GROUND-WATER RESOURCES IN MENDOCINO COUNTY, CALIFORNIA

By C. D. Farrar

U.S. GEOLOGICAL SURVEY

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[Plates are in pocket]

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CONVERSION FACTORS

The inch-pound system of units is used in this report. For those readers who prefer to use International System (SI) of Units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
acres	0.4047	square hectometers
acre-feet	0.001233	cubic hectometers
acre-feet per year (acre-ft/yr)	0.001233	cubic hectometers per annum
feet	0.3048	meters
gallons (gal)	3.785	cubic decimeters
gallons per day (gal/d)	3.785	cubic decimeters per day
gallons per minute (gal/min)	0.06309	cubic decimeters per second
gallons per minute per foot ((gal/min)/ft)	0.2070	meters squared per second
inches	25.4	millimeters
miles	1.609	kilometers
square miles (mi^2)	2.590	square kilometers

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ABSTRACT

Mendocino County includes about 3,500 square miles of coastal northern California. Ground water is the main source for municipal and individual domestic water systems and contributes significantly to irrigation.

Consolidated rocks of the Franciscan Complex are exposed over most of the county. The consolidated rocks are commonly dry and generally supply less than 5 gallons per minute of water to wells.

Unconsolidated fill in the inland valleys consists of gravel, sand, silt, and clay. Low permeability in the fill caused by fine grain size and poor sorting limits well yields to less than 50 gallons per minute in most areas; where the fill is better sorted, yields of 1,000 gallons per minute can be obtained. Storage-capacity estimates for the three largest basins are Ukiah Valley, 90,000 acre-feet; Little Lake Valley, 35,000 acre-feet; and Laytonville Valley, 14,000 acre-feet.

Abundant rainfall (35 to 56 inches per year) generally recharges these basins to capacity. Seasonal water-level fluctuations since the 1950's have been nearly constant, except during the 1976-77 drought.

Chemical quality of water in basement rocks and valley fill is generally acceptable for most uses. Some areas along fault zones yield water with high boron concentrations (>2 milligrams per liter). Sodium chloride water with dissolved-solids concentrations exceeding 1,000 milligrams per liter is found in deeper parts of Little Lake Valley.

INTRODUCTION

In 1979 the U.S. Geological Survey, the California Department of Water Resources, and Mendocino County began a cooperative study to better understand the ground-water resources of Mendocino County.

Mendocino County is experiencing a rapid population growth as a result of the increasing trend of many Californians to change their lifestyle to reflect a rural perspective. The county's population increased by about 30 percent during 1970-80 and is expected to increase by about 18 percent during 1980-85. Estimates of water use in the county show an increase of 62 percent for urban use and 12 percent for irrigation during 1972-80. In order to meet the future demand for water, Mendocino County planners have expressed the view that quantification, utilization, and possible conservation of ground-water resources will be necessary.

The County General Plan has been prepared to provide guidelines for orderly development in the county while recognizing the importance of valuable resources. The plan will be updated as pertinent information becomes available. The planners recognize the present need for more complete information on ground-water supply, especially in Ukiah Valley, Little Lake Valley (Willits area), Laytonville Valley, and along the coast of the county (fig. 1).

Collection of ground-water data has been minimal in Mendocino County during 1960-79. Periodic water-level measurements have been made at a few observation wells in some of the ground-water basins, but no recent comprehensive data-collection effort has been made to define current conditions in the basins.

The cooperative agreement between the U.S. Geological Survey, the California Department of Water Resources, and Mendocino County resulted in a plan to study individually specific high-interest areas. The Department of Water Resources took responsibility for studying and publishing reports for the coastal section of the county and for Anderson Valley. The coastal part of the ground-water study has been completed, and a report describing the findings of the study was published (California Department of Water Resources, 1982). The Anderson Valley study is near completion, and a report covering this area will be published. The U.S. Geological Survey has been responsible for studying and reporting on Ukiah, Little Lake, and Laytonville Valleys and the Leggett area; the study of these areas is the subject of this report.

Mendocino County provided assistance in these studies by contributing data on water wells and the quality of water, furnishing reports and documents concerning water issues and problems, and suggesting which parts of the county had the greatest need for water-resources assessment. The county also provided personnel to make water-level measurements in wells along the coast.

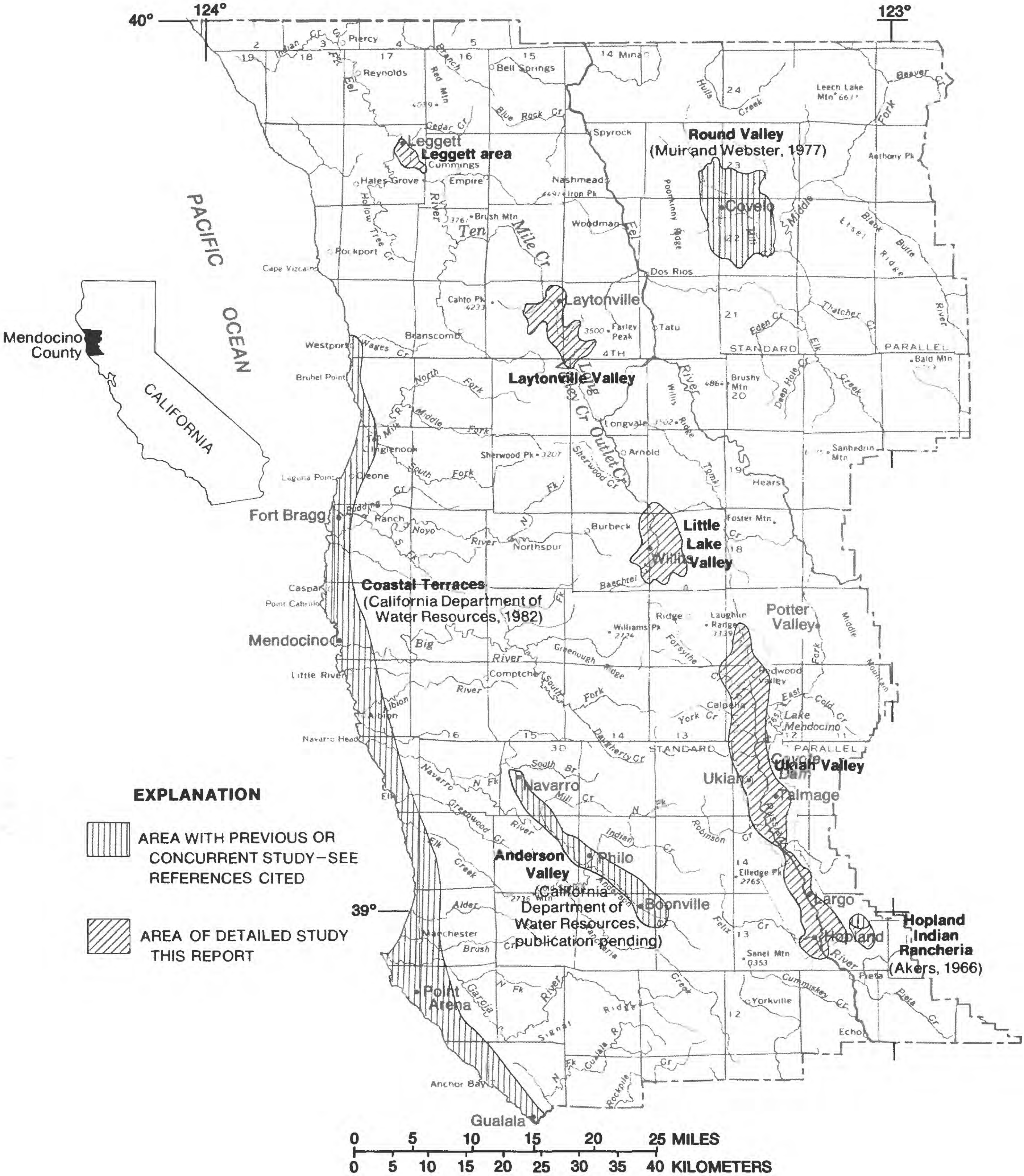


FIGURE 1. — Location of detailed study areas and location of areas previously studied.

Purpose and Scope

Availability of water is among the important factors determining future development in an area. County planners need an assessment of the resource potential of ground water in Mendocino County because ground water is the main source of domestic water, and it contributes significantly to irrigation. The purpose of this study was to determine the present status of ground-water conditions in Mendocino County.

This report emphasizes the ground-water resources in Ukiah Valley, Little Lake Valley, Laytonville Valley, and the Leggett area. The remainder of the county is discussed at a reconnaissance level in the section on "The Mountainous Areas." This report describes the occurrence and availability of ground water and its relation to the geology of Mendocino County. Data that characterize ground-water conditions are presented, and these data are interpreted in terms of resource potential. In addition, water-resources data from earlier investigations have been collated with data collected during field studies for this project to determine if significant changes in the ground-water system have been observed over the last few decades.

Previous and Concurrent Ground-Water Studies

Previous ground-water studies have been made of parts of Mendocino County by the U.S. Geological Survey and the California Department of Water Resources. A reconnaissance geological survey identifying valley-fill areas and a comprehensive survey of water wells to determine sanitary conditions and well-construction practices was made by the California Department of Water Resources (1958).

The Geological Survey, in cooperation with the California Department of Water Resources, prepared a report describing the fundamental geologic and hydrologic conditions in Round, Laytonville, Little Lake, Ukiah, and Potter Valleys (Cardwell, 1965).

Akers (1966) described the ground-water potential in a small area east of Hopland. Muir and Webster (1977) evaluated ground-water conditions in Round Valley. Ground-water resources in the coastal terraces of Mendocino County were described by the California Department of Water Resources (1982). A detailed study of water use and ground-water resources in the town of Mendocino was prepared by the California Department of Water Resources (1985). Anderson Valley is the subject area for a ground-water resource study nearing completion (1986) by the California Department of Water Resources.

