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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
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WATER RESOURCES OF YELLOWSTONE NATIONAL PARK, WYOMING, MONTANA, AND IDAHO

by

Edward R. Cox

Prepared in cooperation with the
National Park Service

Open-file report 73-53

February 1973

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Abstract

The study described in this report is an appraisal of water resources in Yellowstone National Park. Detailed hydrologic investigations are also described at several sites in the park, selected by the U.S. National Park Service, where additional data are needed for use in planning water supplies for public use. Most water supplies in the park are from surface water. Some surface-water sources contain sediment during snowmelt and after heavy rainstorms and become temporarily objectionable to use. Ground water is not subject to seasonal increases in sediment.

Most wells and test holes in the park are near streams and lakes and are in alluvium, glacial deposits, or lacustrine deposits. Pumpage is small compared to natural ground-water discharge. Ground water in stream valleys and lake basins does not move from one drainage basin to another. In general, aquifers adjacent to streams and lakes are recharged by precipitation and by water from the stream or lake. Water moves from the aquifers to the streams and lakes during periods of low streamflow and low lake levels, and, at least near the streams or lakes, water moves from the streams and the lakes to the aquifers during periods of high streamflow and high lake levels. Streamflow is greatest during May to July as a result of melting snow. Streamflow declines during the summer and fall to the lowest flows during the winter. Topographically high areas probably are drained and, except for perched-water zones, contain ground water only at great depths in bedrock.

Quality of ground and surface waters varies with the geologic terrane and the hydrologic sources. In general, thermal water is highly mineralized and affects the quality of water in aquifers, streams, and lakes by adding silica, sodium, chloride, fluoride, boron, and sometimes sulfate and arsenic. Waters in rhyolite terrane and in areas having an abundance of obsidian generally have a fluoride content that exceeds the maximum limit suggested by the U.S. Public Health Service for drinking water. The concentration of all chemical constituents determined in nonthermal water sampled in terranes other than rhyolite are within the recommended limits for drinking water.

Aquifers in stream valleys would yield 1,500 gpm (gallons per minute) near Fountain Paint Pot, 250 gpm near Mud Volcano, 500 gpm near Northeast Entrance, 750 gpm near East Entrance, 200 gpm near South Entrance, and 300 gpm near Madison Junction. Aquifers near Norris Junction and Old Faithful might have yields of 35 and 50 gpm, respectively. An aquifer near Tower Junction would yield 50 to 75 gpm. An aquifer near the Yellowstone River northwest of Mammoth will yield as much as 200 gpm to single wells. Aquifers in places near streams and lakes would yield a few gallons per minute of water to shallow wells equipped with hand-operated pumps to supply water for campgrounds or patrol cabins in remote areas of the park.

Introduction

The increasing number of tourists visiting Yellowstone National Park has required the expansion of public water supplies in the park. Some of the points of tourist interest are near the famous geysers and other areas of thermal-water discharge. Some points of interest are near streams and lakes where tourists enjoy water and mountain scenery. Water supplies that are sufficient in quantity and suitable in quality are needed but are not always readily available near some of these points of interest. Water supplies are also needed in the park at centers of accommodation for tourists and employees. The U.S. National Park Service requires information on hydrologic conditions in the park for use in planning water supplies for public facilities and for its mission of protecting the ecological system.

Most water supplies in the park utilize surface water. Some of these water supplies, although adequate in quantity and chemical quality, contain sediment during spring snowmelt and after heavy rainstorms and become temporarily objectionable to use. Ground water is not subject to seasonal increases in sediment. In areas where ground water is not available, cannot be used, or cannot be developed because of the remoteness of the area, surface water must be used for water supplies.

The U.S. Geological Survey made a study of hydrologic conditions in Yellowstone National Park in cooperation with the National Park Service. Field investigations were begun in September 1966 and most of the investigations were concluded in October 1970.

The main purpose of this study is an overall appraisal of water resources in Yellowstone National Park. Detailed hydrologic investigations were also made at several sites in the park selected by the National Park Service where additional data are needed for use in planning water supplies for public use.

Location and extent of the area

Yellowstone National Park is in the northwest corner of Wyoming and adjacent areas in Montana and Idaho. The park is roughly rectangular in shape, about 62 miles long (north-south) and about 54 miles wide (east-west). The park contains 3,472 square miles, 91 percent of which is in Wyoming, 7 percent in Montana, and 2 percent in Idaho.

Topography and drainage

Most of Yellowstone National Park is a high plateau area ranging in altitude from 6,000 to 9,000 feet, with moderate relief, and bounded by mountains on the north, east, and south. Several plateaus in the park that have been named are: Buffalo Plateau, Blacktail Deer Plateau, Solfatara Plateau, Mirror Plateau, Madison Plateau, Central Plateau, Pitchstone Plateau, and Two Ocean Plateau (fig. 1). The plateau area is bounded on the north by the Gallatin Range and by an upland area known by several names but called the Beartooth Mountains in this report, and on the east by the Absaroka Range (fig. 1). South of the plateau area are uplands associated with the Teton and Washakie Ranges, which extend northward to within about 10 miles of the park. The Red Mountains, Chicken Ridge, and Big Game Ridge (fig. 1) are associated with uplands south of the park. West of the plateau area is the Snake River Plain in Idaho.

The lowest point in Yellowstone National Park is at about altitude 5,160 feet near the Yellowstone River on the north boundary; the highest point is Eagle Peak at altitude 11,358 feet in the Absaroka Range on the east boundary (fig. 1).

Yellowstone National Park lies on the Continental Divide. About 80 percent of the park is east of the divide in the Missouri River drainage and about 20 percent is west of the divide in the Snake River drainage. Principal streams that drain the park are the Madison, Gallatin, Yellowstone, Snake, and Falls Rivers (fig. 1). A small area near East Entrance is drained by Middle Creek, which flows eastward from the park to the North Fork of the Shoshone River.

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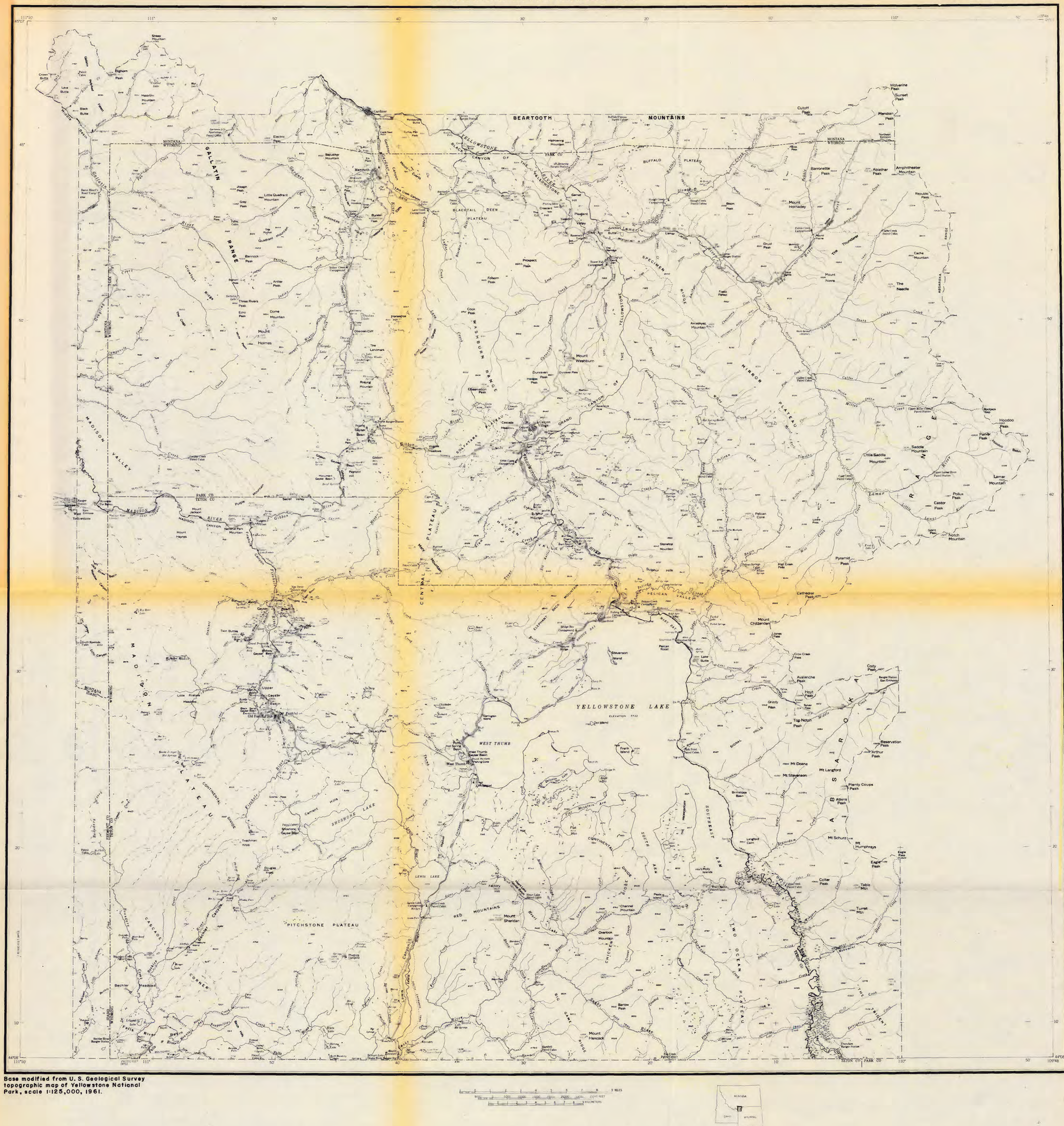
YELLOWSTONE NATIONAL PARK

WYOMING-MONTANA-IDAHO



Base modified from U. S. Geological Survey topographic map of Yellowstone National Park, scale 1:125,000, 1961.

9 MILES
FEET
9 KILOMETERS

MONTANA
IDAHO
WYOMING
MAP LOCATION DIAGRAM

of geographic features

The Madison River is formed by the confluence of the Gibbon and Firehole Rivers at Madison Junction, and this river system drains most of the western part of the plateau area of the park. The Gallatin River drains the west slope of the Gallatin Range in the northwestern part of the park. The Madison and Gallatin Rivers join the Jefferson River near Three Forks, Mont., about 60 miles northwest of Yellowstone National Park, to form the Missouri River.

The Yellowstone River drains the west slope of the Absaroka Range and most of the eastern part of the plateau area. The Yellowstone River also drains most of the northern part of the park, including the east slope of the Gallatin Range and the south slope of the Beartooth Mountains. The Yellowstone River joins the Missouri River near the Montana-North Dakota State line about 350 miles northeast of Yellowstone National Park.

The Snake River drains the uplands in the south-central part of the park and most of the southern part of the plateau area. The Falls River drains the southwestern part of the park. The Falls River joins Henrys Fork of the Snake River about 23 miles southwest of Yellowstone National Park.

Climate

Annual precipitation in Yellowstone National Park ranges from about 10 inches in the lowest part of the park, as shown by records of the U.S. National Oceanic and Atmospheric Administration at Gardiner, Mont., to as much as 60 inches near the Continental Divide in the southwestern part of the park (Thomas and others, 1963, pl. 2). Annual precipitation in most of the park, however, ranges from about 15 to 30 inches.

The orographic effects of mountains and valleys locally influence precipitation amounts, but precipitation generally increases with altitude. Precipitation is greater on the west side of the Continental Divide than it is on the east side of the divide owing to upslope effects of eastward moving storms from the Pacific Ocean. Precipitation occurs as snow during the winter, as rain and snow during the spring and fall, and generally as rain during the summer. Brief snow storms, however, occasionally occur in summer. Snow begins to accumulate in October in the higher parts of the park and commonly reaches depths of 4 feet by spring. The snowpack melts in spring and early summer and contributes much water to runoff in the streams.

According to records of the National Oceanic and Atmospheric Administration, precipitation is distributed quite evenly throughout the year in most of the park as suggested by the average monthly precipitation at Lake (fig. 2). Lake is in the plateau area near the middle of the park and its precipitation record probably represents average conditions for the park more than any other weather station. Precipitation is greatest in spring in lower areas of the park, such as Mammoth (fig. 2), and probably is greatest in winter in that part of the park west of the Continental Divide.

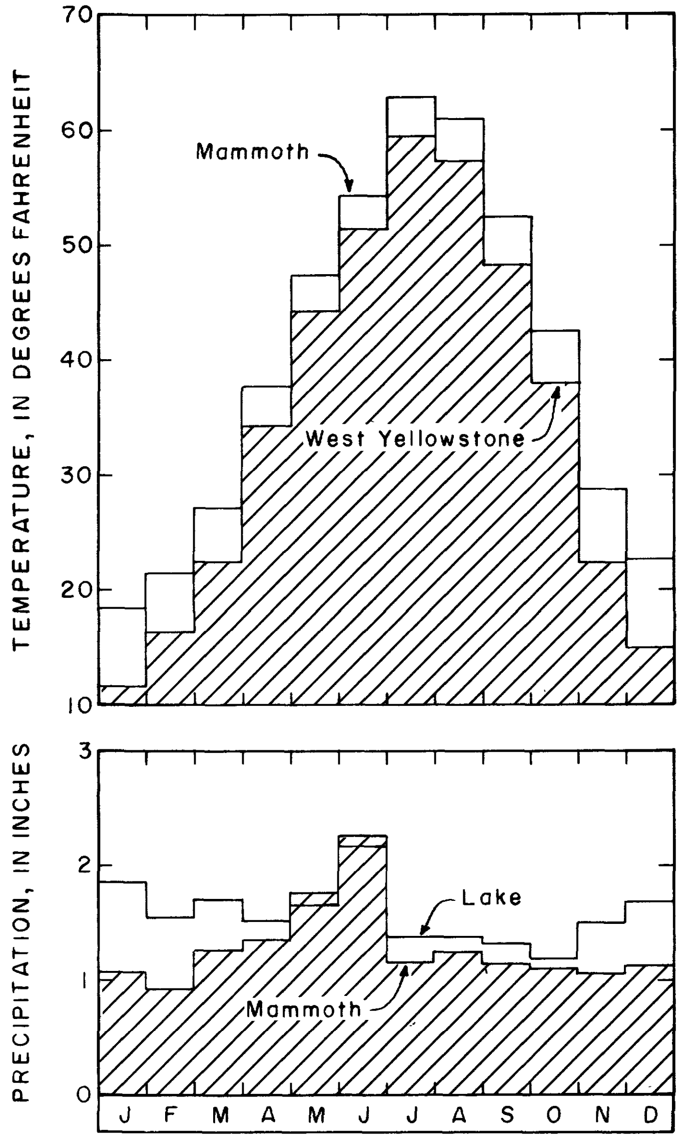


Figure 2.--Average monthly temperature and precipitation at selected locations in and near Yellowstone National Park. Based on records of the National Oceanic and Atmospheric Administration.

The average annual air temperature in Yellowstone National Park is about 35°F. Average temperatures range from about 15°F in winter to about 60°F in summer (fig. 2). During most years, maximum temperatures at most weather stations are generally near 90°F and minimum temperatures are usually less than -30°F. Selected precipitation and temperature data from weather stations in and near Yellowstone National Park are shown in the following table:

[From records of the National Oceanic and Atmospheric Administration]

Weather station	Altitude (feet)	Average precipitation (inches)	Average precipitation Years of record	Precipitation 1970 (inches)	Average temperature (°F)	Average temperature Years of record	Maximum temperature 1970 (°F)	Minimum temperature 1970 (°F)
Gardiner, Mont.	5,300	--------	------	10.43	-----	------	97	-17
Mammoth	6,230	15.38	82	15.29	39.7	78	90	-21
Tower Junction	6,266	16.21	43	21.54	-----	------	92	-32
Lamar Ranger Station	6,470	13.43	47	16.49	35.7	39	86	-42
Cooke City, Mont. (about 4 miles east of Northeast Entrance)	7,553	--------	------	29.03	-----	------	83	-35
West Yellowstone, Mont.	6,662	21.22	41	24.68	35.1	41	91	-41
Lake	7,762	18.86	52	26.16	-----	------	85	-37
South Entrance	6,882	--------	------	41.54	-----	------	87	-32

Previous investigations

Geologic and hydrologic investigations in Yellowstone National Park began in the 19th Century. Gooch and Whitfield (1888) published analyses of water from the park. Hague and others (1896) and Hague and others (1899) described the geology and topography of the park. Allen and Day (1935) made a study of hot springs in the park. Howard (1937) interpreted the geologic history of the Grand Canyon of the Yellowstone. Boyd (1961) studied the rhyolite tuffs and flows in the plateau area and published a geologic map of most of the park. Foose and others (1961) and Brown (1961) made geologic studies in the northern part of the park. Fraser and others (1969) studied the geology of the Gardiner, Mont., area that included part of the park. Witkind (1969) describes the geology of the Tepee Creek quadrangle, part of which is in the northwest part of the park.

The Hebgen Lake, Mont., earthquake of August 17, 1959, which centered near the northwest corner of Yellowstone National Park, resulted in several special studies of geologic and hydrologic effects of the earthquake. These studies were published in Geological Survey Professional Paper 435; some of them include data in the western part of the park.

Water-resources studies in Yellowstone National Park have been limited to investigations of small areas. Gordon and others (1962) investigated ground-water conditions near Grant Village. Lowry and Gordon (1964) investigated ground-water conditions near Northeast Entrance, East Entrance, Bridge Bay, and Cave Falls. Streamflow data have been collected at gaging stations and at miscellaneous sites in the park for many years and are published in the annual reports of water-resources data by the Geological Survey.

Geologic and hydrologic studies have been made by personnel of the National Park Service to collect facts and provide interpretation of features in Yellowstone National Park for visitors. Geologic studies made in and near the park have been published as theses for advanced degrees from universities. At the time of this study (1966-72), personnel of the U.S. Geological Survey were making extensive studies on remote sensing, geology, geophysics, and thermal waters in the park. The U.S. Environmental Protection Agency began a study in 1970 that will lead to the establishment of water-quality standards in the park.

Methods of investigation

Reconnaissance consisting of inspections of surface geology, topography, and hydrologic features were made near the sites selected for detailed study. Locations were selected for test holes to be constructed near the sites to study subsurface features. Observations of features were made and hydrologic data were collected in other areas, including remote parts of the park, for use in the overall appraisal of water resources in the park.

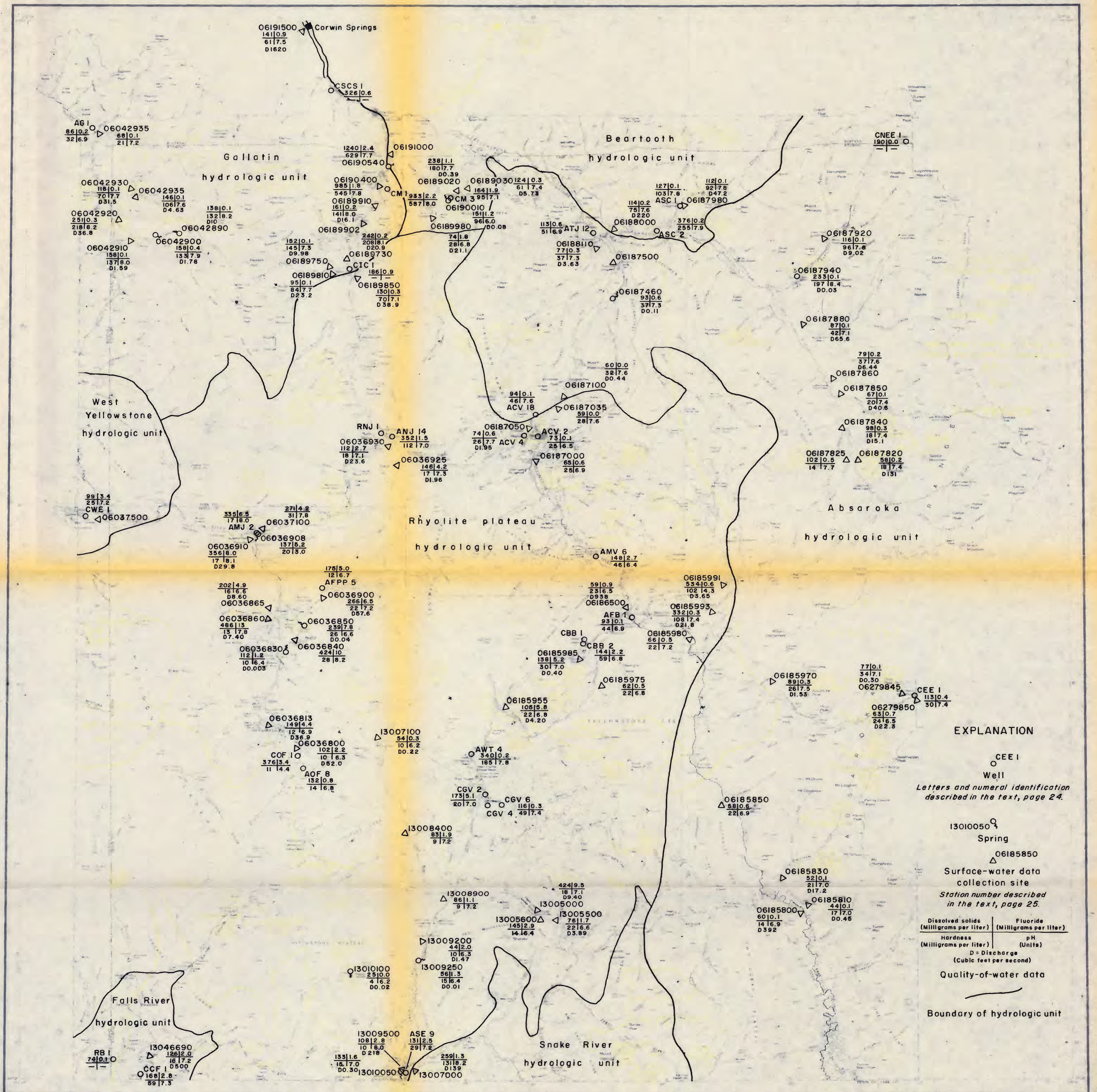
Test holes were constructed with motorized drilling equipment to study the occurrence of ground water and the nature of the water-bearing materials. Some of the test holes were completed as test wells by installing casing and screens, or slotted casing, to determine yields of wells and to measure water levels.

Drilling of test holes in the park was limited to areas near roads. The main roads in the park are Grand Loop Road, connecting roads that join the five entrances to Grand Loop Road, and Norris Canyon Road. The main roads and relatively short scenic drives are paved and maintained for use by park visitors. In addition, service roads, mostly unpaved, have been constructed in the park. Many trails provide access to remote parts of the park. Motorized vehicles, however, cannot be operated on trails.

Water levels were measured in observation wells at intermittent intervals to determine the range of fluctuations of ground-water levels. Discharge measurements were made at some sites on streams and springs in the park to determine magnitude and range of flow of the streams and springs. Water samples were collected from selected wells, springs, and streams and were analyzed for chemical character. Some of the water samples from wells were analyzed for biological character and radioactivity. Some of the water samples from streams were analyzed for suspended sediment.

Remote-sensing data were used to help delineate boundaries between areas of warm and cold ground water. An investigation was made in cooperation with the National Aeronautics and Space Administration to evaluate the usefulness of remote-sensing data in the water-resources study of the park. Remote-sensing data were collected in the park by cameras and scanners from aircraft missions in August 1966, September 1967, August 1969, and May 1970.

Yellowstone National Park has been divided into seven hydrologic units in this report for the purpose of an overall appraisal of water resources of the park. The unit boundaries were made arbitrarily, but they generally follow geologic and geographic boundaries. The units are: Rhyolite plateau, Absaroka, Beartooth, Gallatin, West Yellowstone, Falls River, and Snake River (fig. 2-A).



Base modified from U. S. Geological Survey topographic map of Yellowstone National Park, scale 1:125,000, 1961.

Well and station numbers

Wells are usually numbered by the Geological Survey in Wyoming, Montana, and Idaho according to the location of the wells within the Federal system of land subdivision. However, Yellowstone National Park has not been officially subdivided, and the common Geological Survey well-numbering system is not used in this report.

Abbreviations are used in the text, illustrations, and tables of this report to identify test holes and wells. The first letter indicates the method of construction--A, power-driven auger; C, cable-tool drilling machine; and R, rotary-drilling machine. The succeeding letters are abbreviations of nearby place names as given in the following list:

B	Bechler Ranger Station	M	Mammoth
BB	Bridge Bay	MJ	Madison Junction
CC	Crystal Creek	MV	Mud Volcano
CF	Cave Falls	NEE	Northeast Entrance
CV	Canyon Village	NJ	Norris Junction
EE	East Entrance	OF	Old Faithful
FB	Fishing Bridge	SC	Slough Creek
FPP	Fountain Paint Pot	SCS	Stevens Creek
G	Gallatin Ranger Station	SE	South Entrance
GV	Grant Village	TJ	Tower Junction
IC	Indian Creek	WE	West Entrance

The number gives the order of construction of a particular type of test hole or well. For example, CM 1 (fig. 2-A) was the first test hole drilled by a cable-tool machine near Mammoth, and ACV 4 (fig. 2-A) was the fourth test hole constructed by a power-driven auger near Canyon Village.

As a means of identification, the Geological Survey assigns an 8-digit station number (such as 06036800) to each site where surface-water data are collected. Springs have been assigned surface-water station numbers in this report. The station numbers increase in downstream order. Stations on tributaries are assigned numbers between upstream and downstream stations on main stems. Gaps are left in the numbering system to allow for new stations that may be established. The first two digits of the station number denote the drainage basin. Station numbers beginning with "06" are in Missouri River drainage and those beginning with "13" are in Snake River drainage.

Acknowledgments

Acknowledgment is given personnel of the National Park Service at Yellowstone National Park for their excellent cooperation during this investigation. Advice and assistance on access to areas of the park given by naturalists and rangers were particularly helpful in planning and accomplishing fieldwork.

Geology

Rocks ranging in age from Precambrian to Quaternary crop out in Yellowstone National Park. Most of the plateau area of the park is underlain by rhyolite of Tertiary and Quaternary age. North and south of the plateau are faulted and uplifted blocks of Precambrian metamorphic rocks and Paleozoic and Mesozoic sedimentary rocks. East of the plateau is a mountainous area composed mostly of andesitic breccia of Tertiary age. Glacial deposits, lacustrine deposits, and alluvium are widespread in the park.

Geologic units and their water-bearing characteristics

The geologic units used in this report are those most convenient for discussing the occurrence of ground water in the park. Other studies may divide the geology into different units. Inasmuch as data from wells are limited to Tertiary and Quaternary rocks, the Precambrian, Paleozoic, and Mesozoic rock units are not divided, except to show the stratigraphic position of geologic units and to summarize the water-bearing properties of the rocks. A generalized section of rocks exposed in the park is given in table 1. A generalized geologic map of the park is shown on figure 3. Geologic units are more detailed in the table than on the map. Some equivalent units in the northern part and in the southern part of the park have different names. Both names are given in table 1. Thickness, lithology, and water-bearing properties in table 1 are from observations, tests, reported values, and interpretations. Delineation of units on the map is mostly a compilation of data from published geologic maps.

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YELLOWSTONE NATIONAL PARK

WYOMING-MONTANA-IDAHO

Base modified from U. S. Geological Survey topographic map of Yellowstone National Park, scale 1:125,000, 1961.

Geology generalized from maps by Boyd, 1961; Brown, 1961; Fraser, Waldrop, and Hyden, 1969; Love, Weitz, and Hose, 1955; U. S. Geological Survey, 1964; and Witkind, 1969

EXPLANATION

CENOZOIC

QUATERNARY

Qal
Alluvium
Silt, sand, and gravel
Contains water in stream valleys.

Qls
Landslide deposits
Heterogeneous mass from clay to glide blocks. Higher parts drained, lower parts saturated.

Qag
Alluvium and glacial deposits, undivided
Contains water in stream valleys.

Ql
Lacustrine deposits
Clay, silt, sand, gravel, siltstone, sandstone, and conglomerate.
Contains water in interstices in unconsolidated rocks and in fractures in cemented rocks.

Qg
Glacial deposits
Bouldery clay, sand, and gravel
Contains water in sand and gravel.

QUATERNARY AND TERTIARY

QTb
Basalt flows
Where saturated, contains water in brecciated zones and fractures.

QTr
Rhyolite flows and tuff
Contains water in porous and fractured zones.

TERTIARY

Tab
Andesitic breccia
Where saturated, contains water in fractures and other openings.

Mz
Mesozoic rocks
Shale, siltstone, sandstone, limestone, and conglomerate
Where saturated, contains water in interstices in sandstone and conglomerate and in fractures and solution channels in limestone.

Pz
Paleozoic rocks
Limestone, dolomite, sandstone, and shale
Where saturated, contains water in fractures and solution channels in limestone and dolomite and in interstices in sandstone.

p€
Precambrian rocks
Gneiss, schist, and granite
Where saturated, contains water in fractures.

Contact

Table 1.--Generalized section of rocks exposed in Yellowstone National Park

Era	System	Geologic unit (North / South)	Approximate maximum thickness (feet)	Lithology	Water-bearing properties
CENOZOIC	Quaternary	Alluvium	200	Silt, sand, and gravel.	Contains relatively large quantities of water in stream valleys. Yields as much as 100 gpm (gallons per minute) to test wells. In places, may yield as much as 500 gpm to single wells.
		Landslide deposits	100	Heterogeneous mass from clay to glide blocks.	Higher parts drained; lower parts saturated. Probably would not yield more than a few gallons per minute of water to wells.
		Hot-springs deposits	250	Mostly siliceous sinter and calcareous travertine.	Locally contains water near hot springs.
		Lacustrine deposits	200	Clay, silt, sand, gravel, siltstone, sandstone, and conglomerate.	Contains water in interstices in unconsolidated rocks and in fractures in cemented rocks. Yields as much as 45 gpm to wells in Yellowstone Lake basin.
		Glacial deposits	200	Bouldery clay, sand, and gravel.	Same as alluvium in sand and gravel. Bouldery clay does not yield water readily to wells.
	Quaternary and Tertiary	Basalt	1,000	Basalt flows.	Probably contains relatively small quantities of water in brecciated zones, fractures, and other openings where saturated. Yields 8 gpm to a well at Bechler Ranger Station.
		Rhyolite	10,000+	Rhyolitic lava, breccia, scoria, welded tuff, ash, cinders, and glass (obsidian).	Contains water in porous and fractured zones. Yields water to numerous fumaroles and hot springs. Yielded only 2.6 gpm to test hole near Grant Village. Springs may be yielding 100 to 200 gpm to Blacktail Pond near Mammoth.
	Tertiary	Andesitic breccia	4,000	Intrusive and extrusive andesitic and dacitic rocks.	Probably contains relatively small quantities of water in fractures and other openings where saturated. Probably would not yield more than a few tens of gallons per minute of water to wells.

