Geology and Ground Water in Russian River Valley Areas and in Round, Laytonville and Little Lake Valleys Sonoma and Mendocino Counties, California

By G. T. CARDWELL

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1548

Prepared in cooperation with the California Department of Water Resources

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1965

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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By G. T. CARDWELL

ABSTRACT

This report describes the occurrence, availability, and quality of ground water in seven valley areas along the course of the Russian River in Sonoma and Mendocino Counties, Calif., and in three valleys in the upper drainage reach of the Eel River in Mendocino County.

Except for the westward-trending lower Russian River valley, the remaining valley areas along the Russian River (Healdsburg, Alexander, Cloverdale, Sanel, Ukiah, and Potter Valleys) lie in northwest-trending structurally controlled depressions formed in marine rocks of Jurassic and Cretaceous age. The principal aquifer in all the valleys is the alluvium of Recent age, which includes highly permeable channel deposits of gravel and sand.

Water for domestic, irrigation, industrial, and other uses is developed by (1) direct diversion from the Russian River and its tributaries, (2) withdrawal of ground water and river water from shallow wells near the river, and (3) withdrawals of ground water from wells in alluvial deposits at varying distances from the river.

Surface water in the Russian River and most tributaries is of good chemical quality. The water is a calcium magnesium bicarbonate type and contains 75–200 parts per million of dissolved solids. Ground water is also of good chemical quality throughout most of the drainage basin, but the concentration of dissolved solids (100–300 parts per million) is somewhat higher than that in the surface water.

Round, Laytonville, and Little Lake Valleys are in central and northern Mendocino County in the drainage basin of the northwestward flowing Eel River. In Round Valley the alluvium of Recent age yields water of good chemical quality in large quantities. Yields are lower and the chemical quality poorer in Laytonville Valley. Ground water in Little Lake Valley is relatively undeveloped.

Selected descriptions of wells, drillers' logs, chemical analyses, and hydrographs showing water-level fluctuations are included in the report. Accompanying maps show the distribution of water-bearing formations and the location of wells.

INTRODUCTION

PURPOSE AND SCOPE

This report has been prepared by the U.S. Geological Survey in cooperation with the California Department of Water Resources to provide fundamental geologic and hydrologic information about 10 valleys in Sonoma and Mendocino Counties, Calif.

Included in this report are outlines of the geology and descriptions of the ground-water conditions in seven valleys, or valley areas, along the course of the Russian River in Sonoma and Mendocino Counties, Calif., and in three valleys in the upper drainage basin of the Eel River in Mendocino County.

The work in the Mendocino County part of the area, supplementing previous work by the California Department of Water Resources, was initiated to determine a basis for setting up well construction standards in the county.

LOCATION OF THE AREA

The Russian River basin is in northern Sonoma and southeastern Mendocino Counties, Calif., and lies between lat. 38°25′ and 39°20′ N. and long. 122°45′ and 123°15′ W. (fig. 1).

Round, Laytonville, and Little Lake Valleys are in the southern part of the Eel River drainage basin, in the central and northern parts of Mendocino County. The southernmost, Little Lake Valley, is about 110 miles north-northwest of San Francisco.

The location of individual areas discussed is shown in figure 1.

PREVIOUS INVESTIGATIONS

The earliest report dealing with the water resources of the area was an inventory of the major springs (Waring, 1915). A brief investigation of the water resources and land use of the Russian River basin was made by the U.S. Bureau of Reclamation (1945). The U.S. Army Corps of Engineers (1948) studied the potential effects and benefits of water-storage reservoirs proposed in the Russian River basin for flood control and allied purposes, and the U.S. Department of Agriculture, Soil Conservation Service (1950), surveyed the effects on runoff, erosion, and flood control that might result from the construction of certain stream-control structures in the Russian River watershed.

The California Division of Water Resources (1951) studied the flow and chemical-quality characteristics of the Russian River. Cotton (1953) described possible methods of obtaining water for irrigation in Round Valley. Rantz (1954) reported on some aspects of the hydrology, particularly streamflow, of the north coastal area (Eel River drainage and northward). The author (1958) investigated ground-water conditions in the Santa Rosa and Petaluma Valley areas, which are adjacent to the Healdsburg area. The California Division of Water Resources (1956) investigated the geology and water quality in ground-water basins in Mendocino County to determine standards for well construction.

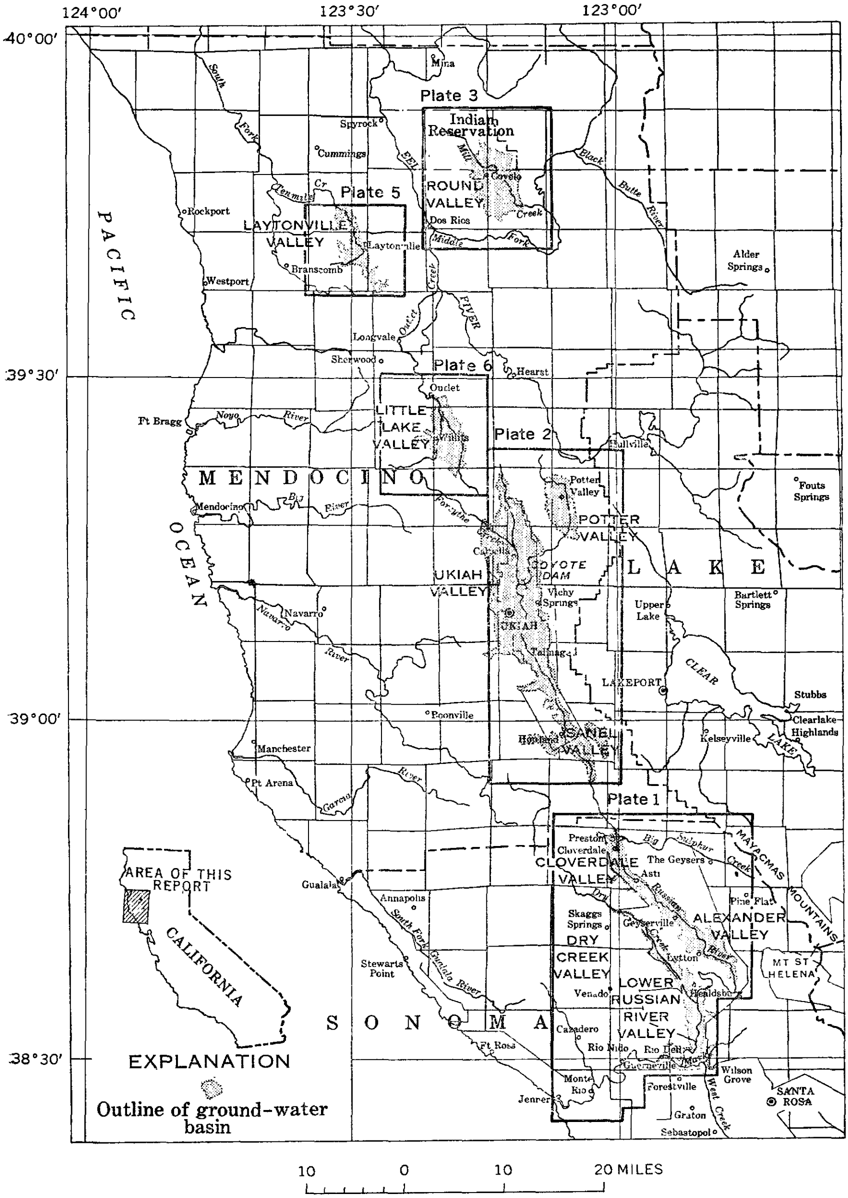

FIGURE 1.—Index map showing location of areas described in this report.

Many geological studies have included all or part of the lower and middle Russian River valley areas. Holway (1913) made a study of the geomorphic history of the Russian River; Gealey (1950) mapped the Healdsburg quadrangle; Travis (1952) mapped the Sebastopol quadrangle; Higgins (1952) mapped the terraces along the lower Russian River valley and the bedrock in the area near the river mouth and studied the physiographic history of the lower and middle Russian River. The soils map of the Healdsburg area (Watson and others, 1917) was used as an aid in mapping the geology of the area of this report.

Local geologic studies in the upper Russian River valley were made by Marliave (in U.S. Army Corps of Engineers, 1948) and Treasher (1955); basin-wide mapping was done by the California Division of Water Resources (1956) and Holway (1913). Watson and Pendleton (1916) mapped the soils of the Ukiah area, and the California State Division of Forestry (1951) mapped the upland soils of Mendocino County.

Previous geologic work relating to ground-water basins within the Eel River drainage basin was done by Clark (1940), who mapped an area in the vicinity of Round Valley; Irwin and Tatlock (oral commun., 1954), who did reconnaissance mapping of bedrock in the Eel River basin; and the California Division of Water Resources (1956), who mapped the ground-water basins. Dean (1920) mapped the soils of the Willits area (Little Lake Valley), and the California State Division of Forestry (1951) mapped the upland soils of Mendocino County.

METHODS OF INVESTIGATION

In the present investigation, an inventory was made of selected wells, including most of the irrigation, public-supply, and large-draft industrial wells. Periodic water-level measurements were made in all valley areas to determine the magnitude and character of water-level fluctuations, and several wells were equipped with automatic water-level recorders to determine the hydrologic characteristics of the aquifers. Most of the wells for which drillers' logs are available were located in the field to obtain information on the subsurface geology. The surface and subsurface geology was studied and correlated, where possible, and some field mapping was done to supplement published and unpublished geologic maps available in 1955. Chemical analyses of water from wells and streams in the area were compiled, and additional samples were collected and analyzed to provide a basis for determining the chemical quality of ground and surface waters. Available data on ground-water pumpage were collected, and estimates of ground-water storage capacity were made for some areas.

The investigation was made under the supervision of J. F. Poland, former Geological Survey district geologist in charge of cooperative ground-water investigations in California. The author was assisted by A. R. Leonard in the field and in the preparation of this report.

ACKNOWLEDGMENTS

The investigation was aided materially by those who gave data and other helpful information. In particular, thanks are expressed to David Hill and James Welsh of the California Department of Water Resources, who supplied data collected as a part of the field study made by their agency in Mendocino County. Grateful acknowledgment is made also to the local well drillers, officials of private and municipal water companies, and the many land owners who permitted access to their properties and wells. W. P. Irwin and D. B. Tatlock, U.S. Geological Survey, provided information concerning the general character of the bedrock in valleys in the Eel River drainage basin.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report is based on the rectangular system of subdividing public land and the location of the well. Many valley areas were privately acquired through land grants made by the Spanish or Mexican Governments and have never been formally subdivided into sections. These areas are subdivided for reference purposes by extending the section lines from adjacent areas or by superimposing an arbitrary land grid.

A well-location number has two basic parts: for example, in well 10/9-26L2 the part preceding the hyphen indicates the township and range (T. 10 N., R. 9 W.), and the part following the hyphen indicates the section (sec. 26) and its subdivisions. The letter indicates the 40-acre subdivision of the section, as shown in figure 2, and the last number indicates that this was the second well inventoried in the 40-acre tract.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

FIGURE 2.—Well-numbering system.

Incomplete numbers, such as 9/8–18, indicate the approximate location of wells, springs, or sampling points and are accurate only to the extent indicated by the symbol. This system is also used to indicate the location of some outcrops or other features.

GEOGRAPHY

PHYSIOGRAPHY AND DRAINAGE

The drainage areas of the Russian and Eel Rivers are in the northern part of the California Coast Ranges section of the Pacific Border province (Fenneman, 1931). The northern Coast Ranges trend northwestward, parallel to the major structural features of the region. The mountain range that lies west of the Russian River valley and extends to the coast is commonly called the Mendocino Range, or the Mendocino Highlands. The highland area east of the lower and middle Russian River valley areas is known as the Mayacmas Mountains (fig. 1). The altitude of the highlands ranges from about 2,000 to 6,000 feet.

The highest point in the Coast Ranges, at an altitude of 6,381 feet, is on Mount Sanhedrin, about 15 miles northeast of Willits. The altitude of the divide on the west side of the Russian River ranges from 1,400 to 3,000 feet; on the east side, from 3,000 to 4,000 feet. The altitude of the mountains bordering the Russian River increases slightly from south to north. In many places the summit areas of the Mendocino Highlands and Mayacmas Mountains are in general accordance and may be remnants of a once-extensive surface of low relief.

The areas studied for this report are drained by the Russian and Eel Rivers, the two principal rivers in the northern coastal area of California between San Francisco and Eureka.

The Russian River rises about 16 miles north of Ukiah and flows southward for about 90 miles through alluvium-filled valleys and mountain gorges to Rio Dell. There the river turns abruptly westward and crosses the Coast Ranges to the Pacific Ocean. The entire river is about 110 miles long, but the drainage basin through which it flows is about 85 miles long. The valley of the Russian River ranges in width from 12 to 32 miles and has an area of 1,485 square miles.

Following the usage of Holway (1913), the term "lower Russian River" in this report refers to the east-west trending part of the river that is intrenched in bedrock and cuts the Coast Ranges transversely. The term "middle Russian River" refers to that part of the river from about 7 miles south of Healdsburg to the head of Cloverdale Valley, near Preston. The remaining upstream part of the river is called the upper Russian River. About 15 percent of the basin is nearly level valley land; the remainder is hilly or mountainous. Altitudes in the basin range from sea level, at the river's mouth, to 4,344 feet on Mount St. Helena (fig. 1). About 45 percent of the land lies at altitudes above 1,000 feet. Stream gradients along the Russian River range from about 2 feet per mile in the lower part to about 8 feet per mile in the upper part. In some rocky gorges the gradient of the Russian River is as much as 45 feet per mile.

The principal tributary to the Russian River, except for Mark West Creek, is Dry Creek, which has a drainage area of 218 square miles. Other large tributaries, in upstream order, are Austin and Green Valley Creeks in the lower Russian River valley; Maacama and Big Sulphur Creeks in the middle Russian River valley; and Pieta, Feliz, and Forsythe Creeks and the East Fork, which enter the upper Russian River. (See pls. 1, 2, and 6.)

The average annual runoff of the Russian River at Guerneville during 1940–56 was about 1,600,000 acre-feet, or about 2,200 cfs (cubic feet per second); the minimum discharge was 61 cfs on July 4, 1950 (U.S. Geol. Survey, 1959, p. 517). The average summer low flow at Guerneville is about 150 cfs. Near Hopland the average discharge is 672 cfs, and the minimum daily discharge was 26 cfs on December 18, 1943, and on June 26, 1949 (U.S. Geol. Survey, 1959, p. 517).

In 1908, water was diverted from the Eel River to the East Fork Russian River at the head of Potter Valley. A tunnel carries the water through the mountains to electric-power generators at Potter Valley Powerhouse. From April to October the diversion averages more than 150 cfs. The flow of the Russian River is regulated by Coyote Dam on the East Fork near Ukiah. Coyote Dam was designed to reduce flood peaks by storing water during periods of high runoff and to make this water available for use during periods of low flow.

Floods are frequent because most of the rainfall in the Russian River basin occurs during the winter when evapotranspiration losses are low, and because the rocks in the mountain terrane have low permeability. During winter storms, runoff in many areas exceeds 50 percent of the precipitation and locally is as high as 65 percent (U.S. Army Corps Engineers, 1948).

The three valleys in northern Mendocino County that are discussed in this report are in the headwater area of the Eel River (fig. 1). Each valley is drained, at least in part, by a different fork of the Eel River. Little Lake valley drains northward to the main stem of the Eel River through Outlet Creek, a perennial stream. The northern and principal part of Laytonville Valley drains northward to the South Fork Eel River through Tenmile Creek; the southern part of the valley drains southward to Outlet Creek and thence northward to the Eel River. Round Valley is drained by Mill Creek, a tributary of the Middle Fork Eel River.

Miscellaneous low-flow measurements of the principal streams draining the three valleys above are listed in table 16 of this report.

DESCRIPTION OF SUBAREAS

The subareas described are sections of seven valleys along the Russian River and three valleys in the headwater area of the Eel River. The subareas along the middle section of the Russian River are connected geographically and hydrologically; the remainder are separate hydrologic units. The valleys along the Russian River, in upstream order, are discussed first. The valleys along the Eel River also are discussed in approximate upstream order. (See fig. 1 and pls. 1–6.)

Lower Russian River valley.—The lower Russian River valley is a narrow canyon that extends from the mouth of the river, near Jenner, eastward to near the mouth of Mark West Creek (pl. 1). The upstream terminus of this valley section is arbitrarily drawn at the town of Rio Dell; this section is about 21½ river miles long (U.S. Army Corps of Engineers, 1948). The canyon ranges in width from about 1/7 to ½ mile and has an average width of slightly more than a quarter of a mile. It contains a thick deposit of alluvium beneath its floodplain, which is locally bordered by remnants of older stream terraces. The altitude of the flood plain ranges from near sea level at the river's mouth to about 50 feet at Rio Dell. The adjacent uplands of the Mendocino Highlands rise steeply along both sides of the valley floor to altitudes of 500–1,000 feet. Tidal effects in the river extend upstream about 10 miles to the vicinity of Monte Rio (pl. 1).

Healdsburg area.—This section includes the flood plain of the middle Russian River and the adjacent area from Rio Dell to the vicinity of Healdsburg and Dry Creek valley (pl. 1). The west side of the river in this area is bounded by almost impermeable bedrock; the east side is composed mainly of water-bearing unconsolidated and poorly consolidated sedimentary rocks. Approximately 18 square miles of alluvial plain is included—about 9½ in the Russian River valley and 8½ in Dry Creek valley. The total area underlain by water-bearing rocks is about 30 square miles.

In the Healdsburg area the Russian River valley is about 10 miles long and ranges in width from less than half a mile to about 2 miles. The Russian River valley is widest where it merges with the valley of Dry Creek. Dry Creek valley is about 14 miles long, and its flood plain ranges in width from about 1½ miles at its mouth to an average of about half a mile from 3 to 13 miles upstream. Beyond this point the valley becomes a gorge between ridges as much as 1,200 feet in altitude. Hills adjacent to the Russian River and lower Dry Creek rise to altitudes of about 200–300 feet.

Alexander Valley.—Alexander Valley lies along the middle Russian River and trends northwestward from 5 miles east of Healdsburg to 1 miles southeast of Asti, a distance of about 14 miles (pl. 1). The valley has a maximum width of about 3 miles and an average width of about 1½ miles, and it contains about 20 square miles of flat-lying land. The total area of the water-bearing rocks is somewhat larger, because the valley floor is locally bounded by unconsolidated sediments. The altitude of the valley floor ranges from about 150 feet in the southern part to about 250 feet in the northern part.

Cloverdale Valley—Cloverdale Valley lies at the head of the middle Russian River valley (pl. 1). The valley is northwest of and on the same structural trend with Alexander Valley and is separated from it by a narrow bedrock gorge. The valleys have some subsurface hydrologic connection through the channel deposits in the gorge between the two valleys. Cloverdale Valley consists of a flood plain about 6 miles long and three-fourths of a mile wide. The valley is bounded by older alluvial terraces on the southwest and by bedrock on the north, northwest, and south sides. Oat Valley is a tributary to Cloverdale Valley at the latter's northwest end. The Russian River is joined by one of its principal tributaries, Big Sulphur Creek, at the upper end of Cloverdale Valley.

Sanel Valley area.—Sanel, or Hopland, Valley lies along the Russian River and the lower part of two large tributaries, Feliz and McDowell Creeks (pl. 2). McDowell Creek valley, 3 miles east of Hopland, is discussed together with the Sanel Valley area in this report. The Sanel Valley is about 10 miles north of Cloverdale Valley, and the two valleys are separated by a section of the bedrock gorge cut by the Russian River. Alluvial deposits in the Sanel Valley cover an area of about 11½ square miles; in McDowell Valley, about 2 square miles.

Ukiah Valley area.—The Ukiah Valley area includes the Ukiah Valley and the valleys of its principal tributaries (pl. 2). Ukiah Valley is immediately north of the Sanel Valley, near the head of the Russian River drainage system. The Ukiah Valley area is about 22 miles long, averages about 3 miles wide, and includes an area of about 65 square miles, all of which is underlain by water-bearing deposits. In Ukiah Valley the principal alluvial plain is about 8 miles long and averages about 2 miles wide. The altitude of the valley floor ranges from about 500 feet at the southern end and about 600 feet in the vicinity of Ukiah to more than 700 feet in the upper part of Redwood Valley.

Potter Valley.—Potter Valley, the northernmost valley in the Russian River drainage basin, is about 12 miles northeast of Ukiah, at the head of the East Fork Russian River (pl. 2). The valley has a northwest-southeast length of about 7 miles, and average width of 1¾ miles, and encompasses about 12 square miles of alluvial deposits. Potter Valley is surrounded by impermeable bedrock except on the south and southwest sides, where water-bearing rocks crop out. The valley is separated from the Ukiah Valley area by a bedrock ridge about 4 miles wide, through which the Russian River has cut a narrow gorge. The altitude of the valley floor ranges from 900 to 1,000 feet; the adjacent mountains rise to an altitude of about 2,000 feet on the west and to about 3,000 feet on the east.

Round Valley.—Round Valley, the northernmost valley described in this report, is in the northeast-central part of Mendocino County about 140 miles north-northwest of San Francisco (pl. 3). It is drained by Mill Creek, a tributary of the Middle Fork Eel River. Round Valley is floored with alluvium and surrounded almost entirely by bedrock. The valley has a nearly elliptical outline whose maximum diameter trends northwest. The valley is about 6½ miles long and averages about 4 miles wide. The alluvial deposits cover an area of about 23 square miles.

Laytonville Valley.—Laytonville Valley, also known as Laytonville Flats or Long Valley, is in northwest-central Mendocino County between the main stream and the South Fork Eel River (pl. 5). Most of the valley drains northward through Tenmile Creek to the South Fork; the southern part is drained by Long Valley Creek, a tributary to the main fork of the Eel River by way of Outlet Creek (pls. 5, 6). The valley consists of a narrow alluvium-filled trough bordered by bedrock on the east side and by discontinuous, dissected alluvial terraces and bedrock on the west side. The main valley is about 6 miles long and half a mile wide; the terraced area has a maximum width of slightly less than 2 miles. Alluvial deposits cover an area of about 12 square miles.

Little Lake Valley.—Little Lake Valley, or the Willits area, is about 24 miles north-northwest of Ukiah and immediately north of the drainage divide between the Russian and Eel Rivers (pl. 6). The valley is drained by Haehl and Davis Creeks, which join at the lower (north) end of the valley to form Outlet Creek. Downstream from Little Lake valley, Outlet Creek flows northward on bedrock to the Eel River.

The long axis of Little Lake valley trends nearly north. The valley is about 7 miles long and has a maximum width of about 3½ miles. The valley contains a thick alluvial fill underlain by older continental deposits that crop out along the southern periphery.

The altitude of the valley floor ranges from 1,400 to 1,500 feet. The adjacent mountainous area rises to altitudes of 2,000–2,500 feet.

CLIMATE

GENERAL FEATURES

The climate of the area is the mediterranean type, characterized by warm dry summers and wet winters. About 85–90 percent of the precipitation occurs from October through March. The percentage of sunshine is high during the summer and relatively low during the winter. Within the area, local variations in climate result from differences in relief and proximity to the Pacific Ocean.

Little Lake valley has cool summers, compared to the other inland valleys, because a topographic low on its west side allows access to cooling breezes. The maximum local seasonal variation in temperature of about 34°F occurs in Round Valley. (See table 1.) Fog is common in Little Lake and Laytonville Valleys and occasionally occurs in the valleys to the south.

During the summer the relative humidity in most of the valleys is between 80 and 90 percent in the early morning and decreases to 50–60 percent by noon. The least humid valleys are Round and Potter. In the Russian River valley areas, the number of frost-free days ranges from about 240 days in the southern part to about 200 days in the northern part. In the northern Mendocino County valleys, which lie at higher altitudes, the frost-free period ranges from 200 to 160 days. Climatological data from eight Weather Bureau stations in the area are listed in table 1.

TABLE 1.—*Climatological data from selected Weather Bureau stations in Sonoma and Mendocino Counties, Calif., through 1955*

Station	Altitude (ft)	Years of record	Mean annual precipitation (in.)	Temperature (°F)			Average number of days between killing frosts
				Mean annual	Lowest mean monthly (Jan.)	Highest mean monthly (July)	
Guerneville (lower Russian River valley)	115	16	48.30				
Healdsburg	102	79	39.72	58.5	46.4	68.8	244
Cloverdale	320	58	39.02	59.8	47.2	71.9	
Ukiah	623	79	35.35	57.8	45.2	72.4	210
Potter Valley (Powerhouse)	1,014	44	41.08	58.4	45.1	73.2	
Willits (Little Lake Valley)	1,365	68	50.07				
Laytonville	1,640	15	[1] 56.20				
Covelo (Round Valley)	1,385	40	38.22	56.1	40.0	73.7	

[1] Based on incomplete records.

PRECIPITATION

Precipitation occurs principally as rain. Light snow sometimes falls on the ridge tops in the southern part of the area; but from Ukiah northward, snow on the higher ridges and peaks is common and occasionally it extends into the valleys. Precipitation during the growing season, April–September, is generally less than 5 inches in the Russian River valley and seldom exceeds 10 inches in the valleys in northern Mendocino County.

The average annual precipitation at eight representative stations is listed in table 1. Of these stations, Ukiah has the lowest average annual precipitation, 35.35 inches, and Laytonville has the highest, 56.20 inches. During the period that water-level observations were made, precipitation at Healdsburg ranged from a low of 31.82 inches (1953) to a high of 51.25 inches (1955). Monthly rainfall at Healdsburg is shown graphically in figure 3. In Little Lake Valley, the minimum rainfall was 49.15 inches (1953) and the maximum was 63.89 inches (1951) at Howard Ranger Station, south of Willits. Precipitation on most of the highland area greatly exceeds that on the valley floors, where most stations cited are situated. Records show that in many years much of the rainfall occurs during storms and runoff rates are high, but the U.S. Army Corps of Engineers estimated (1948) that, on the average, only 25–30 percent of the precipitation in the Russian River basin occurs during storms. The potential recharge from rainfall is largely dependent on the distribution, rate, and duration of precipitation.

CULTURAL FEATURES AND NATURAL RESOURCES

The Redwood Highway (U.S. 101) and the Northwestern Pacific Railroad traverse most of the valley areas. All the valleys are interconnected by paved roads, except for Round Valley. The largest city is Ukiah, which in 1954 had an estimated population of about 10,000. The principal natural resources of the Russian River area are the fertile valley land, timber, and mineral deposits—chiefly cinnabar (mercury ore) and sand and gravel. The principal resources of northern Mendocino County are the forests, which support a large lumber industry, and the grass lands that furnish forage for grazing of livestock. Recreation facilities are also a major source of income in many areas.

Lower Russian River valley.—In the lower Russian River valley from Jenner to Duncans Mills, the economy relies principally on sheep and dairy ranching and fishing. Upstream from Duncans Mills, the resort industry is a large source of income; much of the population is transient, especially during summer months. Additional sources

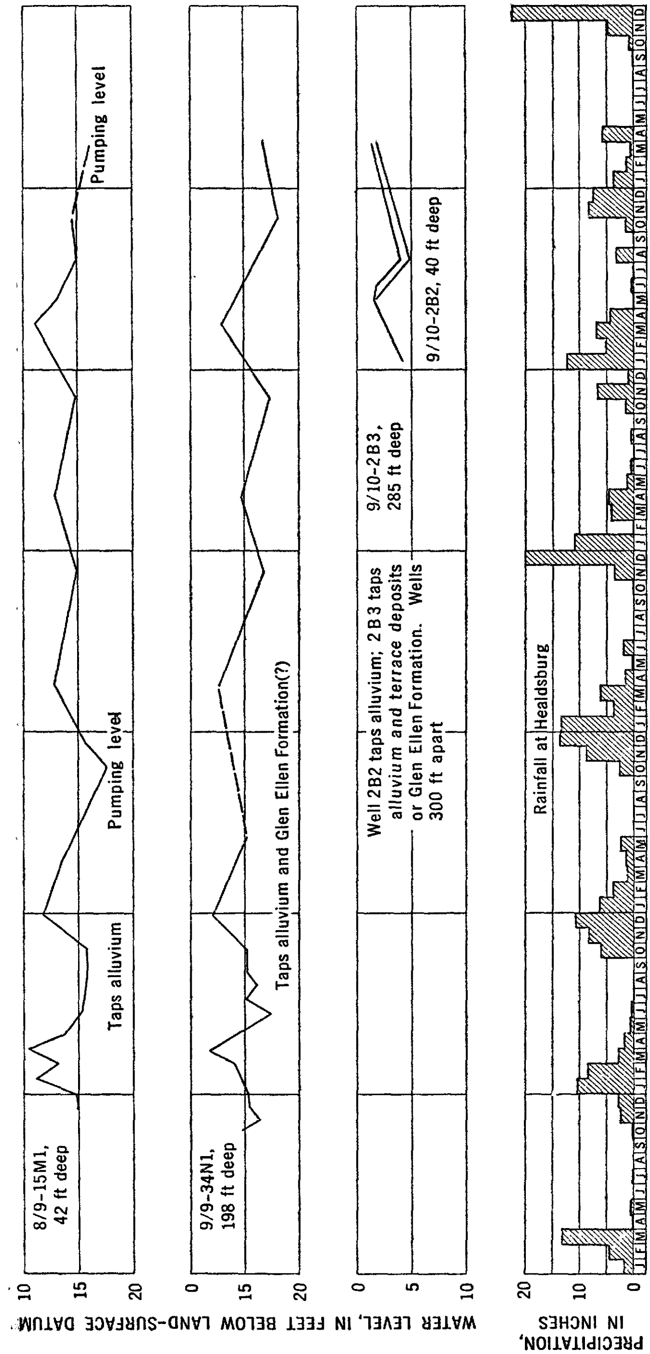

FIGURE 3.—Fluctuation of water levels in four wells in the Healdsburg area 1949–55, and monthly precipitation at Healdsburg.

of income are derived from vineyards, wineries, orchards, timber, and a large cinnabar mine that is operated about 3 miles northeast of Guerneville. Guerneville is the principal town of the lower Russian River valley and is the center of recreational activity.

Healdsburg area.—Healdsburg (1953 population, about 3,400) is the trading center and only town in the Healdsburg area. The economy of the area is based on agriculture, chiefly fruit growing (prunes and wine grapes) and stock raising. Hop growing was formerly a major source of income, but locally it has largely been replaced in recent years by the raising of truck crops. Processing of agricultural products, wine making, and lumbering are the principal industries. A large sand and gravel company utilizes the channel deposits of the Russian River and Dry Creek.

Alexander Valley.—The economy of Alexander Valley is similar to that of the Healdsburg area except that more effort is devoted to stock raising in Alexander Valley. There are numerous large sheep and cattle ranches, some dairies, and several wineries. Hops are grown in the southern part of the valley.

Cloverdale Valley.—Cloverdale Valley is noted chiefly for its production of prunes and wine grapes. The valley is also the home of several wineries, one of which is among the largest in northern California, and a number of sawmills and plywood factories that process both timber cut locally and timber shipped in from the area to the north.

Sanel Valley area.—The population of the Sanel Valley area in 1954 was about 1,200. The principal industry is agriculture. Hopland, the only town, is named for the sizable acreage of hops grown in the valley. Other crops include fruit and hay for winter feeding of livestock. A sawmill in Hopland and a dry ice manufacturing plant about 1½ miles to the northeast, which processes carbon dioxide gas from water wells, are the principal industrial plants. A resort, about 1½ miles southwest of Hopland, is at Duncan Springs. The water from this spring has a high concentration of magnesium bicarbonate.

Ukiah Valley area.—Ukiah is the center of trade in the upper Russian River valley. The population increased from 3,731 in 1940 to 6,120 in 1950 and was estimated to be about 10,000 in 1954. The population of all of Ukiah Valley in 1954 was about 20,000. The increase resulted largely from the expansion of the lumber and related industries.

The area supports a variety of business operations. Several large packing plants are operated to process locally grown fruit, chiefly pears. Large quantities of wine grapes are processed by several wineries. Dairying and sheep and cattle raising are also significant. Several sand and gravel plants exploit channel deposits of the Russian

River. Vichy Springs, a resort, is about 6 miles northeast of Ukiah. The water from this spring is warm and has a high concentration of sodium bicarbonate.

Potter Valley.—Agriculture, the principal industry in Potter Valley, is dependent on irrigation and utilizes water diverted from the tail race of the Potter Valley Powerhouse. Grasses, alfalfa, clover, and pears are the principal crops. In 1954 the population of the valley was estimated to be about 1,200, of which about 350 resided in the town of Potter Valley.

Little Lake Valley.—In 1950 Willits, the only town in Little Lake Valley, had a population of about 2,650, and the population of the entire valley was about 5,300. The economy is based on lumbering, and in 1954 about seven lumber mills were in operation. Agriculture consists principally of livestock raising and the growing of crops for pasture and feed. A sand and gravel industry supplies material for road paving, and a guest ranch on Willits Creek is a tourist attraction during the summer months.

Laytonville Valley area.—The Laytonville Valley area is dependent on the lumber industry, and during 1954 about 10 sawmills were operating in the valley. Natural grazing land was being used by large cattle ranches and in 1954 two of these ranches were irrigating hay and supplemental pasture. The population of Laytonville Valley in 1950 was about 1,600, of which about 350 resided in the town of Laytonville.

Round Valley.—Round Valley has a balanced economy, dependent largely on agriculture and supplemented by lumbering and trade from tourists and sportsmen. Three sawmills were operating in the valley in 1954, and some timber was trucked to other mills outside the valley. The principal crops are hay and pasture for livestock, but small acreages support walnut groves. The Round Valley Indian Reservation includes the northern part of the valley. The population of the valley was about 1,500 in 1954, of which about 500 resided in the town of Covelo.

WATER UTILIZATION

The largest withdrawal use of ground water in most of the area is for irrigation of crops; in the lower Russian River valley, however, the main use is for domestic and public supply. Large quantities of water are also used by industries, especially in the Healdsburg area, near Asti in the southern part of Cloverdale Valley, and in the Ukiah Valley area. Data on the sources of water for public supplies, the number of consumers, and the quantity withdrawn in each area are given in table 2. The use of ground water in each basin or area is described in the section, "Ground Water."

TABLE 2.—*Public water supplies*

Area served	Source and location	Owner	Service: Number of people	Service: Number of service connections	Service: Year	Use [1]: Average (mgd)	Use [1]: Maximum (mgd)	Use [1]: Acre-ft per year	Years of record
Monte Rio and adjacent area	2 wells (7/10-7D1, 7D2) near Russian River and 6 springs in tributary ravines.	Citizens Utilities Company of Calif.		600	1950	0.13	0.28	140	
Guerneville, Rio Nido, and adjacent areas.	2 wells (8/10-29H1, 29H2) near Russian River and 4 springs.	do		1,500	1950	.20	.41	220	
Armstrong Valley, north of Guerneville.	1 well (8/10-20M4) near Fife Creek	Armstrong Valley Water Co.		94	1954	.01		[2] 11	1952-54
Hacienda area	2 wells (8/10-26J1, 26J2) near Russian River.	Hacienda Water Co.		138	1953	.02	.06	20	
Summerhome	Russian River and springs	Summerhome Park Water Co.		140	1953	.03	.08	30	
Healdsburg:									
City	6 wells (9/9-21J1-6) near Russian River. 2 wells (9/9-20K1, 20K2) in Dry Creek well field.	City of Healdsburg	[3] 3,400		1953	[4] .79		[4] 880	1945-54
Small area to east	1 well (9/9-27D1)	Mutual Water Co.		6-8	1950				
Geyserville	2 wells (10/10-13J2, 13J3)	Geyserville Water Co.	[3] 550	142	1954	.09		100	1946-54
Cloverdale	2 wells [5] (11/10-7J1, 7J2) near Russian River.	Town of Cloverdale		[6] 605	1948	.15	.36	170	
Ukiah	3 wells (15/12-16E1, 16E2, 16Q1) near Russian River.	City of Ukiah	[3] 10,000		1954			[3] 2,000	
Area east and south of Talmage.	2 wells (15/12-27N2, N3)	Mendocino State Hospital	[7] 3,150		1954	[8] .92		[8] 1,030	1945-53
Talmage and area south of hospital.	2 wells (15/12-27N2, N3)	do		55	1953	.19		210	
Willits	Morris Dam on Davis Creek	Pacific Gas and Electric Co.		1,243 990	[9] 1954 [9] 1950	[10] .65		[10] 734	
Laytonville	1 well (21/15-13B1)	Laytonville Water Co.		75	1954	.12		135	

[1] Year is same as indicated in preceding column.
[2] 1952 use, 15 acre-feet.
[3] Approximate.
[4] 1954.
[5] Large-diameter dug wells.
[6] 505 metered, 100 outside town limits.
[7] 2,500 patients, 650 employees.
[8] 1953.
[9] May.
[10] 1949. Industry used 330 acre-feet of total.

SOURCE OF WATER SUPPLIES

In the valleys in the northern part of Mendocino County, ground water is the principal source of supply because most of the streams are small and have intermittent flow. Surface water is used locally for irrigation in Laytonville Valley, and a reservoir is the source of supply for Willits in Little Lake valley.

In the Russian River valley, water supplies are developed from both surface- and ground-water sources. In recent years the practice of diverting water directly from the Russian River and its major tributaries by pumping has been replaced largely by withdrawals from shallow wells near the streams. The new method offers the advantage of a permanent installation and clear, filtered water throughout the year.

The chemical quality of water in the Russian River under present development is excellent for most uses. Local variations in chemical quality occur along the stream owing to differences in the quality of water from tributaries.

During periods of low flow, the concentration of all constituents except iron and sometimes nitrate increases slightly downstream in all parts of the river. The average concentration of dissolved solids ranges from less than 100 ppm to about 150 ppm; however, during prolonged periods of low flow, the dissolved-solids concentration may become as high as 200 ppm, owing to the effects of evapotranspiration and return flow from irrigation. The normal downstream increase in the dissolved-solids concentration may not hold locally; during winter and spring, for example, water samples collected near Ukiah and Calpella generally have a greater concentration of dissolved solids than do those collected at sampling stations farther downstream. This irregularity probably results from the more intensive local development of the water accompanied by a larger increment of disposed wastes and leached fertilizer which are diluted by inflow farther downstream. In addition, several tributary streams in the Ukiah Valley contain relatively high concentrations of dissolved solids.

Although the Russian River is a major source of water, the storage capacity of the adjacent sediments, especially the more permeable river-channel deposits, is equally important to the full development of the water resources of the Russian River valley. Many wells adjacent to the river, which divert river water by inducing infiltration through the channel deposits, also withdraw a substantial part of their supply from ground water in the alluvium.

Water moves through the permeable deposits down the valley and toward the stream throughout the year; however, the hydraulic gradient may flatten during the summer and be reversed locally where pumping is intensive. The farther a well is from a stream, the less water it will divert from streamflow. This is because the cone of depression caused by pumping the well flattens out within a short distance in deposits having a high transmissibility. A comparison of chemical analyses of water from pumping wells near streams with those of water from the streams generally indicates that a large proportion of the water pumped is derived from ground water in the alluvium. Where the well is several hundred feet or more from the stream, the well water withdrawn normally differs in detail from the stream water. The well water generally has a higher concentration of dissolved solids and a different temperature but is commonly of the same general chemical type as the stream water.

GENERAL GEOLOGY

The general geology of the 10 ground-water basins discussed in this report is shown on plates 1, 2, 3, 5, and 6. In the lower and middle Russian River valleys (pl. 1), mapping in the Healdsburg quadrangle is modified from Gealey (1950); mapping in the remainder of the area is based on field reconnaissance and interpretation of aerial photographs and soils maps. The geology shown on plates 2, 3, 5, and 6 is modified from a report by the California Division of Water Resources (1956). Geologic maps subsequent to 1956 were not available at the time this report was prepared.

The geologic conditions through the valleys along the Russian River and its tributaries are similar and are described in following sections. The extent, thickness, general character, and water-bearing properties of the formations distinguished in the area are summarized in table 3.

The geology and structure of the northern and more isolated valleys in Mendocino County, while not greatly different from those of the Russian River valleys, are described separately.

SUMMARY OF STRATIGRAPHY AND OCCURRENCE OF GROUND WATER

The rocks in the Russian River valley may be divided into three general groups on the basis of age and water-bearing properties. These groups are, from oldest to youngest, (1) consolidated rocks of Jurassic and Cretaceous age, (2) deformed poorly consolidated or unconsolidated continental, volcanic, and marine rocks of Cenozoic (Pliocene and Pleistocene) age, and (3) undeformed and unconsolidated alluvial deposits of Quaternary age, comprising the terrace deposits of Pleistocene age, dissected alluvium of Pleistocene and Recent age, and alluvium of Recent age.

The oldest rocks in the area are those of the Franciscan and Knoxville Formations of Jurassic and Cretaceous age. These formations constitute the bedrock in most of the northern Coast Ranges and are not differentiated on plates showing geology. Wells tapping these formations are the only source of water for domestic use in many mountain areas.

The Franciscan and Knoxville Formations in the vicinity of Healdsburg and Alexander Valley are overlain by a thick unnamed conglomerate of Late Cretaceous(?) age. Wells tapping the conglomerate in the upland area between the northwestern parts of Dry Creek and Alexander Valleys supply adequate water for domestic use.

In the middle Russian River valley area, the Sonoma Volcanics of Pliocene age, the marine Merced Formation of Pliocene and Pleistocene(?) age, and the continental Glen Ellen Formation of Pliocene(?) and Pleistocene age crop out discontinuously. Although these formations are of limited areal extent, they are important sources of ground water locally.

In the upper Russian River valley, continental deposits considered to be equivalent to the Glen Ellen Formation crop out along the margins of the present alluvial valleys. These deposits are an important source of water for domestic and stock supplies.

Remnants of extensive alluvial terraces occur throughout the Russian River valley. They are best exposed in the Healdsburg and Ukiah Valley areas, where they are extensively developed by wells. In the Ukiah Valley area the younger and older terraces have been differentiated (table 3; pl. 2). Most of the terrace deposits are probably of Pleistocene age, but some of the lower and younger deposits may be of Recent age. In the upper Russian River valley area, the alluvium in several tributary valleys is being incised and dissected because the base level has been lowered. Because the surfaces of the deposits are not being alluviated at present, the deposits are called dissected alluvium; however, they are similar in character to some of the deposits mapped as alluvium in adjacent areas.