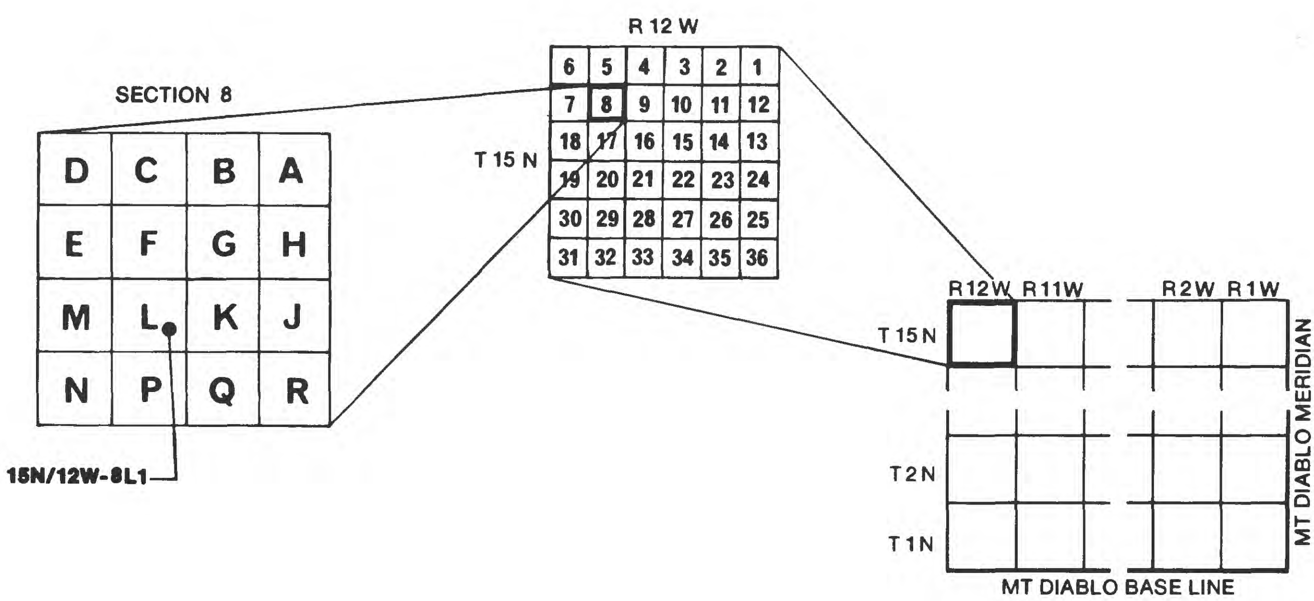
Acknowledgments

Much of the information in this report was taken from other sources. The work of earlier investigators (Cardwell, 1965; California Department of Water Resources, 1958; and California Department of Forestry, 1979) laid the foundation for this study and provided historical data.

The data-collection phase of this study was a success due to the cooperation of the many residents who allowed access to their land and wells and who provided information based on their own observations. Many individuals in county government, local water companies, and industries provided records of water levels, production, and other data. Jerry Davis, County Environmental Health, and Sari Sommarstrom, County Planning Department, were especially helpful in the early stages of this project by providing references, data, and insights into local water concerns.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for subdivision of public land. The part of the number preceding the slash, as in 15N/12W-8L1, indicates the township (T. 15 N.); the number following the slash indicates the range (R. 12 W.); the number following the hyphen indicates the section (sec. 8); and the letter following the section number (L) indicates the 40-acre subdivision of the section according to the lettered diagram below. Wells used routinely for observations by the California Department of Water Resources have a final sequence number following the lettered subdivision; wells used only during this study do not have sequence numbers. The township and range lines are based on the Mount Diablo base line and meridian.



Description of Area

Physical Setting

Mendocino County occupies approximately 3,500 mi^2 along the coast of northern California (fig. 1). The county extends south to north for approximately 80 miles from about 38°45' to 40°00' north latitude and ranges from about 35 to 60 miles in width. About 130 miles of the Pacific Ocean coastline forms the western boundary.

Flat-lying terraces, up to a few hundred feet in altitude, occupy a strip of land extending from the Pacific Ocean to 1 to 6 miles inland. The remainder of the county is mostly rugged mountainous terrain with a maximum altitude of 6,963 feet on Anthony Peak in the northeast part of the county. Within the mountainous terrain are isolated small valleys lying along major drainage systems. The valley floors range from about 500 to 2,000 feet in altitude and are bounded by mountains with 1,000 to 2,000 feet of local relief.

Three major surface-water drainage systems can be defined: the coastal, the Eel River, and the Russian River systems (fig. 2). The coastal drainage system consists of several relatively short streams flowing east to west that drain the western mountains and empty directly into the Pacific Ocean. The interior part of the county is drained by the two larger drainage systems--the Eel River and the Russian River systems; only parts of these drainage systems lie within the county. The headwaters of the South Fork Eel River and parts of the Middle Fork lie within the county; this system drains the northern interior. The headwaters of the Russian River lie near the middle of the county, and the Russian River drains the southern part of the county's interior.

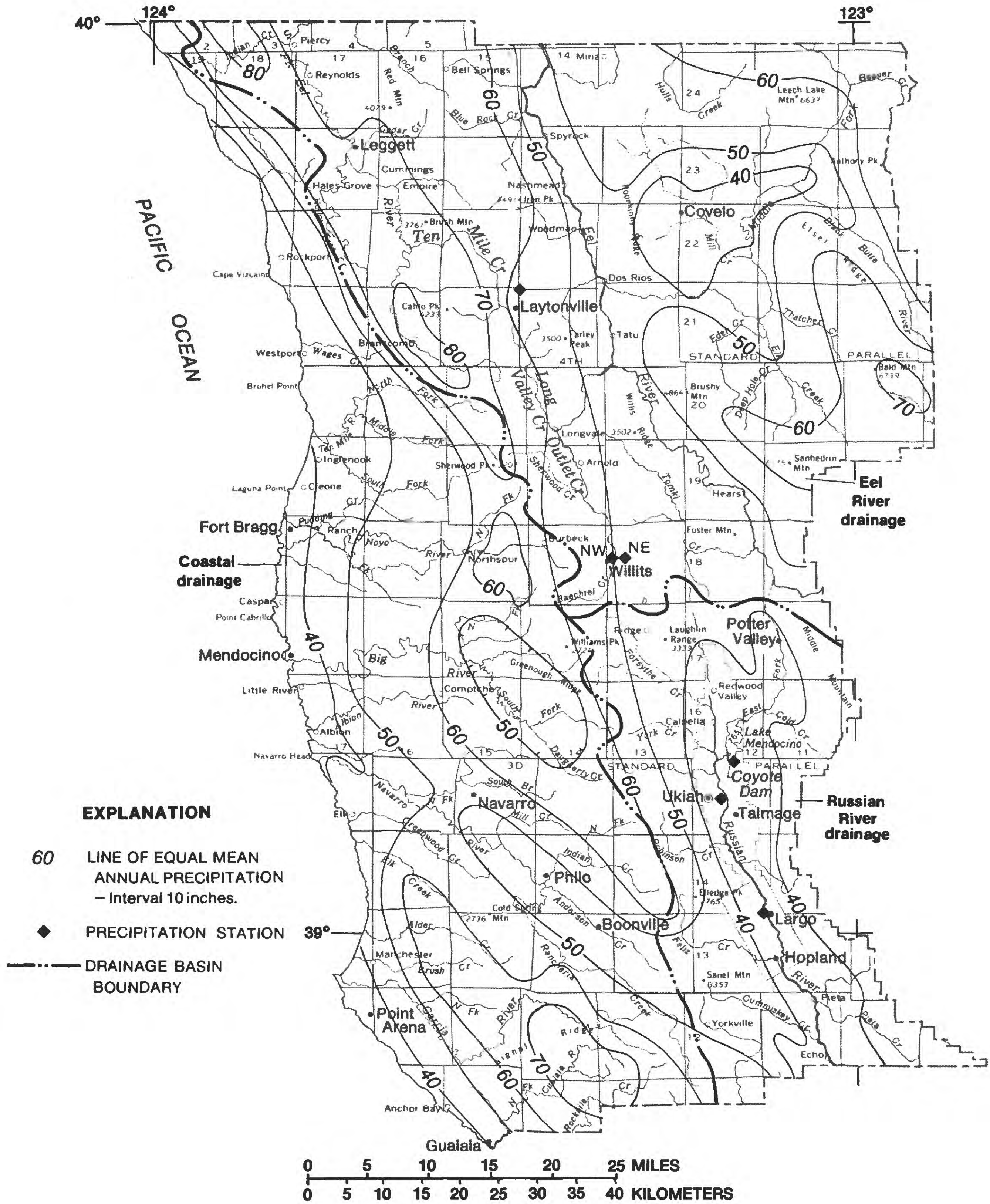


FIGURE 2. – Distribution of mean annual precipitation and boundaries of drainage systems, Mendocino County. (Modified from Rantz, 1968)

Climate

The climate is mild mediterranean, although considerable variation exists between coastal and inland locations. Temperatures along the coast, moderated by the Pacific Ocean, tend to be warmer in winter and cooler in summer than temperatures in inland areas (table 1). Most precipitation in Mendocino County falls as rain rather than snow. Minor accumulations of snow do occur, generally each winter, on the areas of higher elevation.

Mean annual rainfall in the county ranges from less than 40 inches along the coast to more than 80 inches on the higher mountains inland (fig. 2). Most of the rain falls during the months of October through April, with December, January, and February accounting for more than one-half of the total (table 2).

Published rainfall records (California Department of Water Resources, 1981) provide data from 1877 to 1980. These historic records show that marked variations in annual rainfall are common. From published records, the highest recorded rainfall was 92.90 inches at Laytonville in 1974, and the lowest was 13.09 inches at Ukiah in 1924. Records for Ukiah show that 60.97 inches of rain fell in 1890, and the next year only 25.29 inches fell. Similarly, 16.12 inches of rain fell in 1977, and 52.47 inches fell in 1978 (fig. 3). These drastic changes in rainfall from year to year are not unusual and demonstrate the need for considering rainfall over a period of several years before proclaiming drought or surplus conditions. More current data are available from the National Oceanic and Atmospheric Administration.

