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RECONNAISSANCE OF THE GROUND-WATER RESOURCES OF THE UPPER FREMONT RIVER VALLEY, WAYNE COUNTY, UTAH

by

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Prepared by the U. S. Geological Survey
in cooperation with the
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ABSTRACT

The upper Fremont River valley, a depression caused by faulting, altered by erosion, and partly filled by alluvium eroded from surrounding highlands, includes about 40 square miles in south-central Utah. The drainage basin which contributes water to the valley includes about 700 square miles. Water drains to the valley from several high plateaus. Sedimentary rocks of Triassic, Jurassic, Tertiary, and Quaternary age and volcanic rocks of Tertiary age are exposed in the area. The Tertiary volcanic rocks yield water to several large springs and flowing wells; this unit is the principal source of ground water in the valley. The valley fill of Quaternary age, which is more than 500 feet thick in places, is also an important source, yielding water to many wells.

The average annual inflow to the valley via the Fremont River during 1950-57 was 29,120 acre-feet and the average annual outflow during 1909-57 was 64,840 acre-feet.

The source of most of the surface and ground water in the valley is precipitation on the Fish Lake, Awapa, and Aquarius Plateaus, where annual precipitation is between 20 and 40 inches. Recharge to the ground-water reservoir in the valley fill occurs from infiltration of water from precipitation; infiltration from streams, canals, ditches, and irrigated fields; and by subsurface inflow through volcanic rocks of Tertiary age.

A large but undetermined quantity of water is stored under both artesian and water-table conditions in volcanic rocks bordering and underlying the valley. More than 1 million acre-feet of water is stored in the unconsolidated valley fill. Artesian conditions in the valley fill exist in three areas near the western side of the valley; water-table conditions exist mostly along the eastern side of the valley. Perched water-table conditions exist southeast of Loa in the middle of the valley.

The ground-water surface slopes in the same general direction as surface drainage. Water levels fluctuate seasonally as they are affected by recharge and discharge, but no long-term trends were noted during the past 10 years. Ground water moves toward the valley through the volcanic rocks mostly in a northeasterly direction and discharges from springs along the western and southern margins of the valley. In the alluvial valley fill it moves in a downvalley direction, probably not more than a few inches a day, toward springs in Bicknell Bottoms.

About 80,000 acre-feet of water is discharged by springs and seeps in the valley during most years. The ground-water accretion to the Fremont River from springs and seeps in and relatively near the streams, as determined by a seepage run, was about 72 cfs (cubic feet per second). Most of this accretion occurs in Bicknell Bottoms. Areas of high evapotranspiration, including about 5,000 acres, discharge about 9,000 acre-feet of water annually. The principal

phreatophyte in this area is meadow grass; rabbitbrush and greasewood grow in fringe areas. Approximately 3,500 acre-feet of water is discharged from flowing wells and about 700 acre-feet is pumped from wells during a year. The amount of water leaving the valley by subsurface outflow is relatively small—probably not more than 1,000 acre-feet annually.

Irrigation is the principal use of both surface and ground water in the valley. Ground water is used also for the public supplies of Fremont, Loa, Lyman, and Bicknell, for domestic and stock use, and for fish culture.

The least mineralized water, having about 160 ppm (parts per million) of dissolved solids, is from large springs discharging more than 50 cfs of water from volcanic rocks. The most highly mineralized water is discharged from valley fill near outcrops of sedimentary rocks of Mesozoic age.

The ground water in the valley is suitable for most uses. All water sampled had a low-sodium content, which would make it suitable for irrigation; some of the samples, however, had a high-salinity content and such water should not be used excessively on poorly drained land. None of the maximum concentrations of dissolved constituents recommended for drinking water by the U.S. Public Health Service (1962) was exceeded in samples collected from large springs and flowing wells discharging more than 30,000 acre-feet annually from volcanic rocks. Most of the sampled water was hard to very hard. The temperatures of ground water ranged from 47° to 63°F, and the warmest water was from springs issuing from volcanic rocks along the western margin of the valley.

INTRODUCTION

Purpose and scope of the investigation

This report presents the results of an investigation of the ground-water resources of the upper Fremont River valley, Utah, which was carried out during the period July 1966–June 1967, by the U.S. Geological Survey in cooperation with the Utah Department of Natural Resources, Division of Water Rights. The purpose of the investigation was to determine: the source, occurrence, availability, approximate quantity, movement, and chemical quality of ground water in the valley; the recharge to and discharge from the ground-water reservoir; the extent and effects of use and development on the ground-water resources; the relation of ground water to streamflow; and if and where additional studies are needed. The report is concerned primarily with ground water in the valley fill and adjacent volcanic rocks and secondarily with the general hydrology of the upper Fremont River valley drainage basin.

The field investigation was made mostly during the summer and fall of 1966. Data were collected for 63 wells and 16 springs in the valley. Records for wells and springs are given in table 4; drillers' logs of selected wells are given in table 5, and well locations are shown in figure 5. All the wells (except a few small-discharge wells) and all major springs were visited. The specific conductance of water was determined at most wells and springs; chemical analyses were made of water from selected wells and springs. Conductance data are included in table 4 and chemical analyses are given in table 6. The yield of water from wells and the water levels or artesian pressures were measured or estimated. Water-level measurements were made at monthly intervals at 10 selected wells. Altitudes of the land surface at wells and springs were estimated from topographic maps or by hand leveling or determined by altimeter. Aerial photographs were used in the field to locate wells, boundaries of meadows or cultivated areas, edge of valley fill, and other features.

Location, extent, and general features of the area

The upper Fremont River valley is in south-central Utah about 160 miles south of Salt Lake City. In this report the valley is defined as the valley floor plus a small area along the margins of the surrounding uplands. The upper Fremont River valley extends southward from Mill Meadows Dam to a constriction 3 miles southeast of Bicknell, a distance of 19 miles along the river (fig. 1). The valley ranges in width from 1 to 5 miles and includes an area of about 40 square miles; it is roughly C—shaped and is bounded by Fish Lake Mountains (also called Fish Lake Plateau) on the northwest, Awapa Plateau on the west, Aquarius Plateau to the south, Boulder Mountain to the southeast, and Thousand Lake Mountain on the east. The drainage basin includes parts of all the surrounding features and covers about 700 square miles.

The valley supports a population of about 1,000 people, most of whom are engaged in farming and ranching. The principal agricultural products are hay, grains, potatoes, livestock, and dairy products. Tourism is also a source of income. Access to the valley is by highway from Richfield (45 miles) or from Green River (125 miles).

Well- and spring-numbering system

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well or spring, locates its position to the nearest 10-acre tract in the land net. By this system the State is divided into four quadrants by the Salt Lake Base Line and Meridian, and these quadrants are designated by the uppercase letters A, B, C, and D, thus: A, for the northeast quadrant; B, for the northwest; C, for the southwest; and D, for the southeast quadrant. Numbers designating the township and range, respectively, follow the quadrant letter, and the three are enclosed in parentheses. The number after the parentheses designates the section, and the lowercase letters give the location within the section. The first letter indicates the quarter section, which is generally a tract of 160 acres, and second letter indicates the 40-acre tract, and the third letter indicates the 10-acre tract. The numbers that follow the letters indicate the serial number of the well or spring within the 10-acre tract. Thus, well (D-27-2)26ddc-1, in Wayne County, is in the SW¼SE¼SE¼ sec. 26, T. 27 S., R. 2 E., and is the first well constructed or visited in that tract. (See fig. 2.)

When the serial (final) number is preceded by an "S" the number designates a spring; if the spring is located to the nearest 40 acres or larger tract, a suffixed "S" is used without a serial number. When no serial number is suffixed to a location number for a 10-acre tract, the number designates the location of a surface-water sampling site.

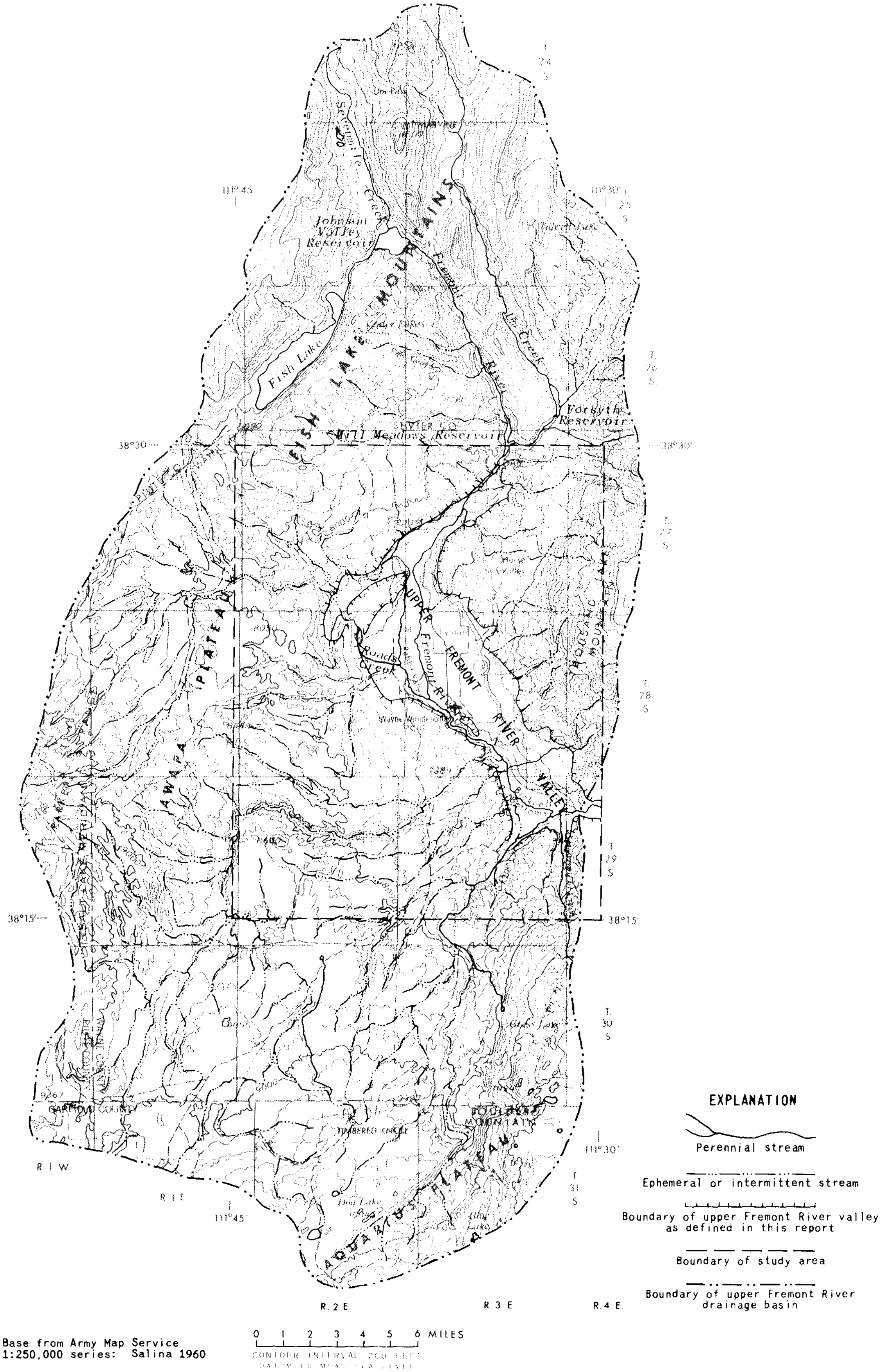

Figure 1.—Upper Fremont River drainage basin.

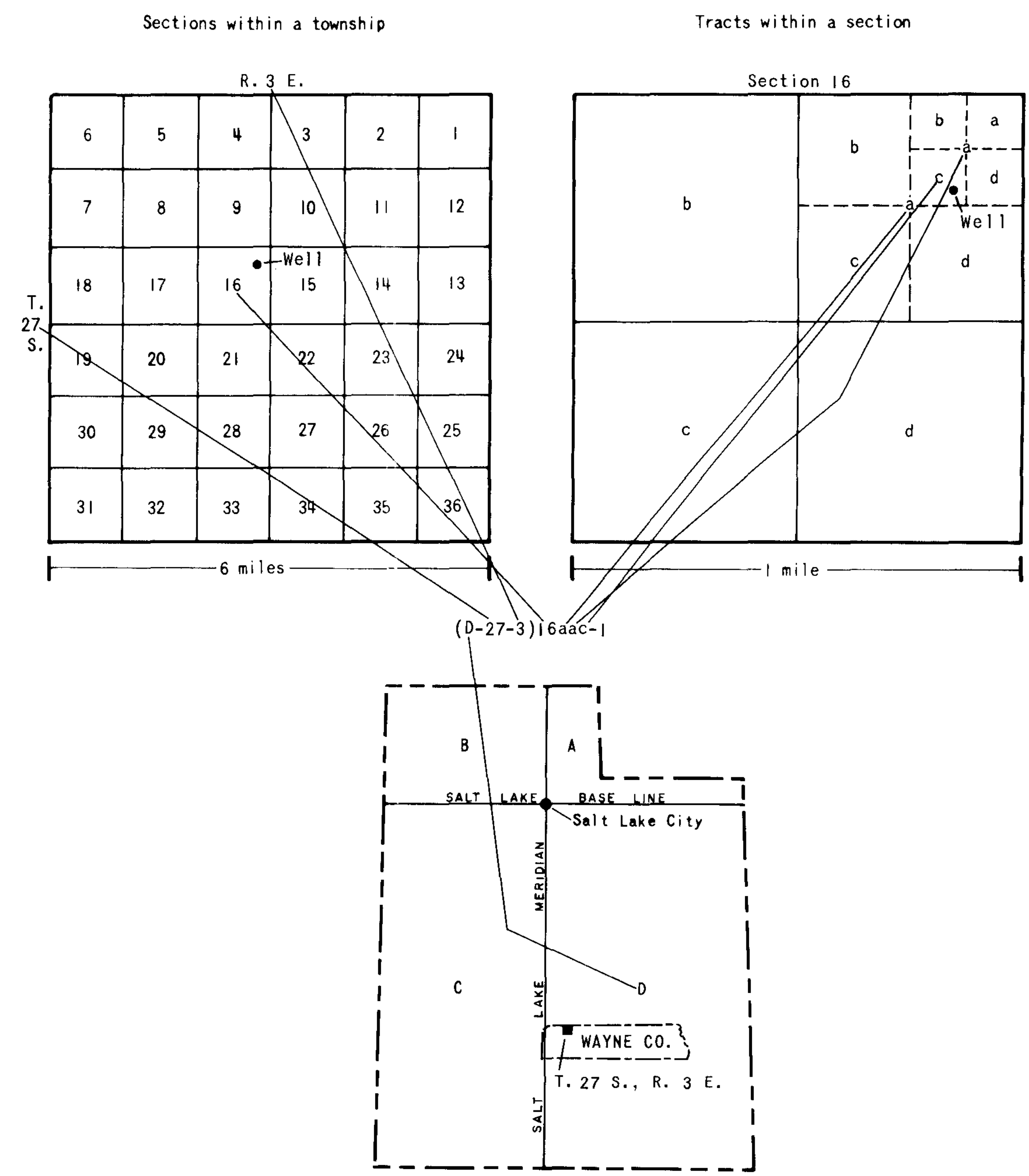

Figure 2.—Well- and spring-numbering system.

Acknowledgments

The cooperation of residents of the valley, officials of towns and irrigation companies, and water masters, who gave information and permitted the collection of data at their springs and wells, is gratefully acknowledged.

GEOGRAPHIC SETTING

Topography and drainage

The highlands surrounding the upper Fremont River valley are high plateaus. (See fig. 1.) Altitudes are more than 11,000 feet on Fish Lake Mountains and Thousand Lake Mountain and on the eastern part of the Aquarius Plateau (Boulder Mountain). They reach more than 10,000 feet on the western part of the Aquarius Plateau and nearly 10,000 feet on the Awapa Plateau. The highlands to the north and east (Fish Lake Mountains and Thousand Lake Mountain) contain many ridges and canyons; the highlands to the south (the Awapa and Aquarius Plateaus), on the other hand, are rolling to almost flat and slope gently toward the valley.

Most of the perennial surface drainage to the valley is from the Fish Lake Mountains, and the principal streams are the Fremont River and its tributary, Um Creek. Runoff is stored in Fish Lake and in the Johnson Valley, Forsyth, and Mill Meadows Reservoirs (fig. 1) and is used for irrigation in the valley. Comparatively little water drains to the valley from the surface of the Awapa and Aquarius Plateaus. The water moves in the subsurface, however, and emerges as springs along the western and southern margins of the valley. Discharge from these springs constitutes most of the base flow in Fremont Spring Creek, Roads Creek, and Pine Creek. Other springs discharge directly into the Fremont River. Another tributary, Government Creek, drains the western slope of Boulder Mountain.

The Fremont River in its 19-mile course through the valley ranges in altitude from 7,440 feet to 6,900 feet—an average gradient of 28 feet per mile. The gradient at the head of the valley, however, is as much as 80 feet per mile and in the lower parts—through Bicknell Bottoms—as little as 4 feet per mile. Gentle alluvial slopes extend to the river from the base of the highlands on both sides.

Climate

Little precipitation, large daily temperature changes (usually 30-40°F), low humidity, and sunny days are characteristic of the upper Fremont River valley. The valley receives only about 7 inches of precipitation annually and the climate can be classified as arid. Much of the surrounding highlands, however, especially on the Fish Lake and Aquarius Plateaus receive between 20 and 40 inches annually, and the climate can be classified as subhumid. Much of the precipitation in the valley falls as summer rains, which sometimes are torrential and cause local floods. Irrigation of most crops is necessary because of insufficient precipitation.