Alluvium includes most of the unconsolidated deposits of Recent age that underlie and form the present alluvial plains in the Russian River valley. The alluvium is the principal source of ground water in all the valley areas. The stream-channel deposits are differentiated from the alluvium in areas where these deposits are areally extensive (pls. 1, 2).

SUMMARY OF STRUCTURAL CONTROL OF TOPOGRAPHY

Northwest-trending faults and folds control the course of the middle and upper Russian River and are the dominant structural features throughout the northern Coast Ranges. Formations that range in age from Jurassic to late Pleistocene are affected by these structural fea-

TABLE 3.—*Stratigraphic units and their water-bearing character in the Russian River Valley area, Calif.*

Geologic age	Formations and symbols on pls. 1 and 2	Location and extent	Thickness (feet)	General character	Water-bearing properties
Recent	River-channel deposits (Qrc)	Deposited in flood channels of Russian River and major tributaries.	0–200±	Coarse unconsolidated sand and gravel with some silt and clay.	Very permeable. Yield large quantities of water to wells. Chemical quality of water is good.
	Alluvium (Qyal)	Includes stream-channel, flood-plain, alluvial-fan, and colluvial deposits underlying valley floors.	0–200±	Unconsolidated and generally poorly sorted lenticular deposits of clay, silt, sand, and gravel.	Yield of wells moderate to large. Water is generally of good chemical quality but locally may be hard or contain excessive amounts of iron.
Pleistocene	Dissected alluvium (Qdal)	Mapped only in Ukiah and Sanel Valley areas.	0–200±	Incised or slightly dissected deposits of unconsolidated clay, silt, sand, and gravel.	Sand and gravel yield small to moderate quantities of water to wells.
	Younger terrace deposits (Qty)	Lower alluvial terraces mapped in Ukiah Valley area.	0–200±	Unconsolidated silty gravel, sand, and clay, locally cemented and indurated at surface.	Yields range from small to moderate. Water is generally hard and contains excessive amounts of iron.
	Terrace deposits (Qt)	Include all terraces mapped in lower and middle Russian River Valley areas and undifferentiated terraces mapped in upper Russian River Valley.	0–200+	Poorly sorted fluvial deposits of gravel, sand, silt, and clay.	Yield small to moderate quantities of water to wells. Water is generally hard and may contain objectionable quantities of iron.
	Older terrace deposits (QTo)	Higher terraces mapped in Ukiah Valley area.	(Generally thin)	Weathered clayey gravel, sand, silt and clay.	Low permeability and generally above zone of saturation of the main water body.
Pleistocene and late Pliocene(?)	Glen Ellen Formation (QTge)	Crops out along east side of Russian River Valley south of Healdsburg, along northeast flank of Dry Creek Valley, around southern margins of Alexander Valley, and west of Cloverdale Valley.	0–1,500±	Poorly sorted lenticular deposits of silty clay, clayey gravel, sand and gravel. Lower part contains coarse conglomerate and tuffaceous beds and is interbedded with Sonoma volcanics and Merced formation.	Low permeability. Supplies adequate quantities of water for domestic wells. Water has high boron content locally.
	Continental deposits of Pleistocene and Pliocene age (QTc)	Mapped in Sanel, Ukiah, and Potter Valley areas.	0–2,000±	Compact and semi-indurated silty clay and gravel deposited as interbedded flood-plain, alluvial-fan, and lacustrine deposits.	Low permeability but supply water to many domestic wells. Water in eastern part of Ukiah Valley area has high boron content locally.

Pleistocene(?) and late Pliocene	Merced Formation (QTm)	Crops out at south end of Healdsburg area and north of Rio Dell.	0–1,000±	Medium- to fine-grained fossiliferous marine sand, sandstone, and silty clay containing pebbly beds and minor gravel lenses. Tuffaceous in part. Interbedded with Sonoma volcanics and Glen Ellen formation.	Low permeability, but small to moderate yields can be obtained from wells penetrating thick saturated sections. The water is generally of good quality but locally contains excessive amounts of iron.
Late and middle Pliocene	Sonoma Volcanics (Tsv)	Crop out discontinuously in Healdsburg area and around south and northeast margins of Alexander Valley.	0–1,000±	Interbedded lava flows, tuff, tuff breccia, agglomerate, and volcanic sand, gravel, and conglomerate.	Moderate to large yields are obtained from wells tapping fractured basalt, permeable lenses of volcanic sediments and openings along flow-contact zones. Water from Sonoma Volcanics in adjacent Santa Rosa Valley area is of good chemical quality.
Cretaceous(?)	Unnamed conglomerate (Kc)	Crops out in prominent band between the northwestern parts of Alexander and Dry Creek Valleys.	5,000+	Massive sheared cobble conglomerate containing occasional sandstone and shale interbeds. Near-surface material is weathered and clayey.	Wells penetrating 100 feet or more of saturated material generally yield quantities of water adequate for domestic purposes from poorly cemented and fractured zones. Water has high boron content locally.
Cretaceous and Jurassic	Franciscan and Knoxville Formations (KJu)	Form bedrock throughout the area.	7,000+	Consolidated sandstone, shale, chert, serpentine, and metamorphic and igneous rocks. Generally fractured and locally cut by extensive shear zones.	Impermeable except along fractured zones, which locally may yield small quantities of water to wells and springs. Chemical quality is generally good.

tures, as is the hydrology locally. Many local segments of the lower Russian River, which cuts across the general structural trend of the Coast Ranges, seem to be adjusted to local structural features, principally faults.

Dry Creek valley follows the northwestern extension of the Windsor syncline, which controlled the origin of adjacent Santa Rosa Valley (Gealey, 1950, p. 31). Surface and subsurface evidence shows that a fault having much vertical displacement runs along the east side of Dry Creek valley.

The middle Russian River also cuts across the structural trend of the Coast Ranges between the Healdsburg area and Alexander Valley, but its course is adjusted to local structural features. Alexander and Cloverdale Valleys occupy a synclinal trough that is locally complicated by faulting.

Ukiah and Sanel Valleys occupy alined structural depressions caused by folding and faulting. Several faults traverse the valleys, and recurrent movement has occurred in Recent time at several localities in the Ukiah Valley area. In the reach of the upper Russian River and its tributaries, movement along faults and damming by landslides has controlled the deposition of alluvium and terrace deposits.

Potter Valley occupies a depression that is probably of both synclinal and fault origin. The Potter Valley depression parallels the trough of Ukiah Valley and is separated from it by a structural high.

GEOLOGIC HISTORY

During the latter part of the Jurassic Period of the Mesozoic Era, the Russian River area was part of a broad slowly subsiding geosyncline in which the predominantly clastic marine sediments of the Franciscan and Knoxville Formations were deposited. The deposition, which continued into the Cretaceous Period, was contemporaneous with local warping, widespread intrusions of mafic and ultramafic igneous rocks, and local volcanic activity. Regional uplift near the end of Cretaceous time, accompanied by folding and faulting, halted sedimentation, and subsequent erosion removed most of the Upper Cretaceous rocks in the Russian River area.

The early history of the Tertiary Period of the Cenozoic Era is obscure. Pre-Pliocene rocks probably were deposited in the Russian River area but subsequently removed by erosion. Uplift of the Coast Ranges by compressive deformation and faulting, which produced ridges that rose above sea level, probably began during middle Miocene time. During Pliocene time, a broad gently undulating erosion surface, the Mendocino Plateau, was cut on the northern Coast Ranges.

Volcanism in the southern part of the area during the Pliocene Epoch resulted in the deposition of the Sonoma Volcanics in the Healdsburg and Alexander Valley areas. At about the same time, an embayment, whose northern margin was in the southern part of the Healdsburg area, began receiving the sediments that now constitute the Merced Formation. Around the margin of the basin, volcanic rocks, marine sand, and volcanic sediments interfingered. As volcanic activity waned near the end of the Pliocene, the volcanic rocks were eroded and the resulting debris was deposited in structural troughs and along the margin of the receding coastal embayment, where they interbeded with the sediments of the Merced Formation.

In the upper Russian River valley area, continental sediments were deposited in local structural basins. Subsequent uplift, accompanied by folding and faulting, caused repeated alluviation and terrace cutting along the Russian River valley during the latter part of the Pleistocene Epoch, and the general form of the present valleys was evolved.

During the latter part of the Pleistocene Epoch, terrace cutting was dominant in the lower and middle Russian River valley. In the lower Russian River valley and in the Healdsburg area, the Russian River carved a trench that was graded to a base level about 300 feet or more below present sea level. As the sea level rose, probably in response to the waning of world-wide glaciation, the trench was alluviated. Studies of terraces along the lower and middle river by Higgins (1952) indicated that the Russian River was entrenched in its present course prior to the latest period of structural deformation. The river was able, therefore, to maintain its antecedent course across the downwarped area of the Windsor syncline and avoid deflection into Santa Rosa Valley. Stream capture in the upper Russian River valley gave the present main stem of the river ascendancy over east-west flowing tributaries in the middle river area, and the increased flow gave the river an added capacity for downcutting.

At the present time, deposition and lateral cutting are continuing in the lower Russian River valley. In upstream areas, downcutting is dominant.

GEOLOGY AND GROUND WATER OF LOWER AND MIDDLE RUSSIAN RIVER BASINS

LOWER RUSSIAN RIVER VALLEY

GEOLOGY AND WATER-BEARING CHARACTER OF ROCK UNITS

The principal rock units in the lower Russian River valley are the alluvium and the consolidated bedrock of Jurassic and Cretaceous age. Also included are river-channel deposits, erosional remnants of terrace deposits, and the Merced Formation (pl. 1; table 3).

FRANCISCAN AND KNOXVILLE FORMATIONS

Bedrock in the lower Russian River valley consists chiefly of sandstone and shale in the Franciscan and Knoxville Formations. Generally the rocks are highly fractured and absorb and store water. Some of this water is discharged through numerous springs along the steep slopes bordering the valley. Although the springs generally yield only small amounts of water, they flow year around except when rainfall is far below normal. Many springs are utilized by small water companies, resorts, ranches, and summer homes. However, many of the wells drilled into bedrock are unsuccessful.

ALLUVIUM AND RIVER-CHANNEL DEPOSITS

Character and thickness.—The alluvial fill in the lower Russian River valley consists largely of sand, gravel, and minor amounts of silt and clay. The alluvium in tributary valleys and in abandoned meanders, such as Armstrong Valley north of Guerneville, is sorted poorly and contains a greater amount of silt and clay.

Selected logs of wells in the lower Russian River valley are listed in table 11. Well 7/11–11J1, 2 miles west of Monte Rio, penetrated 136 feet of sand and gravel, except for a 5-foot stratum of boulders and clay. Well 7/10–7D1, near Monte Rio, penetrated sand and gravel from 27 to 120 feet and bottomed in gravel. East of Guerneville, well 8/10–29H2 penetrated sand and gravel from 23 to 115 feet. The maximum thickness of alluvium in the main bedrock channel has not been determined because no wells have been drilled deeper than 136 feet. Well 7/11–17J1, about 2 miles from the river mouth, penetrated bedrock at a depth of 146 feet; however, the well was drilled at the mouth of a steep tributary valley, where the maximum thickness of alluvium would not occur. Well 8/10–29D1, in Armstrong Valley north of Guerneville, penetrated bedrock at a depth of 120 feet. Well 8/10–20M3, however 0.4 mile farther upstream and 1.5 miles up the small valley from the Russian River, was drilled to a depth of 123 feet and did not reach bedrock.

The maximum depth of fill at the mouth of the Russian River probably exceeds 300 feet, as evidenced by the thickness of alluvium in valleys in the vicinity of and north of San Francisco Bay. The depth to bedrock at Guerneville may be as much as 200 feet, because the gradient of the Russian River was probably low even when the buried channel was cut.

Water-bearing properties.—A few wells designed for large withdrawals in the alluvial valley of the lower Russian River are reported to yield 500 gpm (gallons per minute) or more. Wells with yields in excess of 1,000 gpm could be developed in the lower Russian River provided they were properly located and constructed. The yields from wells in Armstrong Valley are as much as 200 gpm. The specific capacities (yield per foot of drawdown) range from about 1 to about 20 gpm per foot of drawdown. Well 8/10–29N1, 90 feet deep, penetrated 26 feet of sand and gravel and reportedly yields 200 gpm with a drawdown of 14 feet (tables 10, 11).

GROUND WATER

OCCURRENCE, SOURCE, AND MOVEMENT

Ground water in the lower Russian River valley is obtained from the alluvium, where it is unconfined and is hydraulically connected with the Russian River. Near the river mouth, however, and in the larger tributary valleys, the deposits contain considerable silt and clay that may confine ground water locally.

The sources of ground water are rainfall and the Russian River. Because the amount of precipitation and the water-holding capacity of the alluvial soils, terrace remnants, and broken bedrock are high, ground water moves toward the stream during most of the year. Underflow from the bedrock and terrace remnants is probably a sizable source of recharge to the alluvium. In areas of large withdrawals and during high stream stages in the autumn or early winter, water from the river moves laterally into and recharges the ground-water reservoir.

WATER-LEVEL FLUCTUATIONS

Water levels in wells near streams fluctuate with stream levels because of hydraulic connection. However, because ground water moves much more slowly than water in open channels, the water-level changes are more gradual. In general, the amplitude of the seasonal fluctuations in water level is greatest near the Russian River. Near the edge of the flood plain and in tributary valleys, water levels generally are near land surface in the spring and decline about 5–10 feet seasonally, owing largely to natural discharge to streams and evapotranspiration losses. The greatest depth to water during autumn, except in areas of heavy draft, is about 25 feet in local areas near the Russian River. In the cutoff meander north of Guerneville, dug wells 15 feet deep, or shallower, yield perennial supplies of water.

DISCHARGE AND WATER UTILIZATION

Ground-water discharge in the lower Russian River valley occurs largely through seepage into the river and its tributaries; some ground water is withdrawn for domestic and public-supply uses. Water-utilization data for the public-supply systems in use during 1954 are listed in table 2. Ground-water withdrawal for public supply ranged between 450 and 500 acre-feet in 1955. Ground water for rural domestic and stock use is probably less than 300 acre-feet annually.

Irrigation water is mainly from surface-water sources. Near Guerneville, about 60 acres is irrigated from a small creek (8/10–30G, H). Locally, fruit orchards are irrigated by pumping water directly from the river during years when spring rainfall is deficient. The Willig Dairy Ranch, which is close to the mouth of the river, irrigates some pasture utilizing river water during low-tide stages when the water is relatively fresh.

GROUND-WATER STORAGE CAPACITY

The ground-water storage capacity of the alluvium in the lower Russian River valley is large, even though it has a limited lateral extent, because of the thickness and relatively high specific yield of the deposits. The average specific yield is probably between 15 and 20 percent, because the few available logs indicate that the alluvium in the lower Russian River valley consists almost entirely of sand and gravel.

Estimates of storage in five arbitrarily chosen river reaches, or storage units, are given in table 4. All the units except unit I are 5 river miles long, as determined by the Corps of Engineers (1948). Unit V extends into the south end of the Healdsburg area. The storage capacity in the lower Russian River valley, based on a specific yield of 15 percent and the volume of saturated sediments in the storage units shown in table 4, is probably 55,000 acre-feet. Storage to a depth of 50 feet below the average level of the water table probably exceeds 25,000 acre-feet.

TABLE 4.—*Estimated ground-water storage capacity in the lower Russian River valley*

Ground-water storage unit (in upstream order)	Average width of alluvial valley (mile)	Area (acres)	Average maximum depth to bedrock (ft) [1]	Volume of sediments capable of being saturated (acre-feet) [2]	Storage capacity	
					Total, assuming 15 percent specific yield [1]	To depth of 50 ft below average river level [1]
I River mile 1, Jenner, to river mile 5, 1 mile south of Duncans Mills	0.2	500	200	50,000	8,000	3,500
II River mile 5 to river mile 10, Monte Rio	.25	800	190	80,000	12,000	5,500
III River mile 10 to river mile 15, one-half mile upstream from Guerneville	.25	800	180	70,000	10,000	5,000
IV River mile 15 to river mile 20, 2,000 ft upstream from Hacienda	.25	800	170	70,000	10,000	5,000
V River mile 20 to river mile 25, Wilson Grove	.40	1,300	150	100,000	15,000	8,000
Total	----------	4,200	----------	370,000	55,000	27,000

[1] Estimated.
[2] Equals area × maximum average depth to bedrock × ½ (V-shaped cross section assumed); rounded to nearest 10,000 acre-feet.

The encroachment of saline tidal water renders most of the ground water stored in unit I unusable and may limit development in the downstream part of unit II. Ultimate development may depend on the minimum river flow that it is desirable to maintain; large-scale development would tend to deplete streamflow.

CHEMICAL QUALITY OF WATER

The chemical character of the ground water along the lower Russian River is summarized in table 5. Typical analyses of ground and surface waters are shown graphically in figure 4.

Ground water.—The chemical quality of ground water in the lower Russian River valley is generally good, except for that in the lower part of the tidal reach of the river. The water is of the magnesium calcium bicarbonate type, having a hardness of about 150 ppm (parts per million) and a relatively low concentration of dissolved solids. Hardness and concentration of iron range considerably and locally

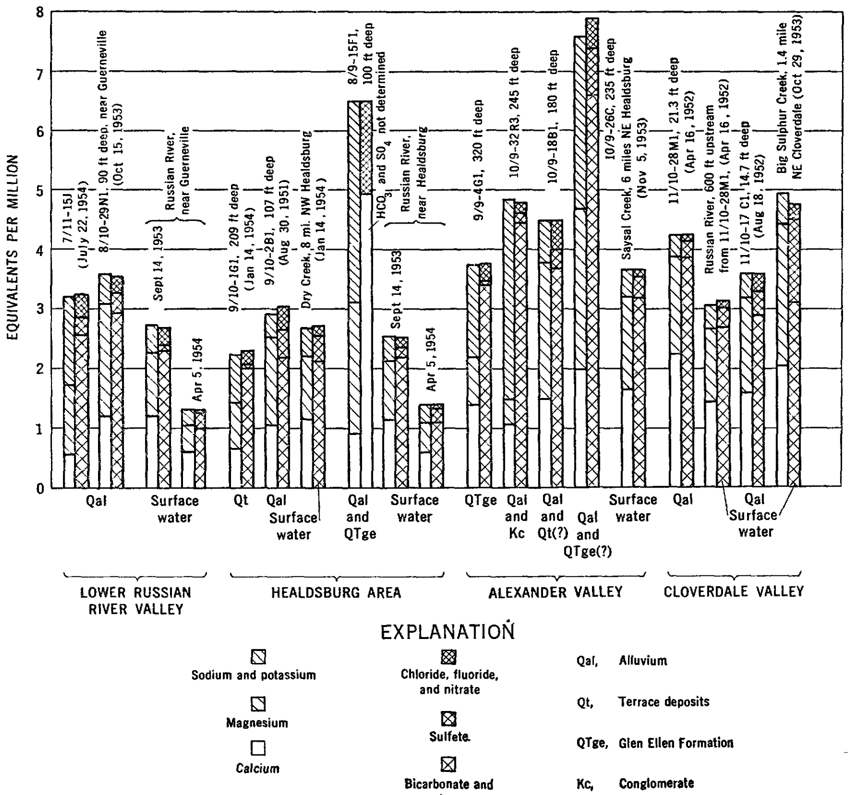

FIGURE 4.—Graphical representation of chemical analyses of typical ground and surface waters in the lower and middle Russian River valley areas.

may exceed desirable limits. The water from most springs is of good quality, but the water from some springs may be highly mineralized.

TABLE 5.—*Summary of chemical character of ground water in lower and middle Russian River valley areas*

[Based on analyses in files of the Geo. Survey; constituents in parts per million]

Constituent or characteristic	Lower Russian River valley	Healdsburg area	Alexander Valley	Cloverdale Valley
Dissolved solids.	120–210	90–500; generally less than 200.	140–500; generally less than 300.	150–600; generally less than 200 in alluvium.
Hardness as $CaCO_3$.	80–220	40–345; generally 75–150.	75–300	14–230; generally 100–200 in alluvium.
Chloride	Generally low, except in area of tidewater encroachment below Duncans Mills.	Generally low	Generally less than 25.	3-110; generally 10–20 in alluvium.
Percent sodium.	Generally low except as indicated above.	Generally less than 50.	Generally less than 50 in alluvium; commonly greater than 50 in older deposits.	8–90; generally low in alluvium.
Boron	Less than 0.5, except in local bedrock areas.	Generally less than 0.5, except locally where wells tap bedrock.	Less than 0.5, except locally in older deposits.	0.3–2.9; generally less than 0.5 in alluvium.
Iron and Manganese.	Generally less than 0.1; locally as much as 1.0.	Generally less than 0.1 in alluvium; higher in older deposits.	Low in alluvium	Generally low—less than 0.1—in alluvium.
pH	Generally in alkaline range.	Generally in alkaline range.	7–8.7	6.8–8.2.
Temperature (°F).	Generally about 60	56–65; generally 60–63.	60–66 in wells less than 200 ft deep.	56–66: generally 58–60.

From the river mouth to below Duncans Mills, a distance of about 5 or 6 miles, brackish water is found in wells near the river. The zone of demarcation between wells containing brackish water and wells containing fresh water seems to be narrow. Water from wells 7/11–14E1 and –15J contained 14 ppm chloride (table 12; fig. 4), whereas water from well 7/11–15P1, 1 mile downstream, contained 3,580 ppm chloride. Water from well 7/11–17J1 contained 2,920 ppm chloride, and well 7/11–20L1 contained 774 ppm chloride. These wells are 2 and 3 miles, respectively, downstream from well 7/11–15P1 (3,580 ppm chloride). Well 7/11–15P1 is close to the river, 7/11–17J1 is next closest, and 7/11–20L1 is farthest from the river. The anomalous upstream increase of chloride content in ground water may reflect the extent of lateral intrusion of brackish river water into the adjacent alluvial deposits. Thus recharge from the river could supply a large part of water pumped from wells very near the river.

The chloride content of ground water in the tidal reach seems to depend on the following factors: (1) Amount of streamflow, or river stage, (2) proximity to the tidal water, (3) amount of local groundwater movement toward stream, and (4) transmissibility of sediments. The chloride content within the tidal reach may be expected to range widely. Large quantities of fresh water cannot be obtained below Duncans Mills, but small amounts of fresh water can be obtained locally for domestic use.

The present upstream limit of brackish-water inflow during low-tide stages is about at, or a short distance downstream from, Duncans Mills; during a period of extremely low streamflow, saline water might extend 10 miles upstream, from the river mouth to Monte Rio. The encroachment of salt water into the ground-water reservoir increases during years in which recharge is deficient and ground-water outflow is correspondingly reduced, especially in areas where withdrawals are large.

Surface water.—Although the concentration of dissolved solids varies with the season and the amount of streamflow, the river water generally is of good quality and normally contains a lower concentration of dissolved solids than does the local ground water (fig. 4). The boron content of river water at Guerneville generally is less than 0.5 ppm.

HEALDSBURG AREA

GEOLOGY AND WATER-BEARING CHARACTER OF ROCK UNITS

In the Healdsburg area the alluvium is the principal source of ground water. Of secondary importance are the Glen Ellen Formation, the terrace deposits, and an unnamed conglomerate of Cretaceous age. In the extreme southern part of the area, wells tap the Merced Formation; and along the western flank of the area, springs and wells in the Franciscan and Knoxville Formations yield water locally. The Sonoma Volcanics are a potential source of water, but because of their limited areal extent in the Healdsburg area, they are discussed in the section, "Alexander Valley."

FRANCISCAN AND KNOXVILLE FORMATIONS

The composition of the Franciscan and Knoxville Formations in the Healdsburg area ranges widely. On the west side of the Russian River, the rocks are mainly sandstone and shale that contain local bodies of schist, greenstone, and serpentine. Rocks on the southwest side of Dry Creek valley consist mainly of gabbro and greenstone but include local bodies of shale, sandstone, chert, and serpentine. The rocks are cut by numerous faults, and at most localities they are intensely fractured. The bedrock was mapped in detail by Gealey (1950). Water sufficient for domestic use is developed from springs and wells in these formations.

MERCED FORMATION

The Merced Formation occurs only in the southern part of the Healdsburg area. At one time the Merced probably extended over the greater part of the area, but only small erosional remnants now remain. The northern extent of the Merced is indicated by clamshells, which are typical of the formation, in a small gully about 6 miles northwest of Healdsburg (9/10–9Q).

The Merced Formation consists mainly of fine- to medium-grained fossiliferous marine sand and sandstone containing sandy clay, pebbly beds, and sparse gravel lenses. The formation is tuffaceous in part and contains at least one persistent bed of tuff. Strata are generally compact but unconsolidated in the upper part of the formation and weakly consolidated in the basal part. In the Healdsburg area the formation ranges in thickness from a few feet to 1,000 feet or more. The Merced is interbedded locally with continental deposits of the Glen Ellen Formation. A more detailed discussion of the Merced Formation is given in Cardwell (1958).

Small to moderate yields are obtained from wells tapping the Merced Formation in the Healdsburg area. The permeability of the Merced generally is low, but large quantities of water may be obtained in areas where wells tap thick sections of unconsolidated sand. Several miles to the south, in the Sebastopol area, some wells in the Merced Formation yield 600 gpm or more. Except in the small area northeast of Rio Dell where the Merced extends beneath terrace deposits and alluvium (pl. 1; logs of wells 8/9–31A1, 32E3, table 11), it is tapped only by domestic wells. Well 8/9–31A1 penetrated about 250 feet of Merced Formation, mostly sandstone, and was reported to yield 43 gpm with a drawdown of 43 feet. However, well 8/9–33D1, which is 178 feet deep and is perforated from 106 to 176 feet, reportedly yields 20 gpm with a drawdown of 120 feet.

GLEN ELLEN FORMATION

Most of the Glen Ellen Formation remaining in the Healdsburg area is preserved in the synclinal trough that extends from the Santa Rosa Valley northwestward up the valley of Dry Creek. In most adjacent areas the formation has been removed by erosion. The hills southeast of Healdsburg and east of the Russian River are composed of large masses of the formation (pl. 1). The outcrop pattern is irregular and narrow along the northeast side of Dry Creek valley; the Glen Ellen is downfaulted against the Jurassic and Cretaceous rocks of the mountains to the northeast and is covered by younger deposits to the southwest. Only small remnants of the formation exist along the southwest side of the valley. One outcrop has been mapped in the foothills about 1 mile west of the Felta School, and a more intensive search would probably show the existence of other small patches.

The Glen Ellen Formation is probably about 1,500 feet thick east of the Russian River and along the east side of Dry Creek valley.

Elsewhere the thickness of the Glen Ellen Formation is difficult to predict, as the surface has been extensively eroded and then covered by terrace deposits and alluvium. The Glen Ellen Formation extends to a depth of more than 285 feet in well 9/10–2B3 beneath alluvium and perhaps terrace deposits. Well 9/10–2B1, only 300 feet southwest, entered bedrock at a depth of 99 feet. The depth to the top of the Glen Ellen Formation in the flood plains of the Russian River and lower Dry Creek is not known, as wells in these areas obtain water from the alluvium at a depth of less than 75 feet. Several wells on the east side of the valley, which are about 200 feet deep, penetrate the Glen Ellen Formation beneath alluvium; various wells on the west side of the valley pass directly into bedrock beneath terrace deposits.

The Glen Ellen Formation is composed mainly of poorly sorted alluvial-fan and flood-plain deposits of gravel, sand, silt, and clay. The lenticular deposits vary widely in extent and thickness and grade rapidly, both laterally and vertically, into each other. Thick lenses of silty gravel and clay and thin strata of silty sand, generally cemented to some degree, are common. The formation is composed largely of debris from the Sonoma Volcanics; locally, basal beds are intercalated with the Sonoma Volcanics.

The water-bearing character of the Glen Ellen Formation ranges widely because of the heterogeneous nature of the formation. Permeability generally is low; however, in adjacent Santa Rosa Valley, numerous irrigation wells, some of which yield more than 500 gpm, have been developed at depths of 300–500 feet. Development from the Glen Ellen Formation in the Healdsburg area is largely for domestic wells, most of which are not designed for optimum yield. The yields from wells range from 1 to 140 gpm (9/9–17H1, 129 ft deep), and the specific capacity generally is less than 2 gpm per foot of drawdown.

TERRACE DEPOSITS

Erosional remnants of terrace deposits of Pleistocene age are exposed discontinuously from Rio Dell to the upper part of Dry Creek valley. The principal outcrops are along the northeastern flank of Dry Creek valley, where the terrace deposits overlie the Glen Ellen Formation and are more than 200 feet thick. Along the west side of the Russian River valley south of Healdsburg, the deposits overlie an irregular bedrock surface and are generally only 50–75 feet thick, although locally they may be as much as 150 feet thick.

In Dry Creek valley the terrace deposits extend beneath the northeastern part of the alluvial plain and are tapped by the deeper wells. Little is known concerning the subsurface extent of the deposits west of the Russian River.

Five different terrace levels have been recognized in the Healdsburg area. Some are underlain by a considerable thickness of unconsolidated deposits; others are cut across older rocks and are underlain only by a veneer of red gravelly soil. Most of the terraces shown on plate 1 are depositional, the possible exceptions being the higher terrace west of Healdsburg and the two terraces shown on the east side of the Russian River. Otherwise, terraces are not shown and contacts between adjacent terraces are omitted. In local areas the older terraces have been subjected to slight warping.

The deposits consist of stream-channel, flood plain, and associated alluvial-fan deposits, consisting largely of poorly sorted crossbedded silty gravel and sand. The higher, and older, deposits are compact and well weathered and are stained red by iron oxide. On the northeast side of lower Dry Creek valley between Lambert and Manzanita Schools, such deposits are well exposed in roadcuts.

Water-bearing properties.—Where the terrace deposits have an appreciable saturated thickness, adequate supplies of water for domestic, stock, commercial, and limited industrial uses can generally be obtained. Except for the youngest terraces most terrace surfaces are dissected and, therefore, not well adapted to irrigation. Wells generally yield from 10 to 50 gpm, and the specific capacities range from less than one to more than 5 gpm per foot of drawdown. Domestic well 9/9–17R1, which is 111 feet deep, reportedly yields 20 gpm with a drawdown in water level of 44 feet, and well 9/9–22P1 yields 24 gpm with a drawdown of 17 feet. Irrigation-test well 8/9–32E3 (table 11) reportedly yielded 60 gpm, largely from terrace deposits, with a drawdown of 50 feet. The highest reported yield for a well tapping terrace deposits is 200 gpm with a drawdown of 28 feet, measured in well 9/10–1G1, which is 209 feet deep; this yield indicates a specific capacity of about 7 gpm per foot. The yield of the well in part may be from the underlying Glen Ellen Formation.

ALLUVIUM AND RIVER-CHANNEL DEPOSITS

Alluvium, considered to be of Recent age, underlies the alluvial plains of the Russian River, Dry Creek, and tributary streams. The alluvium is capable of yielding large quantities of water and currently supplies most of the ground water used in the Healdsburg area. The meander belt of the Russian River, ranging from ½ to 1 mile wide, is underlain by loose, permeable deposits of gravel and sand that range in thickness from 25 feet to more than 75 feet and yield abundant quantities of water to shallow wells. A large part of Dry Creek valley is underlain by similar sand and gravel deposits having a maximum known thickness of 60 feet.

Most wells of large capacity are drilled for irrigation. Because acreages irrigated by individual wells are relatively small, yields greater than 500 gpm are not generally required; however, the specific capacities of irrigations wells that tap the alluvial deposits commonly range from 50 to 200 gpm per foot of drawdown, which indicates high transmissibility. Yields of 1,000 gpm or more can probably be obtained from properly located and constructed wells in the alluvial deposits.

Test wells drilled near Wohler Bridge (8/9–29L) (Ranney Method Western Corp., 1954). The alluvium in the constructed part of the lector well to supply the city of Santa Rosa disclosed the presence of clean gravel and sand ranging in thickness from 53 to more than 85 feet. Subsequent pumping tests by the Ranney Method Western Corp. showed that the aquifer was in good hydraulic connection with the river and had an average coefficient of transmissibility of 850,000 gpd (gallons per day) per foot and an average field coefficient of permeability of about 14,000 gpd per square foot (Ranney Method Western Corp., 1954). The alluvium in the constricted part of the valley at the south end of the Healdsburg area probably has relatively high permeability, because high water velocities through the narrows most likely resulted in the local deposition of only coarse materials.

The specific capacity of a well is principally a function of transmissibility if well entrance and casing friction are small. Thus, if the method of Thomasson (1960, p. 222) is used, the specific capacities of many wells in the Healdsburg area indicate that field permeabilities of about 2,000–15,000 gpd per square foot are common. The specific capacities of a few wells in the alluvium are relatively low—some less than 5 gpm per foot of drawdown. Formational and well-entrance losses result in many specific capacities that are considerably lower than those that would normally result from a given rate of pumping. The yields from some wells near the margins of the principal alluvial valleys and in tributary valleys may be relatively low because the alluvium is thinner, finer grained, and more poorly sorted than that in the central parts of the valleys.

The thickness of the alluvium near Wohler Bridge, southeast of Healdsburg, has been proved by test drilling to exceed 86 feet and may exceed 150 feet in the deepest part of the channel. Porter Creek, a tributary to the Russian River, has a steep gradient, and the valley through which it flows is filled to a depth of at least 63 feet for a distance of about 1 mile upstream from the confluence with the Russian River valley (well 8/9–19K1, table 11). The thickness of the alluvium in the vicinity of Healdsburg is not known because logs of deep wells are lacking and because of the difficulty in distinguishing the alluvium from the underlying terrace deposits and the Glen Ellen Formation.

Well 9/9–21R1 (table 11) penetrated alluvial materials to a depth of 173 feet and bottomed in the shale. However, some of the materials probably are terrace deposits or part of the Glen Ellen Formation. The log of well 10/11–12Q1, near the head of Dry Creek valley, shows that drilling was stopped in the alluvium at a depth of 55 feet.

GROUND WATER

OCCURRENCE, SOURCE, AND MOVEMENT

The principal occurrence of ground water in the Healdsburg area is the continuous body of ground water in the alluvium of the Russian River and Dry Creek valleys. In most areas, permeable deposits extend to or near the land surface, and the water is unconfined; locally, the ground water is semiconfined by layers of flood-plain silt and clay. In some parts of the area, ground water is semiconfined during the spring when water levels are high and unconfined in the autumn when water levels have declined below the less permeable beds.

Ground water in the terrace deposits may locally be continuous with that in the alluvium. Water in the older formations for the most part is semiconfined to confined, and in some places the older formations discharge water into the alluvium. Some flowing wells are obtained in the Glen Ellen Formation near the axis of the Windsor syncline, and a few flowing wells are developed along the east side of the river near Sotoyome School and in Dry Creek valley near Manzanita School.

Infiltration of rain, seepage from streams, and underflow from Santa Rosa Valley are the principal sources of ground-water recharge in the Healdsburg area. The alluvium is replenished from all sources but receives a substantial increment through underflow from underlying rocks. The amount of underflow from Santa Rosa Valley into the Russian River valley probably is large (Cardwell, 1958, p. 86).

Underflow from Dry Creek valley also makes up a relatively large increment to the recharge of ground water in the alluvium of the Russian River valley. Dry Creek does not have through surface flow during the summer and autumn, but ground water continues to move down the valley. The water percolates downward through the gravel of the channel to a water table graded to the Russian River, which is entrenched to a level slightly below that of the channel of Dry Creek.

The annual runoff from the headwaters of Dry Creek, based on streamflow measurements at the gaging station near the head of the alluvial valley (pl. 1), is 102,800 acre-feet (U.S. Geol. Survey, 1959). This runoff constitutes a large part of the surface-water inflow to the ground-water basin in the alluvial valley of Dry Creek.

As withdrawal of ground water in the Healdsburg area increases, the amount of natural discharge to streams will decrease; eventually, it may cease altogether. Seepage loss from streams then will become a principal source of recharge. Although the present ground-water development has relatively little effect on streamflow, the ultimate development may depend on the available surface-water supply.

In general, ground water moves downstream toward the Russian River, where it is discharged as underflow during most of the year. During high river stages, and in areas of large withdrawals, the movement locally is away from the stream. In 1955, water-level altitudes indicated that the hydraulic gradient in the lower reach of Dry Creek valley was approximately 10 feet per mile.

WATER-LEVEL FLUCTUATIONS

Water-level fluctuations indicate changes in ground-water storage and reveal hydraulic characteristics of the aquifers. Periodic water-level measurements have been made in several wells in the Russian River valley since 1949, and measurements in additional wells there and in selected wells in Dry Creek valley were begun in 1954. In 1951 measurements were made in a few wells in Dry Creek valley.

Water levels commonly are 10–15 feet below the alluvial plain in the Healdsburg area, and the seasonal fluctuation generally is about 5 feet or less. In upland areas the depth to water and the seasonal fluctuation are commonly greater. Locally, the seasonal fluctuation is 20 feet or more.

Water levels generally are 5–10 feet below the alluvial plain in Dry Creek valley, and the seasonal fluctuation commonly is less than 5 feet, except in local areas near the margin of the plain, where it is greater. In the vicinity of the juncture of the alluvial plains of the Russian River and Dry Creek valleys and east of Healdsburg, water levels range from 15 to 25 feet below the alluvial plain in the spring of the year.

Figure 3 shows water-level fluctuations in four wells in the Healdsburg area. Wells 8/9–15M1 and 9/9–34N1 are used for irrigation and are pumped each season, yet the maximum seasonal fluctuations seldom exceeded 5 feet during the period of record.

No significant water-level trends had developed in the Healdsburg area to 1959; the character of the fluctuations suggests that water levels, at the present magnitude of withdrawals, are affected principally by natural discharge and recharge. However, the period of water-level observation has not been sufficiently long to cover a representative climatological cycle, and measurements should be maintained for a longer period, particularly because of the continued increase in ground-water use.

DISCHARGE AND WATER UTILIZATION

Natural discharge.—Natural discharge from Dry Creek valley is by underflow into alluvium of the Russian River valley, evapotranspiration, and surface flow from Dry Creek to the Russian River.

The magnitude of the discharge by underflow in the alluvium from Dry Creek valley to the Russian River valley is indicated by the application of Darcy's Law. Darcy's Law, as it pertains to the flow of water, is stated as $Q=PIA$, in which Q is the amount of underflow, or subsurface discharge, in gallons per day; P is the field permeability, in gallons per day per square foot; I is the hydraulic gradient, in feet per mile; and A is the crosssectional area through which the underflow moves.

Approximate and estimated values are substituted for P, I, and A to obtain a crude measure of Q. The values used below are reasonable on the basis of the available data:

$P=2{,}000$ gpd per sq ft
$I=10$ ft per mi
$A=4{,}000$ ft (width) $\times 75$ ft (minimum average depth)

Thus, $Q=$roughly 1 million gpd, or about 3 acre-feet per day. On the basis of the assumption that the rate of underflow is relatively constant from year to year, as suggested by water levels, the above figure would indicate an annual discharge, by underflow, of roughly 1,000 acre-feet. More accurate data, particularly regarding permeability, would be needed to refine this crude estimate of underflow.

In the Healdsburg area of the Russian River valley, a considerable amount of ground water is discharged to the river and much is lost by evapotranspiration along the river and in other areas where the water table is close to the surface of the flood plain. At the south end of the area, the valley is narrow, and ground water moving down the valley rises to augment the flow of the Russian River.

Withdrawals.—Ground water is the principal source of water supply in the Healdsburg area, but large amounts are also pumped from streams. Most of the water pumped from both sources is used for irrigation. Pumpage for irrigation is listed in table 6 by source, area, and use for various crops.

TABLE 6.—*Estimated withdrawals for irrigation in the Healdsburg area, 1954*

Use	Russian River valley				Dry Creek valley				Total			
	Ground water		Surface water		Ground water		Surface water		Ground water		Surface water	
	Area irrigated (acres)	Water used (acre-feet)	Area irrigated (acres)	Water used (acre-feet)	Area irrigated (acres)	Water used (acre-feet)	Area irrigated (acres)	Water used (acre-feet)	Area irrigated (acres)	Water used (acre-feet)	Area irrigated (acres)	Water used (acre-feet)
Pasture [1]	620	1,550	835	2,100	370	930	25	60	990	2,480	860	2,160
Truck [2]	245	245	385	385	45	45	0	0	290	290	385	385
Orchard [3]	285	285	80	80	275	275	70	70	560	560	150	150
Total	1,150	2,080	1,300	2,565	690	1,250	95	130	1,840	3,330	1,395	2,695

[1] Includes pasture grasses, clover, alfalfa, and others, for which the average annual application is estimated to be about 2.5 acre-feet per acre per year.
[2] Includes hops (which had largely been replaced by other crops in 1954), corn, and vegetable crops (beans, tomatoes, and others). Duty varies from crop to crop and year to year, but 1 acre-foot per acre per year is considered to be a reasonable average figure.
[3] Includes prunes, pears, nnrseries, and irrigated vineyards. Duty varies with individual practice, soil type, and crop but averages about 1 acre-foot per acre per year.

In the Russian River valley sector of the area, slightly more surface water than ground water is pumped for irrigation; when withdrawals for other purposes are included, ground-water pumpage is greater. Withdrawals in Dry Creek valley are almost entirely from ground water.

The Corps of Engineers (1948) estimated that a total of 1,229 acres was irrigated in the Healdsburg area in 1944 and that the ultimate development of irrigation would probably total about 3,930 acres. Thus, the acreage irrigated in 1954 (table 6) represents an increase of about 270 percent over 10 years and approaches the estimate of ultimate development.

Pumpage by the town of Healdsburg for public supply amounted to 880 acre-feet in 1954 (table 2). Pumpage for rural domestic, stock, and other uses was mainly from ground water and probably was not more than 1,000 acre-feet. Thus, the total use of water in 1954 was probably about 8,000 acre-feet, of which about 5,000 acre-feet was from ground water.

GROUND-WATER STORAGE CAPACITY

Most of the readily usable ground-water storage capacity in the Healdsburg area is in the alluvial deposits of Recent age. The storage capacity of the deposits in the 40-foot zone between 10 and 50 feet below land surface probably amounts to about 70,000 acre-feet. The estimate was derived in the following manner. Drillers' logs of 16 wells in the alluvium of the Russian River valley and of 25 wells in the alluvium of Dry Creek valley were used to determine the percentage of sand and gravel in the deposits to a depth of 50 feet. The logs show that 43 percent of the material in the Russian River valley and

54 percent of the material in Dry Creek valley is sand and gravel. If one assumes a specific yield of 20 percent for the sand and gravel and an average specific yield of 10 percent for the other material, the average specific yield for material to a depth of 50 feet in the Russian River valley is 14 percent, and, in Dry Creek valley, 15 percent. Based on an area of 5,400 acres for Dry Creek valley, the storage between the depths of 10 and 50 feet below land surface is about 32,000 acre-feet (5,400 acres $\times 0.15 \times 40$ ft). Similarly, storage in the 6,100 acres of the Russian River valley where alluvium composes the material from 10 to 50 feet below land surface is about 34,000 acre-feet (6,100 acres $\times 0.14 \times 40$ ft).