Fog is a common occurrence in the county, especially along the coast and in the inland valleys. Moisture from the fog is significant and is an important water source for native vegetation during the summer season.

Table 1.-- Air temperature, in degrees Fahrenheit, for selected stations in Mendocino County

[Data from National Oceanic and Atmospheric Administration]

Station	Mean			Extreme		Years of record
	January	July	Annual	Lowest	Highest	
Fort Bragg-----	47.9	56.5	52.9	24	90	47
Potter Valley--	44.7	73.6	58.2	14	111	39
Ukiah----------	46.0	73.7	59.2	12	114	88
Willits--------	45.0	70.5	54.2	--	--	21

Table 2.-- Rainfall, in inches, for selected stations, Mendocino County

[Locations shown in figure 2. Data from California Department of Water Resources, 1981]

Station and period of record	Monthly mean												Annual		
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Low	Mean	High
Coyote Dam 1964-80 altitude 720 feet.	1.70	5.21	7.28	8.10	5.27	4.30	2.38	0.45	0.17	0.08	0.27	0.44	17.39	35.56	51.09
Hopland-Largo 1948-69 altitude 550 feet.	2.07	4.83	6.86	8.01	5.79	4.21	2.45	.85	.37	.02	.13	.44	24.87	35.90	58.18
Laytonville 1941-78 altitude 1,640 feet.	3.75	7.73	10.64	12.21	8.22	6.79	3.48	1.43	.41	.10	.41	.78	25.00	56.02	92.90
Ukiah 1877-1980 altitude 623 feet.	1.83	4.38	6.94	7.97	6.17	4.62	2.38	1.03	.32	.04	.06	.46	13.09	36.27	60.97
Willits, NW (PAC RR) 1911-69 altitude 1,365 feet.	2.69	6.47	9.28	9.83	8.31	5.47	3.22	1.39	.41	.03	.09	.49	17.16	47.91	92.82
Willits, NE 1957-80 altitude 1,350 feet.	3.34	7.19	9.16	11.16	8.09	7.15	3.23	1.14	.16	.08	.31	.61	17.57	50.06	76.39

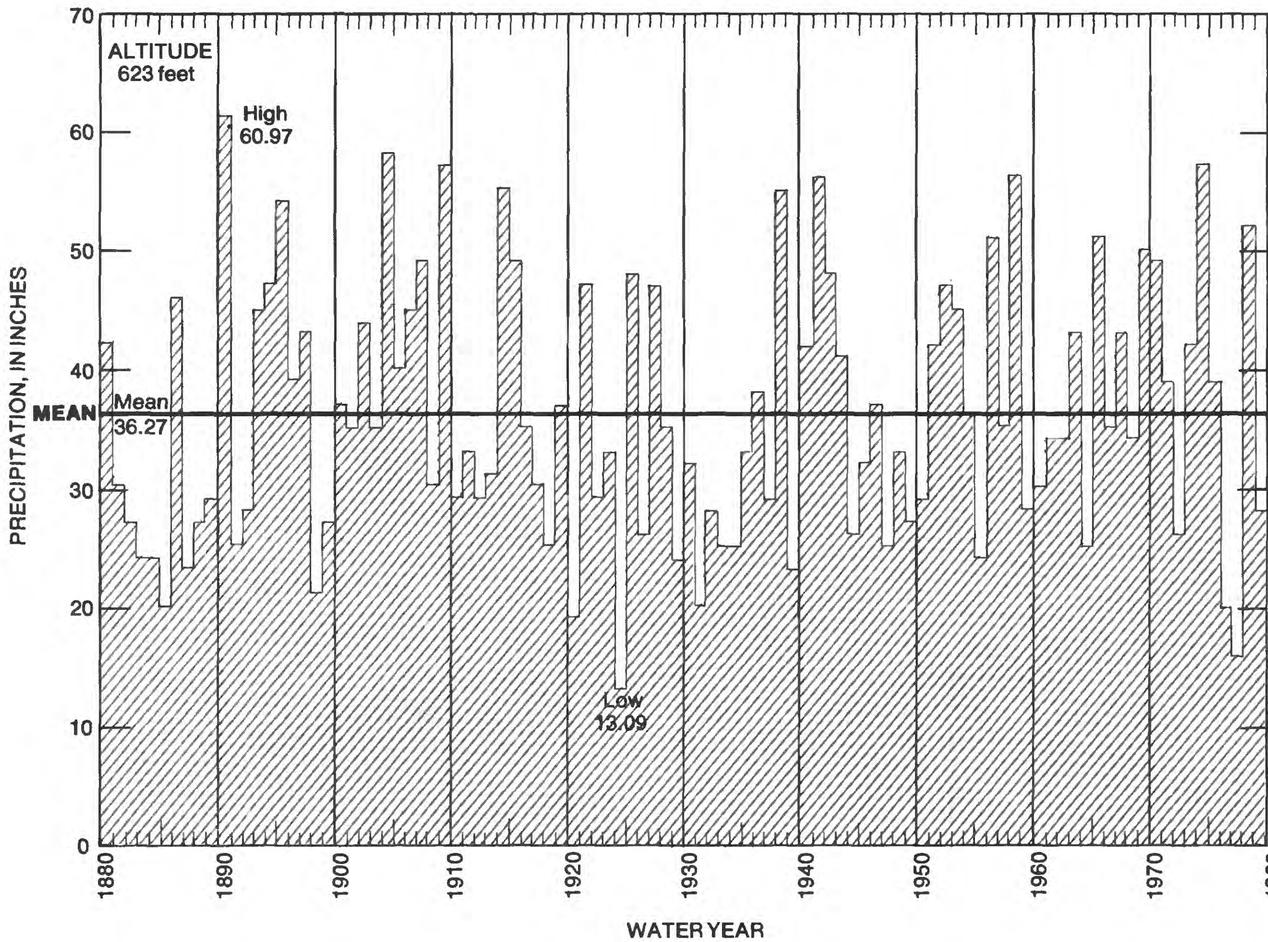


FIGURE 3. – Annual precipitation at Ukiah, water years 1880-1979. (Data from California Department of Water Resources, 1981; values rounded to nearest inch)

Cultural Development

The population of Mendocino County was shown as 66,738 in the 1980 census. About one-third of the population (21,487 people) lived in the four incorporated communities of Fort Bragg, Point Arena, Ukiah, and Willits. Most of the remainder of the population resided in small communities along the coast and in the unincorporated areas of the inland valleys; the mountainous areas were very sparsely settled.

Major economic activities in the area include forestry, fishing, agriculture, tourism, and manufacturing. Manufacturing, primarily related to lumber products, employs about 30 percent of the work force. Chief agricultural crops are wine grapes, fruits, and nuts.

GEOLOGY

Geologic Setting

Mendocino County lies within the Coast Ranges geomorphic province. The Coast Ranges comprise a group of mountain ranges extending 600 miles, from Santa Barbara County to the Oregon border, and ranging from a few to 70 miles in east-west dimension. The Coast Ranges lie between the Central Valley and the Pacific Coast and trend northwest, roughly paralleling the Sierra Nevada on the opposite side of the Central Valley. The northwest trend is seen in numerous elongate ranges and valleys and in the linear geologic structures of this complex province.

Mendocino County is mostly within that part of the Coast Ranges known as the Mendocino Range. This range is underlain almost entirely by rocks of the Franciscan Complex. The Franciscan Complex, the geomorphic features, and the geologic structures in the Coast Ranges are largely the result of global-scale crustal movements (plate tectonics) that involved the underthrusting and subduction of the Pacific oceanic plate beneath the continental margin of Western North America (Bailey and others, 1970). During Mesozoic time, an oceanic trench paralleling the coast marked the zone along which the overlapping of the plates occurred; this was the site of accumulation of the tectonically mixed sediments, which were later uplifted to form the mountainous terrain of the Franciscan Complex.

Geologic Units

The geologic units exposed at the surface can be divided into two major groups--basement rocks and valley fill. For this report, the term "basement rocks" includes all the rocks of pre-Pliocene age; "valley fill" refers to geologic units of Quaternary age or those that span Tertiary and Quaternary age. The geologic units discussed in this report include those that lie east of the coastal terraces and east of the San Andreas fault (fig. 4). Not including the thin mantle of soil locally concealing geologic units, about 95 percent of surface exposures consist of basement rocks. The valley fill is confined to small basins along major stream courses and thin alluvium in stream channels.