Table 1.--Generalized section of rocks exposed in Yellowstone National Park--continued

Era	System	Geologic unit: North	Geologic unit: South	Approximate maximum thickness (feet)	Lithology	Water-bearing properties
PALEOZOIC	Permian	Shedhorn Sandstone	Phosphoria Formation	200	Sandstone and chert.	May yield as much as 10 gpm of water to wells where saturated.
	Pennsylvanian	Quadrant Sandstone	Tensleep Sandstone	300	Mostly sandstone.	May yield as much as 25 gpm of water to wells where saturated.
		Amsden Formation		150	Mostly shaly siltstone.	Probably would not yield more than a few gallons per minute of water to wells.
	Mississippian	Madison Limestone		1,000	Mostly limestone.	May contain relatively large quantities of water in solution channels where saturated. Yields as much as 10 cfs of water to springs. May yield several hundred gallons per minute of water to wells.
	Devonian	Three Forks Formation	Darby Formation	200	Shale and siltstone.	Probably would not yield more than a few gallons per minute of water to wells
		Jefferson Formation		300	Cherty dolomite.	
	Ordovician	Bighorn Dolomite		150	Dolomite.	May yield as much as 100 gpm of water to wells from solution channels where saturated.
	Cambrian	Snowy Range Formation	Gallatin Limestone	100	Limestone and shale.	Probably would not yield more than a few gallons per minute of water to wells.
		Pilgrim Limestone		200	Mostly limestone.	May yield as much as 100 gpm of water to wells from solution channels where saturated.
		Park Shale	Gros Ventre Formation	100	Shale.	Probably would not yield more than a few gallons per minute of water to wells.
		Meagher Limestone		500	Limestone and siltstone.	
		Wolsey Shale		200	Shale and sandstone.	
		Flathead Sandstone		100	Sandstone and conglomerate lenses.	May yield as much as 50 gpm of water to wells where saturated.
	Precambrian	Metamorphic and igneous			Mostly gneiss, schist, and granite.	May contain relatively small quantities of water in fractures. Probably would not yield more than

Table 1.--Generalized section of rocks exposed in Yellowstone National Park--continued

Era	System	Geologic unit: North	Geologic unit: South	Approximate maximum thickness (feet)	Lithology	Water-bearing properties
MESOZOIC	Cretaceous	Landslide Creek Formation	Harebell Formation	2,000	Conglomeratic sandstone, mudstone, and claystone.	May yield a few tens of gallons per minute of water to wells in conglomerate lenses.
		Everts Formation	(missing)	1,250	Lenticular sandstone and mudstone.	Probably would not yield more than a few gallons per minute of water to wells.
		Eagle Sandstone	Bacon Ridge Sandstone	800	Sandstone, shale, and coal.	May yield a few tens of gallons per minute of water to wells in sandstone beds.
		Telegraph Creek Formation		350	Sandstone and shale.	Probably would not yield more than a few gallons per minute of water to wells.
		Cody Shale		1,000	Mostly shale.	Probably would not yield more than a few gallons per minute of water to wells.
		Frontier Formation		500	Mostly sandstone.	May yield a few tens of gallons per minute of water to wells in sandstone beds.
		Mowry Shale		300	Mostly shale.	Probably would not yield more than a few gallons per minute of water to wells.
		Thermopolis Shale		400	Shale and sandstone.	May yield a few tens of gallons per minute of water to wells in Muddy Sandstone Member near top of formation.
		Kootenai Formation	Cloverly Formation	400	Shale, sandstone, and limestone.	Probably would not yield more than a few gallons per minute of water to wells.
	Jurassic	Morrison Formation		400	Claystone, siltstone, and sandstone.	Probably would not yield more than a few gallons per minute of water to wells.
		Ellis Group	Sundance and Gypsum Spring Formations, undivided	500	Claystone, sandstone, and limestone.	May yield a few tens of gallons per minute of water to wells in limestone beds.
	Triassic	Woodside and Thaynes Formations, undivided	Chugwater Formation	500	Mostly siltstone.	Probably would not yield more than a few gallons per minute of water to wells.
		Dinwoody Formation				

Precambrian rocks

The Precambrian rocks exposed in Yellowstone National Park are metamorphic and igneous rocks that constitute the basement complex of the Beartooth Mountains and other uplifted areas in the park (fig. 3). The Precambrian rocks predominantly consist of gneiss, schist, and granite. Outcrops of Precambrian rocks are in mountainous areas of the park, mainly in the Gallatin Range and the Beartooth and Red Mountains.

The Precambrian rocks are hard and dense and have little, if any, permeability except in fractures. In Yellowstone National Park, the Precambrian generally crops out in topographically high areas that are drained of ground water. Near outcrops, however, Precambrian rocks probably contain ground water in fractured zones.

Paleozoic rocks

Paleozoic rocks in Yellowstone National Park are marine limestone, dolomite, sandstone, and shale. Rocks of all systems in the Paleozoic, except the Silurian, occur in the park. Paleozoic rocks crop out chiefly in the uplifted areas of the park such as the Gallatin Range, the Beartooth and Red Mountains, and Chicken Ridge (fig. 3). Isolated outcrops of Paleozoic rocks occur that are surrounded by volcanic rocks of Tertiary and Quaternary age.

The total thickness of Paleozoic rocks in the Beartooth Mountains is about 3,000 feet (Foose and others, 1961, p. 1147). In the Gallatin Range, however, where the Paleozoic rocks are most extensive in Yellowstone National Park, the Paleozoic rocks probably are more than 3,000 feet thick. The Paleozoic rocks are cut by faults, and continuous outcrops of more than a few miles are rare.

In the mountains, the Paleozoic rocks may be in topographically high areas that are drained of ground water. Where the rocks are saturated, ground water occurs in interstices in sandstone, siltstone, and shale, and in fractures and solution channels in limestone and dolomite. Springs occur in Paleozoic rocks in the mountains. Paleozoic rocks that would yield the most water to wells are the Madison Limestone of Mississippian age, the Bighorn Dolomite of Ordovician age, the Pilgrim Limestone and the equivalent part of the Gallatin Limestone of Cambrian age, the Flathead Sandstone of Cambrian age, and the Quadrant Sandstone and the equivalent Tensleep Sandstone of Pennsylvanian age.

Factors controlling the occurrence of ground water in limestone and dolomite in the park probably are similar. Because limestone and, to a lesser degree, dolomite are soluble in water, solution openings have developed along bedding planes, joints, and in brecciated zones. The degree of solution development depends on the present and former topographic position of the rocks. As water moves through the rocks, solution openings are enlarged and connected to other openings to form channels and conduits through which the movement of water is relatively rapid from recharge to discharge areas. Thick deposits of limestone, such as the Madison Limestone, may have extensive development of solution channels; however, thin beds of limestone in other Paleozoic units may also have solution channels.

The Madison Limestone ranges in thickness from about 1,000 to 1,450 feet in the Tepee Creek quadrangle (Witkind, 1969, p. 28-29). Because the Madison thins eastward, it is probably about 1,000 feet thick in the Gallatin Range in Yellowstone National Park. Ruppel (1968, p. 68) reports the thickness of the Bighorn Dolomite as 143 feet, and the Pilgrim Limestone as 207 feet in the Gallatin Range.

The Madison Limestone is an important aquifer in places in Montana and Wyoming, where large yielding wells have been drilled that tap solution channels in the Madison. In Yellowstone National Park, the Madison has been faulted, tilted, and overturned in places, and solution-channel development may not be as widespread as in the areas that have large yielding wells.

The Madison Limestone probably is the source of water discharging from many springs. The Madison probably is the source of water discharging from a large spring--estimated flow of 10 cfs (cubic feet per second)--near an outcrop of Madison in the Gallatin Range. The Madison may be the source of water discharging at Mammoth Hot Springs and nearby Hot River.

The extent of the Madison Limestone is not known, but it may underlie younger rocks at great depth in part of Yellowstone National Park. The only areas where relatively shallow wells could be drilled in the Madison are near its outcrops. Relatively shallow wells could be drilled into the Madison in the Gallatin River valley in the northwestern part of the park. The Madison crops out on both sides of the valley, in places, and it probably directly underlies alluvial and glacial deposits in part of the valley.

Sandstone beds, where saturated, are the principal aquifers in the Paleozoic rocks. The most extensive sandstone beds in the Paleozoic rocks are the Flathead Sandstone of Cambrian age, the Quadrant Sandstone and the equivalent Tensleep Sandstone of Pennsylvanian age, and the Shedhorn Sandstone and the equivalent Phosphoria Formation of Permian age.

The Flathead Sandstone is 75 to 125 feet thick in the Tepee Creek quadrangle and averages 115 feet thick. The Flathead is fine- to coarse-grained quartzose sandstone that is a quartzite locally and contains conglomerate lenses (Witkind, 1969, p. 15). The Flathead has a maximum thickness of 60 feet in the Beartooth Mountains (Foose and others, 1961, p. 1147). The Flathead probably has a maximum thickness of about 100 feet in Yellowstone National Park.

The Flathead Sandstone may contain ground water near outcrops in the Gallatin Range and the Beartooth Mountains. The Flathead apparently crops out near the valley floor along Slough Creek and Soda Butte Creek in the northeastern part of Yellowstone National Park (Brown, 1961, pl. 1). Ground water may occur in the Flathead where the formation underlies alluvium in these valleys. Lowry and Gordon (1964, p. 8) suggest that ground water may occur in the Flathead in Soda Butte Creek valley near Northeast Entrance.

The Quadrant Sandstone and the equivalent Tensleep Sandstone and the overlying Shedhorn Sandstone and the equivalent Phosphoria Formation probably have water-bearing properties similar to the Flathead Sandstone. The Quadrant ranges in thickness from 265 to 315 feet, and the Shedhorn ranges in thickness from about 160 to about 175 feet in the Teepee Creek quadrangle (Witkind, 1969, p. 31-32). In Yellowstone National Park, the approximate maximum thickness of the Quadrant and Tensleep is 300 feet, and the Shedhorn and Phosphoria 200 feet. The Quadrant and Shedhorn crop out in the Gallatin Range and the Tensleep and Phosphoria crop out in the Red Mountains and along Chicken Ridge.

Mesozoic rocks

Mesozoic rocks in Yellowstone National Park are marine and nonmarine sedimentary rocks. These rocks crop out in the Gallatin Range and Mt. Everts area in the northern part of the park, and in the Red Mountains and Chicken Ridge area in the southern part of the park (fig. 3). The Mesozoic rocks are folded and faulted.

Mesozoic rocks in the Gallatin Range are of mostly Triassic, Jurassic, and Lower Cretaceous ages. Upper Cretaceous rocks are exposed in the Mt. Everts area. The Red Mountains and Chicken Ridge area has Triassic, Jurassic, and Lower and Upper Cretaceous rocks.

Triassic, Jurassic, and Lower Cretaceous rocks are mostly nonmarine sandstones and siltstones, but they do contain beds of marine limestone and shale. Upper Cretaceous rocks are mostly a thick unit of marine shale (Cody Shale) underlain and overlain by predominantly sandstone beds. Locally, the Mesozoic rocks are lenticular, and some contain conglomerate.

Ground water in Mesozoic rocks most likely occurs in limestone, sandstone, and conglomerate near outcrops. Mesozoic rocks that would yield the most water to wells are the limestone beds in the Ellis Group and the equivalent Sundance and Gypsum Spring Formations of Jurassic age, the Muddy Sandstone Member of the Thermopolis Shale of Early Cretaceous age, sandstone beds in the Frontier Formation and the Eagle Sandstone and equivalent Bacon Ridge Sandstone of Late Cretaceous age, and conglomerate lenses in the Landslide Creek Formation and the equivalent Harebell Formation of Late Cretaceous age.

Cenozoic rocks

Tertiary rocks in Yellowstone National Park are volcanic breccia, lava, ash, tuff, and sedimentary rocks composed of volcanic-rock fragments. Most of the Tertiary rocks are primarily andesite and, to a lesser degree, dacite, but rhyolite and basalt flows occur in Tertiary rocks. Because water-bearing characteristics of rhyolite are probably similar regardless of age, the Tertiary and Quaternary rhyolites are considered as one geologic unit in this report. Similarly, Tertiary and Quaternary basalts are considered as one geologic unit. The lithology and methods of deposition of the Tertiary volcanic rocks are complex, but the volcanic rocks other than rhyolite and basalt are referred to in this report as the andesitic breccia. Intrusive andesitic and dacitic rocks, as well as extrusive rocks, are included in the andesitic breccia in this report.

Tertiary rocks

The andesitic breccia has been divided, in ascending order, into the Cathedral Cliffs Formation, the Wapiti Formation, the Trout Peak Trachyandesite, and the Wiggins Formation east of Yellowstone National Park. The andesitic breccia, however, is not divided into formations in this report.

Andesitic breccia crops out in the Absaroka, Washburn, and Gallatin Ranges and in the Beartooth Mountains in the eastern and northern parts of Yellowstone National Park (fig. 3). These outcrops are part of extensive deposits of similar rocks in Wyoming and Montana that are generally called the Absaroka volcanic field.

The andesitic breccia contains the famous fossil forests of Yellowstone National Park. The fossils and the stratigraphy of the andesitic breccia have been studied by many geologists.

The andesitic breccia is of Eocene age and has a maximum thickness of about 6,500 feet in the central part of the Absaroka Range, probably east of Yellowstone National Park (Parsons, 1958, p. 38). Prostka (1968a, p. 5) reports a thickness of about 4,000 feet of andesitic breccia in the northeastern part of the park. Chadwick (1968, p. 2) reports the total stratigraphic thickness of the andesitic breccia as 6,000 feet in the Gallatin Range, probably north of the park, but that no more than 3,000 feet is exposed at any one place.

Many geologists have recognized that part of the andesitic breccia has been reworked. The breccia near the source areas is called the vent facies, and reworked material grading outward from the source areas is called the alluvial facies (Prostka, 1968b, p. 62). Most of the andesitic breccia in Yellowstone National Park probably is the reworked material of the alluvial facies.

The andesitic breccia ranges from hard, dense, well indurated, cliff-forming beds to soft, friable, poorly indurated slope-forming beds. The breccia is usually fractured and the fractures commonly contain fine material in outcrop areas. Fractures in the breccia, however, may be relatively free of fine material in hard rock below the zone of weathering. The breccia is gray to dark brown. Most outcrops are brown or dark brown.

Much of the andesitic breccia in Yellowstone National Park occurs in topographically high areas that are drained of ground water. Where saturated, however, ground water occurs in fractures in harder rocks and in interstices in softer and granular rocks.

Tertiary and Quaternary rocks

Rhyolite

Rhyolitic lava flows and tuffs cover much of the plateau area of Yellowstone National Park (fig. 3). Rhyolite is by far the most common rock in the park. The rhyolite generally consists of flow rocks and ash-flow tuff. Most of the tuff has been welded to form a well indurated rock.

The thickness of the rhyolite is variable and the maximum thickness is probably great. Boyd (1961, p. 412) suggests that the plateau area is a collapsed caldera containing rhyolite flows surrounded by ash-flow tuff. Based on information supplied by R. L. Christiansen and H. R. Blank, Jr., Keefer (1972, p. 34-52) delineates and describes the development of a 1,000-square-mile collapsed caldera in the plateau area of the park. The plateau area of the park where the rhyolite may be as much as several tens of thousands of feet thick in the collapsed caldera is called the rhyolite plateau.

Boyd (1961, pl. 1) shows all of his rhyolite units as Pliocene in age. However, he states (p. 410) that subsequent work may show that some of the flows are all or in part Pleistocene in age. Christiansen and others (1968, p. 30) give data obtained by Potassium-Argon dating as 1.5 million years for the age of the oldest ash-flow tuff. This means that all of the rhyolite associated with the collapsed caldera is Quaternary in age. However, the rhyolitic tuff associated with the andesitic breccia in the northeastern part of the park is Tertiary in age. Consequently, rhyolite in this report is both Quaternary and Tertiary in age, because the rhyolites are not differentiated.

The rhyolite consists of rhyolitic lava, breccia, scoria, welded tuff, ash, cinders, and glass. Most common are rhyolitic lavas and welded tuffs. All of the rhyolitic rock types have similar chemical characteristics, and the differences in rock type are due to differences in methods of extrusion and deposition.

The rhyolite is commonly light gray to brown and often has a purple cast. Glassy rhyolite (obsidian) is dark brown and black.

Some of the rhyolite is hard and dense, and some is relatively soft and friable. Brecciated zones and openings resulting from gas bubbles make some parts of the rhyolite porous. Weathering can result in granular rock that is more permeable than fresh rhyolite. Joints and fractures in hard rock increase the permeability.

Rhyolite has been altered by hot water and gas near hot springs, geysers, and fumaroles. The degree of alteration is variable, but in places the rhyolite has been completely altered to clay. The alteration of rhyolite affects the original permeability of the rock. Permeability of altered rhyolite is probably less than unaltered rhyolite because joints and fractures are closed as the rock is altered. Softer altered rhyolite is more easily eroded than harder unaltered rhyolite.

Ground water occurs in porous and fractured zones in rhyolite in most of the plateau areas of the park. Part of the plateau area that is topographically high is drained of ground water.

Fracturing in rhyolite is extensive and is developed to great depths. The fracture systems form avenues for the deep percolation of water as well as avenues for hot water and gas to rise to the surface. Numerous fumaroles and hot springs issuing from the rhyolite indicate connection between near-surface and deep-seated rocks. Commonly accepted theories of hot-spring and geyser occurrence in Yellowstone National Park are that ground water percolates through the rhyolite to depths of several thousand feet, is heated, and rises to the surface.

The upward moving hot water dissolves rhyolite and enlarges the fractures in places. The hot water also alters the rhyolite and deposits minerals in the fractures in other places. The fractures in rhyolite are probably enlarged by solution in the deeper rocks, and diminished in the shallower rocks by deposition of material from the upward moving hot water.

During research of thermal features in the park in 1967 and 1968, eleven test holes were drilled from which cores of altered rhyolite were collected. Hot water under sufficient pressure to flow at land surface was reported from ten of the test holes (White and others, 1968, p. 4-5).

Test holes were drilled during 1959-63 to locate possible ground-water supplies near Norris Junction, Grant Village, and Cave Falls. These test holes provide data regarding water-bearing characteristics of the rhyolite.

The test hole near Norris Junction (RNJ 1, fig. 2-A) was drilled in 1960 to a depth of 125 feet. Rhyolite was penetrated from a depth of 12 feet to the bottom of the hole. Hot water at a temperature of 142°F (61.0°C) flowed to the surface from fractures at depths of 114 to 117 feet, the only water-bearing zone reported. The volume of flow of water is not known.

One of six test holes (CGV 4, fig. 2-A) drilled in 1959 near Grant Village penetrated rhyolite from a depth of 55 feet to the bottom of the hole at 150 feet. In general, the rhyolite was described as porous welded tuff (Gordon and others, 1962, table 1, test well 4). A 20-minute bailing test indicated a yield of 2.6 gpm for the rhyolite from depths of 58 to 150 feet. Temperature of the water was 99°F (37.0°C) at 150 feet (Gordon and others, 1962, p. 186).

The test hole near Cave Falls (CCF 1, fig. 2-A) was drilled in 1963 to a depth of 153 feet at a point about 1,100 feet north of the south boundary of the park and about 1,100 feet west of the Falls River (Lowry and Gordon, 1964, p. 37). The drill penetrated rhyolite from depths of 2 to 103 feet, and sand and gravel from a depth of 103 feet to the bottom of the hole (Lowry and Gordon, 1964, p. 33-34). The main water-bearing zone is the sand and gravel, and the water level was 33 feet below land surface. A 24-hour aquifer test indicated a yield of 10 gpm with a drawdown of 38 feet (Lowry and Gordon, 1964, p. 37). Temperature of the water was 48°F (9.0°C).

The relatively low yields of water from test holes in the rhyolite suggest that even seemingly porous rhyolite may not yield more than a few tens of gallons per minute to wells in the park. However, drilling in the rhyolite has not been extensive, and larger yields of water to wells may be available locally in the rhyolite. Discharge estimated at 100 to 200 gpm of ground water into Blacktail Pond and from springs on Blacktail Flat is probably from a rhyolite aquifer and overlying glacial deposits on the flat.

Crosthwaite and others (1970, p. C10-C12) report yields from irrigation wells of a few hundred to several thousand gallons per minute from silicic volcanic rocks (presumably rhyolite) in Idaho about 15 to 30 miles southwest of Yellowstone National Park. Most of these wells draw water from permeable beds of volcanic ash and basalt interbedded with the massive rhyolite. Apparently, yields from wells nearer the park have not been adequate for irrigation because the permeability of the rhyolite is too low (Crosthwaite and others, 1970, p. C12).

Basalt

Basaltic lava flows occur in the northern, eastern, and southern parts of Yellowstone National Park (fig. 3). Basalt flows are interbedded with andesitic breccia and underlie and overlie rhyolite tuff units.

Brown (1961, p. 1179) reports that basalt 700 to 1,000 feet thick forms the east wall of Mirror Plateau. Most of the basalt exposures in the park, however, are probably less than 100 feet thick. The basalt was extruded mostly into valleys, and continuous outcrops are not widespread. The basalt units commonly consist of several individual flows.

Basalt is commonly gray to dark gray. It generally contains inclusions of associated minerals. The basalt is hard and dense and contains joints and other fractures.

Brecciated zones at the tops and bottoms of individual flows, openings resulting from gas bubbles, and fractures make parts of the basalt permeable. Basalt is an excellent aquifer in the Snake River Plain in Idaho west of Yellowstone National Park where it has great thickness and consists of a series of flows. Crosthwaite and others (1970, p. C13) state that the major water-bearing zones in basalt in the Snake River Plain occur at the contacts between flows.

Much of the basalt in the park occurs along valley walls and is drained of ground water. Basalt probably occurs below the water table in parts of the Lamar River valley in the northeastern part of the park, the Falls River basin in the southwestern part of the park, and at isolated locations in other parts of the park.

The supply well at Bechler Ranger Station (RB 1, fig. 2-A), drilled in 1960, penetrates basalt. A driller's log for this well lists hard gray rock from depths of 12 feet to 48 feet, clay from depths of 48 feet to 61 feet, and hard, firm rock from a depth of 61 feet to the bottom of the well at 240 feet. The rocks between 12 feet and 48 feet and between 61 feet and 240 feet are probably basalt flows. The positions of the water-bearing zones are not known. The well reportedly yielded 8 gpm in 1960. In September 1968, the yield had decreased as sand had partly filled the well. Water level in the well in September 1968 was 35 feet below land surface.

The relatively low yield of the well at Bechler Ranger Station suggests that yields of more than a few tens of gallons per minute of water cannot be expected from wells that penetrate even thick sections of basalt in Yellowstone National Park. However, these data are not conclusive and larger amounts of ground water may occur locally in the basalt. A series of basalt flows would more likely have permeable zones than would a single basalt flow.

Quaternary rocks

Glacial deposits

Most of Yellowstone National Park has been covered by glaciers that originated in the Absaroka Range and the Beartooth Mountains. At least three periods of glaciation have been recognized in the park; they are generally correlated with the Buffalo, Bull Lake, and Pinedale stages of Blackwelder (1915). Most of the glacial deposits exposed in the park probably are from the Pinedale Glaciation, because the Pinedale covered much of the area of previous glaciations. Pinedale glaciers covered 90 percent of Yellowstone National Park (Keefer, 1972, p. 56). The relative ages of the glacial deposits, however, are not pertinent to this investigation.

Glacial deposits in the park consist of till, moraine, outwash, kame, and kame terrace deposits. In addition, lake sediments, alluvial deposits, and landslide material are probably directly related to glaciation, but are described separately in this report. The glacial deposits range from unsorted till composed mostly of bouldery clay to well-sorted outwash composed mostly of sand and gravel.

Glacial debris covers most of Yellowstone National Park. Most geologic maps, however, do not show thin glacial debris that only mantles bedrock. In this report, glacial deposits are not considered important or shown on the geologic map (fig. 3) unless they are thought to be relatively thick or to contain ground water.

Glacial and alluvial deposits in some of the stream valleys in the park are considered as one in this report. Geologists differ on the interpretation of the units in some of these valleys. Moreover, some geologic maps show the units in more detail than is necessary for the purpose of discussion in this report. Many of the glacial and alluvial deposits have similar water-bearing characteristics.

Many stream valleys in the park contain sand and gravel composed of fragments of nearby bedrock that have been eroded and deposited by both glacial and stream action. Stream valleys in and near the rhyolite plateau commonly contain sand and gravel composed of angular fragments of obsidian and quartz derived from nearby rhyolite flows. Because of the abundance of obsidian, the sand and gravel deposits generally are dark gray to black. Stream valleys in and near the Absaroka volcanic field commonly contain sand and gravel composed mostly of andesite. The sand and gravel in the valleys commonly are poorly sorted because the material has been transported only a short distance by streams. The material ranges in size from fine-grained sand to medium gravel.

Morainic deposits occur in several relatively wide valleys in the northern part of Yellowstone National Park. Moraines cover much of the valleys along the Lamar and Gardner Rivers and Blacktail Deer Creek. The moraines contain rock from many different sources. The material is poorly sorted and ranges in size from clay to boulders. Knob-and-kettle topography is common.

Ground water occurs in stream valleys in deposits of sand and gravel that are at least in part of glacial origin. Sand and gravel in some of the valleys are a few hundred feet thick. Some of the valleys are only a few hundred to a few thousand feet wide and many are relatively narrow and deep. Sand and gravel are not continuous along most of the valleys, and bedrock crops out in the valley floors in places. Shallow depths to water tables indicate that a large thickness of the sand and gravel is saturated. The valleys contain perennial streams.

Test holes were drilled in stream valleys during this investigation to determine the extent and the water-bearing characteristics of the sand and gravel. Yields of test wells were as much as 100 gpm where saturated thicknesses are almost 100 feet, but yields were smaller in valleys where saturated thicknesses are thinner. Results of drilling and testing in the stream valleys are given in more detail in this report, in the section on water resources near selected sites.

Ground water occurs in moraines in many of the valleys in the northern part of the park. The moraines are typically bouldery and clayey, and do not yield water readily to wells. Thin lenses of sand and gravel in the moraines, however, might yield water to wells.

Test holes were drilled in moraines to determine water-bearing characteristics of the rocks. Much of the drilling was done with a truck-mounted power auger that had limited drilling capabilities as boulders and tough clay frequently stopped the auger bit. Test drilling indicated that morainic deposits generally have low permeability.

Glacial deposits probably underlie lava flows in parts of Yellowstone National Park. Richmond (1964, p. 228-229) suggests that Bull Lake till underlies rhyolite in places in the western part of the park. Clay in the Bechler Ranger Station well and sand and gravel in the Cave Falls test hole, mentioned previously in this report, are probably glacial deposits that are older than overlying lava flows. Glacial deposits of sand and gravel that underlie lava flows are probably permeable and, where saturated, contain water that could be tapped by wells.

Lacustrine deposits

Lacustrine deposits occur in the park in lake basins and in areas where lakes existed temporarily during and after glaciation (fig. 3). The lacustrine deposits consist of clay, silt, sand, and gravel. In places, the fragments have been cemented to form siltstone, sandstone, and conglomerate. Lacustrine sediments probably occur in minor amounts in areas mapped as glacial deposits. Lacustrine deposits in this report are relatively thick beds that contain only minor amounts of nonlacustrine sediments.

Lacustrine deposits are relatively thick in the basin containing Yellowstone Lake. Test holes drilled in 1959 near Grant Village to depths of as much as 200 feet penetrated only lacustrine deposits (Gordon and others, 1962, table 1). A test hole near Fishing Bridge (AFB 1, fig. 2-A) drilled to a depth of 100 feet in 1970 penetrated only lacustrine deposits. Lacustrine sediments occur at altitudes up to 7,900 feet (Howard, 1937, p. 152), or about 170 feet above the present Yellowstone Lake. Richmond (1968, p. 65) reports widespread beach deposits at altitudes of 7,790 and 7,840 feet, or about 60 and 110 feet, respectively, above the present lake.

The surficial rocks in Hayden valley were mapped as glacial drift by Hague and others (1896), but were called largely lacustrine deposits. overlain and underlain by fluvial deposits, by Howard (1937, p. 152). The surficial rocks in Hayden valley and near Canyon Village are probably mostly lacustrine deposits. Howard (1937, p. 152) states that lacustrine deposits occur up to altitude 8,000 feet in Hayden valley and that the sediments in Hayden valley are not continuous with those in the Yellowstone Lake basin. The method of deposition or the continuity of the lacustrine sediments in Hayden valley and nearby areas, however, are beyond the scope of this investigation. No test holes are known to have been drilled in Hayden valley that give an indication of the thickness of the lacustrine deposits.

Nineteen test holes were drilled in the Canyon Village area in meadows and small clearings along Cascade Creek and the lower reach of Otter Creek. Much of the material penetrated was clay or clayey sand and gravel of lacustrine origin. Some of the holes penetrated bedrock (rhyolite or andesitic breccia), and some penetrated lacustrine deposits to the total depth of the hole. The deepest hole (ACV 4, fig. 2-A), drilled to a depth of 117 feet, penetrated only lacustrine deposits.

Ground water occurs in interstices in unconsolidated lacustrine deposits and probably in fractures in cemented lacustrine deposits in the Yellowstone Lake basin. The water moves through the lacustrine sediments from the topographically high areas of the basin toward the lake. Water levels in wells near the lake fluctuate as the level of the lake fluctuates, indicating hydraulic connection between water in the lake and ground water in the lacustrine deposits. Gordon and others (1962, p. 198) concluded from aquifer tests by bailing and pumping that test well CGV 2 near Grant Village (fig. 2-A) would have a maximum yield of 30 to 35 gpm from lacustrine deposits. Yields from other test wells were smaller.