Annual precipitation at the U.S. Weather Bureau station at Loa and cumulative departure from the 1931-60 normal annual precipitation at Loa for the years 1931-66 are given in figure 3 and monthly and annual normal temperature and precipitation are given in the following tabulation:

	Normal average temperature (°F)	Normal average precipitation (inches)
January	22.7	0.38
February	26.4	.28
March	33.1	.45
April	41.7	.40
May	50.0	.55
June	58.2	.57
July	64.4	1.12
August	62.5	1.22
September	55.7	.72
October	45.2	.81
November	32.5	.35
December	24.8	.38
Annual	43.1	7.23

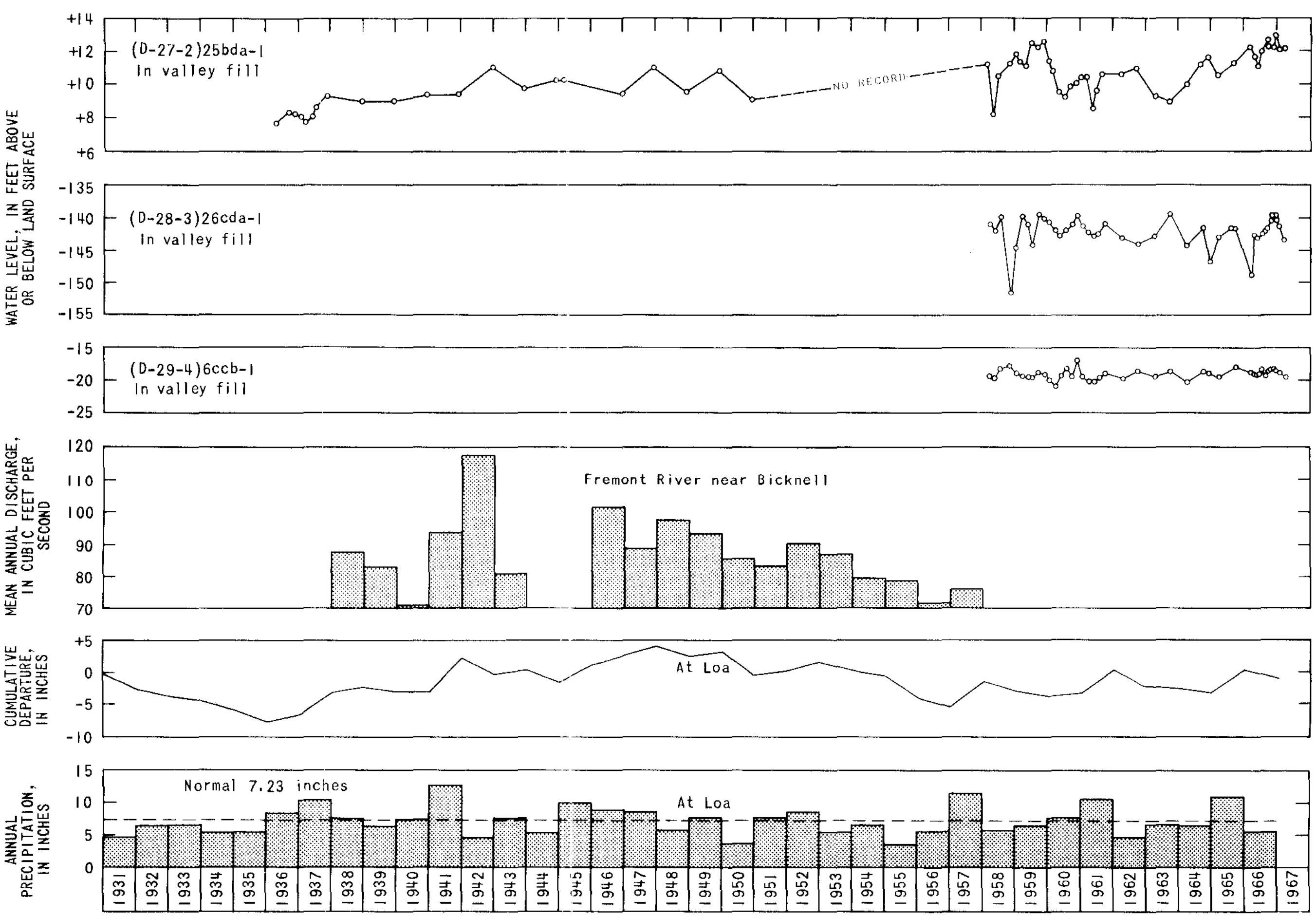

Figure 3.—Mean annual discharge of Fremont River near Bicknell, water levels in selected wells, cumulative departure from the 1931-60 normal annual precipitation at Loa, and the annual precipitation at Loa.

The growing season in the upper Fremont River valley, based on temperatures observed at Loa, is short. During the 10-year period 1957-66, consecutive days with minimum temperatures of 32°F ranged from 66 in 1962 to 103 in 1958 and averaged 80 days per year; consecutive days above 28°F ranged from 68 to 103 and averaged 107 days.

GEOLOGIC SETTING

Sedimentary rocks of Triassic and Jurassic age, igneous and sedimentary rocks of Tertiary age, and sedimentary rocks of Quaternary age are exposed in the upper Fremont River valley and the adjacent highlands. The general surface distribution of these rocks is shown in figure 4. The valley, which was formed by faulting and erosion, is filled to a depth of several hundred feet with boulders, cobbles, gravel, sand, silt, and clay. The character and position of these rocks affect the recharge, movement, discharge, and chemical quality of the ground water in the valley.

Geologic units and their water-bearing properties

Rocks of Mesozoic age

The oldest rocks in the area are sandstone, siltstone, shale, claystone, mudstone, and conglomerate of Triassic and Jurassic age which are exposed along the eastern side of the basin on the slopes of Thousand Lake and Boulder Mountains (fig. 4). These rocks range in total thickness from 3,500 to 5,100 feet, and the approximate thicknesses of individual formations, according to Smith and others (1963, pl. 1), are: Triassic age: Moenkopi Formation (766-968 feet); Chinle Formation, including Shinarump Member (440-540 feet); and Wingate Sandstone (320 feet). Jurassic age: Kayenta Formation (350 feet); Navajo Sandstone (800-1,100 feet); Carmel Formation (300-1,000 feet); and Entrada Sandstone (475-780 feet).

The rocks form cliffs and ledges in some places and in other places are covered with erosional debris derived from overlying Mesozoic rocks and Tertiary volcanic rocks. The erosional debris, which consists of landslide, steep alluvial-fan, and alluvial-slope deposits, is not shown in figure 4.

Rocks of Mesozoic age are relatively unimportant as a source of ground water in the valley. They crop out in inaccessible areas, and their permeability is low. Some springs discharge along the contact between the rocks of Mesozoic age and overlying volcanic rocks of Tertiary age, which cap Thousand Lake and Boulder Mountains.

Sedimentary rocks of Tertiary age

The Flagstaff Limestone contains the only sedimentary rocks of Tertiary age in the area. The Flagstaff consists of white fossiliferous limestone, white biotitic tuff, sandy tuff and tuffaceous sandstone, siltstone, claystone, and conglomerate; its total thickness is 500 feet or more (Smith and others, 1963, p. 35 and pl. 1). The formation is exposed in and between hummocky hills capped with volcanic rock along the eastern side of the valley from north of Lyman to Bicknell (fig. 4). Some small springs, (D-27-3)31aad-S1 and (D-27-3)32bca-S1, and

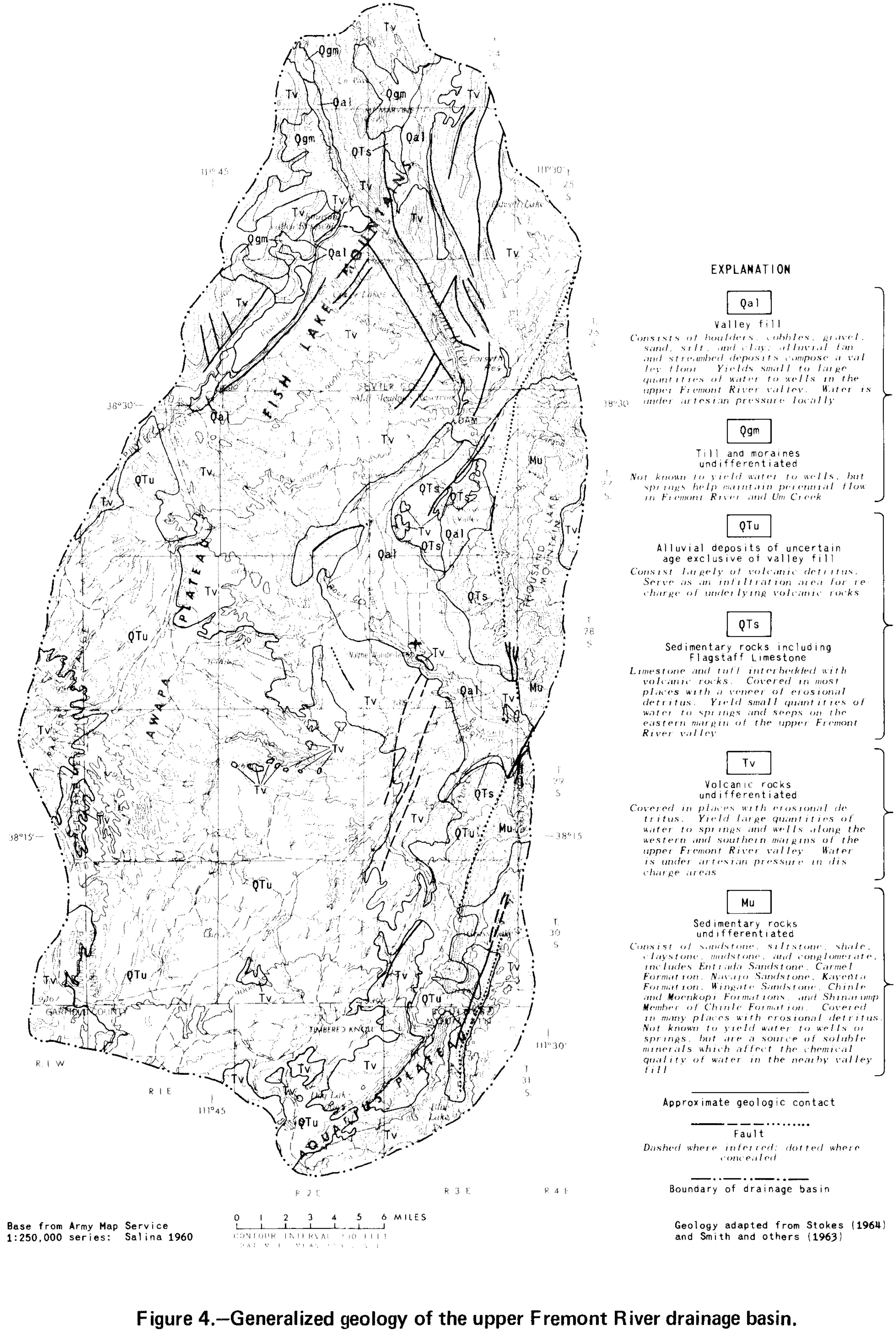

Figure 4.—Generalized geology of the upper Fremont River drainage basin.

seeps flow from tuffaceous rocks of the Flagstaff near the edge of the valley floor. The permeability of the Flagstaff apparently is low locally because some contact springs, such as Tidwell Spring, (D-27-3)22dcb-S1, discharge at the top of the Flagstaff where the formation is overlain with more permeable water-bearing rocks, such as volcanic rubble.

Volcanic rocks of Tertiary age

Volcanic rocks of Tertiary age, the most extensive rock unit exposed in the area (fig. 4), underlie virtually all the Fish Lake Mountains, the Awapa and Aquarius Plateaus, and parts of the alluvial valley floor, but are covered locally by varying thicknesses of younger deposits. According to Smith and others (1963, p. 40), volcanic rocks also cap Thousand Lake and Boulder Mountains, and there average about 350 and 475 feet in thickness, respectively. The rocks probably are much thicker on the Fish Lake Mountains and Awapa Plateau. Lava flows constitute the bulk of the volcanic rocks and they are commonly interbedded with tuffaceous rocks; the rocks are chiefly porphyritic andesite with some scoria and welded tuff (Smith and others, 1963, p. 37-42).

Volcanic rocks, the principal source of ground water in the upper Fremont River valley, yield more than 40,000 acre-feet of water annually to springs and wells. Several large springs including Fremont Spring, (D-27-2)25baa-S1, Pine Creek Spring, (D-29-3)14bcb-S1, several springs feeding Roads Creek west of Loa, and many springs on the south and west margins of Bicknell Bottoms discharge water from volcanic rocks or from alluvium near volcanic rocks. Several large-discharge flowing wells in sec. 3, T. 28 S., R. 2 E., and large-discharge pumped wells in secs. 21 and 28, T. 28 S., R. 3 E., also derive water from volcanic rocks (table 4).

The aquifers in the volcanic sequence are believed to be mostly jointed lava flows and interflow zones (see drillers' logs in table 5). The water flowing from Pine Creek Spring is discharging from joints in the lava exposed in the streambed. In many places the aquifers are confined beneath less permeable volcanic rocks and artesian pressure is built up in the aquifer.

Alluvial deposits of Tertiary and Quaternary age

Alluvial deposits of Tertiary and Quaternary age (Stokes, 1964) mantle about 200 square miles on the Awapa and Aquarius Plateaus (fig. 4). These deposits consist mostly of boulders, cobbles, gravel, sand, and silt, which are derived from and overlie the volcanic rocks in the area. These alluvial deposits are in an area where annual precipitation ranges from about 20 to 40 inches. The deposits presumably are quite permeable and are thought to absorb large quantities of water where no large perennial streams exist. This water recharges the ground-water reservoir by percolating from the alluvial deposits into the underlying volcanic rocks and moving through the most permeable zones toward the many springs that discharge along the southern and western sides of the upper Fremont River valley. The area of exposure of the alluvial deposits could therefore be called a catchment area for ground-water recharge.

Glaciated ground and moraines of Quaternary age

Glacial moraines of Quaternary age, consisting of cobbles, gravel, sand, silt, and clay, are exposed on the Fish Lake Mountains (fig. 4). These deposits store water from snowmelt and rainfall and later discharge it through springs and seeps into the Fremont River and Um Creek and their tributaries. These deposits help to maintain a flow after the snowmelt and runoff season.

Valley fill of Quaternary age

The upper Fremont River valley fill of Quaternary age includes alluvial-fan, streambed, flood-plain and lacustrine deposits, and consists of cobbles, gravel, sand, silt, and clay (fig. 4). Valley-fill deposits, similar to but smaller and thinner than those in the upper Fremont River valley, exist in Horse Valley, Fish Lake valley, Sevenmile Creek valley, upper Um Creek valley (also called Sheep Valley), and other small valleys in and near the project area. The valley fill is as much as 500 feet thick. Logs of wells drilled entirely in valley fill show depths ranging from 75 to 500 feet, whereas wells drilled through valley fill to or into bedrock reached consolidated rock at depths ranging from 35 to 311 feet (table 5). Bedrock is believed to consist of volcanic rock in most places.

The permeability and water-yielding properties of the valley fill vary widely depending upon the type of water-bearing material. Several large-discharge wells, such as wells (D-27-3)19aaa-1, 19ada-1, and 19bcc-1, (D-28-2)12dbc-1, (D-28-3)26cda-1, and (D-29-3)12ddc-1 tap permeable gravel beds in the valley fill (see tables 4 and 5). Wells that tap sand, silt, or thin gravel beds yield moderate to small amounts of water. Some gravel beds apparently underlie most of the valley because all the drillers' logs show some gravel. It is reasonable to assume that wells drilled almost anywhere in the valley will yield small to moderate quantities of water and that wells in favorable locations will probably yield large quantities of water. About 60 wells in the area tap the valley fill.

Structure

The upper Fremont River valley is a depression caused by faulting and erosion, and is partly filled by alluvium eroded from the surrounding highlands. Volcanic rocks dip gently toward the valley from the west and southwest (fig. 4) and extend beneath the valley fill. On the east, uplifted nearly horizontal beds of sedimentary and volcanic rocks compose Thousand Lake and Boulder Mountains and their foothills. These uplifted rocks are cut by several parallel step faults with the upthrown sides to the east and the downthrown sides to the west. The westernmost fault is near and parallel to the northwestern edge of the valley (Smith and others, 1963, pl. 1). Traces of north-south trending, parallel faults in the volcanic rocks south of the valley probably extend across the valley under the valley fill.

SURFACE WATER

Some of the available surface-water data for the upper Fremont River valley are presented here to enable the reader to understand the relationship between surface water and ground water in the valley.

Stream-gaging stations were operated by the U.S. Geological Survey on the Fremont River near Fremont—at the head of the valley—during 1950-57 and near Bicknell—at the foot of the valley— during 1910-12 and 1938-57 (U.S. Geological Survey, 1954, p. 445-447; 1964, p. 354-355) (see fig. 8). Annual mean discharge and annual discharge measured at these stations are presented in table 1.

Water passing the gaging station near Fremont is diverted into canals skirting the eastern and northwestern sides of the valley and is used for irrigation. Some of this water, which seeps into the valley fill from canals, ditches, and irrigated fields, percolates down to and recharges the ground-water reservoir.

Water leaving the valley at the gaging station near Bicknell is derived mostly from springs along the southern and southwestern margins of Bicknell Bottoms. Springflow will be discussed in another section of this report. This water is used mostly for irrigation in areas downstream from the area described in this report.

GROUND WATER

Source and recharge

The source of almost all the ground water and surface water in the upper Fremont River valley is precipitation within the drainage basin (fig. 1). Recharge to the ground-water reservoir in the upper Fremont River valley comes from infiltration of precipitation, infiltration of water from streams, canals, ditches, and irrigated fields, and by subsurface inflow.

Infiltration of precipitation

Recharge due to infiltration of precipitation on the upper Fremont River valley is probably small, because the valley normally receives only about 7 inches of precipitation annually; and most of the water is consumed by evapotranspiration. Recharge from infiltration of precipitation on Fish Lake Mountains and Awapa and Aquarius Plateaus, which receive 20 - 40 inches of precipitation annually, is probably considerable. Much of the plateaus is mantled with permeable sand and gravel that accept water readily. Much of the plateau area also is flat and contains few perennial streams, thus indicating that most of the drainage is through the subsurface.

Table 1.—Annual mean discharge and annual discharge in the Fremont River near Fremont (1950-57) and near Bicknell (1910-12, 1938-57)

Calendar year	Fremont River near Fremont, in NE¼ sec. 9, T. 27 S., R. 3 E., 2.5 miles northeast of Fremont		Fremont River near Bicknell, in NE¼ sec. 7, T. 29 S., R. 4 E., 3 miles southeast of Bicknell	
	Mean annual discharge (cfs)	Annual discharge (acre-feet)	Mean annual discharge (cfs)	Annual discharge (acre-feet)
1910	--	--	118.0	85,300
1911	--	--	84.7	61,400
1912	--	--	117.0	84,900
1938	--	--	87.5	63,380
1939	--	--	82.5	59,710
1940	--	--	70.6	51,240
1941	--	--	93.4	67,570
1942	--	--	117.0	84.400
1943	--	--	80.3	58,120
1946	--	--	101.0	72,950
1947	--	--	89.1	64,550
1948	--	--	97.1	70,480
1949	--	--	92.7	67,110
1950	38.0	27,530	84.8	61,360
1951	32.6	26,220	83.2	60,260
1952	63.2	45,850	90.3	65,570
1953	45.0	32,570	86.5	62,600
1954	35.5	25,730	79.1	57,280
1955	32.6	23,610	78.3	56,720
1956	27.3	19,850	71.7	52,000
1957	43.6	31,570	75.7	54,790
Average (1950-57)	39.7	29,120	81.2	58,820
Average (1910-12, 1938-57)	--	--	89.6	64,840

Infiltration from streams

Infiltration of water from streams is a principal source of recharge in the upper Fremont River valley. The main area of such recharge is in the bed of the Fremont River north of Fremont, where water-table conditions exist below the gravelly streambed. Recharge also occurs at the valley edges where perennial, intermittent, and ephemeral streams flow from canyons onto permeable alluvial fans composed largely of gravel and sand. Recharge does not occur in artesian areas of the valley, such as the wet meadows east and south of Fremont or the Bicknell Bottoms area, because the land surface is already waterlogged by leakage from the artesian aquifer.

