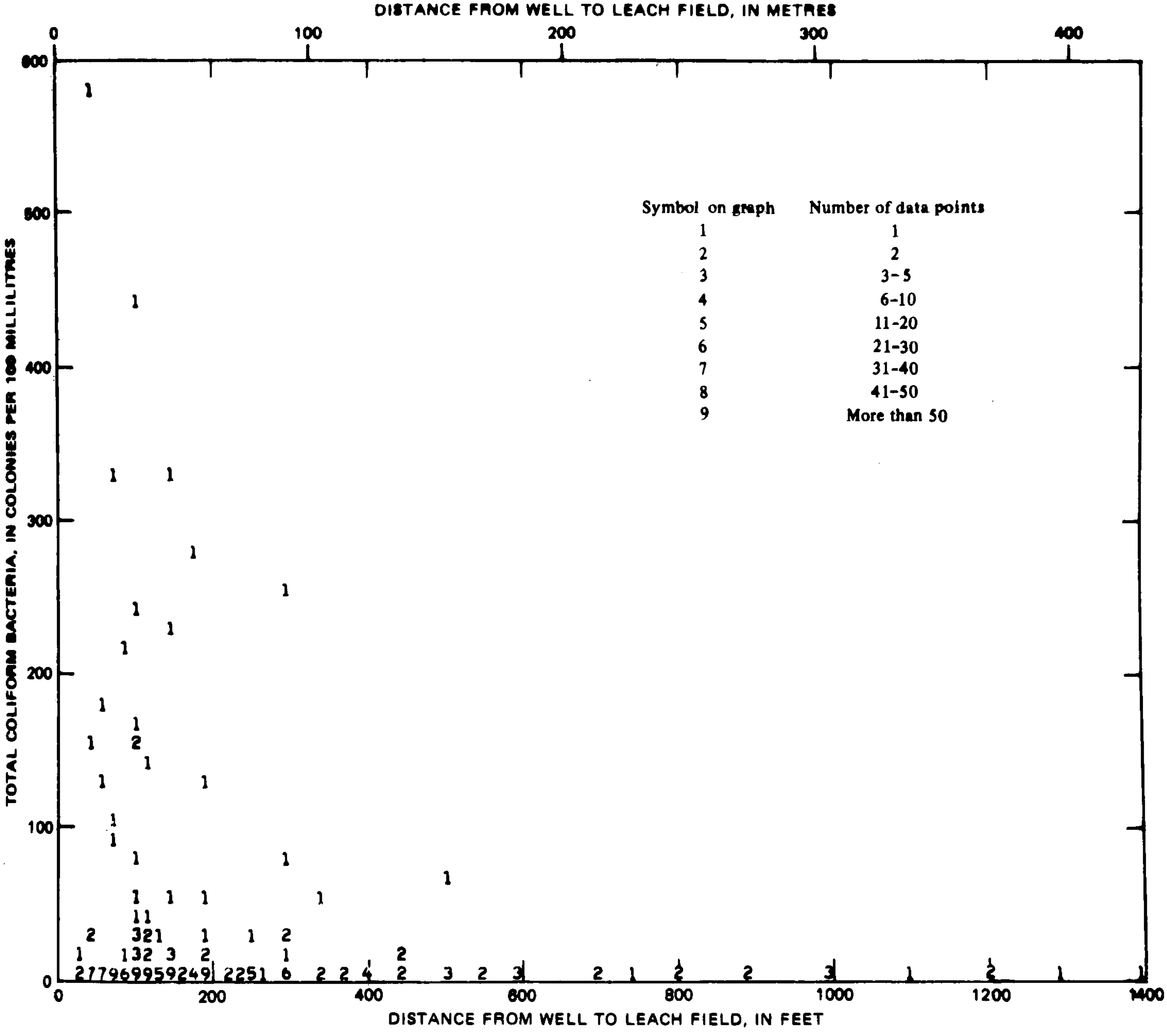


Figure 42.--Relation between total-coliform bacteria and distance from well to leach field.