Wells CBB 1 and CBB 2 at Bridge Bay (fig. 2-A), drilled and tested during 1960-63, tap lacustrine deposits. Lowry and Gordon (1964, p. 13 and 36) conclude that wells CBB 1 and CBB 2 would have maximum yields of 30 and 45 gpm, respectively.

Ground water occurs in lacustrine deposits near Canyon Village and probably in Hayden valley. The lacustrine deposits are clayey and do not yield water readily to wells. Sandy lenses penetrated by some of the test holes near Canyon Village may be beach deposits. These beach deposits probably would yield 5 to 10 gpm to wells.

Hot-springs deposits

Hot springs in Yellowstone National Park have deposited siliceous sinter, calcareous travertine, and other minerals. Hot springs were active during and since the eruption of the rhyolite (Boyd, 1961, p. 409). Glacial drift in many parts of the park contains fragments of sinter and travertine. Hot-springs deposits are not shown on the geologic map (fig. 3).

The terraces at Mammoth Hot Springs are the most extensive deposit of travertine in the park. Travertine from present or former springs at Mammoth occurs from near the Gardner River to the top of Terrace Mountain, a difference in altitude of more than 2,000 feet. Travertine is 250 feet thick at the site of a test hole drilled during a previous study near the upper terrace (Keefer, 1972, p. 77).

Siliceous sinter and other minerals are common in the surficial deposits in the Upper, Midway, and Lower Geyser Basins. Some of the sand and gravel deposits are composed of fragments of these minerals. In places, minerals deposited in beds of sand and gravel by upward-moving hot water formed relatively hard impervious deposits. Glacial drift cemented by minerals from hot springs that issued under the ice occurs at Porcupine Hills and Twin Buttes in the Lower Geyser Basin.

Hot-springs deposits are localized and are not extensive aquifers in the park. Water from the hot springs moving through hot-springs deposits recharges aquifers in adjacent rocks and affects the quantity and quality of ground water in those rocks.

Landslide deposits

Landslides have occurred in some of the valleys in Yellowstone National Park. The most extensive landslide deposits are on the north and east slopes of Sepulcher Mountain near Mammoth. Landslide deposits also are along the valley of Soda Butte Creek in the northeastern part of the park and in the Gallatin Range in the northwestern part. Locations of the landslide deposits on Sepulcher Mountain, in Soda Butte Creek valley, and a large deposit in the Gallatin Range are shown in figure 3. Other landslide deposits in the park are either combined with other units or are too small to delineate on figure 3.

Landslide deposits on the slopes of Sepulcher Mountain are large glide blocks and slump blocks near the mountain and earth flows near the Gardner and Yellowstone Rivers. The earth flows consist of a heterogeneous mass of fragments ranging from 10-foot blocks to clay. Some are mud flows (Waldrop and Hyden, 1963, p. E11). The landslide is active as indicated by frequent slides along the Gardner River.

The landslide deposits in the valley of Soda Butte Creek are generally between the steep slopes of resistant rock and the valley floor. These deposits also consist of a heterogeneous mass of fragments of various size. The landslides near Soda Butte Creek are probably not as active as those near the Gardner River.

A large landslide along Grayling Creek in the Gallatin Range has been mapped by Witkind (1969, pl. 1). He also describes (p. 60-62) smaller landslide deposits in the Gallatin River valley in the park that are earth flows and other landslide deposits west of the park.

Ground water occurs in landslide deposits, particularly in those slides that are active. The topographically higher parts of landslide deposits may have drained, but the lower parts may be saturated. Landslide deposits near Sepulcher Mountain and in the valley of Soda Butte Creek contain water as evidenced by lakes and water discharged to streams. Witkind (1969, p. 61) states that all earth flows he has mapped have springs or small streams near their heads or along their flanks; however, because the landslide deposits are heterogeneous and clayey, they probably would not yield water readily to wells.

Alluvium

Alluvium occurs as flood-plain deposits, terrace deposits, and alluvial fans in valleys in Yellowstone National Park (fig. 3). Alluvium is usually well sorted silt, sand, and gravel. Part of the alluvium is glacial drift that has been reworked by modern streams. The alluvium closely resembles stream deposits of glacial origin. Alluvial and glacial stream deposits in most of the park are combined into one unit in this report. Terraces have formed along some of the larger streams in the park. Alluvial fans have formed in the stream valleys at the mouths of tributaries

Old alluvium that underlies basalt near the north boundary of Yellowstone National Park near Gardiner, Mont., has been described by Fraser and others (1969, p. 56) as poorly cemented conglomerate. Similarly, alluvium may underlie basalt and rhyolite flows in part of the park.

Relatively large quantities of ground water occur in alluvium in stream valleys in the park. Sand and gravel of alluvial and glacial origin yield as much as 100 gpm to test wells. The depth to water is shallow, and a large thickness of the sand and gravel is saturated.

Hydrology

Surface water

Many streams originate or flow through Yellowstone National Park. These streams carry runoff from melting snow and rainfall in the park and nearby mountainous areas. Water discharged from aquifers and from the numerous thermal features in the park enters the streams. The park contains several large natural lakes and many small ones. Numerous springs occur in the park where water discharges at the land surface by gravity flow and by pressure effects in thermal areas. Water in streams, lakes, and springs are the surface-water resources of the park.

Streamflow data have been collected for many years at gaging stations in and near Yellowstone National Park. Nearly continuous record of streamflow is obtained during the time a gaging station is in operation. Periods of record at gaging stations in operation at the end of water year 1970 ranged from 32 to 64 years. (Water year is the 12-month period ending September 30 of the specified year.) Streamflow records are also available from gaging stations that were operated temporarily in the park. In addition, streamflow has been measured at miscellaneous sites in the park.

Streamflow is greatest during May-July as a result of melting snow. Streamflow declines during the summer and fall and is lowest in the winter. The streamflow pattern varies from year to year owing to weather conditions affecting snowmelt and local precipitation, but the pattern of high flows in late spring and early summer and low flows in fall and winter occurs each year. Yearly and monthly mean streamflow at six gaging stations in and near the park for January 1967-September 1970 are shown in figure 4. No other gaging stations were operated in the park during that period. Other data, including daily flow at gaging stations, are listed in State reports and water-supply papers on surface-water records by the U.S. Geological Survey. Locations of gaging stations are shown in figure 2-A, except 13047500 Falls River near Squirrel, which is about 14 miles downstream from the park boundary.

The distribution of streamflow at gaging stations can be shown by duration curves. A duration curve shows the percentage of time a specified flow was equaled or exceeded during the period of record. The longer the period of record the more accurately the duration curve shows the distribution of streamflow. Duration curves for gaging stations that were operated for periods long enough to indicate distribution of streamflow in the park are shown in figure 5.

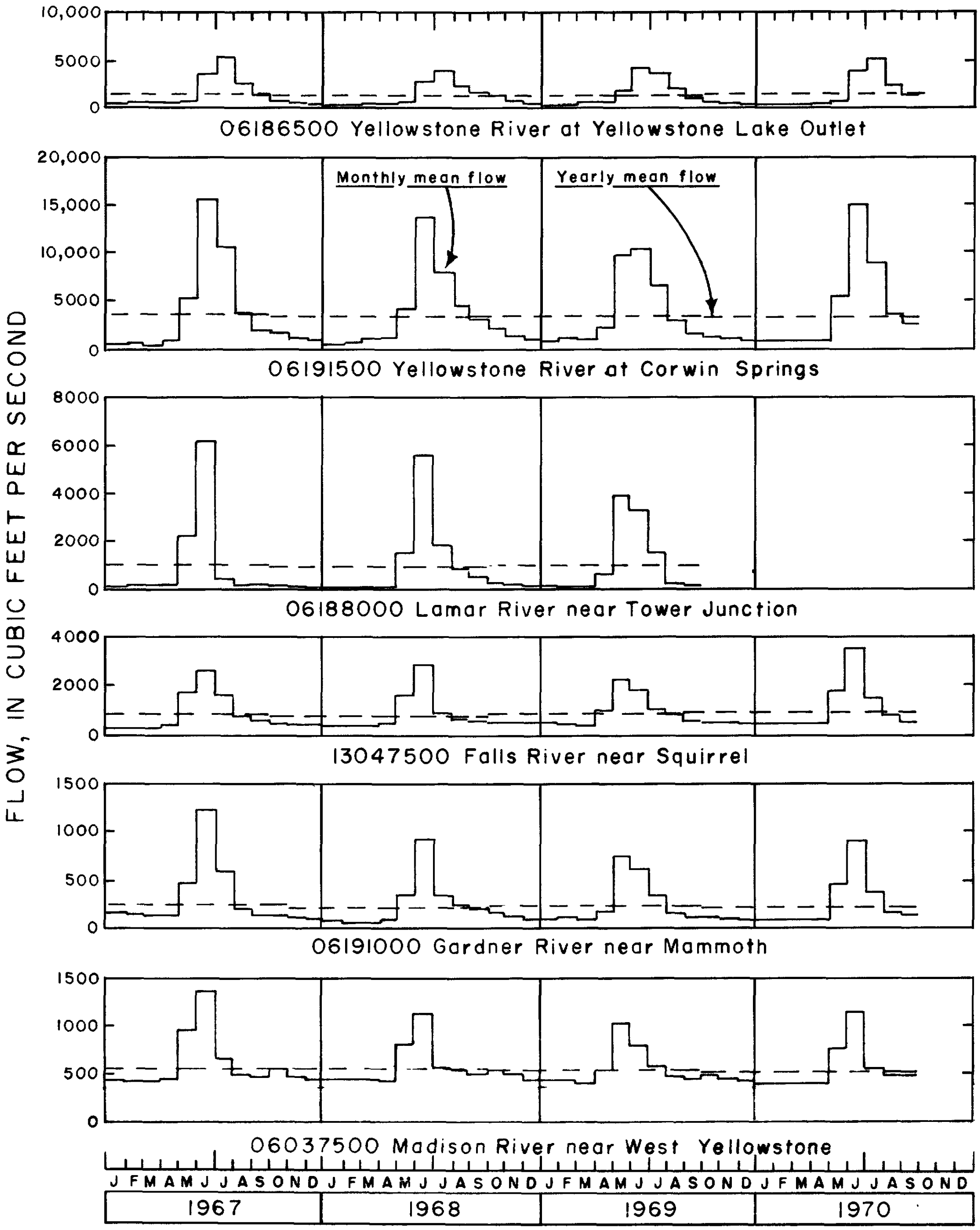

Figure 4.--Yearly and monthly mean flow at gaging stations in and near Yellowstone National Park.

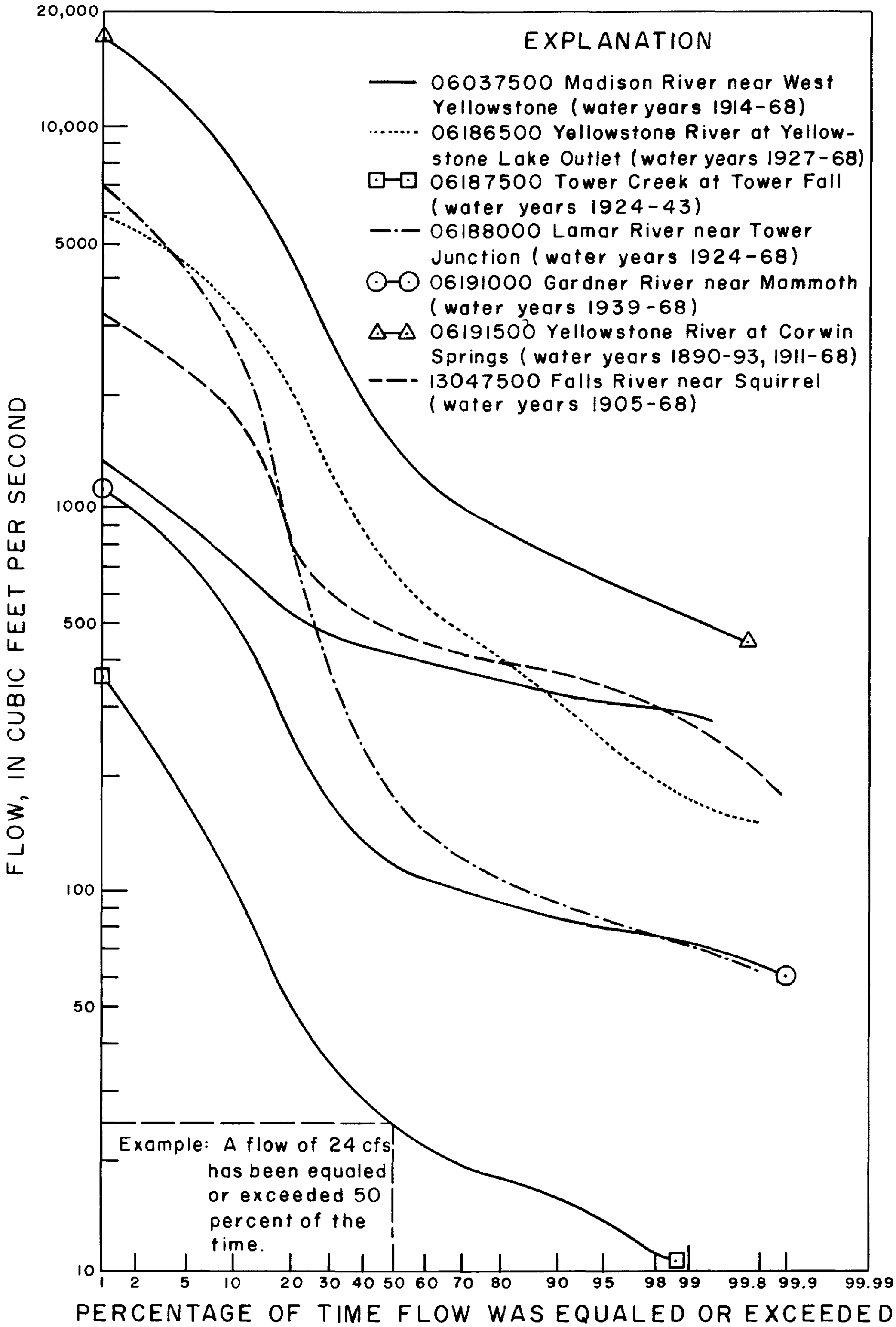

Figure 5.--Duration curves of flow at gaging stations in and near Yellowstone National Park.

Streamflow measurements were made at 18 miscellaneous sites in the park seven times from May 1969 to October 1970. These measurements are listed in table 2. Locations of the measuring sites are shown in figure 2-A. The measurements were made between the eleventh and the twenty-third of the specified month. The selected measuring sites were located on accessible streams of different sizes. The larger streams in the park were not included because wading measurements cannot be made on these streams most of the time. Most of the measurements were made during periods of relatively low flow when the streams could be waded. No facilities were constructed at the sites to measure high flows. Most of the measurements in May 1969 were made after snowmelt had begun; most of those in May 1970 were made before much snow had melted.

Discharge measurements were made at other miscellaneous sites in the park. Only one measurement was made at many of these sites. The location of the other miscellaneous sites where streams and springs were measured and the discharge are shown in figure 2-A.

During this study, measurements of thermal-water discharge were made only at Mammoth Hot Springs (8.20 cfs) and at Hot River (19.0 cfs) on April 4, 1967. However, some of the streams that were measured during the study contain water from thermal features. The total amount of thermal-water discharge to the streams and lakes in the park is unknown, but it is small compared to the amount of water contributed by other sources.

Table 2.--Streamflow at selected miscellaneous sites in Yellowstone National Park.

Station no.	Stream	Streamflow, in cubic feet per second						
		May 1969	July 1969	Sept.1969	Nov. 1969	May 1970	July 1970	Oct. 1970
06036800	Firehole River above Old Faithful	185	75.0	53.9	50.0	34.3	-----	52.0
06036813	Iron Spring Creek	26.4	36.7	36.9	36.6	-----	32.8	36.9
06036900	Nez Perce Creek	151	64.8	53.1	56.7	59.0	63.2	57.6
06036910	Firehole River at Madison Junction	1/ 1,100	352	281	293	310	312	298
06036930	Gibbon River	150	42.9	22.4	21.3	22.2	33.9	23.6
06042920	Gallatin River	162	101	47.1	38.2	29.9	82.4	36.8
06185955	Arnica Creek	33.0	6.25	8.40	4.32	4.90	4.00	4.20
06185970	Cub Creek	43.1	12.2	1.14	-----	.85	8.11	1.53
06185985	Bridge Creek	9.07	.93	.39	.46	.54	.39	.40
06187920	Pebble Creek	209	66.3	10.0	5.58	10.1	44.0	9.02
06187980	Slough Creek	1/ 900	318	30.6	33.0	103	202	47.2
06189030	Blacktail Deer Creek	83.4	22.8	3.17	6.08	9.52	12.4	5.73
06189730	Gardner River	228	81.8	23.4	12.8	-----	53.9	20.9
06189902	Glen Creek	35.4	19.8	16.2	16.6	19.1	19.6	16.1
06189980	Lava Creek	113	53.0	25.2	22.3	18.0	38.9	21.1
06279850	Middle Creek	243	112	18.2	15.6	28.9	98.0	22.3
13007100	Herron Creek	6.11	1.23	.32	-----	-----	.59	.22
13009200	Unnamed tributary to Lewis River	6.29	2.52	1.51	1.66	-----	2.27	1.47

1/ Estimated.

Ground water

At the time of this study, ground water was pumped from wells for public water supplies at Northeast Entrance, West Entrance, Bridge Bay, Indian Creek campground, and Bechler Ranger Station. The amount of ground-water pumpage is not known, but it is small compared to other ground-water discharge such as evapotranspiration and discharge to streams and lakes.

Little is known about the movement of ground water at depths below about 200 feet, except that water percolates to depths of several thousand feet in fracture systems near thermal-water discharge areas. These fracture systems are seemingly localized and ground water probably does not move laterally more than a few miles.

Movement of ground water in the upper 200 feet is largely controlled by the topography. Ground-water divides probably coincide with drainage divides, and ground water does not move from one drainage area to another.

Aquifers in alluvium and glacial deposits along stream valleys in Yellowstone National Park receive most of their recharge from precipitation and from water in streams. These aquifers are generally in sand and gravel and are moderately to highly permeable. The water table is continuous with the stream level, and the stage of the stream controls, at times, the direction of the hydraulic gradient in the aquifer. The bedrock is much less permeable than the sand and gravel, and recharge to the aquifers from bedrock is small. Hot springs issuing from bedrock near the edges of some of the valleys also suggest that water generally does not move from the bedrock to the sand and gravel in the valleys. During periods of low flow in the stream, the hydraulic gradient in the aquifer is toward the stream, and water moves from the aquifer to the stream. During periods of high flow in the stream, the hydraulic gradient, at least near the stream, is toward the aquifer, and water moves from the stream to the aquifer. The rise in the water table throughout a highly permeable aquifer of small areal extent might be about equal to the rise in stage of the stream. The highest stages in streams occur after the snowpack in the valleys has melted and the snowpack in the surrounding higher country is melting. The highest ground-water levels in aquifers that receive recharge from streams occur during the peak runoff period. The lowest ground-water levels occur when streamflow is lowest.

Aquifers in the lacustrine deposits adjacent to the lakes receive most of their recharge from precipitation; however, near the lake shore the aquifer may receive some recharge from the lake when the lake level is high. A rise in lake stage may result in a temporary reversal of gradient in that part of the aquifer near the lake shore. When the lake level lowers, the water that went into ground-water storage from the lake returns to the lake.

The interconnection of these aquifers and surface-water bodies assures the aquifers of a nearby source of recharge. Many of these aquifers are accessible for development by wells. Pumping of wells could cause the ground-water gradient to slope from the surface-water source to the aquifer, thereby inducing recharge to the aquifer even during periods of low stage in the stream or lake.

Water levels have been measured intermittently in water-supply and test wells in the park since the early 1960's. During 1968-70, water levels were measured at approximately monthly intervals in most wells that could be used as observation wells when the wells were accessible and not snow covered. Water levels in four wells are shown in figure 6.

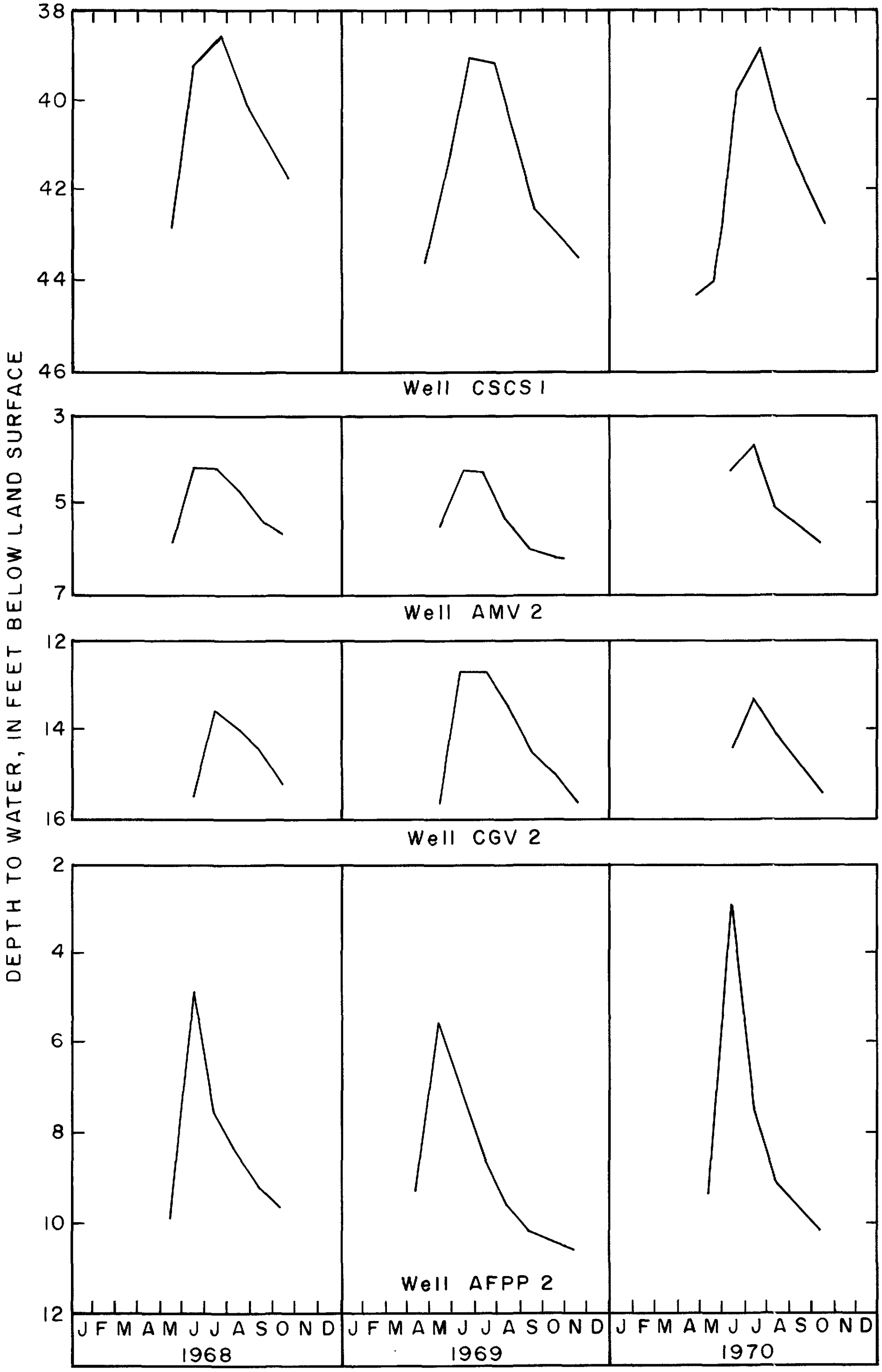

Figure 6.--Water levels in selected wells in Yellowstone National Park.

Quality of water

Water samples were collected from test holes, wells, streams, and springs to determine the general chemical quality of water. Water samples collected from some test wells at sites where ground-water supplies might be developed for public use were analyzed for trace elements and radiochemical content. Water samples for bacteriological analysis were collected from selected test wells. Periodic determinations of suspended-sediment load were made in selected streams near Mammoth and Old Faithful.

Most chemical constituents are expressed in milligrams per liter in this report. The common constituents are also expressed in milliequivalents per liter. Values in milliequivalents per liter are determined by multiplying the milligrams per liter by the reciprocals of the combining weights of the appropriate constituents. Some constituents and trace elements determined by spectrographic analysis are expressed in micrograms per liter. Gross alpha activity and uranium content determined by radiochemical analysis are also expressed in micrograms per liter. A microgram equals 1 thousandth of a milligram. Radioactivity due to radium and gross beta activity are expressed in picocuries per liter. A picocurie is 1 million-millionth of a curie (a standard unit of radioactivity).

The U.S. Geological Survey reported concentrations of chemical constituents in parts per million prior to October 1, 1967. For practical purposes, concentrations less than 7,000 ppm (parts per million) are equal to those in milligrams per liter.

Water temperatures were measured by the U.S. Geological Survey in degrees Fahrenheit (°F) prior to October 1, 1967 and in degrees Celsius (°C) since that date. Water temperatures in this report are given in °C and are rounded to the nearest 0.5°C. Temperatures in °C can be converted into °F by the equation °F = 1.8 (°C) + 32.

The drinking water standards published by the U.S. Public Health Service (1962) can be used in evaluating the quality of the water. The following explanations and tables are from pages 7 and 8 of the above-mentioned report:

"The following chemical substances should not be present in a water supply in excess of the listed concentrations where...other more suitable supplies are or can be made available."

Substance	Concentration (milligrams per liter)
Arsenic (As)	0.01
Chloride (Cl)	250
Copper (Cu)	1
Fluoride (F)	1.7
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Total dissolved solids	500
Zinc (Zn)	5

"The presence of the following substances in excess of the concentrations listed shall constitute grounds for rejection of the supply."

Substance	Concentration (milligrams per liter)
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	.01
Chromium (Hexavalent) (Cr^{+6})	.05
Fluoride (F)	[a] 2.4
Lead (Pb)	.05
Silver (Ag)	.05

[a] Limits of fluoride vary according to annual average of maximum daily air temperature. At Yellowstone National Park, the upper limit is probably 1.7 mg/l (milligrams per liter) and the optimum concentration is probably 1.2 mg/l. The U.S. Public Health Service (1962, p. 8) states, "Presence of fluoride in average concentrations greater than two times the optimum values...shall constitute grounds for rejection of the supply."

Recommended limits for all radioactive materials in water have not been established. Approval of water supplies containing radioactive materials depends on the amount of radiation from all sources, so that total exposure does not exceed that recommended by the Federal Radiation Council. The U.S. Public Health Service (1962, p. 9) states that water supplies can be approved without further consideration of other sources of radioactivity when Radium-226 and Strontium-90 do not exceed 3 and 10 picocuries per liter, respectively. In the known absence of alpha emitters and Strontium-90, the water supply is acceptable if the gross beta concentrations do not exceed 1,000 picocuries per liter.

The U.S. Geological Survey, in order to have a uniform policy in classifying water hardness in the United States, uses the following classification:

Hardness range (milligrams per liter)	Adjective rating
0 - 60	Soft
61 - 120	Moderately hard
121 - 180	Hard
>180	Very hard

Data on the quality of ground water in Yellowstone National Park are not as extensive as data on quality of surface water. Not many wells have been drilled in the park, and most of these penetrate only alluvial, glacial, or lacustrine deposits. Most of the wells are near streams or lakes. Because of the interchange of surface and ground waters near streams and lakes, quality of the ground water is similar in many places to the quality of the surface water. Quality of the water in some bedrock aquifers can be determined by sampling springs. Most springs, however, issue from unconsolidated rock, and the quality of water from these springs may be influenced as much by the unconsolidated rock as by the underlying bedrock.

Water samples were collected from five test wells in the park near the end of periods of test pumping. Chemical analyses of water from these wells near the end of the longest pumping periods are listed in table 3. Spectrographic and radiochemical analyses of water from the five test wells are listed in table 4.

Table 3.--Chemical analyses of water from five wells, Yellowstone National Park

[Analytical results in milligrams per liter (mg/l), milliequivalents per liter (meq/l), or micrograms per liter (µg/l), except as indicated. Analyses by U.S. Geological Survey.]

Constituent	ANJ 14		AFPP 5		AMV 6		ASE 9		ATJ 12	
	Aug. 22, 1970		Aug. 27, 1970		Aug. 20, 1970		Aug. 30, 1970		Aug. 24, 1970	
	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Silica (SiO_2)	44	-----	78	-----	65	-----	42	-----	30	-----
Iron (Fe) (µg/l)	120	-----	70	-----	30	-----	40	-----	90	-----
Calcium (Ca)	30	1.50	4.0	0.20	13	0.65	8.8	0.44	13	0.65
Magnesium (Mg)	9.1	.75	.4	.03	3.4	.28	1.7	.14	4.5	.37
Sodium (Na)	81	3.52	31	1.35	11	.48	23	1.00	13	.56
Potassium (K)	9.2	.24	5.4	.14	5.5	.14	3.2	.08	1.6	.04
Bicarbonate (HCO_3)	320	5.24	59	.97	79	1.29	71	1.16	86	1.41
Carbonate (CO_3)	0	0	0	0	0	0	0	0	0	0
Sulfate (SO_4)	2.6	.05	12	.25	6.2	.13	3.6	.07	6.6	.14
Chloride (Cl)	18	.51	10	.28	1.2	.03	11	.31	1.2	.03
Fluoride (F)	1.5	.08	5.0	.26	2.7	.14	2.5	.13	.6	.03
Nitrate (NO_3)	0	0	.3	0	.6	.01	.1	0	.2	0
Arsenic (As) (µg/l)	$<$10	-----	40	-----	$<$10	-----	50	-----	$<$10	-----
Boron (B) (µg/l)	420	-----	150	-----	20	-----	180	-----	40	-----
Selenium (Se) (µg/l)	1	-----	1	-----	1	-----	2	-----	1	-----
Dissolved solids	352	-----	175	-----	148	-----	131	-----	113	-----
Hardness as $CaCO_3$	112	-----	12	-----	46	-----	29	-----	51	-----
Specific conductance (micromhos at 25°C)	542	-----	175	-----	155	-----	168	-----	150	-----
pH (units)	7.0	-----	6.7	-----	6.4	-----	7.2	-----	6.9	-----
Color (platinum-cobalt units)	6	-----	6	-----	6	-----	4	-----	5	-----
Temperature (°C)	7.5	-----	13.0	-----	10.0	-----	13.0	-----	7.5	-----
Depth (feet)	20	-----	49	-----	35	-----	29	-----	28	-----
Yield (gpm)	20	-----	108	-----	93	-----	60	-----	9	-----
Total cations	-----	6.01	-----	1.72	-----	1.55	-----	1.66	-----	1.62
Total anions	-----	5.88	-----	1.76	-----	1.60	-----	1.67	-----	1.61
Percent sodium	-----	59	-----	78	-----	31	-----	60	-----	35
SO_4/Cl	-----	.10	-----	.89	-----	4.3	-----	.23	-----	4.7
F/Total anions $-HCO_3$	-----	.12	-----	.33	-----	.45	-----	.26	-----	.15

$<$ Less than figure shown.