Infiltration from canals, ditches, and irrigated fields

All the water in the Fremont River system above Fremont is diverted near the head of the valley for irrigation use in the valley. During most years more than 25,000 acre-feet of water is diverted (see table 1). About one-fourth of this water is believed to seep to the ground-water reservoir from canals, ditches, and irrigated fields. According to local farmers, the land in the valley takes in water quite rapidly and makes irrigation by flooding inefficient. Partly for this reason and partly because the terrain is quite irregular in places, flood irrigation in the valley has been largely replaced by sprinkler irrigation, which is much more efficient because less water is lost to seepage.

Subsurface inflow

A large source of recharge to the valley fill is subsurface inflow from volcanic rocks of Tertiary age that dip gently toward the valley and conduct water toward it from the Awapa and Aquarius Plateaus. Springs discharge from the volcanic rocks along the western, southwestern, and southern edges of the valley. Near the springs, the volcanic rocks plunge beneath the valley fill and water also discharges into the fill. This water constitutes most of the discharge from the many springs in the wet meadows in Bicknell Bottoms. Part of the discharge from these springs, however, is water that has moved downvalley through the fill. A comparison of the specific conductance of water from springs discharging from volcanic rocks and of water from springs discharging in Bicknell Bottoms (fig. 10) indicates a common source. An increase in the specific conductance of water sampled at the upstream end of Bicknell Bottoms in secs. 21, 27, 28, and 34, T. 28 S., R. 3 E., indicates a mixing of the more highly mineralized water moving downvalley through the fill and the less highly mineralized water moving laterally into the valley through the volcanic rocks.

Occurrence

Ground water in the upper Fremont River valley occurs mainly in two geologic units—volcanic rocks of Tertiary age and the valley fill. It occurs, to a lesser extent, in all the other geologic units shown in figure 4; the water-bearing properties of these units are described briefly in the section on geologic formations and their water-bearing properties.

Volcanic rocks

Water occurs under both artesian and water-table conditions in the volcanic rocks in joints, cracks, and bedding planes and in pore spaces in volcanic rubble, cinders, and ash. Some of the beds in the volcanic rocks are more permeable than others and serve as aquifers; overlying and less permeable beds act as barriers, confine the water, and cause artesian pressure. In places this pressure is transmitted into permeable layers in the overlying valley fill, as in well (D-27-2)34ccb-1, where the artesian head was 46 feet above the land surface.

A large, but undetermined, quantity of water is stored in the volcanic rocks that underlie and border the valley. This conclusion is inferred from the fact that more than 40,000 acre-feet of water is discharged annually from many springs in the volcanic rocks and adjacent valley fill.

Volcanic rocks on the north, east, and southeast sides of the valley store, transmit, and discharge ground water; but, they do so in much smaller amounts than the volcanic rocks on the west, southwest, and south sides of the valley. Many springs on the high flanks of Thousand Lake and Boulder Mountains discharged water at the edge of lava flows near their contacts with underlying sedimentary rocks. Because this contact is usually covered with erosional detritus, the water comes to the surface farther down the slope. At the base of Thousand Lake Mountain in Horse Valley, Tidwell Spring, (D-27-3)22dcb-S1, discharges about 1 cfs (cubic foot per second) at the base of a volcanic ledge near the top of sedimentary rocks of Tertiary age. Forsyth Spring, (D-26-3)35cb-S, discharges from a steep volcanic slope north of the Fremont River valley, probably from a permeable bed in the volcanic sequence.

Valley fill

Water occurs at some depth almost everywhere in the valley fill. The total quantity of water stored in the fill cannot be estimated because the thickness of the fill is not known everywhere. If an average effective porosity of 20 percent is assumed, however, the water is 1 foot of saturated thickness in the 40 square miles covered by valley fill would amount to about 5,000 acre-feet. Inasmuch as the maximum thickness of the fill, most of which is saturated, is known to exceed 500 feet, it is estimated that more than 1 million acre-feet of water is stored in the valley fill. However, only a relatively small part of this water that is stored in permeable beds of sand and gravel, probably not more than one-fourth of the water in storage, can be obtained from wells in large quantities.

Artesian conditions.—Artesian (confined) conditions are known to exist in the valley fill in the three areas where water levels are shown at or above the land surface in figure 5. The artesian areas are actually larger than the three indicated areas, however, because artesian conditions can occur where the piezometric surface is below the land surface.

The artesian pressure in the wet area east and south of Fremont is a resultant of the movement of ground water from the recharge area at the head of the valley into beds of permeable gravel which are overlain by confining beds of clay. The maximum measured artesian head in this area was 16.3 feet above land surface at well (D-27-3)19aaa-1 (table 4).

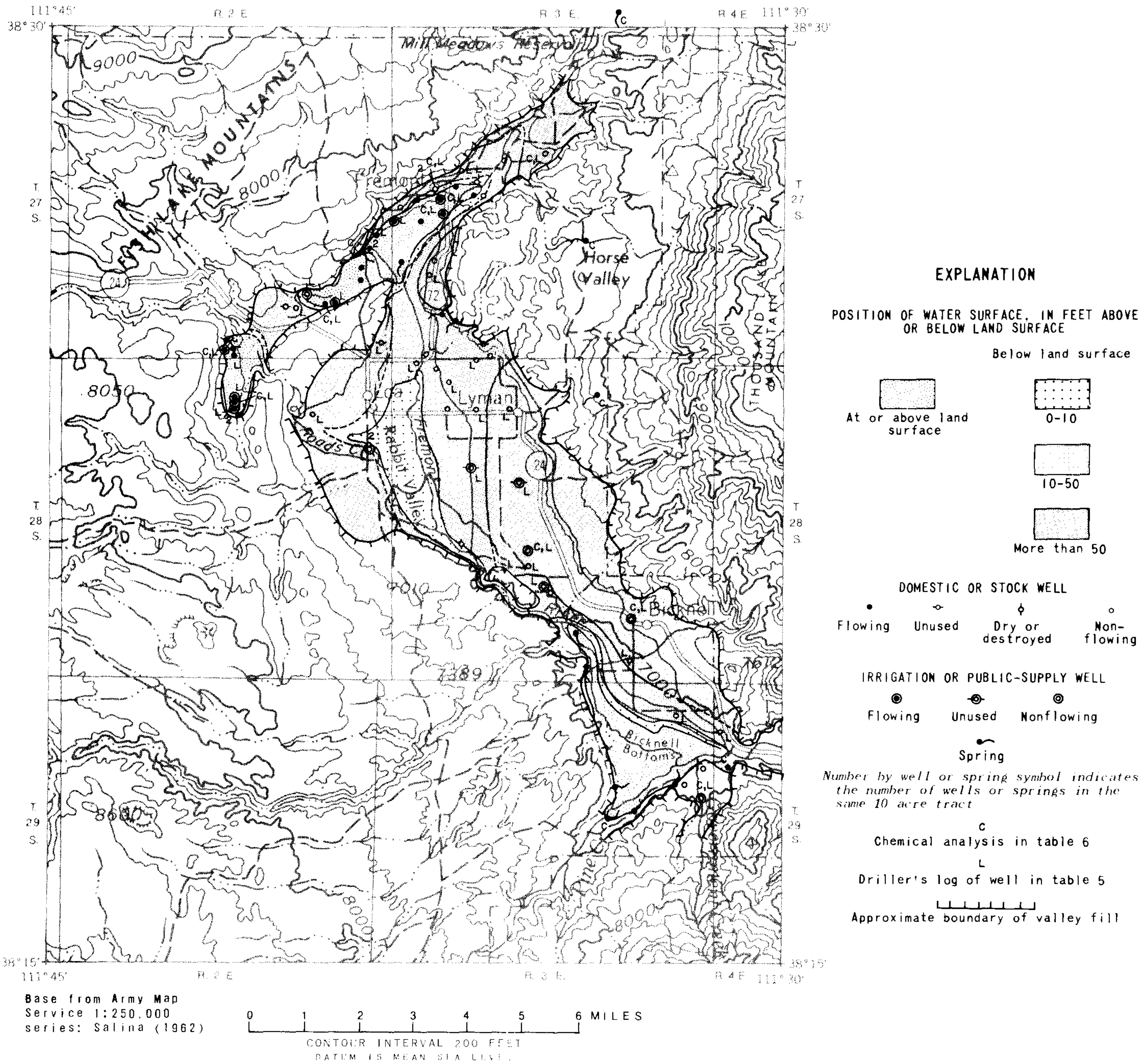

Figure 5.—Location of wells and springs and the relation of the ground-water surface to land surface in the upper Fremont River valley.

The artesian pressures in Roads Creek valley west of Loa and in the Bicknell Bottoms area result from water under pressure moving into the valley fill from underlying volcanic rocks. Confining and semiconfining beds of clay and silt maintain the pressure in the fill. The maximum measured artesian head was 45.8 feet above land surface at well (D-27-2)34ccb-1 east of Loa. No wells exist in the Bicknell Bottoms area, but artesian pressures are indicated by the many springs that emerge at the surface along the southern margin. The larger springs are usually at or near the foot of the slopes toward the Bottoms, and nearby are many small springs and seeps at higher altitudes—as much as 15 feet above the larger springs.

Water-table conditions.—Water-table (unconfined) conditions are assumed to occur in most of the area shown in figure 5 where ground-water levels are below land surface. These areas include alluvial fans, alluvial slopes, and part of the low-lying flood plain southeast of Loa. Water-table conditions are most common along the eastern side of the valley. Most of the wells deriving water from the valley fill tap water under water-table conditions.

Part of the ground water in the meadow southeast of Loa appears to be perched on a relatively impermeable layer of silt or clay that apparently underlies the wet bottom lands. The perched water table is believed to exist on both sides of the valley and it may cover an area of several square miles. Evidence of the perched conditions on the west side of the valley is given by wells (D-28-2)12dbc-1 and (D-28-2)12dbc-3, which are about 1 mile south of Loa and are about 300 feet apart. The first well is an irrigation well at the top of a terrace 16 feet above the nearby wet meadows. It is 283 feet deep, and the water table is 70 feet below land surface (log in table 5). The second well is a stock well near the bottom of the slope from the terrace. It is 15 feet deep, and the water level is 5 feet below land surface—about the same altitude as water in the wet meadows. The shallow well, therefore, exhibited perched-water conditions. Evidence of the perched conditions on the east side of the valley is given by the continuous torrent of water that pours down a 16-inch well, (D-28-3)17baa-1, from a perched ground-water zone 25 feet below land surface to a lower water table reported to be 77 feet below land surface. The torrent can be heard plainly 50 feet from the well and may amount to as much as 100 gpm (gallons per minute).

The perched ground-water is believed to come from irrigation water and water seeping from streams, particularly the Fremont River and Roads Creek. Water in the streams is diverted over the meadow during the nonirrigation season and great quantities of ice form in the meadows and remain until spring. A high water table in the lowland is indicated during dry weather by an accumulation of alkali at the land surface.

Movement

Ground water, like surface water, moves downhill and follows the path of least resistance. The direction of movement of ground water in the upper Fremont River valley is indicated by direction arrows as well as by contour lines in figure 6. The water tends to move at right angles to the contour lines. The general direction of movement can also be inferred if the areas of recharge and discharge are known.

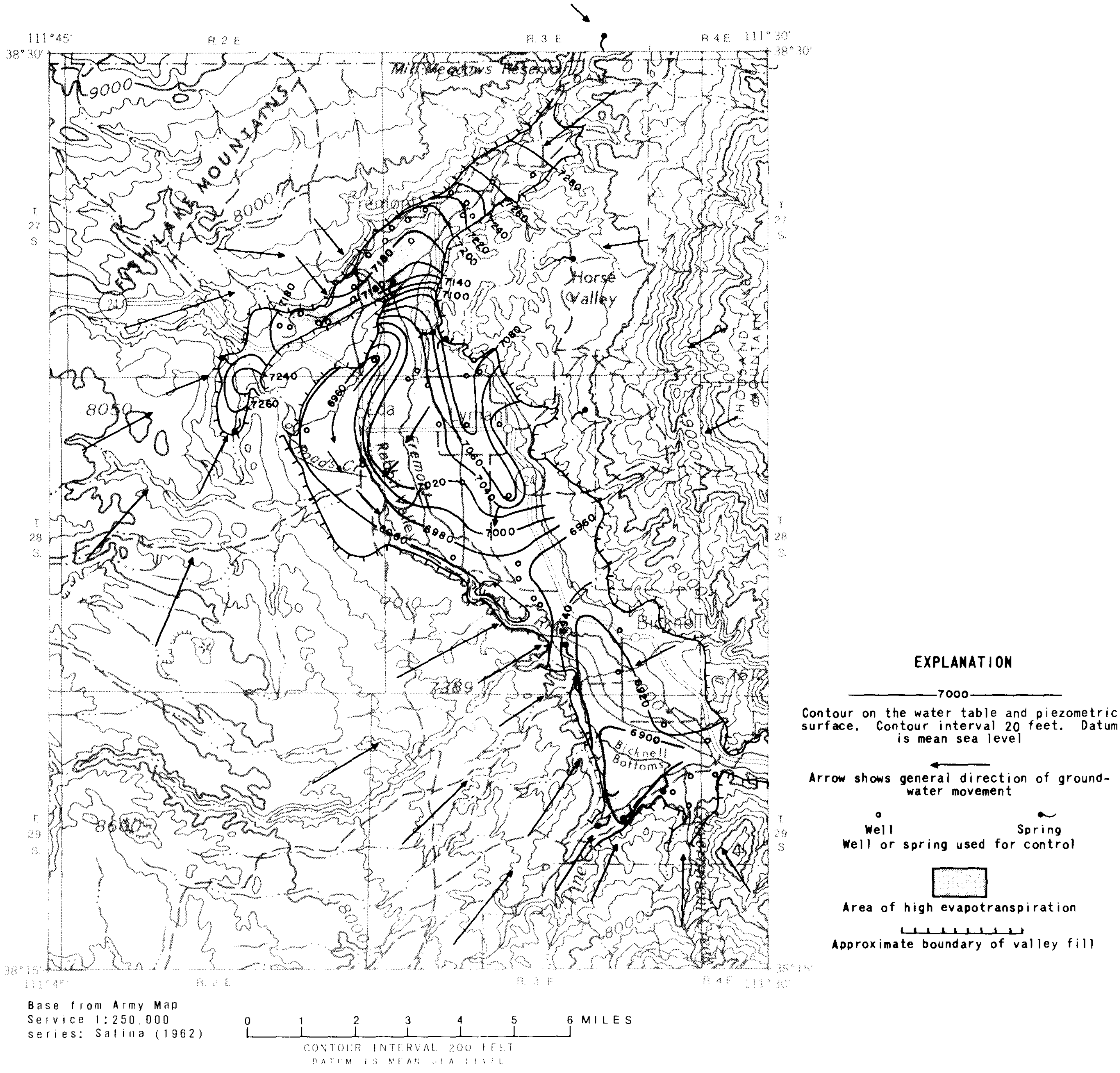

Figure 6.—Areas of high evapotranspiration, approximate configuration of the water table and piezometric surface, and direction of ground-water movement in the upper Fremont River valley. Map is based on water levels measured during the fall of 1966, water levels at time of drilling as reported in drillers' logs, and altitudes estimated from topographic maps.

Movement through volcanic rocks

The direction of movement of ground water through the volcanic rocks adjacent to the upper Fremont River valley is inferred from areas of recharge and discharge. The inferred directions are shown in figure 6 by arrows where ground-water contour lines are missing. Most of the water moves through the volcanic rocks in a northeasterly direction from the areas of recharge on the various high plateaus, especially the Awapa and Aquarius Plateaus, to the points of discharge in the valley fill such as Fremont Spring, (D-27-2)25baa-S1, springs and flowing wells in Roads Creek valley 3 miles west of Loa, Pine Creek Spring, (D-29-3)14bcb-S1, and springs on the southern to western margins of Bicknell Bottoms. Water moving through volcanic rocks in these areas probably amounts to more than 40,000 acre-feet annually.

Water also moves toward the valley from the east and southeast through volcanic rocks capping Thousand Lake and Boulder Mountains and from the northeast through volcanic rocks on Fish Lake Plateau. Most of the drainage from Fish Lake Plateau, however, is by surface flow.

Movement through valley fill

Ground water moves from the areas of recharge around the edge of the valley out into the valley fill and thence downvalley in the fill toward Bicknell Bottoms (fig. 6). The average velocity is slow, probably not more than a few inches a day, and the velocity is greatest through the most permeable materials, such as beds of well sorted gravel.

Fluctuation of water levels

A water level, as used here, is the position of the static-water surface in a well and is expressed in feet below or above land surface. In a flowing well the water level is the position to which water will freely rise if the flow from the well is stopped. Addition or withdrawal of water from the aquifer, barometric pressure changes, and other factors cause water levels to fluctuate; and the fluctuations may be brief, seasonal, or long term. In this report only seasonal and long-term fluctuations are discussed.

Water levels were measured monthly at 10 wells during 1966; three of these wells had been measured at intervals since the spring of 1958. Hydrographs of the 10 wells are presented in figures 3 and 7; and a hydrograph of one of these wells, with additional data for 1936-50, is plotted in figure 3.