Considerable additional storage exists in the alluvium below a depth of 50 feet, but because adequate yields are generally obtained from shallow wells 20–60 feet deep, data for deposits below a depth of 50 feet are not sufficient to allow estimation of the specific yield.

CHEMICAL QUALITY OF WATER

Ground water.—All ground water in the Healdsburg area is of the bicarbonate type and is generally suitable for all uses. The cation type ranges considerably, but the concentration of calcium plus magnesium generally exceeds that of sodium and potassium. Magnesium is the dominant cation in water from areas where serpentine is one of the rock types; sodium predominates in water from the Glen Ellen Formation. The chemical character of typical ground water in each area is summarized in table 5, and analyses are listed in table 12.

Analyses of water from wells tapping several different water bearing formations are compared with analyses of water from the Russian River and from Dry Creek in figure 4. The sum of dissolved solids and percent sodium generally is lower in the surface water than in the ground water. Commonly there is some disparity between waters from different formations; however, because of local variations within formations, many analyses would be needed to establish clearly the differences in quality of water from the several formations.

Water from well 9/9–9K1 contains a gas, probably carbon dioxide, derived from shale of the Knoxville Formation. The well is near an inferred fault. Carbon dioxide gas occurs in ground water from bedrock in many localities in Mendocino County. Well 10/10–27D2, drilled into gabbro, yields water that is high in boron (table 12).

Surface water.—Water in the Russian River at Healdsburg is generally of good chemical quality. Water in the river is made up of a mixture of waters from many tributaries ranging widely in quality. Dry Creek water generally has a greater concentration of boron than does Russian River water. This concentration results principally from inflow of water from Warm Springs Creek, which contained 2.8 ppm of boron on January 14, 1954. The source of much of the boron is Skaggs Springs, which discharge into Warm Springs Creek about 2 miles upstream from Dry Creek. Water from the springs is of the sodium bicarbonate type and contains 40–50 ppm boron (Waring, 1915, p. 81). The spring water is diluted by Warm Springs Creek, whose waters in turn are diluted by Dry Creek, so that concentrations of boron in Dry Creek valley generally are below critical limits for crops irrigated in the valley.

ALEXANDER VALLEY

GEOLOGY AND WATER-BEARING CHARACTER OF ROCK UNITS

Alluvium is the principal source of ground water in Alexander Valley, although the Glen Ellen Formation is also a major source in the southern part of the valley. Conglomerate of Cretaceous(?) age and the Franciscan and Knoxville Formations are significant sources of domestic supply throughout extensive areas in the adjacent mountains. Terrace deposits and the Sonoma Volcanics locally yield water to wells.

FRANCISCAN AND KNOXVILLE FORMATIONS

The sandstone and shale of the Franciscan and Knoxville Formations contain extensive bodies of greenstone and local bodies of chert, schist, serpentine, and silica-carbonate rock. Shale of the Knoxville Formation crops out locally. As in the Healdsburg area, the formations are cut by numerous faults which locally influence the quality of the ground water. Data concerning the water-bearing character of these formations in the Alexander Valley area are not available; however, many springs issue from the fractured rocks and supply the low flow of local tributaries of the Russian River.

CRETACEOUS(?) CONGLOMERATE

Massive pebble and cobble conglomerate of Cretaceous(?) age supplies water to wells in a rolling upland area between Dry Creek and Alexander Valleys. This area of cobble conglomerate is about 2 miles wide and extends from Lytton northwestward for more than 10 miles. The rock consists predominantly of pebbles and cobbles 2–6 inches in diameter in a matrix of medium- to coarse-grained arkosic sand. Included in the formation are local lenses of sandstone, fine gravel, and boulders. The rocks have been subjected to intensive shearing, so that most cobbles are broken along several planes. Surface exposures are well weathered and contain much clay from the decomposition of feldspar minerals in the matrix. The rocks have been folded into a steep northwest-trending syncline. Where confining strata are extensive, ground water near the synclinal axis is under artesian head and flowing wells may be obtained locally. According to Gealey (1950), the conglomerate is at least 5,000 feet thick.

Water-bearing properties.—Ground water in the Cretaceous(?) conglomerate is stored in pores between uncemented grains and in small fractures. Although the permeability is undoubtedly low, the character of the rock is relatively uniform, and, in general, wells that tap rocks having a saturated thickness of 50–150 feet will yield sufficient water for domestic and stock use.

Well 10/10–15J1 (Dry Creek drainage, Healdsburg area; table 10), 122 feet deep, yielded 6 gpm with a drawdown of 70 feet when drilled. At the west edge of Alexander Valley north of Lytton, several wells drilled into the conglomerate near the axis of the syncline had artesian flow in 1952. On April 2, 1952, well 10/9–32R3, 245 feet deep, was flowing at the rate of 19 gpm. Nearby well 32R2, 65 feet deep, reportedly flows during about 6 months of the year and yields sufficient water for domestic use and for the irrigation of a small garden. Many springs issue from the conglomerate along the west side of Alexander Valley. (See 10/9–32R1, table 10.) Some springs are large enough to supply the domestic- and stock-water requirements of small ranches.

SONOMA VOLCANICS

The northernmost extent of the Sonoma Volcanics is in Alexander Valley. The rocks consist principally of basalt, tuff, breccia, and associated sediments. The maximum thickness in the vicinity of Alexander Valley and in the Healdsburg area is probably about 1,000 feet.

No data are available concerning the water-bearing character of the rocks in the above areas. To the south, in Santa Rosa and adjacent valleys, the volcanic rocks yield water to wells, locally in large quantities (Cardwell, 1958). Fractured basalt, flow-contact zones, and coarse-grained volcanic sediments generally are the most prolific water-yielding rocks of the Sonoma Volcanics.

GLEN ELLEN FORMATION

The Glen Ellen Formation ranks second to the alluvium in importance as a source of ground water in Alexander Valley. Extensive outcrops of the formation exist only at the extreme south end of the valley. Evidence from discontinuous exposures and drillers' logs of water wells show that the formation underlies the southern half of the valley at depths ranging from a few feet to 60 feet below the surface. The Glen Ellen may also underlie parts of the northern half of the valley. The formation probably is several thousand feet thick at the south end of the valley. Well 9/8–7Q1 penetrated approximately 400 feet of Glen Ellen strata without entering underlying formations (table 11).

The lithologic and water-bearing character of the formation in Alexander Valley is similar to that exhibited in the Healdsburg area. Specific capacities of wells generally are low, and large yields are obtained only from wells penetrating a thick section of the Glen Ellen Formation (250–500 ft) and having large drawdowns. A few irrigation wells yield several hundred gallons per minute from the Glen Ellen Formation. Well 10/9–26L1, which taps both the alluvium and the Glen Ellen Formation, yielded 240 gpm with a drawdown of 90 feet when originally drilled—a specific capacity of a little less than 3 gpm per foot of drawdown. After the well was deepened from 152 to 244 feet, entirely within the Glen Ellen strata, the yield increased to 400 gpm with a drawdown of 50 feet—a specific capacity of 8 gpm per foot.

The Glen Ellen Formation is tapped by many wells in the southern part of Alexander Valley, where the alluvium is generally thin and contains permeable gravelly deposits only locally. Numerous farm wells in the upland area at the south end of the valley obtain adequate supplies of water from the formation at depths of less than 200 feet.

The distribution of the Glen Ellen Formation in Alexander Valley as shown on plate 1 may include some bodies of tuff and volcanic sediments of the Sonoma Volcanics, because the mapping largely follows that of Gealey (1950). Most of Gealey's "upper member of the Sonoma group" corresponds to the Glen Ellen Formation. Rocks mapped as "Quaternary fanglomerate" by Gealey (1950) have been included with the Glen Ellen and probably form a local facies of that formation.

TERRACE DEPOSITS

Remnants of terrace deposits are numerous but discontinuous and of limited extent. Thus, they yield water to wells only locally. The terrace deposits consist of poorly sorted flood-plain, stream-channel, and alluvial-fan deposits of gravel, sand, silt, and clay laid down during Pleistocene time.

Wells tapping 50–100 feet of saturated materials generally yield an adequate supply for domestic use. Where the deposits are fairly extensive and undissected, they may be capable of yielding relatively large quantities of water. Well 10/9–18B1, 180 feet deep, reportedly yields 435 gpm with a drawdown of 100 feet. The well may tap the Glen Ellen Formation beneath the terrace deposits.

ALLUVIUM AND RIVER-CHANNEL DEPOSITS

Within a zone about 1 mile wide along the course of the Russian River, most wells penetrate alluvium that contains more than 50 percent sand and gravel, and excellent yields are obtained. Farther from the river, the alluvium contains less coarse-grained material and more silt and the poorly sorted sand and gravel deposited by tributary creeks. As a result, the alluvium away from the river is less permeable than alluvium near the river and yields less water to wells.

Near the river, wells 25–50 feet deep generally yield 200–500 gpm and have specific capacities ranging from 10 to more than 100 gpm per foot of drawdown. Specific capacities measured during development tests suggest that at many localities the sand and gravel section has a permeability of from 2,000–4,000 gpd per square foot.

In the marginal areas, where little river-channel gravel exists, wells have relatively low specific capacities—generally less than five and locally less than 2 gpm per foot of drawdown—and few wells yield more than 200 gpm unless they penetrate a considerable distance into the underlying Glen Ellen Formation.

The individual acreages in Alexander Valley irrigated by ground water are relatively small, and yields greater than 500 gpm are generally not required. However, the alluvium is locally capable of sustaining much larger yields. Drilling beyond a depth of 50 or 60 feet to obtain the yields desired is generally not necessary. As a result, wells in the area where deposits of sand and gravel are thickest do not penetrate them fully, and the maximum thickness of the alluvium is not known. The alluvium must exceed 60 feet in maximum thickness, however, and locally it contains bodies of sand and gravel at least 50 feet thick.

Logs of representative wells that tap alluvial deposits of Recent age are listed in table 11, and yields of wells are listed in table 10.

GROUND WATER

OCCURRENCE, SOURCE, AND MOVEMENT

Ground water generally occurs under water-table conditions in the loose sand and gravel of the alluvium. Locally, the water may be semiconfined by overlying deposits of silt and clay; such conditions are more prevalent during spring or at times when the aquifer is full or nearly so. Well 10/9-26K1, 72 feet deep, generally flows during the late winter and early spring months. The partly confined water in the Glen Ellen Formation, in which this well bottoms, no doubt contributes to the flow. The depth to water beneath the alluvial plain varies somewhat depending on the slope of the land surface and the transmissibility of the underlying deposits; at most places water levels in the spring are 5–15 feet below the land surface.

Ground water in the terrace deposits is unconfined to locally confined, as in the alluvium. Water levels in wells may differ widely within short distances, owing to local differences in topography, depth of well, and material penetrated.

Water in the older formations is generally confined, and in synclinal areas the water may be under considerable pressure. Some wells that tap the unnamed conglomerate of Cretaceous(?) age along the synclinal axis near the edge of the alluvial valley have natural artesian flow. In many places, water in the Glen Ellen Formation, the Sonoma Volcanics, and the unnamed Cretaceous(?) conglomerate has a higher head than that in the overlying alluvium. Consequently, water moves into the alluvium from those formations, although hydraulic interconnection may be poor, and the movement, slow.

Water moves from the margins of Alexander Valley toward the Russian River during most of the year. Local movement of river water into the alluvium occurs during high river stages in the autumn and winter and also in summer in areas where large withdrawals are made close to the river. Most of the recharge, however, is derived from the infiltration of rain that falls on the valley floor and from seepage losses into permeable deposits that underlie channels of tributary streams—especially in fanhead areas. As suggested previously, recharge to ground water occurs in the alluvium from the escape of confined water in the Glen Ellen Formation, the Sonoma Volcanics, and the Cretaceous(?) conglomerate. Where bedrock is in contact with the alluvium, it transmits water both by gravity and by upward movement of confined water.

WATER-LEVEL FLUCTUATIONS

Static water levels in wells tapping deposits beneath the alluvial plain generally do not decline more than 10 feet during the dry, summer season, even in irrigation wells pumped periodically, and the seasonal fluctuation in many wells is less than 5 feet. (See fig. 5.) Seasonal fluctuations in the upland area and near the margin of the alluvial plain generally are somewhat greater, depending on the local draft and natural discharge. The greater part of the seasonal water-level decline is caused by natural discharge, because water continues to move toward the Russian River during the summer dry season, when recharge is drastically curtailed. The water-level gradient tends to flatten as the quantity of water moving toward the valley decreases. Water levels that in the spring are near land surface, except those close to entrenched streams, gradually decline during the

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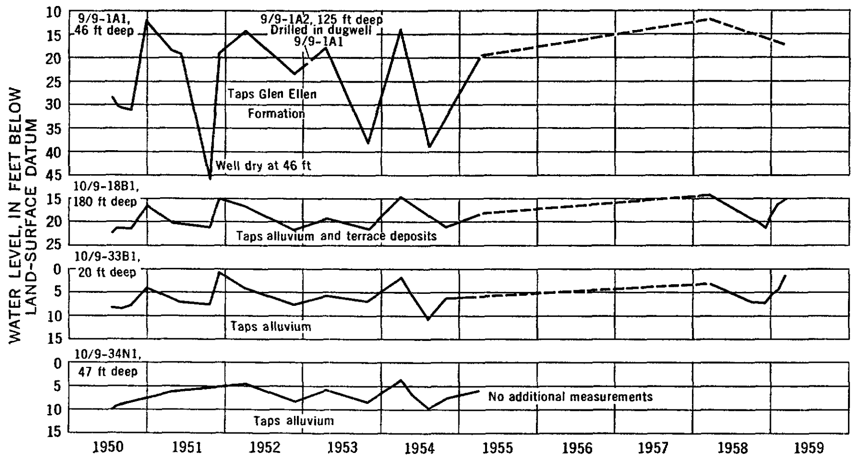

FIGURE 5.—Fluctuation of water levels in four wells in Alexander Valley, 1950–59.

summer and approach river level in autumn. Hydrographs of wells measured periodically suggest that there is no overdraft and, consequently, that there is probably little recharge from the river. In autumn, water levels in most wells decline to near the same point; in spring, they fluctuate depending on the amount and distribution of rainfall. Water levels are highest at the beginning of the pumping season, and the amount of ground water in storage is greatest during those years in which heavy spring rains occur.

DISCHARGE AND WATER UTILIZATION

Although there is a considerable amount of irrigation from ground water in Alexander Valley, the amount of ground water discharged by natural means—discharge to the river, underflow through permeable channel deposits at the south end of the valley, and evapotranspiration—probably exceeds artificial discharge by a sizable amount.

According to the Corps of Engineers (1948), 1,928 acres was under irrigation in 1944 in Alexander and Cloverdale Valleys, of which at least 1,500 acres was in Alexander Valley. About 2,000 acres was irrigated in Alexander Valley in 1954. Most of the irrigation water used in 1944 was diverted directly from the river; but since that time, water has increasingly been taken from permanent well installations located at varying distances from the river. Although a complete canvass of irrigation wells was not made, about 20–25 irrigation wells were in use in 1950 and 30–35 were in use in 1954. If an average well is assumed to irrigate 25 acres, approximately 800 acres was irrigated by ground water in Alexander Valley in 1954. Despite the overall increase in irrigation, the acreage irrigated by surface water has probably decreased, whereas that irrigated by ground water has probably increased. Pumpage by the town of Geyserville amounted to about 100 acre-feet in 1954 (table 2). As estimated from the economy of the area and the amount and distribution of population, the total ground-water pumpage in Alexander Valley in 1954 probably did not exceed 3,000 acre-feet.

Irrigation may be expected to expand in Alexander Valley. The Corps of Engineers (1948) estimated that 7,485 acres might ultimately be irrigated, an increase of about 5,500 acres over the approximately 2,000 acres irrigated in 1954. However, even at maximum development, the water requirement may not be excessive, if the economy remains unchanged, because much of Alexander Valley supports orchards, and orchards require only a small amount of supplemental water.

GROUND-WATER STORAGE CAPACITY

The storage capacity of the alluvium between 10 and 50 feet below land surface in Alexander Valley is about 50,000 acre-feet. The areal extent of alluvial deposits that are at least 50 feet thick is approximately 7,500 acres. Specific yield was estimated in the following manner. Drillers' logs of 24 water wells indicate that about 60 percent of the material in the alluvium is gravel and sand, and about 40 percent is finer material and mixtures of coarse and fine clastics. If one assumes a conservative specific yield of about 25 percent for the coarser materials, and of about 10 percent for the finer materials, the overall average specific yield is about 20 percent.

The wells considered in making the estimate of specific yield are evenly distributed over the area. Eleven wells penetrate the entire 50 feet to the base of the storage zone; 5 wells penetrate 40–50 feet; and 8 wells penetrate 26–40 feet. In the area of the old meander belt of the Russian River, the deposits generally range from 50 to 75 percent sand and gravel; away from the river the alluvial deposits commonly range from 15 to 20 percent gravel and sand.

The estimate of 50,000 acre-feet of ground water in storage in the alluvium is obtained by rounding the product of the area of 7,500 acres, the 40 feet of saturated thickness, and the estimated specific yield of about 20 percent.

Additional storage exists in the alluvium below a depth 50 feet, but data on deeper deposits are lacking. Also, a large but unknown amount of ground water is probably in storage in the Glen Ellen Formation, and a moderate amount, in the terrace deposits.

CHEMICAL QUALITY OF WATER

Ground water.—Ground water in Alexander Valley generally is of the hard, bicarbonate type, although the overall character ranges considerably depending on the source (fig. 4). Representative analyses of water samples are in table 12 and in figure 4; general features of the chemical character of the ground water are summarized in table 5.

Water in the alluvium, although suited for irrigation, generally is hard to very hard and commonly requires softening for satisfactory domestic use. Locally, water in the Glen Ellen Formation and in the conglomerate of Cretaceous(?) age contains a relatively high concentration of sodium.

The concentration of boron, a critical chemical constituent in irrigation waters, generally is less than 0.5 ppm in water from the alluvium and other formations. Local water of high boron content in this region seems to indicate an admixture of water rising along faults from a possible deep-seated volcanic or connate source with the native ground water that originated as precipitation. Water from well 9/9–4E1, 117 feet deep, contained 14 ppm boron in April 1952. Adjacent well 9/9–4E2, 32 feet deep, contained 4.4 ppm boron on the same date; the concentration in the shallower well is less, probably due to dilution by recharge from precipitation. The driller's log of well 4E1 suggests that the well, which begins in alluvium, penetrates an older formation in the interval between 18 and 81 feet (table 11). The well may penetrate the conglomerate of Cretaceous(?) age or the Glen Ellen Formation. The available analyses of water from the Glen Ellen Formation in Alexander Valley and an analysis of water from well 10/9–32R3 (fig. 4), in the Cretaceous(?) conglomerate (near well 9/9–4E1, pl. 1), indicate that water in those formations has a relatively low concentration of boron. Consequently, the high content of boron seems to be a local feature. Several faults traverse the general vicinity of these wells, and an unmapped branch fault may extend beneath the alluvium to near the wells.

Analyses of water collected in both the spring and autumn are available for a few wells. These analyses show that the concentration of dissolved solids in water from shallow wells generally is lower in the spring than in the fall; this difference reflects the diluting effect of abundant recharge in the winter and spring and the concentrating effect of evapotranspiration processes during the summer. The concentration of boron in water from well 9/9–4E1 is also less in the spring, possibly owing to the increased head of water in the alluvium as well as the diluting effect of recharge.

Several springs discharge water of unusual chemical character at the Lytton School for Boys, about half a mile west of Lytton. The principal spring discharges a sodium carbonate chloride water containing about 3,500 ppm dissolved solids, 8 ppm boron, and a high concentration of aluminum (Waring, 1915, p. 165–166). The other springs discharge carbonate water. These springs lie along a branch of the Healdsburg fault (Gealey, 1950).

CLOVERDALE VALLEY

GEOLOGY AND WATER-BEARING CHARACTER OF ROCK UNITS

The rock units mapped in Cloverdale Valley are the Franciscan and Knoxville Formations of Jurassic and Cretaceous age, terrace deposits of Pleistocene age, alluvium of Recent age, and river-channel deposits. The Glen Ellen Formation of Pleistocene and Pliocene(?) age was not recognized in Cloverdale Valley, but erosional remnants of it may be included in the rocks mapped as terrace deposits. The geologic map showing the Cloverdale Valley area (pl. 1) was compiled on a reconnaissance basis from the soils map of the area (Watson, 1917) and from aerial photographs.

All rock units in Cloverdale Valley yield some water, but the principal ground-water reservoir is formed by the alluvium and river-channel deposits, which consist largely of highly permeable deposits of gravel and sand.

FRANCISCAN AND KNOXVILLE FORMATIONS

The Franciscan and Knoxville Formations surround the alluvial valley, except in the southwest quarter, where terrace deposits crop out discontinuously, and probably underlie most of the alluvium of Recent age. In this area, shale and sandstone predominate in the Franciscan and Knoxville Formations, but included also are large bodies of serpentine and some greenstone, schist, and chert. One conspicuous band of serpentine crops out on the east side of the valley, southeast of Cloverdale. The depth to bedrock beneath the alluvial plain is known only in local areas where a few very shallow wells have penetrated bedrock highs. The bedrock apparently lies at depths greater than 40 feet under most of the valley.

The rocks typically are highly fractured, and where these fractures are relatively large and are not filled by weathering products, the rocks transmit water in minor amounts. Wells and springs in bedrock supply water for many rural dwellers in the vicinity of Cloverdale Valley. Well 11/10–19F2, 334 feet deep, obtains its water supply from fractures in bedrock. The specific capacity of the well is reportedly low, but with adequate storage facilities, the well yields sufficient water for domestic use and fire protection at the State Division of Forestry, Cloverdale Fire Station.

TERRACE DEPOSITS

Terrace deposits, which are discontinuous exposed on the southwest side of Cloverdale Valley, are a local source of ground water. They consist of crossbedded deposits of gravel, sand, silt, and clay that underlie three distinct terraces. The oldest deposits underlie the highest and middle terraces, respectively; these deposits are considerably weathered, at least locally and near the surface, and probably have low permeabilities. Deposits underlying the lowest terrace, approximately 20–25 feet above the river, may include permeable lenses of gravel and sand. Most of the deposits are fairly well dissected and, where exposed, as along U.S. Highway 101 south of Icaria Creek, appear to be composed largely of gravel and sand. The maximum thickness of the terrace deposits probably exceeds 100 feet. The deposits rest on bedrock and are overlain locally by the alluvium. Practically no data on wells in the terrace deposits are available.

ALLUVIAL AND RIVER-CHANNEL DEPOSITS

The alluvium in Cloverdale Valley is of Recent age and is composed largely of permeable gravel and sand deposited by the Russian River and Big Sulphur Creek. Yields adequate for irrigation and industrial use are obtained throughout the alluvial valley from wells 20–40 feet deep in these gravelly deposits. All drillers' logs of wells in the central part of the valley show gravel for their entire depth, except for 3–10 feet of silt or sandy soil near the surface (table 11). Logs of wells at the north end of the flood plain indicate that the gravelly deposits exceed 30 feet in thickness.

The depth to bedrock is known at only a few places because wells deeper than about 35–40 feet are not necessary to obtain yields adequate for present needs. At the south end of the valley, near Asti, bedrock was reached in well 11/10–28L1 at a depth of 18½ feet, and in well 33A, at 40 feet. On the east side of the valley, southeast of Cloverdale, well 11/10–17R1, located only about 100 feet from the contact between alluvium and bedrock, penetrated bedrock at a depth of 39 feet. Thus, although the maximum thickness of the alluvium in the area is not known, it probably exceeds 40 feet.

In the area southeast of Cloverdale, where irrigation in the valley is concentrated, ground water from shallow wells is the sole source of supply. Generally only about 40 acres or less is irrigated by a single well; therefore, large yields are generally not required. Well 11/10–17P1, 35 feet deep, yielded 700 gpm when drilled. Well 17P2, 35 feet deep, yields 500 gpm with a drawdown of 2 feet and has a specific capacity of 250 gpm per foot of drawdown. Well 11/10–33A, which penetrates to bedrock, yields 1,000 gpm with a drawdown of 8 feet (table 11). Other wells are pumped at rates of 200–650 gpm with drawdowns of only a few feet. The average permeability of the alluvium seems to be higher in Cloverdale Valley than in other valleys to the south.

Some wells within a few hundred feet of the valley walls have low yields, because they tap only thin river deposits or poorly sorted alluvial-fan and colluvial deposits. The yields of wells tapping the alluvium in Oat Valley seem to be poor. Shallow dug wells supply yields adequate for domestic requirements, but deeper wells have failed to yield sufficient water for irrigation.

GROUND WATER

OCCURRENCE, SOURCE, AND MOVEMENT

The ground water in the alluvium is generally unconfined. Even in the spring when the ground-water reservoir is full, confinement is only negligible, because the overlying soils are very permeable. Depth to water in the alluvium ranges from about 5 feet to about 25 feet, depending on location of the well and the season of the year.

Water levels show that ground water moves down the valley and toward the river. Movement in the flood-plain area east of the river is southwestward. The water-level gradient is about 10 feet per mile or less near the river and increases to 20–30 feet per mile near the valley margins. The gradient is probably on the order of 40–50 feet per mile in the terrace deposits and bedrock on the west side of the valley. This indicates that the main source of the ground water is precipitation on the valley floor and on surrounding upland slopes. Locally, recharge to the ground-water body is from the river as the river stage rises and attains high levels in the autumn and winter. The gravelly alluvial cone of Big Sulphur Creek is a large source of recharge both from infiltrating rain and streamflow.

The recharge from the Russian River is relatively small at the present rate of ground-water development. At present only a few wells near to the river—such as wells 11/10–7J1 and 7J2, public-supply wells for the town of Cloverdale—obtain an appreciable part of their yield from diverted river flow. Because of the high permeability of the gravels of the flood plain, additional large supplies could be developed in wells that are in a position to induce recharge from the river.

WATER-LEVEL FLUCTUATIONS

The water table in the alluvium seldom declines more than about 7 feet during the dry season, even in areas of pumping. The spring and fall levels were low in 1953, when rainfall was below normal.

The overall period of record is short and no long-term water-level trends have been recorded.

DISCHARGE AND WATER UTILIZATION

The natural discharge of ground water to the Russian River exceeds recharge from the river, and the amount discharged to the river during the spring is large. The amount of evapotranspiration is probably large in old flood channels, where the water table is near the land surface, but this amount can not be estimated from the data available.

Pumpage is largely for irrigation, but industrial use is increasing. In 1953, 646 acres was irrigated—414 in orchard crops (prunes, pears, and plums), 144 in pasture and alfalfa, and 88 in wine grapes. Only a few acres is irrigated by pumping directly from the Russian River, because wells can be constructed cheaply and are more convenient to use than river pumps. On the basis of these acreages and the irrigation practices reported by local ranchers, water-use duties for irrigation in 1953 were probably about as follows:

Type of crop	*Average amount of water applied (ft per yr)*	*Area irrigated (acres)*	*Water used (acre-feet)*
Orchard	1	414	414
Pasture and alfalfa	2.5	144	360
Grapes	.3	88	26
Total	--------	--------	800

The amount of water applied per acre to prunes, the principal orchard crop, ranges from about 3/4 to 1 1/3 acre-feet, depending on the amount and distribution of spring and early autumn rainfall and on the practice of individual growers. A few growers irrigate only once (in autumn).

The slightly increased acreage reported for 1954 probably resulted in an increase in pumpage to about 825 acre-feet, if all other acreages were irrigated as in 1953. Owing to the permeable soils, some of the irrigation water applied returns to the water table, so the net draft is somewhat less than the total water pumped. Practically all irrigation in Cloverdale Valley is by the sprinkler method, which began to replace irrigation by flooding in about 1950.

Municipal pumpage for the town of Cloverdale in 1954 was about 200 acre-feet (table 2). Industrial supplies are pumped from wells and from the river by several lumber mills near Cloverdale and between Cloverdale and Asti, the large Italian Swiss Colony Winery at Asti, and several smaller wineries in other parts of the valley. No estimate was made of the rural use of ground water for domestic- and stock-watering purposes, but it is probably small.

The total withdrawal of ground water in Cloverdale Valley during 1954 was on the order of 1,500 acre-feet.

GROUND-WATER STORAGE CAPACITY

The few drillers' logs available for Cloverdale Valley suggest that most of the alluvium below a depth of 10 feet is sand and gravel. For purposes of making a rough estimate of the ground-water storage capacity, the deposits may conservatively be assumed to have an average specific yield of about 20 percent. The total volume of alluvium capable of storing water cannot be accurately determined because of a lack of control on the depth to bedrock. A moderate estimate is that an average of 25 feet of permeable alluvium, containing about 15,000 acre-feet of ground water, exists beneath the water table over an area of 3,000 acres.

CHEMICAL QUALITY OF WATER

Ground water in the alluvial deposits of Cloverdale Valley is the hard, bicarbonate type. The dissolved-solids content, from the analyses available, ranges from 132 to 613 ppm. Hardness ranges from 14 to 230 ppm; the concentration of iron is low, generally less than 0.1 ppm. The major characteristics of the chemical quality of the water are summarized in table 5. Analyses of water from two wells in the alluvium and analyses of surface water from the Russian River 3 miles south of Cloverdale and from Big Sulphur Creek are shown graphically in figure 4.

The quality of water from wells close to the Russian River is commonly similar to that of water in the river.

Locally, where ground water is recharged from several sources, considerable variation in the quality of the water may occur from season to season. This fact is illustrated by figure 6 which shows graphically analyses of water from three wells in which the water quality changes decidedly during the year. Water samples were collected from these wells during the autumn, winter, and spring by the California Department of Water Resources.

Water from well 11/10–28M1, which is only a few hundred feet from the Russian River and is 21 feet deep, contains a lower concentration of dissolved solids during the winter and spring than during the autumn, as is normally expected. The chemical character as shown by the October analysis, however, is decidedly different from that in February and April. In October the percent sodium was 89 and the concentration of boron was 2.9 ppm compared to 8 percent and 0.24 ppm, respectively, in April. The quality in October was similar to that of some water from bedrock, rather than that of the Russian River. Apparently the principal source of the water in October, and, perhaps, generally through late summer and autumn, was underflow from bedrock; the principal source in February and April, or through the winter and spring months, was recharge from precipitation.

The water from well 11/10-33G1 (fig. 6) also changes from a soft, sodium chloride type in the autumn to a hard, calcium magnesium bicarbonate type in the spring. The chief difference from 28M1 is the high chloride in autumn. The boron concentration does not

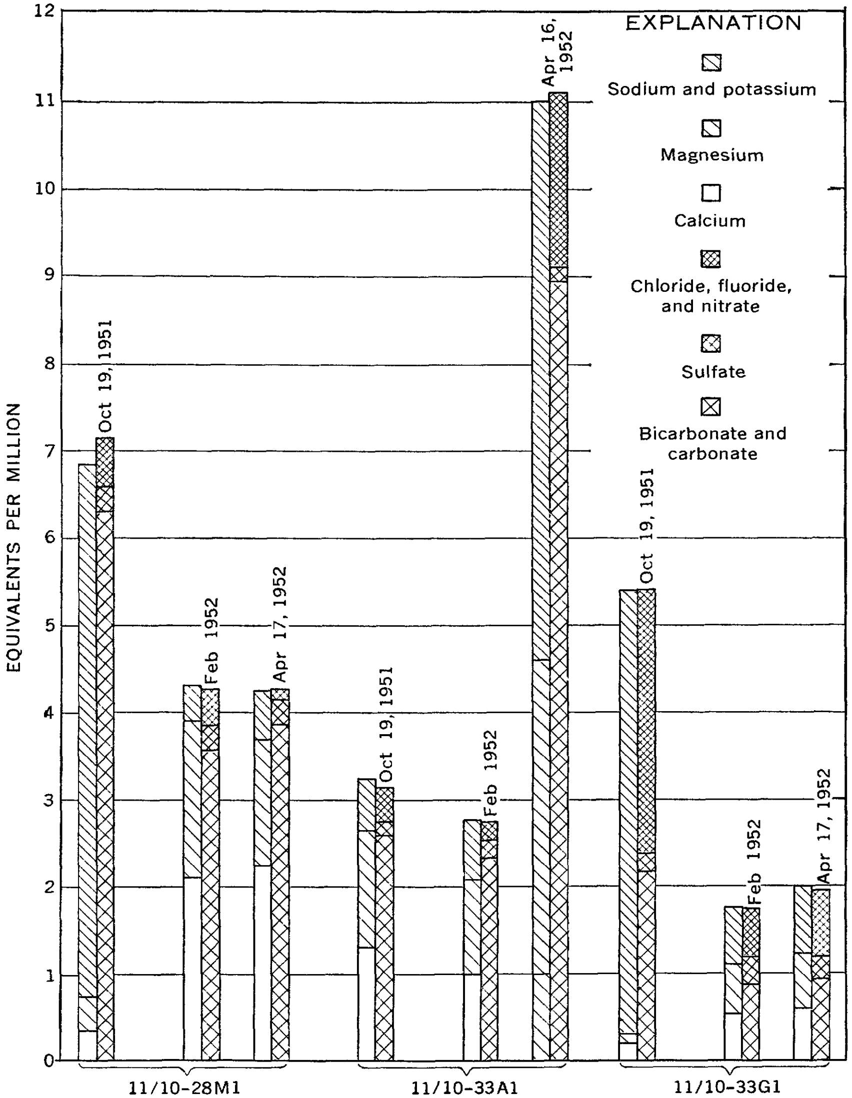

FIGURE 6.—Graphical representation of chemical analyses of water from three wells in Cloverdale Valley, showing seasonal variation in chemical character of ground water, 1951–52.

change. This well probably taps shallow alluvial or colluvial deposits and possibly bedrock. During the spring, when water levels are high, the well is presumably supplied principally by the shallow material that contributes relatively few dissolved solids to the water. During the autumn, when water levels have declined appreciably, the source of the water may be bedrock similar in character to that discharging water in the vicinity of well 28M1. Well 33G1 is about 2,200 feet from the river and definitely is not affected by it.

The water from well 11/10–33A1 changes from a magnesium calcium bicarbonate type in October and February to a sodium bicarbonate type in April, and dissolved solids increase significantly. The spring change is probably caused by recharge from an intermittent creek tributary to the Russian River that flows just north of the well and that probably drains greenstone or other bedrock terrane capable of supplying relatively large amounts of sodium to the ground water. Water from the stream probably is of poor quality only during the spring when rainfall is rare; the flow is largely ground-water discharge from bedrock. The concentration of boron in water from well 11/10–33A1 did not increase greatly.

Analyses of ground water from terrace deposits and bedrock are not available, but the quality of water from bedrock, as indicated from local reports and analyses, varies widely and is probably inferior to that of water from the alluvium. Well 11/10–17R1, at the east side of the valley, penetrates bedrock at a depth of 39 feet. Water from this well reportedly is highly mineralized and unfit for domestic use. Several other wells along the eastern margin of the valley, south of 17R1, reportedly yield water of objectionable quality. These wells are adjacent to serpentine bedrock that may affect adversely the quality of water in the nearby alluvium. Inasmuch as some people complain of "sulphur" in the water, perhaps some of the wells tap water charged with hydrogen sulfide from decaying vegetation in shallow buried channels.

Hubbard (1943, p. 303) reported the occurrence of a carbon dioxide gas seep near the east edge of Cloverdale Valley, apparently in bedrock. The gas probably has a deep-seated origin, and its occurrence generally indicates the presence of a fault that provides a conduit for the upward migration of the gas.

Water in the Russian River increases in dissolved solid content as it flows through Cloverdale Valley, owing to the inflow of water containing a comparatively high concentration of dissolved solids and boron from Big Sulphur Creek, and to disposal of wastes by the city of Cloverdale, lumbering industries, and wineries. Many thermal springs discharge into Big Sulphur Creek, which traverses several zones of shearing and faulting. Included among the tributaries of Big Sulphur Creek are the streams that drain an area of thermal springs known as The Geysers (Waring, 1915). Although these thermal springs have relatively low flows, some discharge water containing 5,470 ppm dissolved solids and 83 ppm boron.

GEOLOGY AND GROUND WATER OF THE UPPER RUSSIAN RIVER BASINS

The upper Russian River ground-water basins—the Sanel and Ukiah Valley areas and Potter Valley—are similar to those in the middle reach of the Russian River. The geology of the upper Russian River region, however, differs somewhat from that of the lower and middle Russian River regions. The structure of the post-Cretaceous rocks seems to be less complex, although only reconnaissance-type geologic mapping has been done. The geologic units mapped (pl. 2) are (1) consolidated rocks of the Franciscan and Knoxville Formations of Jurassic and Cretaceous age, (2) slightly deformed continental deposits, probably of Pliocene and Pleistocene age, (3) terrace deposits of Pleistocene age, (4) dissected alluvium of Pleistocene age, and (5) alluvium of Recent age. The areas marked by relatively broad exposures of coarse stream-channel deposits have been delineated as a subdivision of the alluvium. The geologic mapping in the upper Russian River valley shown on plate 2 is based on work by the California Division (now Department) of Water Resources (1956).

SANEL VALLEY AREA

GEOLOGY AND WATER-BEARING CHARACTER OF ROCK UNITS

FRANCISCAN AND KNOXVILLE FORMATIONS

The Franciscan and Knoxville Formations consist principally of sandstone and mudstone that contain local bodies of serpentine, greenstone, mafic igneous rocks, schist, shale, chert, and limestone. The serpentine terrane is marked by blocky outcrops that parallel the regional structure. A band of serpentine trends diagonally northwestward through 13/11–29 along a topographic "low" that probably marks a zone of crustal weakness along which differential movement has periodically occurred.

The bedrock has been folded and faulted and is intensively fractured near fault zones. At places the process of surface weathering has also created fractures. The character and extent of fracture openings generally determine the occurrence of ground water in bedrock. Therefore, although the existence of ground water in bedrock is shown by the discharge of many springs, drilled wells may be failures unless the fractures are closely spaced, interconnected, and not filled by weathering products. The primary porosity has invariably been destroyed by deposition of cementing material in rock interstices, so it is useless to drill in rocks that are not fractured or in which the fractures are not open and interconnected.

Mineral springs are plentiful in the vicinity of Sanel Valley, because many faults serve as avenues for ascending mineralized waters and because some of the rocks weather relatively easily and release soluble minerals.

CONTINENTAL DEPOSITS

The moderately to considerably deformed continental deposits of Pliocene and Pleistocene age crop out in the area east and southeast of Hopland. They consist of massive crossbedded yellow and brown compact silty and clayey gravel and yellow and blue silty clay. Several good exposures can be seen along McDowell Creek. The deposits are inferred, from drillers' logs, to underlie most of the alluvium east of East Hopland, in the Sanel Valley, and in McDowell Valley. The log of a well on the Pratt Ranch (13/11–8H1, table 11), lists the lithology typical of the deposits and indicates their occurrence along Parsons Creek, which is beyond the area mapped. Local areas of poorly exposed continental deposits form terrane not readily distinguished from that developed on sandstone of the Franciscan Formation, and probably some were not mapped.

The deposits originated as alluvial fans, lacustrine sediments, and valley alluvium. They are equivalent to the sediments exposed northward in Ukiah and Potter Valley and are at least in part equivalent to the Glen Ellen Formation of the middle Russian River valley. The continental deposits rest on bedrock and are overlain by alluvium, dissected alluvium, and terrace deposits. The thickness of the deposits cannot be estimated accurately because the structure is not well known. Probably several thousand feet of the beds are exposed, and water wells southeast of East Hopland penetrate 150 feet or more of the beds. The deposits strike northwestward and apparently dip rather steeply beneath the thin alluvium east of East Hopland.

The water-bearing potentialities of the continental deposits vary with the character of the materials. Despite the occurrence of thick gravelly deposits, the specific capacities of most wells that tap the formation indicate low permeabilities, because silt and clay largely fill the interstices of the coarse material. Specific capacities of most domestic wells are less than 1 gpm per foot of drawdown, and yields as low as 7 gpm with a drawdown of 55 feet have been reported. However, many domestic wells probably are not constructed so as to develop efficiently the entire saturated section that they penetrate. A yield sufficient to supply average domestic needs can usually be obtained from 50–150 feet of saturated formation. Well 13/11–8H1, 187 feet deep, reportedly yielded 75 gpm with a drawdown of 70 feet when drilled. Well 13/11–21L2 penetrates about 40 feet of alluvium and about 120 feet of the continental deposits and yielded 550 gpm with a drawdown of 155 feet when tested. The top of the perforations in this gravel-packed well is at a depth of 60 feet, and therefore most of the yield is from the continental deposits, although the overlying alluvium probably contributes some water.

A 12-inch well, drilled by the Mendocino Mining and Milling Co. to develop a placer deposit of platinum southeast of Hopland, obtained an artesian flow at a depth of 151 feet, according to Boalich (1920, p. 147); but later the water ceased to flow, and a pump was installed. He reported, "This pump has supplied as much as 180 gpm for 5 hours, without materially lowering the water level, which is sufficient for all needs." The well apparently was in 13/11–21R, near the edge of the alluvial plain. (See O'Brien, 1953, pl. 10b.) The source of the artesian supply probably is semiconfined water in the continental deposits.

TERRACE DEPOSITS

Terrace deposits are not extensive in the Sanel Valley area. The deposits are not known to be tapped by wells and probably are relatively thin. They are not considered to be a potential source of large quantities of ground water. The terrace deposits locally may underlie the alluvium of Recent age.

DISSECTED ALLUVIUM

The alluvium in McDowell Valley has been termed "dissected alluvium." It dates from a period when the valley drained southward through Coleman Creek to the Russian River. Headward erosion by McDowell Creek breached the narrow band of bedrock at the west side of the valley, captured the upper reaches of Coleman Creek, and lowered the stream gradient, with the result that the alluvium is now being dissected. The entrenchment may have begun in Recent time, but most of the alluvium is probably of Pleistocene age.