Table 4.--Spectrographic and radiochemical analyses of water from five wells, Yellowstone National Park

[Analytical results in micrograms per liter except as indicated. Analyses by U.S. Geological Survey.]

Constituent	ANJ 14		AFPP 5		AMV 6		ASE 9		ATJ 12
	7-30-68	8-22-70	8-1-68	8-27-70	8-2-68	8-20-70	8-6-68	8-30-70	8-24-70
Aluminum (Al)------------	20	17	100	100	32	140	23	50	80
Barium (Ba)--------------	17	23	3	5	24	25	18	16	35
Beryllium (Be)-----------	<2	<.9	4	3	2	4	<.7	<.3	<.3
Bismuth (Bi)-------------	ND	<5	ND	<2	ND	<2	ND	<2	<2
Boron (B)----------------	290	340	100	100	25	24	110	100	50
Cadmium (Cd)-------------	ND	<85	ND	<35	ND	<35	ND	<30	<25
Cesium (Cs)--------------	7	-----	20	-----	2	-----	7	-----	-----
Chromium (Cr)------------	<8	<7	<4	<3	<3	<3	<4	<3	<2
Cobalt (Co)--------------	<16	<5	<7	<2	<6	<2	<7	<2	<2
Copper (Cu)--------------	.9	4	.9	<2	3	4	.8	2	6
Germanium (Ge)-----------	ND	<5	ND	<2	ND	<2	ND	<2	<2
Iron (Fe)----------------	33	150	75	50	20	42	15	31	85
Lead (Pb)----------------	<8	3	<4	17	<3	1	<4	<1	1
Lithium (Li)-------------	180	130	75	37	27	11	85	34	1
Manganese (Mn)-----------	<4	<4	5	<2	<2	<2	<2	<2	3
Molybdenum (Mo)----------	4	5	5	5	2	2	4	4	1
Nickel (Ni)--------------	<8	<4	<4	<2	2	1	<3	<2	<1
Rubidium (Rb)------------	35	42	20	27	20	30	12	15	<.6
Silver (Ag)--------------	<.8	<.5	<.4	<.2	<.3	<.2	<.3	<.2	<.2
Strontium (Sr)-----------	80	80	5	6	60	46	35	24	90
Tin (Sn)-----------------	<16	<9	<7	<4	<6	<4	<7	<3	<3
Titanium (Ti)------------	<4	4	<2	3	<2	2	<2	2	3
Vanadium (V)-------------	<8	<4	<4	<2	<3	2	<4	<2	2
Zinc (Zn)----------------	<340	<340	<150	210	<120	<130	<130	<120	<100
Gross alpha activity-----	1.4	-----	2.3	-----	1.3	-----	1.6	-----	-----
Gross beta activity (picocuries per liter)-	8.0	-----	5.5	-----	5.7	-----	3.8	-----	-----
Radium (Ra) (picocuries per liter)	<.1	-----	<.1	-----	<.1	-----	<.1	-----	-----
Uranium (U)--------------	2.1	-----	<.4	-----	<.4	-----	<.4	-----	-----

< Less than figure shown.

ND Specifically sought, not detected.

The quality of ground water in Yellowstone National Park varies with the geologic terrane. The quality of surface water in the park varies with the geologic terrane and with the season. Streams flowing over similar types of rocks have similar chemical quality of water and similar suspended-sediment loads. Seasonal variations in the quality of surface water occur because runoff from snowmelt and precipitation has low dissolved-solids content and high suspended-sediment load. Conversely, base flow made up of ground water discharging into the stream channels may have relatively high dissolved-solids content and low suspended-sediment load. Factors such as temperature, acidity, and salinity affect the solubility of constituents and the quality of water. However, waters from similar geologic and hydrologic sources have similar percentages of key constituents.

During this study, a total of 268 samples were collected from test holes, wells, springs, streams, and lakes in the park and were analyzed for major chemical constituents and properties. Dissolved-solids content ranged from 20 mg/l for Herron Creek, a small stream about midway between Old Faithful and West Thumb, to 1,240 mg/l for Hot River, a thermal-water discharge area near Mammoth. Most of the cool waters have dissolved-solids content of less than 200 mg/l.

All water sampled in the park has relatively high bicarbonate content. Most of the bicarbonate, however, is from atmospheric carbon dioxide dissolved in surface water and from carbon dioxide concentrated in soil by vegetation and dissolved by water percolating to the water table. Bicarbonate content is high from dissolved carbonate rocks in limestone terrane, in areas having travertine, and in some thermal waters such as Mammoth Hot Springs.

Concentrations of constituents other than bicarbonate, groups of constituents, and ratios of selected constituents in water are indicative of a geologic terrane and the presence of thermal water. Many streams in the park, however, have water from more than one geologic terrane.

In general, thermal water discharging into aquifers, streams, and lakes in the park is highly mineralized and adversely affects the quality of the water in the aquifers, streams, and lakes. The quantity of thermal-water discharge is small compared to the total amount of water, but the effect on the quality of the water is large. Most thermal water in the park is relatively high in silica, sodium, chloride, fluoride, and boron. Some thermal water in the park is high in arsenic (Scott, 1964, p. 180-181) and in sulfate. The percent sodium (ratio of sodium to total cations) is high and the SO_4/Cl (sulfate to chloride) ratio is low in thermal waters on the rhyolite plateau. Although the fluoride content is high, the ratio F/Total anions $-HCO_3$ (fluoride to total anions minus bicarbonate) is relatively low, owing to the relatively high chloride content. This type of thermal water is soft because of the low calcium and magnesium content. Other thermal water such as from Mammoth Hot Springs and Hot River has high calcium, magnesium, and sulfate contents and is very hard. Chemical analyses of water from three streams on the rhyolite plateau that contain thermal-water discharge and a chemical analysis of water from Hot River are listed in table 5.

Table 5.--Chemical analyses of water from selected streams containing thermal-water discharge.

[Analytical results in milligrams per liter, milliequivalents per liter, or micrograms per liter, except as indicated. Analyses by U.S. Geological Survey.]

Constituent	06036840 Tangled Creek Oct. 15, 1968 mg/l	meq/l	06036860 Fairy Creek Oct. 13, 1969 mg/l	meq/l	13005000 Witch Creek Oct. 10, 1969 mg/l	meq/l	06190540 Hot River May 11, 1967 mg/l	meq/l
Silica (SiO_2)	132	-----	103	-----	94	-----	48	-----
Iron (Fe) (µg/l)	20	-----	160	-----	----	-----	----	-----
Calcium (Ca)	11	0.55	3.8	0.19	3.2	0.16	156	7.76
Magnesium (Mg)	.1	.01	.8	.07	2.4	.20	59	4.82
Sodium (Na)	95	4.13	150	6.52	116	5.05	117	5.09
Potassium (K)	15	.38	8.0	.20	9.0	.23	51	1.30
Bicarbonate (HCO_3)	169	2.77	183	3.00	98	1.61	208	3.41
Carbonate (CO_3)	0	0	0	0	0	0	0	0
Sulfate (SO_4)	30	.62	14	.29	53	1.10	547	11.38
Chloride (Cl)	47	1.33	102	2.88	87	2.45	149	4.20
Fluoride (F)	10	.53	13	.68	9.5	.50	2.4	.13
Nitrate (NO_3)	.3	0	0	0	.2	0	.2	0
Boron (B) (µg/l)	570	-----	1,600	-----	1,200	-----	3,200	-----
Dissolved solids	424	-----	486	-----	424	-----	1,240	-----
Hardness as $CaCO_3$	28	-----	13	-----	18	-----	629	-----
Specific conductance (micromhos at 25°C)	539	-----	699	-----	608	-----	1,740	-----
pH (units)	8.2	-----	7.8	-----	7.1	-----	7.7	-----
Color (platinum-cobalt units)	----	-----	6	-----	20	-----	----	-----
Temperature (°C)	15.0	-----	13.0	-----	18.5	-----	52.0	-----
Discharge (cfs)	----	-----	7.40	----	9.40	----	----	-----
Total cations	----	5.07	----	6.98	----	5.64	----	18.97
Total anions	----	5.25	----	6.85	----	5.66	----	19.12
Percent sodium	----	81	----	93	----	90	----	27
SO_4/Cl	----	.47	----	.10	----	.45	----	2.7
F/Total anions -HCO_3	----	.21	----	.18	----	.12	----	.01

Waters in rhyolite and in streams flowing through rhyolite terrane generally have low dissolved solids. These waters are soft and commonly slightly acidic. The relatively high fluoride content of water in rhyolite terrane is unique and is mostly dependent on the amount of obsidian in the bedrock and the surficial deposits. Obsidian is abundant in stream valleys and lake basins on the rhyolite plateau and nearby areas in the park. The fluoride content of water in rhyolite and in many streams in rhyolite terrane generally exceeds 2.4 mg/1, the maximum limit suggested by the U.S. Public Health Service for drinking water. The percent sodium is high but not as high as that of thermal water on the rhyolite plateau. The SO_4/Cl ratio is commonly more than one. The ratio F/Total anions $-HCO_3$ is high and as such is a good indicator of water from rhyolite terrane. Chemical analyses from two springs and a stream in rhyolite terrane are listed in table 6.

Water from andesite terrane has low dissolved solids. The water is soft and is near neutral in acidity or is slightly alkaline. The fluoride content is low and is almost nil in some analyses. The percent sodium is generally lower than in water from rhyolite terrane. The SO_4/Cl ratio is relatively high in most analyses, owing to the low chloride content. The ratio F/Total anions $-HCO_3$ is low and is nil in some analyses. Chemical analyses of water from selected streams in andesite terrane are listed in table 7.

Table 6.--Chemical analyses of water from two springs and a stream in rhyolite terrane.

[Analytical results in milligrams per liter, milliequivalents per liter, or micrograms per liter, except as indicated. Analyses by U.S. Geological Survey.]

Constituent	06036850 Spring near Fountain Paint Pot Aug. 22, 1967		06036915 Supply spring at Madison Junction June 11, 1968		06185955 Arnica Creek Sept. 15, 1969	
	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Silica (SiO_2)----------	111	-----	48	-----	50	-----
Iron (Fe) (μg/l)-------	120	-----	100	-----	170	-----
Calcium (Ca)-----------	10	0.52	7.4	0.37	7.8	0.39
Magnesium (Mg)---------	0	0	.4	.03	1.6	.13
Sodium (Na)------------	38	1.65	27	1.17	14	.61
Potassium (K)----------	6.9	.18	3.0	.08	2.9	.07
Bicarbonate (HCO_3)-----	99	1.63	57	.94	44	.72
Carbonate (CO_3)--------	0	0	0	0	0	0
Sulfate (SO_4)----------	10	.21	4.8	.10	4.4	.09
Chloride (Cl)----------	5.7	.16	13	.37	1.3	.04
Fluoride (F)-----------	7.8	.41	5.2	.27	5.4	.28
Nitrate (NO_3)----------	0	0	.3	0	0	0
Boron (B) (μg/l)-------	0	-----	120	-----	20	-----
Dissolved solids-------	239	-----	158	-----	110	-----
Hardness as $CaCO_3$------	26	-----	20	-----	26	-----
Specific conductance (micromhos at 25°C)---	228	-----	172	-----	105	-----
pH (units)-------------	6.6	-----	8.0	-----	6.9	-----
Color (platinum-(cobalt units)--------	----	-----	----	-----	2	-----
Temperature (°C)-------	17.0	-----	9.0	-----	15.0	-----
Discharge (cfs)--------	----	-----	----	-----	8.40	-----
Total cations----------	----	2.35	----	1.65	----	1.27
Total anions-----------	----	2.41	----	1.68	----	1.13
Percent sodium---------	----	70	----	71	----	51
SO_4/Cl----------------	----	1.3	----	.27	----	2.2
F/Total anions -HCO_3---	----	.53	----	.36	----	.68

Table 7.--Chemical analyses of water from selected streams in andesite terrane.

[Analytical results in milligrams per liter, milliequivalents per liter, or micrograms per liter, except as indicated. Analyses by U.S. Geological Survey.]

Constituent	06042950 Specimen Creek Sept. 20, 1968 mg/l	meq/l	06185810 Cabin Creek Sept. 9, 1970 mg/l	meq/l	06185830 Beaverdam Creek Sept. 10, 1970 mg/l	meq/l
Silica (SiO_2)	33	-----	18	-----	21	-----
Iron (Fe) (µg/l)	30	-----	----	-----	----	-----
Calcium (Ca)	5.6	0.28	4.4	0.22	4.8	0.24
Magnesium (Mg)	1.7	.14	1.4	.12	2.2	.18
Sodium (Na)	4.4	.19	3.7	.16	3.5	.15
Potassium (K)	1.2	.03	.3	.01	1.1	.03
Bicarbonate (HCO_3)	38	.62	30	.49	34	.56
Carbonate (CO_3)	0	0	0	0	0	0
Sulfate (SO_4)	2.5	.05	1.2	.02	1.6	.03
Chloride (Cl)	.4	.01	.2	0	.3	.01
Fluoride (F)	.1	.01	.1	0	.1	0
Nitrate (NO_3)	.1	0	0	0	0	0
Boron (B) (µg/l)	0	-----	10	-----	10	-----
Dissolved solids	68	-----	44	-----	52	-----
Hardness as $CaCO_3$	21	-----	17	-----	21	-----
Specific conductance (micromhos at 25°C)	62	-----	50	-----	58	-----
pH (units)	7.2	-----	7.0	-----	7.0	-----
Color (platinum-cobalt units)	5	-----	10	-----	4	-----
Temperature (°C)	6.0	-----	6.5	-----	4.5	-----
Discharge (cfs)	----	-----	.45	-----	17.2	-----
Total cations	----	.64	----	.51	----	.60
Total anions	----	.69	----	.51	----	.60
Percent sodium	----	30	----	31	----	25
SO_4/Cl	----	5.0	----	-----	----	3.0
F/Total anions $-HCO_3$	----	.14	----	0	----	0

No wells, springs, or streams in the park are known to have water entirely from basalt terrane. Streams that flow on basalt and andesite and on basalt and rhyolite were sampled, and the analyses gave some indication of the effects of basalt on the quality of water in the streams. Chemical analyses from selected streams are listed in table 8. Percent sodium and the SO_4/Cl ratio are higher in water from basalt and andesite than in water from andesite. The fluoride content is higher and the ratio F/Total anions $-HCO_3$ is lower in water from basalt and rhyolite than in most water solely from rhyolite.

Streams flowing on Paleozoic rocks usually have higher dissolved solids than streams flowing on andesite or rhyolite terranes, but lower than streams containing thermal water. The fluoride content and the percent sodium are low. The SO_4/Cl ratio is high. The quality of surface water flowing on all Paleozoic rocks is not identical as indicated by a comparison of analyses of water from the Gallatin River, which flows on Mississippian and Pennsylvanian rocks, and from Slough Creek, which flows mostly on Cambrian, Ordovician, and Devonian rocks. Water from the Gallatin River has a lower percent sodium and a higher SO_4/Cl ratio than water from Slough Creek. Water from the Gallatin River is very hard; water from Slough Creek is moderately hard. A spring issuing from glacial deposits near the Gallatin River probably has water from the Madison Limestone as well as the glacial deposits. Water from this spring is moderately hard, slightly alkaline, and has relatively high calcium, magnesium, and bicarbonate contents. Chemical analyses of water from the Gallatin River, Slough Creek, and the spring near the Gallatin River are listed in table 9.

Table 8.--Chemical analyses of water from selected streams in basalt and andesite terrane (Willow Creek and Middle Creek) and in basalt and rhyolite terrane (Lava Creek).

[Analytical results in milligrams per liter, milliequivalents per liter, or micrograms per liter, except as indicated. Analyses by U.S. Geological Survey.]

Constituent	06187825 Willow Creek July 23, 1969		06279850 Middle Creek Sept.15, 1969		06189980 Lava Creek Sept.18, 1969	
	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Silica (SiO_2)	28	-----	19	-----	34	-----
Iron (Fe) (μg/l)	----	-----	160	-----	250	-----
Calcium (Ca)	3.9	0.19	7.1	0.35	5.0	0.25
Magnesium (Mg)	1.1	.09	2.3	.19	3.3	.27
Sodium (Na)	25	1.09	9.4	.41	6.4	.28
Potassium (K)	.6	.02	.7	.02	1.7	.04
Bicarbonate (HCO_3)	78	1.28	43	.70	41	.67
Carbonate (CO_3)	0	0	0	0	0	0
Sulfate (SO_4)	4.8	.10	11	.23	2.8	.06
Chloride (Cl)	.4	.01	.5	.01	.7	.02
Fluoride (F)	.5	.03	.1	0	1.6	.08
Nitrate (NO_3)	0	0	0	0	0	0
Boron (B) (μg/l)	20	-----	10	-----	20	-----
Dissolved solids	102	-----	71	-----	76	-----
Hardness as $CaCO_3$	14	-----	27	-----	26	-----
Specific conductance (micromhos at 25°C)	128	-----	90	-----	77	-----
pH (units)	7.7	-----	6.4	-----	6.5	-----
Color (platinum-cobalt units)	5	-----	5	-----	4	-----
Temperature (°C)	20.5	-----	7.0	-----	6.0	-----
Discharge (cfs)	9.28	-----	18.2	-----	25.2	-----
Total cations	----	1.39	----	.97	----	.84
Total anions	----	1.42	----	.94	----	.83
Percent sodium	----	78	----	42	----	33
SO_4/Cl	----	10	----	23	----	3.0
F/Total anions -HCO_3	----	.21	----	0	----	.50

Table 9.--Chemical analyses of water from two streams and a spring in Paleozoic rocks.

[Analytical results in milligrams per liter, milliequivalents per liter, or micrograms per liter, except as indicated. Analyses by U.S. Geological Survey.]

Constituent	06042920 Gallatin River Sept.17, 1969 mg/l	meq/l	06187980 Slough Creek Sept.18, 1969 mg/l	meq/l	06042890 Spring near Gallatin River Aug. 21, 1969 mg/l	meq/l
Silica (SiO_2)	6.1	-----	20	-----	6.6	-----
Iron (Fe) (µg/l)	230	-----	50	-----	----	-----
Calcium (Ca)	55	2.74	28	1.40	30	1.50
Magnesium (Mg)	20	1.64	7.8	.64	14	1.14
Sodium (Na)	1.1	.05	3.3	.14	.6	.03
Potassium (K)	.8	.02	1.7	.04	.4	.01
Bicarbonate (HCO_3)	163	2.67	127	2.08	152	2.49
Carbonate (CO_3)	0	0	0	0	0	0
Sulfate (SO_4)	78	1.62	4.4	.09	11	.23
Chloride (Cl)	.4	.01	.9	.02	.2	0
Fluoride (F)	.2	.01	.1	0	.1	0
Nitrate (NO_3)	.1	0	.1	0	.1	0
Boron (B) (µg/l)	0	-----	0	-----	90	-----
Dissolved solids	242	-----	128	-----	138	-----
Hardness as $CaCO_3$	219	-----	102	-----	132	-----
Specific conductance (micromhos at 25°C)	399	-----	211	-----	246	-----
pH (units)	7.4	-----	7.0	-----	8.2	-----
Color (platinum-cobalt units)	2	-----	4	-----	4	-----
Temperature (°C)	8.0	-----	9.0	-----	5.0	-----
Discharge (cfs)	47.1	-----	30.6	-----	1/ 10	-----
Total cations	----	4.45	----	2.22	----	2.68
Total anions	----	4.31	----	2.19	----	2.72
Percent sodium	----	1	----	6	----	1
SO_4/Cl	----	162	----	4.5	----	-----
F/Total anions -HCO_3	----	.01	----	0	----	0

1/ Estimated.

Data are not available on quality of water from Precambrian or Mesozoic rocks in Yellowstone National Park. Quality of water in streams flowing on Precambrian and Mesozoic rocks in Yellowstone National Park, however, is probably similar to that in streams flowing on similar rocks in Grand Teton National Park. The author collected samples in Grand Teton National Park from streams having principally Precambrian and Mesozoic rocks in their drainage areas. Cottonwood Creek has water draining from Precambrian rocks, and the Gros Ventre River has water draining from Mesozoic rocks. Cottonwood Creek and the Gros Ventre River flow into the Snake River about 32 and 40 miles, respectively, south of Yellowstone National Park. Chemical analyses of water from Cottonwood Creek and the Gros Ventre River are listed in table 10.

Streams flowing on Precambrian rocks have low dissolved solids. The water is soft and slightly alkaline. The fluoride content is relatively low. Percent sodium is relatively high. The SO_4/Cl ratio is more than one. The ratio F/Total anions $-HCO_3$ is relatively high, owing to the low dissolved solids in the water.

Streams flowing on Mesozoic rocks have relatively high dissolved solids. The water is hard and slightly alkaline. The fluoride content and the percent sodium are low. The SO_4/Cl ratio is high. The ratio F/Total anions $-HCO_3$ is low.

Table 10.--Chemical analyses of water from Precambrian rocks (Cottonwood Creek) and Mesozoic rocks (Gros Ventre River).

[Analytical results in milligrams per liter, milliequivalents per liter, or micrograms per liter, except as indicated. Analyses by U.S. Geological Survey.]

Constituent	13012800 Cottonwood Creek Grand Teton National Park Aug. 16, 1971		13014400 Gros Ventre River Grand Teton National Park Oct. 13, 1971	
	mg/l	meq/l	mg/l	meq/l
Silica (SiO_2)	2.2	-----	5.8	-----
Iron (Fe) (µg/l)	10	-----	10	-----
Calcium (Ca)	3.0	0.15	51	2.54
Magnesium (Mg)	.1	.01	13	1.07
Sodium (Na)	3.7	.16	7.4	.32
Potassium (K)	.5	.01	1.0	.03
Bicarbonate (HCO_3)	20	.33	160	2.62
Carbonate (CO_3)	0	0	0	0
Sulfate (SO_4)	1.3	.03	71	1.48
Chloride (Cl)	.3	.01	1.2	.03
Fluoride (F)	.4	.02	.1	.01
Nitrate (NO_3)	0	0	0	0
Boron (B) (µg/l)	0	-----	20	-----
Dissolved solids	22	-----	229	-----
Hardness as $CaCO_3$	8	-----	180	-----
Specific conductance (micromhos at 25°C)	23	-----	383	-----
pH (units)	7.4	-----	8.0	-----
Color (platinum-cobalt units)	----	-----	----	-----
Temperature (°C)	18.0	-----	7.0	-----
Discharge (cfs)	268	-----	261	-----
Total cations	----	.33	----	3.96
Total anions	----	.39	----	4.14
Percent sodium	----	49	----	8
SO_4/Cl	----	3	----	49
F/Total anions -HCO_3	----	.33	----	.01

Most water in Yellowstone National Park is a mixture of water from more than one source. A common combination is water from rhyolite and thermal water, because thermal-water features are widespread on the rhyolite plateau. Examples of water from this combination are the Firehole and Bechler Rivers and Nez Perce Creek (table 11). The fluoride content, percent sodium, and boron content are high, but not as high as streams containing mostly thermal water. The ratio F/Total anions $-HCO_3$ is smaller than that in water from rhyolite terrane and is similar to that in thermal water.

A comparison of analyses from the Firehole River above Old Faithful and the same stream at Madison Junction shows the result of adding a relatively large amount of thermal water to the stream. Increases in silica, sodium, chloride, fluoride, and boron are apparent. These are some of the principal constituents in thermal water.

Lakes in Yellowstone National Park are catchment and mixing basins for some of the streamflow and ground water. Although mixing is probably not complete, the quality of water in the lakes represents a composite of the quality of water in the tributary streams and adjacent aquifers. Yellowstone, Shoshone, Lewis, and Heart Lakes, the four larger lakes in the park, were sampled during this study (table 12). The samples were collected near the surface of the lakes. The analyses probably do not indicate the quality of the water in all parts of the lakes, but they do suggest the general quality of the water.

Table 11.--Chemical analyses of water from selected streams in rhyolite terrane having thermal-water discharge.

[Analytical results in milligrams per liter, milliequivalents per liter, or micrograms per liter, except as indicated. Analyses by U.S. Geological Survey.]

Constituent	06036800 Firehole River above Old Faithful Sept.16, 1969		06036910 Firehole River at Madison Junction Sept.17, 1969		13046690 Bechler River Aug. 22, 1969		06036900 Nez Perce Creek Sept.16, 1969	
	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Silica (SiO_2)----------	44	-----	94	-----	43	-----	80	-----
Iron (Fe) (μg/l)-------	110	-----	130	-----	----	-----	440	-----
Calcium (Ca)-----------	1.6	0.08	3.8	0.19	4.1	0.20	6.0	0.30
Magnesium (Mg)---------	1.9	.16	1.8	.15	1.4	.12	1.9	.16
Sodium (Na)------------	12	.52	92	4.00	26	1.13	52	2.26
Potassium (K)----------	3.8	.10	8.7	.22	2.8	.07	8.7	.22
Bicarbonate (HCO_3)-----	21	.34	128	2.10	60	.98	78	1.28
Carbonate (CO_3)--------	0	0	0	0	0	0	0	0
Sulfate (SO_4)----------	4.6	.10	13	.27	5.4	.11	30	.62
Chloride (Cl)----------	9.3	.26	63	1.78	11	.31	28	.79
Fluoride (F)-----------	2.2	.12	8.0	.42	2.0	.10	6.2	.33
Nitrate (NO_3)----------	0	0	0	0	0	0	0	0
Boron (B) (μg/l)-------	80	-----	310	-----	230	-----	440	-----
Dissolved solids-------	90	-----	348	-----	126	-----	252	-----
Hardness as $CaCO_3$------	12	-----	17	-----	16	-----	23	-----
Specific conductance (micromhos at 25°C)---	86	-----	468	-----	179	-----	311	-----
pH (units)-------------	6.4	-----	7.7	-----	7.2	-----	7.0	-----
Color (platinum-cobalt units)---------	5	-----	4	-----	3	-----	5	-----
Temperature (°C)-------	4.0	-----	15.0	-----	16.0	-----	17.0	-----
Discharge (cfs)--------	53.9	-----	281	-----	1/ 500	-----	53.1	-----
Total cations----------	----	.86	----	4.56	----	1.52	----	2.94
Total anions-----------	----	.82	----	4.57	----	1.50	----	3.02
Percent sodium---------	----	60	----	88	----	74	----	77
SO_4/Cl----------------	----	.38	----	.15	----	.36	----	.78
F/Total anions -HCO_3---	----	.25	----	.17	----	.19	----	.19

1/ Estimated.

Table 12.--Chemical analyses of water from Yellowstone, Heart, Shoshone, and Lewis Lakes.

[Analytical results in milligrams per liter, milliequivalents per liter, or micrograms per liter, except as indicated. Analyses by U.S. Geological Survey.]

Constituent	6185850 Yellowstone Lake Southeast Arm Sept.10, 1970		6185975 Yellowstone Lake near Sand Point Sept.22, 1971		6185980 Yellowstone Lake near Lake Butte Sept.22, 1971		13005600 Heart Lake Oct. 11, 1969		13008400 Shoshone Lake Oct. 15, 1971		13008900 Lewis Lake Sept. 22, 1971	
	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Silica (SiO_2)----------	8.6	-----	11	-----	11	-----	28	-----	36	-----	38	-----
Iron (Fe) (µg/l)-------	----	-----	10	-----	20	-----	----	-----	20	-----	30	-----
Calcium (Ca)-----------	4.8	0.24	5.5	0.28	5.5	0.28	4.1	0.20	3.1	0.16	3.2	0.16
Magnesium (Mg)---------	2.3	.19	2.0	.16	2.1	.17	1.0	.08	.2	.02	.2	.02
Sodium (Na)------------	9.5	.41	9.2	.40	10	.44	37	1.61	14	.61	13	.57
Potassium (K)----------	1.5	.04	1.8	.05	1.8	.05	3.9	.10	4.5	.12	3.1	.08
Bicarbonate (HCO_3)-----	40	.66	35	.57	39	.64	48	.79	25	.41	34	.56
Carbonate (CO_3)--------	0	0	0	0	0	0	0	0	0	0	0	0
Sulfate (SO_4)----------	7.0	.14	8.3	.17	9.5	.20	17	.35	4.3	.09	4.3	.09
Chloride (Cl)----------	4.1	.12	6.0	.17	5.8	.16	27	.76	7.0	.20	5.9	.17
Fluoride (F)-----------	.6	.03	.5	.03	.5	.03	2.9	.15	1.9	.10	1.1	.06
Nitrate (NO_3)----------	0	0	0	0	0	0	.1	0	0	0	0	0
Boron (B) (µg/l)-------	90	-----	100	-----	140	-----	380	-----	100	-----	100	-----
Dissolved solids-------	58	-----	62	-----	66	-----	145	-----	83	-----	86	-----
Hardness as $CaCO_3$------	22	-----	22	-----	22	-----	14	-----	9	-----	9	-----
Specific conductance (micromhos at 25°C)---	91	-----	94	-----	104	-----	218	-----	86	-----	95	-----
pH (units)-------------	6.9	-----	6.8	-----	7.2	-----	6.4	-----	7.2	-----	7.2	-----
Color (platinum-cobalt units)---------	8	-----	----	-----	----	-----	6	-----	----	-----	----	-----
Temperature (°C)-------	13.0	-----	12.0	-----	13.0	-----	7.0	-----	6.0	-----	9.0	-----
Discharge (cfs)--------	----	-----	----	-----	----	-----	----	-----	----	-----	----	-----
Total cations----------	----	.88	----	.89	----	.94	----	1.99	----	.91	----	.83
Total anions-----------	----	.95	----	.94	----	1.03	----	2.05	----	.80	----	.88
Percent sodium---------	----	47	----	45	----	47	----	81	----	68	----	69
SO_4/Cl----------------	----	1.2	----	1.0	----	1.2	----	.46	----	.45	----	.53
F/Total anions -HCO_3--	----	.10	----	.08	----	.08	----	.12	----	.26	----	.19

Shoshone, Lewis, and Heart Lakes and their tributaries are in rhyolite terrane. The lakes also receive thermal water. The chemical characteristics of water in the lakes are similar to streams having water from rhyolite terrane and thermal water. The analysis from Heart Lake indicates a greater percentage of thermal water than the other lakes, owing to greater fluoride and boron contents, dissolved solids, and percent sodium. This is probably because Heart Lake was sampled in the northern part of the lake near Witch Creek, which contains thermal water, and Shoshone and Lewis Lakes were sampled in the southeastern parts of the lakes far from thermal-water inflow.