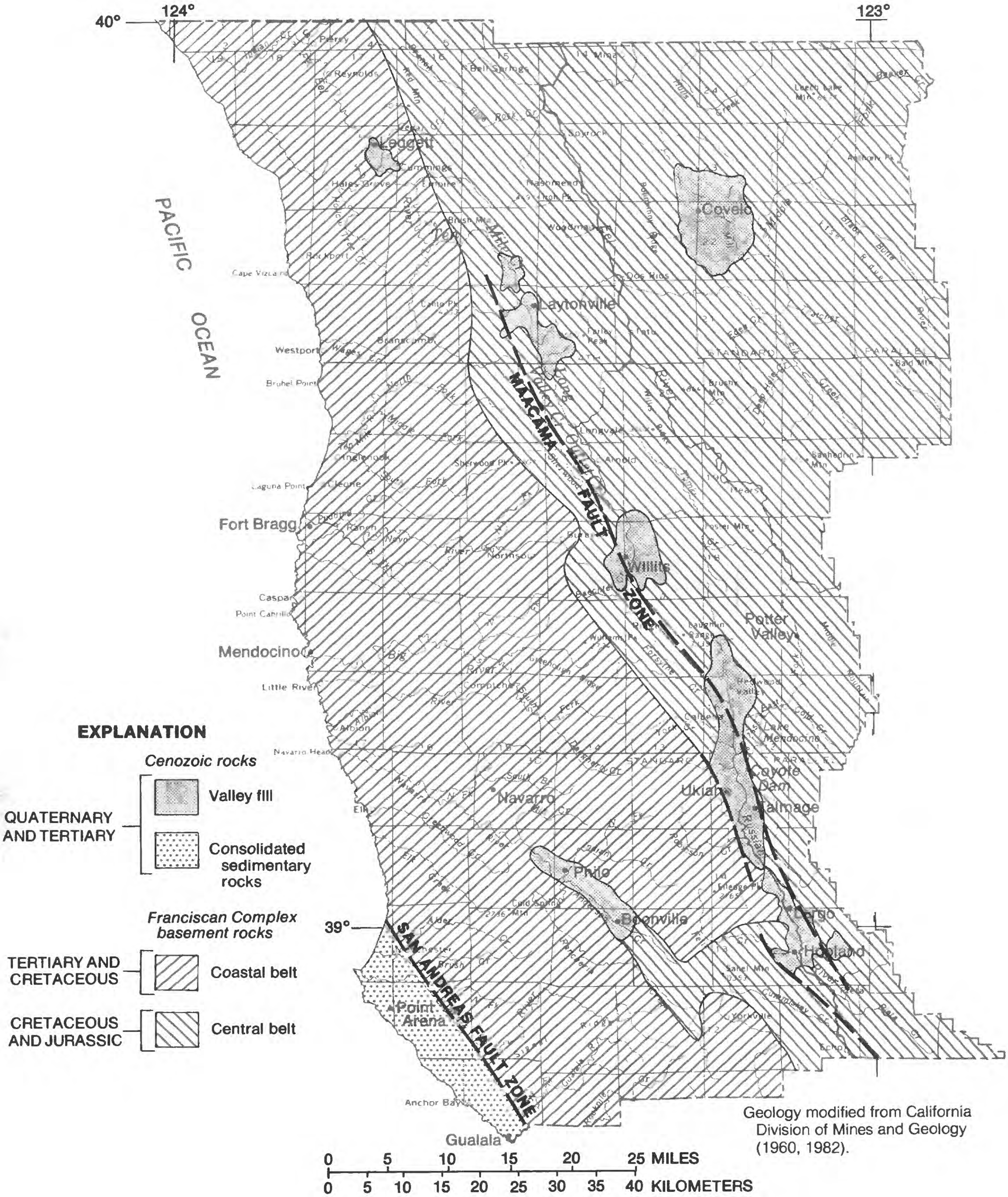


FIGURE 4. — Generalized geology of Mendocino County.

Basement Rocks

The basement rocks consist of rocks of the Franciscan Complex, a few small patches of rocks of the Great Valley sequence superimposed on the Franciscan, and outcrops of upper Tertiary sedimentary rocks. The incorporation of Great Valley rocks into the Franciscan terrane may have resulted from thrust faulting, gravity sliding, or original deposition (Maxwell, 1974). For this report, the two units are undifferentiated because of the minor presence of Great Valley rocks and their geohydrologic similarity to some of the lithologic units of the Franciscan. Upper Tertiary sedimentary rocks crop out in two areas, west of Piercy and southwest of Covelo. These rocks are present only in small areas and are not considered further in this report.

The basement rocks as defined above underlie the entire county, with the exception of the small sliver of land west of the San Andreas fault. The thickness of the basement rocks is unknown because of the complex structural relation with adjacent geologic units; however, it is estimated to be about 50,000 feet (Bailey and others, 1970).

The Franciscan Complex is a structural complex and a rock stratigraphic unit consisting of a structural aggregation of intact blocks of bedded sedimentary rocks in a faulted and sheared matrix of melange and broken formations. It has been subdivided into three major northwest-trending subparallel belts named, from west to east, the Coastal belt, Central belt and Yolla Bolly belt (Blake and Jones, 1981). In this report the Franciscan Complex is subdivided into Coastal-belt and Central-belt rocks. Rocks of the Yolla Bolly belt lie mostly east of the county; the few isolated outcrops within the Central belt are not differentiated.

Coastal-belt rocks of Cretaceous and Tertiary age lie mostly west of a line coinciding with U.S. Highway 101 and occupy about one-half of the county; Central-belt rocks cover the rest of the county. The Coastal-belt rocks consist of graywacke, mudstone, and minor conglomerate. These lithologic units contain abundant mica and potassium feldspar; low-grade metamorphism to the zeolite facies is found locally. Coastal-belt rocks are less deformed than Central-belt rocks. In places the Coastal belt includes undeformed blocks of graywacke in a highly sheared matrix of mudstone, but the Coastal belt is characterized generally by coherent rock units with a predominantly homoclinal structure striking northwest and dipping northeast under the Central-belt rocks.

The Central belt of Jurassic and Cretaceous age is a melange (Hsu, 1968; Fox, 1983a) consisting of a matrix of highly sheared graywacke and mudstone enclosing coherent blocks of graywacke, chert, greenstone, serpentine, blueschist, and limestone. Although the mudstone matrix is easily eroded, the coherent blocks are resistant to erosion. This results in a characteristic topography of resistant knobs, house-sized to boulder-sized, projecting through the hummocky hillsides. The grass-covered sheared mudstone units are unable to support dense stands of trees due to the unstable ground moving downslope by creep and debris flows.

Valley Fill

Valley fill refers to the unconsolidated to loosely cemented gravel, sand, silt, and clay deposited in the major valleys. The valley fill was deposited in topographically separated structural basins. As a consequence, the units are correlative from one basin to another but are not continuous between basins.

In this report the fill is subdivided into three distinct units--continental basin deposits, continental terrace deposits, and Holocene alluvium, based on the geologic age and origin of the units. The distinctive geologic attributes of each unit result in differences in water-bearing properties significant to this study.

The discussion of the valley-fill units presented here emphasizes the general lithologic characteristics of each and the geologic relations among the units. Not all units are present in each of the valleys studied. Specific discussion of units present in each valley and the water-bearing characteristics of each are presented later in this report under the heading "Ground-Water Conditions."

Continental basin deposits.--The oldest and stratigraphically lowest unit of the valley fill, this unit was deposited directly on the basement rocks in structural basins during late Pliocene and Pleistocene time. A schematic section of Ukiah Valley (fig. 5) shows stratigraphic relations. Lithologically, the continental basin deposits comprise a heterogeneous mixture of loosely cemented gravel, sand, silt, and clay. Bedding ranges from massive to thin. The lateral extent of individual beds is generally small for the coarse-grained material and larger for fine-grained materials. Beds of sand and gravel are typically lenticular and interfinger with beds above and below. From studies of structural basins 30 miles south of Ukiah by McLaughlin and Nilsen (1982), the origin of this unit may be inferred. The highly erodible Franciscan Complex provided material for landslides and debris flows, which built fans and talus slopes around the valley margins. Braided streams flowed across the fans and deposited sediments as they meandered out onto the valley floor. Each valley was partly occupied by a lake around which deltas were built by the inflowing streams. These sedimentary processes combined to produce and leave behind a highly complex distribution of gravel, sand, silt, and clay.

Deposition of the continental basin deposits began about 3 to 4 million years ago and continued until at least 0.45 million years ago (McLaughlin and Nilson, 1982). Since that time minor deformation of these beds has occurred, resulting from regional tectonics and movement along faults. In some outcrops at the margins of the valleys, beds are tilted as much as 10° from horizontal.

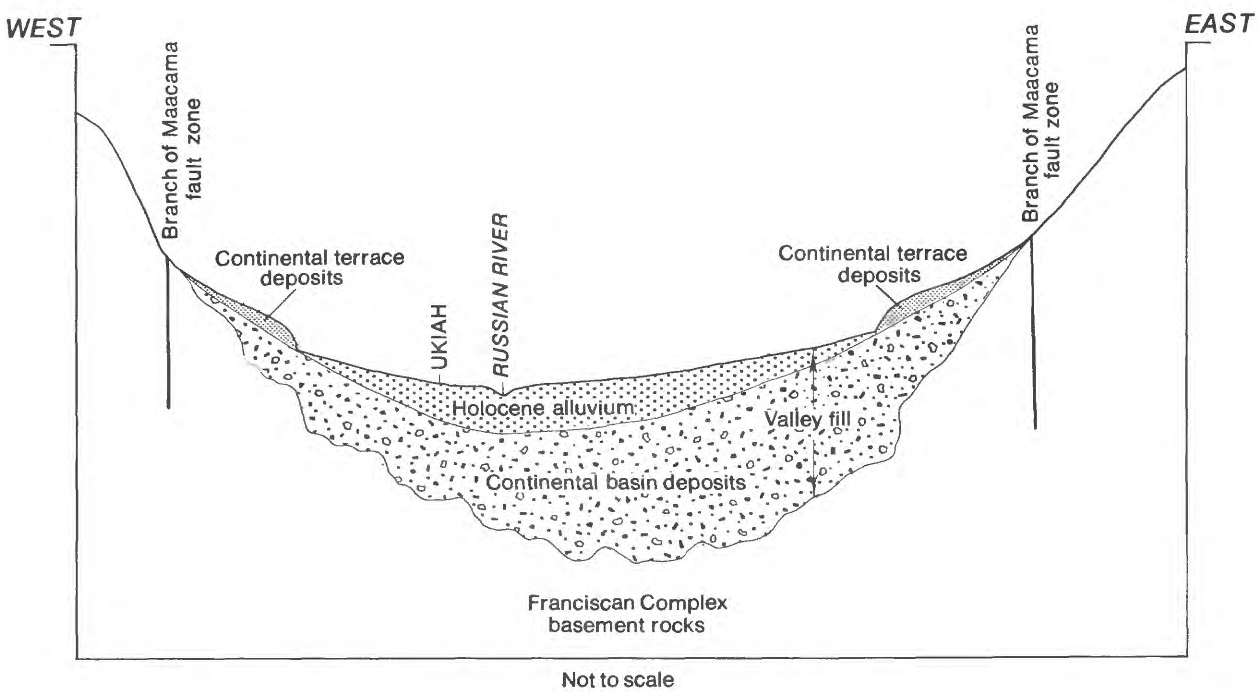


FIGURE 5. – Generalized geologic section of Ukiah Valley.