Seasonal fluctuations

The seven hydrographs in figure 7 include about a year's record and show seasonal fluctuations of water levels in the valley. Most of the wells in the valley fill show a rise in water level during the summer due to recharge from irrigated fields. The water levels in wells (D-27-2)26ddc-1, (D-28-3)6baa-1, and (D-28-3)16bdb-1, all of which are finished in the valley

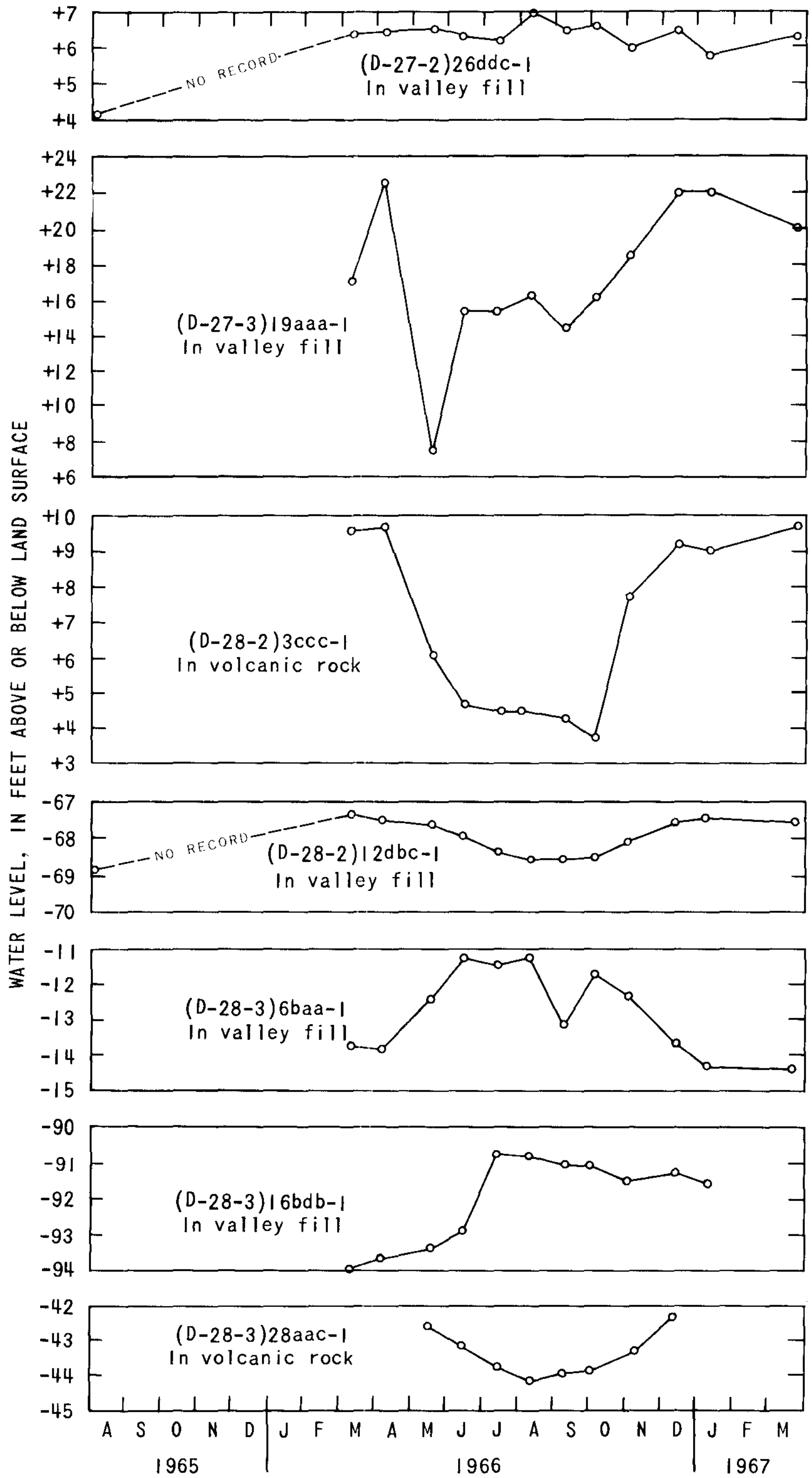

Figure 7.—Water-level fluctuations in seven wells during 1965-67.

fill, rise during the summer. Water levels in wells (D-27-3)19aaa-1, which is finished in the valley fill, and (D-28-2)3ccc-1, which is finished in volcanic rock, decline in the summer due to the discharge of water by large flowing irrigation wells nearby. The water level in well (D-28-3)28aac-1, finished in volcanic rock, declines in the summer because it and another well in the vicinity are pumped heavily for irrigation. The water level in well (D-28-2)12dbc-1, an irrigation well reported to be finished in the valley fill, declines in the summer even though this well, or any large-discharge well in the valley fill within 5 miles, has not been pumped for several years. A possible explanation is that the well is actually finished in volcanic rocks and the decline in water level is caused by discharge from four large irrigation wells that flow from volcanic rock 3 miles to the west in sec. 3, T. 28 S., R. 2 E., or from two large irrigation wells that pump from volcanic rock 4 miles to the southeast in secs. 21 and 28, T. 28 S., R. 3 E. The log of well (D-28-2)12dbc-1 (table 5) lists 120 feet of "lava cinders" at its base; therefore, the well could derive part of its water from volcanic rocks.

Long-term fluctuations

Long-term fluctuations of water levels are shown in figure 3 by hydrographs for three wells finished in the valley fill. The hydrographs for two of the wells, (D-28-3)26cda-1 and (D-29-4)6ccb-1, show no long-term upward or downward trends during 1958-67 and indicate that the ground-water reservoir in the valley has been in a state of equilibrium between recharge and discharge during the past 10 years. The hydrographs further indicate that withdrawals of ground water have not significantly affected the amount of ground water in storage in the valley fill over the 10-year period 1958-67.

The hydrograph of well (D-27-2)25bda-1 shows a rise in water levels since 1935. This rise may be caused by two factors: (1) recovery from low water levels that generally occurred during the drought of the early 1930's and (2) infiltration of surface water used to irrigate fields to the west.

Discharge

Ground-water discharge is the withdrawal or loss of water from the ground-water reservoir. In the upper Fremont River valley ground water is discharged by springs and seeps, evapotranspiration, and wells.

Springs and seeps

About 75,000 acre-feet of water is discharged by springs and seeps during most years. This amount is based on the following estimates:

	Acre-feet
Discharge from spring and seep areas to the Fremont River, including gain in Bicknell Bottoms (based on 1951-57 average flow near Bicknell)	58,000
Runoff from meadowlands south of Fremont (est. 1966; see fig. 8)	1,100
Runoff from Fremont Spring (est. 1966; see fig. 8)	12,000
Runoff from springs and seeps in Roads Creek valley (est. 1966; see fig. 8)	3,000
Runoff from other springs (est. 1966; see fig. 8)	1,000
Total (rounded)	75,000

About half of the estimated spring and seep discharge in the upper Fremont River valley is from a few principal springs in the area. In the Fremont River-Bicknell Bottoms area, the principal springs are Dab Keel Spring, (D-28-3)34baa-S1, 1,975 gpm; Hugh King Spring, (D-29-3)11cca-S1, 693 gpm; Bullard Spring, (D-29-3)14abc-S1, 1,380 gpm; and Pine Creek Spring, (D-29-3)14bcb-S1, 7,900 gpm. In the meadowlands south of Fremont an unnamed spring at (D-27-3)30bbd-S1 discharged 675 gpm. In Roads Creek valley, West Spring, (D-27-2)33dad-S1, discharged about 450 gpm and South Spring, (D-28-2)10bba-S1, discharged 545 gpm. Fremont Spring, (D-27-2)25baa-S1, discharged 7,300 gpm. Other springs include Forsyth Spring, (D-26-3)35cb-S, 225 gpm, and Tidwell Spring, (D-27-3)22dcb-S1, 450 gpm. All these discharges amount to about 35,000 acre-feet a year or about one-half of the total discharge from springs and seeps.

A seepage run was made on the Fremont River in November 1966 to determine losses in streamflow and gains in streamflow from seeps and springs in the 19-mile reach of the river between Mill Meadows Dam and the valley narrows, 3 miles southeast of Bicknell. The river was gaged at intervals, tributary inflow and diversions were measured, and the specific conductance of water at various sites on the river was determined in order to indicate general chemical quality. Details of the seepage run are given in table 2 and figure 8.

The overall ground-water accretion to the river during the seepage run was calculated to be about 72 cfs. Discharges from Fremont Spring, springs in Roads Creek valley, and springs in the valley fill south of Fremont were not included in the results of the seepage run, because the water from these sources was diverted for irrigation and only a small part of it reached the river as surface flow.

Measurable ground-water accretion to the Fremont River occurred in two of the three wet meadow areas intercepted by the river—the area of shallow ground water east and south of Fremont and the vicinity of Bicknell Bottoms (fig. 5). The greatest gains were in the vicinity of Bicknell Bottoms where many springs discharge from volcanic rocks and valley fill bordering the bottoms at the south and west.

Table 2.—Approximate gain in discharge of the Fremont River due to ground-water inflow between Mill Meadows Dam and the lower part of the valley near Bicknell, November 10, 1966

Location and description of measuring section	Approximate distance from Mill Meadows Dam (miles)	Discharge at measuring station (cfs)	Specific conductance (micromhos/cm at 25°C)	Discharge at station due to ground-water inflow (cfs)	Net gain due to ground-water inflow from preceding station (cfs)	Cumulative gain in river due to ground-water inflow (cfs)
SE¼SW¼ sec. 3, T. 27 S., R. 3 E., below Mill Meadows Dam at bridge	0.6	0.6	290	0	0	0
SW¼SW¼ sec. 10, T. 27 S., R. 3 E., at bridge	1.7	.3	310	0	0	0
NE¼SE¼ sec. 19, T. 27 S., R. 3 E., above diversion dam	4.6	2.2	1,080	1.9	1.9	1.9
NE¼SE¼ sec. 19, T. 27 S., R. 3 E., below diversion dam	4.6	.7	1,080	.7	0	1.9
NE¼NW¼ sec. 7, T. 28 S., R. 3 E., at culvert under highway	8.2	.6	770	.6	0	1.9
SE¼SE¼ sec. 28, T. 28 S., R. 3 E., above diversion dam (measured in diversion)	13.1	3.8	660	3.8	3.2	5.1
SE¼SE¼ sec. 28, T. 28 S., R. 3 E., below diversion dam	13.2	0	--	0	0	5.1
NW¼SE¼ sec. 34, T. 28 S., R. 3 E., 300 feet upstream from bridge	14.4	5.0	640	5.0	5.0	10.1
NE¼NE¼ sec. 7, T. 29 S., R. 4 E., near former USGS gaging station, Fremont River near Bicknell	18.8	66.8	500	66.8	61.8	71.9

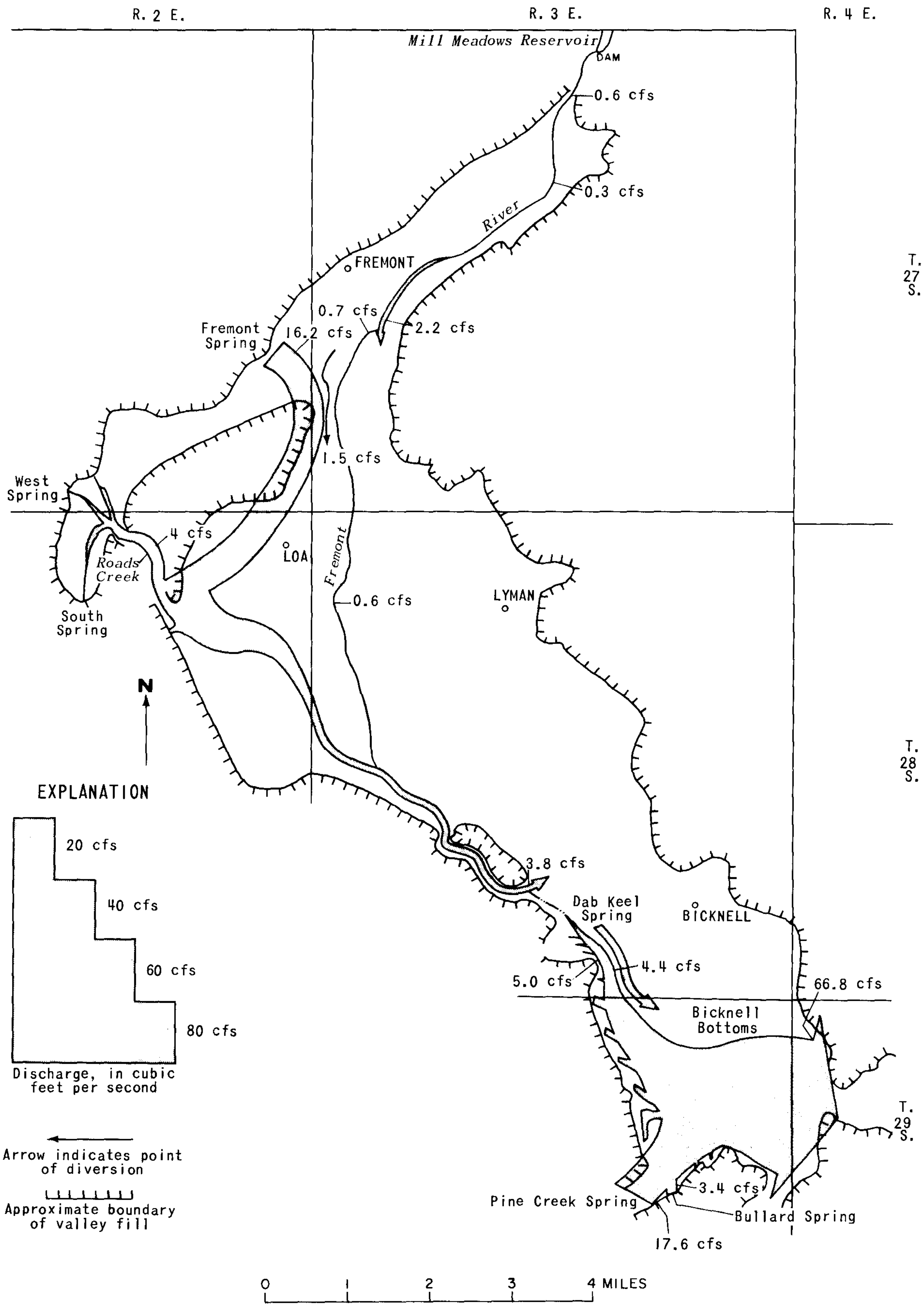

Figure 8.—Discharge in the Fremont River and tributaries, November 10, 1966.

Little, if any, gain was noted in the third meadow area, from 1 to 3 miles east and southeast of Loa. The reason for this is that a high perched water table in that area results from excess water applied for irrigation and from seepage from streams, whereas the meadows near Fremont and Bicknell are caused by ground water under artesian pressure being forced to the surface.

Very little of the water in the Fremont River system above Mill Meadows Dam reaches Bicknell Bottoms as surface flow. It is stored at Fish Lake, Johnson Valley, Forsyth, and Mill Meadows Reservoirs and is diverted near Mill Meadows Dam for irrigation in the upper Fremont River valley. Some of this water, however, percolates to the ground-water reservoir in the valley fill and eventually reaches the river or tributary springs in Bicknell Bottoms.

Only during the late fall and winter months, when water is not diverted, does water originating in the upper part of the valley below Mill Meadows Dam reach Bicknell Bottoms and eventually leave the valley as surface flow. Much of this water accumulates as ice in the meadows and flows to the Bottoms during periods of thaw.

The approximate ground-water accretion to the Fremont River as indicated in table 2 and figure 8 probably is roughly representative for 1966 and for most years in the past decade, because ground-water levels in the valley have not changed greatly in the past several years (figs. 3 and 7). Also, most of the accretion is discharge from volcanic rocks or valley fill near volcanic rocks and the ground water in the volcanic rocks is affected little, if at all, by a lowering of ground-water levels in the valley. However, periods of excessive precipitation or drought on the recharge areas of the high plateaus surrounding the valley could greatly increase or decrease the flow of water from the springs in and near the volcanic rocks. The graphs in figure 3 showing mean annual discharge in the Fremont River near Bicknell and the annual precipitation at Loa for the years 1938-57 indicate that maximum accretion to the river took place during years following years of maximum precipitation.

Evapotranspiration

Evapotranspiration of ground water includes evaporation from wetland surfaces and transpiration from plants that tap the ground-water reservoir. Plants that commonly extend roots into the zone of saturation or the moist capillary fringe immediately above it are called phreatophytes. The most common native phreatophytes in the upper Fremont River valley are meadow grasses, rabbitbrush (*Chrysothamnus* sp.) and greasewood (*Sarcobatus vermiculatus*). The meadow grasses grow in the wettest areas, and rabbitbrush and greasewood grow in the fringe areas. Saltcedar (*Tamarix gallica*), a phreatophyte representing a serious threat to water resources in other parts of the State, does not presently grow in the upper Fremont River valley possibly because the growing season is too short and cool. However, this plant thrives in parts of the lower Fremont River valley.

The upper Fremont River valley contains four areas of high evapotranspiration (fig. 6). These areas include about 5,000 acres of wet or damp meadowlands where 9,000 acre-feet of water is discharged by evapotranspiration annually. The amount of evapotranspiration was estimated using an annual potential evapotranspiration of 21 inches from the wetlands. (See Utah State University and Utah Water and Power Board, 1963, fig. 3.)

Evapotranspiration of soil moisture amounts to about 9,000 acre-feet annually from about 8,000 acres of uncultivated brushland and about 24,000 acre-feet annually from about 12,000 acres of cultivated farmland. In the uncultivated brushland the evapotranspiration is chiefly from rabbitbrush, greasewood, and sagebrush (*Artemisia* sp.). It is approximately equal to the precipitation plus an unknown additional amount where rabbitbrush and greasewood tap the ground-water reservoir in fringe areas adjacent to meadows and on some alluvial slopes. In the cultivated farmland the amount of evapotranspiration depends in part upon the crop being raised and the amount of water applied for irrigation and the amount of precipitation (Criddle, 1962). In this report it is assumed that about 24 inches of water per acre is consumed from cultivated farmland.

Wells

Flowing and pumped wells discharged about 4,200 acre-feet of water from the upper Fremont River valley during 1966. Approximately 3,500 acre-feet of water was discharged from 20 flowing wells. About 2,800 acre-feet of water was discharged during the irrigation season from 6 large-discharge flowing wells, 4 that tap volcanic rocks in Roads Creek valley and 2 that tap beds in the valley fill near Fremont. The remaining 700 acre-feet of water was discharged from 15 wells that flow the year around and was used partly for domestic and livestock supply and partly for irrigating small areas of native pasture.

Approximately 715 acre-feet of water was pumped from five large-discharge wells. All these wells were equipped with electrically driven turbine pumps. Water from four of these wells was used for irrigation and water from one was used for public water supply at Bicknell. Three wells derived water from volcanic rocks and two tapped gravel beds in the valley fill. Several large-discharge nonflowing wells in the valley were not pumped during 1966. About 30 wells in the valley are pumped to provide water for domestic and livestock use, but these wells probably do not supply more than 20 acre-feet of water annually.

Subsurface outflow of ground water

Subsurface outflow of ground water from the upper Fremont River valley is likely at only one site—the valley constriction 3 miles southeast of Bicknell. The width of the valley at the constriction is less than a quarter of a mile; sedimentary rocks of Mesozoic age consisting of sandstone, siltstone, and shale are exposed at both sides, and the valley fill at the site probably is not more than 100 feet thick. Virtually all the ground water escaping from the valley would move through the valley fill, because the sedimentary rocks abutting the fill would have low permeability. Thus the amount of water moving through the constriction is believed to be small in comparison with the flow of the river, and probably not more than 1,000 acre-feet a year.

Utilization and development

Irrigation supplies

In the upper Fremont River valley, most of the water used for irrigation comes from the Fremont River, but ground-water sources supplement the supply.

Most of the water in the Fremont River (average for the period 1951-57 was 29,000 acre-feet) is diverted near Mill Meadows Dam to canals bordering the sides of the valley. This water is stored and regulated upstream at Fish Lake and Johnson Valley, Forsyth, and Mill Meadows Reservoirs (see fig. 1).

A small amount of ground-water inflow to the Fremont River downstream from Mill Meadows Dam is diverted at various places along the channel. About 20 cfs of water from Fremont Springs and springs in Roads Creek valley is diverted and used for irrigation in the vicinity of Loa. Four large flowing wells discharging about 8 cfs in sec. 3, T. 28 S., R. 2 E., decrease the flow in nearby springs but increase the net flow in Roads Creek about 4 cfs to about 7 cfs during the irrigation season. Another flowing well, (D-27-3)19ada-1, delivers 0.6 cfs directly to the Fremont River to be used downstream. Four pumped wells deliver about 700 acre-feet of water annually for irrigation of individual farms. Several wells equipped with pumps have been idle for several years, reportedly because pumping costs were too high.

Sprinkler irrigation, using both water diverted from the river and water from wells and springs, is used on many farms in the valley. The farmers report that it is more efficient to use sprinklers than conventional flooding irrigation due to a relatively high soil permeability and in places to irregular terrain.