Yellowstone Lake and its tributaries are in rhyolite, andesite, and basalt terrane. The lake also receives thermal water. The largest tributary, the Yellowstone River, flows through andesite and basalt terrane. Yellowstone Lake was sampled at three locations during this study. The chemical characteristics of the water from the three samples are similar. Water in the lake has low dissolved solids. The water is soft and near neutral in acidity. The fluoride content and the percent sodium indicate that the water is a mixture of water from andesite and rhyolite terranes. The higher boron content and the lower SO_4/Cl ratio of water in the lake than of water from either andesite or rhyolite terranes indicate that the lake contains a small amount of thermal water.

Yellowstone Lake was sampled in July 1959 (Gordon and others, 1962, table 2) at four locations: Southeast arm, West Thumb, center of the lake, and near the outlet. The chemical characteristics of the water from these samples are similar to samples collected from the lake in 1970 and 1971, except for fluoride in the sample from West Thumb in 1959. Fluoride content was 2.6 ppm in the sample from West Thumb in 1959, 0.5 ppm from the other three samples collected in 1959, 0.6 mg/l from the sample collected in southeast arm in 1970, and 0.5 mg/l from the samples collected near Sand Point and Lake Butte in 1971. The high fluoride content of water in the West Thumb part of the lake is attributed to thermal water discharging into the lake at West Thumb Geyser Basin and inflow from Arnica Creek, which has high fluoride content.

Water resources near selected sites

One purpose of this study is to make detailed hydrologic investigations near selected sites in Yellowstone National Park. The sites were selected by the National Park Service where data are needed on water supplies for public use. Near the beginning of the study, the National Park Service stipulated the water requirements at the sites. Since that time, the water requirements have changed and the original water requirements were used only as guidelines during the study. As the study progressed, water problems became apparent at sites other than those previously selected for investigation, and these sites were added to the study.

Mammoth

Water for use at Mammoth is diverted from Glen Creek in Golden Gate Canyon below Rustic Falls. The flow of Glen Creek is supplemented by water from the Gardner River, Panther, and Indian Creeks through a pipeline system that discharges water into Glen Creek above Rustic Falls (fig. 7). Water from Glen, Panther, and Indian Creeks and the Gardner River contains sediment during spring runoff and after heavy rainstorms in their drainage areas. Moreover, the streams are becoming more subject to contamination by human traffic in the park.

A study was made in the Mammoth area in an effort to locate a ground-water supply of about 1 million gpd (gallons per day), or about 700 gpm, or a surface-water source that would be more satisfactory than the present source from Glen Creek. Thirty-three test holes (not all are shown in fig. 7) were drilled in the vicinity of Mammoth. Streamflow measurements were made of the Gardner River and tributaries, and water samples were collected for analysis of chemical quality and suspended-sediment load.

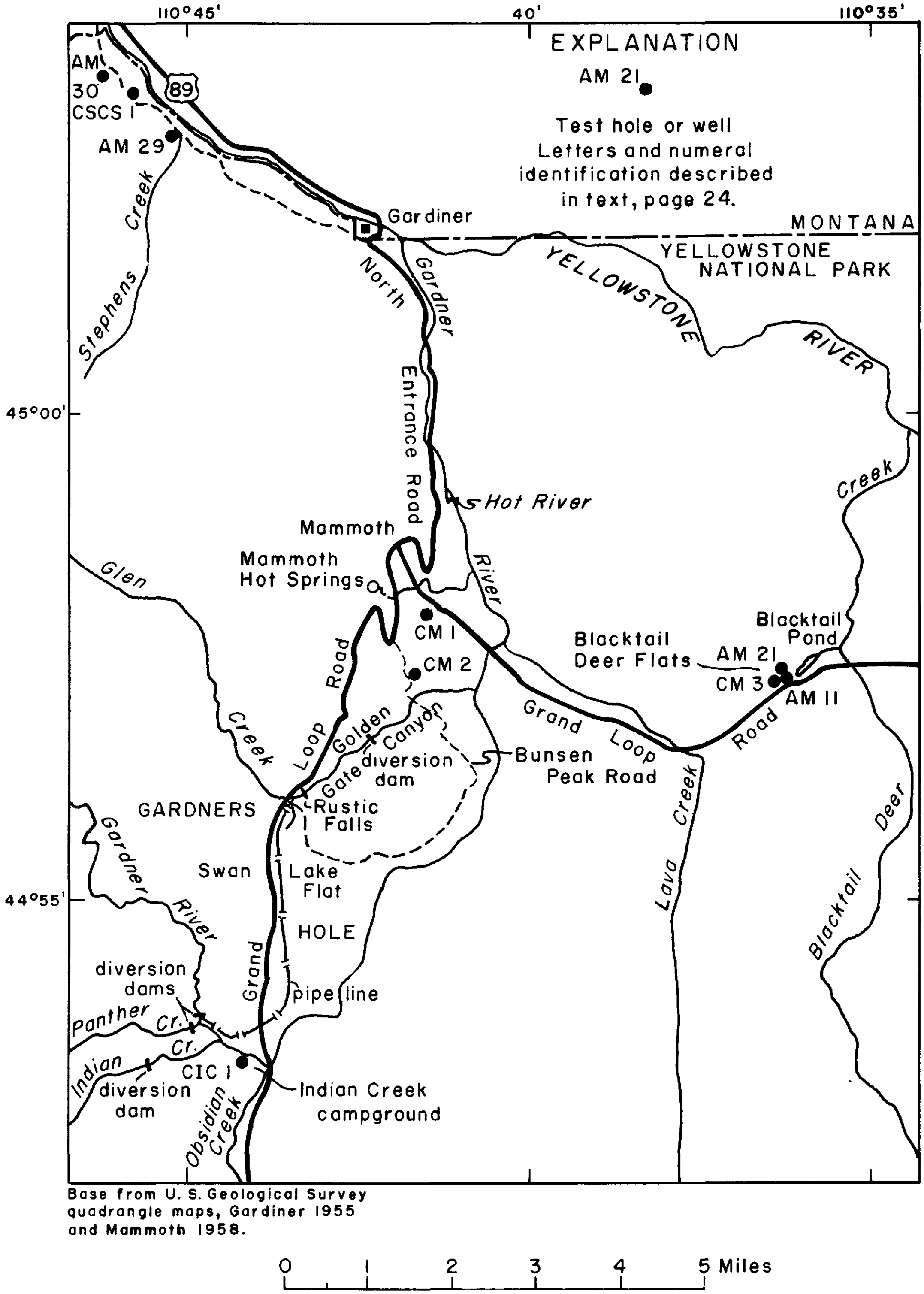

Figure 7.--Location of diversion dams, a pipeline, selected test holes, and a well near Mammoth.

Two test holes (CM 1 and CM 2) were drilled in the glaciated area south of Mammoth. Hole CM 1 penetrated clay, silt, sand, gravel, and boulders from land surface to 47 feet and tough gray clay from 47 to 75 feet. The material above 47 feet is glacial drift and that below 47 feet is shale of Cretaceous age. Water-bearing zones are at depths of 27 to 28 feet and 32 to 33 feet. After perforating the casing opposite the water-bearing zones, the test well was bailed at about 16 gpm for 13 minutes; drawdown was about 0.3 foot. Hole CM 2, drilled to bedrock at 60 feet, did not penetrate any water-bearing zones of sufficient thickness for testing.

Water from test well CM 1 exceeds the recommended limits in sulfates and dissolved solids and is near the limit in fluorides. Water in the aquifer tapped by test well CM 1 probably could not be used for public supply because of the high sulfate content (393 mg/1).

Test holes were augered along the Gardner River near the diversion dam, and at Indian Creek campground; in Blacktail Deer Flats; along Blacktail Deer Creek; and along Bunsen Peak Road. Data from these test holes indicated that the Blacktail Deer Flats area near Blacktail Pond was the only area promising enough to warrant further testing.

Based on indications of water-bearing sand and gravel from test hole AM 11, test hole CM 3 was drilled to bedrock at 34 feet in the flat just west of Blacktail Pond. Test hole CM 3 did not penetrate any water-bearing zones of sufficient thickness for testing. Results from drilling test hole CM 3 indicate that a ground-water supply of 1 million gpd probably cannot be obtained from glacial drift in Blacktail Deer Flats west of Blacktail Pond.

Water from an aquifer in glacial drift or underlying bedrock in Blacktail Deer Flats discharges into Blacktail Pond. This is evident by the continuous discharge of water through a narrow outlet from Blacktail Pond to Blacktail Deer Creek while the level of the pond apparently remains relatively steady. Discharge through the outlet was measured as 0.10 cfs in September 1967, 1.33 cfs in May 1969, 0.35 cfs in July 1969, 0.17 cfs in September 1969, and 0.39 cfs in June 1970. Streamflow measured above and below a half-mile reach of Blacktail Deer Creek east of Blacktail Pond shows a gain in streamflow that probably represents discharge of an aquifer in Blacktail Deer Flats. The gain in streamflow was 0.34 cfs in September 1967, 1.0 cfs in August 1968, and 2.9 cfs in April 1969.

Development of ground water might be possible in Blacktail Deer Flats if the aquifer discharging to Blacktail Pond and Blacktail Deer Creek could be tapped. Test drilling would be required in glacial drift and bedrock in the eastern part of Blacktail Deer Flats. A study should be made of the relationship between the aquifer and Blacktail Pond. The natural discharge of the aquifer includes evapotranspiration in the flats and flow into Blacktail Deer Creek. Pumping from the aquifer in amounts exceeding that part of the natural discharge of the aquifer flowing to Blacktail Deer Creek would probably lower the level of Blacktail Pond. Maintaining the natural pond level may be important to the ecosystem of that part of Yellowstone National Park.

It is doubtful that a ground-water supply of 1 million gpd could be developed anywhere in Blacktail Deer Flats. A few hundred thousand gallons per day of ground water, however, might be developed in Blacktail Deer Flats as an alternate supply for Mammoth to be used during that part of the year when streams contain much suspended sediment.

Two test holes, AM 29 and 30, were drilled near the Yellowstone River northwest of Mammoth (fig. 7). Drilling in these holes was stopped before reaching the water table because the auger bit could not penetrate beds of cobbles and boulders in AM 29 and dry, tough clay in AM 30.

A test hole was drilled in October 1964 and completed as test well CSCS 1 by a contractor hired by the National Park Service. The test hole was drilled to locate a water supply for a proposed Job Corps campsite, called the Stephens Creek site in this report. The test hole is near the Yellowstone River northwest of Mammoth on a line between test holes AM 29 and 30 (fig. 7). According to the completion report, the hole was drilled to a depth of 85 feet. Water-bearing zones were penetrated at depths of 57 to 60 feet and 70 to 85 feet; the lower aquifer extends to an unknown depth below 85 feet. These aquifers are probably in alluvium or glacial-outwash deposits.

The test well was equipped with a screen 15 feet long, opposite the lower aquifer, and 70 feet of 6-inch diameter casing. The test well was pumped for 13.5 hours on November 19, 1964 at a rate of 92 gpm and the drawdown was 4.4 feet. The specific capacity was 21 gpm per foot of drawdown. The water level was about 44 feet below land surface before pumping began.

A water sample from the test well, collected during the aquifer test, was analyzed by the Wyoming Department of Agriculture laboratory. The dissolved-solids content was 326 ppm, and the concentration of each chemical constituent analyzed was below the recommended limit. Temperature of the water was 46°F (8.0°C). The Job Corps campsite was not built, and the test well has been capped and used only as an observation well since the aquifer test.

Developing a water supply for Mammoth might be possible from aquifers in the alluvium or glacial-outwash deposits in the vicinity of test well CSCS 1. Yields of as much as 200 gpm might be expected from single wells. The areal extent and thickness of the principal aquifer penetrated in test well CSCS 1 (70-85 feet) is unknown, and additional test holes should be drilled before consideration is given to developing a ground-water supply for Mammoth in this area. Test holes should be located near the Yellowstone River north and northwest of the landslide deposits that are on the north slope of Sepulcher Mountain.

A comparison of fluctuations of the water level in well CSCS 1 and streamflow at the nearby gaging station on the Yellowstone River at Corwin Springs, Mont. indicates that the aquifer and the river are hydraulically connected. The aquifer is recharged by water from the river.

A water-supply well for the Indian Creek campground was drilled in November 1961 by a contractor hired by the National Park Service. The well, CIC 1 in this report, is 32 feet deep and is finished in sand and gravel near the Gardner River (fig. 7). The well was pumped for 24 hours on November 21 and 22, 1961 at a rate of 30 gpm and the drawdown was 7 feet. The specific capacity was 4.3 gpm per foot of drawdown. The water level was 7.5 feet below land surface before pumping began. A test hole was drilled near well CIC 1 in September 1966 to bedrock at a depth of 41 feet. Silt and clay were penetrated in the test hole below a depth of 37 feet. The aquifer tapped by well CIC 1 apparently is not extensive, and it probably would not yield more than a few tens of thousands of gallons per day.

Investigations were made in 1967 and 1968 of quantity and quality of surface water in the Gardner River and tributaries Glen and Lava Creeks to determine the most desirable source of a surface-water supply for Mammoth. Data collected show that during spring runoff the suspended-sediment concentration is greater in the Gardner River than in either Glen Creek or Lava Creek, and is greater in Lava Creek than in Glen Creek. Moreover, the relatively high suspended-sediment concentration from spring runoff continues longer in the Gardner River than in Glen Creek and Lava Creek (table 13). No samples were collected in 1967 and 1968 from two other tributaries, Panther Creek and Indian Creek, because the streams were inaccessible during spring runoff. They appeared, however, to have approximately the same suspended-sediment concentration at their mouths as the Gardner River.

Table 13.--Periodic determinations of temperature, discharge, and suspended sediment in the Gardner River, Glen Creek, and Lava Creek near Mammoth, Yellowstone National Park.

[Determinations by U.S. Geological Survey.]

Date 1967	Time (24 hour)	Temperature (°C)	Discharge (cubic feet per second)	Sediment concentration (milligrams per liter)	Sediment discharge (tons per day)
Station 06189730 Gardner River above diversion dam					
May 23	0815	--	280	88	66
	1520	1	420	325	370
	1945	1	410	205	230
May 24	0745	1	300	91	74
	1715	3	540	312	450
May 25	1830	5	430	141	160
May 26	1720	7	290	103	81
May 27	1845	8	310	136	110
May 28	1745	8	300	134	110
May 29	1830	5	320	98	85
May 30	1810	7	280	68	51
May 31	1825	7	280	44	33
June 4	1630	7	270	51	37
June 12	1845	8	220	16	9.5
June 17	1325	7	280	65	49
July 3	1325	8	210	57	32
July 17	1640	9	140	72	27
July 26	1000	8	66.4	---	-----
Sept. 20	1600	12	23.7	2	.13

Table 13.--Periodic determinations--continued

Date 1967	Time (24 hour)	Temperature (°C)	Discharge (cubic feet per second)	Sediment concentration (milligrams per liter)	Sediment discharge (tons per day)
		Station 06189890 Glen Creek above Rustic Falls			
May 2	1435	--	1/ 2.5	8	0.05
May 23	1400	7	33.1	34	3.0
May 24	0730	3	1/ 25	2	.14
	1910	9	49.7	23	3.0
May 25	1855	11	1/ 35	2	.19
May 27	1905	12	1/ 30	3	.24
June 4	1610	12	27.8	9	.68
June 12	1900	10	1/ 25	3	.20
June 17	0930	8	20.1	3	.16
July 3	0830	7	11.5	4	.12
July 17	1620	9	9.43	1/ 3	.07
Sept. 20	1425	9	3.10	10	.08
		Station 06189980 Lava Creek			
May 2	1620	4	14.4	3	0.12
May 23	1100	--	95.3	33	8.5
May 25	0625	3	1/ 105	87	25
May 26	1345	8	112	18	5.4
May 28	0735	3	1/ 125	19	6.4
June 2	1250	8	147	15	6.0
June 12	1925	7	1/ 150	11	4.5
June 17	1015	7	1/ 155	34	14
July 3	1010	8	148	17	6.8
July 17	1450	9	84.9	16	3.7
Aug. 23	1400	13	39.2	---	-----
Sept. 20	1035	8	27.3	2	.15

1/ Estimated.

Data indicate that the overall quality of water for use at Mammoth would not be improved by changing the point of diversion from Glen Creek to Lava Creek. Each water source, however, has advantages and disadvantages. Water in Glen Creek has more color but less suspended sediment than water in Lava Creek during spring runoff. Both streams have sufficient flow to satisfy the water needs at Mammoth during spring runoff. Lava Creek has sufficient flow the entire year, and Glen Creek has sufficient flow until the Gardner River clears and becomes suitable for use in the public supply (table 14).

Chemically, the water from both Glen Creek and Lava Creek is apparently suitable for public use at Mammoth. Lava Creek, at times, may have fluoride content above recommended limits, judging by a sample collected in August 1967 that had 3.4 mg/l of fluoride. Other samples collected from Lava Creek had fluoride contents ranging from 0.9 to 1.7 mg/l. Water from Lava Creek has lower dissolved solids than water from Glen Creek. Water from Lava Creek is soft; whereas, water from Glen Creek ranges from moderately hard to very hard.

The drainage area of Lava Creek upstream from Grand Loop Road is remote and not subject to heavy use by visitors. The drainage areas of the Gardner River and its tributaries in Gardners Hole (including Glen Creek) are easily accessible to park visitors. A water supply from Lava Creek, therefore, would be less subject to contamination by humans than the supply from the Gardner River and its tributaries in Gardners Hole. If the Mammoth water-supply system becomes inadequate, consideration might be given to changing the point of diversion from Glen Creek to Lava Creek.

Table 14.--Periodic determinations of discharge, sediment concentration, and color of water in Lava Creek and Glen Creek near Mammoth, Yellowstone National Park.

[Determinations by U.S. Geological Survey.]

Station 06189980 Lava Creek

Date 1968	Time (24 hour)	Discharge (cubic feet per second)	Sediment concentration (milligrams per liter)	Color (platinum-cobalt units)
May				
27	0930	40	5	10
29	0925	58	46	10
29	1935	67	68	10
30	1020	87	61	15
30	1835	87	36	10
31	0940	83	23	10
31	1915	80	17	10
June				
1	0955	73	--	10
2	1105	83	18	10
3	1015	105	66	10
3	1800	103	49	10
4	0940	114	56	10
4	1720	116	51	10
5	0710	120	53	10
5	1800	114	28	10
6	0905	109	23	10
6	1410	129	76	--
7	0845	129	33	10
7	1725	131	38	10
8	1100	125	18	10
9	1110	139	43	10
9	1710	146	42	20
10	1020	141	29	10
10	1735	143	29	10
11	0810	134	18	10
11	1820	129	16	10
12	0905	129	17	10
12	1915	134	18	10
13	1400	143	29	10
21	1410	166	30	--
27	1720	125	13	--
July				
15	1415	63	5	--

Station 06189910 Glen Creek at diversion dam

Date 1968	Time (24 hour)	Discharge (cubic feet per second)	Sediment concentration (milligrams per liter)	Color (platinum-cobalt units)
May				
27	1100	19	5	5
29	1010	19	5	10
30	1155	19	4	15
31	1155	18	5	20
June				
1	1050	18	5	20
2	1145	18	5	20
3	1105	18	5	20
4	1025	19	11	30
4	1815	21	8	30
5	0805	22	10	30
6	1015	23	7	30
6	1505	29	25	30
6	1900	34	32	30
7	1010	30	8	30
7	1750	31	10	30
8	1355	29	11	20
9	1205	31	21	25
9	2030	40	16	30
10	1115	36	11	20
10	1850	37	16	25
11	0900	34	11	20
11	1845	33	6	20
12	0955	33	5	20
12	1955	31	5	20
13	1435	36	9	20
21	1705	19	2	--
27	1755	14	16	--
July				
15	1105	22	5	--

If Lava Creek were used as a surface-water supply for Mammoth and a supplementary ground-water supply were developed from aquifers in Blacktail Deer Flats near Blacktail Pond, the water from both sources could be transported to Mammoth in the same pipeline system. Ground water could be used during spring runoff when Lava Creek contains high suspended-sediment concentration, generally during May and June. The pumpage should be less than the natural discharge of the aquifer to Blacktail Deer Creek so that the level of Blacktail Pond would not decline. The ground-water supply would be less than 1 million gpd, but the water requirements for Mammoth may be lower in May and June because precipitation is highest at that time of year and the number of park visitors is fewer than during July and August.

East Entrance

The water supply for East Entrance is diverted from a small unnamed tributary of Middle Creek about half a mile west of the entrance station (fig. 2-A). Chemically, the water in the stream is adequate for public use, but, at times, the flow of the stream may not be sufficient to meet the water requirements of 20,000 gpd (14 gpm). The streamflow was measured as 0.30 cfs (about 135 gpm) on July 16, 1970. Lowry and Gordon (1964, p. 11) reported that 20 gpm was flowing into the storage reservoir from the stream on September 12, 1962. Although the streamflow was more than the required 14 gpm at the times of the two measurements, it may decline during droughts. A larger and more dependable supply might be obtained from ground water.

A test hole, CEE 1, was drilled in June 1967 in alluvium along Middle Creek 350 feet west of the station at East Entrance. Drilling in this hole was stopped in alluvium at a depth of 100 feet because the water-bearing zones penetrated yielded more than the amount of water required at the site. The casing was perforated opposite several water-bearing zones in sand and gravel from depths of 29 to 92 feet. The test well was pumped at 128 gpm for 6 hours with a drawdown of 5.3 feet, for a specific capacity of about 24 gpm per foot of drawdown. The water level was 3.5 feet below land surface before pumping began.

The water from test well CEE 1 appeared to be clear at the end of the 6-hour aquifer test, but, if another well is drilled for production, it should be screened in a manner to minimize pumping sand and to obtain maximum yield. Water-bearing zones penetrated in the upper part of test well CEE 1 indicate that a production well drilled at that site to a depth of 50 feet should yield about 50 gpm with a drawdown of less than 10 feet. Yields of 250 gpm or more could be obtained from wells 90 feet deep near the site of test well CEE 1. The alluvium along Middle Creek is probably sufficiently extensive to yield water to three such wells near East Entrance. As much as 750 gpm (about 1 million gpd) of ground water, therefore, probably could be developed near East Entrance.

The specific conductance of the water yielded to test well CEE 1 below a depth of 90 feet was 890 micromhos, whereas the specific conductance of water from zones between 19 and 90 feet ranged from 120 to 240 micromhos. The yield from that part of the well below 90 feet was small. A production well, therefore, should not be drilled deeper than 90 feet to minimize the pumping of this poor-quality water. The quality of water in test well CEE 1 above 90 feet is excellent. The water is soft and is below the recommended limits for all chemical constituents analyzed. The aquifer tapped by the well is recharged by water percolating from Middle Creek.

Norris Junction

The investigation at Norris Junction was an effort to locate a ground-water supply of 50,000 gpd (35 gpm) to replace the surface-water supply diverted from Castle Creek. The flow of Castle Creek seems adequate to supply Norris Junction. The drainage above the diversion facility is remote and relatively free from human traffic. However, the stream reportedly has high suspended-sediment concentration, color, and turbidity during spring runoff and the water is temporarily objectionable to use. The fluoride content of the water was 4.2 mg/l on September 19, 1967. This is more than the recommended limit for fluoride.

Test holes ANJ 1 and 2 were drilled in September 1966 near Castle Creek, and test holes ANJ 3-10 and CNJ 1 were drilled in June and July 1967 near the Gibbon River in an effort to locate a ground-water supply near Norris Junction (fig. 8). Information from these test holes (not all are shown on fig. 8) indicated a potential aquifer in sand and gravel from near land surface to an underlying tight gray clay and clayey sand (probably weathered and altered rhyolite). The aquifer is at shallow depth, thin, and not extensive. Information from a test hole drilled in 1960 by a contractor hired by the National Park Service in an effort to locate a ground-water supply for the Norris campground suggests that ground water below the shallow aquifer in sand and gravel would be hot and probably highly mineralized. The test hole, RNJ 1 in this report, was drilled to a depth of 125 feet. The only water-bearing zone reported was hot water that flowed to the surface from fractures in rhyolite at depths of 114 to 117 feet. Test holes ANJ 11-14 were drilled in June 1968 to establish a screened test well in the thickest part of the aquifer in order to make capacity tests. Tight gray clay was penetrated in these holes at depths ranging from 18 to 20.4 feet. Four-inch diameter casing and a 3-inch screen 5 feet long were installed in test hole ANJ 14.

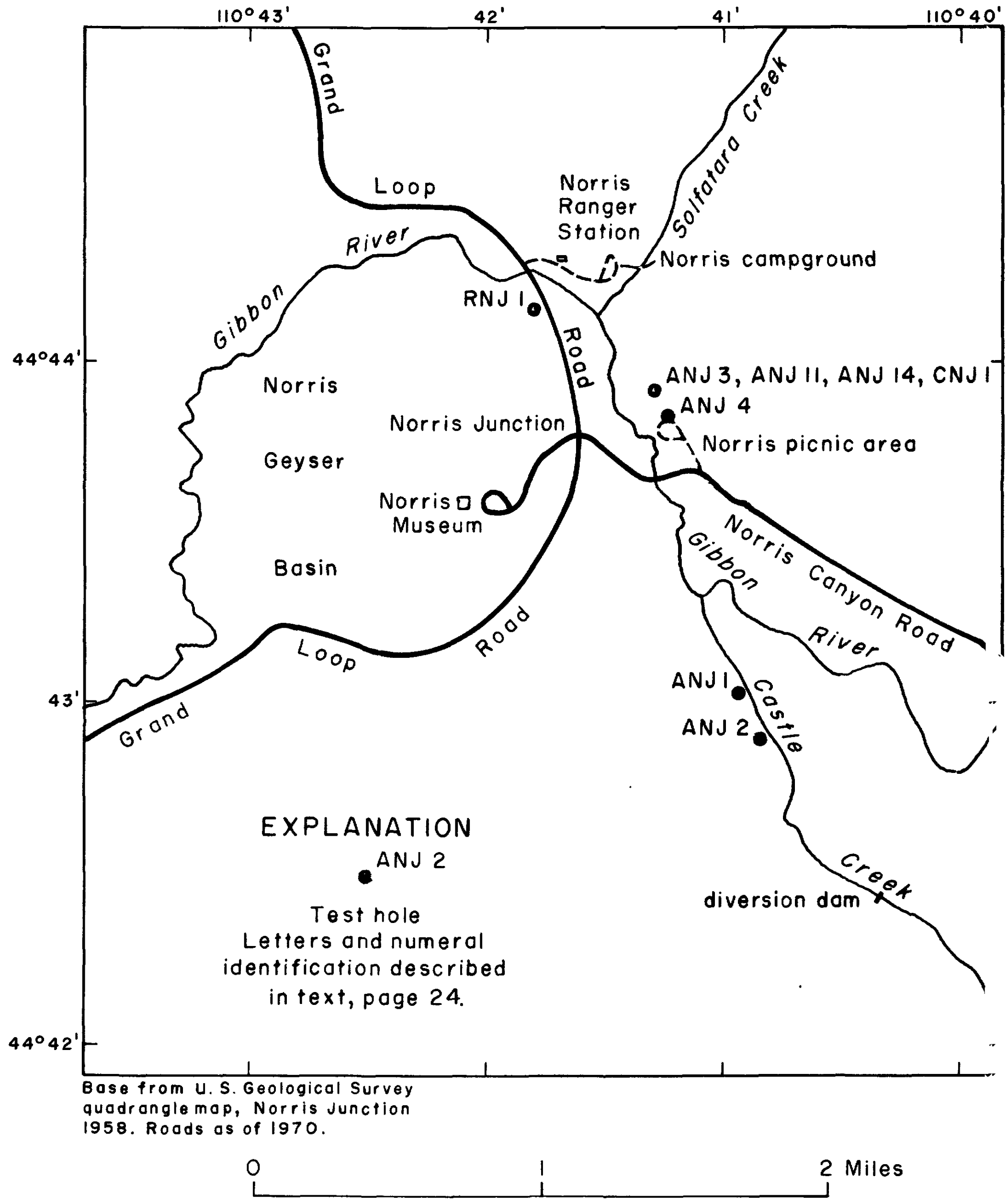

Figure 8.--Location of a diversion dam and selected test holes near Norris Junction.

In July 1968, test well ANJ 14 was pumped at a rate of 35 gpm for 4 hours, and the drawdown was 9.3 feet. The specific capacity was about 3.8 gpm per foot of drawdown. The water level was 3.7 feet below land surface before pumping began. The top of the screen is about 15 feet below land surface; therefore, the water level inside the well was lowered to about 2 feet above the top of the screen during the 4-hour test.