Well logs show that the dissected alluvium is mainly gravelly and sandy clay, with thin beds of gravel, or sand and gravel, and some thick sections of clay, the whole representing an assemblage of coalescent alluvial fans and lake beds. Near the MacFarlane Ranch (13/11–22G, not shown on map), a well penetrated alluvial deposits to a depth of 204 feet before hitting bedrock. The driller reported "blue clay" from 83 to 191 feet. The well was bailed at the rate of 100 gpm, yielding water from gravel at depths of from 191 to 202 feet. Gravel beds higher in the section were thin, and the driller indicated that they appeared to be incapable of yielding much water. The log of a nearby well, 120 feet deep, shows 50 feet of blue clay from a depth of 70 feet to the bottom. Such gravelly strata as exist are probably lenticular and incapable of providing large sustained yields.

ALLUVIUM AND RIVER-CHANNEL DEPOSITS

Alluvium is the principal source of ground water in the Sanel Valley area and is capable of supplying sustained yields of 500 gpm or more to wells. The deposits beneath the flood plain of the Russian River and its major tributaries, particularly Feliz Creek, consist largely of coarse gravels that were laid down in stream channels and on flood plains. Drillers' logs of 11 wells that penetrate 50 feet or more of the alluvium show that gravel and sand make up 85–90 percent of the material between 10 and 50 feet below the land surface. Outside of the present channels the gravelly deposits are generally overlain by "topsoil," silt, sandy clay, or sandy clay and gravel ranging in thickness from a few inches to about 20 feet. The maximum thickness reported for such material of low permeability is 28 feet in well 13/11–19C1.

The thickness of the alluvium probably ranges considerably, because bedrock profiles across the valley are undoubtedly irregular. Few wells penetrate to the underlying bedrock, and none are known to do so in the central part of the valley. A few wells in the central part of the valley penetrate clayey sediments that may be remnants of terrace deposits or the continental deposits of Pliocene and Pleistocene age. Well 13/11–18D1 penetrated clay and gravel at 55 feet; 18M1, at 63 feet; and 19Q1, at 75 feet (table 11). Many wells penetrate 40–50 feet of sand and gravel. Well 12/11–2C1, which is about 1 mile upstream from Squaw Rock, where the river enters a bedrock-floored canyon, is reported to have penetrated 73 feet of gravel without encountering bedrock. Logs of wells in Feliz Creek valley show gravel to depths exceeding 50 feet near the mouth and to 40 feet about 1 mile upstream. Thus, the thickness of the alluvium apparently exceeds 50 feet in many places, but the maximum thickness is not known. The depths of wells tapping the alluvium range from about 12 feet to more than 100 feet, although most are 30–60 feet deep.

The yields of irrigation wells in the alluvium range from about 500 to 1,200 gpm. Specific capacities range from about 20 to more than 100 gpm per foot of drawdown. Properly constructed large-diameter wells in favorable locations probably would yield more than 1,500 gpm of water.

The alluvial deposits along streams tributary to the Russian River generally are more poorly sorted than those of the Russian River and contain larger amounts of silt and clay. Therefore, wells tapping the alluvium of tributary streams commonly yield less water than do those in the Russian River valley.

GROUND WATER

OCCURRENCE, SOURCE, AND MOVEMENT

Ground water in Sanel Valley occurs under both water-table and artesian conditions. In the alluvium, ground water is generally under water-table conditions, except where fine-grained flood-plain, colluvial, and alluvial-fan deposits extend below the water table to produce local semiartesian conditions. In some places the water is slightly confined during the spring season of high water levels; later in the year, water-table conditions prevail as water levels decline below the clay beds. The water in the continental deposits of Pleistocene and Pliocene age is confined to semiconfined, as is most ground water in McDowell Valley.

Ground water is replenished from rain and by infiltration from streams. Feliz Creek, in particular, is a large source of recharge in the area south of Hopland. In addition, some water moves from adjacent and underlying bedrock and the older continental deposits into the water body in the alluvium.

The movement of ground water is, in general, from the margins of the valley toward the Russian River. Water levels measured in June 1953 indicate a fairly large component of ground-water movement toward the Russian River. The water-level gradient is steepest near the margins of the valley and in tributary valleys, where the alluvium is thin and generally of low permeability. The water table near the river has approximately the same gradient as the stream. Water moves from the river into the sediments in the autumn and winter when the water stage in the river is high. Heavy withdrawals from wells in summer in some localities reverse the normal gradient—that is, toward the river.

WATER-LEVEL FLUCTUATIONS

Hydrographs of three wells that are considered to be characteristic of those in Sanel Valley are shown in figure 7. Water levels in wells that tap deposits beneath the alluvial plain generally show seasonal fluctuations of less than 10 feet, and locally of less than 5 feet. The largest natural fluctuations occur in wells near the river, where water levels are strongly affected by changing river stages. The relatively large seasonal fluctuation of about 15 feet in well 13/12–24J1 (fig. 7),

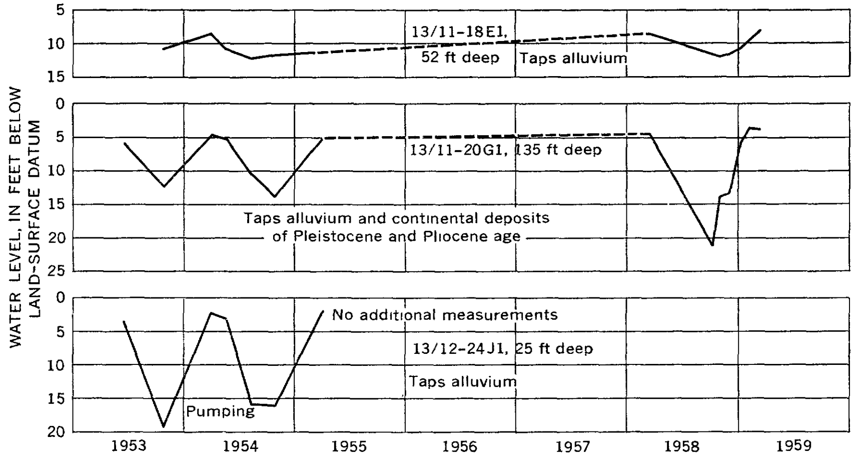

FIGURE 7.—Fluctuation of water levels in three wells in the Sanel Valley area, 1953–59.

which taps permeable deposits in the alluvial cone of Feliz Creek, is caused by variations in recharge from streamflow. During the spring period of high streamflow, water from the creek percolates through coarse channel deposits and spreads out laterally to sustain water levels within 2–3 feet of the land surface. In the autumn, the flow several miles upstream at the bedrock-alluvium contact is a mere trickle, and the recharge is correspondingly small; however, ground water continues to move through the permeable channel deposits toward its base level, the Russian River, and the water level declines.

Seasonal fluctuations of water levels in the older continental deposits show a considerable range, which probably depends on the balance between recharge and discharge and on the transmissibility of the deposits.

Although the periods of water-level records are short, the records indicate that no overdraft occurs and that water levels are principally affected by natural discharge and recharge rather than by pumping.

DISCHARGE AND WATER UTILIZATION

The principal use of water in the Sanel Valley area is for irrigation. The Corps of Engineers (1948, app. 5, p. 17) reported that 941 acres was irrigated in 1944. Owing to an expansion of about 50 percent since then, about 1,400 acres, or about half the ultimate irrigated area of 2,611 acres estimated by the Corps of Engineers, probably was irrigated in 1954. About half the acreage was irrigated by ground water; the remainder, by surface water. There were no large industrial users of water, and pumpage from municipal and rural domestic use was small, because the population of the entire valley was only

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1,163 in 1950. Thus, if one assumes that the average irrigation requirement was about 1.5 acre-feet per acre, the pumpage for all uses in 1954 probably was between 1,000 and 1,500 acre-feet.

Natural discharge, principally as effluent flow to the Russian River and partly by evapotranspiration, probably exceeds ground-water pumpage by a sizable amount.

GROUND-WATER STORAGE CAPACITY

In Sanel Valley, about 20,000 acre-feet of ground-water storage capacity is available in the alluvium and river-channel deposits of Recent age lying between 10 and 50 feet below the land surface in the flood plain of the Russian River. This estimate is based on (1) an area of about 2,500 acres for the main valley, (2) a saturated thickness of 40 feet, and (3) and average specific yield of 20 percent.

A considerable amount of ground water also is stored in the marginal alluvial deposits, the continental deposits of Pliocene and Pleistocene age, the terrace deposits, and the bedrock; however, the water in these aquifers is not as readily available as that in the main body of alluvium.

CHEMICAL QUALITY OF WATER

Table 7 provides a summary of the chemical characteristics of the ground water in the principal aquifers of the Sanel Valley area and other areas of the upper Russian River valley. Analyses of representative ground and surface waters are shown graphically in figure 8.

The ground water in the alluvium is generally of good chemical quality. In several local areas, however, it is mixed with water having

TABLE 7.—*Summary of chemical character of ground waters in the upper Russian River valley area*

[Based on analyses in files of the Geol. Survey; constituents in parts per million]

Constituent or characteristic	Sanel Valley area	Ukiah Valley area	Potter Valley
Dissolved solids	143–327	100–1,030	140–395, except 1,020 in well tapping bedrock.
Hardness ($CaCO_3$).	96–230	78–272; generally 100–150	105–345; generally 100–200.
Chloride	4.8–16	4.8–466; generally 5–25	Generally low.
Percent sodium	5–34	0–77; generally 10–35	Generally less than 20.
Boron	0.02–3.4 except in local areas where very high.	0.1–73; generally 0.1–0.6	Highest concentration in well tapping alluvium, 0.61; 1.0 in one deep well tapping bedrock.
Iron	0.1–9.5	0–7.3; generally less than 0.3.	Local wells yield water containing iron in objectionable quantities.
pH	6.7–7.9	6.5–8.0	6.6–7.9.
Temperature (°F)	No data. Probably similar to temperature of water in Ukiah Valley.	55°–60°F. Temperature of water in shallow wells near river increases 2°–3° during pumping season.	Averages about 64°F. Higher than in other areas, owing to summer recharge from over irrigation.

a high boron content that probably migrates upward from underlying bedrock. The water is a moderately hard to hard bicarbonate type; magnesium is generally the predominant cation. In an average analysis, the relative proportion of cations is as follows: Magnesium, 45 percent; calcium, 35 percent, and sodium, 20 percent.

Water in the continental deposits of Pliocene and Pleistocene ages, especially that obtained from the deeper wells, tends to contain a higher percentage of sodium and a higher concentration of dissolved solids than does the water from the younger sediments.

The quality of ground water in the Franciscan and Knoxville Formations is affected by differences in rock type, faulting, and extent and nature of rock fracturing; therefore, the water is highly variable in chemical composition. Some water from bedrock contains large quantities of dissolved substances and would commonly be referred to as mineral water.

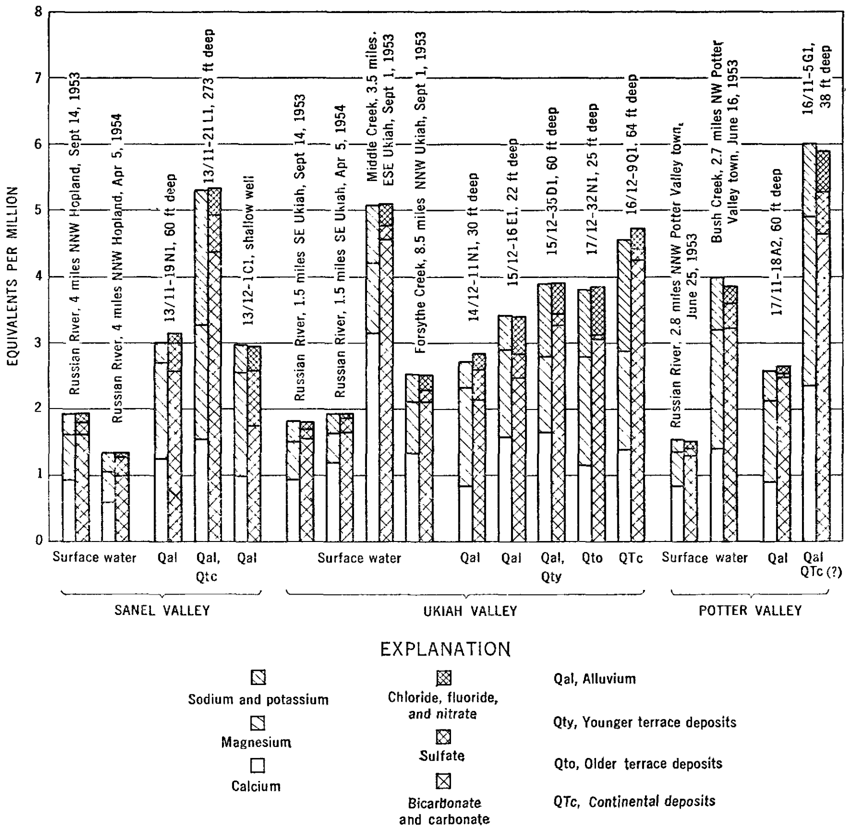

FIGURE 8.—Graphical representation of chemical analyses of ground and surface waters in Sanel, Ukiah, and Potter Valley areas.

Mineral springs are numerous in the Sanel Valley area, and several have been developed for commercial use. (See Waring, 1915, and O'Brien, 1953.) Duncan Springs, a group of five cold springs about 1½ miles southwest of Hopland, has been developed for a resort. The water of the springs is of the magnesium bicarbonate type and rises in serpentine bedrock. Waring (1915, p. 168) reported that McDowell Springs, which is about 5 miles southeast of Hopland, at the south edge of McDowell Valley, and discharges into Coleman Creek, yields a calcium magnesium bicarbonate water that contains a high concentration of iron. An analysis of water from these springs made in 1908 shows a concentration of 53 ppm iron (Waring, 1915, p. 169). Waring also reported that the Humanity Springs, located about 2 miles north of Hopland, at the west edge of the Russian River, discharges carbonated water into the river.

"Dry ice" made from the carbon dioxide associated with hot ground water is produced by the Cal-Dri Ice Co. on the east side of the Russian River about 2 miles north of Hopland. The gas is obtained from seven wells 350–790 feet deep that penetrate bedrock beneath the river alluvium. According to Hubbard (1943, p. 301), the wells were drilled "* * * close to strong seeps of carbon dioxide gas bubbling up through the Russian River." He reported that analyses of the gas show 97 percent carbon dioxide (CO_2), 1.75 percent methane (CH_4), 0.75 percent oxygen (O_2), and 0.50 percent nitrogen (N_2). The hot-spring water reportedly contains a high concentration of boron and thus is a source of boron both to the river water and, locally, to water in the alluvial deposits. This water, with its unusual chemical composition, probably rises from deep-seated sources along a fault that cuts the underlying bedrock.

Analyses of samples of river water collected during the autumn of 1953 and spring of 1954 at the head of Sanel Valley are shown graphically in figure 8. The river water is of excellent quality. The variation in dissolved-solids content normally is not great, although the turbidity and temperature vary widely. The water is similar in character to that in the alluvium, but it has less dissolved solids and is softer. During periods of low flow, the concentration of boron increases to nearly the critical limit for most crops, owing to the inflow of boron-rich water from springs in and near the river.

UKIAH VALLEY AREA

GEOLOGY AND WATER-BEARING CHARACTER OF ROCK UNITS

The Ukiah Valley area, comprising Ukiah Valley and its tributary valleys, is the largest of the ground-water basins along the Russian River. The geology of the area, modified from reconnaissance mapping by the California Division of Water Resources (1956), is shown on pl. 2. The general character and water-bearing properties of the rock units are summarized in table 3. The principal source of ground water is the alluvium of Recent age. Continental deposits of Pliocene and Pleistocene age yield small to moderate amounts of water to wells over an extensive area. Terrace deposits, dissected alluvium, and the Franciscan and Knoxville Formations also yield limited quantities of water to wells.

FRANCISCAN AND KNOXVILLE FORMATIONS

The Franciscan and Knoxville Formations in the Ukiah Valley area consist principally of sandstone, mudstone, and shale, with subordinate amounts of limestone and chert; many conspicuous masses of intrusive serpentine and occasional beds of greenstone and pillow basalt also occur. The rocks generally are fractured and contain numerous faults and local zones of intense shearing.

The ability of these rocks to absorb, store, and transmit water varies with the degree of fracturing; however, they generally yield water slowly to wells. Many springs and the base flow of streams tributary to the Russian River are sustained mainly by ground-water discharge from the large upland areas that are underlain by the Franciscan and Knoxville Formations.

CONTINENTAL DEPOSITS

Continental deposits of probable Pliocene and Pleistocene age crop out almost continuously along the east side of Ukiah Valley as far north as Calpella, in Redwood Valley, where they extend across the valley. The deposits crop out over an area of about 20 square miles and probably underlie an additional 20–25 square miles beneath a mantle of terrace deposits and alluvium.

These deposits correlate with those of similar character in the Sanel and Potter Valleys and probably with the Glen Ellen Formation in Sonoma County. The deposits were described briefly by Marliave (in U.S. Army Corps of Engineers, 1948) and by Treasher (1955). Treasher studied the strata with special reference to their occurrence in the Coyote Valley area and referred to them as the Ukiah beds.

The deposits are remnants of a once-extensive thick fill that was deposited in elongated basins or troughs which were formed on the Mendocino Plateau probably during the latter part of Pliocene time. After their deposition, the beds were uplifted, tilted slightly, and cut by northwest-trending faults. The regional dip is 5°–7° NW; locally, however, the beds are steeply tilted, apparently as a result of faulting. Marliave (in U.S. Army Corps of Engineers, 1948) reported that the deposits are 1,500 feet thick at the Coyote Valley dam site, about 4 miles northeast of Ukiah. The maximum thickness of the beds in the Ukiah Valley area is probably about 2,000 feet. However, because the beds are inclined and overlie an uneven bedrock surface, the thickness probably varies from place to place.

The rocks consist of poorly consolidated and poorly sorted clayey and sandy gravel, clayey sand, and sandy clay. The beds generally are lenticular, and locally they are massive. Thick lenses of moderately indurated gravel interfinger with large bodies of blue-gray sandy silt and clay. Concretionary masses as much as 18 inches in diameter occur commonly in the thick clay beds. The gravelly deposits generally are buff to brown in color, although occasionally they are blue gray. The finer grained deposits range from brown to yellow to blue gray. The interbedded materials were deposited in alluvial fans and as flood-plain, stream-channel, and lake sediments.

Gravels of the formation are well exposed in the bluff at the east edge of the alluvial valley, northeast of the city of Ukiah. The buff-colored gravels are coarse and cobbly; the matrix is coarse silty sand. The pebbles and cobbles consist of sandstone, chert, greenstone, and rock types typical of the Franciscan Formation.

Northeast of Calpella, and also along the road that trends east from Calpella, the beds consist of crossbedded massive buff-colored silty and sandy gravel, sandy silt, and silty clay. Locally the beds weather to a reddish-brown color. Blue-gray beds are not so common near Calpella as in the areas east and southeast of Ukiah.

Terraced remnants of the continental deposits are exposed along U.S. Highway 101 in the steep-walled valley of Forsythe Creek. In several places, 75–100 feet of gravel containing boulders as much as 1 foot in diameter in a matrix of silty sand is exposed. Lenses of unoxidized blue-gray silt and clay containing some interbeds of gravel also occur here.

The subsurface character of the continental deposits is illustrated in table 11 by drillers' logs of wells, particularly by the log of the Corps of Engineers test hole 16/12–34N2.

The continental deposits of Pliocene and Pleistocene age in the Ukiah Valley area generally have low permeability, because the interstices between the coarser textured materials are partly clogged with silt and clay derived from the weathering of the bedrock formations. The condition resembles that of the Glen Ellen Formation in the lower and middle Russian River valley.

Most wells drilled in the continental deposits of Pliocene and Pleistocene age are designed to produce small yields for domestic and stock use. Specific capacities are generally less than 1 gpm per foot of drawdown. A few wells yield about 50 gpm. Commonly only a few feet of the well casing is perforated, and water is obtained predominantly from the strata opposite the perforations. Yields could probably be increased by constructing wells by the gravel-pack technique or by increasing the length of the perforated section.

Many drillers' logs of wells in the vicinity of Calpella show a thick strata of blue clay, and wells commonly are drilled to depths of 150–250 feet before reaching a stratum that will yield the desired quantity of water. A few wells drilled to depths of as much as 250–300 feet reportedly do not yield sufficient water for domestic and stock use.

TERRACE DEPOSITS

A series of alluvial-terrace deposits, mainly of Pleistocene age, overlie large areas of older continental deposits and locally overlie bedrock. These deposits were mapped by the California Division (now Department) of Water Resources (1956) (pl. 2) and separated into (1) younger terrace deposits beneath the low, undissected to slightly dissected terraces adjacent to the flood plain and (2) older terrace deposits beneath the higher, somewhat dissected terraces. These terrace deposits have not been mapped in detail, and small patches likely occur where the geologic map shows continental deposits.

The older terrace deposits veneer a large part of the higher valley flats north of Calpella. The deposits in many places consist only of a red, gravelly clay soil. They are remnants of deposits that were once much more extensive and perhaps thicker. These deposits are generally too thin to be a source of water to wells.

The younger, and topographically lower, terrace deposits occur discontinuously on both sides of the river from several miles north of Calpella to the south end of Ukiah Valley. The terraces are best developed on the west side of the river, notably where they form the prominent broad, flat terrace north and west of the city of Ukiah. The private road of the Masonite Co. cuts through this younger terrace near the U.S. Highway 101 overpass at 15/12–8L, and 15/12–8M and exposes about 30 feet of these beds. The deposits consist mostly of sandy or silty gravel, including fragments as large as cobbles, and contain occasional lenses of sandy silt as much as 2 feet thick. All the material was apparently derived from the Franciscan Formation. The beds are compact, although unconsolidated, and nearly flat-lying except for local depositional dips. The younger terrace deposits locally may attain a thickness of as much as 200 feet.

Wells in the younger terrace deposits generally yield quantities of water adequate for domestic uses if an appreciable thickness of the deposits occurs beneath the water table. Well 15/12–8N1, 80 feet deep (table 10), yielded 63 gpm with a drawdown of 30 feet when drilled. Well 14/12–5K1, 94 feet deep, penetrates bedrock at 84 feet, thus indicating the local thickness of the terrace deposits plus a thin veneer of alluvium. The yield of the well is reportedly only 5 gpm with a drawdown of 56 feet (table 11). Many of the wells drilled into the younger terrace deposits extend into the underlying older continental deposits, but the contact between the units generally cannot be determined from drillers' logs.

Except for local high concentrations of boron, the overall quality of ground water in the terrace deposits is good.

DISSECTED ALLUVIUM

The alluvium along Sulphur Creek below Vichy Springs and along McNab Creek has been termed "dissected alluvium" because it is found some distance above the levels of the streams and is being dissected in their downstream edges. The gravelly alluvium along Sulphur Creek is thin, and headward erosion would have removed it long ago but for the fact that it is cemented, locally to concrete hardness, by carbonate precipitated from water discharged by the Vichy Springs. At the lower end of the narrow deposits along Sulphur Creek, the cemented stratum is being undercut and gradually worn back.

The alluvium of McNab Creek valley is at least 60 feet thick, and it consists mainly of sand and gravel. (See well 14/12–26H, table 11.)

ALLUVIUM AND RIVER-CHANNEL DEPOSITS

The alluvium, of Recent age, is the principal geologic unit of the valley from the standpoint of ground-water supply. It occupies the central part of the Ukiah Valley trough from just north of the juncture of Russian River and East Fork south to Morrison Creek, a distance of nearly 10 miles. The maximum width of the alluvial plain in this reach is slightly more than 2 miles, and the average width is about 1½ miles. The main body is joined by narrow tongues of alluvium in the tributary valleys. The areas in which gravelly stream-channel deposits are now being deposited have been delineated (pl. 2) as a subdivision of the alluvium of Recent age.

The alluvial materials consist of unconsolidated gravel, sand, silt, and minor amounts of clay, deposited in channels and on flood plains of the Russian River and its tributaries, on alluvial fans, and as colluvium on interfan slopes. The gravel in the old buried channels of the Russian River tends to be coarse and bouldery, with coarse sand as a matrix. In the central part of the valley, the alluvium extends from the surface to depths of 50–80 feet. The loose deposits of coarse sand and gravel are highly permeable and are hydraulically connected with the Russian River. A local well driller reported that he has drilled numerous wells 40–50 feet deep in loose gravel in the central part of Ukiah Valley without reaching older, consolidated deposits. A test hole drilled for the city of Ukiah about 1 mile northeast of Ukiah (15/12–16F) penetrated sand and gravel from depths of 2 to 80 feet and bottomed in loose gravel and boulders. Another test hole for the city, drilled at 15/12–20R, penetrated loose sand and gravel to a depth of 40 feet, "tight gravel" to a depth of 68 feet, and stratified clay, gravel, and clay and gravel to a depth of 282 feet. In this well the material below a depth of 68 feet, and possibly below a depth of 40 feet, probably consists of buried terrace deposits and continental deposits of Pliocene and Pleistocene age.

Drillers report that highly productive wells can be obtained almost anywhere in the alluvial valley. Specific capacities of wells range from about five to about 400 gpm per foot of drawdown, and commonly exceed 100 gpm per foot. Two of the public-supply wells for Ukiah, 15/12–16E1 and 16E2, have specific capacities of about 400 gpm per foot of drawndown; pumping tests show that they yield about 1,200 gpm with a drawdown of 3 feet (table 10). The wells are 22 and 34 feet deep and 8 and 7 feet in diameter, respectively, and they are near the river in the belt where thick channel deposits extend to the surface. Dug irrigation well 15/12–28R2, 35 feet deep and located more than half a mile from the river, has a specific capacity of about 130 gpm per foot of drawdown; the yield during a pumping test was 1,040 gpm, and the pumping level was 18 feet. Other things being equal, wells near the river will show higher specific capacities, especially during prolonged pumping, than do those farther away.

GROUND WATER

OCCURRENCE, SOURCE, AND MOVEMENT

In the Ukiah Valley area, recoverable ground water occurs in permeable bodies of sand and gravel, unconsolidated and semiconsolidated alluvial deposits, and interconnected secondary openings (fractures, joints) in the consolidated bedrock. Water in the alluvium is generally unconfined in the interconnected lenses and channels of sand and gravel. The body of water in the younger terrace deposits at most places merges with that in the alluvium; however, the lenses of silt and clay in the younger terrace deposits confine water locally. Water in the older, continental deposits generally is confined to some extent by silt and clay beds and rises in wells after being tapped; perched bodies of water also occur. Water in bedrock generally is confined.

Water levels in wells in the alluvial plain generally lie a few feet to about 20 feet below the land surface. Water levels in wells in the upland area, however, range from near the land surface to depths of 60 feet or more, reflecting differences in topography and degree of confinement in the water body.

The principal source of the ground water is precipitation. Replenishment occurs chiefly by the direct infiltration of rainfall and by seepage loss from streams that cross the low terraces and the alluvial plain. In areas where large quantities of water are withdrawn from wells near the river, recharge may be induced from streamflow. Water discharged from the adjacent and underlying formations is a continuous source of recharge to the alluvium. In areas where surface water is used for irrigation, some recharge to the alluvium is by deep percolation of excess irrigation water.

The ground water generally moves downvalley—toward the Russian River. Water-level gradients in the alluvium seem to range between 5 and 20 feet per mile. Gradients are lowest in the thick permeable channel deposits in the central part of the valley and steepest near the valley margins, where the alluvial deposits become thinner and less permeable.

Water levels in wells tapping the continental desposits of Pliocene and Pleistocene age indicate water-level gradients of 50 feet per mile or more. These deposits have inherently low permeability, and the movement of water is probably impeded locally by the barrier effect produced by faults that cut the deposits.

WATER-LEVEL FLUCTUATIONS

Since 1951, water levels have been measured periodically in five wells in Ukiah Valley. The hydrographs of two of these are shown in figure 9. They show that the seasonal decline in water levels in the alluvium generally does not exceed 10 feet— even in pumped irrigation wells. In the terrace deposits the seasonal fluctuation may be somewhat greater; the seasonal decline in well 15/12–8L1 (fig. 9) is generally about 15 feet.

In those wells measured, the water levels return to about the same level each spring, which indicates that discharge of ground water does not exceed recharge. Apparently, the imposition of pumping onto the natural regimen of discharge and recharge has not greatly affected the behavior of water levels in the principal water body in Ukiah Valley.

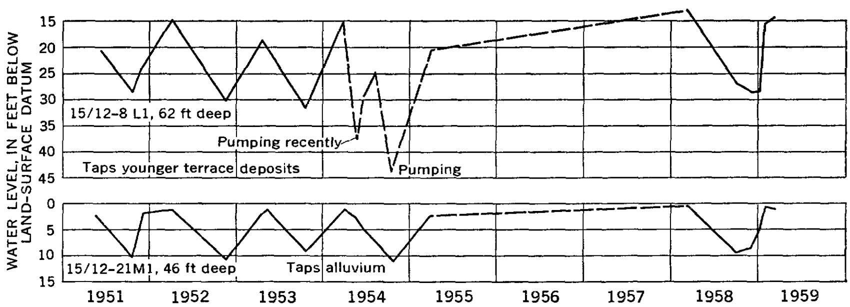

FIGURE 9.—Fluctuation of water levels in two wells in Ukiah Valley, 1951–59.

DISCHARGE AND WATER UTILIZATION

Ground water in the Ukiah Valley area is discharged by effluent seepage to the Russian River and tributaries, evapotranspiration processes, discharge through springs, underflow out of the valley, and pumping from wells.

Discharge to streams is large, especially during spring and late winter. During the summer, some of the water that moves toward areas of discharge is intercepted by pumping wells. Ground-water losses by evapotranspiration occur principally along the major streams, where growths of water-loving vegetation abound and where the water table is perenially shallow. Spring discharge, mainly from bedrock, sustains the low flow of numerous tributary streams. Much of the discharge of springs in the older, continental deposits is dissipated by evapotranspiration.

The discharge of ground water from the valley by underflow is probably small, because the cross-sectional area of the permeable deposits in the narrow segment at the south end of the valley is small. However, the constriction of the alluvial valley at its south end forces much ground water to the surface, where it is discharged as streamflow. Increased pumping of ground water would salvage some of the water now lost by seepage to streams.

Use of water in the Ukiah Valley area exceeds that in any other basin along the Russian River. The largest use is for irrigation, although large amounts are withdrawn for domestic and industrial purposes.

Irrigation in the Ukiah Valley on a moderate scale began in about 1910 (Carpenter and Millberry, 1914, p. 79), earlier than in other Russian River and North Bay valleys. By 1940, according to the U.S. Bureau of Reclamation (1945, p. 21), 3,200 acres was irrigated, mostly from the Russian River. Since 1940, shallow ground-water supplies that underlie the alluvial plain have increasingly been used.

The Corps of Engineers (1948) reported that 3,821 acres, or 60 percent of the estimated ultimate irrigation development, was irrigated in 1944. In 1954 more than 60 irrigation wells plus a somewhat smaller number of river pumps irrigated approximately 4,000 acres. The total withdrawal was about 6,000 acre-feet, half from surface water and half from ground water.

The average duty-of-water factors for the major irrigated crops in the Ukiah Valley area have been estimated from data supplied by the Mendocino County Farm Advisor's office, as follows:

Crop	*Acre-feet per acre*
Alfalfa	2.0
Permanent pasture	2.0
Hops	1.5
Pears	1.0
Prunes	1.0

The population of the Ukiah Valley area was approximately 20,000 in 1954. About 10,000 people were served by the Ukiah public-supply system and used about 2,000 acre-feet of water annually; the amount of water used is based on the 1950 per capita use of 177 gpd reported by the California Department of Public Health, Bureau of Sanitary Engineering. In addition, slightly over 1,000 acre-feet was pumped annually by the Mendocino State Hospital at Talmage (table 2). Use by the remaining population, approximately 7,500 persons, probably was on the order of 800 acre-feet, based on an estimated average use of 100 gpd per capita, the figure commonly used to estimate rural pumpage. Most of the public and domestic supply in the Ukiah Valley area was withdrawn from ground water.

Industrial use of water has increased rapidly since World War II and probably now amounts to several million gallons per day, mainly from ground water. The largest industrial users of water are sawmills and plants manufacturing wood products. The manufacturing plants, however, return much of the water to the Russian River.

Other uses of water are of negligible magnitude as compared to those listed above. The total use of water in the Ukiah Valley area is approximately 13,000–14,000 acre-feet per year, of which about 10,000 acre-feet is from ground water.

GROUND-WATER STORAGE CAPACITY

The bulk of the readily available ground water is in the alluvium and the younger terrace deposits. A rough estimate of the total amount of ground water stored in those deposits is 75,000–100,000 acre-feet.

The major part of the present ground-water draft is from the zone of coarse alluvial deposits along the Russian River. The area of development extends from the juncture of Russian River and East Fork south to Morrison Creek (pl. 2) and averages about 1 mile in width. The area includes a minimum of about 7 square miles and is underlain by gravelly deposits to a depth of 50 feet or more. Drillers' logs of wells and verbal reports indicate that most of the material in the zone between depths of 10 and 50 feet consists of sand and gravel. The amount of ground water stored in this belt of channel deposits to a depth of 50 feet below the land surface is about 35,000 acre-feet, if one assumes an average depth to water of 10 feet and an average specific yield of 20 percent.

This figure of 35,000 acre-feet is more than double the total amount of water—ground and surface—now used annually in the Ukiah Valley area, and it is greater than the foreseeable ultimate ground-water development. The channel deposits are in hydraulic connection with the Russian River, and large-scale use of ground water in storage will affect the flow of the river.

CHEMICAL QUALITY OF WATER

Most of the water in the Ukiah Valley area is of good quality, particularly that in the alluvium; however, locally the content of chemical constituents varies widely. The water is generally of the moderately hard to hard bicarbonate type; analyses show that on the average the water contains about 40 percent calcium, 40 percent magnesium, and 20 percent sodium. Representative analyses are listed in table 12, a summary of the chemical character is given in table 7, and selected analyses are shown graphically in figure 8.

Water in the alluvium is chemically similar to water in the Russian River but generally contains more dissolved solids and slightly larger amounts of chloride (fig. 8). Water in the terrace deposits and in the continental deposits of Pliocene and Pleistocene age generally contains a greater concentration of dissolved solids and sodium than does water in the alluvium.

The chemical quality of water in the bedrock ranges widely depending on the type of rock in which it occurs and the location with respect to geologic structural features. Water from some bedrock springs is highly mineralized, whereas water from others is of good chemical quality. The Vichy Springs, site of a resort about 3 miles northeast of Ukiah (pl. 2), consist of three springs that issue from beneath a bed of calcareous tufa on the south side of Sulphur Creek. Analyses (Waring, 1915) show that the water is of the sodium carbonate type. Water from Vichy Spring, the largest of the three springs, contains about 4,600 ppm dissolved solids plus about 2,000 ppm carbon dioxide.

The total hardness is over 700 ppm, and the concentration of chloride is about 300 ppm. Temperature of the water is generally about 90° F. The smaller springs contain significant quantities of boron.

Spring 15/12–22D2 (pl. 2) yields water containing a low concentration of dissolved solids (table 12). The dissolved solids include 69 percent magnesium, which suggests that the source may be in serpentine.

Temperature of ground water from shallow wells, less than 100 feet deep, ranges from 55° to 60° F but generally is 56°–58° F.

Approximately 20 wells in the area are known to yield water containing concentrations of boron ranging from 1 to 73 ppm. Most of the water that contains as much as 14 ppm boron shows no other abnormality in chemical composition. Water that contains more than about 14 ppm boron generally is nearly, or is, the sodium chloride type. In Ukiah Valley, as in other Russian River valleys, the source of the boron is probably water of volcanic origin that rises from depth along faults. Recent volcanic activity has occurred about 20 miles to the east, in Lake County. The areas in which water from some wells is known to contain objectionable concentrations of boron are (1) east of Ukiah and north of Talmadge, (2) southeast of Talmage, (3) at the north end of Redwood Valley, (4) in Coyote Valley, and (5) in McNab Creek valley.

Verbal reports indicate that local wells on the west side of both Redwood and northern Ukiah valleys yield water of poor quality, and flammable gas was reported in a well in 17/12–32E. Such gas may be derived from decomposed organic material in the continental deposits.

As in the Sanel Valley, the ground water locally contains carbon dioxide gas. Two wells in the city of Ukiah, 235 and 465 feet deep, yielded carbon dioxide gas and water under pressure when drilled (O'Brien, 1953, p. 353, 356). The wells are no longer in use, and no analyses are available. Both wells probably penetrated bedrock. The carbon dioxide undoubtedly originates in the bedrock, but it may move up into the unconsolidated sediments. Gas believed to be carbon dioxide was noted by the Corps of Engineers in "subsurface openings" in continental deposits of Pliocene and Pleistocene age in Coyote Valley (Treasher, 1955). Carbon dioxide seeps were reported near Talmadge and southwest of Ukiah by Hubbard (1943, p. 320). The carbon dioxide may be derived from deep-seated volcanic rocks or from the heating of limestone rocks at depth.

Surface water in the Russian River is generally of good chemical quality. The seasonal range in quality is usually small (fig. 8). During the low-flow period, the quality is largely determined by that of water diverted from the Eel River into the East Fork Russian River (See section. "Physiography and Drainage," p. 6). The low flow of most tributary streams is of good chemical quality, but certain tributaries contribute water of relatively poor quality. Water from Sulphur Creek, into which Vichy Springs discharge, contained 13 ppm boron on September 1, 1953. The low flows of Morrison Creek and Middle Creek (Mill Creek) are sustained by the flow of springs that rise along fault traces. Water from these streams contains relatively high concentrations of dissolved solids and of boron.

POTTER VALLEY

GEOLOGY AND WATER-BEARING CHARACTER OF ROCK UNITS

Potter Valley is at the head of the East Fork Russian River and is generally similar to the other Russian River ground-water basins in origin and appearance. Its geologic and hydrologic conditions, however, are less favorable for the development of ground-water supplies. The alluvium in Potter Valley is finer grained, thinner, and less permeable than the cobbly gravels along the main course of the Russian River farther downstream.

A large part of the present flow of the East Fork Russian River southward through Potter Valley is water diverted from the Eel River through a tunnel under the divide on the north side of Potter Valley.

The surficial extent of the geologic units mapped in Potter Valley is shown on plate 2. The mapping, in general, follows that of the California Division of Water Resources (1956), but it was modified in places, on the basis of field reconnaissance and the "Soils map of the Ukiah area" (Watson and Pendleton, 1916).

FRANCISCAN AND KNOXVILLE FORMATIONS

The bedrock that appears at the margins of the valley is dominantly sandstone and shale, probably of the Franciscan and Knoxville formations of Jurassic and Cretaceous age. Pillow basalt crops out at the north end of the valley, and a long conspicuous band of serpentine roughly parallels the east side of the valley for most of its length. Serpentine is exposed also at the extreme southeastern margin of the valley. The high concentration of magnesium in water from Bush Creek at the northwest side of Potter Valley suggests the upstream presence of serpentine.

CONTINENTAL DEPOSITS

Continental deposits, which undoubtedly are contemporary with similar deposits in the Ukiah Valley area, crop out discontinuously along the southern and western margins of Potter Valley. The total area of outcrop is about 3 square miles, and the maximum width of outcrop is about 1 mile. The formation is poorly consolidated and not well exposed. In the northern part of the valley (17/11–18N), the beds consist of yellow-brown sandy silt and clay. The chief basis for distinguishing the continental deposits from bedrock in that area is the subdued topography formed on the continental deposits, compared to that formed on older rocks, and soil type. The formation is also exposed along the road in the southwestern part of the valley (16/11–5B). The deposits are compact, and some lenses are poorly cemented. The material consists of yellow to red-brown gravel, friable yellow-brown to blue-gray silty sandstone, and blue-gray mudstone. The beds contain numerous concretions. The sandstone and silt in Potter Valley were probably deposited in shallow parts of intermittent lakes, and the gravels were probably laid down in stream channels and on alluvial fans. The large thicknesses of clay reported in drillers' logs are evidence of the existence of lakes.

The continental deposits appear to dip to the northeast beneath the alluvium. The thickness beneath the valley is unknown but probably ranges from a few feet to several hundred feet. The "blue clay" penetrated at depth from 17 to 375 feet in well 17/11–33D1 (table 11) probably represents the formation at that point. The apparent altitude and width of outcrop of the beds on the west side of Potter Valley suggest that the exposed deposits are at least several hundred feet thick locally.

The lithology of these continental deposits suggests that, in general, they have low permeabilities, although the beds of sand and gravel should yield small amounts of water to wells locally. The formation is probably tapped by most of the deeper wells in the southwest half of the valley. Well 17/11–29P1, 104 feet deep, yields sufficient water for domestic purposes and a private swimming pool.

TERRACE DEPOSITS

Terrace deposits, probably of Pleistocene age, are exposed discontinuously in the southeastern part of Potter Valley. They overlie the continental deposits of Pliocene and Pleistocene age and bedrock of Jurassic and Cretaceous age, and underlie the alluvium of Recent age. The terrace deposits, composed of flood-plain, fan, and lacustrine deposits, accumulated after the present valley was formed, and to a large extent were eroded away before the deposition of the alluvium. The exposed deposits are about 10–30 feet thick in most places, but the maximum thickness is possibly about 100 feet. On the southeast side of the valley, the underlying bedrock surface is irregular, and thus the thickness of the terrace deposits is variable. The deposits are characterized by an abundance of silt and clay and seem to be relatively impermeable, although they may contain local lenses of poorly sorted sand and gravel. Most of the shallow wells that tap the terrace deposits yield only a few gallons per minute.

ALLUVIUM

The alluvium consists mainly of clay and silt, with some sand and thin lenses of gravel. Coarse deposits are not extensive and are poorly connected. Extensive clay strata confine water in the alluvium under artesian pressure. One such stratum of blue clay or silt is 30–40 feet thick and, in the vicinity of the town of Potter Valley, occurs at depths of 15–30 feet.

The alluvium overlies continental deposits of Pliocene and Pleistocene age on the west side of the valley and bedrock and terrace deposits on the east side.

The alluvium is generally between 40 and 60 feet thick. The depth of the subsurface contact with the older deposits of similar lithology cannot be clearly ascertained from the available drillers' logs. The "brown cemented gravel," "brown clay and gravel," "hardpan," and some of the thick deeper bodies of "blue clay" reported by drillers probably are older deposits below the alluvium. Wells are known to have penetrated bedrock only on the east side of the valley. Mr. C. T. Smalley, the principal water-well driller in the area, reported that bedrock was penetrated at a depth of 35 feet in well 17/11–20J; well 17/11–7Q, drilled to a depth of 105 feet, did not reach bedrock. These two wells were not located during the field canvass.