Continental terrace deposits.--The partially-to-loosely cemented beds of gravel, sand, silt, and clay underlying elevated terraces along the margins of Laytonville and Hopland-Ukiah Valleys compose the continental terrace deposits. Lithologically these deposits are similar to the underlying continental basin deposits (fig. 5); however, this unit generally contains less silt and clay. The terrace deposits are identified in part by their geomorphic expression--long, narrow, elevated, gently inclined surfaces formed by aggradation of eroded materials.

The continental terrace deposits comprise the materials deposited by streams draining the area during Pleistocene time. Downslope movement along the valley margins supplied Franciscan-derived sediment to streams that eroded and deposited material by processes similar to those active today along modern streams draining the valleys.

The fluvial origin resulted in lithologic heterogeneity of these deposits. Beds within the terrace deposits tend to be lens-shaped, laterally interfingering with neighboring beds. At depth, coarse- and fine-grained materials alternate as a result of changing hydraulic conditions at the time of deposition.

In this report the terrace deposits in parts of Ukiah Valley have been subdivided into older and younger terrace deposits, based on geomorphology. Where terraces of two distinct elevations are present, the higher terraces, generally nearest the valley margins, are considered to have formed earlier than the terraces at lower elevations.

The older terrace deposits tend to be more dissected than the younger terrace deposits and form a veneer of reddish-brown gravelly and sandy silt and clay generally less than 10 feet thick. The younger terrace deposits underlie less dissected terraces and have accumulated to thicknesses of several tens of feet.

Holocene alluvium.--The gravel, sand, silt, and clay deposited along stream channels and on flood plains during approximately the last 10,000 years compose the Holocene alluvium. The Holocene alluvium is present in all major valleys of the county and in many minor valleys along stream courses throughout the county. Appreciable thicknesses of alluvium, however, are found only in those areas with valley fill shown in figure 4. Because of its young age, the alluvium is generally uncemented and less weathered than the older valley-fill units.

In some areas along stream courses the alluvium is being reworked; deposition or erosion predominates depending on hydraulic and geologic conditions. Particle size of alluvium tends to be largest along the axis of a stream and becomes finer on the flood plain as distance from the stream axis increases. Because of the dynamic nature of stream channels, however, the alluvium in any location tends to be heterogeneous with depth due to the lateral shifting of main channels and flood plains.

In the major structural valleys the alluvium overlies either basement rocks or continental basin deposits. The alluvium is generally less than a few tens of feet thick but may exceed 100 feet in places. The material deposited is derived mostly from rocks of the Franciscan Complex, but both the continental terrace deposits and continental basin deposits contribute material as well.

Geologic Structures

Major geologic structures in Mendocino County have a predominant northwest to north-northwest trend. This trend is followed by topographic features and stream courses throughout much of coastal California from Santa Barbara northward and is related to geologic processes that affected the entire western continental margin of North America.

The courses of both the Eel and the Russian Rivers are controlled by the north-northwest trending structural grain. The main inland valleys (fig. 4) are also aligned along the north-northwest trending line. The long axis of Anderson Valley follows a northwest trend, approximately parallel with the San Andreas fault.

Within this regional setting of northwest to north-northwest structure, much of the area shows chaotic structure. Many road cuts around the county expose rocks that appear quite disrupted and with little lateral continuity. Often beds of rock are buckled and broken so they dip at various angles within one road cut.

The chaotic structure makes geologic mapping in the county extremely difficult. Generalized maps such as figure 4 can be produced emphasizing the regional geology. On the other hand, very detailed geologic maps can be produced for areas with good rock exposures, but the greatest part of the county is covered by soil and dense forest with poor rock exposures. Because of the chaotic structure, the areas lacking exposures can not be mapped with a high degree of detail or confidence.

Faults

Mendocino County occupies an area that has been subjected to a long history of compressional forces and related northwest-southeast translational movements. The translational movements have taken place along two major fault zones in the county (fig. 4). Numerous faults of lesser displacement or with more obscure surface manifestation exist throughout the county.

San Andreas fault.--The San Andreas fault is widely known due to the damaging earthquakes it has produced during historic time; its surface trace runs northwest across the extreme southwestern part of Mendocino County. The San Andreas fault is a major structural discontinuity along which the rocks on the southwest side have been displaced northwestward relative to rocks on the opposite side of the fault.

The San Andreas fault, shown as a single dashed line in figure 4, is actually a zone of en echelon faults. The individual fault-breaks trend parallel or subparallel to one another and respond to crustal stresses with similar displacement actions. Horizontal surface displacements of as much as 15 feet occurred near Point Arena in 1906 (Fox, 1983b). This segment of the fault is still considered active although there has been no measured displacement along it since 1906 (Brown and Wolfe, 1973).

Maacama fault.--The Maacama fault trends northwest through the central part of the county. Like the San Andreas, the Maacama fault is actually a zone of parallel or subparallel en echelon breaks with right-lateral displacement. As shown in figure 4, the Maacama fault can be seen to pass through or border the structural basins containing valley fill in the Ukiah, Willits, and Laytonville areas, and is related to their formation. The Maacama is an active fault zone--as attested by earthquakes centered near Willits during recent years (Simon and others, 1978).

Structural Basins

Ukiah, Little Lake, and Laytonville Valleys all are present along the trend of the Maacama fault zone. This relation is not merely coincidental; rather, the basins were created by oblique pull-apart extension between en echelon and minor branching faults of the Maacama fault zone (McLaughlin and Nilsen, 1982). The right-lateral strike-slip movement along parallel fault segments results in a wrenching apart and downdropping of the intervening crustal block. The grabens thus formed are bounded by faults on all sides. Sedimentation begins in-filling at the onset of basin formation and continues concurrent with the further down-dropping of the graben. In this way a considerable thickness of valley fill may be deposited without changing the base level of erosion.

Studies of regional tectonics (Blake and others, 1978) have demonstrated that the development of pull-apart basins in the Coast Ranges has propagated northward over time. This suggests that within Mendocino County the Ukiah Valley basin began forming first and was followed by Little Lake Valley and then Laytonville Valley. The basins began developing less than 4 million years ago and may have been undergoing subsidence until less than 0.5 million years ago.

GROUND-WATER CONDITIONS

Ukiah Valley

Description of Area

Ukiah Valley, the largest of the interior valleys, is located in the south-eastern part of the county. It occupies an area about 30 miles long and 4 to 6 miles wide along the course of the Russian River from near its headwaters to south of Hopland. The Hopland area, also known as Sanel Valley, lies at the southern end of Ukiah Valley. This area is separated from the main part of the valley by low hills, about 4 miles north of Hopland, through which the Russian River has cut a narrow gorge. Except for stream-gravel deposits this narrow gorge contains no valley fill. Hopland Valley is included as part of Ukiah Valley in this report because of the proximity of the valleys and because both areas contain similar geologic units.

Main population centers include the incorporated city of Ukiah in the central part of the valley and, from north to south, the smaller communities of Redwood Valley, Calpella, Talmage, Hopland, and Old Hopland. These communities are served by municipal and community water systems that obtain water from wells; surplus water from Lake Mendocino augments the water supply for Redwood Valley.

Residents living in rural parts of the valley obtain their water from private domestic wells. Irrigation water is obtained from wells and from direct pumping from the Russian River and its tributaries.

Lake Mendocino, 4 miles northeast of Ukiah, stores a maximum of 122,500 acre-ft. Eight thousand acre-ft of this water is currently appropriated for supply to the Flood Control and Water Conservation Improvement District. The Sonoma County Water Agency (SCWA) has established water rights for diversion of 37,544 acre-ft annually, part of which is contracted for use in Marin County. Recently the SCWA has petitioned the State of California to increase its appropriation to 75,000 acre-ft per year.

Water-Bearing Formations

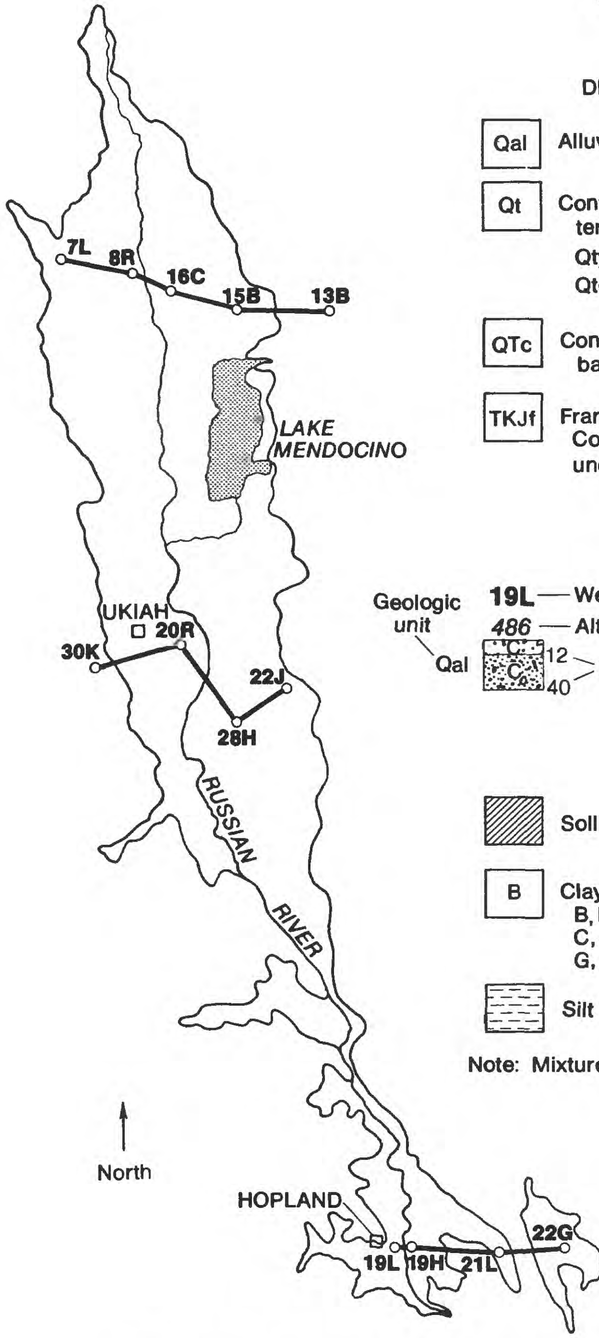
Valley fill occupies about 70 mi^2 in Ukiah Valley. The fill has been subdivided into continental basin deposits, continental terrace deposits, and Holocene alluvium (pl. 1).