In August 1970, test well ANJ 14 was pumped at a rate of 20 gpm for 24 hours. The drawdown was 5.6 feet; the specific capacity was about 3.6 gpm per foot of drawdown. The water level was about 4.2 feet below land surface before pumping began.

The lowest water-level measured in test well ANJ 14 (except during aquifer tests) was 4.6 feet below land surface in September 1969. At that time, the water level was about 10.4 feet above the top of the well screen. If the specific capacity of the well was 3.6 gpm per foot of drawdown, the well could have been pumped at a rate of 37 gpm for 24 hours without the water level being lowered below the top of the screen. A pumping rate of 37 gpm should be considered a maximum rate. If the water level were lowered below the top of the screen, the pump would suck air and the yield would decline. The sustained yield from test well ANJ 14 is probably less than 35 gpm.

Although test well ANJ 14 probably would not yield the 50,000 gpd required for a water supply at Norris Junction, two or more production wells, properly spaced, would yield 50,000 gpd. If production wells are drilled for a water supply at Norris Junction, they should be located between test well ANJ 14 and test hole ANJ 4 in the area within a quarter of a mile of Norris picnic area. Ground water could be used during part of the year to supplement and replace the surface-water supply from Castle Creek.

The area between test well ANJ 14 and Solfatara Creek and within a quarter of a mile of the Gibbon River may be a potential site for wells. The area was not tested, however, because streams could not be crossed with drilling equipment.

Water from test well ANJ 14 has higher dissolved solids (352 mg/l) than water from Castle Creek (146 mg/l). However, all chemical constituents that were determined in water from test well ANJ 14 are below recommended limits. Water from the well is relatively high in bicarbonate and boron, which may indicate recharge to the aquifer by thermal water. The water is apparently suitable for public use, but it is moderately hard.

The thin aquifer in sand and gravel penetrated by the test holes is probably glacial drift that overlies weathered and altered rhyolite. This aquifer and other thin aquifers in nearby areas are drained by numerous cool springs and seeps along the Gibbon River, Solfatara Creek, in meadows, and at the edges of forested areas. Two isolated warm springs near the Gibbon River and one near Solfatara Creek indicate that some of the shallow aquifers may contain thermal water. Because the shallow aquifers may have hydraulic connection with thermal water, the maximum pumpage of water from them should be 50,000 gpd.

Old Faithful

The water supply for facilities at Old Faithful is diverted from the Firehole River about 1.8 miles upstream from Old Faithful (fig. 9). Flow of the Firehole River is sufficient to supply the required 1 million gpd (700 gpm) of water for Old Faithful facilities, but the stream contains suspended sediment and colored water during spring runoff. The Firehole River at the diversion dam has a relatively high fluoride content. The fluoride content was 2.7 mg/l and 3.1 mg/l in November 1969 and April 1970, respectively, but it ranged from 0.9 mg/l to 2.4 mg/l in other samples collected during 1967-70. An access road to Lone Star Geyser is adjacent to the Firehole River for about 2 miles above the diversion dam; consequently, the stream is subject to contamination by humans. The investigation in the Old Faithful area was an effort to locate a ground-water supply to replace the surface-water supply.

Twelve test holes were drilled in the Old Faithful area in September 1966, and two test holes were drilled in September 1968. Three test holes were drilled along Iron Spring Creek and 11 were drilled near the Firehole River along the Lone Star Geyser road and the Shoshone Lake Trail. (Not all test holes are shown in fig. 9.)

The results of the 1966 testing indicated that the best location for a test well was near the Firehole River at the site of test hole AOF 4 (fig. 9). Test hole COF 1 was drilled near this site in June 1967 to a depth of 50 feet and stopped in bedrock (rhyolite). The casing in the interval from 32 to 35 feet was perforated, but sand entered the well and prevented testing by bailing or pumping. A properly screened well drilled to bedrock at this site probably would not yield more than 50 gpm. The aquifer tapped by test well COF 1 is sufficiently extensive to yield water to only one well at a rate of 50 gpm.

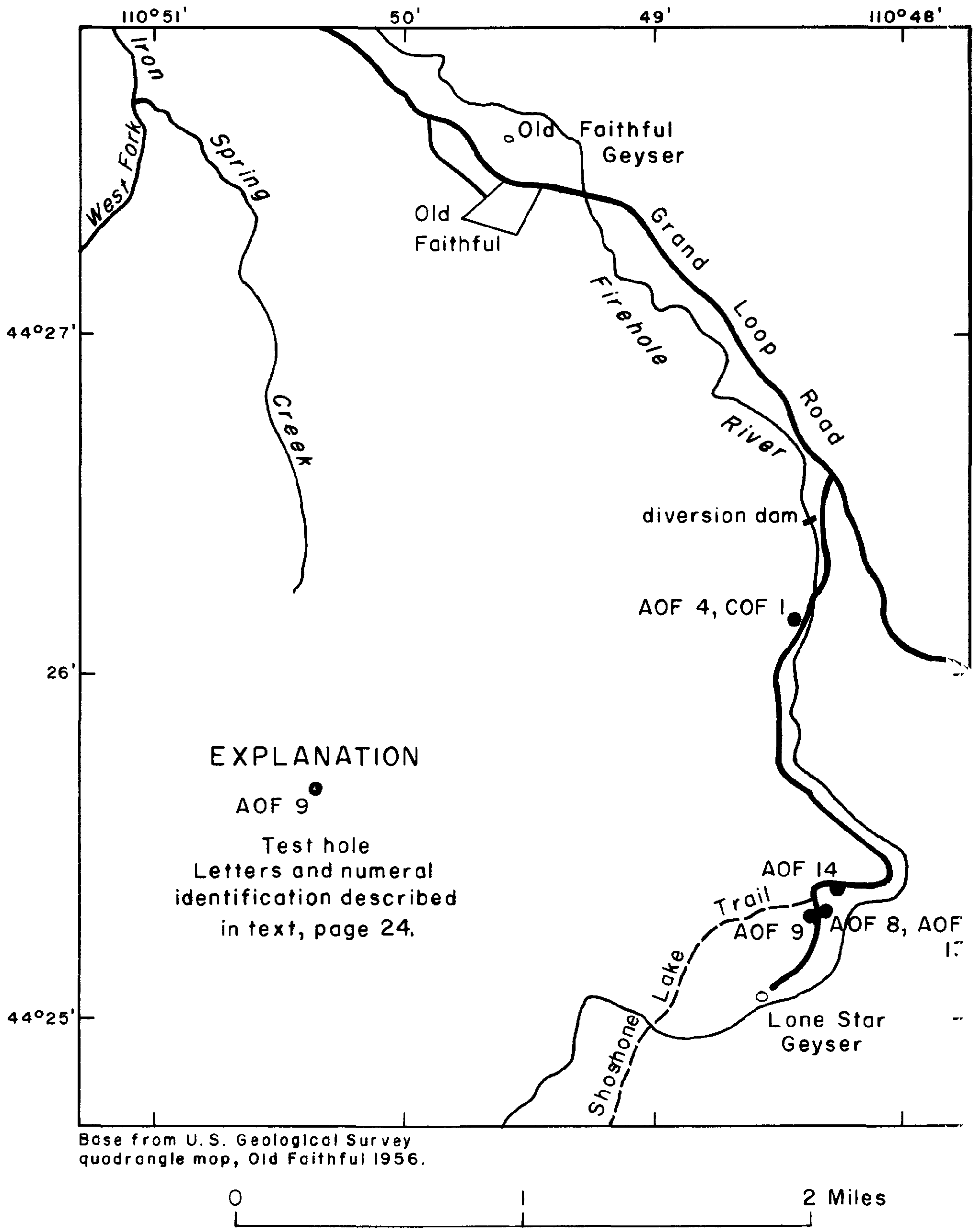

Figure 9.--Location of a diversion dam and selected test holes near Old Faithful.

The high fluoride content (3.4 mg/l) of water from test well COF 1 is above the recommended limit. The dissolved-iron content (850 μg/l) also exceeds the recommended limit. The water is acidic (pH 4.4) and probably would be corrosive. Water in the aquifer tapped by test well COF 1 is not suitable for use as a public supply at Old Faithful.

Test holes AOF 8-12 near the Firehole River penetrated from 35 to 80 feet of sand and gravel. The sand and gravel are thickest at test holes AOF 8 and 9. Test holes AOF 13 and 14 were augered in September 1968 near test hole AOF 8 in sand and gravel to depths of 68 and 32 feet, respectively, before bedrock (rhyolite) was struck.

The best location for a well to supply water for Old Faithful is near the sites of test holes AOF 8 and 13. A well drilled to bedrock at this location would tap about 60 feet of saturated sand and gravel and might yield as much as 50 gpm. Wells at nearby locations would tap less than 60 feet of saturated sand and gravel; consequently, they would yield less than 50 gpm. Interference between nearby wells might occur. Total yield of water from wells at this location probably would be about 50 gpm. Water in sand and gravel in this area probably is recharged by seepage from the Firehole River.

In October 1968, a water sample was collected from test hole AOF 8. The dissolved-solids content was 132 mg/l and the fluoride content was 0.8 mg/l. The water was soft and only slightly acidic (pH 6.8). The iron content was 2,100 μg/l, which is higher than the recommended limit. Concentrations of all other chemical constituents determined were below the recommended limits. If a ground-water supply for public use were developed in sand and gravel near the sites of test holes AOF 8 and 13, the water should be treated to reduce the iron concentration.

Reconnaissance in the Old Faithful area has not indicated a potential ground-water supply of more than 50 gpm from any single aquifer. Ground water in the Upper Geyser Basin is undoubtedly hot, highly mineralized, and under pressure higher than atmospheric pressure at many places. Thermal features are widespread near the Firehole River above the Upper Geyser Basin and near tributaries to the Firehole at the edges of the Upper Geyser Basin.

The lower part of the valley of the West Fork of Iron Spring Creek may have cool ground water. Interpretation of infrared imagery from remote-sensing missions, field inspections, and aerial photographs of snowpack conditions suggest that the land surface and the ground water are relatively cool in this area. No test holes were constructed in the valley of the West Fork of Iron Spring Creek because the area is inaccessible with motorized drilling equipment. Total yield of water from wells in this valley probably would be less than 50 gpm.

Mud Volcano

The investigation near Mud Volcano was an effort to locate a ground-water supply of 20,000 gpd (14 gpm) for a proposed comfort station. Six test holes, AMV 1-5 and CMV 1, were drilled in 1967 in the vicinity of the Buffalo Ford picnic area about 1 mile southeast of Mud Volcano (fig. 10). Water-bearing sand and gravel were penetrated in test holes AMV 2, AMV 4, and CMV 1. These holes were finished as observation wells. Water from test wells AMV 4 and CMV 1 is probably not potable owing to dissolved carbon dioxide that gives the water a bad taste. Water from test wells AMV 4 and CMV 1 is acidic (pH of 5.6 and 5.5, respectively). Water from test well AMV 2 does not have a bad taste, is only slightly acidic (pH of 6.7), and is considered potable.

Reconnaissance and test drilling indicate that the best location for a water-supply well near Mud Volcano is near test well AMV 2. Locations closer to Mud Volcano have either bedrock near the surface or thermal features. Tight gray clay (altered rhyolite) was penetrated at a depth of 12 feet below the land surface in test holes AMV 1 and 3, which are less than a quarter of a mile west of test well AMV 2. Water-bearing sand and gravel extend to a depth of 78 feet at test well AMV 2.

Test hole AMV 6 was completed in June 1968 near test well AMV 2 as a test well in which to perform capacity tests. The well was finished by installing 18 feet of 4-inch diameter casing and 6 feet of 3-inch diameter well screen.

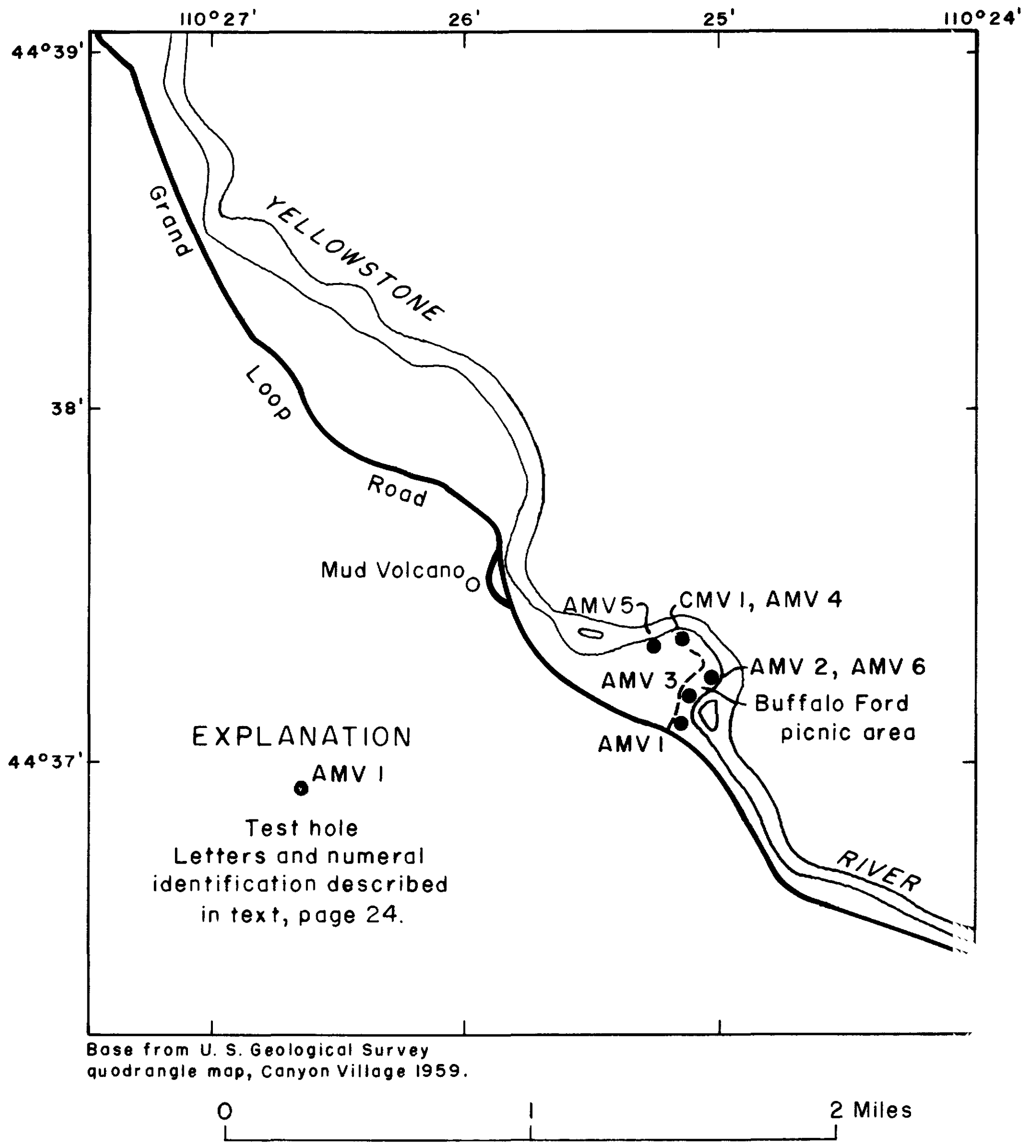

Figure 10.--Location of test holes near Mud Volcano.

In August 1968, test well AMV 6 was pumped at 37 gpm for 4 hours, and the drawdown was 2.2 feet. Specific capacity of the well was about 17 gpm per foot of drawdown. The water level was 6.0 feet below land surface before pumping began. In August 1969, the well was pumped at 33 gpm for 18 hours, and the drawdown was 1.8 feet. Specific capacity of the well was about 18 gpm per foot of drawdown during this test. The water level was 6.4 feet below land surface before pumping began. In August 1970, the well was pumped at 87 gpm for 24 hours, and the drawdown was 6.6 feet. Specific capacity of the well was about 14 gpm per foot of drawdown during this test. The water level was 6.5 feet below land surface before pumping began.

The aquifer tapped by test well AMV 6 would yield sufficient water to satisfy the requirements for a comfort station near Mud Volcano. The specific capacity of test well AMV 6 ranged from 14 to 18 gpm per foot of drawdown during tests that ranged from 4 to 24 hours. At a specific capacity of 14 gpm per foot of drawdown, the maximum yield from test well AMV 6 would be about 140 gpm for 24 hours. At this pumping rate, the water level in the well would remain above the top of the screen, if the water level before pumping began were at the lowest water level measured in the well during 1968-70. A well with a yield of more than 140 gpm could be drilled near test well AMV 6, if it were drilled deeper than the test well and more of the aquifer were screened. A well 78 feet deep would completely penetrate the aquifer in sand and gravel and, if properly screened, would yield at least 250 gpm. The aquifer tapped by test well AMV 6 is sufficiently extensive to yield water to only one such well.

The chemical quality of water from test well AMV 6 is suitable for public use, although the fluoride at times exceeds the recommended limit. The fluoride content was 2.4 mg/l in June 1968, 2.2 mg/l in August 1968, 1.2 mg/l in August 1969, and 2.7 mg/l in August 1970. The water was sampled near the end of the 24-hour aquifer test in August 1970, and the dissolved-solids content was 148 mg/l. The water was soft and slightly acidic (pH of 6.4). The concentration of each chemical constituent determined, except fluoride, was within the recommended limit.

The aquifer in sand and gravel at Buffalo Ford picnic area, tapped by test well AMV 6, is recharged by seepage from the Yellowstone River.

South Entrance

The water supply for South Entrance is a spring about three quarters of a mile north of the entrance station (fig. 11). The spring flows into a small stream that heads in a marshy area about a quarter of a mile above the spring. An intake structure has been built over the spring, and water not diverted for use at South Entrance flows into the stream. During periods of relatively high flow in the stream, water from the stream may enter the intake structure and mix with water from the spring. The flow of the spring could not be measured directly, but it was determined by measuring the stream above and below the spring and estimating the flow of smaller springs entering the stream between the measuring sites. The flow of the supply spring was 0.30 cfs (about 135 gpm) on October 17, 1970, when the flow of the stream above the spring was only 0.05 cfs.

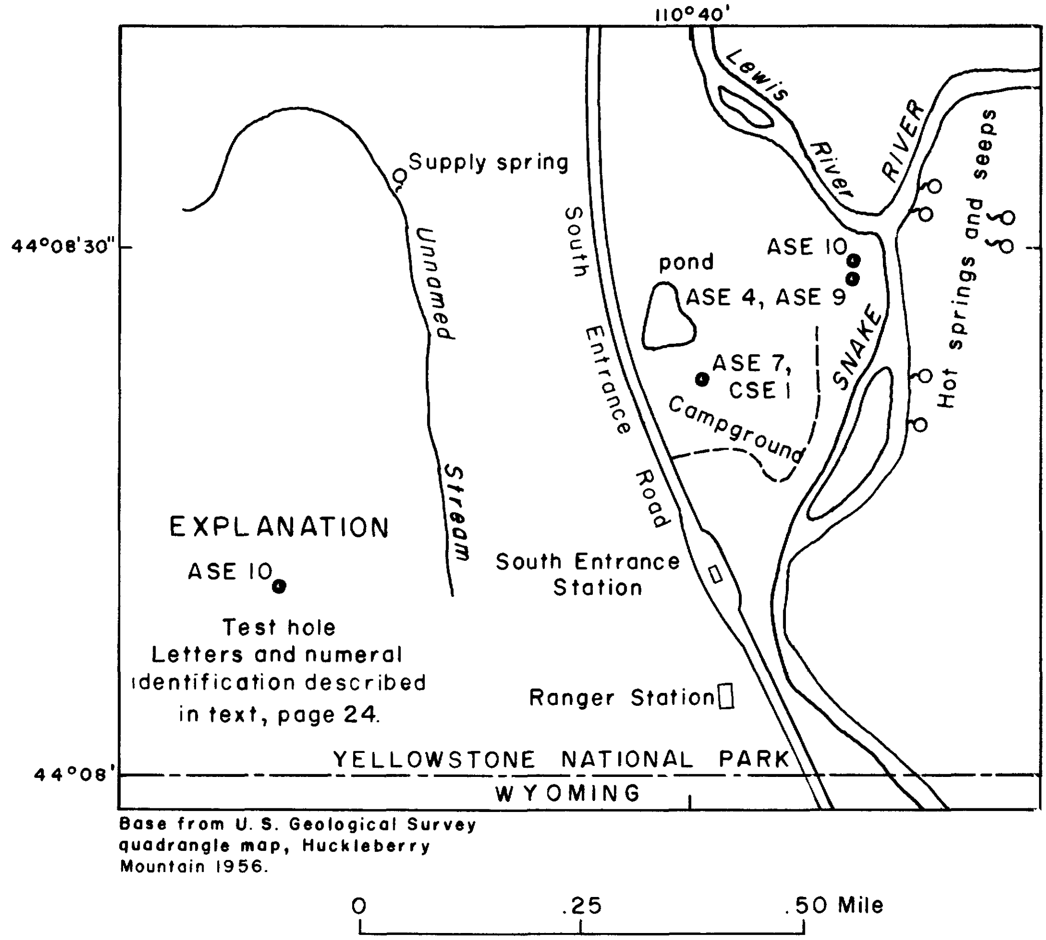

Figure 11.--Location of a supply spring and selected test holes near South Entrance

The water requirements for South Entrance were given as 20,000 gpd (14 gpm). Based on one measurement in October 1970, the discharge of the spring is sufficient to supply 20,000 gpd. A chemical analysis indicates that the chemical character of the water is within the recommended limits. An investigation was made, however, in an effort to locate a ground-water supply for South Entrance.

Eight test holes were drilled in September 1966 (not all are shown in fig. 11). Data from these test holes indicated good sites for further drilling in the north end of the campground (ASE 7) and near the confluence of the Lewis and Snake Rivers (ASE 4) (fig. 11).

In June and July 1967, test hole CSE 1 was drilled in the north end of the campground to a depth of 100 feet without penetrating bedrock. Water-bearing sand and gravel were penetrated in the hole, and it was completed as a test well. Sand heaving into the well through the perforated casing made a good aquifer test impossible. A properly screened well, 100 feet deep, at this site would probably yield about 50 gpm. The aquifer is sufficiently extensive to yield water to only one such well. A well 60 feet deep at the site of test well CSE 1 should yield at least 15 gpm.

Two test holes, ASE 9 and 10, were drilled on a terrace near the confluence of the Lewis and Snake Rivers in June 1968 to establish a screened test well to perform capacity tests (fig. 11). Test well ASE 9 was finished as the well to be pumped by installing 16 feet of 4-inch diameter casing and 6 feet of 3-inch diameter well screen; test well ASE 10 was finished as an observation well.

In August 1968, test well ASE 9 was pumped at a rate of about 38 gpm for 4 hours, and the drawdown was about 1.6 feet. The specific capacity of the well was about 24 gpm per foot of drawdown. The water level was 9.4 feet below land surface before pumping began. In August 1970, the well was pumped at a rate of 59 gpm for 24 hours, and the drawdown was 3.6 feet. The specific capacity of the well was about 16 gpm per foot of drawdown for this test. The water level was 9.6 feet below land surface before pumping began.

The aquifer tapped by test well ASE 9 would yield sufficient water to satisfy the requirements at South Entrance. A properly screened well about 50 feet in depth on the terrace near test wells ASE 4, 9, and 10 would probably yield at least 100 gpm. The aquifer is sufficiently extensive to yield water to two such wells. The aquifer in sand and gravel under this terrace is recharged by seepage from the Lewis and Snake Rivers. Wells should not be drilled deeper than necessary to obtain the desired yield because thermal water, such as discharges in hot springs and seeps on the terraces east of the Snake River, might underlie the terrace west of the Snake River. Test hole ASE 4 was drilled to a depth of 62 feet without penetrating thermal water or bedrock.

All chemical constituents determined, except arsenic and fluoride, in the water from test wells ASE 9 and CSE 1 are below the recommended limits. Water from test well ASE 9 had an arsenic content of 50 μg/l in August 1970, which is equal to the maximum limit suggested by the U.S. Public Health Service of 0.05 mg/l. A water sample collected from test well ASE 4 in August 1967 had an arsenic content of 0.02 mg/l. No other analyses for arsenic were made in water samples collected near South Entrance.

Water from test well ASE 9 had a fluoride content of 2.0 mg/l in June 1968, 2.4 mg/l in August 1968, and 2.5 mg/l in August 1970. Water from test well CSE 1 had a fluoride content of 3.2 mg/l in July 1967. Fluoride contents of water from the wells are more than the fluoride content of 1.6 mg/l in a sample collected from the supply spring in October 1970, but less than the fluoride content of 3.6 mg/l in a sample collected in October 1967 that was probably a combination of water from the spring and from the stream above the spring. Additional samples, particularly from the spring, would be needed to determine if water from the spring has higher fluoride than water from the wells.

In August 1968, a water sample from test well ASE 9 was submitted to the Wyoming Department of Public Health for bacteriological analysis. The sample indicated the water from this well to be unsafe. The well was sampled near the end of the 24-hour aquifer test in August 1970, and a test for coliforms was made in the field. The test indicated that coliforms were present in the sample, but no quantitative determination was made. The presence of coliforms suggests that either the aquifer or the well is contaminated. If the contamination is from the aquifer, bacteriological treatment of the water from any well drilled in the vicinity of test well ASE 9 will be necessary before it can be used in the water supply at South Entrance.

Tower Junction

The investigation at Tower Junction was an effort to locate the best site to obtain 200,000 gpd (140 gpm) of ground water to replace surface-water supplies for Tower Junction Ranger Station and Roosevelt Lodge and for possible new facilities proposed for this area. A spring about a quarter of a mile southwest of the ranger station is used as a water supply for that facility. Water is diverted from Lost Creek for use at Roosevelt Lodge (fig. 12). The ranger station was connected to the Roosevelt Lodge system in 1961 to supplement the supply from the spring. Water shortages reportedly occur in the Tower Junction area. The flow of Lost Creek above the diversion was measured as 3.63 cfs (about 1,630 gpm) on July 17, 1969. However, the flow of Lost Creek declines during the summer, and the creek is usually dry in late summer and fall at Grand Loop Road bridge about 2,000 feet below the diversion.

Eleven test holes were drilled near Tower Junction in September 1967 (not all are shown in fig. 12). Most of the holes are in the flat north of Grand Loop Road and on both sides of Northeast Entrance Road. The area west of Northeast Entrance Road showed more promise for establishing wells than that east of Northeast Entrance Road where boulders or bedrock occur at shallow depths. In addition, the material above the bedrock east of Northeast Entrance Road is glacial drift and does not contain enough water to warrant further exploration.

The flat north of Grand Loop Road and west of Northeast Entrance Road is bounded on the west by a ridge between Yancey Creek and Lost Creek and is approximately bisected by Lost Creek. Data from test drilling indicated that the west half of this area is the most promising area in which to develop a ground-water supply for facilities at Tower Junction.

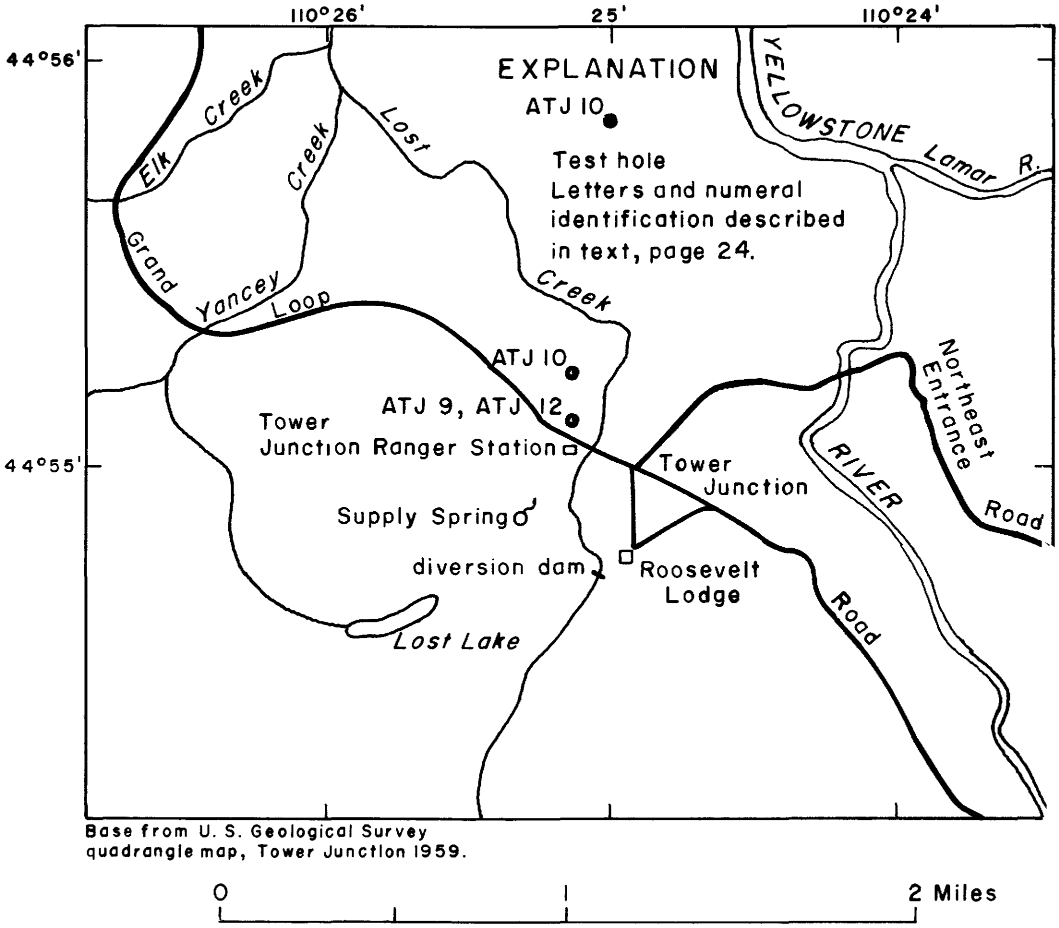

Figure 12.--Location of a supply spring, diversion dam, and selected test holes near Tower Junction.