Yields of wells tapping the alluvium generally are relatively low, but because of the abundance of surface water available for irrigation use, few large-capacity wells have been drilled. Several wells reportedly yield 50–75 gpm, and the maximum yield is about 100 gpm. Specific capacities of most wells range from about 1 to 5 gpm per foot of drawdown. Most wells are less than 100 feet deep and include only 4–8 feet of perforated casing.

GROUND WATER

OCCURRENCE, SOURCE, AND MOVEMENT

The ground water in Potter Valley is semiconfined beneath beds of silt and clay, except in the upper part of the alluvium and at the heads of alluvial fans on the valley margins, where the water is generally unconfined. Confinement is especially marked in the north-central part of the valley, where some wells have seasonal artesian flow.

The major source of ground water is precipitation that falls within the drainage basin. As shown by water-level records, however, a

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significant amount of recharge occurs by seepage from irrigation canals, laterals, and fields that receive water in excess of consumption. The abnormally high ground-water temperatures are another indication that irrigation-return water is a source of recharge.

Large-scale irrigation with surface water began in 1922 and was accelerated in 1924. The Potter Valley Irrigation District, formed in 1924, diverts water directly from the tailrace of the Potter Valley Powerhouse, at the head of the valley, and pumps the water into a gravity canal that was built around the perimeter of the valley. The District in 1954 had appropriative rights to a maximum of 50 cfs of surface water during the irrigation season and irrigated about 3,800 acres, mainly pasture grasses, alfalfa, ladino clover, and some pears, prunes, vineyards, and truck and row crops. In addition, several ranches (four in 1950) outside the irrigation district pump directly from the Russian River.

The water-level gradient is toward the river throughout the year because (1) little ground water is pumped; (2) recharge is abundant at the margins of the valley; and (3) the East Fork Russian River, with the additional water imported from the Eel River, has cut its channel below the flood plain and lowered the water table in the central part of Potter Valley.

WATER-LEVEL FLUCTUATIONS

Seasonal water-level fluctuations in Potter Valley are small—in most wells, less than 10 feet—and annual spring water levels are about constant for the period of record (fig. 10). Because the specific yield of the alluvium is low, short-term fluctuations may locally be large compared to seasonal changes. When irrigation with surface water is discontinued early in the year, or not practiced, pumping may cause marked local depressions in the water surface. This may be the explanation for the low autumn 1951 levels measured in three wells, as shown in figure 10.

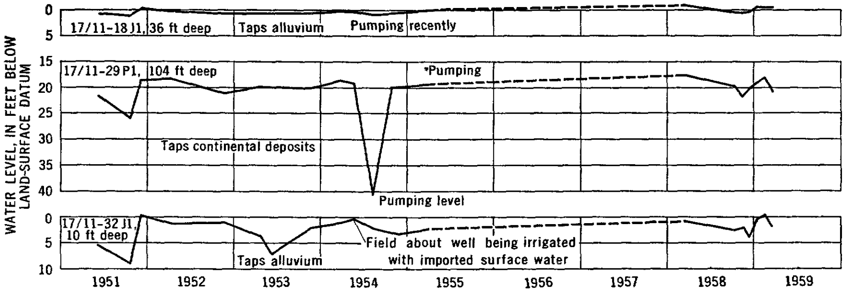

FIGURE 10.—Fluctuation of water levels in three wells in Potter Valley, 1951–59.

Water levels in many wells in Potter Valley generally show small declines in summer (fig. 10). In some instances, however, water levels may actually be higher during the summer than in the spring—normally the time of highest levels—because of the application of surface water in excess of irrigation needs. (See well 17/11–32J1, fig. 10.) Both wells 17/11–18J1 and 32J1 are in or near irrigated fields. Well 17/11–29P1 is not near irrigated fields, and the small seasonal fluctuation probably reflects the maintenance of water levels during the dry season by irrigation losses over broad areas beyond the irrigated tracts. The depth to water in well 29P1 is greater than that in the other wells shown in figure 10 because it is on a low knoll.

DISCHARGE AND WATER UTILIZATION

Natural discharge by effluent seepage to streams and by evapotranspiration undoubtedly accounts for most of the ground-water discharge from the water body in Potter Valley. Less than 200 acres is irrigated by ground water pumped from about six wells. All domestic and some stock requirements are served by ground water. The population of Potter Valley in 1954 was about 1,200. Based on the assumption of a per capita use of 100 gpd, the total domestic use in 1954 was about 130 acre-feet. Ground-water use by livestock was probably on the order of 20 acre-feet. Therefore, the total annual ground-water withdrawal, including that for irrigation, was on the order of 500 acre-feet.

GROUND-WATER STORAGE CAPACITY

The few drillers' logs available indicate that the percentage of permeable materials in the alluvium in Potter Valley is much lower than in the valleys along the main stem of the Russian River. The deposits contain a significant amount of storage capacity, however, for most wells in the valley obtain adequate domestic supplies from wells 40–60 feet deep. Data are insufficient to make a direct estimate of the average specific yield of these deposits, but similar deposits in the Santa Rosa Valley have an average specific yield of 5–8 percent (Cardwell, 1958). The amount of ground water in storage beneath the Potter Valley alluvial plain can be roughly estimated by using a conservative figure of 5 percent for specific yield. The area of the valley is about 4,500 acres, beneath which the alluvium probably has an average thickness of about 50 feet, and the average depth to water is about 5 feet. Based on these assumptions, the storage in Potter Valley to a depth of 50 feet is approximately 10,000 acre-feet, or about the amount of water that would be required annually to irrigate the entire valley.

CHEMICAL QUALITY OF WATER

Analyses of water from wells that tap alluvium, terrace deposits, and older, continental deposits, show that the ground water is of the calcium magnesium or magnesium calcium bicarbonate type containing from 140 to 395 ppm dissolved solids. Sodium ranges from 5 to 19 percent, and the maximum boron concentration recorded is 0.6 ppm. The range in chemical character is shown graphically in figure 8, and the general character of the ground water, as indicated by analyses, is shown in table 7.

An appreciable part of the water from well 17/11–33D1 probably comes from bedrock, for the well penetrates bedrock at depths from 375 to 658 feet (table 11). The water contains 1,020 ppm dissolved solids, 1.0 ppm boron, and 48 percent sodium.

The quality of ground water in all formations except the bedrock is excellent for irrigation use. Water for domestic use is considered to be moderately hard to hard, having a hardness range from 105 to 345 ppm. The water may contain objectionable concentrations of iron.

The chemical character of shallow ground water in much of Potter Valley has undoubtably been altered by summer recharge from the deep infiltration of irrigation water. In addition, the temperature of the shallow ground water has risen to 64°–66° F from the original temperature of about 56°–58° F.

The water from four creeks in Potter Valley was sampled in the last half of June 1953, when the low streamflows were sustained mainly by ground-water discharge. All the streams have calcium magnesium bicarbonate type water and contain significant amounts of sodium, which ranges from 12 to 19 percent. The concentration of dissolved solids ranges from 129 to 227 ppm, and the total hardness, from 100 to 175 ppm. The water in Bush Creek, which probably drains serpentine terrane, contains more magnesium than calcium and contains 0.67 ppm boron, more than any of the other streams.

Three analyses of water from the Eel River where it joins the Russian River at the Potter Valley Powerhouse show that it is a calcium magnesium bicarbonate water having 13–15 percent sodium. Water from this source is periodically sampled by the California Department of Water Resources. The Eel River water is of better quality than the water of tributary creeks in Potter Valley, because the dissolved solids range from about 80 to 96 ppm, and hardness ranges from 58 to 71 ppm. The main river acquires a higher content of dissolved solids downstream from the flow of tributaries and accessions of ground water into the stream.

GEOLOGY AND GROUND WATER OF THE NORTHERN MENDOCINO COUNTY BASINS

ROUND VALLEY

GEOLOGY AND WATER-BEARING CHARACTER OF ROCK UNITS

Three general geologic units are exposed in the immediate vicinity of Round Valley. In ascending order, these are (1) consolidated bedrock of Jurassic and Cretaceous age—the Franciscan and Knoxville Formations, (2) continental deposits of Pliocene and (or) Pleistocene age, and (3) alluvium and river-channel deposits of Recent age. The surface distribution of rock units in Round Valley is shown on plate 3; their general character and water-bearing properties are summarized in table 8.

STRUCTURE AND GEOLOGIC HISTORY

Round Valley is a down-faulted block, or graben, partly filled with alluvial deposits of more than one age. Bodies of sheared and slightly metamorphosed rocks mark the main zones of faulting on the northwest and southeast sides of the valley. Clark (1940, p. 139) suggested that the valley is bounded on all sides by a complex set of faults. Formation of the valley probably occurred later than Miocene time, because rocks of Miocene age are involved in normal faulting about 1 mile southwest of Round Valley.

Continental sediments of probable Pliocene and Pleistocene age were then deposited in the valley. Subsequent faulting and uplift tilted the strata slightly to the northwest, and the rocks were extensively eroded. Still later, the lower parts of the valley were filled with alluvium.

At the south end of Round Valley, the continental deposits appear to have been dropped down by faulting against the Franciscan and Knoxville Formations. Subsidence of the valley with respect to the adjacent mountains probably occurred repeatedly, creating closed-basin conditions and lakes. The fine-grained rocks that are found in the center of the valley accumulated in lakes, where they interfingered with the coarser alluvial sediments now found at the valley margins. Stream and fan deposits accumulated over the entire valley floor after the lakes were filled or drained.

At the present time, deposition is dominant in the upstream part of the valley, and some entrenchment is occurring in the lower part, as Mill Creek slowly deepens the outlet valley.

TABLE 8.—*Stratigraphic units and their water-bearing character in Round, Laytonville, and Little Lake Valleys, Calif.*

Geologic age	Formation and symbol on pls. 3, 5, 6 and in figs. 13, 14	Location and extent	Thickness (feet)	General character	Water-bearing properties
Recent	River-channel deposits (Qrc)	Occur along streams, generally in fanhead areas where streams debauch into valleys. Mapped only in Round Valley. Of limited extent in Laytonville and Little Lake Valleys.	Generally 0–20 ft; thicker in Round Valley.	Largely loose coarse sand and gravel.	Moderately to highly permeable. Tapped by wells in Round Valley; upstream salients tapped by wells in Laytonville and Little Lake Valleys. Deposits afford a principal avenue of recharge.
Recent	Alluvium (Qal)	Underlies flat-lying parts of valleys; includes all sediments deposited during Recent time by alluvial and colluvial processes.	Ranges from featheredge to more than 400 ft in Round Valley; about 150 ft in Laytonville Valley; more than 250 ft in Little Lake Valley.	Unconsolidated clay, silt, sand, and gravel generally in lenticular bodies; some intercalated lacustrine deposits may be relatively extensive.	Generally moderately permeable; locally highly permeable. Specific capacities of wells in Round Valley range from about 2 to 50; in Laytonville Valley, from less than 1 to 35; in Little Lake Valley from less than 1 to 100. Principal source of water in all valleys.
Pleistocene	Terrace deposits (Qt)	Mapped only in Laytonville Valley area.	Generally 0–50 ft in outcrop area; attains thickness of about 200 ft beneath valley alluvium.	Unconsolidated and dissected deposits of gravel, sand, clay and gravel, silt, and clay; locally weathered.	Low to moderate permeability. Generally yields sufficient water to supply domestic and stock wells.
Pleistocene and Pliocene	Continental deposits of Pleistocene and Pliocene age (QTc)	Deposits crop out at south end of Round and Little Lake Valleys and extend valleyward beneath younger alluvium. Crop out as erosional remnants in northern part of Laytonville Valley area.	More than 400 ft in Round Valley; more than 1,500 ft in Little Lake Valley.	Continental deposits of silty and clayey gravel, silty sand and sandstone, and clay and silty clay; local diatomaceous shale in Little Lake Valley.	Generally low permeability; locally yields sufficient water for domestic and stock needs.
Cretaceous and Jurassic	Franciscan and Knoxville Formations (KJu)	Form bedrock in all valley areas.	Not known; possibly exceeds 10,000 ft.	Largely consolidated sandstone (graywacke), mudstone, shale, and chert; local bodies and bands of greenstone, serpentine, and schist. Limestone occurs locally in Laytonville Valley. Rocks generally are fractured and locally are highly sheared.	Rocks that are intensely fractured have low to moderate permeability. Many springs issue from bedrock and furnish domestic and stock supplies, especially in Laytonville Valley area. Locally water is of poor chemical quality.

FRANCISCAN AND KNOXVILLE FORMATIONS

The bedrock that surrounds and underlies the alluvial deposits is presumed to belong mainly to the Franciscan and Knoxville Formations. These rocks, as discussed elsewhere in this report, were probably deposited during the Jurassic and Cretaceous Periods.

The rocks on the southwestern margin of the valley are highly sheared and include a large body of serpentine and some greenstone. The serpentine crops out in 22/13–24 and affects the chemical quality of water in Turner Creek. North of the south fork of Town Creek, the rocks bordering the valley consist mainly of impure sandstone and mudstone or siltstone. The bedrock salient that extends into the northeastern part of the valley (23/12–33) probably consists of greenstone, because the same type of red soil cover typically forms on greenstone elsewhere in the area. A band of sheared shale, greenstone, graywacke, and phyllite, or slightly metamorphosed shale bound the northeastern part of the valley. Massive gray sandstone is exposed at the mouth of Short Creek. The bedrock on the east and southeast sides of Round Valley consists mainly of siltstone or mudstone but includes some beds of sandstone. An area of red soil in 22/12–15 may indicate the occurrence of greenstone, although the soil could be formed on weathered deposits of an old terraced surface. The rocks on the southern margin of the valley are largely serpentine and greenstone.

No wells canvassed are known to obtain water from bedrock, and only two or three wells are known to penetrate bedrock. Well 22/13–2A3 (pl. 3; table 14) bottoms in bedrock at depth of 146 feet. The rock reported by the driller to be at the bottom of well 22/12–18N1, 452 feet deep, may be a cemented sedimentary stratum (table 14). Shallow wells might obtain small yields of water locally from sheared and broken bedrock, but water from such wells probably would be more mineralized than water from wells deriving their water from the alluvium.

CONTINENTAL DEPOSITS

Old basin deposits are exposed over an area of about 2 square miles at the south end of Round Valley. They were described briefly by Clark (1940, p. 138–139), who termed them "earlier alluvium" and assigned them to the Quaternary period. These deposits may have accumulated in either Pliocene or Pleistocene time, but their age is not definitely known. They are classified here as Pliocene and Pleistocene because they appear to be correlative with similar deposits in Little Lake Valley and in the basins along the Russian River. They are the eroded remnants of an old valley fill that has been elevated and tilted slightly to the west.

The continental deposits are well exposed only along the county road in 22/12–21H, where about 75 feet of reddish-stained silty gravel, sand, sandy silt, silty clay, and siltstone are exposed. The section includes several clay beds 4–6 feet thick. These sediments appear to dip 5°–6° in a west to northwestward direction, but the attitude cannot be measured accurately. The maximum thickness of the beds in this locality is about 200 feet.

The total thickness of the continental, basin-filling sediments is not known, but in some places it apparently is greater than 400 feet. The driller's log of well 22/12–19G2, 508 feet deep (table 14), indicates that the top of the continental deposits may be at a depth of either 410 or 450 feet, and nearby well 22/12–19B1, 860 feet deep, did not reach bedrock; therefore, the base of the continental deposits is below a depth of 860 feet.

The permeability of the beds that are exposed is low. The exposed beds, however, are only a small part of the total section and may not be representative of the deposits as a whole. Continental deposits are probably tapped only by the deep wells in 22/12–19. Although it was not possible to determine where the water enters these wells, most of the water undoubtedly comes from the overlying alluvium. The continental deposits locally contain coarse materials that may yield water readily to wells. Draft from such deposits, however, might well produce excessive drawdowns, because of slow recharge due to poor interconnection of permeable bodies.

ALLUVIUM AND RIVER-CHANNEL DEPOSITS

The alluvium of Recent age forms the principal ground-water reservoir in Round Valley. The alluvium was deposited on alluvial fans, on flood plains, and along stream channels; also included are deposits of deltaic sand and silt and lake-bed clay. The cross section of figure 11, based on the logs of a few widely-spaced wells, depicts the general subsurface conditions and the vertical alternation of coarse and fine-grained materials to a depth of about 200 feet.

Near the margins of the valley, the deposits are lenticular and consist primarily of coarse and poorly sorted gravel and sand. These deposits apparently were deposited on alluvial fans that had an original inclination of several degrees toward the valley. With increasing distance from the margin of the valley, the deposits grade into fine gravel, sand, silt, and clay; the sorting improves also, so that the gravels and sands contain less silt and clay. Presumably the bodies of permeable material also become more extensive laterally. In the central part of the valley, the sand is thick and locally so fine grained as to be termed "quicksand" by well drillers, according to Mr. Glen Barrass.

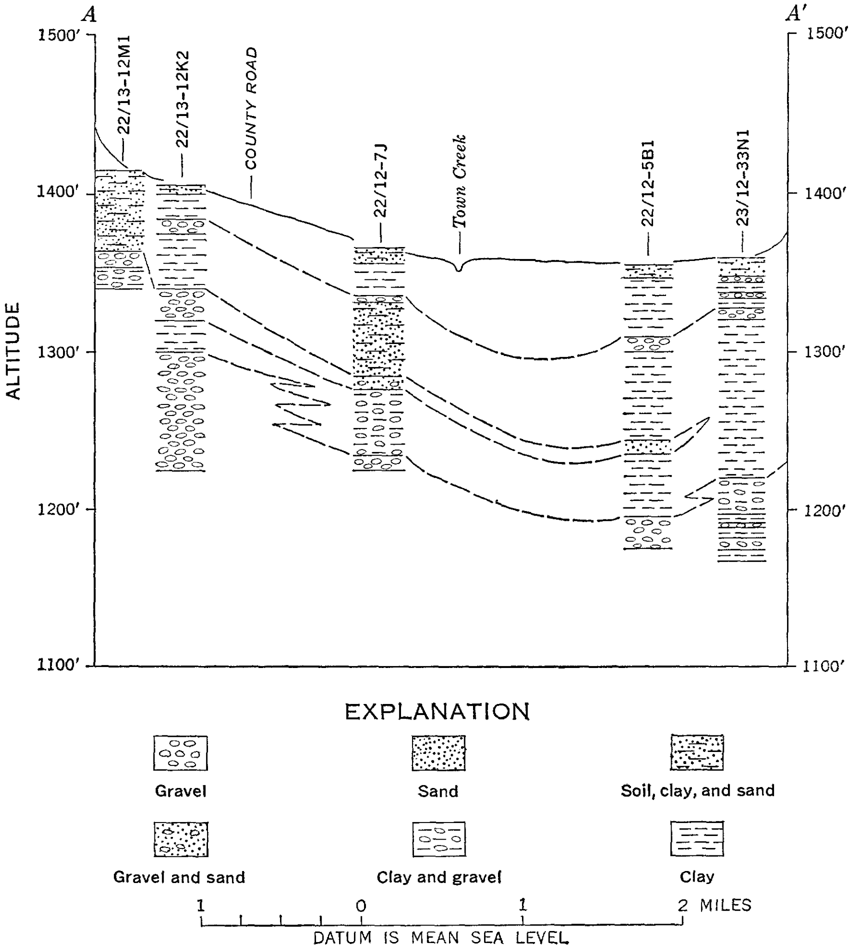

FIGURE 11.—Geologic section of upper part of alluvium in Round Valley. See plate 3 for location of section.

In the southern part of the basin, where Mill Creek leaves the valley, the upper part of the alluvium appears to be largely silt and clay with occasional interbedded lenses of channel gravels and sands.

The driller's log of well 22/12–19G2, in the southwestern part of the basin, appears to show that the alluvial deposits are about 410 or 450 feet thick. The deposits may be thicker in the center of Round Valley, but at the time of this report (1955) no wells there were known to be more than 300 feet deep.

The coarse-textured deposits along the margins of the valley provide yields to wells that range from less than 100 gpm to as much as 1,000 gpm, and have specific capacities ranging from about one to more than 50 gpm per foot of drawdown. Most of the poorer wells are in interfan areas and penetrate only small thickness of gravel that have low permeabilities due to the presence of fine-grained material in the interstices. Many of the wells, however, are not constructed to develop the water-bearing potentialities of the material they penetrate.

The sand in the central part of the valley can apparently yield large quantities of water. Few attempts have been made to develop wells of large capacity, because subirrigation from the water table at very shallow depth makes supplemental irrigation unnecessary for grass, hay, and tree crops in most years. Several wells that are perforated for short distances near the bottom yield more than 300 gpm and have specific capacities of 10–20 gpm per foot of drawdown.

Throughout the valley, and especially in the central part, fine sand enters wells, and a number of wells have failed because of excessive inflow of sand. As a result, many ranchers are reluctant to pump existing wells heavily or to drill irrigation wells. Many flowing artesian wells in the central part of the valley are allowed to flow constantly, because the owners fear that closing them might allow sand to clog the well bottoms and cause the wells to cease flowing. Many of the difficulties caused by fine sand could be eliminated by methods of well construction more refined than those employed in the past—that is, by the use of an adequate amount of screen with the proper size openings, gravel-packing when necessary, and proper development techniques.

The areas in which the present streams are depositing coarse-grained material are shown on plate 3. The surficial deposits were mapped principally because they form good recharge areas. The present surface extent of the coarse deposits bears little relation to the extent of similar deposits at depth, because the stream courses are constantly shifting and have meandered widely over the valley floor.

GROUND WATER

OCCURRENCE, SOURCE, AND MOVEMENT

Both unconfined and confined ground water occur in Round Valley. Plate 4 shows the approximate areas where unconfined and confined water occur and shows contours on the water surface.

Unconfined water is found in the heads of the alluvial fans and in a belt of unconsolidated sediments about 1 mile wide around the valley. The water level in gravel-packed well 22/12–19N1, 1,105 feet deep, represents the composite head in the strata tapped by the well. In June 1954, this water level was the same as the water level in the shallow pit surrounding the casing, which indicates that no appreciable confinement occurs in the southwestern part of the valley. Unconfined water is tapped at shallow depths in the west-central part of the valley, where the deeper water is confined.

Ground water is mainly confined in the central part of the valley. The confinement results from the overlap of fine-grained deposits, mostly the lake beds on the coarser alluvium. The highest water levels occur near the center of the valley. The water level in well 22/12–6L2, 112 feet deep, reportedly attains a height of about 25 feet above the land surface. Locally the water in very shallow water-bearing strata is confined during periods of high water level; the dug wells 22/12–6K1 and 6K2, about 14 feet deep, generally flow during the winter and spring. These wells apparently tap buried channel deposits of Mill Creek or Town Creek.

The deeper confined water generally has a higher head than does local ground water that occurs under water-table conditions. This fact is illustrated by wells 22/12–9D2 and 9D3, which are less than 50 feet apart and are at the same altitude. On June 25, 1954, the water level in well 9D2, 13 feet deep, was 6.47 feet below the land surface, whereas well 9D3, 90 feet deep, flowed at a point 1 foot above the land surface. There is a difference of about 6 feet in the water levels of wells 22/13–1H1, 214 feet deep, and 1J1, 50 feet deep. Pairs of adjacent shallow and deep wells in other parts of the valley exhibit similar or greater head differences.

The eastern boundary of the area of flowing wells shown on plate 4 is approximate. Additional data may show that the zone extends farther southeastward.

The source of ground water in Round Valley is that part of the precipitation upon the drainage basin that percolates underground and is stored in permeable deposits underlying the valley floor. Recharge is principally by infiltration and deep penetration of precipitation and intercepted runoff in the stream channels and permeable soils of alluvial fan areas along the western and northern margins of the valley. In the remainder of the valley, conditions are generally unfavorable for recharge because of perennially high water levels and near-surface deposits of low permeability. Recharge might occur in local areas where ground water is currently discharging if the water table were drawn down by substantially increased ground-water development. A large potential source of recharge—and one that may now make a sizable contribution—is underflow from the surrounding bedrock. Local areas of highly fractured rocks are capable of storing and transmitting water readily. Therefore, increasing the valleyward gradient by drawing down water levels might result in increased recharge to the adjacent alluvium and diminished discharge to springs.

Based on the estimated natural ground-water discharge, recharge now amounts to approximately 30,000 acre-feet per year, which probably is nearly the ultimate water requirement for full development of the valley.

Ground water in Round Valley moves from the principal intake or recharge areas, which are at the heads of alluvial fans on the north and west sides of the valley, to the lower parts of the valley trough and finally discharges into Mill Creek. The water-level contours (pl. 4) show that the general direction of ground-water movement is from west to east and then to the southeast, which indicates that the greatest amount of recharge is from the west.

WATER-LEVEL FLUCTUATIONS

The seasonal fluctuations of water levels in five wells in Round Valley are shown in figure 12.

In general, seasonal fluctuations are greatest in wells that tap unconfined water in the southwestern part of the valley and in the higher parts of the alluvial fans along the western margin of the valley. For example, the average seasonal fluctuation in well 22/12–19M1 is about 25 feet. The fluctuations of water level in this well seem to be chiefly related to seasonal recharge and discharge, and no increase in the seasonal water-level decline has been noted since 1953, when pump-

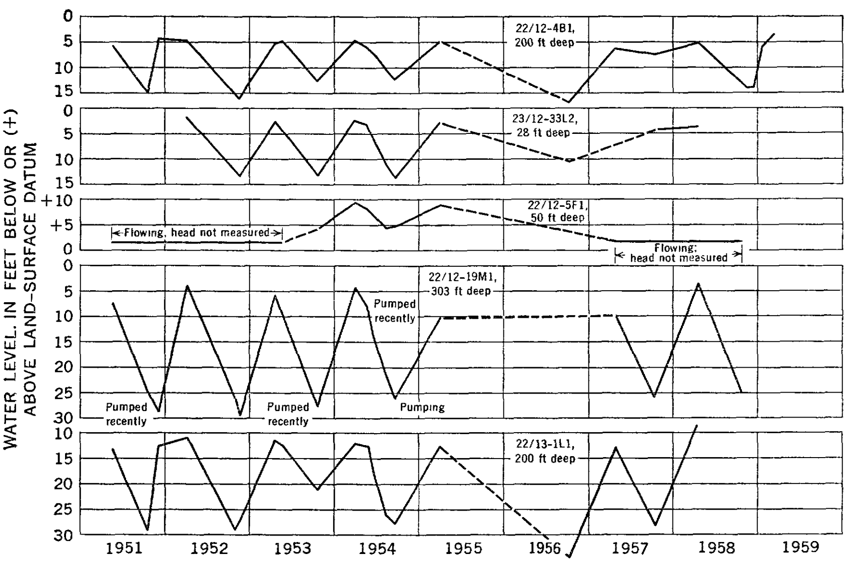

FIGURE 12.—Fluctuation of water levels in five wells in Round Valley, 1951–59.

ing for irrigation began in the vicinity. The average seasonal decline in well 22/13–1L1 is generally about 15 feet.

Spring water levels in the fan area on the west side of the valley generally are 5–15 feet below the land surface. Lowest dry-season levels seldom exceed 30 feet below the land surface.

In the northeastern part of the valley, water levels in unused well 23/12–33L2, 28 feet deep, and in irrigation well 22/12–4B1, 200 feet deep, fluctuate similarly (fig. 12); this fact suggests that the wells are influenced chiefly by recharge rather than by pumping. The largest fluctuation in either well has been about 11 feet.

Water levels are near or above the land surface during the spring in the central part of the valley floor and only locally exceed a depth of 10 feet below land surface during the autumn. Water levels in many wells in the central part of the valley are perennially above land surface (see well 22/12–5F1, fig. 12), but they show small seasonal changes.

DISCHARGE AND WATER UTILIZATION

Discharge from the Round Valley ground-water reservoir is divided into two categories: (1) natural discharge, consisting of evapotranspiration losses, ground-water discharge to streams—including the discharge from springs—and underflow; and (2) artificial discharge, consisting of pumpage and natural flow from wells. In the present state of development, natural discharge probably far exceeds artificial discharge.

Natural discharge.—Large areas exist in the valley where the water table is near the land surface and ground water is discharged upward by evapotranspiration. Because of the relatively hot, dry summers, evapotranspiration is probably the largest single element of natural discharge. Approximately half of the valley floor or about 7,500 acres, is subject to evapotranspiration loss during the year. In some of the wet areas, the rate of evapotranspiration loss decreases with the seasonal decline in water level; however, many areas are fed by upward leakage from artesian aquifers, so that a decline in water level greater than the normal seasonal decline would be necessary to stop the discharge. In Lake County, Calif., where the temperature and altitude are similar to those of Round Valley, the water requirement of native grass, according to Blaney and Ewing (1951), is about 3 feet per year; of swampland, about 4 feet; and of alfalfa, 2.5 feet. Weeds are similar to swampland vegetation in that they generally require considerably more water than do crops—possibly 4 feet or more. On the basis of the above figures, the seasonal evapotranspiration losses and the potential recoverable losses are estimated below:

	Acre-feet
Losses from natural grasslands (5,500 acres × 3 acre-ft per acre)	16,500
Losses from swampland and weed-covered areas (2,000 acres × 4 acre-ft per acre)	8,000
Total evapotranspiration loss (rounded)	25,000
Water requirement of same area in planted pasture, alfalfa, and other crops (maximum water requirement 2.5–3.0 acre-ft per acre; water table drawn down to cut excess evaporation) (rounded)	20,000
Excess of present water requirement or loss over beneficial-use requirements	[1] 5,000

[1] Sufficient water to irrigate approximately 2,000 additional acres.

Ground-water discharge to streams, except small seepage and evapotranspiration losses in stream channels, is estimated by the outflow at the lower end of the valley minus the inflow into the valley. The ground-water discharge estimated in this fashion includes the contributions from springs in the valley and on its margins. Table 16 lists periodic measurements of the low flow in Mill Creek near the valley outlet and similar measurements made in Short Creek where it enters Round Valley. Short Creek, supplied by ground-water outflow from Williams Valley (pl. 3), is the principal source of inflow during the late spring and early summer. On the assumption, based on measurements listed in table 16, that the average outflow is 15 cfs during May and 4 cfs during June, the ground-water outflow to streams that occurs at a time so as to be potentially recoverable is roughly about 1,000 acre-feet per year.

Underflow from the ground-water reservoir of Round Valley by way of Mill Creek is probably small. Therefore, that part of the total natural discharge from Round Valley during an average year which is potentially recoverable is probably on the order of 30,000 acre-feet.

On the other hand, if water levels were drawn down appreciably owing to large withdrawals, additional recharge would occur by seepage loss from streams in areas where water levels now are near or at channel level and where recharge is rejected. Thus, considerably more than 30,000 acre-feet per year is a conservative estimate of the water resources that could be salvaged for beneficial use in Round Valley.

Artificial discharge.—Artificial discharge consists of ground water withdrawn from wells for domestic, irrigation, stock, and industrial or commercial use, plus the water wasted by uncapped flowing wells. In the present state of water-resources development, the waste from uncapped flowing wells is of little consequence, except that it tends to lower the artesian pressure and is a needless waste of water.

About 40 artesian wells that have a pressure head sufficient to cause them to flow above the land surface at some time during the year were inventoried during the canvass of wells made by the California Division of Water Resources, 1952–53, and the Geological Survey, 1954. Only about one-fourth of these wells are known to be capped; the remaining wells flow freely or are controlled so that they flow slowly. The rates of flow range from less than 1 gpm to 75 gpm or more. Not all wells were recorded, and probably about 60 uncapped flowing wells are in Round Valley. Without careful measurements of the rate and duration of flow from each well, the amount of ground water discharged cannot be estimated with any degree of certainty. The magnitude of the ground water discharge from flowing wells, however, is probably at least 250 acre-feet; this estimate is based on the assumption that a minimum of 60 wells flow freely at the average rate of 5 gpm for a period of 6 months (4 acre-feet per well).

Approximately 350 water wells were in use in Round Valley in 1954. The majority of the wells supplied water for domestic and stock use. In 1950, 10 irrigation wells were used to irrigate 275 acres of pasture and alfalfa. In 1954, 17 wells were used to irrigate 750 acres of pasture and alfalfa. Applying a duty-of-water factor of 2 acre-feet per acre, the 1954 irrigation pumpage amounted to about 1,500 acre-feet. The domestic pumpage is about 170 acre-feet for the population of approximately 1,500, if one assumes a per capita rate of use of 100 gpd. Industrial pumpage by three sawmills and by several small commercial establishments in the town of Covelo is included in the estimate of domestic use. Use of ground water by livestock is about 50 acre-feet, based on an assumed rate of consumption of 15 gpd per head for the about 3,000 head of cattle in the valley. The consumption of water by sheep and horses is small compared to the cattle use and is not estimated separately.

The estimated artificial discharge in Round Valley during the year 1954 is summarized in the following table.

Use	*Acre-feet*
Irrigation	1, 500
Domestic and industrial	170
Stock	50
Discharge from flowing wells	250
Total, rounded	2, 000

GROUND-WATER STORAGE CAPACITY

Approximately 15,000 acres in Round Valley is underlain by water-bearing deposits of alluvium having a thickness of 200 feet or more. To estimate the storage capacity of the upper 200 feet of the ground-water reservoir, it is first necessary to determine the average specific yield of the deposits comprising it. Inspection of 35 drillers' logs indicated that about 30 percent of the material consists of gravel and sand. Applying a specific yield value of 20 percent to that coarse-grained fraction and a value of 3 percent to the remaining 70 percent of the material, which constitutes the fine-grained and poorly sorted fraction, an average specific yield of 8 percent is obtained.

Estimates based on much better subsurface data in other alluvial valleys in northern California (Cardwell, 1958, p. 100–106) show that 8 percent is a conservative value for alluvium consisting of 30 percent coarse-grained material. Nevertheless, applying the value of 8 percent, the ground-water storage capacity of the alluvium in Round Valley can be computed, by depth zones, as follows (upper 10 ft of storage assumed not usable):

Depth zone, in feet below land surface	*Acre-feet*
10–50	48,000
50–100	60,000
100–200	120,000
Total, rounded	230,000

The estimated storage capacity of nearly 50,000 acre-feet in the 10- to 50-foot zone amounts to more than twice the ultimate irrigation requirement estimated by Cotton (1953, p. 14).

CHEMICAL QUALITY OF WATER

Ground water.—The general quality of ground water in Round Valley is summarized in table 9, and representative analyses are shown graphically in figure 13. Representative analyses of ground water are given in table 15.

Nearly all ground water from the alluvium in Round Valley is of the bicarbonate type and generally has calcium as the principal cation. Water from wells in the southwestern part of the valley are of the magnesium bicarbonate type as is water in Turner Creek (fig. 13). The quality of the water is excellent for irrigation and acceptable for domestic use, except locally where the iron content may be objectionable. The hardness of most well water is less than 200 ppm.

Water from well 22/12–21A1 (fig. 13) had a percent sodium of 52, highest of all water samples analyzed. The well is in the lower part of the valley (pl. 3) and probably taps deeply circulated ground water, which has undergone base exchange by passage through fine-grained sediments.

TABLE 9.—*Summary of chemical character of ground water in Round, Laytonville, and Little Lake Valleys*

[Based on analyses in files of the Geol. Survey; constituents in parts per million]

Constituent or characteristic	Round Valley	Laytonville Valley	Little Lake Valley
Dissolved solids	116–392	66–472	70–522.
Hardness ($CaCO_3$)	87–300	23–339	3–326.
Chloride	3–28	3–73; 456 in water from bedrock spring.	3–62.
Percent sodium	9–27; 52 in one well	14–53	11–34; 98 in one we .
Boron	0–0.24	0.05–9.8; 23 in water from spring in bedrock.	0.04–3.8.
Iron	1.6–7.4 (4 wells)	0.10–7.9	0.2–9.6.
pH	7.2–8.3	6.4–7.9	6.4–7.3.
Temperature (°F)	57–62 in shallow wells; 62 in one well 800 ft deep.	Generally about 60	57–60 in shallow wells; 67 in well 454 ft deep.

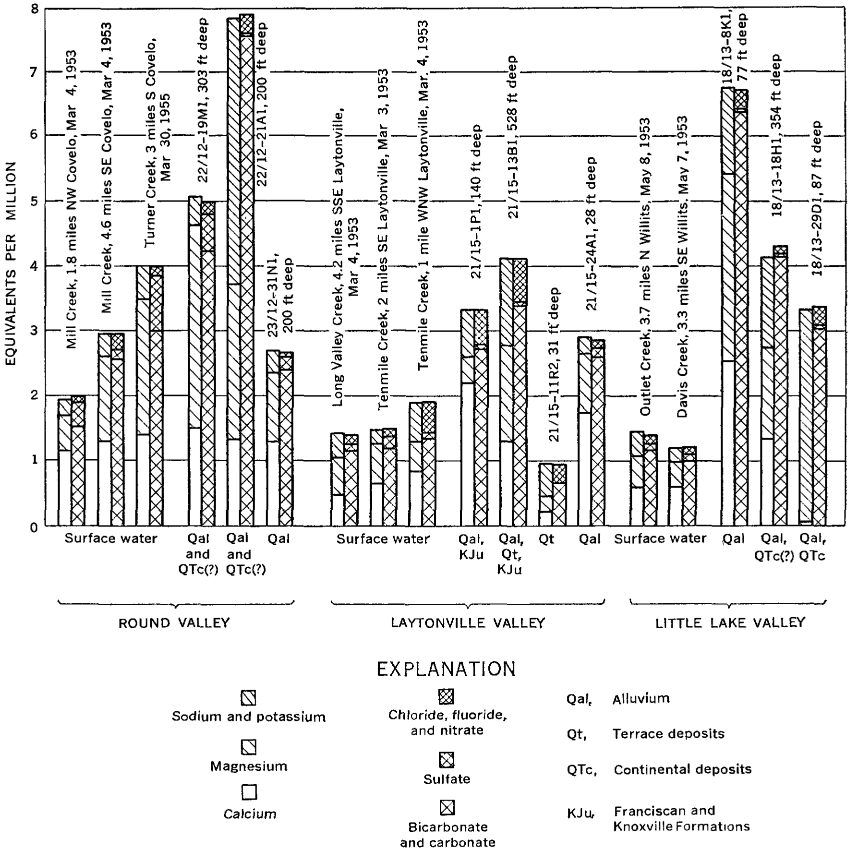

FIGURE 13.—Graphical representation of chemical analyses of ground and surface waters in Round, Laytonville, and Little Lake Valleys.

Surface water.—The surface water of Round Valley is similar in overall character to the ground water, but it contains less dissolved solids, iron, and manganese, and has a lower hardness. Streams draining different bedrock terranes may carry water of slightly different chemical character. The presence of high percentages of magnesium in water from several streams, notably Turner Creek, reflects the presence of bodies of serpentine in the bedrock.

The quality of the stream water varies from season to season. The concentration of dissolved solids is lowest when stream discharge is greatest and highest in summer when the low stream discharge is maintained by the discharge of ground water.

The water of Mill Creek shows a significant increase in dissolved solids down stream (fig. 13). Two samples taken on the same day at the head and at the outlet of the valley show, respectively, 114 and 158 ppm dissolved solids. This change is due to the inflow of ground water that has a higher concentration of dissolved solids.

LAYTONVILLE VALLEY

GEOLOGY AND WATER-BEARING CHARACTER OF ROCK UNITS

Laytonville Valley is an alluviated valley formed in bedrock of Jurassic and Cretaceous age. The alluvium consists of two units: an extensive alluvial fill that has been strongly terraced and dissected, and the alluvial deposits that floor the present valleys and form the principal ground-water reservoirs. The areal extent of the alluvial units is shown on plate 5, and the general character and water-bearing properties of rock units are summarized in table 8.

STRUCTURE AND GEOLOGIC HISTORY

Laytonville Valley is in a trough originally formed by faulting, probably in late Miocene or early Pliocene time, and modified by erosion and subsequent movement along faults. Alluvial sediments, presumably correlative with the continental sediments of Pliocene or Pleistocene age in Round Valley and in the basins along the Russian River, were deposited and then tilted during renewed movement along fault zones. These strata were largely removed and are known to occur at only one small exposure (22/15–27A). This outcrop is too small to show on the geologic map (pl. 5). The valley was probably widened considerably by erosion during some part of Pleistocene time. The enlarged valley was filled to a depth of at least 450 feet, mainly with stream alluvium, in later Pleistocene time. This alluvium was partly eroded and is represented by terraces standing above a broad alluvial flood plain.

Steep valley walls, warm mineral springs, and mud volcanoes, such as those 6 miles southwest of Laytonville, indicate that the area was structurally active in late Quaternary time.

The valley is drained largely by Tenmile Creek, a tributary of the Middle Fork Eel River, and partly drained by tributaries of two other forks of the Eel River. In the course of headward erosion during Recent time, Tenmile Creek has pirated several minor streams that previously drained into the South Fork Eel River and into Long Valley Creek.

FRANCISCAN AND KNOXVILLE FORMATIONS

The consolidated rocks of Jurassic and Cretaceous age that constitute the bedrock in the Laytonville Valley area are mostly marine clastics such as dark-colored impure sandstone, shale, and fine-grained nonfissile mudstone. Some bodies of limestone and chert occur. Volcanic rocks and bodies of intrusive serpentine are associated with the sedimentary rocks; greenstone, blue schist, and chert occur at the south end of the valley. Some drillers' logs report "porous red volcanic rock" at places beneath the valley floor. These may be volcanic rocks or buried equivalents of the red limestone that crops out 1 mile north of Laytonville.

The bedrock is intensely sheared and broken. Shattered impure sandstone occurs on the east side of the valley in the vicinity of Laytonville.

Bedrock on the west side of the valley consists mainly of graywacke, mudstone, and shale; basalt crops out prominently along U.S. Highway 101 in the extreme northern part of the area (22/15–22E).

A large body of limestone along the Redwood Highway, about 1 mile north of Laytonville, trends N. 30° E. and dips about 30° SE. The rock is pale red to grayish red on weathered surfaces and darker shades of these colors when fresh. The limestone is highly fractured and locally serves as an aquifer for several domestic wells.