Table 5.--*Water quality and aquifer type*

The number of samples for the various groups is given first. The modal range, which was selected for each group from a histogram as the most frequent group, is given second. The modal range values typify the character of the group. Third, an estimate of the percentage of extreme values for a group is given, based on health standards for drinking water (Colorado Department of Health, 1971; U.S. Public Health Service, 1962); or, arbitrarily, by choosing a concentration that was exceeded by about 10 percent of the samples in the grouped data ("All data" column). The wells in these extreme-value categories are considered to be highly degraded or contaminated. The data values for all groups are considered as the norms. Values for the specific subgroups are considered different if the modal range is different from that for the norm, or if the percentage of extreme values is higher or lower by more than one-tenth of the value for the norm]

		Precambrian							
	Alluvium	Pikes Peak Granite	Silver Plume Granite	Boulder Creek Granite	Biotite gneiss	Quartzo-feld-spathic gneiss	Amphibo-lite and calcsil-icate gneiss	Unknown	All data
	SPECIFIC CONDUCTANCE								
Number of samples------------------------------	196	22	141	22	246	58	31	48	764
Modal range (µmhos/cm at 25°C)-----------------	100-200	100-200	200-300	200-300	200-300	300-400	300-400	100-200	200-300
Percentage over 500 µmhos/cm at 25°C-----------	11.2	13.6	4.3	31.2	5.7	19.0	19.4	8.3	9.6
	DISSOLVED CHLORIDE								
Number of samples------------------------------	196	22	141	22	246	58	31	48	764
Modal range (mg/l)-----------------------------	2-3	3-4	1-2	2-3	1-2	2-3	1-3	1-3	1-2
Percentage over 25 mg/l------------------------	11.2	18.2	7.8	31.8	6.1	22.4	19.4	6.2	10.6
	DISSOLVED NITRITE PLUS NITRATE AS NITROGEN								
Number of samples------------------------------	196	22	141	22	246	58	31	48	764
Modal range (mg/l)-----------------------------	0-0.1	0-0.1	0-0.1	0-0.1	0-0.1	0-0.1	0-0.1	0-0.1	0-0.1
Percentage over 5 mg/l-------------------------	9.7	9.1	7.1	31.8	8.9	25.9	12.9	6.2	10.4
Percentage at 10 or more mg/l------------------	4.6	4.5	2.8	9.1	4.1	19.0	9.7	2.1	5.4
	TOTAL-COLIFORM BACTERIA								
Number of samples------------------------------	194	22	137	22	245	56	31	48	755
Modal range (colonies per 100 ml)--------------	0	0	0	0	0	0	0	0	0
Percentage at one or more colonies per 100 ml---	43.8	18.2	22.6	40.9	17.6	19.6	29.0	22.9	26.9
Percentage at two or more colonies per 100 ml---	34.5	13.6	12.4	27.3	13.1	10.7	16.1	14.6	18.9
	FECAL-COLIFORM BACTERIA								
Number of samples------------------------------	194	22	137	22	245	56	31	48	755
Modal range (colonies per 100 ml)--------------	0	0	0	0	0	0	0	0	0
Percentage at one or more colonies per 100 ml---	4.1	0.0	2.9	0.0	2.0	3.6	0.0	2.1	2.6

Table 6.--*Water quality and location in community*

[The number of samples for the various groups is given first. The modal range, which was selected for each group from a histogram as the most frequent group, is given second. The modal range values typify the character of the group. Third, an estimate of the percentage of extreme values for a group is given, based on health standards for drinking water (Colorado Department of Health, 1971; U.S. Public Health Service, 1962); or, arbitrarily, by choosing a concentration that was exceeded by about 10 percent of the samples in the grouped data ("All data" column). The wells in these extreme-value categories are considered to be highly degraded or contaminated. The data values for all groups are considered as the norms. Values for the specific subgroups are considered different if the modal range is different from that for the norm, or if the percentage of extreme values is higher or lower by more than one-tenth of the value for the norm]

	Strip communities	Cluster communities		Isolated wells	All data
		Inside	Edge		
SPECIFIC CONDUCTANCE					
Number of samples	217	299	200	43	759
Modal range (µmhos/cm at 25°C)	250-300	250-300	250-300	200-250	250-300
Percentage over 500 µmhos/cm at 25°C	8.8	9.0	13.0	0.0	9.5
DISSOLVED CHLORIDE					
Number of samples	217	299	200	43	759
Modal range (mg/l)	2-3	1-2	2-3	1-2	1-2
Percentage over 25 mg/l	9.7	8.4	17.0	0	10.5
DISSOLVED NITRITE AND NITRATE AS NITROGEN					
Number of samples	217	299	200	43	759
Modal range (mg/l)	0-0.1	0-0.1	0-0.1	0-0.2	0-0.1
Percentage over 5 mg/l	8.8	9.4	16.5	0	10.5
Percentage at 10 or more mg/l	2.8	5.0	9.5	0	5.3
TOTAL-COLIFORM BACTERIA					
Number of samples	217	296	198	43	754
Modal range (colonies per 100 ml)	0	0	0	0	0
Percentage at one or more colonies per 100 ml	29.5	20.6	24.2	25.6	26.9
Percentage at two or more colonies per 100 ml	25.8	16.6	14.6	20.9	20.0
FECAL-COLIFORM BACTERIA					
Number of samples	217	296	198	43	754
Modal range (colonies per 100 ml)	0	0	0	0	0
Percentage at one or more colonies per 100 ml	1.8	3.4	2.5	2.3	2.7