Public supplies

Four communities in the upper Fremont River valley have public water systems—all deriving water from ground-water sources. In downstream order they are: Fremont, Loa, Lyman, and Bicknell. Fremont, having a population of 50, is supplied from several community wells. Well (D-27-3)18ddb-1, which supplies water to 13 homes, serves about half of the community; a water supply of better chemical quality utilizing the flow from Forsyth Spring, (D-26-3)35cb-S, is planned. Loa, having a population of 359, is supplied with water from well (D-27-2)33dda-1. Lyman is supplied from spring (D-28-3)3dac-S1 discharging from volcanic rocks on the west slope of Thousand Lake Mountain. Bicknell, having a population of 366, is supplied from a spring on the north slope of Thousand Lake Mountain. The supply is supplemented by well (D-28-3)26cda-1 that taps gravel beds in the valley fill.

Domestic and stock supplies

More than half of the wells in the upper Fremont River valley are pumped wells which were drilled for domestic and stock use and are generally 2 - 6 inches in diameter. Most of these wells are drilled into valley fill and are equipped with a jet, piston, or centrifugal pump and pressure tank installed in a pit at the top of the well to prevent freezing. From the pressure tank water is piped to the house and livestock enclosures. Several small-discharge flowing wells are also used for domestic and stock supplies. Probably not more than 20 acre-feet of ground water is used during a year for domestic and stock use.

Industrial supplies

The principal industrial use of ground water in the valley is fish culture. Water from Fremont Spring, (D-27-2)25baa-S1, and North Fremont Spring, (D-27-2)24cdd-S1, supplies a hatchery at the Fremont Spring site. No significant amount of water is consumed in the process, and the water is reused downstream for irrigation. A hatchery at Pine Creek Spring, (D-29-3)14bcb-S1, is planned.

Effects of development

The hydrographs of observation wells in figures 3 and 7 show no significant effects of development of ground water during recent years. It is apparent, therefore, that ground-water development has not significantly decreased the quantity of water stored in the ground-water reservoir or affected the flow of surface water in the valley. Some minor effects, such as well interference, however, have been reported. Large-discharge flowing wells near Fremont reportedly affected the flow from small-discharge flowing wells and depressed the water levels in some domestic and stock wells in the vicinity. Also some mutual interference has been reported to exist between the large-discharge pumped wells (D-28-3)21dbb-1 and (D-28-3)28aac-1, both of which withdraw water from volcanic rocks. Discharge measurements taken at South Spring, (D-28-2)10bba-S1, during 1966, indicate that the flow from the spring is affected by four large-discharge flowing wells in sec. 3, T. 28 S., R. 2 E., which flowed from mid-May until mid-October in 1966. Discharge measurements made at the spring during 1966 are as follows:

Date	Discharge (cfs)
March 9	1.42
August 3	.45
September 3	.30
November 29	1.21

The hydrograph of well (D-28-2)3ccc-1 (fig. 7) shows, however, that the flowing wells had no significant overall effect on water levels in the vicinity during the period from March 1966 to March 1967, and that the amount of water in storage over the year did not significantly change.

INFLOW-OUTFLOW ANALYSIS OF UPPER FREMONT RIVER VALLEY

An estimate of the amount of water entering and leaving the valley annually, based partly on estimates derived from old and current records and partly on field observations, is presented in table 3. The table is intended to indicate magnitude rather than precise quantities.

Table 3.—Approximate inflow and outflow of water, upper Fremont River valley

	Units of 1,000 acre-feet
Inflow	
Fremont River (annual average discharge, 1950-57, near Fremont)	29
Ground-water inflow at Bicknell Bottoms area (est. 1966, see fig. 8)	46
Ground-water inflow at Fremont Spring (est. 1966, see fig. 8)	12
Ground-water inflow into Roads Creek valley (est. 1966, see fig. 8)	3
Precipitation on valley floor (5.65 inches on 40 square miles during 1966)	12
Total	102
Outflow	
Fremont River (average of 1950-57 record near Bicknell)	59
Ground-water outflow through constriction of valley, 3 miles southeast of Bicknell	1
Evapotranspiration from wet meadowlands (5,000 acres)	9
Evapotranspiration from uncultivated brushlands (est. 8,000 acres; includes sagebrush, rabbitbrush, and greasewood)	9
Evapotranspiration from cultivated farmland (est. 12,000 acres)	24
Total	102

CHEMICAL QUALITY OF WATER

The principal chemical constituents of water in the upper Fremont River valley are silica, calcium, magnesium, sodium, potassium, chloride, sulfate, and nitrate. Other constituents present in small amounts are iron, fluoride, manganese, and boron. Generally the chemical quality of the water is best when the concentration of dissolved solids is lowest. Other properties of water that have a bearing on the quality are specific conductance, pH, and hardness. The chemical analyses of water from selected wells and springs and from two sites on the Fremont River are given in table 6. Specific conductances of water determined in the field are included in table 4.

The concentration of dissolved solids in water is usually expressed in parts per million and is classified as follows.

Classification	Dissolved solids (ppm)
Fresh water	Less than 1,000
Slightly saline water	1,000 - 3,000
Moderately saline water	3,000 - 10,000

Fresh to moderately saline water was observed in the valley.

The specific conductance of water is easy and inexpensive to determine and may be used to estimate the concentration of dissolved solids. The ratio of specific conductance to the concentration of dissolved solids in the ground water in the upper Fremont River valley is 0.71 (fig. 9). Thus, one may obtain the concentration of dissolved solids by multiplying the specific conductance by 0.71.

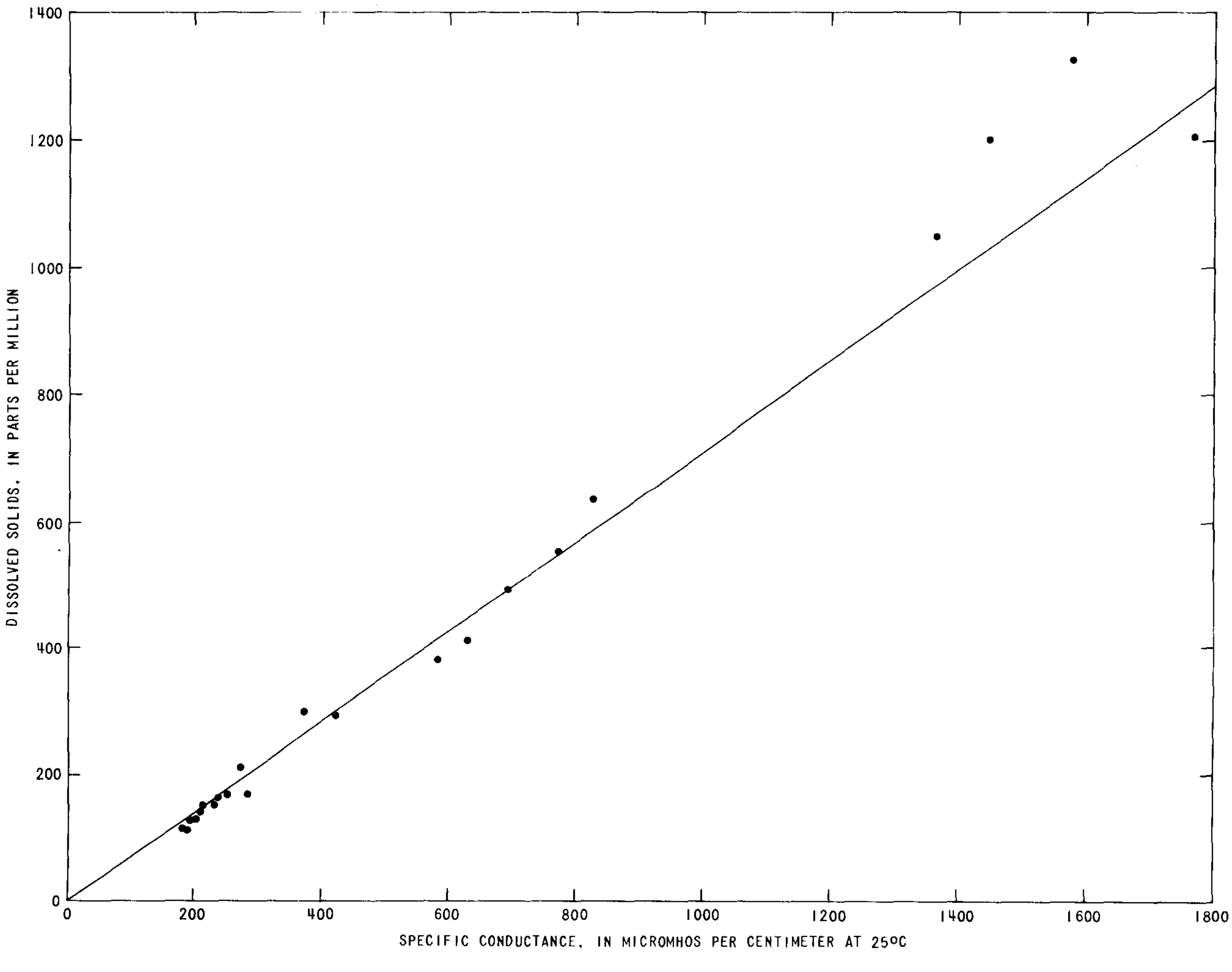

Figure 9.—Relation of specific conductance to the concentration of dissolved solids in selected ground-water samples collected in the upper Fremont River valley.

Specific conductance determinations were made for most wells and springs during the field investigation in the valley. These values are plotted in figure 10 to indicate the general chemical quality of the ground water in the valley.

Quality in relation to geology

Water containing the lowest concentrations of dissolved solids is from large springs flowing from volcanic rocks of Tertiary age on the west and south margins of the valley. The average specific conductance of the water is about 220 micromhos per centimeter at 25°C (fig. 10), and the average concentration of dissolved solids is about 156 ppm (parts per million).

The most highly mineralized water in the valley, having a specific conductance of 5,960 micromhos per centimeter at 25°C and a concentration of dissolved solids of 3,840 ppm, was collected from well (D-29-4)7bcd-1 at the southeastern end of the valley. This well flows from valley fill near the base of sedimentary cliffs of the Wingate Sandstone and the Chinle Formation of Triassic age. The water probably derives its excessive concentration of dissolved solids from contact with the Wingate and Chinle and other nearby formations of Mesozoic age. Water from several other wells in the vicinity have specific conductances ranging from 1,200 to 1,770 micromhos per centimeter at 25°C (fig. 10); the source of most of the dissolved solids is thought to be sedimentary rocks of Mesozoic age and valley fill derived from those rocks.

Specific conductances in two areas east and northeast of Fremont range from 1,370 to 1,990 and average 1,640 micromhos per centimeter at 25°C. The average concentration of dissolved solids is, therefore, about 1,160 ppm. The water probably derives most of the dissolved solids from contact with sedimentary rocks of Mesozoic age and detritus of those rocks in the valley fill. The water is quite cold, mostly less than 50°F, therefore, it is unlikely that faulting has had any bearing on the chemical quality of the water.

Quality in relation to use

Irrigation

The total concentration of soluble salts and the relative proportion of sodium to other cations are the principal factors in determining the suitability of water for irrigation (U.S. Salinity Lab. Staff, 1954, p. 69).

The concentration of soluble salts affects the plant growth by limiting the ability of the plant to take in water by osmosis. The rate at which water can enter the roots depends on the difference between the salinity of water in the plant and the salinity of water in the soil. The degree of salinity in irrigation water is called the salinity hazard.

The relative proportion of sodium to other cations in irrigation water affects plant growth by affecting the extent to which a soil will adsorb sodium from the water. The adsorption of the

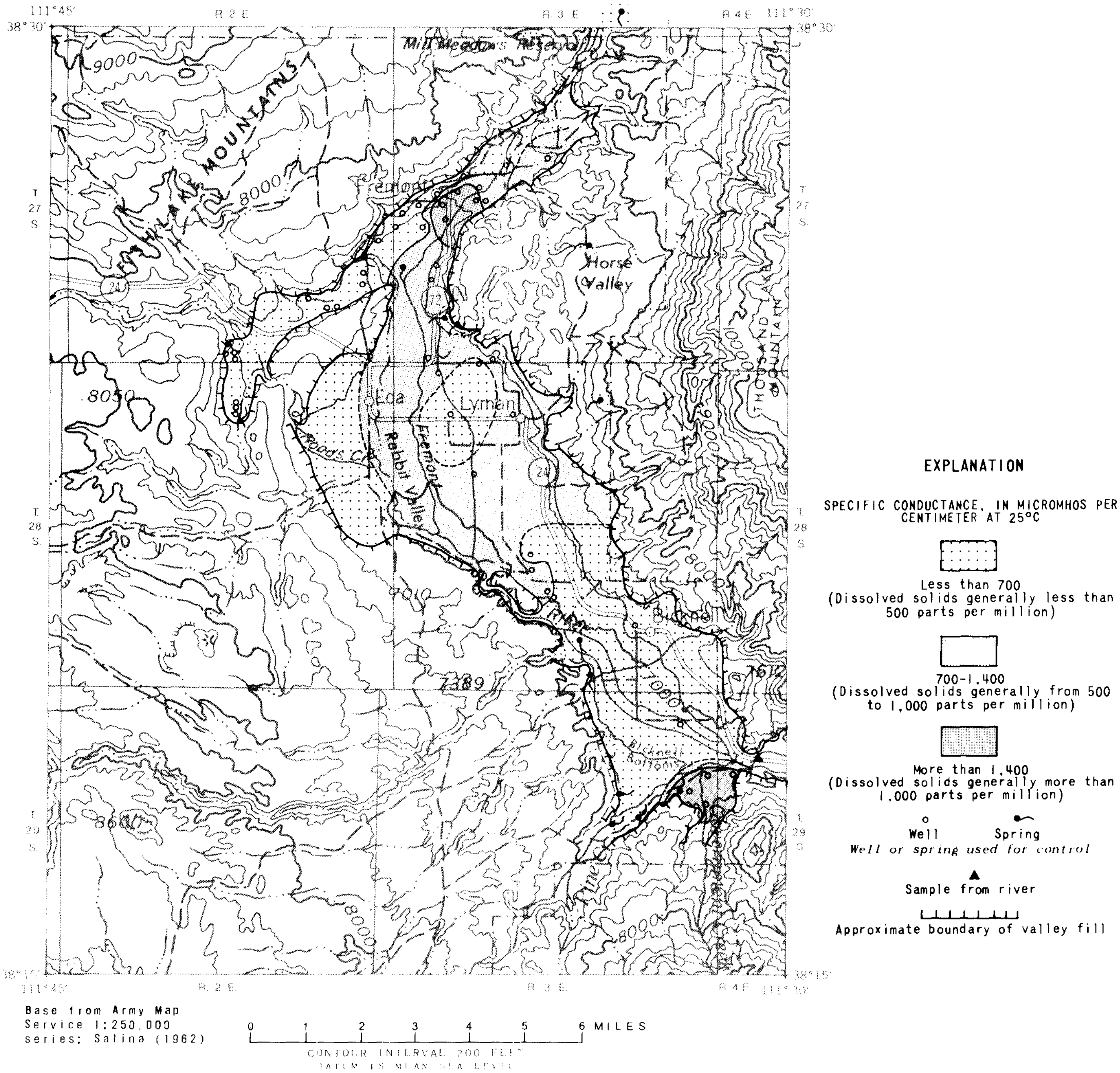

Figure 10.—Specific conductance of water and inferred general chemical quality of ground water in the upper Fremont River valley.

sodium breaks down the flocculation of the soil, making it gummy, less permeable, less fertile, and difficult to reclaim. An index to the sodium hazard is called the sodium-adsorption ratio (SAR), and it is expressed as

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

where the concentrations of sodium, calcium, and magnesium are expressed as equivalents per million. The SAR values for samples collected in the valley are included in table 6.

The classification of 25 water samples collected in the upper Fremont River valley with respect to salinity and sodium hazard is shown in figure 11. All the ground water classified in figure 11 have a low-sodium hazard and a low-, medium-, or high-salinity hazard. One ground-water sample, however, had a salinity hazard that exceeded the upper limit of the diagram. All the waters having a low-salinity hazard were collected from springs and wells in volcanic rocks along the western and southern margins of the valley. Medium and high salinity waters were collected from wells and springs deriving water from valley fill, and from volcanic rocks beneath the valley fill. Such water should not be used excessively on undrained land. Water having a salinity hazard outside the upper limit of the diagram was collected from well (D-29-4)7bcd-1, which derives water from alluvium near the base of cliffs of sedimentary rocks of Mesozoic age.

Domestic and public supply

Drinking water standards for public supply are recommended by the U.S. Public Health Service (1962). The recommended concentrations of some of the common chemical constituents are:

Constituent	Concentration (ppm)
Chloride	250
Fluoride	([1])
Iron	.3
Manganese	.05
Nitrate	45
Sulfate	250
Dissolved solids	500

[1] Lower, optimum, and upper limits of fluoride concentration are based on the annual average of maximum daily air temperatures. For the upper Fremont River valley, the limits are 0.8 ppm (lower), 1.0 ppm (optimum), and 1.3 ppm (upper). Concentrations of twice the optimum limit (2.0 ppm) are grounds for rejection of the supply.

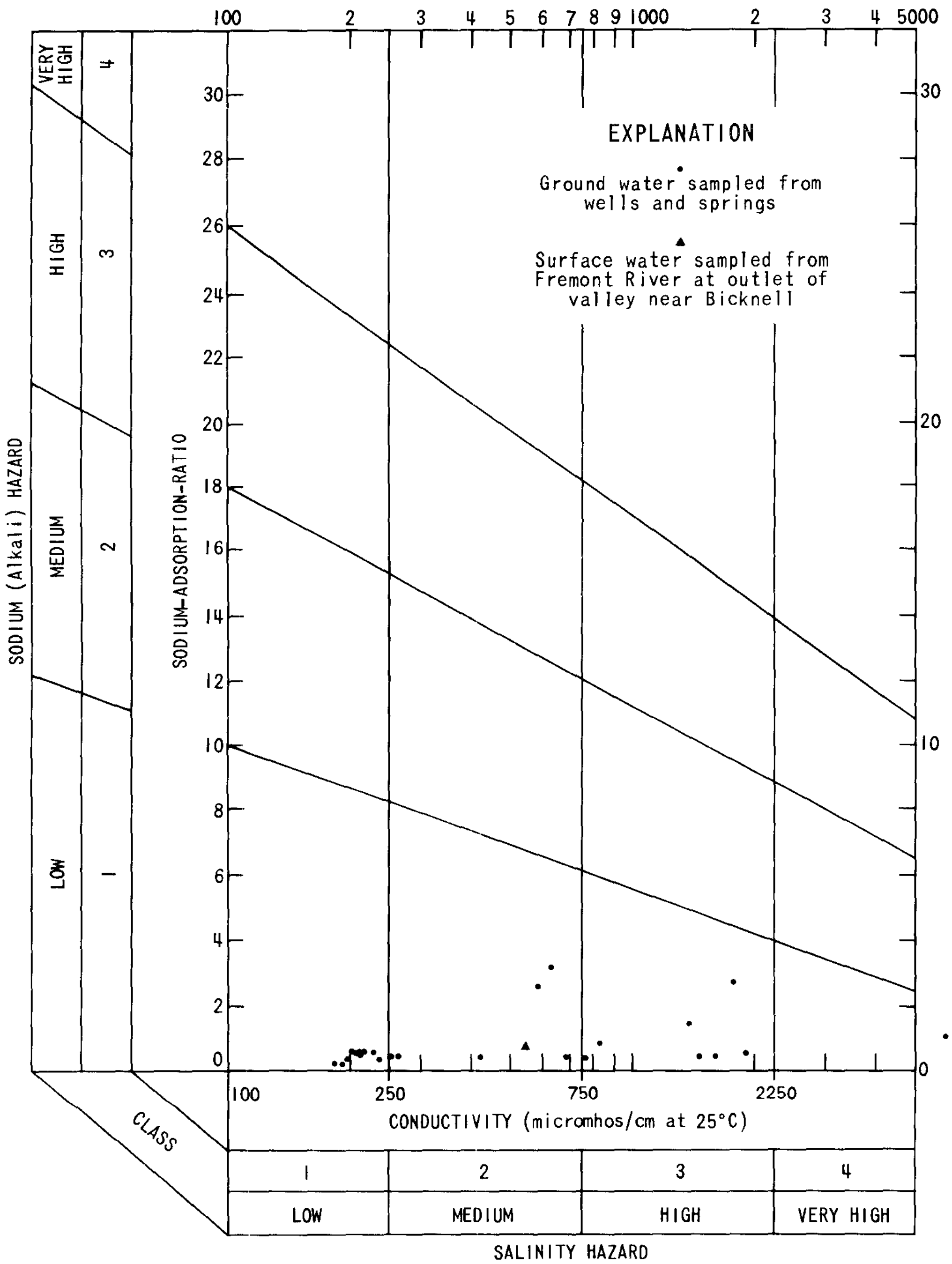

Figure 11.—Classification of water for irrigation in the upper Fremont River valley.