The consolidated bedrock stores and yields significant amounts of ground water, especially where it is shattered and broken, as along the valley margins. Well 21/14–19M2 obtains all of its supply from bedrock and yielded 15 gpm with a drawdown of 45 feet when tested in August 1953. Several deep wells in the valley that penetrate bedrock beneath alluvium, such as public supply well 21/15–13B1, which penetrates about 200 feet of bedrock (table 14), probably obtain some of their yield from bedrock. Many homes and ranches along the margins of the alluviated part of the valley and in the adjacent foothills are supplied by springs emanating from bedrock.

Somewhat mineralized water accompanied by gas emerges from certain of the bedrock springs. The Pinches Spring (21/15–1Q1), in bluish-gray fine-grained schist at the east side of the valley, is probably related to a fault near the margin of the valley. The water is of the sodium bicarbonate type; it contains 1,050 ppm dissolved solids and has a temperature of 70°F. The spring flows at a rate of about 270 gpm the year round (table 13). Mr. D. L. Pinches reported that the flow of this spring was greatly increased for a short time after the earthquake of 1906, so that the water "boiled up out of the ground." Flammable gas having a sulfurous odor bubbles from the water. Gas bubbles to the surface at the north side of an artificial lake (21/15–24M) about 2 miles south of Laytonville, and a well drilled several hundred yards to the northeast tapped gas in "shale." Fine-grained gray schist crops out at the surface. Public supply well 21/15–13B1, which penetrates 200 feet into bedrock, produces sufficient gas to cause difficulties in the water-distribution lines. At times, flammable gas is emitted from water taps.

Depth to bedrock in the south end of Laytonville Valley is 110 feet in well 21/14–31J1 and 120 feet in well 21/14–19N1. South of Laytonville, bedrock is 201 feet deep in well 21/15–12K2; near the axial trough of the valley, it is 320 feet deep in 13G1 and 330 feet deep in 13B1.

CONTINENTAL DEPOSITS

About 50 feet of predominantly fine-grained flood plain or lake sediments, which includes a bed of massive blue clay or silt, is exposed in the southwest bank of Tenmile Creek, about 3½ miles northwest of Laytonville (22/15–27A). The area of exposure is too small to be shown by pattern on the geologic map (pl. 5). The beds strike northeast and are inclined 10° or more to the northwest. These strata are probably equivalent to the continental deposits of Pliocene or Pleistocene age that are exposed more extensively in other valleys described in this report.

TERRACE DEPOSITS

The terrace deposits, which crop out discontinuously over an area of approximately 4 square miles west of the present alluvial valley, are erosional remnants of an extensive alluvial valley fill laid down during Pleistocene time. These deposits are strongly dissected and are poorly exposed because of a heavy cover of vegetation. They consist of sand, gravel, silt, and clay. The sand and gravel are stream laid and the silt and clay were probably deposited on flood plains, in backwaters, and in lakes. In the logs of wells, such as 21/15–13B1 (table 14), these rocks are distinguished from the alluvium by higher proportions of fine-grained material and the moderate cementation of some of the beds of sand and gravel. In general, the thickness of the terrace deposits is about 50 feet or less, although locally they accumulated to a thickness of 200 feet or more. (See well 21/15-13B1, table 14.) The subsurface occurrence and thickness of the terrace deposits is indicated by the generalized geologic section in figure 14.

The terrace deposits can probably sustain only small yields to wells. Wells tapping terrace deposits on the dissected upland, however, generally yield sufficient water for domestic and stock use. Most wells in the alluvial valley that tap terrace deposits also tap alluvium, and the alluvium probably provides most of the yield of the wells. In the several deep wells tapping both alluvium and the underlying terrace deposits, most of the water reportedly occurs between the surface and a depth of 100 feet or less, which indicates that the alluvium is the chief source.

ALLUVIUM AND RIVER-CHANNEL DEPOSITS

The alluvium in Laytonville Valley was deposited during Recent time as flood-plain and channel deposits, alluvial fans, and colluvium. The alluvium is perhaps 150 feet thick in the central part of the

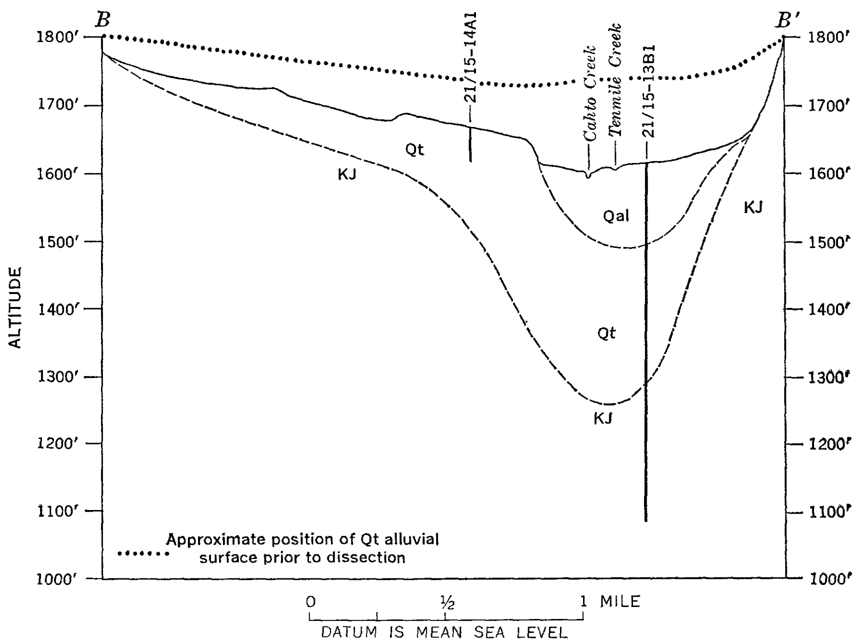

FIGURE 14.—Geologic section across Laytonville Valley. See plate 5 for location of section.

valley and thins toward the margins. The deposits generally consist of lenticular bodies of poorly sorted sand and gravel, silt, and clay. The deposits are of low to moderate permeability, except for local thick interconnected bodies of coarse channel deposits.

Beneath about two-thirds of the main alluvial valley along Tenmile and Long Valley Creeks, the alluvium is fairly coarse-grained and has sufficient vertical extent to store and yield an appreciable amount of ground water. Relatively high local permeability is suggested by the yields of two of the four deep gravel-packed wells that were drilled in the valley during 1951. Well 21/15–13B1, 528 feet deep, flowed when drilled (static head probably several feet above ground level) and yielded 700 gpm at a pumping level of 18 feet, which indicates a specific capacity of about 35 gpm per foot of drawdown. Well 21/15–13G1, 423 feet deep, yielded 575 gpm with a drawdown of 27 feet when drilled, which indicates a specific capacity of about 21 gpm per foot of drawdown. The static water level was at land surface. The wells tap terrace deposits and bedrock as well as the alluvium, but the permeable sand and gravel of the alluvium doubtlessly furnishes most of the yield.

GROUND WATER

OCCURRENCE, SOURCE, AND MOVEMENT

Ground water occurs in all rock units in the Laytonville Valley area. The ground water obtained from bedrock in the valley area generally is confined, and the wells commonly flow. In certain localities, the flow from wells that penetrate bedrock is due in part to the lifting effect of escaping gases. The ground water in the exposed terrace deposits west of Laytonville occurs under water-table conditions but is confined or semiconfined where these strata lie buried under the alluvium. The water in the alluvium occurs both unconfined to semiconfined; degree of confinement depends on the extent to which the coarse materials that supply a well are overlapped by fine-grained deposits and by the water level. Locally, ground water may be perched at a shallow depth. For example, the water level in well 21/15–12F2, 27 feet deep, generally is 10 to 15 feet higher than that in adjacent well 12F1, 50–60 feet deep (fig. 15).

The source of most ground water in the Laytonville Valley is precipitation on the area and on the drainage basins of streams tributary to the area. The average annual precipitation of the Laytonville area is about 70 inches; of this, about 25 inches goes to evaporation, transpiration, and ground-water recharge, and about 45 inches becomes stream runoff (Rantz, 1954, p. 44).

Replenishment of the ground water stored in bedrock occurs principally in zones where the rock is highly fractured. The terrace deposits west of the valley are recharged by the infiltration of precipitation and by percolation from permeable stream channels, particularly where streams enter the terrace deposits from bedrock and have built overlying alluvial cones. Underflow from the surrounding bedrock is probably a source of recharge to both the terrace deposits and the alluvium. The alluvium is recharged also by water moving eastward from the terrace deposits. Locally, the deep penetration of precipitation and percolation from stream channels contribute recharge to the alluvial deposits.

The ground water in the Laytonville Valley area moves generally from the valley margins and downstream to points of discharge along Tenmile Creek and its tributaries and into Long Valley Creek. The water in the broad areas of dissected terrace deposits west of the main valley moves eastward and into the alluvium of the valley.

WATER-LEVEL FLUCTUATIONS

Periodic water-level measurements in 13 wells at 8 different localities in the Laytonville Valley area were begun in the autumn of 1952 and show no significant long-term trend for the period of record. Hydrographs of representative wells are shown in figure 15. The hydrographs reflect chiefly the effects of the natural discharge-replenishment cycle and show that the effect of pumping is minute under the present rainfall regimen. In the spring of 1955, water levels in some wells were slightly lower than in 1953 and 1954, owing to abnormally low winter rainfall.

Wells in the dissected terrace deposits generally have large seasonal water-level declines compared to wells tapping bedrock or alluvium. The seasonal fluctuation in well 21/15–11R3, 44 feet deep, is generally 20–25 feet; the water level is about 15 feet below land surface in spring and 35–40 feet below land surface in autumn. The water levels in adjacent unused wells 21/15–12F1, 50–60 feet deep, and 12F2, 27 feet deep, fluctuate similarly (fig. 15), but the level of 12F2 is generally 10–15 feet above that of 12F1. The water level of well 12F2 probably represents a zone of perched water, and the seasonal decline is most likely due mainly to evapotranspiration; the decline in well 12F1 is probably the result of ground-water discharge to Tenmile Creek. Well 21/14–30M1, 23 feet deep, taps alluvium, and the water level generally declines from 4–5 feet below land surface in spring to 15–17 feet below land surface in autumn. Well 21/14–31J1, 405 feet deep, taps alluvium and bedrock and has a lower spring water level and a higher autumn water level than does 30M1. The small seasonal de-

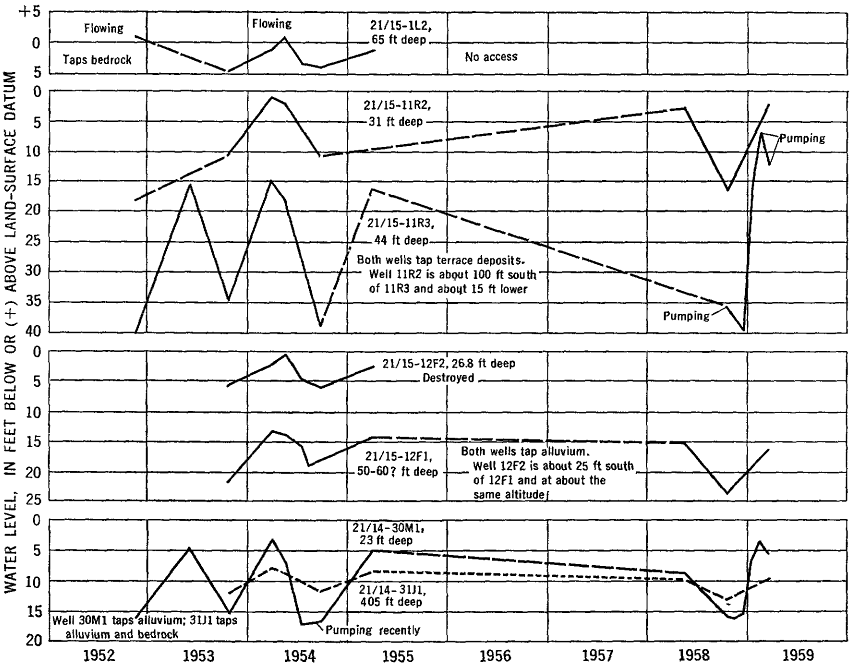

FIGURE 15.—Fluctuation of water levels in seven wells in Laytonville Valley.

cline, 5 feet or less, may be indicative of a relatively small amount of ground-water discharge in the vicinity. However, if ground water in the bedrock is confined here as elsewhere, possibly a relatively stable composite head is maintained by ground water moving up from the bedrock into the alluvium as the water level in the alluvium declines seasonally.

DISCHARGE AND WATER UTILIZATION

Natural discharge, consisting of evapotranspiration, ground-water discharge to streams, discharge from springs, and underflow, constitutes the major part of the total ground-water discharge from the Laytonville Valley reservoir. No data are available for estimating the amount lost by evapotranspiration, but the amount is undoubtedly large. Ground-water outflow to streams occurs mainly along Tenmile Creek and its tributaries. Miscellaneous streamflow measurements (table 16) indicate that the ground-water discharge from the part of Laytonville Valley above the gaging station in 21/15-11H (pl. 5) was about 750 acre-feet during the period May–October 1954. Of this amount, approximately 450 acre-feet was discharged during the month of May. Perhaps an equal amount of inflow was received in the part of the valley below the gaging station. The ground-water outflow through Long Valley Creek during 1954 was relatively small, probably on the order of 60 acre-feet, based on average discharges of 0.8 cfs during May, 0.2 cfs during June, and 0.02 cfs during July (table 16). The small seasonal water-level decline shown by the hydrograph of well 21/14–31J1 (fig. 15) also suggests that ground-water discharge from the southern part of Laytonville Valley is small.

The quantity of discharge from springs is not known. Some of the spring discharge is dissipated by evapotranspiration, but the larger part becomes streamflow and is part of that measured as ground-water outflow. The yearly discharge of spring 21/15–1Q1, the largest spring observed during this investigation, is about 440 acre-feet.

Artificial discharge in the Laytonville Valley, consisting of the water pumped and flowing from about 175 wells, was about 900 acre-feet in 1954. The one irrigation well being pumped during 1954 (21/15–13G1) provided about 600 acre-feet of water to 300 acres of pasture. The Laytonville Water Co. was pumping about 120,000 gpd from well 21/15–13B1 in 1954, or a total of about 135 acre-feet a year. The rural population, approximately 1,300 in 1954, used about 140 acre-feet per year, if one assumes a per capita use of 100 gpd; some of this water was derived from springs rather than from wells. A relatively small amount of ground water was pumped from wells to supply stock and to replenish the millponds of some of the 10–12 sawmills that operated in the area.

GROUND-WATER STORAGE CAPACITY

About 3 square miles of the main alluvial valley in the Laytonville area is underlain by deposits of alluvium that are probably 100 feet or more thick. Based on a conservative value of 10 percent for specific yield, an estimate of the amount of ground water that the deposits store is as follows:

Zone	*Acre-feet*
10–50 feet below land surface	8,000
50–100 feet below land surface	10,000
Total storage capacity, 10–100 ft	18,000

The storage capacity of the marginal alluvial deposits that have a thickness of less than 100 feet is probably on the order of 4,000 acre-feet. Assuming, conservatively, a minimum average saturated thickness of 20 feet for the terrace deposits exposed on the west side of the valley, and assuming a value of 5 percent for specific yield, one finds that those deposits store about 3,000 acre-feet of ground water.

From the above figures, it seems that about 25,000 acre-feet of water is stored in near-surface deposits in the Laytonville Valley area.

Probably a comparable or larger amount of water is stored in the alluvial deposits below a depth of 100 feet and in bedrock. If half the ground water in shallow storage, or about 12,000 acre-feet, is susceptible to cyclic recovery and replenishment, more than enough water is available for the approximately 3,000 acres that are irrigable in the Laytonville Valley.

CHEMICAL QUALITY OF WATER

Ground water.—The general character of the ground water in the Laytonville Valley area is summarized in table 9, and selected analysis are shown graphically in figure 13.

Water from the alluvium is mainly of the calcium magnesium bicarbonate type and is very hard. Water from relatively deep wells that are perforated only near the bottom tends to be considerably softer than that from shallow wells. This difference may be due to the process of base exchange in clay beds at depth, or it may indicate contributions of soft, sodium bicarbonate water from the underlying bedrock.

In general, water from the thin terrace deposits west of Laytonville contains less dissolved solids than water from the alluvium or the bedrock.

The character of water from bedrock exhibits considerable variety. The analysis of water from well 21/15–13B1, which obtains some of its yield from the 200 feet of bedrock it penetrates beneath the valley fill, suggests that sodium bicarbonate water and carbon dioxide gas occur locally in the bedrock, as they do in other valleys described in this report.

The two analyses of water from Pinches Spring (21/15–1Q1) show it to be a sodium chloride type water containing about 1,050 ppm dissolved solids. The water emerges at a temperature of 70°F, more than 10° warmer than the average shallow ground water in Laytonville Valley. The water presumably rises along a fault and is probably a mixture of deeply circulated ground water of shallow origin, connate water, and some water from a deep volcanic source. The water from this saline spring is a source of recharge locally to the ground-water body, for the water from well 21/15–1P2, 60 feet deep, shows a relatively high concentration of sodium and boron and is similar in character to water from the spring. Well 21/15–24N1, which is 34 feet deep, yields a water having exceptionally high proportions of sodium, bicarbonate, and chloride; this fact suggests that mineralized water is moving into the alluvium from the bedrock directly or through the discharge of local springs.

The local effect of limestone bedrock on the character of the ground water is illustrated by water from well 21/15–1P1, which has a high calcium content.

Surface water.—The water from the principal streams in the Laytonville Valley, except Sulphur Creek, is of excellent chemical quality. The content of dissolved solids is low—66–132 ppm for 9 of 10 samples—and the water is generally soft. The concentration of boron does not exceed 0.53 ppm. The water is of the calcium magnesium bicarbonate type; the concentration of calcium generally slightly exceeds that of magnesium, and the percent sodium is generally 15–35.

Sulphur Creek discharges sodium chloride water that contained 918 ppm dissolved solids when sampled on March 3, 1953. The high dissolved solids content is due to the discharge of mineral spring 21/15–1Q1. The discharge of Sulphur Creek results in a marked increase in total dissolved solids and amounts of sodium and chloride in Tenmile Creek, as shown by samples taken from Tenmile Creek above and below its junction with Sulphur Creek (fig. 13).

LITTLE LAKE VALLEY

GEOLOGY AND WATER-BEARING CHARACTER OF ROCK UNITS

Little Lake Valley is in intermontane structural valley containing a considerable thickness of continental deposits of at least two different ages. An area of approximately 17 square miles is underlain by unconsolidated or poorly consolidated deposits that yield water. In addition, ground water is locally available in the underlying and surrounding consolidated bedrock. The distribution of the geologic formations mapped in Little Lake Valley is shown on plate 6, and geology and water-bearing characters are summarized in table 8.

STRUCTURE AND GEOLOGIC HISTORY

Little Lake Valley presumably was formed by faulting, but its margins have been altered considerably by erosion. A major fault zone is suggested by the alinement of the valleys occupied by Davis Creek, Dutch Henry Creek, and the stream immediately to the north. The zone trends about N. 30° W. along the southwest side of the valley and is marked by sheared and broken bedrock. Another parallel zone of probable faulting follows the northeastern margin of Little Lake Valley. This faulting, as indicated by evidence from elsewhere in the region, probably occurred after Miocene time. Subsequent fault movement may have occurred during Pleistocene time.

Thick sedimentary deposits accumulated in the valley during Pliocene and the early part of Pleistocene time. The sediments were gravels and sands of alluvial fans and stream channels interbedded with the silts and clays of flood plain and lake environments. Although fossil evidence is lacking, the rocks are probably equivalent to the older, continental deposits in the other valleys discussed in this report.

The continental deposits have been disturbed by faulting and warping. Attitudes of beds in the southern part of the valley suggest the presence of a broad anticline plunging toward the north. The local occurrence of oil and gas tends to support the surficial evidence that indicates the presence of an anticlinal structure. Carpenter and Millberry (1914, p. 114) reported that in 1885 "Hiram Willits struck gas and oil in a well and laid pipes to his store," and that in 1907, "Gas and petroleum were struck near town" (Willits). Boalich (1920, p. 147) stated that "Austin Muir has been using natural gas for 5 years from a well 200 feet deep on his place, 3 miles east of Willits."

The continental deposits were largely removed from the valley during Pleistocene time. The floor of the valley is now underlain by alluvium deposited in Recent time.

FRANCISCAN FORMATION

Bedrock in the vicinity of Little Lake Valley consists of consolidated rocks of Jurassic and Cretaceous age, probably of the Franciscan Formation (pl. 6). Sedimentary rocks of marine origin predominate, principally sandstone, graywacke, mudstone, and shale containing local bodies of chert. Associated with these rocks are bodies of blue schist, greenstone, and serpentine. Schist crops out north of Dutch Henry Creek, north of Berry Creek, and at the south end of the valley on the west side of U.S. Highway 101. Greenstone was noted at the north end of the valley, south of Broaddus Creek, south of Willits; it may also underlie the area on the northeast flank of the valley that is mantled by a distinctive red soil. A body of serpentine crops out southwest of Forestry Camp. Throughout the area the bedrock has been extensively sheared and fractured.

A few domestic wells around the margins of Little Lake Valley obtain water from the bedrock, but no data concerning their yield is available. Locally ground water in the bedrock is mineralized.

CONTINENTAL DEPOSITS

Continental deposits of probable Pliocene and Pleistocene age crop out around the margins of the southern half of Little Lake Valley (pl. 6). They form low discontinuous foothills that stand above the main valley floor and below the surrounding mountains. The outcrop area of the deposits occupies about 5 square miles. The deposits consist of poorly sorted gravel, sand and sandstone, silt, clay, and diatomaceous shale. The beds are generally compact to semiconsolidated.

The beds are somewhat warped into an anticlinal structure that appears to plunge northward beneath the alluvium. The deposits south-southeast of Willits are strongly deformed and, dip 30°–40° WNW.

The continental deposits are approximately 1,500 feet thick in the southwestern part of the valley, if one disregards the possibility of structural discontinuities.

The strata exposed in the southwestern part of the valley are largely clay, silt, shale, and mudstone. In the bed of Haehl Creek, about 1.5 miles south of Willits (18/13–30B), the deposits consist of blue-gray to tan massive silty clay, beneath about 15 feet of Recent alluvium. Farther upstream, near Forestry Camp (18/13–30J), the deposits are thinly bedded light-gray diatomaceous shale that contains plant impressions and an abundance of woody material. About three-quarters of a mile southeast of Forestry Camp (18/13–32D), along U.S. Highway 101, blue and yellow-brown silty and clayey gravels containing sandstone interbeds, silty sandstone, and silty and sandy clay are exposed. These beds contain more coarse material than do those exposed elsewhere in this valley; however, they also are probably of low permeability. About three-tenths of a mile to the northwest, well 18/13–31A1 (table 14) penetrated 289 feet of "clay" and "clay and gravel." The well yielded 10 gpm with a drawdown of 140 feet from 2 feet of sand and gravel at a depth of 285 feet.

Along the east side of the valley, near well 18/13–16G1, the deposits consist of white to cream-colored massive silty sandstone and sandy siltstone containing finely disseminated carbonized wood. The rocks are poorly exposed but can be traced along the east side of the valley to north of Berry Creek (pl. 6).

The yields of wells tapping the continental deposits generally are low, and the water is confined. The log of well 18/13–20P2, 95 feet deep, shows that 25 feet of gravel and sand interbedded with blue clay were penetrated. The driller reported that the well originally flowed at the rate of 250 gpm (1947), but the flow was only about 15 gpm on July 14, 1954. Nearby well 18/13–29C1, 40 feet deep, was reported by the driller to yield 10 gpm with a drawdown of 20 feet. Gravel-packed well 18/13–19B1, 454 feet deep, penetrates several hundred feet of probable continental deposits and reportedly yields 190 gpm with a drawdown of 210 feet; most of the yield comes from the upper hundred feet of material, which indicates that the well is supplied largely by alluvium.

ALLUVIUM

The alluvium underlies an area of about 12 square miles in Little Lake Valley and also extends up the valleys of the principal tributary creeks (pl. 6). It is the only formation in the area that supplies large yields to wells. Drillers' logs indicate that the material consists of sand and gravel and silt and clay. The coarse material was laid down in lenticular bodies on alluvial fans and in stream channels and is very thick in places; the driller's log of well 18/13–18H1 shows 182 feet of gravel, from depths of 68 to 250 feet. The finer grained sediments were apparently deposited as more extensive sheets on flood plains and in lakes.

The alluvium may be as much as 250 feet thick in parts of the valley. Well 18/13–18H1, near Willits, is 354 feet deep and apparently penetrates 250 feet of the alluvium before entering the underlying continental deposits. Well 18/13–6B1, in the northern part of the valley, bottomed at a depth of 249 feet in coarse alluvial gravel and sand. Most of the wells in the valley are not so deep, commonly obtaining adequate yields at depths of less than 100 feet.

Many of the tributary valleys contain channel deposits of sand and gravel to a depth of 15–20 feet several miles upstream from the floor of the main valley. Well 18/14–2P1 penetrated 14 feet of gravel along Dutch Henry Creek. Along Haehl Creek, in 18/13–30B, the alluvium is about 15 feet thick and consists of silty sand and pebble gravel containing large fragments of the underlying diatomaceous shale, which is exposed a short distance upstream.

The alluvium yields several hundred gallons per minute to properly constructed wells throughout the valley, except in some marginal locations. Gravel-packed well 18/13–6Q1, 145 feet deep, has a specific capacity of 100 gpm per foot; the static water level was 4 feet above land surface on July 13, 1954, and at a pumping rate of slightly more than 300 gpm, the pumping level was about 1 foot above land surface.

When drilled, well 18/13–6H1 (table 13), 60 feet deep, reportedly yielded a natural flow of 220 gpm and was pumped at a rate of 500 gpm at a pumping level of 6 feet below land surface. This record indicates a specific capacity of somewhat more than 50 gpm per foot of drawdown. The yield of the well was subsequently reduced by a partial collapse of the casing due to excessive sand pumping. In 1955, gravel-packed well 18/13–18H1, 354 feet deep was pumped at 950 gpm with a drawdown of 90 feet, which indicates a specific capacity of 10½ gpm per foot of drawdown. The well probably penetrates alluvium to a depth of about 250 feet. Nearby well 17E1, 77 feet deep, had a specific capacity of 7 gpm per foot of drawdown when drilled and yielded 45 gpm at a drawdown of 7 feet. Well 18/13–19B1, 454 feet deep (table 14), has an apparent specific capacity of about 1. The well probably penetrates less than 200 feet of alluvium. The yield undoubtedly is not indicative of the potential of the deposits, because the well is perforated only below a depth of 176 feet. Large head losses in the gravel pack due to bridging and local deposition of fine-grained material probably lower the yield considerably. Most of the present yield is probably obtained from the base of the alluvium and from the deeper, continental deposits. Reperforating and developing the upper part of the well might greatly increase the yield.

GROUND WATER

OCCURRENCE, SOURCE, AND MOVEMENT

Few wells in Little Lake Valley derive water from bedrock. If conditions in this valley are like those in the other valleys described in this report, wells probably would obtain yields sufficient for domestic supply where the bedrock is sheared and broken. The water is likely to be unconfined, but it may be confined locally, as along fault zones.

Water in the older, continental deposits is usually confined in lenses of permeable rock that are interbedded with fine grained and relatively impermeable strata. Through much of the southern part of the valley, the artesian head in these deposits stands near or above the land surface, and many wells flow. Water levels in the continental deposits along the east side of the valley range from a few feet above land surface to 40 feet below it. In general, the hydraulic head in these deposits show considerable range within limited areas, because interconnection between the permeable zones is poor, especially vertically.

Most of the water in the alluvium is confined, or at least semiconfined, beneath the extensive sheets of fine-grained sediments. In the southern part of the valley, shallow wells may tap unconfined ground water, but deep wells obtain artesian water. In the northern part of the valley, wells 50–60 feet deep flow at the land surface.

Water occurs unconfined in the upper parts of the alluvial fans on the margins of the valley and in the shallow alluvium along creeks.

The water level in well 18/13–18H1, 354 feet deep, is 10–15 feet lower than it is in the nearby well 18H2, 14 feet deep (fig. 16). The water level in the shallow well is not affected by pumping the deep well, which indicates poor hydraulic interconnection between shallow and deep strata.

Precipitation, which is the chief source of all ground water in Little Lake Valley, averages about 50 inches annually and occurs mostly during November–April. Much of the bedrock surrounding the valley is highly fractured and, where not covered by soils of low permeability, intercepts some of the runoff. Some of this water percolates down gradient to discharge through springs or as effluent seepage into streams, and some enters the unconsolidated deposits that form the main part of the ground-water reservoir. Recharge to the alluvium probably occurs principally by percolation of runoff through the permeable channels and soils of alluvial fans that extend into the valley along the courses of Broaddus, Davis, and Berry Creeks. Most of the recharge to the alluvium occurs at the southern margin of the alluvial plain, because ground water is being discharged in the northern part of the valley.

Deeply circulated waters may make small contributions to the ground-water reservoir locally, as they do in the other valleys of this region.

General relations clearly indicate that the ground water moves to the north end of the valley, where it is forced to the surface by the rising bedrock floor of the valley and is discharged through seeps over a broad waterlogged area. Some years ago, Menefee (1873, p. 337) reported that the valley "* * * in winter has quite a lake in the north or lower end * * *," but this condition has been partly corrected by artificial drainage.

WATER-LEVEL FLUCTUATIONS

The seasonal fluctuation of water levels in shallow water-table wells in Little Lake Valley varies considerably from well to well. During 1954 the seasonal decline in well 18/13–18H2, 14 feet deep, amounted to 6 feet, and the decline in well 18/13–8L1, 18.5 feet deep, was about the same (fig. 16). The seasonal fluctuation in deeper wells is slightly greater, possibly owing to larger withdrawals from the deeper aquifers.

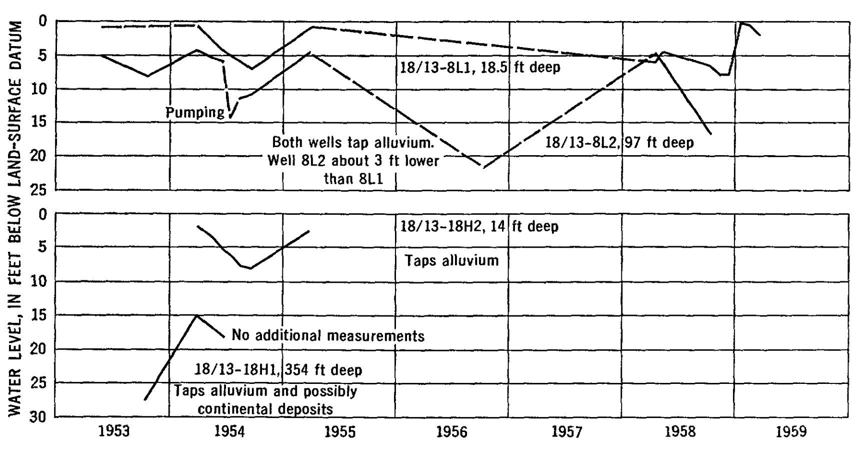

FIGURE 16.—Fluctuation of water levels in four wells in Little Lake Valley.

The period during which water-level fluctuations have been observed is too short to indicate much about water-level trends; however, measurements in two wells in 1956 indicated "lows" from which recovery had been made by 1958. Artesian pressures in the southern and central parts of the valley may have been somewhat lowered over the years. Although the water level in well 18/13–8L2 was reportedly above land surface at the time the well was drilled in 1946, the highest water level observed in this well during the period 1953–58 was about 5 feet below the land surface.

DISCHARGE AND WATER UTILIZATION

Ground water in Little Lake Valley is discharged chiefly as effluent seepage to streams and by evapotranspiration. Little underflow occurs through the narrow valley of Outlet Creek. The amount of pumpage from wells is currently small.

Some ground water is discharged from the continental deposits at the south end of the valley, through springs on the lower slopes of the hills, and by seepage into streams that incise the deposits. A small amount of ground water is discharged from uncapped flowing wells that tap the continental deposits.

A large amount of natural discharge from the alluvium occurs in the north end of Little Lake Valley by seepage into drainage channels and by evaporation and transpiration through the extensive area in which ground water is near, or is discharging at, the surface. The rate of evapotranspiration loss in Little Lake Valley is probably less than that in Round and Laytonville Valleys, because of the somewhat cooler and more humid climate.

Ground water is pumped chiefly for rural-domestic, irrigation, and stock uses. The municipal supply for the town of Willits is taken from the lake formed by Morris Dam on Davis Creek. This source of supply also serves all but two of the many lumber mills in or near Willits. In 1950 the valley had a population of 5,293, of which 2,651 resided in the town of Willits. The rural population served by wells and springs in 1954 was about 2,700, and the estimated domestic pumpage amounted to about 300 acre-feet, based on per capita consumptive use of 100 gallons per day.

In 1954, six wells in the north end of the valley were being pumped to irrigate a total of about 120 acres of pasture and hay. Two of these wells were also supplying water to sawmill ponds. The amount of water pumped during 1954 for irrigation was about 180 acre-feet, based on application of 1.5 feet of water per acre. Water pumped for mill ponds probably amounted to about 10 acre-feet, and the stock pumpage may have amounted to 10 acre-feet.

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The total ground-water pumpage in Little Lake Valley during 1954 probably was not more than 500 acre-feet. Natural discharge, much of which is potentially recoverable, was far greater. The surface-water outflow at the lower end of the valley amounted to about 2,100 acre-feet in 1954 during the dry season May–October, the period when streamflow is largely maintained by the discharge of ground water (table 16).

The development of ground water for irrigation is expected to increase somewhat in the future. A new well (18/13–7C1) was placed in use in 1955, and owners of several of the wells in use during 1954 indicated that they planned to expand their irrigated acreage. Many times the amount of ground water now pumped in Little Lake Valley probably can ultimately be developed without overdraft of the aquifer.

GROUND-WATER STORAGE CAPACITY

Most of the usable ground water in storage in Little Lake Valley is in the alluvial deposits of Recent age that underlie approximately 12 square miles of valley area. Deposits having a thickness of 50 feet or more probably occupy about 10 square miles, and the deposits are probably 100 feet thick or more beneath 8 of these 10 square miles. To estimate the amount of storage in those deposits, an average specific yield was first estimated from the nature of the materials recorded in 19 drillers' logs of wells tapping the alluvium.

Previous experience in other alluvial valleys of northern California shows that values of 20 and 5 percent for specific yield may be assigned, conservatively, to coarse-grained and fine-grained alluvium. On the basis of the available well logs and these assigned values, an estimate of 10 percent for specific yield was derived. The ground-water storage capacity of the deposits is estimated to be:

Zone	*Acre-feet (rounded)*
10–50 feet below land surface, 6,400 acres	25,000
50–100 feet below land surface, 5,120 acres	25,000
Total	50,000

The amount of this storage capacity that can be utilized perennially without exceeding the yield of the basin is dependent on the amount of replenishment that can be induced. The ultimate ground-water requirement of the valley probably will not exceed 15,000 acre-feet, if no more than 10,000 acres is irrigated and if no other major industries are established in the valley.

CHEMICAL QUALITY OF WATER

The chemical character of ground water in Little Lake Valley is summarized in table 9, and representative analyses are shown graphically in figure 13. Data from selected analyses are given in table 15.

Most of the ground water is the bicarbonate type; water from the deeper wells in the alluvium and from some wells in the continental deposits contains approximately equal proportions of calcium, magnesium, and sodium. Water from shallow wells in the alluvium contains a lesser proportion of sodium. The content of chloride and sulfate is low, and boron and sodium are not present in objectionable quantities. The content of iron and manganese, however, is high in the water from a large percentage of the wells that were sampled.

The water from well 18/13-29D1, which taps alluvium and continental deposits, is distinctly a sodium bicarbonate water; sodium amounts to 98 percent of the cations, and the hardness is only 3 ppm. The high sodium content probably was acquired by base exchange with clay minerals in lake deposits as the water circulated through the continental deposits. In the southern part of the valley, ground water from the continental deposits discharges into the alluvium.

The water from bedrock, in general, seems to differ from that from the younger formations. Well 18/14-12H1, which probably taps bedrock, yields water having a relatively high concentration of chloride and boron. The temperature of the water from this well was 66° F. when measured—about 6°-8° warmer than the normal temperature of water from wells of comparable depth in Little Lake Valley. The higher temperature suggests a contribution to the ground water from a deep source.

Both flammable gas and nonflammable gas, perhaps carbon dioxide, are emitted from various water wells in the valley. The carbon dioxide is probably derived from a source deep in the bedrock. Some flammable gas may be derived from organic materials in the continental deposits and alluvium; however, natural gas is produced with ground water from bedrock on Muir Ranch, on the east side of the valley.

The maximum temperature of ground water from shallow wells is 58°-60°F. The maximum temperature observed was 67° for water from well 18/13-19B1, 454 feet deep. The temperature of water from well 18/13-18H1, 354 feet deep, was 64° during the 1953 pumping season and 57°F when the pump was first turned on the following spring.

Chemical analyses are available for the water from seven tributary streams that enter Little Lake Valley and for the water from Outlet Creek at the downstream end of the valley; two analyses of these are shown graphically (fig. 13). The analyses show that all the stream water is similar in chemical character and is of the bicarbonate type. The average of the analyses shows that the proportion of cation constituents is about 40 percent calcium, 35 percent magnesium, and

25 percent sodium. The chemical character of water discharged by Outlet Creek is similar to that of the tributary streams except that the sum of dissolved constituents is slightly higher, owing to large contributions from ground water. For the eight streams sampled, the sum of dissolved constituents was 64–109 ppm; hardness, 31–77 ppm; chloride, 2.5–4.2 ppm; and boron, 0.01–0.19 ppm. The concentration of iron was slightly higher than that generally observed in water from northern California streams, ranging from 0.1 to 0.6 ppm.

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DESCRIPTION OF WELLS AND SPRINGS, RUSSIAN RIVER VALLEY AREA

Table 10 presents descriptive data concerning the water wells in the Russian River valley area. The wells are tabulated by valleys or valley areas, in upstream order. Included are irrigation, industrial, public-supply, domestic, stock, and other wells for which logs, chemical analyses, or other data were available. The location of wells and springs is shown on plates 1 and 2. The following paragraphs explain the headings and symbols used in the columns of table 10.

Well.—The well-numbering system used by the Geological Survey in California is described in the text.

A number, such as DWR 2F1, following the Geological Survey number indicates that the number previously assigned by the California

Department of Water Resources differs from that assigned by the Geological Survey because of differences in base maps or differences in subdividing abnormally shaped or sized sections. The canvass of wells in the lower and middle Russian River valley was chiefly by the Geological Survey; in the upper Russian River valley, chiefly by the California Department of Water Resources and partly by the Geological Survey. Field-data sheets for the wells in the lower and middle Russian River valley are available in Geological Survey files; data for most of the wells in the upper Russian River valley were copied from California Department of Water Resources field forms.

Owner or user.—The name of the individual, company, or group owning the property at the time of the field canvass by the Geological Survey or the California Department of Water Resources is listed where known. In a few cases the name of the tenant or operator is given.

Year completed.—The year completed was obtained from the well log or owner. For wells that have been subsequently deepened or otherwise altered, the year of original construction is reported.

Altitude of land-surface datum.—For comparison of data, particularly water levels, a datum plane defined as the average land surface at the well was used. Altitudes were obtained by interpolation from topographic maps and by use of an altimeter. For maps having a contour interval of 25 feet, altitudes generally are reported to the nearest 5 feet. For maps having a contour interval of 100 feet, altitudes are reported to the nearest 5, 10, or 25 feet; the interval used depends on the available auxiliary control, such as road points, U.S. Coast and Geodetic Survey level lines, and altimeter levels. Altitudes of wells leveled by altimeter are generally reported to the nearest foot. Some altitudes in the Healdsburg area were taken from advance sheets of new 7½-minute quadrangles prepared by the Geological Survey. The topographic contours, especially as shown on Corps of Engineers maps having a contour interval of 100 feet, are locally only approximate.

Depth.—Well depths shown to the nearest foot were reported by the owner or obtained from a driller's log. Depths listed to the nearest one-tenth of a foot were measured by the Geological Survey.

Type of well and casing diameter.—The type of well refers to the method of construction and is indicated by symbol, as follows:

B, Bored (augered)
D, Drilled, method unknown
DC, Drilled by cabletool method
DR, Drilled by rotary method
Dug, Dug well
G, Gravel-packed well

At the right side of this column, the casing diameter is given in inches. For rectangularly shaped dug wells, the dimensions are generally given in feet; thus: 3×3. Where more than one casing size was used, the largest and smallest are listed in that order.

Geologic formation.—The geologic formation or formations from which the well is judged to obtain its supply is given where possible. Symbols used are the same as those on the geologic maps (pls. 1, 2).

Measuring point.—The measuring point is described by letter symbol as follows:

Bap, Bottom of access pipe
Bpb, Bottom of pump base
Hc, Hole in casing
Hpb, Hole in pump base
Nc, Notch in casing
Phf, Pumphouse floor
Tap, Top of access pipe
Tb, Top of board cover
Tc, Top of casing (N, S, SE, and such affixes indicate side of casing where measurement was made)
Tcc, Top of concrete curbing
Tps, Top of pump support
Tw, Top of well (California Dept. Water Resources; measuring point not precisely indicated)
Twc, Top of wood curbing
V, Valve (observation point for flowing wells)

Water level.—All water levels and dates of measurement are listed for wells in which no more than four measurements were made. If five or more measurements were made in a single well only the initial measurement is listed; other measurements are shown on a hydrograph included in this report or are available in the files of the Geological Survey. Measurements by the Geological Survey and most of those by the California Department of Water Resources are referenced to "land-surface datum," which is the average land surface at the well. Measurements made by the driller or owner are indicated by footnote and are reported verbatim, generally to the nearest foot. Not all of these measurements are referenced to the same datum as are Geological Survey measurements.

Temperature.—Temperature is expressed in degrees Fahrenheit opposite the date of measurement and represent the temperature of the pump discharge measured at land surface with a mercury thermometer.

Use.—The use of water is indicated by symbol, as follows:

A, Abandoned and destroyed
D, Domestic
Dy, Dairy
F, Fire protection
Ind, Industrial
Irr, Irrigation, more than 5 acres
irr, Irrigation, less than 5 acres
O, Orchard
PS, Public supply
S, Stock
Sw, Swimming pool
U, Unused

Type of pump and horsepower.—The letter symbol indicates the type of pump, as follows:

C, Centrifugal
J, Jet
L, Lift (cylinder)
P, Pitcher (suction)
T, Turbine
Ts, Submersible turbine

The numeral indicates the rated horsepower of electric motors. "Gas" indicates that the source of power is a gasoline engine.