Test hole ATJ 12 was drilled near test hole ATJ 9 in June 1968. A well to perform capacity tests was established at ATJ 12 with 4-inch diameter casing and a 3-inch diameter well screen. The well screen was broken from the casing during construction of test well ATJ 12, and a capacity test could not be made. In September 1968, the casing was pulled, equipped with a new well screen, and installed in a new hole. The test well has 19 feet of 4-inch diameter casing and a 3-inch diameter well screen 5 feet long. A capacity test was not made, but the well was developed by pumping at a rate of 24 gpm for about 2 hours with the pump mounted on the drilling rig. Drawdown in the well could not be measured during this pumping period.

In August 1970, well ATJ 12 was pumped at a rate of 9 gpm for 10 hours, and the drawdown was 2.7 feet. The specific capacity was about 3.3 gpm per foot of drawdown. The water level was 10.2 feet below land surface before pumping began.

At a specific capacity of 3.3 gpm per foot of drawdown, the maximum yield from test well ATJ 12 would be about 25 gpm for 10 hours. At this pumping rate, the water level in the well would remain above the top of the screen, if the water level before pumping began were at the lowest level measured in the well during 1968-70. The maximum sustained yield from test well ATJ 12 probably would be less than 25 gpm.

Water-supply wells could be drilled in the flat near test wells ATJ 9, 10, and 12. The supply wells should be as shallow as possible because sand and gravel penetrated in the test holes became finer grained with increased depth; bedrock was not penetrated. Logs of test holes ATJ 9 and 10 indicate that drilling deeper than 26 feet would result in little or no additional yield from the well because of fine-grained sand between 26 and 36 feet and silt and clay below 36 feet. At depths of 26 feet, maximum yields from wells would be less than 25 gpm; consequently, at least six wells would be required to yield the 140 gpm needed at Tower Junction facilities.

The aquifer in sand and gravel in the flat near the test wells probably is not sufficiently extensive or thick enough to yield water to six wells at 25 gpm each for long periods of time. However, the aquifer would yield water to two or three properly spaced wells to supplement the present supplies when springflow and streamflow are low or when Lost Creek contains suspended sediment. Yields of the wells would be less than 25 gpm each.

Chemical constituents determined in the water from the test wells, Lost Creek, and the supply spring are below the recommended limits for all chemical constituents except iron in water from test well ATJ 10. The source of the high iron content (1,880 μg/l) in water from test well ATJ 10 is not known, and it may be from the well casing and not from the aquifer. Water from a sample collected from test well ATJ 12 near the end of the 10-hour pumping test in August 1970 had a dissolved-solids content of 113 mg/l. The water was soft and had a pH of 6.9. The iron content was 90 μg/l, and the fluoride content was 0.6 mg/l.

Lost Creek is a source of intermittent recharge to the aquifer in sand and gravel in the flat west of the Northeast Entrance Road. Most of the recharge occurs during spring runoff. A storm in May 1967 resulted in excessive runoff that flooded almost the entire flat and damaged the Grand Loop and Northeast Entrance Roads. Recharge from these flood waters was higher than normal.

Fountain Paint Pot

About 20,000 gpd (14 gpm) of water is needed for a proposed comfort station at the parking area near Fountain Paint Pot (fig. 13). This popular roadside attraction and nature trail is in the eastern part of the Lower Geyser Basin. Ground water in the Lower Geyser Basin is undoubtedly hot and probably too highly mineralized to use for the comfort station. An investigation to locate a ground-water source for the comfort station was made in the valley of Nez Perce Creek, the area nearest Fountain Paint Pot where reconnaissance indicated cool ground water might occur. Another possible source of water for the comfort station is a spring 0.4 mile north-northeast of Fountain Paint Pot. This spring was formerly used as a water supply for a hotel, now destroyed. A flow of 16 gpm was measured from this spring in October 1968.

Four test holes were drilled in October 1967 in Nez Perce Creek valley about 3 miles northeast of Fountain Paint Pot (fig. 13). Test holes AFPP 1 and 2 drilled to bedrock penetrated 87 and 100 feet, respectively, of sand and gravel, composed mostly of angular fragments of obsidian. Test hole AFPP 2 was finished as an observation well. Warm sand was penetrated below 11 feet at test holes AFPP 3 and 4. The valley upstream from test hole AFPP 1 was not tested, because it was inaccessible with motorized drilling equipment.

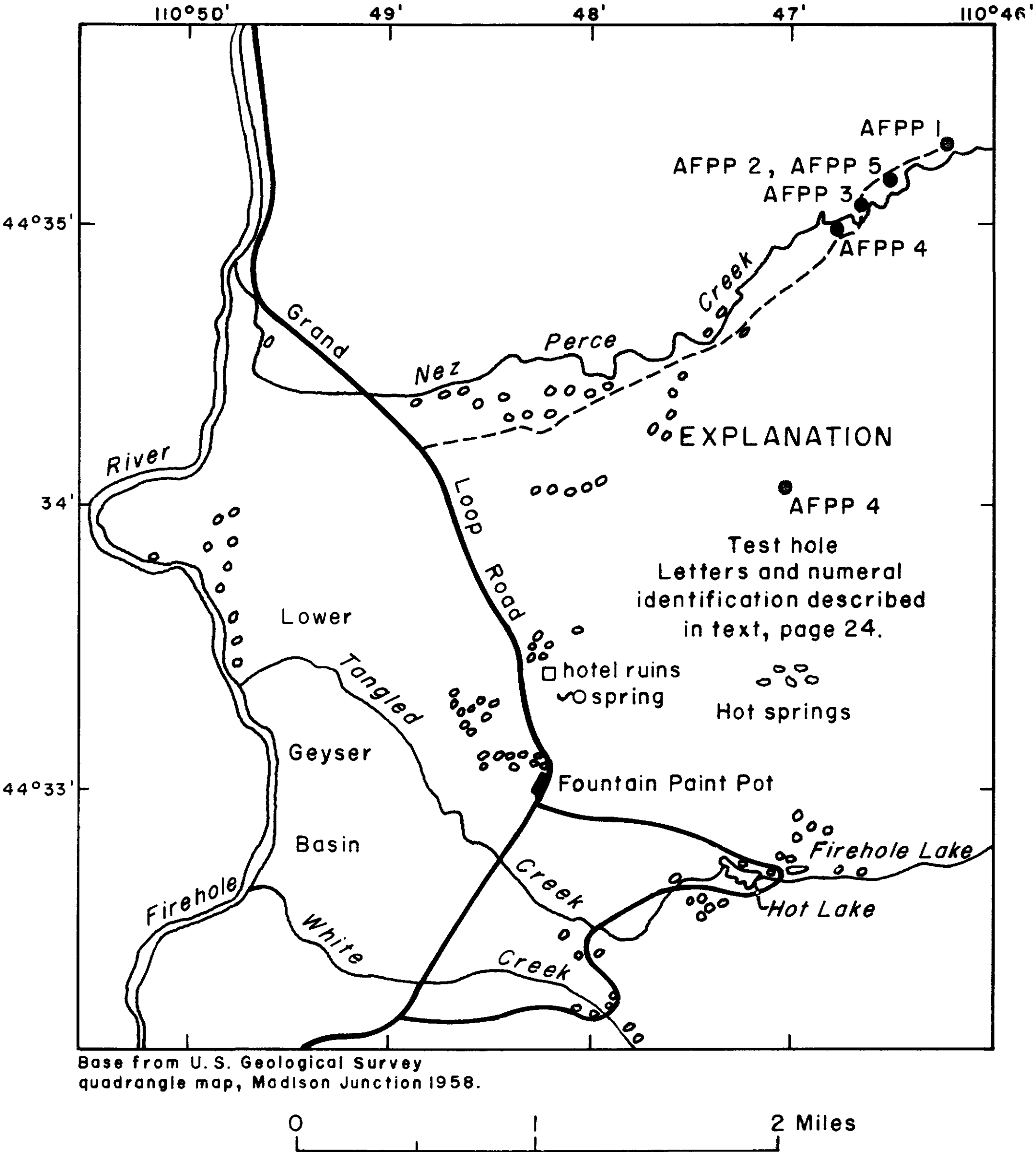

Figure 13.--Location of a spring, hotel ruins, and test holes near Fountain Paint Pot.

Test hole AFPP 5 was augered in June 1968 near test well AFPP 2, and was finished as a test well by installing 42 feet of 4-inch diameter casing and a 3-inch diameter screen 6 feet long. In August 1968, test well AFPP 5 was pumped 4 hours at a rate of 35 gpm, and the drawdown was 0.64 foot. The specific capacity was 55 gpm per foot of drawdown. The water level was 8.1 feet below land surface before pumping began. In August 1970, the well was pumped for 24 hours at a rate of 108 gpm, and the drawdown was 2.8 feet. The specific capacity was about 39 gpm per foot of drawdown for this test. The water level was 8.8 feet below land surface before pumping began. The aquifer tapped by test well AFPP 5 would yield sufficient quantities of water for a comfort station at Fountain Paint Pot. Yields of 500 gpm or more could be obtained from each properly constructed well in sand and gravel in the Nez Perce Creek valley between the sites of test holes AFPP 1 and 5. The aquifer is sufficiently extensive to yield water to three such wells.

In Nez Perce Creek valley, cool ground water occurs adjacent to warm ground water as determined from test holes AFPP 1-4. Differences in ground-water temperatures are also indicated by differences in soil temperatures at land surface. During a field survey in August 1969, the difference in surface-soil temperatures between areas of cool and areas of warm ground water averaged about 7°C.

On November 16, 1969, the surface soil was frozen in the area of cool ground water, but it was not frozen in the area of warm ground water. On April 17, 1969 and May 14, 1970, the area of cool ground water was covered by about 2 feet of snow, whereas the area of warm ground water was almost completely free of snow.

The boundary between cool and warm ground water is about 400 feet down the valley from test well AFPP 5. Production wells should not be drilled down the valley from test well AFPP 5 because hot ground water might be penetrated by the well or move to the well during pumping.

If ground water were pumped from sand and gravel in Nez Perce Creek valley, water would move toward the pumping well to recharge the dewatered part of the aquifer near the well. Eventually, water would move from Nez Perce Creek toward the well. This would result in a decrease in streamflow approximately equal to the amount of ground-water pumpage. Loss in streamflow because of ground-water pumpage, however, would be small compared to the total flow of the stream.

The flow of Nez Perce Creek was measured eight times from August 1968 to October 1970 and ranged from 53.1 cfs on September 16, 1969 to 151 cfs on May 21, 1969. Based on these measurements, a relationship between the flow and the stage of the stream was established. Additional observations made of the stage of the stream indicate that the streamflow ranged from about 50 cfs in October 1969 to about 200 cfs in June 1970 during August 1968-October 1970.

A water sample collected from test well AFPP 5 near the end of the 24-hour aquifer test in August 1970 had a dissolved-solids content of 175 mg/l, a fluoride content of 5.0 mg/l, and an arsenic content of 40 μg/l. The water was soft and had a pH of 6.7. The water temperature was 13.0°C during the entire test. All chemical constituents determined except fluoride and arsenic are within recommended limits. Arsenic is within the maximum limit suggested by the U.S. Public Health Service of 0.05 mg/l. The chemical constituents sought in analyzing water from Nez Perce Creek and the spring near the destroyed hotel are within recommended limits except for fluoride. Arsenic was not sought. Nez Perce Creek has a fluoride content of about 2.5 mg/l during spring runoff and about 6.5 mg/l during other times. The spring had a fluoride content of 7.8 mg/l in August 1967. Water from any of these sources would have to be defluorinated to meet the drinking water standard of the U.S. Public Health Service.

Canyon Village

About 1 million gpd (700 gpm) of water is needed to supply facilities at Canyon Village. Presently, water is diverted by gravity flow from unnamed tributaries of Cascade Creek and Sulphur Creek 2.0 and 2.5 miles, respectively, northeast of Canyon Village. Sulphur Creek flows into the Yellowstone River about 6 miles below the mouth of Cascade Creek. An auxiliary pump is located on a water line from a diversion dam on Cascade Creek about 0.5 mile northwest of Canyon Village (fig. 14). Flow in these creeks declines during the summer and may become too small during dry years to supply the needs at Canyon Village. No water shortages were reported, however, during 1967-70.

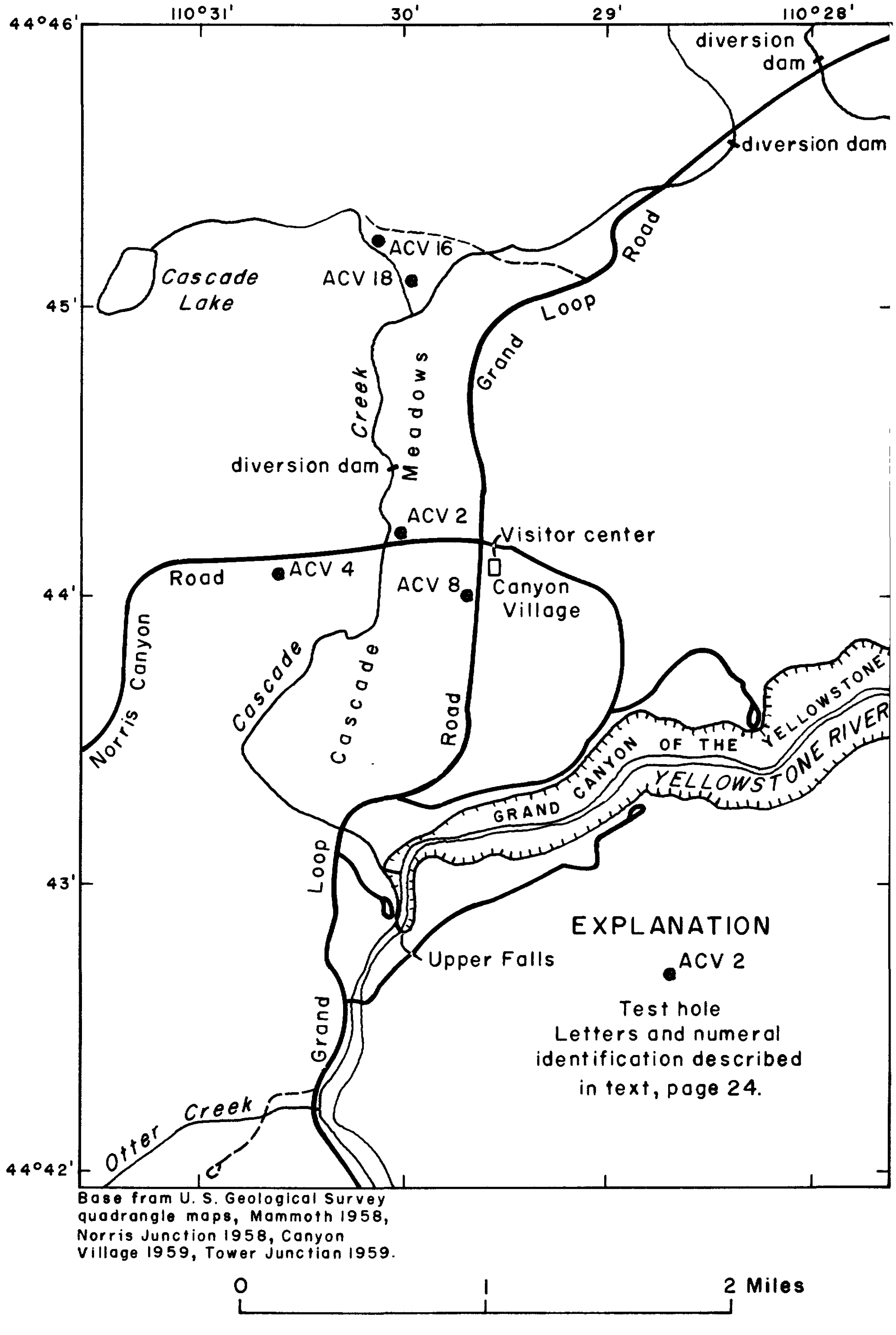

Figure 14.--Location of diversion dams and selected test holes near Canyon Village.

Streamflow was measured above the diversion dams on the three sources of water for Canyon Village on July 25, 1968. Flow of the tributary to Sulphur Creek was 0.44 cfs, the tributary to Cascade Creek was 0.27 cfs, and Cascade Creek was 4.64 cfs. In addition, flow of Cascade Creek above the diversion dam was 7.78 cfs on July 18, 1969 and 1.95 cfs on August 27, 1969.

Chemical quality of the water from the three sources for Canyon Village is excellent. Water in the tributaries to Sulphur and Cascade Creeks had dissolved-solids contents of 60 mg/l and 59 mg/l, respectively, in July 1968. Water from both streams had no fluoride, a pH of 7.6, and was soft. In August 1969, water from Cascade Creek had a dissolved-solids content of 74 mg/l, a fluoride content of 0.6 mg/l, a pH of 7.7, and was soft. All chemical constituents determined in water from the three sources for Canyon Village are below the recommended limits.

The drainage areas of the three sources of water for Canyon Village are accessible to park visitors; consequently, the streams are becoming more subject to contamination by human traffic in the park. The use of ground water for a water supply at Canyon Village would eliminate these problems.

Nineteen test holes were drilled in the Canyon Village area in September 1967 (not all are shown in fig. 14). These holes were augered in Cascade Meadows, other clearings along Cascade Creek, and along the lower reach of Otter Creek. Testing was limited to these sites, because other nearby areas are inaccessible with motorized drilling equipment or bedrock is at or near land surface.

None of the test holes penetrated water-bearing material from which water can be developed by wells at the rate of 700 gpm. Much of the material penetrated was clay or clayey sand and gravel of lacustrine origin. Sandy and gravelly lenses were penetrated in test holes ACV 2, 4, 8, 16, and 18 (fig. 14). Some of the sandy lenses penetrated by the test holes may be beach deposits. These beach deposits may yield water to wells, but not 700 gpm. A properly screened well drilled to bedrock at a depth of about 50 feet near test hole ACV 8, the most promising site tested, probably would yield 5 to 10 gpm from sandy and gravelly lenses. No other sites in the unconsolidated rock seem to be more promising for wells near Canyon Village than the sites tested.

Exploration for a ground-water supply for Canyon Village has been limited to unconsolidated rock because the auger bit cannot penetrate hard rock. Some of the test holes, however, penetrated relatively soft, probably weathered, bedrock. Little was learned from the testing about the occurrence of water in the bedrock.

Bedrock in the Canyon Village area is mostly rhyolite and andesitic breccia. The rhyolite has low permeability, except possibly in fractured zones. Rhyolite in the Canyon Village area probably does not contain much water even in fractured zones. Fractures in the walls of the nearby Grand Canyon of the Yellowstone are dry or discharge water as small seeps. Aquifers in rhyolite within about 500 feet of land surface at Canyon Village probably would discharge into the Yellowstone River in Grand Canyon. The river is about 750 feet below the canyon rim. Numerous fumeroles, hot springs, and much hydrothermally altered rhyolite within a 5-mile radius of Canyon Village may be evidence that any water in deep aquifers in rhyolite probably would be warm, possibly highly mineralized, and not suitable for a water supply for Canyon Village. Andesitic breccia crops out in the Washburn Range about 3 miles north of Canyon Village and may underlie rhyolite at great depth at Canyon Village. The breccia is well cemented and dense and, like rhyolite, probably would yield water only in fractured zones. The andesitic breccia probably cannot be considered a potential aquifer in the Canyon Village area, unless water occurs in fractures at relatively shallow depth between Canyon Village and outcrops in the Washburn Range.

Additional drilling would be required to test the bedrock aquifers in the Canyon Village area. It is doubtful, however, that a ground-water supply could be developed from rhyolite or andesitic breccia to provide the 1 million gpd required for Canyon Village.

Surface water could be used to supply additional water for Canyon Village. Water could be pumped from the Yellowstone River above Grand Canyon, treated, and distributed to Canyon Village facilities. The Yellowstone River is a relatively large stream, and pumpage of water for Canyon Village would be a small fraction of the flow of the stream.

Chemical quality of the water from the Yellowstone River is excellent. A water sample collected from the river above the Upper Falls in June 1969 had a dissolved-solids content of 65 mg/l and a fluoride content of 0.6 mg/l. The water was soft and had a pH of 6.9. This sample was collected during spring runoff, and the water is likely to be more highly mineralized during low-flow periods. However, the water in the river probably does not contain any chemical constituents in excess of the recommended limits at any time during the year.

Gallatin Ranger Station

The water requirement given near the beginning of the study was 20,000 gpd (14 gpm) for facilities at Gallatin Ranger Station, including Specimen Creek campground. The ranger station and campground, located near the mouth of Specimen Creek, were destroyed in 1969.

A test hole, AG 1, was drilled in September 1968 in the southeastern part of the campground near Specimen Creek (fig. 2-A). The test hole was drilled with great difficulty to a depth of 17 feet through poorly sorted material, probably glacial drift, ranging in size from clay to boulders. A test well was established at the site by installing 14 feet of 1-inch diameter pipe and 2 feet of 1-inch diameter well screen. The well was developed by pumping for about an hour. Yield of the test well increased from 1 to 4 gpm during pumping, but the water did not clear.

Water from the test well at the end of the pumping period had a dissolved-solids content of 86 mg/l and a fluoride content of 0.2 mg/l. The water was soft and had a pH of 6.9. All chemical constituents determined in the water were below the recommended limits.

A well drilled near the site of test well AG 1 probably would yield 14 gpm. In order to obtain the highest yield and clear water, the well should be drilled to bedrock and finished in material that is well sorted. Three or four wells yielding 10 to 15 gpm each probably could be drilled in unconsolidated rock near Specimen Creek. Ground water is probably recharged by percolation from Specimen Creek, especially during spring runoff.

West Thumb

According to the water requirements given near the beginning of the study, as much as 120,000 gpd (83 gpm) of water will be needed at West Thumb. A ground-water supply is desired to replace the surface-water supply obtained from Duck Lake (fig. 15). If an adequate ground-water supply cannot be developed near West Thumb, consideration reportedly will be given to extending the Grant Village supply to serve West Thumb.

A study was made by the Geological Survey (Gordon and others, 1962) of ground-water conditions in the vicinity of Grant Village before facilities at Grant Village were constructed. During that investigation, 17 test holes were drilled from 1 to 3 miles south and southeast of West Thumb between South Entrance Road and Yellowstone Lake (not all are shown in fig. 15). Pumping and bailing tests were made at test wells 2 and 6 (CGV 2 and CGV 6 in this report, fig. 15), the only sites that indicated a potential ground-water supply for Grant Village.

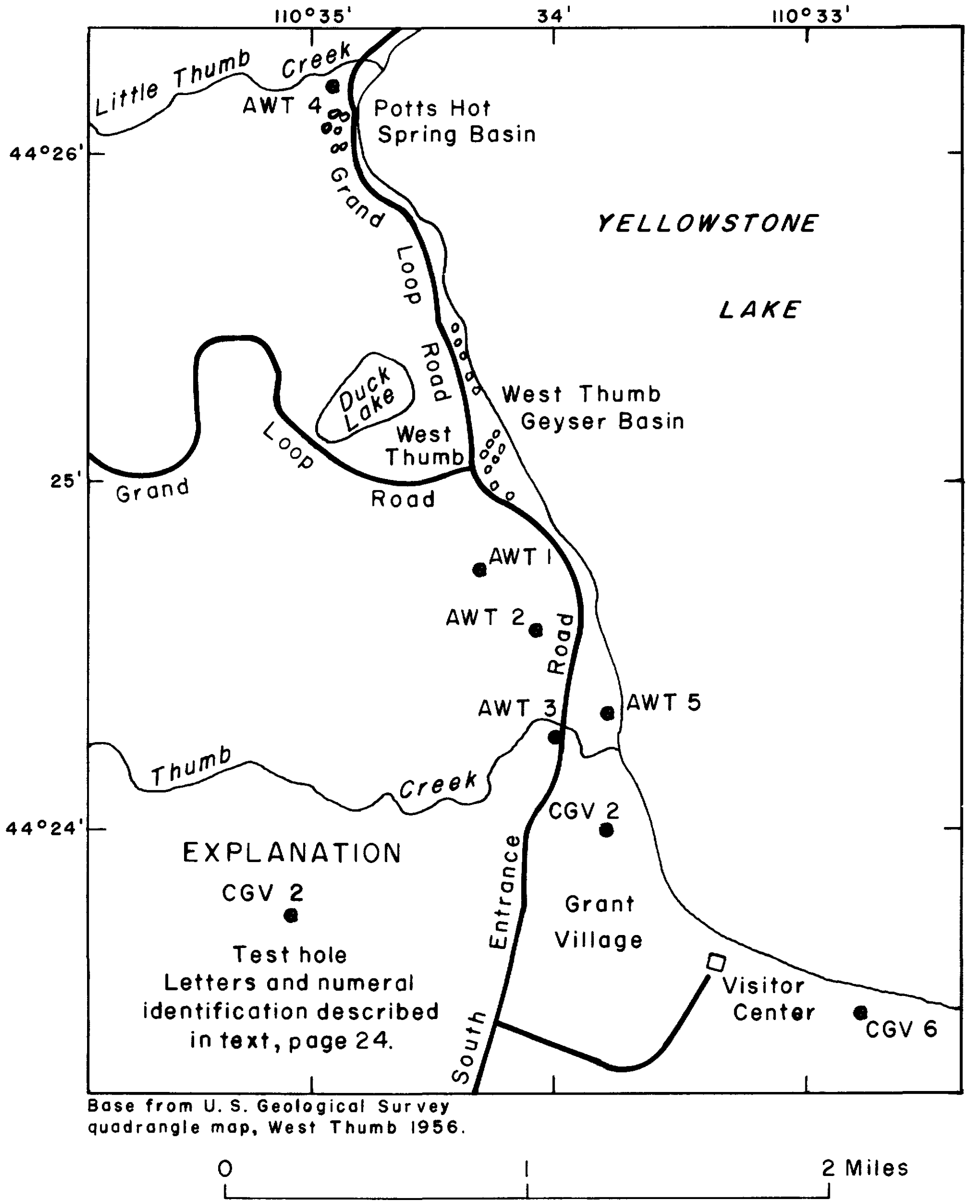

Figure 15.--Location of selected test holes near West Thumb.

Test well CGV 2 was drilled to a depth of 118 feet, and the 6-inch diameter casing was perforated from depths of 70 to 118 feet. The water-bearing material is lacustrine sediments composed chiefly of sand and gravel. In July 1959, the well was pumped at a rate of 45 gpm for 10 hours and at a rate of 36 gpm for 48 hours. Drawdown at the end of the 48-hour test was 71.4 feet.

Test well CGV 6 was drilled to a depth of 120 feet, and the 6-inch diameter casing was perforated from depths of 77 to 111 feet. The water-bearing material is lacustrine sandstone. In August 1959, the well was bailed at a rate of 18 gpm for 3 hours. Drawdown at the end of the test was about 80 feet.

Gordon and others (1962, p. 198) concluded that test well CGV 2 would yield about 30 to 35 gpm of water at a temperature of nearly 100°F (38°C) and test well CGV 6 would yield about 15 gpm of water at a temperature of about 45 to 50°F (7 to 10°C). The yield from test well CGV 6 possibly could be increased by perforating the casing from depths of 55 to 77 feet. The iron content of the water from both wells is above the recommended limit. The fluoride content of the water from test well CGV 2 is also above the recommended limit.

Ground water was not used as the water supply for Grant Village. Instead, a system was constructed that uses water from Yellowstone Lake.

In September 1966, three test holes were drilled between West Thumb and Grant Village. Test holes AWT 1 and 2 between West Thumb and Thumb Creek were drilled to depths of 102 feet. Test Hole AWT 3 near the south bank of Thumb Creek was drilled to a depth of 74 feet (fig. 15). Sand, silt, and clay were penetrated in these holes. Data from the test holes indicated that none of the sites are favorable for water-supply wells.

In September 1970, two test holes were drilled near Yellowstone Lake in the West Thumb area. Test Hole AWT 4 was about 500 feet north of Potts Hot Spring Basin near Little Thumb Creek, and test hole AWT 5 was about a mile south of West Thumb Geyser Basin (fig. 15). The locations were chosen primarily to compare field and remote-sensing data. Both test holes were drilled to depths of 45 feet in lacustrine deposits of silt, sand, and gravel. Temperature of the water at the bottom of each hole was measured at 5-foot intervals as the holes were drilled from depths of 20 to 45 feet. Temperatures increased from 20°C at 20 feet to 34°C at 45 feet in test hole AWT 4 and from 18.5°C at 20 feet to 35.5°C at 45 feet in test hole AWT 5. A test hole augered in 1959 to a depth of 103 feet near the site of test hole AWT 5 had a water temperature of 105°F (41°C) at the bottom of the hole (Gordon and others, 1962, p. 187-188).

A test well was established at AWT 4 by installing 27 feet of 1-inch diameter pipe and 2 feet of 1-inch diameter well screen. The well was pumped at a rate of 2 gpm for 1.5 hours.

Water from the test well at the end of the pumping period had a dissolved-solids content of 340 mg/l and a fluoride content of 0.2 mg/l. Temperature of the water was 25°C. The water was very hard and had a pH of 7.8. All chemical constituents determined in the water were below the recommended limits.

Ground water in lacustrine deposits near West Thumb and Grant Village is recharged by precipitation, snowmelt, and percolation of water from streams and Yellowstone Lake. This water mixes with upward-moving thermal water that discharges at Potts Hot Spring Basin and West Thumb Geyser Basin. Ground water generally becomes warmer and probably more highly mineralized at increasing depths in the lacustrine deposits near West Thumb and Grant Village.

Information available suggests that it is not feasible to develop 120,000 gpd from ground-water sources near West Thumb. Consideration should be given, therefore, to extending the water system from Grant Village to West Thumb, if the Duck Lake supply is abandoned.

A small supply of ground water can be developed from lacustrine deposits near Grant Village and West Thumb. A properly constructed well at the site of test well CGV 6 would yield at least 15 gpm of water of suitable temperature and quality for public supply; however, the water should be treated to reduce iron content. Also, a well could be drilled near test well AWT 4 that might yield about 10 gpm of water suitable for public supply.

Shoshone Lake

A ground-water supply is needed for a small campground, about 10 campsites, and a patrol cabin near the southeast tip of Shoshone Lake. The area is accessible by trail. The nearest trail head is near the northern shore of Lewis Lake about 3 miles from the campground and about a mile west of South Entrance Road.