Community

Location within a community and the type of community seemed to have some effect on pollution of the water supply. Ground water sampled from strip-type communities was high for chloride but low in extreme concentrations of nitrate and high in total-coliform bacteria, and low in fecal-coliform bacteria (table 6). These tend to be older communities located along stream valleys. Water sampled inside cluster-type communities was high for extreme concentrations of chloride, low in incidence of total-coliform bacteria, and high in incidence of fecal-coliform bacteria. Samples from the edges of cluster-type communities were generally high for extremes of conductance, chloride, and nitrate, and low in total-coliform bacteria. Water samples from isolated dwellings were very low in specific conductance, and in extremes of chloride and nitrate.

Table 7.--*Water quality and topography*

[The number of samples for the various groups is given first. The modal range, which was selected for each group from a histogram as the most frequent group, is given second. The modal range values typify the character of the group. Third, an estimate of the percentage of extreme values for a group is given, based on health standards for drinking water (Colorado Department of Health, 1971; U.S. Public Health Service, 1962); or, arbitrarily, by choosing a concentration that was exceeded by about 10 percent of the samples in the grouped data ("All data" column). The wells in these extreme-value categories are considered to be highly degraded or contaminated. The data values for all groups are considered as the norms. Values for the specific subgroups are considered different if the modal range is different from that for the norm, or if the percentage of extreme values is higher or lower by more than one-tenth of the value for the norm]

	Hilltops	Hillsides	Valleys	All data
SPECIFIC CONDUCTANCE				
Number of samples	90	442	218	750
Modal range (µmhos/cm at 25°C)	300-350	250-300	250-300	250-300
Percentage over 500 µmhos/cm at 25°C	12.2	8.6	10.6	9.6
DISSOLVED CHLORIDE				
Number of samples	90	442	218	750
Modal range (mg/l)	1-2	2-3	2-4	1-2
Percentage over 25 mg/l	10.0	10.2	11.5	10.5
DISSOLVED NITRITE AND NITRATE AS NITROGEN				
Number of samples	90	442	218	750
Modal range (mg/l)	0.1-0.2	0-0.1	0-0.1	0-0.1
Percentage over 5 mg/l	15.6	11.1	7.8	10.7
Percentage at 10 or more mg/l	10.0	5.7	3.2	5.5
TOTAL-COLIFORM BACTERIA				
Number of samples	89	439	215	743
Modal range (colonies per 100 ml)	0	0	0	0
Percentage at one or more colonies per 100 ml	24.7	23.9	34.9	27.2
Percentage at two or more colonies per 100 ml	14.6	16.2	27.0	19.1
FECAL-COLIFORM BACTERIA				
Number of samples	89	439	215	743
Modal range (colonies per 100 ml)	0	0	0	0
Percentage at one or more colonies per 100 ml	3.4	1.8	4.2	2.7

Topography

Topography also seems to be a factor affecting the quality of ground water. Water from wells on hilltops seemed to be high in specific conductance and extremes of nitrate, and slightly low in total-coliform bacteria, but high for fecal-coliform bacteria. (Note that the fecal-coliform data are often based on a small number of positive samples.) Water from wells in the valleys was high in chloride, low in nitrate extremes, and high in both classes of coliform bacteria (table 7). Water from wells on hillsides was intermediate, except somewhat lower than the norm for the presence of fecal-coliform bacteria.