Yield.—The pumping or bailing rates, in gallons per minute, with resultant drawdowns (pumping level minus static level), in feet, are listed where available. Yields reported by the driller, in gallons per hour, have been converted to gallons per minute (gpm) and rounded to the nearest whole number where necessary. Most of the bailer tests are for incompletely developed and partly perforated wells drilled for domestic use and, in general, probably do not indicate true aquifer performance.

Remarks and perforation data.—Included in this column is any additional pertinent information concerning the well that may be available. Symbols indicate the data for the well that is available in the files of the Geological Survey. Much of the data is included in tables 10–16. Symbols are as follows:

C, Chemical analysis
Cp, Partial chemical analysis
L, Driller's Log
W, Periodic water-level measurements

Figures separated by dashes indicate perforated intervals.

TABLE 10.—*Description of water wells and springs in the Russian River valley area, California*

Well	Well and owner or user	Year completed	Altitude of land-surface datum (ft)	Depth (ft)	Type of well and casing diameter (in.)	Geologic formation	Measuring point and distance above or below (−) land-surface datum (ft)	Water level: Date measured	Water level: Distance above (+) or below land-surface datum (ft)	Temperature (°F)	Use	Type of pump and horsepower	Yield (gpm) and drawdown (ft)	Remarks and perforation data (ft)
Lower Russian River valley														
	T. 7 N., R. 10 W.													
7D1	Citizens Utilities Co. of Calif.		25	120	D, 12	Qal					PS	T, 20		C, L; 40–115.
7D2	do		40	152	D, G, 12	Qal					PS	T, 20		L.
	T. 7 N., R. 11 W.													
11J1	D. Murphy	1948	40	130.5	DC, 12	Qal	TcS, 2.0	9–12–51	26.01		A		500	L; 108–136.
14E1	Morrill		25	47	D	Qal	TcS, .5	9–12–51	19.11		D	J, ½		Cp.
15J [1]	Russian River Sportsmen's Club.		25		D	Qal					D			C.
15P1	E. A. Cole	1951	20	83	DC, 6	Qal	Tc, 4.0	9–12–51	16.05		A			Cp; 73–83.
17J1	E. J. Willig	1949	15	148	D, 12	Qal	Nc, 1.5	10–15–53	1.97		Irr	T, 7½	150	C, L.
20L1 [1]	do		5		D	Qal					A			C.
	T. 8 N., R. 10 W.													
20M3	Dr. Barney	1940	80	123	DC	Qal		3– –40	[2] 10		D	J	20/0	L.
20M4	E. J. Guidotti	1948	85	106.0	DC, 12	Qal	TcN, .5	10–15–53	11.06		PS	T, 7½		L, Cp; 62–68, 74–78, 95–108.
26J1	Hacienda Water Co.	1943	35	28	DC, 8	Qal	Tc, 1.0	10–16–53	11.27		PS	C, 3		L.
26J2	do		35	28.0	DC, 8	Qal	Tc, 1.0	10–16–53	[3] 22.50		PS	L, 7½	70	
29D1	Dr. Makaroff	1951	60	183	DR, G, 8	Qal					D, irr	T, 5	110/50	L; 60–80, 143–183.
29H1	Citizens Utilities Co. of Calif.		30	30	D, 12	Qal					PS	Ts		
29H2	do		30	125	D, 16	Qal	HpbS, 1.0	10–15–53	21.19		PS	T, 75		C, L; 56–110.
29N1	Brookside Lodge	1952	45	90	DC, 8	Qal	HpbN, 2.0	{11–28–52 {10–15–53	[2] 15 10.15	} 60	D	T, 7½	200/14	C, L; 82–88.

See footnotes at end of table, p. 122.

TABLE 10.—*Description of water wells and springs in the Russian River valley area, California*—Continued

Well	Owner or user	Year completed	Altitude of land-surface datum (ft)	Depth (ft)	Type of well and casing diameter (in.)	Geologic formation	Measuring point and distance above or below(−) land-surface datum (ft)	Water level: Date measured	Water level: Distance above (+) or below land-surface datum (ft)	Temperature (°F)	Use	Type of pump and horsepower	Yield (gpm) and drawdown (ft)	Remarks and perforation data (ft)
Healdsburg area														
T. 8 N., R. 9 W.														
15F1	Warren Richardson.		70	100	D, 8	Qal, QTge(?)	NcE, 5.0	11-29-49	32.51		D, S	J, 3		Cp, W.
15M1	L. S. Quinan	1930±	72	42.0	D, 12	Qal	NcE, .5	11-23-49	14.9		Irr	T, 20	375/5	W.
16J2	do		65	35.0	D, 6	Qal	TcN, 1.0	5-21-54 6-22-54 8- 9-54 3-31-55	7.17 7.98 8.30 7.65		U			
19K1	F. McMurray	1941	80	64	DC, 8	Qal					D, irr	T, 3	30/	L.
31A1	Everett Ballard	1952	65	352	DC, 8	Qt, QTm	BpbE, 1.5	7-11-52 10-16-53	[2] 10 17.4		Irr	T, 7½	43/43	L; 100–130, open hole 130–325 ft.
32E3	do	1953	60	83	DC, 12	Qt, QTm					A			
33D1	U.S. Government	1953	135	178	DC, 8	Qtm	Tc, 1.0	10-16-53	40.75		PS		60/50 20/120	L; casing pulled. L; 106–176.
T. 9 N., R. 9 W.														
9K1	Smith	1951	240	180	DR	KJu					D			
17H1	Savers Wood Products Co.	1951	130	129	DC, 10	Qal, QTge		4-24-51	[2] 20		D, Ind		140/90	L.
17R1	Norman O. Wilson.	1951	125	111	DR, G, 8	Qt		5-12-51 7- -53	[2] 29 [4] 12		D	J, 1	20/44	L; 90–110.
20K1	City of Healdsburg.	1945	95	151	DC, 12	Qal, Qt					PS	T, 40	400/86	L; 127–147.
20K2	do	1944	95	146	DC, 12	Qal, Qt					PS	T, 40	400/	Cp, L; 126–146.
21J1-6	do	1940±	90	([5])	D, 12	Qal					PS	T, 3	150/	Cp, L.
21R1	do	1941	85	177	DC, 6	Qal					A			L.
22P1	J. M. Bunin	1946	125	56	D, 8	Qt	Bpb, 1.0	10-19-49 4-11-51	44.7 36.31		D	J, 1½	24/17	L.
27D1	Mutual Water Co.	1947	100	65	D, 8	Qal					PS	J, 2	25/	

33E2	O. Ollino	1952	90	66	DC,	8	Qal	Hpb,	4.0	5-16-52 11-11-53 5-21-54 6-23-54	[3] 20 24.92 20.46 [3] 22.8	---- 56	Irr	C,	7½	400/2	L; 29-62.
34D1	Louis Foppiano	1922	105	120.5	D,	10	Qt, QTge	Tc,	.8	10-20-49	30.19	----	U				W.
34N1	W. C. Beaumont	1946	84	198	DC,	12	Qal, QTge	Hpb,	3.3	10-20-49	14.82	----	Irr	T,	15	500/20	L. W.
	T. 9 N., R. 10 W.																
1G1	Frei Bros	1948	170	209	DC,	10	Qt, QTge	Nc,	1.0	3- -46 1-14-54	[3] 26 30.95	----	D, Ind, Irr	T,	15	200/28	C, L; 55-209.
2B1	Paul LeBaron	1950	140	107	DR, G,	12	Qal, Qt(?)					----	Irr	C,	15		C, L.
2B2	do		145	40	D		Qal	Bpb,	1.5	5-21-54 6-23-54 8- 9-54 3-31-55	1.80 3.00 4.95 1.99	----	D, S	J,	2		
2B3	do	1944	142	285	DC,	12	Qal, Qt, QTge(?).	Tc,	1.0	1-15-54	4.3	----	U			240/45	L, W; 30-100, 150-180.
2R1	W. G. Tevendale	1951	132	31	DC,	12	Qal	Tc,	3.5	7-18-51 1-13-54	[3] 8 12.64	----	U			400/2	L; 14-31.
2R3	P. D. Austin	1945	134	30	D,	10	Qal	Tc,	.5	1-13-54	14.21	[4] 62	Irr	C		330/3	L.
	T. 10 N., R. 10 W.																
15J1	Artino Muzzin	1951	345	122	DC,	7½	Kc			10-11-51	[3] 30	----	D			6/70	L; 44-52, 103-122.
27B1	H. F. Phillips	1951	160	23	Dug,	24	Qal	Tb,	.5	5-21-54 8- 9-54	9.61 12.98	----	Irr, S	C,	20	350/3	L.
27D2	P. Mancini	1949	185	126			Qal, KJu(?).										C.
	T. 10 N., R. 11 W.																
12Q1	John Henderlong	1950	220	55	DR,	10	Qal	Tcc,	.5	11- 5-53	8.68	----	Irr	C,	25		35-55.

See footnotes at end of table, p. 122.

TABLE 10.—*Description of water wells and springs in the Russian River valley area, California*—Continued

Well and owner or user		Year completed	Altitude of land-surface datum (ft)	Depth (ft)	Type of well and casing diameter (in.)	Geologic formation	Measuring point and distance above or below (−) land-surface datum (ft)	Water level: Date measured	Water level: Distance above (+) or below land-surface datum (ft)	Temperature (°F)	Use	Type of pump and horsepower	Yield (gpm) and drawdown (ft)	Remarks and perforation data (ft)
Alexander Valley														
	T. 9 N., R. 8 W.													
7M1	L. N. Johnson	1949	150	454	DR, G, 12	Qal, QTge	Nc, 1.0	7-20-50	15.90		U		250/205	L.
7Q1	do	1949	160	490	DR, G, 12	Qal, QTge	Bap, 1.0	7-20-50	[6]23.29		D, Irr, S	T, 10	250/195	C, L.
	T. 9 N., R. 9 W.													
1A1	Alexander Valley School District.	1870±	215	46.0	Dug, 4×4	QTge(?)	Tb, −2.5	7-27-50	28.47		A	P, Hand		W.
1A2	Goodyear	1953	215	125	DC, 8	QTge(?)	Bpb, 1.0	4-16-54	17.76		D	J, 1½		L, W; drilled in 1A1; perforated.
4E1	E. Ghizzardi	1950	180	117	DR, G, 6	Qal, Kc(?)	Bpb, 1.0	4-2-52	4.04	60	U	J, 1		C; 85-117.
4E2	do	Old	180	32	Dug, 48	Qal					D	J		Cp.
4G1	C. E. Adams	1951	220	320	DR, G, 6	QTge		7-10-51	[2]60		D, Irr	J, 1	10/100	C, L; 220-280, 300-320.
	T. 10 N., R. 9 W.													
18B1	John Fay	1944	230	180	DR, G, 10	Qal, Qt	Hpb, 1.0	7-19-50 9-7-50 8-10-54	22.14 -------- --------	------ 66 66	Irr	T, 10	435/100	C, L, W.
26K1	W. R. Hoskinson	1939	205	30 72	Dug, 6×6 DC, 8	Qal, QTge(?)	Twc	7-19-50 4-18-51	4.65 (?)		Irr	C, Gas	300/15	L; artesian flow during winter and spring.
26L1	Dana	1950	205	152	DR, G, 10	Qal, QTge	Hpb, 1.0	7-19-50 4-18-51	8.61 3.40	64	Irr	T, 15	240/90	Cp, L; 43-79, 115-151.
26L1 [8]	do	1952		244	DC, 8⅝	QTge		7-27-52	[2]35				400/50	L; 200-244.
26L2	do	1900±	205	40.0	D, 6	Qal	Tcc, .2	7-19-50	6.72		D, S	C, 1		Cp, W.
32R1 [9]	D. W. Fredson		200	6	Dug, 12×24	Kc	TccS, 2.0	4-2-52	2.5		D			Cp.

32R2	W. L. Wheeler	1949±	180	65	D,	6	Kc						D, S	J			Cp; reported to have artesian flow 6 months of year.
32R3	Hedgpeth Logging Co.	1952	175	245	D,	8	Kc			4- 2-52	([7])	63	Ind			[10]19	C.
33B1	A. G. Anderson		180	20.3	B,	6	Qal	Tc,	2.5	7-18-50	7.75		D				W.
34N1	J. T. Grace Farms		175	47.0	D,	8	Qal	Tc,	1.0	7-20-50	9.98		D, Ind	J,	1		Cp, W.
	T. 10 N., R. 10 W.																
13J2	Geyserville Water Co.		210		D,	8	Qal						PS	C,	20		
13J3	do	1950	210	30	D,	10	Qal						PS	C,	20		
							Cloverdale Valley										
	T. 11 N., R. 10 W.																
7J1	City of Cloverdale	1923	299	15.3	Dug,	96	Qal	Tps,	10.0	6-13-51 4- 3-52	8.33 4.01		PS	T,	30	460/	C, L; no perforations, open bottom.
7J2	do	1950	300	16	Dug,	48	Qal	Tc,	10	6-13-51	9.41		PS	T,	30	440/	L; 12-16, open bottom.
17C1	Shelford Hiatt		300	14.7	Dug		Qal	Tb,	.0	10-28-53	9.70		Irr	C,	15	650/	C.
17P1	Guido Impeirale	1951	295	35	D		Qal	Tc,	1.5	10-29-53	7.9		Irr	C,	10	700/	L.
17P2	Howard French	1952	292	35	DC,	10	Qal	Tc,	.5	10-28-53	7.52		Irr	C,	7½	500/2	L, W; 28-36.
17R1	E. E. Hastings	1950	300	41	DC,	6	Qal, KJu(?)			5-26-50	[2]15		D			10/15	L; 25-40.
19F2	California State Div. Forestry.	1951	346	334	DR, G		Qt, KJu	Tc,	1.5	4- 3-52	3.61		D, F	L,	¾		L, W; 90-110, 130-150, 170-230, 270-290, 310-330.
28L1	James Black	1952	255	18	DC,	16	Qrc						Irr	C			L.
28M1	Italian Swiss Colony Winery.		260	21.3	Dug,	72	Qal	Tcc,	5.0	6-12-51	[3]8.12		Ind	L,	5		C.
33A1[1]	do		255	20	Dug,	72	Qal			10-19-51	11		Ind				C.
33G1[1]	Paul Pellagrini		290	18.0	Dug,	36	KJu			10-19-51	10		D				C.

See footnotes at end of table, p. 122.

TABLE 10.—*Description of water wells and springs in the Russian River valley area, California*—Continued

Well and owner or user		Year completed	Altitude of land-surface datum (ft)	Depth (ft)	Type of well and casing diameter (in.)	Geologic formation	Measuring point and distance above or below(−) land-surface datum (ft)	Water level: Date measured	Water level: Distance above (+) or below land-surface datum (ft)	Temperature (°F)	Use	Type of pump and horsepower	Yield (gpm) and drawdown (ft)	Remarks and perforation data (ft)
Sanel Valley														
T. 12 N., R. 11 W.														
2C1[1] (DWR 2F1)	A. DeMarcantonio	1952	450	73	DC, 8	Qal	Tc, 5.0	6-13-52 10-13-53	[2] 12 14		D	J, 2	30/40	C, L; 53-73.
T. 13 N., R. 11 W.														
8H1[1]	University of California.	1936	825	187	DC, 8	QTc		11- -36	[2] 10				75/70	L; 40-60, 80-100, 140-187.
18D1	Barber	1950	490	61	DR, G, 16	Qal		8-23-50	[2] 15		Irr	T, 50	100/5	L; 30-60.
18E1	A. Damiano	1947	490	52	DC, 12	Qal	Tc, .5	10-27-53	10.96		D, Irr	C, 20 C, 5	800	C, W.
18M1	F. W. Renfro		490	18 63	Dug, 5×5 DC, 8	Qal	Tc, 1.5	6-23-53	9.4		Irr	T	550	L, W.
19C1[1]	J. F. Manning	1953	485	36	DC, 8	Qal	Tc, .7	2-28-53 6-18-53	[2] 10 11.3		irr	½		L; 26-34.
19N1[1]	Pacific Gas & Electric Co.	Old	490	60	DC, 36	Qal	Tcc, 2.6	6-16-53	6.4		PS	10	1,000	C; 40-60.
19Q1[1]	F. J. Hellman	1949	475	114	DR, 14	Qal, QTc(?)					Irr	T, 40	900	L.
20G1	I. Bliss		515	135	B, 8	QTc(?)	TcN, 2.0	6-18-53	5.9		D	L, ½		W.
21L1[1]	C. Fitzgerald		550	273±	DC, G, 12	Qal, QTc	Tc, 2.2	6-18-53	[3] 74.3		Irr	T, 50		C; gravel packed 228-273 ft.
21L2[1] (DWR 21Q1)	do	1950	550	220	DR, G, 12	QTc		8-14-50 6- -53	[2] 44 [4] 37		U		550/155	L; 60-120, 145-165, 178-198; reported sanded in.
T. 13 N., R. 12 W.														
1C1[1]	P. C. Crawford	Old	500		Dug, 6×6	Qal	Tw, .5	6-18-53	2.9		O, S			C.
24J1	Allen Cooper		492	25	Dug, 5×5	Qal	Tb, 2.5	6-17-53	3.7		Irr	J, 3		W.

Ukiah Valley

T. 14 N., R. 12 W.																	
5K1	Gilley	1952	610	94	DC,	8	Qty	Tc		11- 8-52 5-12-53	[2] 38 [6] 33.1		D, Ir	J,		5/56	C, L; 69-85.
11N1	Lonis Johnson		575	30±	D		Qal	Tb,	1,0	6-12-51	.52		D	J,			C, W.
T. 15 N., R. 12 W.																	
8L1	Arnold Bogner	1948	665	62.0	D,	12	Qty	TcE,	1.0	6-12-51	20.83		D	J,	1½		W.
8N1 [1]	Dan Cohen	1952	670	80	DC,	10	Qty						D, irr	J,	2	63/30	L; cased to 75 ft, perforated.
16E1 [1]	City of Ukiah (well 1).	1906	600	22	Dug, 8×8		Qrc	Tcc,	5.0	4- -53 4-30-53 8- 5-53	5.4 8.2	55	PS		125	1,350/3.3	C; no perforations.
16E2 [1]	do (well 2)	1950	600	34	Dug,	84	Qal	Tcc,	5.0	4- -53	19		PS		125	1,200/3	
16F1 [1]	Jones	1905±	605	22	Dug,	72	Qal	Tw		5-13-53	[11] 13.2		D				
16Q1 [1]	City of Ukiah (well 3).	1946	595	34	Dug,	84	Qal	Tcc,	3.0	4- -53	21		PS	T,	50	425/8.4	C; 20-34.
21M1	McCarty Bros	1946	590	46.1	Dug,	24	Qal	Tc,	.5	5-18-51	2.20		D Irr	J, T,	1 15		W.
22D2 [1]	Frank Rogina		625	(9)			KJu										C.
27N2	Mendocino State Hospital (well 6).		597		D,	14	Qal						D	T,	7½	160/[3]44	Standby well.
27N3	Mendocino State Hospital (well 4).		582	46	Dug, 10×10		Qal						PS	T,	7.5	450/[3]24	
28R2	Mendocino State Hospital (well 3).		582	35.1	Dug, 9×9		Qal	(12)		5-18-51 8-12-54	[3] 16.30	58	Irr	T,	15	1,040/[3]18	W.
35D1 [1]	D. Broggi		620	60	D,	12	Qal, Qty	Tc,	1.0	5-13-53	4.2		D, Irr				C.
T. 16 N., R. 12 W.																	
9Q1 [1]	Pacific Gas & Electric Co.	1951	740	64	DC,	8	QTc	Tc,	1.0	6-21-51	[2] 7.5		D, Ind.	T,	7½	18/16.5	C, L; 36-44, 56-64.
34N2 [1]	U.S. Army Corps of Engineers.	1953	821.3		D		QTc										L; exploratory test hole.
T. 17 N., R. 12 W.																	
32N1	Frank Brown	1948	750	25	Dug,	64	QTo	Tw,	0.5	8-12-53	9.9		D		½		C; water obtained at 10 ft.

See footnotes end of tables, p. 122

TABLE.—*Description of water wells and springs in the Russian River valley area, California*—Continued

Well	Owner or user	Year completed	Altitude of land-surface datum (ft)	Depth (ft)	Type of well and casing diameter (in.)	Geologic formation	Measuring point and distance above or below (−) land-surface datum (ft)	Water level: Date measured	Water level: Distance above (+) or below land-surface datum (ft)	Temperature (°F)	Use	Type of pump and horsepower	Yield (gpm) and drawdown (ft)	Remarks and perforation data (ft)
Potter Valley														
T. 16 N., R. 11 W.														
5G1[1]	L. T. Hotell	1947±	875	38	DC, 8	Qal, QTc(?)	Tc, 0.5	6-11-53	14.4		D			C.
T. 17 N., R. 11 W.														
18A2[1]	J. W. Fraser		955	60	DC, 12	Qal		6-10-53	(7)		Irr	J, 5		C.
18J1	J. T. Phillips	1951	955	35.6	D, 8	Qal	Tc, 1.0	6-12-51	.80		D, S	½		W.
29P1[1] (DWR 32C2)	G. Harrison	1946	940	104	DC, 12	QTc	Tc, 1.0	6-12-51	21.87		D, W		11	L, W; 21-24, 41-43, 89-101.
32J1	E. Foster	Old	895	10.1	Dug, 36	Qal	Tw, 1.5	6-11-53	7.2		D	C		W; gravel at 7 ft.
33D1[1]	W. L. Reiter		920	658	DR, 8	KJu		9-23-52	[4] 13	64	U		5	C, L; cased to 420 ft.

[1] Field location by California Department of Water Resources.
[2] Reported by driller.
[3] Pumping level.
[4] Reported by owner.
[5] Six closely spaced wells; depths range from 50 to 70 ft.
[6] Pumping recently.
[7] Well flowing; static level above land-surface datum.
[8] Data for deepening of above well.
[9] Spring.
[10] Estimated natural flow.
[11] Depth to water from measuring point; relation of measuring point to land-surface datum not ascertained.
[12] Measuring point is top edge of concrete block at west side of pumphouse floor, 0.5 ft above land-surface datum.

LOGS OF WELLS, RUSSIAN RIVER VALLEY AREA

Table 11 contains drillers' logs of water wells drilled in the Russian River valley. They were selected from approximately 450 logs collected during the investigation, about 220 of which were field located. Approximate location was obtained for about 120 additional logs. Most of these logs are available for inspection in the files of the Ground Water Branch, Geological Survey, or of the California State Department of Water Resources, both located in Sacramento, Calif. Included are logs of wells representing subsurface conditions in the various valley areas. Included are most logs cited in the preceding text plus additional ones to give general coverage. The logs, as reproduced here, are in the same form as those received from the drillers except for minor punctuation and spelling changes and, in some logs, rearrangement of descriptive terms. In a few logs, explanations or interpretations of the drillers' terms have been entered in brackets. At the beginning of a log, the well number, name of owner or user, driller, topographic location, and altitude appear, respectively. In some instances, perforations and yield data are given. Stratigraphic assignments have been made where possible.

TABLE 11.—*Selected drillers' logs of wells in the Russian River valley area, California*

[Stratigraphic correlations by G. T. Cardwell, U.S. Geol. Survey]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)

LOWER RUSSIAN RIVER VALLEY

7/10-7D1

[Citizens Utilities Co. of California. Drilled by Western Drilling Co. Altitude: 25 ft. On low stream terrace. Casing perforated from 40 to 55, 67 to 71, 80 to 84, and 94 to 115 ft]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Alluvium—Continued		
Clay and sand	27	27	Sand and gravel	9	80
Sand and gravel	13	40	Gravel	4	84
Gravel	15	55	Sand and gravel	10	94
Sand and gravel	22	67	Coarse gravel	26	120
Gravel	4	71			

7/11-11J1

[Hugh Brown. Drilled by Pearson. Altitude: 40 ft. On flood plain. Casing perforated from 108 to 136 ft. Yield: 500 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Alluvium—Continued		
Surface	3	3	Boulders and yellow clay	5	107
Sand	99	102	Gravel, free	29	136

761-400—65——9

TABLE 11.—*Selected drillers' logs of wells in the Russian River valley area, California*—Continued

7/11-17J1

[E. J. Willig. Altitude: 15 ft. On flood plain]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Jurassic and Cretaceous rocks, undifferentiated:		
Blue clay and gravel	146	146	Serpentine	2	148

8/10-20M3

[Dr. Edna Barney. Drilled by N. F. Keyt. Altitude: 80 ft. On alluvial plain. Bailed at rate of 20 gpm with no observable drawdown]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Alluvium—Continued		
Soil	2	2	Redwood log	4	59
Gravel	4	6	Mud, blue	6	65
Clay, yellow, and gravel	24	30	Clay, blue, soft	19	84
Gravel	17	47	Clay, yellow, soft, and gravel	26	110
Clay, blue, soft	3	50	Gravel	10	120
Gravel	5	55	Clay, yellow, and gravel	3	123

8/10-29D1

[Dr. Makaroff. Drilled by Weeks Hardware Co. Altitude: 60 ft. On alluvial plain. Casing perforated from 60 to 80 and 143 to 183 ft; gravel packed. Pumping test. 110 gpm at drawdown of 50 ft]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Jurassic and Cretaceous rocks, undifferentiated:		
Sand	30	30			
Gravel	90	120	Basalt	63	183

8/10-29H2

[Citizens Utilities Co. of California. Drilled by Western Drilling Co. Altitude: 30 ft. On flood plain. Casing perforated from 56 to 110 ft]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Alluvium—Continued		
Top clay and sand	23	23	Fine gravel	4	111
Sand and gravel	5	28	Sand and gravel	4	115
Gravel	20	48	Jurassic and Cretaceous rocks,		
Sand and gravel	8	56	undifferentiated(?):		
Fine gravel	14	70	Gray shale and gravel [re-		
Coarse gravel	4	74	ported by observer to be		
Fine gravel	2	76	bedrock]	10	125
Gravel	31	107			

8/10-29N1

[Brookside Lodge. Drilled by Crislip Drilling Co. Altitude: 45 ft. On alluvial plain. Casing perforated from 82 to 88 ft. Pumping test: 200 gpm at drawdown of 14 ft]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Alluvium—Continued		
Sandy yellow loam	12	12	Green clay	29	72
Blue clay	6	18	Blue sand	3	75
Gravel	12	30	Blue sand and clay	4	79
Blue clay	5	35	Blue sand and gravel	9	88
Yellow clay	5	40	Blue sand	2	90
Blue clay	3	43			

TABLE 11.—*Selected drillers' logs of wells in the Russian River valley area, California*—Continued

HEALDSBURG AREA

8/9–19K1

[Fred MacMurray. Drilled by W. A. Duer. Altitude: 80 ft. On alluvial plain. Yield: 30 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Jurassic and Cretaceous rocks, undifferentiated:		
Soil	4	4	Serpentine rock	1	64
Clay, brown	21	25			
Blue clay and sand	37	62			
Gravel	1	63			

8/9–31A1

[Everett Ballard. Drilled by Crislip Drilling Co. Altitude: 65 ft. On alluvial terrace. Cased to 130 ft; casing perforated from 100 to 130 ft. Pumping test: water level prior to pumping, 10 ft; pumping level 53 ft at 43 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Terrace deposits:			Merced Formation:		
Black loam	4	4	Blue sand and clay	2	74
Yellow clay	13	17	Blue sandy clay	36	110
Yellow sand and gravel	3	20	Blue sand	20	130
Gravel	10	30	Blue sandstone	105	235
Yellow sand and gravel	4	34	Blue clay	25	260
Black sandy clay	38	72	Blue sandstone	65	325

8/9–32E3

[Everett Ballard. Drilled by Crislip Drilling Co. Altitude: 60 ft. On alluvial terrace. Cased to 56 ft; perforated from 31 to 55 ft. Pumping test: 60 gpm at drawdown of 50 ft. Well subsequently destroyed]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Terrace deposits:			Terrace deposits—Continued		
Black loam	3	3	Yellow clay	13	56
River silt, brown	28	31	Black sand and clay	4	60
Yellow sand and gravel	6	37	Merced Formation:		
Yellow clay and gravel	6	43	Blue sandstone	23	83

9/9–21R1

[City of Healdsburg. Drilled by L. H. McCollum. Altitude: 85 ft. On flood plain. Well destroyed—plugged and filled]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Alluvium—Continued		
Sediment	20	20	Blue clay	16	154
Gravel	10	30	Brown shale	10	164
Gravel and boulders	6	36	Blue clay	3	167
Boulders and clay	5	41	Brown clay	3	170
Boulders	14	55	Blue clay	3	173
Blue clay	58	113	Jurassic and Cretaceous rocks, undifferentiated:		
Gravel	1	114	Shale	4½	177½
Blue clay	22	136			
Gravel	2	138			

9/9–33E2

[O. Ollino. Drilled by Crislip Drilling Co. Altitude: 90 ft. On alluvial plain. Casing perforated from 33 to 66 ft. Pumping test: 400 gpm at drawdown of 2 ft]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Alluvium—Continued		
Yellow clay	27	27	Gravel and coarse sand	26	53
			Gravel	13	66

TABLE 11.—*Selected drillers' logs of wells in the Russian River valley area, California*—Continued

9/10–2B1

[Paul LeBaron. Drilled by F. B. Dykes. Altitude: 140 ft. On alluvial plain. Gravel-packed well]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Alluvium—Continued		
Topsoil	17	17	Shale [hard blue clay]	24	73
Sand	6	23	Sticky gumbo [like rubber]	14	87
Clay	14	37	Sand and clay, mixed	2	89
Gravel, pea	6	43	Gravel	10	99
Boulders, large [to 1 ft diameter]	6	49	Jurassic and Cretaceous rocks, undifferentiated:		
			Shale and serpentine	8	107

9/10–2B3

[Paul LeBaron. Drilled by Rocco. Altitude: 142 ft. On alluvial plain. Casing perforated from 30 to 100 and 150 to 180 ft. Yield: 240 gpm at pumping level of 50 ft]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium, terrace deposits, and Glen Ellen(?) Formation:			Alluvium, terrace deposits, and Glen Ellen(?) Formation—Continued		
Clay and silt	18	18	[Not logged]	105±	160±
Gravel	12	30	Gravel [7 ft thick] near 160 ft	7	167±
Mostly clay and clay and gravel	20	50±	[Not logged]	167±	285
Gravel [6 ft thick] near 55 ft	6	56±	Bottom in soft clay and gravel	--------	285

10/11–12Q1

[John Henderlong. Drilled by Davis and Alcorn Drilling Co. Altitude: 220 ft. On alluvial plain. Casing perforated from 35 to 55 ft]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Gravel and sand	10	10	Clay and brown gravel	4	42
Gravel and small boulders	10	20	Large gravel	5	47
Big rocks and gravel	18	38	Blue clay	8	55

ALEXANDER VALLEY

9/8–7Q1

[L. N. Johnson. Drilled by Davis and Alcorn Drilling Co. Altitude: 160 ft. On alluvial plain. Gravel-packed well. Pumping test: 250 gpm at pumping level of 220 ft]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium and Glen Ellen Formation:			Alluvium and Glen Ellen Formation—Continued		
Topsoil	4	4	Soft blue sand	17	147
Brown clay	15	19	Hard blue shale	13	160
Blue sand and large gravel	21	40	Soft sand	40	200
Blue clay and sand	35	75	Soft blue sand, and shale streaks	276	476
Soft blue clay	17	92	Blue clay	14	490
Hard blue clay	38	130			

TABLE 11.—*Selected drillers' logs of wells in the Russian River valley area, California*—Continued

9/9-4E1

[E. Ghizzardi. Drilled by F. B. Dykes. Altitude: 180 ft. Alluvial plain. Casing perforated from 85 to 117 ft; gravel packed]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium and Jurassic and Cretaceous rocks, undifferentiated(?):			Alluvium and Jurassic and Cretaceous rocks, undifferentiated(?)—Continued		
Topsoil	12	12	Clay	2	98
Sand and small gravel	6	18	Rock	6	104
Clay and mixed gravel	19	37	Clay	4	108
Clay	39	76	Clay, boulders	4	112
Clay and mixed boulders	5	81	Boulders, small gravel, and sand	4	116
Shale	8	89	Shale	1	117
Rock	7	96			

10/9-26L1

[Dana. Drilled by F. B. Dykes and Crislip Drilling Co. Altitude: 205 ft. On alluvial plain. Casing perforated from 43 to 79, 115 to 151, and 200 to 244 ft; gravel packed 0-152 ft. Pumping test of original well drilled to 152 ft: 240 gpm at pumping level of 100 ft. Pumping test of deepened well: static level 35 ft; pumping level 85 ft at pumping rate of 400 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium and Glen Ellen Formation:			Alluvium and Glen Ellen Formation—Continued		
Topsoil	29	29	Clay	5	150
Sand and small gravel	8	37	Yellow sand and gravel	5	155
Tight clay, yellow	7	44	Sandy yellow clay	8	163
Medium small gravel	7	51	Gray clay	7	170
Sticky clay	29	80	Gravel	2	172
Sand	7	87	Sandy soil	20	192
Blue clay	22	109	Gray clay and sand	18	210
Clay and mixed sand	10	119	Gravel	6	216
Tight mica sand	8	127	Gray mud	4	220
Sand and small gravel	7	134	Gravel	4	224
Pea gravel and sand	8	142	Gravel and blue mud	16	240
Pea gravel	3	145	Gray mud	4	244

CLOVERDALE VALLEY

11/10-17R1

[Hastings. Drilled by Crislip Drilling Co. Altitude: 300 ft. Edge of alluvial plain. Casing perforated from 25 to 40 ft. Bailing test: 10 gpm at drawdown of 15 ft]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Alluvium—Continued		
Surface soil	2	2	Loose gravel and yellow sand	21	39
Yellow sand and scattered gravel	10	12	Jurassic and Cretaceous rocks, undifferentiated:		
Brown silt, moist	6	18	Hard blue rock, broken	2	41

11/10-28L1

[James Black. Drilled by Sitze and Jensen. Altitude 255 ft. On flood plain]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Jurassic and Cretaceous rocks, undifferentiated:		
River gravel	18½	18½	Bedrock	--------	18½

TABLE 11.—*Selected drillers' logs of wells in the Russian River valley area, California*—Continued

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)

11/10-33A

[Italian Swiss Colony Winery. Drilled by Crislip Drilling Co. Altitude: 255 ft. On flood plain. Casing perforated from 10 to 40 ft. Pumping test: 1,000 gpm at drawdown of 8 ft]

Alluvium:			Jurassic and Cretaceous rocks, undifferentiated:		
Gravel [dry]	12	12	Shale	--------	40
Gravel [water]	28	40			

SANEL VALLEY

13/11-8H1

[University of California. Drilled by Harold Nutting. Altitude: 825 ft. On valley slope. Casing perforated from 40 to 60, 80 to 100, and 140 to 187 ft. Pumping test: static level 10 ft, pumping level 80 ft at 75 gpm]

Continental deposits of Pliocene and Pleistocene age:			Continental deposits of Pliocene and Pleistocene age—Continued		
Medium gravelly brown soil	10	10	Blue sedimentary sandy clay	50	147
Fine gravelly yellow clay	20	30	Decayed vegetation	5	152
Blue sand; water	2	32	Blue packed coarse gravel	14	166
Yellow sandy clay	16	46	Fine blue sand and gravel; water	2	168
Fine blue sand; water	4	50	Light blue sandstone	10	178
Sedimentary lake debris	27	77	Large brown gravel; water	9	187
Large blue gravel; water	20	97			

13/11-18D1

[Barber. Drilled by N. F. Keyt. Altitude: 490 ft. On alluvial plain. Casing perforated from 30 to 80 ft; gravel packed. Pumping test: static level 15 ft; pumping level 20 ft at 100 gpm]

Alluvium:			Alluvium—Continued		
Topsoil	2	2	Blue gravel, coarse	26	51
Yellow clay	8	10	Gravel	4	55
Sand	15	25	Blue clay and gravel	6	61

13/11-18M1

[F. W. Renfro. Driller unknown. Altitude: 490 ft. On alluvial plain. Yield: 550 gpm]

Alluvium:			Alluvium—Continued		
Topsoil	22	22	Blue clay	--------	63
Gravel	41	63			

13/11-19Q1

[F. J. Hellman. Drilled by Davis and Alcorn Drilling Co. Altitude: 475 ft. On alluvial plain. Yield: 900 gpm]

Alluvium and continental deposits of Pliocene and Pleistocene age(?):			Alluvium and continental deposits of Pliocene and Pleistocene age(?)—Continued		
Surface	3	3	Gravel, large blue	21	75
Gravel, large, and sand	11	14	Clay, blue	2	77
Gravel	26	40	Clay, blue, and gravel	2	79
Gravel, large	12	52	Clay, sticky blue	21	100
Clay, blue	2	54	Gravel	14	114

TABLE 11.—*Selected drillers' logs of wells in the Russian River valley area, California*—Continued

13/11-21L2

[C. Fitzgerald. Drilled by D. C. Crew. Altitude: 550 ft. On alluvial plain. Gravel-packed well; casing perforated from 60 to 120, 145 to 165, and 178 to 198 ft. Pumping test: drawdown 155 ft after pumping 3 days at 550 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Continental deposits of Pliocene and Pleistocene age—Con.		
Soil	8	8	Clay, soft	10	106
Yellow clay	10	18	Broken gravel and sand	6	112
Sand, coarse	8	26	Hard clay	38	150
Blue clay	8	34	Boulders, rough	15	165
Gravel	12	46	Jurassic and Cretaceous rocks, undifferentiated:		
Continental deposits of Pliocene and Pleistocene age:			Hard clay	4	169
Clay, broken	7	53	Hard blue shale	31	200
Gravel	25	78	Gravel	2	202
Clay, broken	10	88	Blue shale and rock	18	220
Sand and gravel	8	96			

13/11-22G

[D. L. MacFarlane. Drilled by N. F. Keyt. Altitude: 775 ft. On older alluvial plain. Casing perforated from 170 to 182 and 185 to 205 ft. Yield from bailer test: 100 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Dissected alluvium and continental deposits of Pliocene and Pleistocene age(?):			Dissected alluvium and continental deposits of Pliocene and Pleistocene age(?)—Con.		
Soil	1	1	Gravel	5	83
Brown clay and gravel	19	20	Blue clay	108	191
Sandy blue clay	12	32	Good gravel	11	202
Gravel, some water	2	34	Blue clay	2	204
Sandy blue clay	16	50	Jurassic and Cretaceous rocks, undifferentiated:		
Gravel	3	53	Bedrock	1	205
Blue clay	25	78			

UKIAH VALLEY AREA

14/12-5K1

[Gilley. Drilled by Crislip Drilling Co. Altitude: 610 ft. On terrace. Cased to 85 ft. Casing perforated from 69 to 85 ft. Pumping test: static level 38 ft; pumping level 94 ft at 5 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Younger terrace deposits:			Younger terrace deposits—Con.		
Surface	2	2	Yellow sand	4	64
Clay, sand, and gravel	13	15	Yellow cemented gravel	14	78
Boulders and clay	5	20	Blue clay and gravel	6	84
Yellow sand, clay and gravel	18	38	Jurassic and Cretaceous rocks, undifferentiated:		
Yellow clay, hard	7	45	Blue rock	10	94
Yellow cemented gravel	15	60			

14N/12-26H

[O'Neil. Drilled by Crislip Drilling Co. Altitude: about 550 ft. On alluvial plain. Pumping test: static level 12 ft; pumping level 17 ft at 40 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Dissected alluvium:			Dissected alluvium—Continued		
Sand	10	10	Cemented gravel, hard	30	55
Loose gravel	7	17	Soft gravel	7	62
Yellow sandy clay gravel	8	25	Hard	3	65

TABLE 11.—*Selected drillers' logs of wells in the Russian River valley area, California*—Continued

16/12W-34N2

[U.S. Army Corps of Engineers. Drilled by Corps of Engineers. Altitude: 821.3 ft. Near crest of hill]

Material	Thickness (feet)	Depth (feet)
Terrace deposits, undifferentiated:		
Yellow-brown gravelly clay, 1 to 3 in. angular gravel, small percentage of sand	14.5	14.5
Brown sandy gravel, small percent clay	3.5	18
Brown sandy gravel, 1 to 4 in. angular to round, small percentage of clay	7	25
Continental deposits of Pliocene and Pleistocene age:		
Olive-drab sandy clay, well-consolidated	5.5	30.5
Blue clayey sand, very tight	1.5	32
Brown sandy clay, well-consolidated, occasional streaks of blue sand, and small percentage of small pebbles	7	39
Blue gravelly sand, 1 to 2-in. angular to round	1	40
Blue sandy gravel, loosely cemented, 1 to 3 in. angular to round	17	57
Blue gravel conglomerate, very well consolidated	1	58
Blue sandy gravel, loosely cemented, 1 to 3 in. angular to round	7	65
Blue clayey sandy gravel	1	66
Blue clayey sand with some pebbles	2.5	68.5
Blue sandy clayey gravel, 1 to 3 in. angular to round, consolidated with clayey matrix	7.5	76
Blue gravelly clayey sand, 1 to 4 in. angular to round	1	77
Blue clayey sand, well-consolidated, occasional streaks of olive-drab fine sandy clay	6.5	83.5
Blue gravelly clayey sand, well-consolidated	1.5	85
Blue clayey sand, with streaks of pebbles and streaks of olive-drab fine sandy clay	3.5	88.5
Continental deposits of Pliocene and Pleistocene age—Con.		
Olive-drab sandy clay, extremely well consolidated	4.5	93
Olive-drab clayey sand, extremely well consolidated	1	94
Blue clayey sand with streaks of olive-drab clay	2.5	96.5
Blue clayey sand with pebbles	2	97.5
Blue clayey gravelly sand	1.5	99
Blue sandy gravel, loosely consolidated, 1 to 4 in. angular to round	8	107
Blue sandy clayey gravel, 1 to 3 in. angular to round, well-consolidated, clay matrix [losing water in hole]	47	154
Blue sandy clayey gravel, 1 to 2 in. angular to round, well-consolidated, clayey matrix	17.5	171.5
Blue clayey gravelly sand, streaks of olive-drab clayey sand, well-consolidated	1.5	173
Olive-drab clayey sand, well-consolidated, occasional streaks of blue sandy clay	3.5	176.5
Blue sandy clay with occasional streaks of olive-drab clayey sand	2	178.5
Blue clayey sand with pebbles	1	179.5
Blue sandy clayey gravel, well-consolidated, clay matrix, 1 to 3 in. angular to round	16	195.5
Blue sandy clayey gravel, well-consolidated, clayey matrix, 1 to 2 in. angular to round. Some conglomerate in last 3.5 ft	15	210.5

POTTER VALLEY

17/11-33D1

[W. L. Reiter. Drilled by C. T. Smalley. Altitude: 950 ft. At edge of alluvial plain]

Material	Thickness (feet)	Depth (feet)
Alluvium:		
Topsoil	2½	2½
Terrace deposits(?):		
Yellow clay	14½	17
Continental deposits of Pliocene and Pleistocene age:		
Blue clay	358	375
Jurassic and Cretaceous rocks, undifferentiated:		
Rock	55	430
Hard formation	1	431
Jurassic and Cretaceous rocks, undifferentiated—Continued		
Shale	28	459
Hard blue rock	111	570
Rock	47	617
Hard blue rock	41	658
[Interval from 375 to 658 ft further described as gray fairly coarse textured rock in hard and soft layers.]		