The campground and patrol cabin are about a quarter of a mile north of the outlet of Shoshone Lake (Lewis River) and about 500 feet from the shore of the lake. The facilities do not have a developed water supply, and water from Shoshone Lake is used by occupants of the campground and the patrol cabin. A small-diameter shallow well equipped with a hand-operated pump would yield the few gallons per minute needed at the site.

A well to supply water could be dug or driven into sand and gravel near the shore of Shoshone Lake. The water table is probably less than 10 feet below land surface in this area. A well should be located within 50 feet of the shore of the lake to avoid a swampy area between the campground and the lake. The chemical quality of ground water within 50 feet of Shoshone Lake should be similar to water in the lake. The chemical quality of water in the lake is excellent. In October 1971, a sample of water from the shore of the lake near the campground had a dissolved-solids content of 83 mg/l and a fluoride content of 1.9 mg/l. The water was soft and had a pH of 7.2. All chemical constituents determined in the water were below the recommended limits.

Other locations where shallow wells might be dug or driven near the shore of Shoshone Lake are near the mouth of De Lacy Creek at the northeast tip of the lake, near the mouth of Moose Creek on the southern shore of the lake, and along most of the western shore of the lake. Potable ground water possibly cannot be obtained near a patrol cabin about half a mile west of the northwest tip of the lake because of a thermal-water discharge area near the cabin.

Heart Lake

A ground-water supply is needed for a small campground, about six campsites, and a patrol cabin near the mouth of Witch Creek at the northwest tip of Heart Lake. These facilities do not have a developed water supply, and water from Heart Lake is used by occupants of the campground and the patrol cabin. A small-diameter shallow well equipped with a hand-operated pump would yield the few gallons per minute needed at the site. The area is accessible by trail, and the nearest trail head is on South Entrance Road near the north shore of Lewis Lake about 8 miles from Heart Lake.

A well to supply water for the campground and the patrol cabin could be dug or driven into sand and gravel near the shore of Heart Lake near the mouth of Witch Creek. The water table in this area is shallow, probably 5 feet or less below land surface. Ground water reportedly is high enough in early summer to enter a cellar at the patrol cabin.

Thermal water discharges into Witch Creek along most of the stream. Besides being warm, the water in Witch Creek had a fluoride content of 9.5 mg/l in October 1969. Water in Heart Lake is apparently potable, but a sample of water collected in October 1969 from the lake about a quarter of a mile east of the mouth of Witch Creek and about 200 feet from shore had a fluoride content of 2.9 mg/l. The dissolved-solids content of water in the lake was 145 mg/l. The water was soft and had a pH of 6.4. All chemical constituents determined in the water, except fluoride, were below the recommended limits.

The best location for a well is about 50 feet from the lake and about 500 feet east of the mouth of Witch Creek. The high fluoride content that might be in ground water near Witch Creek could be avoided by placing the well at this location. The chemical quality of water in a well at this location would be similar to that of water in Heart Lake.

Other locations where shallow wells might be dug or driven near the shore of Heart Lake are near the mouth of Beaver Creek at the west end of the peninsula on the northeast shore of the lake, at the east end of the same peninsula, and near the outlet of the lake at its southeast tip.

Madison Junction

An investigation was made to determine if a ground-water supply could be developed for facilities at Madison Junction. The present water supply is obtained from a group of springs in a canyon near the Firehole River about 0.8 mile south of Madison Junction (fig. 16). Flow of the springs is apparently sufficient to provide for water needs at Madison Junction, but fluoride in the water exceeds the recommended limit. A sample of water collected from the springs in June 1968 had a fluoride content of 5.2 mg/l and a dissolved-solids content of 137 mg/l. The springs issue from rhyolite.

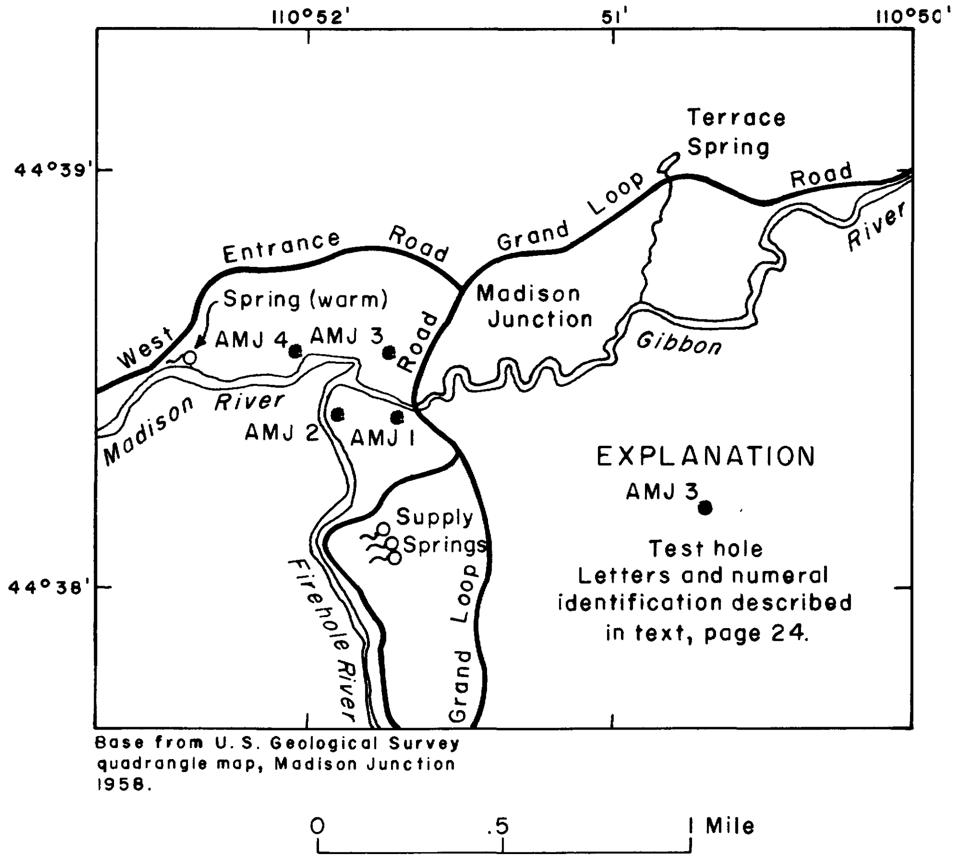

Figure 16.--Location of supply springs and test holes near Madison Junction.

Reconnaissance near Madison Junction indicates that sand and gravel in the valleys along the Gibbon, Madison, and Firehole Rivers might yield water to wells. However, Terrace Spring, a thermal spring about 0.7 mile east of Madison Junction, and an unnamed warm spring about 0.8 mile west of Madison Junction (fig. 16) are indications that sand and gravel near these springs may contain warm and possibly highly mineralized water. Sand and gravel near the streams may contain water of quality and temperature similar to that of the streams owing to percolation of water from the streams into the sand and gravel. The area near the confluence of the Gibbon and Firehole Rivers was selected as the most likely area near Madison Junction where cool, potable ground water might occur.

Four test holes were drilled in September 1968 near the confluence of the Gibbon and Firehole Rivers (fig. 16). Test holes AMJ 1 and 2 were drilled to depths of 99 feet, the maximum amount of auger stem available. Test holes AMJ 3 and 4 were drilled to depths of 49 and 19 feet, respectively. These holes penetrated only sand and gravel. Test holes AMJ 1, 2, and 3 were completed as test wells by installing well screens and 1-inch diameter pipe. Yields of as much as 100 gpm probably could be obtained from each properly constructed well in sand and gravel near the sites of test holes AMJ 1, 2, and 3.

Water samples from test wells AMJ 1, 2, and 3 had fluoride contents of 6.2, 6.5, and 6.8 mg/l and dissolved-solids contents of 699, 335, and 949 mg/l, respectively, in September 1968. Fluoride and other chemical constituents in water in the test wells are higher than in the supply springs; therefore, quality of water for use at Madison Junction facilities would not be improved by changing the source of water from the supply springs to wells in sand and gravel.

Temperatures at the bottom of test holes AMJ 1, 3, and 4 increased appreciably as the holes were drilled deeper. The temperatures increased from 20°C at 10 feet to 25°C at 50 feet in test hole AMJ 1, from 20°C at 9 feet to 37°C at 49 feet in test hole AMJ 3, and from 26°C at 14 feet to 30°C at 19 feet in test hole AMJ 4. However, the temperature at the bottom of test hole AMJ 2 increased only 2°C from 15°C at 24 feet to 17°C at 50 feet.

The increase in temperature with the increase in depth indicates that water in the sand and gravel is recharged by upward-moving thermal water. This is probably from the same thermal-water system that discharges at Terrace Spring and at the unnamed warm spring west of Madison Junction. Ground water in the sand and gravel at Madison Junction is a mixture of cool water from precipitation, snowmelt, and percolation from streams and thermal water.

Temperature of water from test wells AMJ 1, 2, and 3 was 28, 16, and 37°C, respectively, in September 1968. These temperatures suggest that more recharge to sand and gravel from streams occurs near test well AMJ 2 than at other areas near Madison Junction.

If a ground-water supply is needed near Madison Junction regardless of quality, the area near test well AMJ 2 would be the best location for wells. Water from a well in sand and gravel near test well AMJ 2, however, would contain fluoride above the recommended limit because the water is recharged by percolation from the Firehole River. Water in the river apparently has fluoride above the recommended limit as based on samples collected in May, July, September, and November 1969, and in May, July, and October 1970. All chemical constituents determined except fluoride in the water from test well AMJ 2 were below the recommended limit in September 1968. The water was soft and had a pH of 8.0.

Crystal Creek

Three test holes were drilled in June 1968 near Crystal Creek, a tributary of the Lamar River, about 5 miles east of Tower Junction, near a site being considered for a new ranger station. Test hole ACC 1 was drilled only to a depth of 20 feet because a boulder at that depth prevented drilling deeper. Test holes ACC 2 and 3 were drilled to depths of 29 and 30 feet, respectively. Tough gray clay was struck at a depth of 25 feet in test hole ACC 2. Gray and brown siltstone was penetrated at a depth of 16 feet in test hole ACC 3. The material penetrated in these holes is glacial drift.

Glacial drift penetrated in the three test holes near Crystal Creek is poorly sorted and ranges in size from clay to boulders. Maximum yield that would be expected from a well near Crystal Creek would be 5 gpm and that would be possible only near test hole ACC 1. Rocks underlying the glacial drift were not tested, but they probably have low permeability.

In September 1970, test hole ASC 2 was augered about 1.5 miles northwest of the Crystal Creek site near Slough Creek. Sand and gravel were penetrated in this hole to a depth of 20 feet. Tough greenish-gray claystone was penetrated between 20 feet and the bottom of the hole at 21.5 feet. A test well was established at this site by installing a well screen and 1-inch diameter pipe. The well was pumped at a rate of 5 gpm for about 2 hours. A properly constructed well in sand and gravel at this site probably would yield about 15 gpm. The aquifer is sufficiently extensive to yield water to three or four such wells.

Water from the test well at the end of the pumping period had a dissolved-solids content of 376 mg/l and a fluoride content of 0.2 mg/l. The water was very hard and had a pH of 7.9. All chemical constituents determined in the water were below the recommended limits.

Slough Creek campground

A test hole, ASC 1, was drilled at the Slough Creek campground, 6.0 miles northeast of Tower Junction in September 1967 to determine if a ground-water supply could be obtained for the campground. No water supply is provided at the campground. The test hole was drilled near Slough Creek with great difficulty through sand, gravel, cobbles, and boulders to a depth of 31 feet. A test well was established at the site by installing 26 feet of 1-inch diameter pipe and 2 feet of 1-inch diameter well screen and developed with a hand-operated pitcher pump. The test well yields about 6 gpm. Three or four wells yielding at least 15 gpm each could be drilled near Slough Creek in the vicinity of the campground.

The test well was sampled in October 1967. Water from the well had a dissolved-solids content of 127 mg/l and a fluoride content of 0.1 mg/l. The water was moderately hard and had a pH of 7.8. All chemical constituents determined in the water were below the recommended limits.

Water resources by hydrologic units

Yellowstone National Park has been divided into seven hydrologic units in this report for the purpose of an overall appraisal of water resources of the park. The unit boundaries were made arbitrarily, but they generally follow geologic and geographic boundaries. The units are: Rhyolite plateau, Absaroka, Beartooth, Gallatin, West Yellowstone, Falls River, and Snake River (fig. 2-A).

Rhyolite plateau hydrologic unit

The rhyolite plateau unit includes most of the plateau area and most of the rhyolite terrane in the park. Many streams originate on the rhyolite plateau and flow entirely on rhyolite terrane. Aquifers are either in rhyolite bedrock or in surficial rocks derived from rhyolite. The surficial rocks contain much obsidian. Thermal-water discharge areas are widespread on the rhyolite plateau, and thermal water discharges into streams, lakes, and aquifers at many localities. Much of the surface water and ground water is a mixture of water from rhyolite terrane and thermal water.

Information from wells drilled into rhyolite bedrock indicate that even seemingly porous rock may not yield more than a few tens of gallons of water per minute to wells. However, drilling in the rhyolite has not been extensive, and larger amounts of ground water may occur locally in the rhyolite. If the rhyolite is permeable enough to transmit much ground water, however, the aquifer may contain thermal water.

Test wells drilled into sand and gravel in stream valleys on the rhyolite plateau yield as much as 100 gpm. Highest yields were measured in test wells along Nez Perce Creek near Fountain Paint Pot, along the Yellowstone River near Mud Volcano, and near the confluence of the Lewis and Snake Rivers near South Entrance. The aquifers are sufficiently extensive to yield 500 gpm each to three wells near Fountain Paint Pot and 250 gpm to one well near Mud Volcano. Aquifers near South Entrance would yield 100 gpm each to two wells near the confluence of the Lewis and Snake Rivers and 50 gpm to one well at the north end of the campground. Yields of as much as 100 gpm each probably could be obtained from properly constructed wells in sand and gravel at three sites near the confluence of the Firehole and Gibbon Rivers near Madison Junction. Aquifers in sand and gravel near the Gibbon River, near Norris Junction, and near the Firehole River above Upper Geyser Basin might have total yields of 35 and 50 gpm, respectively.

The larger lakes in the park are on the rhyolite plateau. Ground water occurs in lacustrine deposits in lake basins and in areas where lakes formerly existed. The lacustrine deposits consist of clay, silt, sand, and gravel. Single wells in lacustrine deposits near Grant Village might yield as much as 35 gpm at one site and 15 gpm at another. Single wells near West Thumb and Canyon Village would not yield more than 10 gpm at the most favorable sites tested. Wells to supply water for campgrounds and patrol cabins near Shoshone and Heart Lakes could be dug or driven into sand and gravel near the shores of the lakes. Dug or driven wells also probably could be constructed near the northwest corners of Riddle and Lewis Lakes and at many locations near the shore of Yellowstone Lake.

Most of the thermal water discharging into aquifers, streams, and lakes on the rhyolite plateau is relatively high in silica, sodium, chloride, fluoride, boron, and dissolved solids. Some thermal water is relatively high in arsenic. The percent sodium is high and the SO_4/Cl ratio is low. Water containing thermal-water discharge is usually soft, although ground water near Norris Junction that probably contains thermal water has high bicarbonate and is moderately hard.

Water on the rhyolite plateau that does not contain thermal water usually has low dissolved solids. The water is soft and commonly slightly acidic. The water has relatively high fluoride depending upon the amount of obsidian in the bedrock and the surficial deposits. The percent sodium is high but not as high as water containing thermal water. The SO_4/Cl ratio is more than one.

The fluoride content of water on the rhyolite plateau commonly exceeds 2.4 mg/1, the maximum limit for drinking water suggested by the U.S. Public Health Service. Notable exceptions are water in Yellowstone Lake and water in some of the lacustrine deposits near the lake. This is because more of the inflow to the lake is from the Absaroka Range than from the rhyolite plateau.

Absaroka hydrologic unit

The Absaroka hydrologic unit includes the Absaroka Range in the park, the Washburn Range, Two Ocean Plateau, and part of Mirror Plateau. This includes most of the andesitic terrane in the eastern part of the park, part of the basalt terrane, and a small part of the rhyolite terrane. Paleozoic rocks, mostly sandstone and limestone, also occur in this unit. Many streams originate in the Absaroka Range. Aquifers are in either bedrock or surficial rocks derived from the bedrock. Thermal-water discharge areas occur in the Absaroka unit, but they are neither as large nor as widespread as in the rhyolite plateau unit.

No wells are known to have been drilled in bedrock aquifers in the Absaroka unit. However, ground water probably occurs in fractures in relatively hard andesite, basalt, and rhyolite and in interstices in relatively soft and granular andesite. Ground water may also occur in openings at the tops and bottoms of basalt flows, in interstices in sandstone, and in solution openings in limestone.

Test holes have been drilled in alluvium near East Entrance, Tower Junction, and Northeast Entrance and in glacial deposits near Tower Junction, Crystal Creek, the Lamar River, and Soda Butte Creek.

Test wells in alluvium at East Entrance, Tower Junction, and Northeast Entrance yielded 128 gpm, 9 gpm, and 150 gpm, respectively, during aquifer tests. Aquifers at these locations would yield 750 gpm, 50 to 75 gpm, and 500 gpm, respectively. The total yields could be obtained by 3 wells of 250 gpm each, 2 or 3 wells of 25 gpm each, and 2 wells of 250 gpm each at the respective locations. Test holes in glacial deposits in the Absaroka unit penetrated either material of low permeability or material too difficult to be drilled by a power auger to depths sufficient for adequate testing.

Ground water occurs at shallow depths in alluvium and glacial deposits in other stream valleys in the Absaroka unit. Alluvium more likely contains well sorted sand and gravel and is a better aquifer than glacial deposits.

The Yellowstone River valley above Yellowstone Lake and the Lamar River valley above Soda Butte Creek are relatively large valleys that are inaccessible with truck-mounted drilling equipment. Reconnaissance in these valleys indicates that the depth to water in alluvium would be less than 10 feet near the streams. Wells located in gravelly areas near the streams would yield at least 10 gpm.

Water from the Absaroka unit has low dissolved solids. The water is soft and is commonly slightly alkaline. The fluoride is low. The percent sodium is lower than water from the rhyolite plateau. The SO_4/Cl ratio is relatively high. All chemical constituents analyzed in water sampled in the Absaroka unit are below the recommended limits for drinking water.

Beartooth hydrologic unit

The Beartooth hydrologic unit includes the Beartooth Mountains in the park, Buffalo Plateau, part of Blacktail Deer Plateau, and Mt. Everts. The unit contains most of the rock types that crop out in the park. Bedrock aquifers most likely occur in Precambrian rocks, Paleozoic rocks, rhyolite, and basalt. Thermal-water discharge areas do not occur in the Beartooth unit.

No wells are known to have been drilled in bedrock aquifers in the Beartooth hydrologic unit. Ground water, however, probably occurs in fractures and other openings in bedrock. Water from bedrock or overlying glacial drift in Blacktail Deer Flats discharges into Blacktail Pond. Information from test holes west of the pond did not indicate an extensive aquifer. However, test holes were not drilled in glacial drift east of the pond or in bedrock. The fluoride content of water from the pond and two springs on the flat indicate that the water is discharged from an aquifer in rhyolite.

Data from two test holes drilled in alluvial or glacial deposits near Slough Creek indicate that properly constructed wells at these sites would yield as much as 15 gpm each. Wells of similar yield could be located at several sites near the stream in and below Slough Creek campground.

Streams in the Beartooth unit other than Slough Creek, including the Yellowstone and Lamar Rivers, are entrenched in relatively steep walled canyons. In places, the streams flow on bedrock. Alluvium or glacial deposits in which wells could be constructed are not of common occurrence in these canyons.

The chemical quality of water in the Beartooth unit is variable because of the different kinds of rocks in the area. However, all chemical constituents analyzed in water sampled in the unit are below the recommended limits for drinking water.

Gallatin hydrologic unit

The Gallatin hydrologic unit includes the Gallatin Range in the park, the Gallatin River valley, Grayling Creek valley, Gardners Hole, and the area near Mammoth. The unit contains most of the rock types that crop out in the park. The Gallatin Range and nearby areas have been faulted and tilted, exposing Precambrian, Paleozoic, and Mesozoic rocks. Springs are common in Paleozoic rocks in the mountains. Streams originating in the Gallatin Range flow either westward into the Gallatin River and Grayling Creek or eastward into the Gardner and Yellowstone Rivers. The only thermal-water discharge areas in the Gallatin unit are Mammoth Hot Springs and Hot River.

No wells are known to have been drilled in bedrock aquifers in the Gallatin unit. However, ground water probably occurs in fractures in relatively hard rocks, in interstices in granular rocks, and in solution openings in soluble rocks. Geologic formations most likely to contain ground water in the Gallatin unit are the Madison and Pilgrim Limestones, the Bighorn Dolomite, and the Flathead and Quadrant Sandstones. These formations may be reached by relatively shallow wells near their outcrops.

The Madison Limestone is an important aquifer in places in Montana and Wyoming, where large yielding wells have been drilled that tap solution channels in the Madison. In the Gallatin Range, where the Madison has been faulted and tilted, solution-channel development may not be as widespread as in other areas. The Madison, however, may be the source of water discharging at Mammoth Hot Springs and at Hot River. The Madison is the source of many springs in the Gallatin Range.

Ground water occurs in alluvium and glacial deposits in the valleys of the Gallatin River, Fan Creek, Specimen Creek, and Grayling Creek. The glacial deposits are poorly sorted and range in size from clay to boulders. The alluvium is generally well sorted sand and gravel and probably would yield more water to wells than would be obtained from the glacial deposits. The alluvium is probably thickest where tributary streams have built up alluvial fans in the Gallatin River valley.

Wells drilled in the valleys west of the Gallatin Range should penetrate glacial deposits and alluvium to bedrock to test all water-bearing zones and should be completed in the zone having the best sorted material. Water-bearing characteristics of bedrock also should be tested.

Alluvial fans and much gravel are exposed in a 3-mile reach of the valley from Specimen Creek south to the bridge over the Gallatin River. Wells could be developed in that area. Bedrock on both sides of the valley is Madison Limestone and may contain much ground water in fractures and solution openings.

Glacial drift in Gardners Hole and near Mammoth has, in general, low permeability. A test well near Mammoth would yield at least 50 gpm from thin beds of sand in glacial drift, but the water has high sulfate.

A test well in alluvium or glacial outwash near the Yellowstone River northwest of Mammoth yielded 92 gpm during an aquifer test. The areal extent and thickness of the aquifer is unknown but yields of as much as 200 gpm might be expected from single wells drilled near this test well.

The chemical quality of water in the Gallatin unit is variable because of the different kinds of rocks in the area. All chemical constituents analyzed in water sampled in the unit are below the recommended limits for drinking water except for dissolved solids and sulfate in thermal water discharging at Mammoth Hot Springs and at Hot River and in water from a test well in glacial drift near Mammoth.

West Yellowstone hydrologic unit

The West Yellowstone hydrologic unit is the eastern half of the West Yellowstone basin, an oval-shaped basin between the Madison Range in southwestern Montana and the rhyolite plateau. The basin is called Madison Valley on Geological Survey topographic maps, but the name West Yellowstone basin is also used and is preferred to avoid confusion with the larger Madison Valley along the Madison River in Montana. (See Witkind, 1969, p. 7.)

The eastern part of the West Yellowstone basin contains alluvial, glacial, and lacustrine deposits to a depth of about 200 feet, as suggested by oil-test wells drilled near West Yellowstone, Mont. (Witkind, 1969, p. 84). These deposits, consisting mostly of obsidian, are underlain by rhyolite and other volcanic rocks. Most water-supply wells at West Yellowstone are at least 175 feet deep and penetrate several water-bearing sand and gravel beds. A supply well at West Entrance is reported to be 90 feet deep. Dug wells near West Entrance are reported to be 50 feet or less in depth.

The Madison River and other streams flow across the West Yellowstone basin and probably recharge aquifers in sand and gravel. According to water levels in wells near West Entrance, sand and gravel below the level of the streams probably are saturated. Additional water-supply wells that would yield at least a hundred gallons per minute of water each could be drilled in sand and gravel in the West Yellowstone unit.

Based on a sample collected from the supply well at West Entrance, water in the West Yellowstone hydrologic unit has low dissolved-solids content (99 mg/l) but a high fluoride content (3.4 mg/l). All chemical constituents determined are below the recommended limits for drinking water except fluoride. Chemical quality of water from two springs near West Yellowstone sampled in 1959 (Scott, 1964, p. 180-181) is similar to that of the supply well at West Entrance. The relatively high fluoride in water in the West Yellowstone basin is due to the abundance of obsidian in the sand and gravel. Also, the Madison River and other streams that probably recharge the sand and gravel originate on the rhyolite plateau and have relatively high fluoride.

Falls River hydrologic unit

The Falls River hydrologic unit is in the Falls River basin in the southwest corner of Yellowstone National Park, generally southwest of Madison and Pitchstone Plateaus. The unit contains rhyolite, basalt, alluvium, and glacial deposits. Alluvium and glacial deposits overlie rhyolite and basalt in most of the unit, and glacial deposits underlie flows of rhyolite and basalt in places.

Wells known to have been drilled in the Falls River unit are a water-supply well at Bechler Ranger Station and a test well near Cave Falls. Neither well yields more than 10 gpm. Water-bearing zones are in basalt in the well at Bechler Ranger Station and in sand and gravel below rhyolite in the well near Cave Falls.

Additional wells probably could be drilled near Bechler Ranger Station and Cave Falls, but individual wells probably would not yield more than about 15 gpm. Wells to supply water for campgrounds or patrol cabins could be dug or driven in sand and gravel at places near the Bechler River and other streams.

Water from the two wells in the Falls River unit and from the Bechler River has low dissolved-solids content. The fluoride content of water from the test well near Cave Falls and from the Bechler River was 2.8 and 2.0 mg/l, respectively, and the fluoride content of water from the water-supply well at Bechler Ranger Station was only 0.1 mg/l. This suggests that in the eastern part of the unit water has relatively high fluoride and is similar in chemical quality to that in rhyolite; whereas, in the western part of the unit water has relatively low fluoride and is similar to that in basalt.

Snake River hydrologic unit

The Snake River hydrologic unit is an upland area in the south-central part of the park. The unit includes Chicken Ridge, parts of Huckleberry and Big Game Ridges, and part of the Red Mountains. Rocks exposed in the unit are mostly Paleozoic and Mesozoic rocks, but rhyolite and andesitic breccia also crop out. Valleys along the Snake River and some of its tributaries contain alluvium and glacial deposits. No wells have been drilled in the Snake River unit.

Ground water occurs in interstices in sandstone and in fractures and solution openings in limestone where the rocks are saturated. The Tensleep Sandstone and the Madison Limestone are the geologic formations most likely to yield water to wells in the Snake River hydrologic unit.

Ground water occurs in sand and gravel in alluvium and glacial deposits near the Snake River and some of its tributaries. Thermal-water discharge areas are near the Snake River on the east bank near the mouth of the Lewis River, near the north end of Huckleberry Ridge, and near the mouth of the Heart River.

Wells to supply water for campgrounds or patrol cabins could be dug or driven in sand and gravel at places near the Snake River and its tributaries. Thermal-water discharge areas, however, should be avoided as well locations.

Conclusions

Potable ground-water supplies can be developed in places by drilling wells in alluvium, glacial deposits, or lacustrine deposits near streams and lakes in Yellowstone National Park. Aquifers in stream valleys would yield 1,500 gpm near Fountain Paint Pot, 250 gpm near Mud Volcano, 500 gpm near Northeast Entrance, 750 gpm near East Entrance, 200 gpm near South Entrance, and 300 gpm near Madison Junction. Aquifers near Norris Junction and Old Faithful might have yields of 35 and 50 gpm, respectively. An aquifer near Tower Junction would yield 50 to 75 gpm. An aquifer near the Yellowstone River northwest of Mammoth will yield as much as 200 gpm to single wells. Aquifers in places near streams and lakes would yield a few gallons per minute of water to shallow wells equipped with hand-operated pumps to supply water for campgrounds or patrol cabins in remote areas of the park.

In general, aquifers adjacent to streams and lakes are recharged by precipitation and by water from the stream or lake. Water moves from the aquifers to the streams and lakes during periods of low streamflow and low lake levels, and, at least near the streams or lakes, water moves from the streams and the lakes to the aquifers during periods of high streamflow and high lake levels. Streamflow is greatest during May-July as a result of melting snow. Streamflow declines during the summer and fall to the lowest flows in the winter.

Of the bedrock aquifers, the Flathead Sandstone may yield as much as 50 gpm of water to wells; the Pilgrim Limestone, the Gallatin Limestone, and the Bighorn Dolomite may yield as much as 100 gpm of water to wells; and the Madison Limestone may yield as much as several hundred gallons per minute of water to wells. Other bedrock aquifers in the park would yield from a few to a few tens of gallons per minute of water to wells.

In the mountains, the topographically high areas between stream valleys probably are drained and contain ground water in bedrock only at great depths. In stream valleys, ground water may occur at relatively shallow depths in bedrock. Ground water probably does not move from one drainage basin to another. Perched water zones may occur in topographically high areas in the mountains.

Quality of ground and surface waters varies with the geologic terrane and the hydrologic sources. In general, thermal water is highly mineralized and affects the quality of water in aquifers, streams, and lakes by adding silica, sodium, chloride, fluoride, boron, and sometimes sulfate and arsenic. Water in rhyolite terrane and areas having an abundance of obsidian generally has a fluoride content that exceeds the maximum limit for drinking water suggested by the U.S. Public Health Service. The concentration of all chemical constituents determined in nonthermal water sampled in terranes other than rhyolite are below the recommended limits for drinking water.

Yellowstone National Park has been divided into seven hydrologic units in this report for the purpose of an overall appraisal of the water resources of the park. The unit boundaries were made arbitrarily, but they generally follow geologic and geographic boundaries. The units are: Rhyolite plateau, Absaroka, Beartooth, Gallatin, West Yellowstone, Falls River, and Snake River.

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