In the 27 analyses of ground water in the upper Fremont River valley listed in table 6, the recommended maximum concentrations of chemical constituents were exceeded in only 1 analysis for chloride, 1 for fluoride, 7 for sulfate, 8 for dissolved solids, and none for iron, nitrate, or manganese. All the excesses were in samples collected from wells along the eastern side of the valley. None of the recommended concentrations were exceeded in samples collected from springs and wells discharging more than 30,000 acre-feet of water annually from volcanic rocks along the western and southern margins of the valley. The water supplies for Loa and Lyman did not contain concentrations that exceeded any of the recommended maximum concentrations. The supply for Fremont contained an excess of sulfate and dissolved solids; however, a new supply, Forsyth Spring, (D-26-3)35cb-S, is planned for the community, and concentrations in the water from this spring exceeded none of the recommended concentrations. Water in a public-supply well at Bicknell, which is supplementary to a spring on Thousand Lake Mountain as a source of water for the town, contained an excess of fluoride.

The chemical analyses of ground water that is or will be used for domestic and public supply is summarized below:

		Constituent, in parts per million							
Source	Town	Chloride	Fluoride	Iron	Manganese	Nitrate	Sulfate	Dissolved solids	Hardness as $CaCO_3$
(D-26-3)35cb-S	Fremont	6.5	---	---	---	0.1	3.6	168	114
(D-27-2)33dda-1	Loa	7.0	0.3	0.01	0.00	2.5	3.0	173	81
		5.6	---	---	---	1.3	3.9	141	80
(D-27-3)18ddb-1	Fremont	38	---	---	---	2.3	290	604	390
(D-28-3)3dac-S1	Lyman	12	.1	.00	---	0	69	293	193
(D-28-3)26cda-1	Bicknell	30	3.5	.02	.00	14	58	415	143

The hardness of water should be considered in any domestic or public supply because it affects the cleansing properties of water and the amount of soap consumed and is related to the incrustation of water (Hem, 1959, p. 145-148). The principal constituents that cause hardness in water are calcium and magnesium. The U.S. Geological Survey classifies water with respect to hardness as follows:

Classification	Hardness as $CaCO_3$ (ppm)
Soft	0 to 60
Moderately hard	61 to 120
Hard	121 to 180
Very hard	More than 180

Of the five ground-water sources that are or will be used for domestic and public supply, two yielded moderately hard water, one yielded hard water, and two yielded very hard water.

Temperature of water

The temperature of water is important in considering its suitability for use in industry, particularly for cooling. The temperature of water in streams directly reflects local atmospheric conditions and may range from 32° to about 90°F during the course of a year. The temperature of ground water, however, generally remains within a few degrees of the mean annual air temperature, regardless of the season. The temperatures of ground water in the upper Fremont River valley at 62 wells and springs ranged from 47° to 63°F. (See table 4.) The warmest water, having temperatures of 62° and 63°F, was sampled from the large springs and flowing wells discharging from volcanic rocks on the western margin of the valley. Pine Creek Spring, (D-29-3)14bcb-S1, on the southern margin, on the other hand, yielded water from volcanic rocks at 50°F, which indicates that the spring is closer to the area of recharge than those on the western margin of the valley. From Pine Creek Spring westward the water in springs in or near volcanic rocks became warmer. Water from Hugh King Spring, (D-29-3)11cca-S1, had a temperature of 56°F; water from both Dab Keel Spring, (D-28-3)34baa-S1, and unnamed springs at (D-28-3)34dba-S1, had a temperature of 54°F. The temperature of the water from wells and springs in the valley fill and from springs on the northern and eastern margins of the valley ranged from 47° to 55°F, but most of the temperatures were within 2 degrees of 50°F.

CONCLUSIONS

No significant trends in the fluctuation of ground-water levels in the upper Fremont River valley have been caused by withdrawal of water from wells during at least the past 10 years according to data collected since 1958. However, seasonal fluctuations caused by withdrawals are present. It can be concluded that additional ground-water development in the valley is feasible. Additional flowing and pumped wells drilled into volcanic rocks probably would not increase the net supply of water because existing wells cause a decrease in spring flow, but the wells would increase the supply when and where water is needed.

Additional pumped wells in the valley fill probably would reduce areas of high evapotranspiration and save some water. Measurements of key observation wells should be continued at least semiannually to determine any future trends in the fluctuation of water levels in the valley.

Several test holes should be drilled to determine the nature and total thickness of the valley fill, and some aquifer tests should be made to determine the hydraulic characteristics of the water-bearing formations.

SELECTED REFERENCES

Bentall, Ray, compiler, 1963, Methods of determining permeability, transmissibility, and drawdown: U. S. Geol. Survey Water-Supply Paper 1536-I.

Conner, J. G., Mitchell, C. G., and others, 1958, A compilation of chemical quality data for ground and surface waters in Utah: Utah State Engineer Tech. Pub. 10.

Criddle, W. D., Harris, Karl, and Willardson, L. S., 1962, Consumptive use and water requirements for Utah: Utah State Engineer Tech. Pub. 8 (revised).

Fenneman, N. M., 1931, Physiography of Western United States: New York, McGraw-Hill Book Co., 534 p.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U. S. Geol. Survey Water-Supply Paper 1536-E.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U. S. Geol. Survey Water-Supply Paper 1473.

Meinzer, O. E., 1923a, Outline of ground-water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494.

........................1923b, The occurrence of ground water in the United States, with a discussion of principles: U. S. Geol. Survey Water-Supply Paper 489.

Robinson, T. W., 1958, Phreatophytes: U. S. Geol. Survey Water-Supply Paper 1423.

Smith, J. F., Jr., and others, 1963, Geology of the Capitol Reef area, Wayne and Garfield Counties, Utah: U. S. Geol. Survey Prof. Paper 363.

Spieker, E. M., 1949, The transition between the Colorado Plateau and the Great Basin in central Utah: Utah Geol. Soc. Guidebook to the Geology of Utah No. 4.

Stokes, W. L., 1964, Geologic map of Utah: Utah Univ.

Theis, C. V., Brown, R. H., and Meyer, R. R., 1963, Estimating the transmissibility of aquifers from the specific capacity of wells in Methods of determining permeability, transmissibility, and drawdown: U.S. Geol. Survey Water-Supply Paper 1536-I, p. 331-340.

U.S. Geological Survey, 1954, Compilation of records of surface waters of the United States through September 1950, Part 9, Colorado River Basin: U.S. Geol. Survey Water-Supply Paper 1313.

........................1961, 1962, 1963, Surface-water records of Utah, 1961, 1962, 1963: Water Resources Div.

........................1964, Compilation of records of surface waters of the United States, October 1950 to September 1960, Part 9, Colorado River Basin: U.S. Geol. Survey Water-Supply Paper 1733.

U.S. Public Health Service, 1962, Drinking water standards: U.S. Public Health Service Pub. 956.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Dept. Agriculture Handb. 60.

U.S. Weather Bureau, 1963, Normal annual precipitation (1931-60) for the State of Utah: Map of Utah, scale 1:500,000.

Utah State University and Utah Water and Power Board, 1963, Developing a state water plan—Utah's water resources—problems and need—a challenge: Utah Water and Power Board-Utah State Univ.

Wenzel, L. K., 1942, Methods of determining permeability of water-bearing materials, with special reference to discharging-well methods, with a section on direct laboratory methods and bibliography on permeability and laminar flow by V. C. Fishel: U.S. Geol. Survey Water-Supply Paper 887.

BASIC DATA

Table 4.—Records of wells and springs in the upper Fremont River valley

Location: See text for description of well- and spring-numbering system.
Owner or name: Name listed was obtained at time of visit or is the name listed on records of the Utah State Engineer.
Application or claim number: A, application number; C, claim number.
Altitude above sea level: Altitudes at land-surface datum estimated from topographic maps and hand leveling or determined by altimeter.
Type of well: C, drilled by cable tool; D, dug; H, drilled by hydraulic rotary; J, jetted.
Depth of well: Depths are reported unless indicated by m, measured.
Character of material - First column (adjectives): A, argillaceous; J, jointed; 3, medium grained; 4 coarse grained. Second column (lithology): A, alluvium; C, conglomerate; G, gravel; I, igneous, aphanitic, or glassy (basalt, etc.); Q, silt; R, sand and gravel; S, sand.
Geologic source: Qal, valley fill of Quaternary age; Tv, volcanic rocks of Tertiary age; Ts, sedimentary rocks of Tertiary age.
Water level: Measured depths given in feet and tenths; reported or estimated depths given in feet and indicated by e, estimated, or r, reported.
Method of lift and type of power: Letter - C, centrifugal pump; F, flows; J, jet pump; N, none; P, piston pump; S, submersible turbine pump; T, turbine pump. Number - 3, gasoline engine; 5, electric motor.
Yield and drawdown: e, estimated; m, measured; r, reported.
Use of water (major use is listed first): H, domestic; I, irrigation; N, industrial; O, observation; P, public supply; S, stock; U, unused.
Specific conductance: Field measurement unless followed by L, laboratory.
Remarks and other data available: C, chemical analysis in table 6; F, driller's log available in files of the Utah State Engineer; L, driller's log in table 5.

Location	Owner or name	Application or claim number	Year drilled	Altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Character of material	Geologic source	Water level: Above(+) or below(-) land-surface datum (feet)	Water level: Date of measurement	Method of lift and type of power	Yield and drawdown: Yield (gpm) / Drawdown (feet)	Yield and drawdown: Date of measurement	Use of water	Specific conductance (micromhos/cm at 25°C)	Temperature (°F)	Remarks and other data available
(D-26-3)																		
35cb-S	Forsyth Spring	-	-	7,600	-	-	-	J-I	Tv	-	-	F	225m	10-27-66	P	239L	50	Intended public supply for town of Fremont. Spring is a short distance north of mapped area. C.
(D-27-2)																		
24cdd-S1	North Fremont Spring	-	-	7,170	S	-	-	4-R	Qal	-	-	F	150e	10-10-66	N	350	53	Used in fish culture.
24dbd-1	W. G. Taylor	C-11701	1933	7,180	J	120	2	4-R	Qal	+2.0	10- 6-66	F	1e	10- 6-66	S	-	54	
24dbd-2	do	A-13847	1940	7,180	C	170	8	4-R	Qal	+10.0	10- 6-66	F	70e / 9e	10- 6-66	H,S,I	400	54	Flows constantly. Plugged back from 307 ft. L.
25baa-S1	Fremont Spring	-	-	7,170	-	-	-	J-I	Tv	-	-	F	7,300m	10-10-66	N,I	203L	62	Used first for fish culture and then for irrigation. Twelve major discharge points. C.
25bda-1	Clinton Tanner	-	19-5	7,170	J	289	2	4-R	Qal	+12.8	9- 9-66	F	15e / 9e	9- 9-66	H,S,O	260	55	Flows constantly.
25caa-1	do	-	1915	7,155	J	178	2	4-R	Qal	+6.1	9- 9-66	F	5m / 5e	9- 9-66	S	460	54	Do.
26cda-1	Blaine Chapple	A-31957	1962	7,175	C	192	12	J-I	Tv	-1r	-	T-5	450e	9-20-66	I	200	62	Pumps into sprinkler system. L.
26ddc-1	L. D. Jackson	A-27426	1955	7,160	H	270	6	4-R	Qal	+7.0	8- 8-66	F	31m / 7e	4- 6-66	S,I	252L	52	Flows constantly. C, L.
26ddd-1	do	A-31932	1964	7,150	C	275	12	4-G	Qal	+8.5	9-21-66	F	42m	9-21-66	I,S	310	54	L.
33dad-S1	West Spring	-	-	7,280	-	-	-	J-I	Tv	-	-	F	450e	10-20-54	I,S	212L	63	Flows directly from volcanic rocks on hillside. C.
33dda-1	Loa Water Works Co.	A-31869	1960	7,280	C	255	10	J-I	Tv	-	-	F	143m	9-20-66	P	211L	62	Well drilled in spring (West Springs) area. C, L.
34ccb-1	W. G. Taylor	-	1935	-	C	-	2	4-R	Qal	+45.8	10- 6-66	F	5e	10- 6-66	S	190	62	Valley fill is recharged by movement of water from volcanic rocks. Highest head measured in area.
34ccc-1	do	A-14502	1941	-	C	300	10	A-C	Qal	-	-	F	15m	9-21-66	S	190	62	Valley fill is recharged by movement of water from volcanic rocks. L.
35bba-1	Spencer Rees	A-14606	1942	7,200	C	370	4	4-R	Qal	-21.9	9-20-66	J-5	12r / 5r	6-20-42	S	-	-	L.
35bbb-1	do	-	1917	7,220	J	45	2	4-R	Qal	-42.0	9-20-66	N	-	-	U	-	-	
36dac-1	W. C. Potter	A-14430	1941	7,080	C	130m	4	4-G	Qal	-127.6	11-14-66	N	3m	11-14-66	U	-	-	L.
(D-27-3)																		
16aac-1	Rex Albrecht	A-18140	1946	7,394	C	182	5	4-R	Qal	-127r	12- 2-46	J-5	15r / 22r	10-17-66	S	1,370L	50	C, L.
16bcb-1	River Inn	-	-	7,274	D	-	-	4-G	Qal	-21.1	10-14-66	J-5	-	-	H	310	50	Well near river bank.
17cab-1	Frank Salt	A-14136	1941	7,248	C	97	6	4-R	Qal	-23.5	10-18-66	S-5	10r / 1r	6-20-41	H,S	600	50	L.
17cca-1	Millie Ellett	-	1922	7,215	J	114m	2	4-R	Qal	-	-	F	10e	10-14-66	H,S	1,860	50	Water reported to be very hard.
17dbc-1	O. C. Taylor	A-15077	1943	7,234	C	154	6	4-R	Qal	-1.8	10-18-66	N	-	-	U	900	51	Reported to have flowed 5 gpm when drilled; reported head was 2 ft above land surface. L.
17dcc-1	do	-	1900	7,215	J	-	2	4-R	Qal	+3.0	10-18-66	F	4m / 3e	10-18-66	I,S	1,550	50	Irrigates small garden.
17dcd-1	Julia DeLang	-	1948	7,223	D	18	72	3-A	Qal	-6.2	10-18-66	C-5	-	-	H,S	970	50	
18ddb-1	Town of Fremont	-	1922	7,213	C	127	4	4-R	Qal	-	-	C-5	-	-	P	832L	-	Supplies 13 families, about half of Fremont. C.
18ddb-2	J. W. Jackson	A-15061	1942	7,225	C	122	4	4-R	Qal	-20r	12-23-42	J-5	10r / 4r	12-23-42	H	520	-	L.
19aaa-1	Clarence Albrecht	A-18060	1947	7,190	C	285	8	4-C	Qal	+16.3	8- 8-66	F	350m / 15e	3-10-66	I,S	1,450L	52	C, L.
19acc-1	Clifford Olson	C-14294	1933	7,147	J	95	2	4-C	Qal	+9.8	10- 3-66	F	2m / 7e	10- 3-66	S	540	50	F.