CHEMICAL ANALYSES OF WATER, RUSSIAN RIVER VALLEY AREA

Table 12 contains analyses from wells and springs in the Russian River valley area consisting of comprehensive and partial analyses. The comprehensive analyses include at least determinations for each of the three principal cations and anions; the partial analyses are varied depending on the purpose of the analysis. For most analyses, constituents are reported on both parts per million (ppm), represented by the upright figures, and equivalents per million (epm), represented by the italicized figures. A part per million is a unit weight of a constituent in a million unit weights of water. An equivalent per million is the unit chemical combining weight of a constituent in a million unit weights of the water.

As indicated in the table, the analyses were obtained from several sources. A considerable number, obtained from the Sonoma County Farm Advisor, were of water samples collected by personnel in the Farm Advisor's office or received from the well owner and transmitted to the University of California, Berkeley, where the analyses were made by the Division of Plant Nutrition, under the direction of Mr. J. C. Martin. These analyses were made primarily to determine the agricultural suitability of the water, and the results, in most instances are reported to the nearest 5 ppm. Several analyses by Brown and Caldwell, consultants, were obtained from water companies or municipalities. Other sources of chemical analyses are mentioned in footnotes.

Wells for which water analyses from the above sources were obtained were located in the field by the Geological Survey. Samples were collected from additional wells to complete areal coverage and were analyzed by the Quality of Water Branch of the Geological Survey. Most samples from the upper Russian River valley were collected by the California Department of Water Resources.

The "sum of determined constituents," as indicated in the table heading, is the arithmetic sum of all constituents determined, with the following qualifications: (1) Bicarbonate for all analyses, except those indicated by the symbol "UC," was divided by 2.03 to obtain carbonate equivalent; (2) for many samples, boron and phosphate were not determined, and the standard practice of adding them to the table only if they exceed 1.0 ppm was adopted. For some analyses, "sum of the determined constituents," as computed by the Geological Survey, may differ from the figure for "total dissolved solids" listed on the original analysis. This is usually due to slight differences in the manner in which the sum was determined, or, in some instances, the original figure may represent total solids by evaporation.

With the exception of analyses by the Geological Survey and some by the University of California, most sodium concentrations were obtained by subtracting from the sum of the anions the sum of calcium and magnesium, in equivalents per million. The value reported, therefore, includes the equivalent of the potassium concentration also.

For the University of California analyses, the "sum of determined constituents" and in most instances, the hardness were computed by the Geological Survey. "Percent sodium" and "sum of determined constituents" were computed by the Geological Survey for some Brown and Caldwell analyses.

Because of the diversity among analyses in constituents determined, the "sum of determined constituents" may not be used as a basis for general comparison of waters. Analyses by other laboratories have been modified to agree with Geological Survey practice, except for those by the University of California, who report their results in equivalents per million.

Except when footnoted, the value for iron is that in solution at the time of analysis. Values for pH were measured in the laboratory.

TABLE 12.—*Chemical analyses of water from wells and springs in the Russian River valley area, California*

[Results in parts per million except as indicated; equivalents per million shown in italic; only parts per million are given for most partial analyses]

Well	Depth (ft)	Date collected	Temperature (°F)	Specific conductance (micromhos at 25°C)	Sum of determined constituents (ppm)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Percent sodium	Hardness as $CaCO_3$ (ppm) Total	Hardness as $CaCO_3$ (ppm) Noncarbonate	pH
Lower Russian River valley																							
7/10-7D1 [1]	120	7-11-50	----	----	135	----	0.00	0.00	18	22	4.6	----	0	167	0	9.6	0	0	----	7	132	0	7.4
									0.868	*1.793*	*0.200*			*2.737*		*0.271*							
7/11-14E1	47	9-12-51	----	430	----	----	----	----	----	----	----	----	----	----	----	14	----	----	----	----	220	----	----
15P1	83	9-12-51	----	11,000	----	----	----	----	----	----	----	----	----	----	----	3. 580	----	----	----	----	1,130	----	----
17J1	148	7-22-54	72	9,400	5,400	14	.02	.00	85	206	1. 620	66	0	165	405	2. 920	.1	3.8	0.13	75	1,060	925	7.9
									4.24	*16.96*	*70.44*	*1.69*		*2.70*	*8.43*	*82.35*	*.01*	*.06*					
20L1	----	8-21-54	59	2,740	1,400	2.9	.10	.00	39	85	360	19	0	184	54	744	.1	3.0	.52	62	445	294	8.2
									1.95	*6.95*	*15.65*	*.49*		*3.02*	*1.12*	*20.98*	*.01*	*.05*					
8/10-20M4 [2]	108	2- -49	----	----	----	----	.10	----	27	20	----	----	----	----	12	15	----	----	----	----	149	----	6.2
29H2 [1]	125	7-10-50	----	285	184	----	.00	.60	25	21	18	----	0	212	5.7	9.0	0	1.8	----	21	149	0	7.3
									1.238	*1.694*	*.783*			*3.474*	*.119*	*.254*		*.028*					
Healdsburg area [Includes Russian River valley from Rio Dell to Healdsburg and Dry Creek valley]																							
9/9-20K2 [2]	146	1- -47	----	----	----	----	0.10	----	17	18	----	----	----	180	5	15	----	----	----	----	116	----	7.2
(2)	----	3- -48	----	----	----	----	----	----	15	12	----	----	----	200	3	15	----	----	----	----	86	----	7.6
21J1-6 [2,3]	55-70	1- -47	----	----	----	----	.00	----	17	23	----	----	----	180	5	10	----	----	----	----	137	----	7.0
10/10-27D2 [4]	126	4- 3-50	----	1,110	----	----	----	----	----	----	105	----	----	----	----	----	----	----	13.36	----	----	----	7.0

See footnotes at end of table.

TABLE 12.—*Chemical analyses of water from wells and springs in the Russian River valley area, California*—Continued

[Results in parts per million except as indicated; equivalents per million shown in italic; only parts per million are given for most partial analyses]

Well	Depth (ft)	Date collected	Temperature (°F)	Specific conductance (micromhos at 25°C)	Sum of determined constituents (ppm)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Percent sodium	Hardness as $CaCO_3$ (ppm) Total	Hardness as $CaCO_3$ (ppm) Noncarbonate	pH
Alexander Valley																							
9/8-7Q1 [4]	490	10-12-50	----	510	450	----	----	----	0.5	40	120	----	----	300	----	135	----	----	0.32	60	175	----	----
									.2	*3.3*	*5.2*	----	----	*4.9*	----	*3.8*							
9/9-4E1 [4]	117	8-23-50	----	2,650	1,320	----	----	----	60	275	40	----	----	680	15	555	----	----	40	6	1,280	----	7.3
									3.1	*22.4*	*1.7*			*11.2*	*.3*	*15.7*							
		4- 2-52	----	776	----	----	----	----	18	18	143	----	----	----	----	97	----	----	14	72	119	----	----
									.90	*1.48*	*6.22*					*2.74*							
4E2	32	4- 2-52	----	431	----	----	----	----	13	11	74	----	----	----	----	41	----	----	4.4	68	78	----	----
									.648	*.905*	*3.218*					*1.156*							
10/9-26L1	152	10-17-50	----	483	----	----	----	----	----	----	----	----	----	----	----	9.2	----	----	----	----	231	----	----
26L2	40	10-17-50	----	405	----	----	----	----	----	----	----	----	----	----	----	9.0	----	----	----	----	196	----	----
32R1	(5)	4- 2-52	----	442	----	----	----	----	48	13	32	----	----	----	----	9.0	----	----	.00	29	173	----	----
									2.400	*1.069*	*1.392*					*.254*							
32R2	65	4- 2-52	----	356	----	----	----	----	14	11	62	----	----	----	----	8.5	----	----	.28	63	80	----	----
									.698	*.904*	*2.699*					*.240*							
Cloverdale Valley																							
11/10-7J1 [1]	15	7-27-50	----	283	188	----	0	0	32	18	15	----	0	202	14	9.3	0	0	----	17	155	----	7.1
									1.597	*1.480*	*.652*			*3.313*	*.291*	*.262*							
Sanel Valley area																							
12/11-2C1	73	10-13-53	----	403	236	15	----	----	43	22	12	1.6	0	234	21	5.8	0	0.5	0.27	12	198	6	7.7
									2.146	*1.809*	*0.522*	*0.041*		*3.835*	*0.437*	*0.164*		*0.008*					
13/11-18E1 [4]	52	10-22-52	----	390	225	----	----	----	25	15	35	----	----	195	20	25	----	----	6.2	31	145	----	----
									1.3	*1.4*	*1.5*			*3.2*	*.4*	*.7*							

Ukiah Valley area																							
14/12-5K1	94	5-12-53	----	759	401	23	[6] 2.2	----	58 *2.89*	31 *2.55*	41 *1.78*	2.0 *.05*	0	357 *5.85*	64 *1.33*	5.2 *.15*	0.3 *.02*	0.7 *.01*	0.60	24	272	0	7.3
15/12-16Q1 [1]	34	7- 6-50	----	----	108	----	.00	0.00	15 *.758*	17 *1.365*	0	----	0	120 *1.962*	0	5.1 *.106*	0	2.6 *.043*	----	0	106	----	7.7
22D2 [4]	([5])	12- -50	----	----	137	----	----	----	10 *.5*	20 *1.8*	10 *.3*	----	----	65 *1.1*	55 *1.2*	10 *.3*	----	----	.24	12	115	----	8.0
35D [4]	----	8-25-48	----	450	250	----	----	----	55 *2.7*	10 *1.0*	25 *1.0*	----	----	230 *3.8*	25 *.5*	15 *.4*	----	----	4.7	21	185	----	----
Potter Valley																							
17/11-33D1	658	9-23-52	64	1,580	1,020	35	----	----	93 *4.64*	63 *5.18*	218 *9.48*	9.6 *.25*	0	1,100 *18.03*	0.9 *.02*	58 *1.64*	0.1 *.01*	0.2 *.00*	1.0	48	491	0	7.9

[1] Analyzed by California Department of Public Health, Bureau of Sanitary Engineering.
[2] Analyst not known.
[3] Sample taken after chlorination.
[4] Analyzed by University of California, Division of Plant Nutrition.
[5] Spring.
[6] Total iron.

DESCRIPTION OF WELLS AND SPRINGS, MENDOCINO COUNTY

Table 13 presents descriptive data on water wells and springs in the Round, Laytonville, and Little Lake Valleys. Included are some of the irrigation, industrial, public-supply, domestic, stock, and other wells that were selected from among those for which logs, chemical analyses, or other data were available. The location of wells and springs is shown on plates 3, 5, and 6. The explanation of the headings used in table 13 is the same as given for table 10. The symbols used to denote the geologic formation are the same as those used on the geologic maps (pls. 3, 5, 6).

Under "Remarks," the term "artesian," unless accompanied by a qualifying phrase, indicates that the well was flowing when visited or was reported either to flow or to have flowed in the past.

TABLE 13.—*Description of water wells and springs in Round, Laytonville, and Little Lake Valleys, Mendocino County, Calif.*

Well	Owner or user	Year completed	Altitude of land-surface datum (ft)	Depth (ft)	Type of well and casing diameter (in.)	Geologic formation	Measuring point and distance above or below (−) land-surface datum (ft)	Water level: Date measured	Water level: Distance above (+) or below land-surface datum (ft)	Temperature (° F)	Use	Type of pump and horsepower	Yield (gpm) and drawdown (ft)	Remarks and perforation data (ft)
	Round Valley													
	T. 22 N. R., 12 W.													
4B1	John Perata	1946	1,351	200	DR, 12	Qal	TcN, 1.0	5-18-51	5.93		Irr	T, 20	250	L, W.
5B1 [1]	F. Rhyne	1946	1,355	180	D, 12	Qal					Irr			L; reported artesian. Perforated 110-118.
5F1	Dr. R. E. Welch		1,349	50	D,	Qal	[2]	5-18-51 4-3-52 5-17-54 6-25-54	[3] 	 59 58 60	D, S			Cp; W.
6K1 (DWR 6J1)	Evan Rohrabaugh	1950	1,365	14	Dug, 40×40	Qal					Irr			Flows during winter.
6K2	do	1952	1,365	14	Dug, 30×90	Qal					Irr			
6L2	W. B. Mooy	1947	1,375	112	DR, 12	Qal	Tap, 1.0	10- -52 5-23-53	[3] [3]		D, irr			Maximum head above land surface reported, 25 ft.
9D2	Glenn Barrass		1,340	13.2	D, 10	Qal	Tc, 0	6-25-54	6.47		U	P		
9D3	do		1,340	90	B, 4	Qal	V, 1.0	6-25-54	[3]	61	D, S			
18N1	H. T. Tuttle	1946	1,400	452	DC, 14	Qal, QTc(?).	Tc, 3.0	4-3-52	2.84		S	J, ¼	150/[4]50	L, W; "perforated all the way."
19B1	Diamond H Ranch	1952	1,380	860	DR, G, 16	Qal, QTc	HcW, 1.0	11-12-52 5-19-53 6-24-53 8-12-54	19.7 3.4 [4]101	 60	Irr	T, 100	[5]1,000	

See footnotes at end of table, p. 141.

TABLE 13.—*Description of water wells and springs in Round, Laytonville, and Little Lake Valleys, Mendocino County, Calif.*—Continued

Well	Owner or user	Year completed	Altitude of land surface datum (ft)	Depth (ft)	Type of well and casing diameter (in.)	Geologic formation	Measuring point and distance above or below (−) land surface datum (ft)	Water level: Date measured	Water level: Distance above (+) or below land-surface datum (ft)	Temperature (°F)	Use	Type of pump and horsepower	Yield (gpm) and drawdown (ft)	Remarks and perforation data (ft)
	Round Valley													
19E1	Diamond H Ranch	1952	1,405	400	DR, G, 16	Qal	Tc, 1.5	11-12-52	29.5				100	W.
19G2 (DWR 19F3)	do	1951	1,385	508	DR, G, 12-10	Qal, QTc	Tc, 1.0	10-30-52	31.4		Irr			L; 100-508.
19M1	do	1939	1,410	303	DC, 12	Qal, QTc	TcNE, .5	5-18-51	7.87		D, S	J, 1½		C, L, W; 98-102, 119-208, 212-267
19N1	do	1952	1,405	1,130	DR, G, 18	Qal, QTc, KJu.	Tc, 1.0	10-30-52 5-19-53 6-25-54 8-12-54	21.7 5.5 10.42 16.44		U			
21A1[1]	P. J. Rohrabaugh	1950	1,315	200	D, 8	Qal	Tc, 1.0	11-12-52 5-18-53	15.3 11.1		D	J, ½		C, L.
	T. 22 N., R. 13 W.													
1H1	L. W. Maxwell	1952	1,398	214	D, 12	Qal	Tc, .5	5-23-53	2.0		Irr	T, 25		50-60, 195-214.
1J1[1]	C. F. Gutcher		1,400	50	DR, 8	Qal	Tc, .5	10-30-52 5-24-53	20.7 8.1		D	J, ⅓		C.
1L1	Covelo Union School.	1932	1,409	200±	D, 12	Qal	BpbW, .5	5-18-51	13.57		D	J, 1		
2A3	R. T. Hurt	1948	1,420	146	D	Qal							150	L; bedrock at 146 ft.
12K2[1]	L. C. Hurt	1946	1,405	[6] 180	D, 12	Qal					Irr			L; 22-30, 65-85, 105-180.
12M1	Frank Weymouth	1946	1,415	74	D, 8	Qal					D, S		7	L; 56 and 68 ft.
	T. 23 N., R. 12 W.													
31N1	George Gravier	1951	1,388.5	200	D, 12	Qal	(7)	5-18-51 4-3-52 3-30-54	(3) (3) (3)	 57 58	Irr	T, 7.5		C, L, W.

33L2	Elmer Bauer		1,366	28	D,	8	Qal	TcW,	1.0	4-3-52	1.97		U	P			W.
33N1	do	1946	1,360	192	D,	12	Qal			6-24-54	([3])		S			300/8/18	162-172.
Laytonville Valley																	
T. 21 N., R. 14 W.																	
19M2	Toyken Springs Motel.	1953	1,710	160	DC,	8	KJu			8-1-53	52		D			15/45	L; cased to 42 ft.
19N1[1]	John Gates	1936	1,685	125	DC,	10	Qal	Tc,	1.0	11-21-52	1.5		D				C, L; artesian flow 8 months of year; 12-120.
30M1	Mary E. Tracy	1929	1,688	23	Dug,	60	Qal	Tw,	1.5	11-19-52	16.2						
31J1	J. D. Imperatrice	1951	1,680	405	DR, G,	10	Qal, KJu	HpbNW,	1.0	10-23-53	12.02		Irr	T,	25		C, L, W; cased to 120 ft; 20-120.
T. 21 N., R. 15 W.																	
1L2 (DWR 1K1)	California Div. Forestry.		1,682	65	DC,	8	KJu	TcN,	1.0	11- -52	([3])		D, F	J,	2		C, W.
1P1[1] (DWR 12C1)	Cutler	1952	1,640	133	DC,	8	Qal, KJu(?).			11- -52	([3])		D		1	15/70	C, L; 100-133.
1P2 (DWR 12C2)	do		1,640	25 60	Dug, D,	24 12	Qal, KJu(?).	Tc,	0	11-5-52 6-2-53	11.8 .7		U				C.
1Q1	Elesa Cole and Elaine Reese.		1,700	([9])			KJu			9-24-54 3-30-55		69 70	U			[10] 275 [10] 270	C.
11R2	Paul Oldenburg		1,645	31	Dug,	4 × 4	Qt	Tb,	0	11-24-52	18.0		U				C, W.
11R3	do		1,660	44.0	Dug,	48	Qt	Tb,	1.5	11-24-52	39.7		D	J,	½		C, W.
12F1	Laytonville District High School.		1,622	50-60	DC,	8	Qal	Bpb,	0.5	10-23-53	21.6		U	L,	½		W.
12F2	do		1,622	26.8	Dug,	4 × 4	Qal	TccS,	2.5	10-23-53	5.62		U				W.
12K2	do	1940	1,625	250	DC,	8	Qal	Tc,	.3	9-16-40 11-24-52	[8] 16 5.9		A			7/1	L; 50-85, 125-135, 230-250. Filled with gravel October 1953.
13B1	Laytonville Water Co.	1951	1,610	528	DR, G, 12-8		Qal, Qt(?), KJu,			6-15-51	([3] [8])		PS			700/[4] 18	C, L; 40-528.
13G1[1]	J. M. Janssen	1951	1,615	423	DR, G, 10-8		Qal, Qt(?), KJu.	Phf,	1+	7-3-51 5-20-53 7-16-54	[8] 0 1.7 61		Irr	T, 50		575/27	L; 20-423.

See footnotes at end of table, p. 141.

TABLE 13.—*Description of water wells and springs, Laytonville, and Little Lake Valleys, Mendocino County, Calif.*—Continued

Well and owner or user		Year completed	Altitude of land-surface datum (ft)	Depth (ft)	Type of well and casing diameter (in.)	Geologic formation	Measuring point and distance above or below(−) land-surface datum (ft)	Water level: Date measured	Water level: Distance above (+) or below land-surface datum (ft)	Temperature (°F)	Use	Type of pump and horsepower	Yield (gpm) and drawdown (ft)	Remarks and perforation data (ft)
Round Valley—Continued														
T. 21 N., R. 15 W.—Con.														
14A [1]	C. C. Brown	1951	1,670	49	DC, 8	Qt	Tc, .2	3-15-51 11-24-52 6-2-53	[2] 3 15.7 3.5		D		10/35	C, L; 19-49.
24A1 [1]	Ray Evans		1,653	28.5	Dug, 48-36	Qal	Tw, .5	11-24-52	25.7		U			C, W.
24N1 [1]	Gerald Oden	1932	1,750	34	Dug, 60	Qal	Tw, 2.0	11-21-52 6-3-53	30.9 4.4		D			C.
Little Lake Valley														
T. 18 N., R. 13 W.														
6B1 (DWR 6G1)	E. H. Maize	1952	1,320	249	DC, 12	Qal	Tc, 3.5	6-9-53 7-15-54	(3) [4] 35.55		Irr	T, 10	250/[4] 35	L; 50-70, 74-88, 235-245. Flammable gas.
6H1 (DWR 5D1)	do	1947	1,325	60	DC, 16-8	Qal		7-20-47 7-14-54	(3) +.52		U		500/[4] 6	Cp; L; 32-48. Natural flow, 7-20-47, 220 gpm.
6Q1 (DWR 7M1)	R. H. Corbett	1952	1,325	145	DR, G, 10	Qal	Tc, 5.0	7-13-54	+4.00		Irr	T, 15	100/1	L; 74-134.
7C1	L. C. Allen	[11] 1953	1,325	214	DC, 12-10	Qal		7-11-53	[8] 0		Irr		[8] 1,500	L; 152-161, 207-210.
8K1 [1]	G. Mott	1946	1,340	77	DC, 8	Qal		5-10-46 6-8-53	(3 12) [13] 0		D			C, L.
8L1 (DWR 8Q1)	Luther Sherburn	Old	1,340	18.5	Dug, 48	Qal	Tb, 2.0	6-8-53	1.0		D	J, ¼		W.

8L2 (DWR 8P1)	do	1946	1,337	97	DC,	12	Qal	Tc,	2.0	6-8-53	5.3		Dy, Irr	C,	5		Cp, L, W; 52-93.
16G1	J. Muir	1952	1,475	112	DC,	8	QTc						D	J,	¾		L; bedrock at 77 ft.
17E1 (DWR 17L1)	E. E. Safford	1939	1,345	77	DC,	8	Qal			9- -39	[8] 7		D			45/7	L.
18H1	Don Coleman	1952	1,340	354	DR, G,	10	Qal, QTc(?).	BpbS	1.0	6-9-53		64	Irr	T,	30	952/90	C, L; 165-225, 245-265, 285-305.
										10-23-53	27.4						
										3-31-54	15.15	[14] 57					
										6-26-54	18.4						
18H2	do	Old	1,340	14	Dug,	60	Qal	Tcc,	0	3-31-54	2.08		D				W.
19B1	Philip Colli	1952	1,360	454	DR, G,	12-10	Qal, QTc	Tap,	1.5	7-14-54	[4] 182.5	67	Ind, Irr	T,	20	190/210	L; 176-440.
19G1	Industrial Plywood Corp.	1950	1,375	197	DC,	12	Qal, QTc(?).	Tc,	3.5	7-14-54	37.8		U				L; perforated. Yields carbon dioxide(?) gas.
20P2	P. Regano	1947	1,405	95	DC,	8	QTc	Tap,	.2	7-14-55	(3)		irr, S			[10] 15	Cp, L; 72-82, 90-95. Artesian flow tapped at 72 ft.
29C1 [1]	Wm. Burrell	1952	1,415	40	DC,	10	QTc	Tc,	.5	6-8-53	5.9		D	J,	⅛	10/20	C, L; 14-39.
29D1 [1]	Ed Hayes	1949	1,395	87	DC,	8	Qal, QTc										C.
31A1	John DelSol	1939	1,450	289	DC,	8	QTc			9-28-39	[15] 26		D			10/144	L; 270-289.
T. 18 N., R. 14 W.																	
2P1 [1]	Anderson	1952		14	Dug,	42	Qal			9-30-53	7.5		D, Sw				C, L.
12H1 [1]	R. E. Sanders		1,390	71	DC,	6	KJu(?)	Tc		6-9-53	[13] 7	66	D	J			C.

[1] Field location by California Department of Water Resources.
[2] Measuring point is valve at north side of casing, 1.5 ft above land-surface datum.
[3] Well flowing; static level above land-surface datum.
[4] Pumping level.
[5] Measured by Geological Survey.
[6] Casing reportedly is partly collapsed owing to excessive sanding.
[7] Measuring point is bottom edge of discharge pipe, 1.5 ft vertically and 2.2 ft horizontally (3.7 ft) above land-surface datum.
[8] Reported.
[9] Spring.
[10] Estimated natural flow.
[11] Date deepened.
[12] Measured natural flow.
[13] Depth to water from measuring point; relation to land-surface datum not ascertained.
[14] Pumping 3 minutes.
[15] Subsequently deepened to 156 ft after extensive collapse due to sand pumping reduced natural flow.

LOGS OF WELLS, MENDOCINO COUNTY

Table 14 contains drillers' logs of wells in Round Valley, Laytonville Valley, and Little Lake Valley. The logs were selected from approximately 125 drillers' logs of which 106 were field located. The additional logs not listed are available in the files of the Geological Survey or the California Department of Water Resources, both located in Sacramento, Calif. Some of the unlisted logs are classified as confidential and limited to official use without express permission from the driller or owner.

For explanation of the log heading and other details, refer to the explanation preceding table 11.

TABLE 14—*Selected drillers' logs of wells in Round, Laytonville, and Little Lake Valleys, Mendocino County, Calif.*

ROUND VALLEY

22/12-18N1

[H. T. Tuttle. Drilled by Jessee. Altitude: 1,400 ft. On alluvial fan. Perforated "all the way." Yield: 150 gpm at pumping level of 50 ft]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Alluvium—Continued		
Soil	9	9	Gravel	2	116
Gravel	2	11	Clay and gravel	64	180
Clay, gravelly	11	22	Gravel	3	183
Gravel	1	23	Clay	91	274
Clay, gravelly	8	31	Clay, hard, sandy	19	293
Gravel	4	35	Rocks	2	295
Clay	23	58	Gravel and clay	64	359
Gravel	5	63	Gravel	2	361
Clay and gravel	34	97	Gravel and clay	91	452
Gravel	4	101	Rock		452
Clay, gravelly	13	114			

22/12-19G2

[Diamond H Ranch. Drilled by Precision Drilling Co. Altitude: 1,385 ft. On alluvial fan. Casing perforated from 100 to 508 ft. Gravel packed]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Alluvium—Continued		
Surface soil and yellow clay	10	10	Fine blue sand and gravel	10	280
Yellow clay and gravel	10	20	Yellow clay and gravel	20	300
Clay	10	30	Blue clay	10	310
Gravel and yellow clay	10	40	Blue sandy clay	10	320
Coarse sand	10	50	Streaked blue clay and gravel	10	330
Yellow clay	20	70	Gray clay and gravel	10	340
Sand and blue clay	20	90	Coarse sand and gravel	40	380
Coarse sand	30	120	Gravel	10	390
Pea gravel	10	130	Blue clay and gravel	20	410
Sand and gravel	30	160	Continental deposits(?):		
Gravel	10	170	Brown clay	10	420
Gray clay	20	190	Blue clay	10	430
Yellow clay	10	200	Fine gravel	10	400
Sandy clay	10	210	Yellow clay and fine gravel	10	450
Gravel, fine	20	230	Hard red rock	10	460
Sand with streaks of blue clay	10	240	Broken rock, shattered	20	480
Yellow clay and gravel	10	250	Blue clay and coarse gravel	20	500
Sand and gravel, small	10	260	Yellow clay	8	508
Blue sand, fine	10	270			

22/13-2A3

[R. T. Hurt. Drilled by C. F. Gutcher. Altitude: 1,420 ft. On alluvial fan. Reported yield: 150 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Jurassic and Cretaceous rocks, undifferentiated:		
Gravel and boulders	146	146	Bedrock		146

TABLE 14.—*Selected drillers' log of wells in Round, Laytonville, and Little Lake Valleys, Mendocino County, Calif.*—Continued

LAYTONVILLE VALLEY

21/14-30M1

[Mary E. Tracy. Dug well. Altitude: 1,688 ft. Near foot of alluvial slope]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Alluvium—Continued		
Topsoil	1	1	Blue clay	3	18
Brown clay	14	15	Gravel	5	23

21/14-31J1

[J. D. Imperatrice. Drilled by Precision Drilling Co. Altitude: 1,680 ft. On alluvial flat. Cased to 120 ft; perforated from 20 to 120 ft]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Jurassic and Cretaceous rocks, undifferentiated:		
Top soil and yellow clay	10	10	Red and black rock	20	130
Yellow clay and pea gravel	10	20	Blue and black rock	10	140
Blue clay	10	30	Blue and black rock with salt-white ashy streaks	265	405
Coarse sand	20	50			
Sand and fine gravel	30	80			
Blue sand	20	100			
Green sandy silt	10	110			

21/15-12K2

[Laytonville School District. Drilled by N. F. Keyt. Altitude: 1,622 ft. On alluvial fan. Casing perforated from 50 to 85, 125 to 135, and 230 to 250 ft. Yield: 450 gallons per hour with drawdown of 1 ft]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium and terrace deposits(?):			Alluvium and terrace deposits(?)—Continued		
Soil	3	3	Blue clay and gravel	51	180
Yellow clay	18	21	Yellow clay	21	201
Yellow clay and gravel	16	37	Jurassic and Cretaceous rocks, undifferentiated:		
Blue clay	13	50	Blue shale	49	250
Blue clay and gravel [water]	75	125			
Gravel	4	129			

21/15-13B1

[Laytonville Water Co. Drilled by Precision Drilling Co. Altitude: 1,610 ft. On flood plain. Casing perforated from 40 to 528 ft. Pumping test: pumping level 18 ft after 60 hrs pumping at 700 gpm. Well flowing at beginning of test]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium:			Alluvium—Continued		
Surface soil	10	10	Hard blue rock with streaks of sand	40	320
Coarse sand	30	40	Blue clay with large gravel	10	330
Pea gravel	20	60	Jurassic and Cretaceous rocks, undifferentiated:		
Gray sand	20	80	Red rock, hard	10	340
Gray sand and gravel	40	120	Porous red volcanic rock	10	350
Terrace deposits:			Red volcanic rock	20	370
Hard shale	10	130	Black basalt rock	30	400
Cemented gravel	10	140	Red volcanic rock	40	440
Brown clay and large gravel	30	170	Red and black rock	60	500
Pea gravel	20	190	Black and green rock, hard	28	528
Blue clay and gravel	30	220			
Green sand	30	250			
Blue clay and green sand	30	280			

21/15-14A1

[C. C. Brown. Drilled by Crislip Drilling Co. Altitude: 1,670 ft. On alluvial terrace. Casing perforated from 19 to 49 ft. Bailer test: static level 3 ft; pumping level 38 ft at 10 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Terrace deposits:			Terrace deposits—Continued		
Surface soil	2	2	Blue clay	4	29
Yellow clay and gravel	23	25	Yellow clay and gravel	20	49

TABLE 14.—*Selected drillers' log of wells in Round, Laytonville, and Little Lake Valleys, Mendocino County, Calif.*—Continued

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)

18/13-18H1

[Don Coleman. Drilled by Weeks Hardward Co. Altitude: 1,340 ft. On alluvial plain. Gravel-packed well; casing perforated from 165 to 225, 245 to 265, and 285 to 305 ft. Pumping test: drawdown of 90 ft at pumping rate of 952 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium and continental deposits(?):			Alluvium and continental deposits(?)—Continued		
Surface soil	25	25	Coarse gravel	182	250
Brown clay	5	30	Coarse gravel and blue clay	55	305
Coarse sand	10	40	Blue clay	27	332
Blue clay	28	68	Blue clay with gravel	22	354

18/13-19B1

[Philip Colli. Drilled by Weeks Hardward Co. Altitude: 1,360 ft. On alluvial plain. Gravel-packed well; casing perforated from 176 to 194, 220 to 240, 260 to 280, 300 to 320, 340 to 360, 380 to 400, and 420 to 440 ft. Pumping test, 1952: drawdown of 210 ft at pumping rate of 190 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Alluvium and continental deposits			Alluvium and continental deposits—Continued		
Topsoil	14	14	Blue clay	86	282
Fine sand	2	16	Sand and gravel	7	289
Clay	7	23	Blue sand, coarse	31	320
Fine sand	4	27	Brown sand, coarse	25	345
Blue clay	2	29	Gray sand, coarse	5	350
Coarse sand	7	36	Multicolored sand, coarse	12	362
Blue clay	2	38	Yellow sandy clay	10	372
Coarse gravel	41	79	Blue clay	38	410
Blue clay	3	82	Coarse brown sand	20	430
Coarse gravel	70	152	Brown sandy clay with gravel	14	444
Blue clay	22	174	Blue clay and gravel	10	454
Sand and gravel	22	196			

18/13-20P2

[P. Regano. Drilled by Ray Shaw. Altitude: 1,405 ft. On low knoll at edge of valley. Casing perforated from 72 to 82 and 90 to 95 ft. Reported to flow 250 gmp when drilled May 1947. Flowing 15 gpm July 14, 1954]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Continental deposits:			Continental deposits—Continued		
Yellow clay	14	14	Gravel up to 4-in. diameter with much fine sand [artesian water]	10	82
Water gravel	8	22	Blue clay	8	90
Blue clay	33	55	Artesian water	5	95
Water gravel [50 gpm]	5	60	Blue clay	--------	95
Blue clay [buried coniferous forest at 72 ft]	12	72			

18/13-31A1

[J. F. DelSol. Drilled by N. F. Keyt. Altitude: 1,450 ft. On low knoll at edge of valley. Casing perforated from 269 to 289 ft. Bailing test: static level 26 ft; bailing level 170 ft at 10 gpm]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Continental deposits:			Continental deposits—Continued		
Soil	2	2	Yellow clay and gravel	7	158
Yellow clay and gravel	32	34	Blue clay	29	187
Blue clay and gravel	3	37	Blue clay and gravel	5	192
Blue clay, sticky	2	39	Blue clay and boulders	8	200
[No record]	12	51	Yellow clay and gravel	14	214
Blue clay	9	60	Blue clay and gravel	26	240
Blue clay and gravel	7	67	Blue clay	10	250
Blue clay	12	79	Yellow clay	10	260
Blue clay and gravel	1	80	Blue clay	25	285
Blue clay	20	100	Yellow sand and gravel	2	287
Yellow cemented gravel	24	124	Yellow clay	2	289
Blue clay	27	151			

CHEMICAL ANALYSES OF WATER, MENDOCINO COUNTY

Except as noted, the analyses presented in table 15 were made by the Geological Survey. The water samples were collected by the California Department of Water Resources and the Geological Survey.

"Sum of determined constituents" was determined as explained in the introduction to table 12. The value for iron, where not footnoted, is the amount in solution at the time of analysis. Values for pH were determined in the laboratory.

TABLE 15.—*Chemical analyses of water from wells and springs in Round, Laytonville, and Little Lake Valleys, Mendocino County, Calif.*

[Results in parts per million except as indicated; equivalents per million shown in italic; only parts per million given for most partial analyses]

Well	Depth (ft)	Date collected	Temperature (°F)	Specific conductance (micromhos at 25°C)	Sum of determined constituents (ppm)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Percent sodium	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Noncarbonate	pH
Round Valley																							
22/12-5F1	50	4- 3-52	59	409	---	---	---	---	---	---	---	---	---	---	---	3.5	---	---	---	---	166	---	---
22/13-1J1	50	10-30-52	---	209	116	6.0	---	---	22	9.5	6.9	0.7	0	114	11	3.2	0	0.9	0.11	14	94	1	7.6
									1.098	*.781*	*.300*	*.018*		*1.868*	*.229*	*.090*		*.015*					
Laytonville Valley																							
21/14-31J1	405	11-18-52	---	462	244	0.5	---	---	28	26	34	1.1	0	262	2.5	22	0	0.8	0.07	29	177	0	7.6
									1.397	*2.138*	*1.478*	*0.028*		*4.294*	*.052*	*.620*		*.013*					
21/15-1L2	65	8-27-53	---	442	284	45	[1] 0.10	---	49	20	19	1.3	0	272	1.2	14	.4	.2	.07	17	204	0	7.6
									2.445	*1.645*	*.826*	*.033*		*4.458*	*.025*	*.395*	*.021*	*.003*					
1P2	60	11- 5-52	---	608	338	5.2	---	---	49	4.4	73	1.6	0	236	4.5	73	0	1.5	9.8	53	140	0	7.8
									2.45	*.36*	*3.17*	*.04*		*3.87*	*.09*	*2.06*		*.02*					
1Q1	[2]	9-24-54	69	1,820	---	---	---	---	90	9.6	273	3.2	0	280	---	440	---	---	---	69	264	34	7.1
									4.49	*.79*	*11.87*	*.08*		*4.59*		*12.41*							
	[2]	3-30-55	70	1,870	1,050	36	.03	---	96	9.8	281	3.2	0	274	4.8	456	.3	1.8	23	68	280	55	7.1
									4.79	*.81*	*12.22*	*.08*		*4.49*	*.10*	*12.86*	*.02*	*.03*					
24N1	34	11-21-52	---	297	157	8.8	---	---	13	8	34	1.0	0	82	3.0	48	0	.8	.09	53	65	0	7.3
									.649	*.658*	*1.478*	*.026*		*1.344*	*.062*	*1.354*		*.013*					

Little Lake Valley

18/13-6H1 [3]	156	11-11-50	----	316	-------	------	[1] 0.47	2.6	-------	-------	-------	-------	----	-------	-------	-------	-------	-------	-------	----	148	----	7.7
8L2 [3]	96	11-11-50	----	507	-------	------	[1] .96	7.1	-------	-------	-------	-------	----	-------	2.5	-------	-------	-------	-------	----	232	----	7.9
20P2 [3]	95	11-11-50	----	144	-------	------	[1] 1.0	.94	-------	-------	-------	-------	----	-------	-------	4	-------	-------	-------	----	54	----	6.5
29C1 [4]	40	5-21-52	----	-------	130	1.5	[1] 9.6	------	9.6	7.9	31	130	----	108	6.5	21	-------	-------	-------	----	72	----	6.4
									.48	*.65*	*1.37*	*2.50*		*1.77*	*.14*	*.59*							
18/14-2P1	14	9-30-53	----	110	70	17	------	------	8.9	2.6	7.8	1.1	0	49	2.6	5.5	0.1	0.4	0.10	33	33	0	6.7
									.444	*.214*	*.339*	*.028*		*.803*	*.054*	*.155*	*.005*	*.006*					
12H1	71	6- 9-53	66	446	258	29.3	[1] 8.3	.71	40	12	12	1.2	0	154	2.1	62	.3	0	3.8	32	149	23	7.1
									1.996	*.987*	*1.391*	*.031*		*2.524*	*.044*	*1.749*	*.016*						

[1] Total iron.
[2] Spring.
[3] Analyzed by Brown and Caldwell, consulting engineers.
[4] Analysis by Pacific Pump and Supply Co.

MISCELLANEOUS STREAMFLOW MEASUREMENTS, MENDOCINO COUNTY

The miscellaneous streamflow measurements in table 16 were made for the purpose of estimating ground-water discharge from Round, Laytonville, and Little Lake Valleys. Current-meter measurements of outflow were made at sites described in the table. These sites were chosen near bedrock closures that force ground water to the surface and allow reliable measurements of outflow to be made.

Insofar as practicable, measurements made during a year were begun in late spring shortly after the last general rainstorms and were discontinued at the onset of the rainy season the following autumn.

TABLE 16.—*Miscellaneous streamflow measurements in Round, Laytonville, and Little Lake Valleys, Mendocino County, Calif.*

[Measurements by U.S. Geological Survey, Surface Water Branch]

ROUND VALLEY

Short Creek near Covelo, Calif.

[At mouth of canyon between prominent rock outcrops]

Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
1954		*1954*		*1954*	
May 11	5.27	July 15	0	Sept. 23	0
June 10	1.58	Aug. 12	0	Nov. 3	[1] 0
June 24	.51				

[1] Water in pools.

Mill Creek near Covelo, Calif.

[Near county road bridge near valley outlet, about 3½ miles southeast of Covelo]

Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
1952		*1952*		*1954*	
May 6	24.2	Oct. 25	0	May 11	23.6
May 20	13.7	Nov. 28	.05	June 10	5.89
June 4	4.10			June 24	2.61
June 19	3.43	*1953*		July 15	0
July 10	.60			Aug. 12	0
Aug. 11	.24	Sept. 17	0	Sept. 23	[1] 0
Aug. 27	0	Oct. 2	0	Nov. 4	[2] .02
Sept. 25	0	Oct. 14	0		
Oct. 12	0				

[1] Water in pools.
[2] Estimated.

LAYTONVILLE VALLEY

Long Valley Creek near Laytonville, Calif.

[About 80 ft upstream from U.S. Highway 101 bridge 5 miles south-southeast of Laytonville]

Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
1954		*1954*		*1954*	
May 13	0.86	July 14	[1] 0.01	Sept. 22	[1] 0.01
June 25	.12	Aug. 11	0	Nov. 2	[1] 0.01

[1] Estimated.

TABLE 16.—*Miscellaneous streamflow measurements in Round, Laytonville, and Little Lake Valleys, Mendocino County, Calif.*—Continued

[Measurements by U.S. Geological Survey, Surface Water Branch]

Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)

LAYTONVILLE VALLEY

Tenmile Creek at Laytonville, Calif.

[About 20 ft above creek ford on private road 0.8 mile west of Laytonville]

Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
1954		*1954*		*1954*	
May 13	7.98	July 14	.38	Sept. 22	.87
June 10	3.48	Aug. 11	0.13	Nov. 2	.87
June 25	1.11				

LITTLE LAKE VALLEY

Outlet (Deep) Creek near Willits, Calif.

[At bridge on U.S. Highway 101, 3½ miles north of Willits]

Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
1953		*1954*		*1954*	
July 2	1.20	May 11	22.4	Sept. 22	.49
Aug. 28	.74	June 9	25.6	Nov. 2	1.06
Sept. 18	.29	June 25	4.29		
Oct. 2	.24	July 14	1.49		
Oct. 21	1.38	Aug. 13	0		

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[Italic page numbers indicate major references]

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