Hydraulic Gradient

The hydraulic gradient is the change in head (the static head is usually equal to the water level) between two points. It indicates the general direction of movement of water between the two points. The hydraulic gradient between the leach field and the well could, therefore, be important in controlling the infiltration of leachate into the aquifer near the well. In general, the hydraulic head follows the contour of the land, so the slope of the land surface between the leach field and the well would be in the same direction as the hydraulic gradient. A downslope would indicate a hydraulic gradient toward the

Table 8.--*Water quality and the position of well site relative to leach field*

[The number of samples for the various groups is given first. The modal range, which was selected for each group from a histogram as the most frequent group, is given second. The modal range values typify the character of the group. Third, an estimate of the percentage of extreme values for a group is given, based on health standards for drinking water (Colorado Department of Health, 1971; U.S. Public Health Service 1962); or, arbitrarily, by choosing a concentration that was exceeded by about 10 percent of the samples in the grouped data ("All data" column). The wells in these extreme-value categories are considered to be highly degraded or contaminated. The data values for all groups are considered as the norms. Values for the specific subgroups are considered different if the modal range is different from that for the norm, or if the percentage of extreme values is higher or lower by more than one-tenth of the value for the norm]

	Downslope	Upslope	No slope	All data
SPECIFIC CONDUCTANCE				
Number of samples	114	391	170	675
Modal range (µmhos/cm at 25°C)	250-300	250-300	250-300	250-300
Percentage over 500 µmhos/cm at 25°C	11.4	8.7	12.9	10.2
DISSOLVED CHLORIDE				
Number of samples	114	391	170	675
Modal range (mg/l)	2-3	1-2	1-2	1-2
Percentage over 25 mg/l	13.2	9.2	14.1	11.1
DISSOLVED NITRITE AND NITRATE AS NITROGEN				
Number of samples	114	391	170	675
Modal range (mg/l)	0-0.1	0-0.1	0-0.1	0-0.1
Percentage over 5 mg/l	10.5	11.3	11.8	11.3
Percentage at 10 or more mg/l	6.1	5.4	5.3	5.5
TOTAL-COLIFORM BACTERIA				
Number of samples	111	387	169	667
Modal range (colonies per 100 ml)	0	0	0	0
Percentage at one or more colonies per 100 ml	40.5	22.5	24.9	26.1
Percentage at two or more colonies per 100 ml	30.6	15.5	16.0	18.1
FECAL-COLIFORM BACTERIA				
Number of samples	111	387	169	667
Modal range (colonies per 100 ml)	0	0	0	0
Percentage at one or more colonies per 100 ml	4.5	3.1	1.2	2.8

well; an upslope, a gradient away from the well; and no slope, no gradient.

The modal ranges of indicator concentrations did not change with slope, except for an increase in chloride when the well was downslope from the leach field (table 8). The percentage of extremes was usually elevated where the well was downslope and decreased or unchanged when the well was upslope from the leach field. With no slope, extreme values changed variably.

These results indicate that the hydraulic gradient has some control on the movement of leachate from the leach field to the well, but also the variability of the data indicates that the system is complex and that other factors, such as distance, are even more important as controlling variables.

MANAGING THE WATER SYSTEM

Man's earliest control of water included diverting surface water from streams and digging shallow holes to obtain ground water. From this simple beginning developed a sophisticated technology that involves construction of giant reservoirs and tunnels, and complicated diversion and distribution systems; development of deep-well drilling and powerful lifting systems; design of artificial recharge projects; purification and treatment systems for wastes; and the evolution of the science of hydrology.

Water-Related Problems

Management and use of surface-water supplies seem simple to the uninitiated. In the study area, surface water is suitable for domestic use and is locally abundant. The problems associated with utilization are many and difficult. They are created by natural cycles, physical problems of collection and distribution, legal considerations, economic factors, and man's use of land and water.

To utilize the natural cycle of streamflow, with a few months of abundant supply and many months of decreased supply, water would need to be stored in reservoirs and rationed through the year. Distribution of water in rugged mountain terrain requires pipeline construction, booster pumps, and other sophisticated engineering facilities. Legal considerations are important, as most streamflow was appropriated many years ago under Colorado's water law, and the water is now private property. Purchase of water rights and costs of water collection and distribution may prevent utilization of surface water in many mountain communities. Cessation of waste-disposal practices that contaminate mountain streams is necessary for maximum utilization of streamflow.

Management and use of ground-water supplies require the solution of similar problems. Like surface water, this resource in its natural state has great appeal as a water supply. It is free of impurities and transportation problems, and it occurs throughout the mountainous area of Jefferson County. The problems today (1974) are low well yields, contamination, and legal considerations of use and ownership.

In the sense that few wells are capable of supplying large volumes of water, ground water is scarce in the study area. Wells capable of yielding a minimum to adequate supply for a household are the rule. Our study indicates that ground water is continually recycled from leach field to well, often with inadequate treatment. Due to inadequacies of well construction or geologic factors, some leachate flows directly into wells.