Continental basin deposits.--Continental basin deposits crop out over about 20 mi^2 of the valley floor. Surface exposures are widespread over the northern part of the valley and along the east side of the valley from Lake Mendocino to about 5 miles north of Hopland. About 2 mi^2 of exposures is present east of Hopland. These deposits also underlie younger valley-fill units and, where not exposed at the surface, probably are present at depth throughout most of the remaining area of valley fill (figs. 5 and 6).

Thickness ranges from 0 feet along the valley margins to an estimated maximum of 2,000 feet near the axis of the valley. The estimate of maximum thickness is based on stratigraphic analysis of outcrops. No wells have penetrated the full thickness of valley fill in the Ukiah area. The deepest well completed, 15N/12W-20R, penetrated about 500 feet of continental basin deposits.

These deposits consist of poorly sorted, heterogeneous mixtures of gravel, sand, silt, and clay. Drillers' logs show clay to be the most abundant constituent of this unit (fig. 6). The clay occurs both as beds, as much as several tens of feet thick, and as interstitial material between coarser grains of sand and gravel. The high clay content and poor sorting result in low permeability in this unit. The small average grain size and lack of cementing, however, provide high porosity. Because permeable materials are interbedded with impermeable clays, ground water occurs under confined conditions.

EXPLANATION FOR FIGURE 6



UKIAH-HOPLAND VALLEY — Outline of valley fill and locations of wells used for lithologic sections

DESCRIPTION OF GEOLOGIC UNITS

Qal	Alluvium	Holocene	Quaternary
Qt	Continental terrace deposits Qty-younger Qto-older	Pleistocene	Quaternary
QTc	Continental basin deposits	Pleistocene and Pliocene	Quaternary and Tertiary
		Unconformity	
TKJf	Franciscan Complex, undifferentiated		Tertiary, Cretaceous, and Jurassic

DESCRIPTION OF LITHOLOGY

Geologic unit — Qal

19L — Well number

486 — Altitude of land surface, in feet above sea level

12, 40 — Depth to corresponding changes in lithology, in feet below land surface

Lithologic units

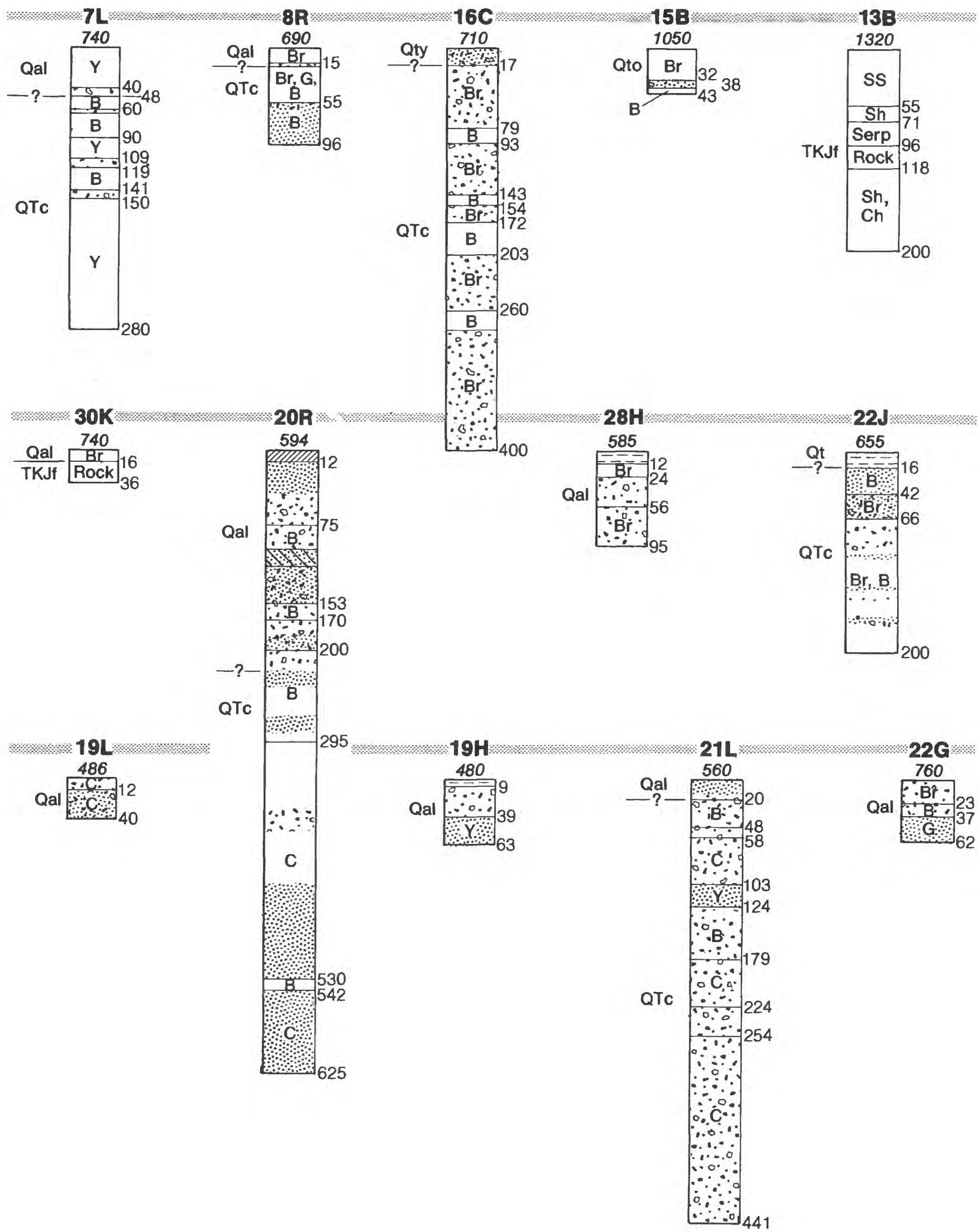
- Soil
- B — Clay; letter indicates color; B, blue; Br, brown; C, color not specified; G, grey; Y-yellow
- Silt
- Sand, crosshatching indicates cemented
- Gravel
- Rock — SS-sandstone, Sh-shale, Serp-serpentine, Ch-chert, Rock — unspecified

Note: Mixtures of these materials are shown as combinations of symbols

LINE OF SECTION

19L — WELL AND NUMBER

FIGURE 6 — Well-log profiles, Ukiah Valley.


7L
740
Qal
Y
B
B
Y
B
Y
QTc
40
48
60
90
109
119
141
150
280
8R
690
Qal
QTc
Br
Br, G, B
B
15
55
96
16C
710
Qty
QTc
Br
B
Br
B
Br
B
Br
B
Br
17
79
93
143
154
172
203
260
400
15B
1050
Qto
Br
B
32
38
43
13B
1320
TKJf
SS
Sh
Serp
Rock
Sh, Ch
55
71
96
118
200
30K
740
Qal
TKJf
Br
Rock
16
36
20R
594
Qal
QTc
B
B
B
C
B
C
12
75
153
170
200
295
530
542
625
28H
585
Qal
Br
Br
12
24
56
95
22J
655
Qt
QTc
B
Br
Br, B
16
42
66
200
19L
486
Qal
C
C
12
40
19H
480
Qal
Y
9
39
63
21L
560
Qal
QTc
B
C
Y
B
C
C
20
48
58
103
124
179
224
254
441
22G
760
Qal
Br
B
G
23
37
62

Wells completed in the continental deposits produce water slowly because of the fine-grained material and consequent low permeability. Information available for 30 wells tapping continental deposits shows a range in yield of 0.75 to 50 gal/min. Specific capacities range from 0.004 to 1.33 (gal/min)/ft. Dry holes are commonly encountered. The following tabulation for 30 wells shows no clear relation between well depth and yield:

Well depth, in feet	Number wells	Yield (gal/min)	Specific capacity (gal/min)/ft
0-100	7	0.75-50	0.027-1.25
101-200	14	2.5 -40	.044-1.33
201-300	5	1 -20	.004-0.14
Greater than 300	4	1.25-20	.10 -0.44

These data are taken from short-term pumping tests, generally 2 hours or less, and the yields listed may overestimate the long-term yield available.

The quantity of water supplied to wells depends in part upon the total thickness of coarse materials penetrated. While deep wells do have a better chance of encountering a greater thickness of coarse material, some reduction in permeability probably occurs with depth due to compaction and cementation. Drilling deeper at any particular location does not guarantee obtaining a significantly greater yield. Instead of drilling deeper than 200 feet to increase well yield, often it may be more economical to choose a new site for drilling where permeable beds occur at more shallow depths.

In summary, this unit is large in areal extent, is generally thick, is high in porosity, and stores a large quantity of water--but because it is low in permeability, it yields water slowly to wells.

Continental terrace deposits.--Continental terrace deposits occupy about 20 mi^2 of valley floor. Surface exposures are observed in the northern part of the valley, along the west side in the vicinity of Ukiah, and along the east side near Talmage. A few small exposures occur around Morrison Creek and to the south. The terrace deposits are subdivided into older and younger based on their topographic expression and degree of dissection.

The older terrace deposits are exposed mostly in the northern part of the area around Redwood Valley. The older terrace deposits range from zero at the valley margins to a maximum thickness of 25 feet. Generally, this unit is present only as a few feet of reddish-brown gravelly-to-sandy soil. Because it is thin, the unit is generally unsaturated during summer and autumn and therefore cannot be considered an important source of water.

The younger terrace deposits crop out discontinuously along both sides of the valley from Redwood Valley to near Morrison Creek. Less affected by erosion, the younger terraces are thicker than the older terraces, and their original topographic form is better preserved. The younger terraces consist of gravel and sand, with silt and clay filling the intergranular spaces. This unit is of low-to-moderate permeability. The maximum thickness is difficult to estimate because it is generally not possible to distinguish this unit from the underlying continental basin deposits on drillers' logs. However, maximum thickness may reach 100 feet or more. In general, these deposits are partially saturated during all or part of the year.