Table 4.–(Continued)

Location	Owner or name	Application or claim number	Year drilled	Altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Character of material	Geologic source	Water level: Above(+) or below(-) land-surface datum (feet)	Water level: Date of measurement	Method of lift and type of power	Yield and drawdown: Yield (gpm) / Drawdown (feet)	Yield and drawdown: Date of measurement	Use of water	Specific conductance (micromhos/cm at 25°C)	Temperature (°F)	Remarks and other data available
(D-27-3) 19ada-1	Clarence Albrecht	A-18060	1947	7,179	C	435	8	4-G	Qal	-	-	F	270m	10-10-66	I	1,990L	52	Flows during irrigation season and leaks about half flow during remainder of year. C, L.
19baa-1	Clifford Olson	C-14295	1927	7,212	J	270	2	4-G	Qal	+2e	10-13-66	C-5	-	-	H,S	420	-	Flows less than 1 gpm when not pumped.
19bbd-1	Matt Behunin	-	-	7,230	C	48	12	4-R	Qal	-33.0	10-13-66	J-5	70r / 21r	12-24-41	H,S	700	52	C.
19bcc-1	do	A-14107	1941	7,190	C	152	8	4-R	Qal	+4r	5-25-41	T-5	-	-	I	640	50	Flows about 60 gpm when not pumped; has not been pumped since 1963. L.
22dcb-S1	Tidwell Spring	-	-	7,650	-	-	-	J-I	Tv	-	-	F	450m	9-29-66	I	776L	48	Discharge at base of volcanic cliff. C.
30aac-1	DeVon Nelson	-	1928	7,152	C	400	2	4-R	Qal	-120r	-	P-5	-	-	H,S	730	50	
30acd-1	C. L. Nelson	A-14870	1943	7,145	C	256	5	4-G	Qal	-65r	7-20-42	P-5	9r / 10r	5- 2-43	H,S	710	50	L.
30bbd-S1	-	-	-	7,160	-	-	-	4-R	Qal	-	-	F	675m	10-17-66	I	920	50	Discharge from many points in wet meadow area.
31aad-S1	Ward Taylor	-	-	7,145	-	-	-	A-Q	Ts	-	-	F	10m	10-24-66	H	400	51	Supplies three families. Source of water reported to be mostly seepage from Hi-Line Canal.
31dcd-1	H. F. Johansen	A-28433	1956	7,060	C	75	4	4-G	Qal	-30r	8-25-56	J-5	8r / 2r	8-25-56	H,S	760	51	L.
32bca-S1	Pratt Taylor	-	-	7,200	-	-	-	A-Q	Ts	-	-	F	6m	10-24-66	S	340	51	Source of water reported to be mostly seepage from Hi-Line Canal.
32dbd-1	Clinton Peterson	-	1944	7,210	D	36	60	4-R	Qal	-28.6	11-16-66	N	-	-	U	-	-	
32ddc-1	Vaughn Taylor	-	1944	7,185	D	30	48	4-S	Qal	-23.6	11-15-66	J-5	-	-	S	840	48	
(D-28-2) 3cbc-1	Spencer Rees	A-15684	1944	-	C	193	8	J-I	Tv	-	-	F	1,150m	8- 4-66	I	200	63	Flows throughout irrigation season. L.
3ccb-1	Roads Creek Water Users	A-22972	1944	-	C	333	10	J-I	Tv	-	-	F	1,750m	8- 4-66	I	215L	63	Largest flowing well in area; flows throughout irrigation season. C, L.
3ccc-1	Spencer Rees	A-22972	1944	-	C	276	8	J-I	Tv	+9.7	4- 4-66	F	352m / 6e	8- 4-66	I,O	200	63	Flows throughout irrigation season. L.
3ccc-2	do	A-22973	1944	-	C	286	6	J-I	Tv	+14.5	3- 9-66	F	386m / 6e	8- 4-66	I	210	63	Flows throughout irrigation season.
10bba-S1	South Spring	-	-	7,280	-	-	-	J-I	Tv	-	-	F	545m	11-29-66	I	220	60	Flows from 135 to 200 gpm when four nearby large artesian wells are flowing
11abb-1	Thane Taylor	A-14907	1942	7,076	C	130	3½	4-R	Qal	-115r	8-17-42	P-5	10r / 4r	8-17-42	S	-	-	L.
12dbc-1	Dolan Brian	A-23027	1951	7,040	C	283	12	4-G	Qal	-69.5	8-10-66	T-4	1,400r	-	I,O	-	-	Well has not been pumped for several years. L.
12dbc-2	do	-	-	-	D	40	60	4-R	Qal	-25r	11-21-66	J-5	-	-	H	620	48	Water rises in well during irrigation season; water evidently is perched.
12dbc-3	do	-	-	7,025	D	15	60	4-R	Qal	-5.3	11-21-66	C-5	-	-	S	880	50	Do.
(D-28-3) 3dac-S1	Lyman Spring	-	-	7,820	-	-	-	J-I	Tv	-	-	F	-	-	P	425L	-	Public supply for town of Lyman. Contact spring. C.
4ccd-1	W. A. Oldroyd	A-23025	1951	7,156	C	185	6	4-R	Qal	-130r	10-30-51	P-5	4r / 30r	10-30-51	S	880	50	Well has not been used for 2 years. L.
5abb-1	Wayne Blackburn	A-29394	1957	7,160	C	132	6	4-R	Qal	-23r	6-10-57	J-5	25r	6-10-57	S	580	50	L.
5bcc-1	Verle Sorenson	A-14566	1941	7,080	C	65	6	4-R	Qal	-32.9	11-15-66	P-3	25r / 9r	12-10-41	S	-	-	L.
5ccc-1	Reed Brian	-	1955	7,063	C	250	6	4-R	Qal	-32.0	11-28-66	S-5	-	-	S	490	50	Pumped intermittently; water level includes some residual drawdown.
5dcc-1	Ralph Pace	A-23244	1951	7,095	C	161	6	4-S	Qal	-11.9	11-28-66	C-3	10r / 12r	11-19-51	S	-	-	L.
6aac-1	Worth Sorenson	-	1958	7,053	C	60	6	4-R	Qal	-14r	11-16-66	J-5	-	-	S	730	50	
6baa-1	C. V. Peterson	A-29240	1957	7,052	C	50	5	4-G	Qal	-13.1	9- 9-66	N	15r / 3r	6-15-57	S,O	-	-	Has been equipped with pump. L.
16bdb-1	Lloyd Chappel	A-26707	1956	7,130	C	432	12	4-G	Qal	-91.0	9- 9-66	T	1,350r	5-10-56	U,O	-	-	Well shows signs of caving, is equipped with pump but has not been pumped for several years. L.

Table 4.–(Continued)

Location	Owner or name	Application or claim number	Year drilled	Altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Character of material	Geologic source	Water level: Above(+) or below(-) land-surface datum (feet)	Water level: Date of measurement	Method of lift and type of power	Yield and drawdown: Yield (gpm) / Drawdown (feet)	Yield and drawdown: Date of measurement	Use of water	Specific conductance (micromhos/cm at 25°C)	Temperature (°F)	Remarks and other data available
(D-28-3) 17baa-1	Peterson and Sorenson	A-28991	1957	7,045	C	375	16	4-C	Qal	-77r	6- 5-57	N	-	-	U	910	47	Drilled for irrigation but never used. Water is tumbling down well from perched zone at 25 ft below land surface. L.
20bdc-1	W. C. Morrell	-	1930	6,985	J	20	1	4-R	Qal	-10r	11- 3-66	N	-	-	U	-	-	Well is filled with pebbles. Formerly domestic use with pitcher pump.
21dbb-1	H. DeLeeuw	A-21748	1951	7,058	C	225	12	J-I	Tv	-96.0	11-17-66	T-5	2,050m / 25r	8-10-66	I	693L	54	Irrigates 150 acres. C, L.
21dcb-1	Glenn DeLeeuw	-	1940	7,035	C	97	5	4-C	Qal	-72r	11- 5-40	J-5	7r	11- 5-40	H,S	1,920	50	Better water is reported in volcanic rock at slightly greater depth. L.
26cda-1	Town of Bicknell	A-26890	1951	7,068	C	360	12	4-E	Qal	-141.4	8-11-66	T-5	580r / 100r	8-30-51	P,O	585L	55	Supplements town water supply from a spring on Thousand Lake Mountain. C, L.
28aac-1	Don Edwards	A-15064	1956	7,005	C	136	16	J-I	Tv	-43.9	9- 9-66	T-5	1,930m / 3r	9- 9-66	I,O	710	52	L.
28ada-1	do	A-15064	1943	7,014	C	124	4	4-R	Qal	-51.2	11-17-66	J-5	11r / 5r	1-20-43	S	550	54	L.
34baa-S1	Dab Keel Spring	-	-	6,925	-	-	-	4-R	Qal	-	-	F	1,975m	11- 2-66	I	460	54	Flow measurement made in Spring Ditch, a half mile below spring area.
34dbd-S1	Unnamed springs	-	-	6,920	-	-	-	J-I	Tv	-	-	F	1,350e	11- 3-66	I	590	54	Springs are in meadow at foot of volcanic ledges.
35caa-1	Wayne Smith	A-15093	1943	6,998	C	171	4	4-R	Qal	-65r	1-23-43	N	8r / 13r	1-23-43	U	-	-	Well has not been used since Bicknell water system was extended to local farms. Open casing now filled with pebbles. L.
(D-29-3) 1cab-1	M. L. Taft	A-13995	1941	6,945	C	433	6	4-R	Qal	-16r	10-27-66	C-5	12r / 7r	2- 7-41	H,S	190	52	Water level reported to be same as when well was drilled. L.
11cca-S1	Hugh King Spring	-	-	6,892	-	-	-	J-I	Tv	-	-	F	693m	10-28-66	I	190	56	Discharges from valley fill near base of volcanic bluffs.
12adc-1	June Ellett	-	1922	6,915	C	80	2	4-R	Qal	-9r	10-28-66	C-5	-	-	H,S	1,200	52	
12cac-S1	Unnamed springs	-	-	6,920	-	-	-	4-S	Qal	-	-	F	1e	10-11-66	U	1,680	50	Seeps from silt at base of volcanic hill.
12cad-1	Rulon Ellett	-	1922	6,915	C	80	2	4-R	Qal	-9r	10-27-66	C-5	-	-	H,S	1,610	50	
12ddc-1	do	A-19682	1948	6,980	C	500	10	4-R	Qal	-80r	12-20-48	T-5	404m / 28e	8-23-66	I	1,770L	50	C, L.
14abc-S1	Bullard Spring	-	-	6,895	-	-	-	J-I	Tv	-	-	F	1,380m	10-27-66	I,H,S	290	51	Discharges at surface from valley fill but in subsurface from volcanic rock.
14bcb-S1	Pine Creek Spring	-	-	6,920	-	-	-	J-I	Tv	-	-	F	7,900m	10-11-66	I	192L	50	Spring discharges at many openings along Pine Creek channel, about 300 ft. Is being planned for fish culture. C.
(D-29-4) 6ccb-1	Royal Harward	A-18863	-	6,935	C	365	4	4-R	Qal	-19.3	8-11-66	P	3r	12- 4-47	U,O	-	-	Was industrial use for dairy; unused for several years. L.
7bdc-1	do	-	-	6,920	C	-	4	4-A	Qal	-	-	F	-	-	S	5,960L	47	Well is at foot of hillside composed of sedimentary rocks of Triassic age. The highly mineralized water probably is derived from these sources. C.

Table 5.—Drillers' logs of selected wells in the upper Fremont River valley

Altitudes are estimated from topographic maps and hand leveling or determined by altimeter, in feet above mean sea level for land surface at the well.
Thickness in feet.
Depth in feet below the land surface.

Material	Thickness	Depth
(D-27-2)24dbd-2. Log by C. W. Anderson. Alt. 7,180 ft.		
Topsoil	1	1
Clay; water at 21 ft.	20	21
Clay	52	73
Sand and gravel; minor flow of water	17	90
Clay	22	112
Sand and gravel; flow of water	45	157
Sand, cemented; no water pressure; well plugged at 170 ft.	150	307
(D-27-2)26cda-1. Log by S. Stephenson Drilling Co. Alt. 7,175 ft.		
Topsoil	8	8
Boulders, sand, and clay; water at 8 ft.	12	20
Boulders	10	30
Boulders and clay	25	55
Lava rock, mostly solid	110	165
Lava rock with sand and clay	17	182
Lava rock, solid	10	192
(D-27-2)26ddc-1. Log by A. R. Pierce. Alt. 7,160 ft.		
Clay	32	32
Sand, black	6	38
Clay and sand	202	240
Gravel and sand	24	264
Clay	6	270
(D-27-2)26ddd-1. Log by L. L. Benning. Alt. 7,150 ft.		
Clay	8	8
Gravel; water	2	10
Gravel and blue clay	50	60
Sand and clay; water flow 3 gpm.	5	65
Clay, blue	20	85
Sand and red clay	10	95
Gravel and sand; water flow 75 gpm	15	110
Clay, yellow	3	113
Gravel; water flow 60 gpm	7	120
Clay, red	3	123
Gravel and sand; yields water	25	148
Clay, red	10	158
Clay, white	10	168
Clay, red	14	182
Gravel and sand; yields water	2	184
Gravel and white clay	8	192
Clay, red	10	202
Gravel and white clay	11	213
Clay, pink	15	228
Clay, red	7	235
Clay, white	5	240
Gravel and white clay	6	246
Gravel and red clay	16	262
Clay, white	13	275
(D-27-2)33dda-1. Log by B. B. Gardner. Alt. 7,280 ft.		
Topsoil	4	4
Boulders and gravel, lava rock	8	12
Gravel and lava rock; water	6	18
Boulders and clay	17	35
Lava, red, and cinders; water	220	255
(D-27-2)34ccc-1. Log by B. B. Gardner.		
Gravel and boulders	20	20
Clay	20	40
Gravel and coarse sand; water	58	98
Clay	102	200
Hardpan; yielding much water	85	285
Boulders and clay; no water	15	300
(D-27-2)35bba-1. Log by B. B. Gardner. Alt. 7,200 ft.		
Boulders and gravel	10	10
Clay	10	20
Sand; water	6	26
Clay	32	58
Gravel and sand; water	5	63
Clay	27	90
Gravel and sand; water	30	120
Clay	50	170
Gravel and sand; water	13	183
(D-27-2)35bba-1 - Continued		
Hardpan	13	196
Sand	34	230
Clay	35	265
Sand, fine; water	35	300
Clay	10	310
Sand, fine	20	330
Clay	18	348
Sand, fine; water	5	353
Clay	12	365
Gravel and sand; water	5	370
(D-27-2)36dac-1. Log by B. B. Gardner. Alt. 7,080 ft.		
Soil	6	6
Boulders and gravel	14	20
Conglomerate	15	35
Gravel; water	6	41
Conglomerate	34	75
Boulders, volcanic	10	85
Boulders	5	90
Rock, solid	30	120
Ash, volcanic	15	135
Gravel and sand; water	7	142
(D-27-3)16aac-1. Log by B. B. Gardner. Alt. 7,394 ft.		
Loam, sandy	5	5
Clay, sandy	75	80
Hardpan	47	127
Sand and gravel; water	48	175
Gravel; water	7	182
(D-27-3)17cab-1. Log by B. B. Gardner. Alt. 7,248 ft.		
Topsoil	8	8
Boulders	42	50
Gravel and sand; water bearing	5	55
Sandstone, red	20	75
Clay, red	17	92
Gravel and sand; water bearing	5	97
(D-27-3)17dbc-1. Log by B. B. Gardner. Alt. 7,234 ft.		
Topsoil	7	7
Boulders and gravel; water	18	25
Clay	11	36
Boulders and gravel; water	34	70
Clay	12	82
Sand and gravel; water	18	100
Clay	15	115
Sand and gravel; water	39	154
(D-27-3)18ddb-2. Log by B. B. Gardner. Alt. 7,225 ft.		
Gravel	10	10
Hardpan	25	35
Sand and gravel; water	13	48
Clay	47	95
Sand and gravel; water	8	103
Clay	17	120
Sand and gravel; water	2	122
(D-27-3)19aaa-1. Log by B. B. Gardner. Alt. 7,190 ft.		
Loam, sandy	5	5
Gravel and boulders; water	60	65
Clay	30	95
Gravel; flowing water	7	102
Clay	43	145
Gravel; flowing water	8	153
Clay	12	165
Gravel; flowing water	5	170
Clay	38	208
Gravel; flowing water	17	225
Clay	38	263
Gravel; flowing water	9	272
Clay	8	280
Gravel; flowing water	5	285
(D-27-3)19ada-1. Log by B. B. Gardner. Alt. 7,179 ft.		
Loam, sandy	4	4
Gravel and boulders; water	81	85
Clay	115	200
Gravel; flowing water	12	212
Clay	23	235
Sand and gravel; flowing water	7	242
(D-27-3)19ada-1 - Continued		
Clay	38	280
Sand	32	312
Gravel; flowing water	13	325
Clay, sandy	35	360
Gravel; flowing water	14	374
Clay	22	396
Gravel; flowing water	19	415
Clay, sandy	15	430
Gravel and sand; flowing water	5	435
(D-27-3)19bcc-1. Log by B. B. Gardner. Alt. 7,190 ft.		
Gravel and boulders	10	10
Boulders	15	25
Gravel and boulders; water	5	30
Clay, blue	51	81
Sand and gravel; flowing water, 8 gpm	4	85
Clay	32	117
Sand and gravel; water bearing	35	152
(D-27-3)30acd-1. Log by B. B. Gardner. Alt. 7,145 ft.		
Gravel	10	10
Hardpan	25	35
Boulders	50	85
Gravel and boulders; water	9	94
Conglomerate, hard	68	162
Gravel and boulders	6	168
Conglomerate and hardpan	32	200
Gravel and boulders	10	210
Conglomerate and hardpan	40	250
Sand and gravel; water	6	256
(D-27-3)31dcd-1. Log by Sharp Welding Co. Alt. 7,060 ft.		
Sand and clay; water at 31 ft.	74	74
Gravel; water bearing	1	75
(D-28-2)3cbc-1. Log by B. B. Gardner.		
Topsoil, sandy	4	4
Boulders	6	10
Clay	110	120
Sand and gravel, water; flow 50 gpm	9	129
Boulders	6	135
Lava rock; flowing water	63	198
(D-28-2)3ccb-1. Log by B. B. Gardner.		
Lava boulders and clay	20	20
Gravel	15	35
Clay	135	170
Gravel; flowing water 50 gpm	13	183
Clay	18	201
Lava rock; flowing water	132	333
(D-28-2)3ccc-1. Log by B. B. Gardner.		
Topsoil	5	5
Clay	19	24
Gravel; water	6	30
Clay	63	93
Gravel; flowing water 10 gpm	7	100
Clay	90	190
Lava boulders	13	203
Lava rock; flowing water	73	276
(D-28-2)11abb-1. Log by B. B. Gardner. Alt. 7,076 ft.		
Loam, sandy	8	8
Gravel and boulders	15	23
Conglomerate, hard	91	114
Gravel; water	2	116
Hardpan	9	125
Sand, fine, black; water bearing	5	130
(D-28-2)12dbc-1. Log by B. B. Gardner. Alt. 7,040 ft.		
Gravel and boulders	20	20
Gravel; water bearing	24	44
Gravel, sandy, and clay	119	163
Lava cinders; water bearing	120	283

Table 5.--(Continued)