New to the legal scene is the 1965 ruling that all ground water in the mountains is tributary to the flowing streams of the area. This has resulted in a law requiring that well permits be granted for household use only if consumptive use is minimized. No use of water outside of the residence is allowed and new sewage-disposal systems that prevent pollution but consume the waste water are illegal.

Water-Management Alternatives

Utilization of natural cycles and processes can result in maximum benefits and minimum degradation of the environment. Good quality surface water is available at times of maximum flow. If this water could be diverted for storage and subsequent use, some of this stored water could be released during low flow for domestic use and for dilution of wastes. This would improve the esthetics of nearly dry streams during the summer months. This type of regulation of flow has not been attempted to any large extent in the study area.

Throughout the study area, there are major fault and fracture zones that should be capable of supplying substantial quantities of water for some communities. Often they are not at great distances from developing areas, and are located where future pollution is not likely.

In some situations, it may be possible to reduce sewage input at times of low flow. Improved sewage-treatment systems can return surface water in mountain streams to quality suitable for water-contact sports and fishing. With treatment to kill pathogenic organisms, the water would also be acceptable for municipal water supply.

Many areas in the mountains do not have surface materials that are thick enough for leach fields; the filtration characteristics may not be suitable for proper sewage treatment. In such areas, other waste-disposal systems need to be used. Combined sewage-treatment systems for small communities offer a good alternative to individual systems under the present laws if the waste waters are purified and returned to the aquifers. In problem areas where the surface materials are unsuitable, engineered leach-field beds using imported, sized, sand materials have excellent potential for reducing ground-water degradation and retaining the advantages of individual treatment facilities. If the legal problems can be solved, the sealed type of waste-treatment system using plants and evaporation to consume waste water could be a pollution-free alternative.

The importance of careful construction and maintenance of wells and waste-treatment systems cannot be overemphasized. Our studies show that very few wells are cased to the base of the highly fractured rocks near the land surface. The simple procedure of drilling into more solid, undecomposed rock, usually encountered at about 40 ft (12 m), and grouting the casing to the surface can prevent both direct well contamination by surface flow down the well and direct flow of septic-tank fluids into the well bore.

Maintenance of septic tanks is a simple precaution that can improve the treatment of wastes and prolong the life of the leach field. When solids accumulate in a septic tank, the anaerobic phase of treatment, which breaks down some of the nitrogen into ammonia, ceases. In addition, solids flow through the septic tank and clog the leach field. Periodic removal of solids when they accumulate in the septic tank is often neglected by residents in the study area.

Careful location of water-supply sources with respect to waste-disposal systems can alleviate many water-degradation problems. Our study indicates that concentrations of chemicals decrease in the well water if well and leach fields are spaced more than 250 ft (76 m) apart.

Finally, collective sewage treatment in large communities has several advantages. Closer control of the treatment could be exerted so that the treated waste would have a minimal effect on the water quality in ground-water reservoirs. The treated-waste effluents that meet control agencies' standards could be placed in mountain streams that have a limited capability to purify water. Downstream this water could then be fit for reuse.

There is no easy way to limit the build-up of nitrate in ground water when individual waste-treatment systems, such as septic tanks, are used. The build-up is caused by recycling a limited amount of ground water with continual additions of small amounts of nitrates. Maintaining maximum efficiency of septic tanks by periodic removal of solids is important because some nitrogen is removed as ammonia in a properly working septic tank. Nitrates can be removed in modern sewage-treatment plants. A new water source that is not polluted is an alternative to the situation where the ground water in a whole community is high in nitrates. Relocation of the well or leach field at a greater relative distance could reduce chemical and bacterial input in isolated wells. Finally, if nitrate concentrations are high, bottled water can be provided for infants or pregnant women, and livestock could be watered with an alternate supply, such as surface water.

Two general circumstances lead to bacterial contamination of ground water: (1) a continual source of bacteria, such as a flowing stream adjacent to a well in the alluvium; and (2) rapid movement of bacteria-laden waste water to the water table. Efficient leach fields should remove most bacteria by filtering and allowing time for most remaining bacteria to die during the slow movement of fluids through the field. It may be prudent to abandon contaminated wells in alluvium and drill new wells in an uncontaminated body of ground water. If none of the foregoing alternatives are feasible, there remains the alternative of chlorinating the water using individual water-treatment systems. Because ground water from the alluvial aquifers often contains coliform bacteria, some treatment, such as chlorination, to insure that drinking water standards be met with regard to coliform bacteria, is necessary. Surface water is even more likely to contain coliform bacteria, so with this source of supply, treatment to kill bacteria may be desirable in almost all instances.

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