The younger terrace deposits are not considered a major ground-water source because they are relatively thin and have low permeability. Wells completed in younger terrace deposits may provide enough water for low-capacity domestic or stock-watering wells. Many wells on terraces are drilled deep enough to obtain part of their water from the underlying continental basin deposits.

Wells completed in terrace deposits generally yield from 1 to 10 gal/min; yields as high as 100 gal/min have been reported. These values are based on short-term pump tests that may overestimate the long-term yield. Seasonal fluctuations in the water table can drastically affect the rate at which water can be withdrawn from shallow wells. Specific capacities calculated for 25 wells tapping the terraces range from 0.02 to 7.1 (gal/min)/ft. Of these wells, 17 had specific capacities of less than 1.0 (gal/min)/ft, and only 4 had specific capacities greater than 2.0 (gal/min)/ft.

<u>Holocene alluvium.</u>--Alluvial deposits of Holocene age cover about 30 mi^2 of the valley floor. The alluvium is distributed as narrow bands along tributary streams and along the Russian River north of The Forks. The alluvium occupies broad areas of the flood plain, as much as 2 miles wide, in the Ukiah-Talmage and Hopland areas.

The alluvium of uncemented gravel, sand, silt, and clay varies in thickness from place to place. The thickest sections occur along the course of the Russian River. Exact thicknesses are difficult to ascertain because the underlying basin deposits cannot be distinguished from the alluvium based on the descriptions given on many well logs. Although the maximum thickness is probably about 200 feet, the thickness is generally less than 100 feet.

Porosity and permeability are high because the alluvium generally consists of uncemented coarse-grained material. The low topographic position of this unit generally insures that it is partially saturated throughout the year. Where thin, as near valley margins or along tributary streams, the alluvium may not contain water during dry months.

The alluvium is the most productive aquifer in Ukiah Valley and can provide sufficient water for sustained pumpage from municipal and irrigation wells. Properly constructed wells in favorable locations could yield 1,000 gal/min or more. Areas of known high-production capacities exist east of the Russian River and south of Talmage near Howell Creek, where wells yielding more than 1,000 gal/min have been completed. A second area of high-capacity wells is near the northern end of Sanel Valley, west of the Russian River and east of U.S. Highway 101; well yields in this area have exceeded 1,000 gal/min. A third area is south of Hopland and east of U.S. Highway 101, where yields range from 100 to about 1,000 gal/min.

Ground water in the alluvium occurs under unconfined conditions. Because the Russian River and tributary streams generally occupy channels cut into alluvial deposits, surface water and ground water are in connection. Wells drilled near the banks of streams derive a part of their production from surface water that is induced to flow through permeable alluvial deposits as the ground-water level is lowered by pumping.

The permeable nature of the alluvium allows infiltration of considerable precipitation. This captured precipitation recharges the alluvial aquifer and underlying units. During most river stages, water moves from the alluvium into the Russian River. During periods of high river stage, water moves from the river into the alluvial aquifer and is held temporarily as bank storage. The bank storage is depleted as the river declines to normal flow stages.

Ground-Water Availability

The availability of ground water in any given area of Ukiah Valley is classified into one of four categories (pl. 2).

The Type I area, the most favorable area for ground-water development, is underlain by alluvial deposits that provide year-round supplies of water for domestic use; in many parts of the Type I area, properly constructed wells may obtain as much as 100 to 1,000 gal/min. The Type I area is generally narrow, except in the central part of the valley where the width broadens to 2 miles and near Hopland where it is about 1.5 miles wide.

The Type II areas, distributed along the margins of the valley, are generally underlain by terrace deposits or thin alluvium. In these areas, the quantity yielded to wells may be less than 10 gal/min. Wells in Type II areas generally provide only enough water for domestic use or limited irrigation.

Type III areas, underlain by thin terrace deposits and continental basin deposits, cover much of the northern part of the valley and smaller areas along the eastern side of the valley. Wells drilled in these areas generally provide only a few gallons per minute, and some sites may be dry.

Type IV areas include all the mountainous terrain around the valley floor and are underlain mostly by rocks of the Franciscan Complex. Ground-water conditions in the mountainous areas are described in more detail later in this report. In general, the prospect for obtaining ground water in these areas is very poor. Before attempting to drill for water in Type IV areas, site-specific studies to determine the most favorable drilling locations would be warranted. Sufficient supplies of water for domestic use are available locally along fractures, but these favorable sites are widely spaced.

Estimated Storage Capacity

The quantity of available ground water stored in the upper 100 feet of the most productive area of valley fill (Type I) is estimated to be about 90,000 acre-ft. This estimate was computed by determining the volume of saturated fill within 100 feet of the surface and multiplying the result by the estimated specific yield. The volume of saturated Type I fill is derived from the known area of 20 mi^2 (12,800 acres) and an assumed saturated thickness of about 85 feet (water levels average about 15 feet below land surface in spring). The computed volume of 1,088,000 acre-ft is probably within 10 percent of the actual volume. The quantity of water that can be withdrawn from this volume of aquifer depends on the specific yield of the aquifer materials. The specific yield was estimated from lithologic descriptions in drillers' reports and observations at outcrops. The average specific yield used in the storage-capacity computation was 8 percent. This estimated specific yield may be in error by about 25 percent, giving a possible range of 6 to 10 percent. When the possible errors in estimating the saturated volume and specific yield are considered, the storage capacity ranges from 60,000 to 120,000 acre-ft.

Additional ground water is stored in aquifer materials underlying the areas designated as Type II on the ground-water availability map. The estimated storage capacity in the upper 100 feet of Type II aquifer materials is 45,000 acre-ft, assuming an average specific yield of 5 percent.

No estimates were made of the storage capacity for areas designated as Type III or Type IV on the availability maps because these areas have marginal capacities to yield water to wells.

The above estimates of storage capacity give the maximum quantity of water that could be removed from the aquifers by pumping. The consequences of totally depleting ground water in storage are not covered in detail in this report because they involve not only geohydrology but economic and social issues as well. The geohydrologic consequences of removing all or a large part of ground water in storage include possible land subsidence, degradation of water quality, permanent loss of part of the storage capacity through compaction, and diminished baseflow to streams.

Water-Level Fluctuations

Water-level fluctuations in wells in Ukiah Valley can be classified as either seasonal or long term; the rapid short-term changes in levels caused by pumping cycles are not considered because of their transient nature. Seasonal water-level fluctuations are most closely related to precipitation patterns; long-term fluctuations are related to consumptive use.

Water-level records for periods greater than 10 years are available for eight wells in Ukiah Valley. Hydrographs for these wells (fig. 7) show seasonal fluctuations and long-term trends. Generally, both a high and a low water level for each year of record are available for each well. It should be noted that, depending on the timing of the measurement, the true high or low water level may be missed. Monthly water-level measurements made by the California Department of Water Resources at a number of wells during the 1960's show that during most years water levels are highest in March or early April and lowest in October.

Average seasonal water-level fluctuations range between 5 and 15 feet. Variations in seasonal water-level fluctuations can be seen in the hydrographs for years of precipitation extremes. During the drought years of 1976 and 1977, precipitation at Ukiah was 54 and 44 percent of normal, respectively. All hydrographs spanning the 2 drought years show that water levels were below normal. Variations from normal are not evident during years of above-average precipitation. This is apparently due to rejection of excess precipitation. Aquifers are recharged to their maximum during years of normal (mean annual precipitation is 36 inches) or slightly below-normal rainfall. Rainfall significantly greater than normal cannot be retained in the aquifer, and the excess is lost quickly through interflow to streams. The hydrographs show a conspicuous spike in the water-level high for 1975 even though precipitation was only 7 percent above normal. The reason for this apparent anomaly is that the high water levels were measured in late March, and rainfall during March that year was 266 percent of normal.

None of the hydrographs show any prominent long-term declines. Water levels measured during the 1980's are remarkably similar to those measured during the 1960's and 1970's; records for the 1950's are not sufficiently complete to make good comparisons. Even though water levels were significantly depressed during the 1976-77 drought, they recovered to normal by the end of the 1978 rainfall season.

Analysis of the hydrographs indicates that the ground-water reservoir is recharged fully each year except when precipitation falls below about 60 percent of normal. After 2 years of drought, the reservoir can be fully recharged by 1 year of normal or above-normal precipitation.