Material	Thickness	Depth
(D-28-3)4ccd-1. Log by W. J. Hill. Alt. 7,156 ft.		
Topsoil	1	1
Clay, sandy	16	17
Lava boulders and clay	29	46
Clay, sandy	17	63
Sand, fine; water	12	75
Gravel; water	1	76
Clay	70	146
Sand, fine; water	9	155
Clay, sandy	10	165
Gravel and sand; water	5	170
Clay, sandy	15	185
(D-28-3)5abb-1. Log by B. B. Gardner. Alt. 7,160 ft.		
Hardpan	10	10
Clay, sandy	27	37
Sand and gravel; water bearing	8	45
Clay, sandy	55	100
Clay and hardpan	27	127
Sand	2	129
Gravel and lava cinders, clay at base	3	132
(D-28-3)5bcc-1. Log by B. B. Gardner. Alt. 7,080 ft.		
Topsoil	7	7
Clay	33	40
Sand; water bearing	2	42
Clay	14	56
Gravel and sand; water bearing	3	59
Clay	3	62
Gravel and sand; water bearing	3	65
(D-28-3)5dcc-1. Log by W. J. Hill. Alt. 7,095 ft.		
Topsoil, sandy clay	1	1
Clay and pebbles	14	15
Sand; water bearing	19	34
Clay	101	135
"Rocks"; water bearing	5	140
Clay, sandy	9	149
"Rocks" and sand; water bearing	11	160
Clay	1	161
(D-28-3)6baa-1. Log by B. B. Gardner. Alt. 7,052 ft.		
Topsoil	5	5
Gravel and boulders; water bearing	13	18
Clay, sandy	27	45
Gravel; water	5	50
(D-28-3)16bdb-1. Log by H. S. Petersen. Alt. 7,130 ft.		
Clay	13	13
Gravel; water bearing	1	14
Clay	31	45
Gravel and sand; water bearing	13	58
Gravel; water bearing	2	60
Clay	17	77
Gravel and sand	1	78
Gravel and clay	34	112
(D-28-3)16bdb-1 - Continued		
Gravel; water bearing	1	113
Clay	2	115
Gravel, in thin layers	10	125
Gravel, fine; water bearing	12	137
Clay	8	145
Gravel	2	147
Clay	56	203
Gravel and sand	30	233
Clay	10	243
Gravel	5	248
Clay	6	254
Gravel	1	255
Gravel and clay layers	119	374
Rock; water bearing	58	432
(D-28-3)17baa-1. Log by B. B. Gardner. Alt. 7,045 ft.		
Loam, sandy	10	10
Gravel and sand; water bearing	8	18
Clay	14	32
Gravel; water bearing	6	38
Clay	8	46
Gravel; water bearing	5	51
Clay	37	88
Gravel; water bearing	3	91
Clay	17	108
Gravel; water bearing	6	114
Gravel in streaks; water bearing	21	135
Clay	19	154
Gravel; water bearing	3	157
Clay	21	178
Gravel; water bearing	6	184
Clay	6	190
Gravel and clay	25	215
Streaks of gravel and clay	96	311
Lava rock	64	375
(D-28-3)21dbb-1. Log by W. J. Hill. Alt. 7,038 ft.		
Topsoil, sandy	1	1
Gravel, sand, and clay, cemented	96	97
Gravel and sand; water bearing	13	110
Cobbles, gravel, sand, and clay, cemented	75	185
Lava ledge; water bearing	35	220
Lava, large blocks; water bearing	5	225
(D-28-3)21dcb-1. Log by C. W. Anderson. Alt. 7,035 ft.		
Old excavated cistern	12	12
Conglomerate	45	57
Lava rock	15	72
Lava, porous; water bearing	25	97
(D-28-3)26cda-1. Log by B. B. Gardner, Alt. 7,068 ft.		
Gravel and boulders	25	25
Conglomerate	32	57
Clay, sandy	98	155
Gravel and sand; water bearing	13	168
Clay, sandy	182	350
Gravel and sand, water bearing	10	360
(D-28-3)28aac-1. Log by B. B. Gardner. Alt. 7,005 ft.		
Topsoil	5	5
Gravel and boulders	39	44
Lava rock; water bearing	92	136
(D-28-3)28ada-1. Log by B. B. Gardner. Alt. 7,014 ft.		
Topsoil	7	7
Gravel and hard clay	58	65
Gravel and sand; water bearing	3	68
Clay	7	75
Gravel and hard clay	15	90
Gravel and sand; water bearing	6	96
Hardpan and boulders	14	110
Boulders	11	121
Gravel and sand; water bearing	3	124
(D-28-3)35caa-1. Log by B. B. Gardner. Alt. 6,998 ft.		
Clay, red	6	6
Sand and clay, red	99	105
Gravel and sand; water bearing	7	112
Clay, red	6	118
Gravel and boulders	22	140
Gravel and sand; water bearing	7	147
Sand and red clay, mixed	21	168
Gravel and sand; water bearing	3	171
(D-29-3)1cab-1. Log by B. B. Gardner. Alt. 6,945 ft.		
Topsoil	3	3
Boulders	32	35
Gravel and sand; water bearing	12	47
Clay, red	231	278
Clay, red, with layers of silt	155	433
Gravel, water bearing	-	433
(D-29-3)12ddc-1. Log by B. B. Gardner. Alt. 6,980 ft.		
Loam, sandy	5	5
Gravel and boulders	20	25
Clay, sandy	55	80
Gravel and sand; water bearing	32	112
Clay, sandy	148	260
Gravel and sand; water bearing	20	280
Clay, sandy	210	490
Gravel; water bearing	10	500
(D-29-4)6ccb-1. Log by B. B. Gardner. Alt. 6,935 ft.		
Topsoil	1	1
Soil and boulders	24	25
Sand; water bearing	39	64
Clay	11	75
Gravel, fine and sandy clay; water bearing	32	107
Clay	9	116
Clay, sandy; water bearing	69	185
Clay	15	200
Clay, sandy; water bearing	5	205
Gravel, sand, clay, and hardpan	150	355
Clay, sandy, gravel and boulders; water bearing	10	365

Table 6.—Chemical analyses of water from selected wells, springs, and streams in the upper Fremont River valley

Sodium: Where no value is shown for potassium, sodium and potassium values are calculated and reported as sodium.
Dissolved solids: Dissolved-solids values greater than 1,000 parts per million are calculated from determined constituents, those less than 1,000 parts per million are residue on evaporation at 180°C.
Agency making analysis: AC, Utah State University; GS, U.S. Geological Survey; PH, Utah State Department of Public Health; SC, Utah State Chemist.

Location	Date of collection	Temperature (°F)	Parts per million															Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos/cm at 25°C)	pH	Agency making analysis
			Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$					
(D-26-3)35cb-S	10-25-66	50	32	29	10	7.5		143	0	3.6	6.5	-	0.1	-	168	114	0	12	0.3	239	7.9	GS
(D-27-2)25baa-S1 1/	9-27-62	61	36	35	8.0	11		135	0	18	10	-	1.4	-	173	121	10	16	.4	265	7.9	GS
2/	9-27-62	59	38	28	6.6	14		122	0	9.5	11	-	1.4	-	154	97	0	23	.6	231	8.0	GS
	10-10-66	62	35	20	7.3	12		110	0	3.4	7.8	-	.9	-	136	80	0	24	.6	203	7.4	GS
26ddc-1	9- 9-66	52	40	27	7.3	12		124	0	15	4.1	-	.9	-	169	98	0	21	.5	252	7.7	GS
33dad-S1	5-17-41	-	33	22	4.8	15		123	0	2.6	12	0.3	0	-	158	74	0	30	.8	-	7.7	SC
3/	8-12-53	-	44	24	5.8	18		121	0	11	5.8	.1	.8	-	155	82	0	32	.9	-	8.0	SC
4/	10-20-54	63	38	22	5.1	13	3.6	115	0	3.1	5.5	.2	2.1	-	152	76	0	26	.7	212	7.8	GS
33dda-1 5/	1-21-64	-	38	21	7.0	12	2.7	116	1.0	3.0	7.0	.3	2.5	0.07	173	82	0	23	.6	215	8.0	PH
	9-20-66	62	39	22	6.3	12		114	0	3.9	5.6	-	1.3	-	141	80	0	25	.6	211	7.6	GS
(D-27-3)16aac-1	4-24-59	-	26	154	65	88		316	0	542	10	.1	8.2	.43	1,050	652	393	23	1.5	1,370	7.8	GS
18ddb-1	10-14-66	-	30	104	32	39		143	0	290	38	-	2.3	-	604	390	273	18	.9	832	7.5	GS
19aaa-1	4-24-59	-	30	289	51	35		152	0	813	23	0	3.4	.12	1,320	930	805	8	.5	1,580	7.6	GS
	8- 8-66	52	27	263	46	36		180	0	714	20	-	3.1	-	1,200	844	696	8	.5	1,450	7.9	GS
19ada-1	4-24-59	-	32	373	75	49		177	0	1,110	30	.1	5.2	.10	1,760	1,240	1,090	8	.6	1,990	7.7	GS
22dcb-S1	9-29-66	48	30	110	34	17		239	0	221	12	-	9.8	-	558	415	219	8	.4	776	7.7	GS
(D-28-2)3ccb-1	8- 4-66	63	38	24	6.1	12		124	0	3.7	3.6	-	.9	-	152	86	0	23	.5	215	7.5	GS
(D-28-3)3dac-S1	5-16-41	-	36	56	13	50		150	-	69	12	.1	0	-	293	193	70	36	1.6	-	7.6	SC
6/	1-30-61	-	31	57	14	7.5	2.8	164	23	72	7.0	.2	.9	.21	296	200	65	8	.2	425	8.4	PH
21dbb-1	8-10-66	54	34	98	20	22		170	0	191	22	-	7.0	-	493	328	189	13	.5	693	7.7	GS
26cda-1 7/	1-21-64	-	41	35	13	90	5.0	272	3.0	58	30	3.5	14	.60	415	141	0	57	3.3	635	8.3	PH
	8-11-66	55	43	38	14	73		266	0	70	9.9	-	3.6	-	382	150	0	51	2.6	585	7.8	GS
(D-29-3)12ddc-1	8-23-66	50	33	156	55	158		166	0	499	216	-	.2	-	1,200	616	480	36	2.8	1,770	7.5	GS
14bcb-S1 1/	5- 2-62	48	32	22	7.8	5.1	1.8	114	0	2.1	2.0	.1	.1	.03	119	88	0	11	.2	185	7.9	GS
1/	9-27-62	48	30	28	7.3	6.5		125	0	3.9	4.0	-	1.1	-	128	99	0	12	.3	199	7.9	GS
	10-11-66	50	28	21	9.2	5.4		117	0	1.9	2.2	-	.9	-	118	90	0	12	.2	192	7.5	GS
(D-29-4)7bdc-1	8-12-66	47	14	303	140	861		130	0	1,020	1,440	-	1.9	-	3,840	1,330	1,220	58	10	5,960	7.7	GS
Fremont River near Fremont	7- 1-49	-	-	19	6.2	5.1	3.1	124	-	7.2	3.9	-	.2	-	-	73	0	12	.3	180	-	AC
Fremont River near Bicknell	8- 3-49	-	-	51	18	17	5.9	159	-	99	14	-	.2	-	-	201	71	15	.5	500	-	AC
	9-11-49	-	-	36	14	20	7.0	142	-	124	15	-	.4	-	-	148	31	22	.7	520	-	AC
	11- 1-66	52	-	-	-	26		176	0	126	16	-	-	-	373	242	98	19	.7	543	7.2	GS

1/ Analysis includes 0.01 ppm iron.
2/ Analysis includes 0.00 ppm iron.
3/ Analysis includes 0.02 ppm iron.
4/ Analysis includes 0.00 ppm iron and 0.00 ppm manganese.
5/ Analysis includes 0.01 ppm iron and 0.00 ppm manganese.
6/ Analysis includes 0.23 ppm iron and 0.00 ppm manganese.
7/ Analysis includes 0.02 ppm iron and 0.00 ppm manganese.

PUBLICATIONS OF THE UTAH DEPARTMENT OF NATURAL RESOURCES, DIVISION OF WATER RIGHTS

(*)—Out of Print

TECHNICAL PUBLICATIONS

No. 1. Underground leakage from artesian wells in the Flowell area, near Fillmore, Utah, by Penn Livingston and G. B. Maxey, U.S. Geological Survey, 1944.

No. 2. The Ogden Valley artesian reservoir, Weber County, Utah, by H. E. Thomas, U.S. Geological Survey, 1945.

*No. 3. Ground water in Pavant Valley, Millard County, Utah, by P. E. Dennis, G. B. Maxey, and H. E. Thomas, U.S. Geological Survey, 1946.

*No. 4. Ground water in Tooele Valley, Tooele County, Utah, by H. E. Thomas, U.S. Geological Survey, in Utah State Eng. 25th Bienn. Rept., p. 91-238, pls. 1-6, 1946.

*No. 5. Ground water in the East Shore area, Utah: Part I, Bountiful District, Davis County, Utah, by H. E. Thomas and W. B. Nelson, U.S. Geological Survey, in Utah State Eng. 26th Bienn. Rept., p. 53-206, pls. 1-2, 1948.

*No. 6. Ground water in the Escalante Valley, Beaver, Iron, and Washington Counties, Utah, by P. F. Fix, W. B. Nelson, B. E. Lofgren, and R. G. Butler, U.S. Geological Survey, in Utah State Eng. 27th Bienn. Rept., p. 107-210, pls. 1-10, 1950.

No. 7. Status of development of selected ground-water basins in Utah, by H. E. Thomas, W. B. Nelson, B. E. Lofgren, and R. G. Butler, U.S. Geological Survey, 1952.

*No. 8. Consumptive use of water and irrigation requirements of crops in Utah, by C. O. Roskelly and Wayne D. Criddle, 1952.

No. 8. (Revised) Consumptive use and water requirements for Utah, by W. D. Criddle, K. Harris, and L. S. Willardson, 1962.

No. 9. Progress report on selected ground water basins in Utah, by H. A. Waite, W. B. Nelson, and others, U.S. Geological Survey, 1954.

No. 10. A compilation of chemical quality data for ground and surface waters in Utah, by J. G. Connor, C. G. Mitchell, and others, U.S. Geological Survey, 1958.

No. 11. Ground water in northern Utah Valley, Utah: A progress report for the period 1948-1963, by R. M. Cordova and Seymour Subitzky, U.S. Geological Survey, 1965.

No. 12. Reevaluation of the ground-water resources of Tooele Valley, Utah, by Joseph S. Gates, U.S. Geological Survey, 1965.

*No. 13. Ground-water resources of selected basins in southwestern Utah, by G. W. Sandberg, U.S. Geological Survey, 1966.

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No. 16. Ground-water conditions in Cedar Valley, Utah County, Utah, by R. D. Feltis, U.S. Geological Survey, 1967.

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No. 19. Appraisal of the quality of surface water in the Sevier Lake basin, Utah, by D. C. Hahl and J. C. Mundorff, U. S. Geological Survey, 1968.

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No. 21. Summary of maximum discharges in Utah streams, by G. L. Whitaker, U. S. Geological Survey, 1969.

WATER CIRCULAR

No. 1. Ground water in the Jordan Valley, Salt Lake County, Utah, by Ted Arnow, U.S. Geological Survey, 1965.

BASIC-DATA REPORTS

No. 1. Records and water-level measurements of selected wells and chemical analyses of ground water, East Shore area, Davis, Weber, and Box Elder Counties, Utah, by R. E. Smith, U.S. Geological Survey, 1961.

No. 2. Records of selected wells and springs, selected drillers' logs of wells, and chemical analyses of ground and surface waters, northern Utah Valley, Utah County, Utah, by Seymour Subitzky, U.S. Geological Survey, 1962.

No. 3. Ground-water data, central Sevier Valley, parts of Sanpete, Sevier, and Piute Counties, Utah, by C. H. Carpenter and R. A. Young, U.S. Geological Survey, 1963.

No. 4. Selected hydrologic data, Jordan Valley, Salt Lake County, Utah, by I. W. Marine and Don Price, U.S. Geological Survey, 1963.

No. 5. Selected hydrologic data, Pavant Valley, Millard County, Utah, by R. W. Mower, U.S. Geological Survey, 1963.

*No. 6. Ground-water data, parts of Washington, Iron, Beaver, and Millard Counties, Utah, by G. W. Sandberg, U.S. Geological Survey, 1963.

No. 7. Selected hydrologic data, Tooele Valley, Tooele County, Utah, by J. S. Gates, U.S. Geological Survey, 1963.

No. 8. Selected hydrologic data, upper Sevier River basin, Utah, by C. H. Carpenter, G. B. Robinson, Jr., and L. J. Bjorklund, U.S. Geological Survey, 1964.

No. 9. Ground-water data, Sevier Desert, Utah, by R. W. Mower and R. D. Feltis, U.S. Geological Survey, 1964.

No. 10. Quality of surface water in the Sevier Lake basin, Utah, by D. C. Hahl and R. E. Cabell, U.S. Geological Survey, 1965.

No. 11. Hydrologic and climatologic data, collected through 1964, Salt Lake County, Utah by W. V. Iorns, R. W. Mower, and C. A. Horr, U.S. Geological Survey, 1966.

No. 12. Hydrologic and climatologic data, 1965, Salt Lake County, Utah, by W. V. Iorns, R. W. Mower, and C. A. Horr, U.S. Geological Survey, 1966.

No. 13. Hydrologic and climatologic data, 1966, Salt Lake County, Utah, by A. G. Hely, R. W. Mower, and C. A. Horr, U.S. Geological Survey, 1967.

No. 14. Selected hydrologic data, San Pitch River drainage basin, Utah, by G. B. Robinson, Jr., U.S. Geological Survey, 1968.

No. 15. Hydrologic and climatologic data. 1967, Salt Lake County, Utah, by A. G. Hely, R. W. Mower, and C. A. Horr, U.S. Geological Survey, 1968.

INFORMATION BULLETINS

*No. 1. Plan of work for the Sevier River Basin (Sec. 6, P.L. 566), U.S. Department of Agriculture, 1960.

No. 2. Water production from oil wells in Utah, by Jerry Tuttle, Utah State Engineer's Office, 1960.

No. 3. Ground-water areas and well logs, central Sevier Valley, Utah, by R. A. Young, U.S. Geological Survey, 1960.

*No. 4. Ground-water investigations in Utah in 1960 and reports published by the U.S. Geological Survey or the Utah State Engineer prior to 1960, by H. D. Goode, U.S. Geological Survey, 1960.

No. 5. Developing ground water in the central Sevier Valley, Utah, by R. A. Young and C. H. Carpenter, U.S. Geological Survey, 1961.

*No. 6. Work outline and report outline for Sevier River basin survey, (Sec. 6, P.L. 566), U.S. Department of Agriculture, 1961.

No. 7. Relation of the deep and shallow artesian aquifers near Lynndyl, Utah, by R. W. Mower, U.S. Geological Survey, 1961.

No. 8. Projected 1975 municipal water-use requirements, Davis County, Utah, by Utah State Engineer's Office, 1962.

No. 9. Projected 1975 municipal water-use requirements, Weber County, Utah, by Utah State Engineer's Office, 1962.

No. 10. Effects on the shallow artesian aquifer of withdrawing water from the deep artesian aquifer near Sugarville, Millard County, Utah, by R. W. Mower, U.S. Geological Survey, 1963.

No. 11. Amendments to plan of work and work outline for the Sevier River basin (Sec. 6, P.L. 566), U.S. Department of Agriculture, 1964.

No. 12. Test drilling in the upper Sevier River drainage basin, Garfield and Piute Counties, Utah, by R. D. Feltis and G. B. Robinson, Jr., U.S. Geological Survey, 1963.

No. 13. Water requirements of lower Jordan River, Utah, by Karl Harris, Irrigation Engineer, Agricultural Research Service, Phoenix, Arizona, prepared under informal cooperation approved by Mr. William W. Donnan, Chief, Southwest Branch (Riverside, California) Soil and Water Conservation Research Division, Agricultural Research Service, U.S.D.A. and by Wayne D. Criddle, State Engineer, State of Utah, Salt Lake City, Utah, 1964.

*No. 14. Consumptive use of water by native vegetation and irrigated crops in the Virgin River area of Utah, by Wayne D. Criddle, Jay M. Bagley, R. Keith Higginson, and David W. Hendricks, through cooperation of Utah Agricultural Experiment Station, Agricultural Research Service, Soil and Water Conservation Branch, Western Soil and Water Management Section, Utah Water and Power Board, and Utah State Engineer, Salt Lake City, Utah, 1964.

No. 15. Ground-water conditions and related water-administration problems in Cedar City Valley, Iron County, Utah, February, 1966, by Jack A. Barnett and Francis T. Mayo, Utah State Engineer's Office.

No. 16. Summary of water well drilling activities in Utah, 1960 through 1965, compiled by Utah State Engineer's Office, 1966.

No. 17. Bibliography of U.S. Geological Survey Water Resources Reports for Utah, compiled by Olive A. Keller, U.S. Geological Survey, 1966.

No. 18. The effect of pumping large-discharge wells on the ground-water reservoir in southern Utah Valley, Utah County, Utah, by R. M. Cordova and R. W. Mower, U.S. Geological Survey, 1967.

No. 19. Ground-water hydrology of southern Cache Valley, Utah, by L. P. Beer, 1967.

No. 20. Fluvial sediment in Utah, 1905-65, A data compilation, by J. C. Mundorff, U. S. Geological Survey, 1968.