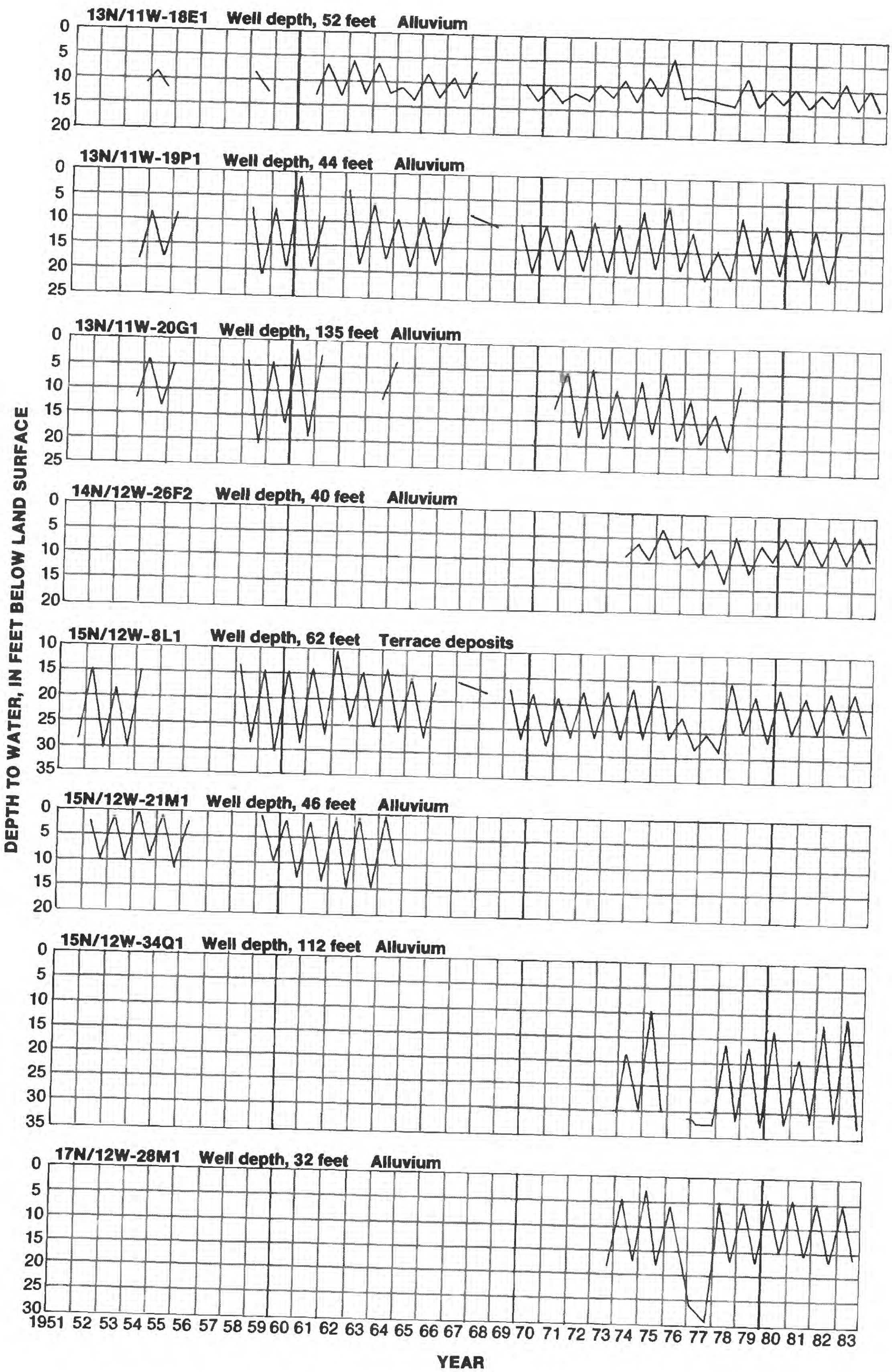


FIGURE 7. – Hydrographs for wells in Ukiah Valley. (Locations shown on plate 3)

Ground-Water Movement

The water-level contour map (pl. 3) shows the approximate altitude of the water table in the valley fill and the approximate directions of ground-water flow. Although the water-level measurements were made in wells of differing depths, the water-level contours closely approximate the altitude of the water table. The water-level measurements used to prepare the contour map were made during the period September to November 1982, at a time when the water table was at its lowest level for the year. Contours are not shown in some parts of the valley because insufficient data were available.

At any location, ground water moves downgradient approximately perpendicular to the contours. Ground water generally moves from the valley sides toward the Russian River and generally moves from north to south. The spacing of the contours is quite variable. Where closely spaced, the contours indicate steep ground-water gradients. Areas of steep gradients may be underlain by materials of low transmissivity. The geologic map (pl. 1) shows that these areas are underlain by valley-fill units of low permeability, lending support to this view. Likewise, areas where the gradient is flatter coincide with areas underlain by the most permeable units of valley fill.

Analysis of river stage and water levels in wells close to the river shows that in some reaches ground water discharges to the river; in other reaches river water infiltrates the aquifer. This analysis assumes that the river-channel material is permeable and that good hydraulic connection exists between river and aquifer. This assumption is probably valid for most of the central part of Ukiah Valley. Seasonal changes in river stage and ground-water levels cause changing patterns of water exchange between the river and aquifer. During the autumn when the water table is usually lowest, river water infiltrates to the aquifer along the reach between the 600-foot and 520-foot ground-water contours shown on plate 3. During the spring when the water table is highest, river water infiltrates to the aquifer along the reach between a point midway between the 580- and 560-foot contours and the 540-foot contour shown on plate 3.

The movement of river water into the alluvial aquifer is also caused by pumping water from wells located within a few hundred feet of the river. This happens when a drawdown cone is produced by pumping, causing a local reversal of the ground-water gradient and allowing river water to be pulled through the alluvial gravels toward the well. In this case the exchange of ground water and river water will depend on the pumping cycle of the well.

Recharge and Discharge

The quantity of ground water in storage in Ukiah Valley varies over time in response to variations in recharge and discharge. Likewise, the quantity of recharge to or discharge from the ground-water reservoir varies over time in response to variations in the quantity of water stored in the reservoir. When a ground-water reservoir is filled to capacity, further potential recharge is rejected. At times when the reservoir is at less than capacity, the quantity of discharge is reduced.

Recharge sources in Ukiah Valley include precipitation, surface-water infiltration, return flows from sewage and irrigation, and possibly ground-water inflow from outside the basin. The main source of recharge is precipitation as rainfall. Recharge to aquifers by direct infiltration occurs when rain falls over permeable aquifer materials. Indirect recharge occurs when rain falls over relatively impermeable materials either exposed at the surface or lying at shallow depth. The rejected rain moves laterally over the relatively impermeable material to contacts with permeable materials. These contacts between the permeable units (Holocene alluvium and, to a lesser extent, continental terrace deposits) and relatively impermeable units (rocks of the Franciscan Complex and continental basin deposits) constitute important recharge zones. If extensive portions of recharge areas are covered over by paving or buildings, surface runoff will increase, and recharge to aquifers will be diminished.

Surface-water infiltration occurs along the Russian River and tributary channels and from leakage from surface impoundments. Removal of sand and gravel along stream channels may locally impact recharge to aquifers by making the streambeds and channel walls less permeable to infiltration. Recharge from the Russian River along some reaches is demonstrated by water levels in wells near the river that are lower than river stage.

Return flows from sewage-disposal systems and from irrigated lands are minor sources of recharge in Ukiah Valley. In sewered areas, municipal systems dispose secondary-treated sewage by discharge to the Russian River, during high river stage, when dilution ratios equal or exceed 100:1. During low river stage the sewage is evaporated or applied to land areas by sprinklers. In either case, very little of the treated municipal sewage recharges the ground-water reservoir. In rural areas leakage from septic systems provides some water for recharge.

Ground water moving up along faults in the Franciscan rocks and recharging the reservoir may be a recharge source from outside the basin. The quantity of recharge from this source, however, is probably very minor compared to that from precipitation and surface-water infiltration.

Sources of ground-water discharge in Ukiah Valley include seepage to the Russian River, evapotranspiration, and pumpage from wells. Ground-water discharge to the Russian River is not significant during times of low ground-water levels. Discharge measurements during October 1981 at several points along the Russian River between Coyote Dam and Pieta Creek show no variation greater than the potential error in measurement. During periods of high ground-water levels, water is discharged from the ground-water reservoir to the Russian River and tributaries; the amount of this discharge is not known but is probably considerable.

Evapotranspiration includes all water transpired by plants (both crops and native vegetation) and that water lost by evaporation. Based on data for vegetative water use (California Department of Water Resources, 1975) and land-use classification (California Department of Water Resources, 1980), an estimated 30,000 acre-ft per year of water is consumed by crops, by grasses in pastureland, and by evaporation from lakes and reservoirs in Ukiah Valley. Part of this water is pumped directly from the Russian River and from small catchment reservoirs and, therefore, does not directly affect ground-water supplies. Another portion of the 30,000 acre-ft is pumped from wells that tap alluvium close to the Russian River; part of this well water is captured from the river. Another unknown portion of the 30,000 acre-ft is pumped directly from the ground-water reservoir.

Little is known about the water requirements of native vegetation. Within the Russian River drainage basin, of which Ukiah Valley is a part, about 90 percent of the land area is occupied by native vegetation. Although the consumptive use of water by native vegetation is considerably less than for irrigated crops, the large area of coverage indicates that native vegetation consumes a significant part of the rainfall that provides recharge to the ground-water reservoir in Ukiah Valley.

The California Department of Water Resources (1977) projected urban water use for 1980 to be about 11,000 acre-ft. This quantity includes water used by industry and water for domestic and municipal use. Most of this water is pumped from wells; a small portion is pumped directly from surface-water sources.

Available Supply

The estimates for ground-water storage, water use, and potential recharge indicate that sufficient ground water is available to meet present rates of consumption. Ground-water storage is estimated at 90,000 acre-ft, which is more than twice the estimated 41,000 acre-ft (part of which is surface water) consumed annually by evapotranspiration and urban water uses. During years when precipitation at Ukiah equals or exceeds about 60 percent of the average, the ground-water reservoir is filled to capacity. Thus extraction of ground water could be increased by an indeterminant amount without depleting the reservoir over the long term.

Chemical Quality of Water

The quality of water can be defined in terms of chemical, physical, and biological properties. Ground water, because it moves slowly through earth materials, undergoes a natural filtration process. As ground water passes through porous media, the solid particles in suspension tend to be removed; however, additional constituents may be taken into solution as water reacts with rock. Isolated from the atmosphere and sunlight, organisms generally do not survive long in a ground-water environment. Because suspended matter and organisms tend to be excluded from ground water, ground-water quality is most commonly described in terms of dissolved chemical constituents. In the dissolved state, chemical constituents are present as electrically charged particles or ions. In this report water quality is described in terms of the concentrations of various ions detected in water samples.

General chemical quality.--For this study, 26 water samples were collected from 22 wells in Ukiah Valley. The samples were analyzed at the U.S. Geological Survey's Denver Central Laboratory in Arvada, Colorado. The areal variation within Ukiah Valley in terms of the relative abundance and actual concentrations of dissolved constituents is shown on plate 2. In terms of major constituents, the ground water could be classified generally as calcium bicarbonate or calcium magnesium bicarbonate. Some samples, however, show a predominance of sodium over calcium and magnesium. The range in concentrations of major and minor constituents is shown in table 3.

The quality of ground water is generally good, and the water is suitable for most uses. A comparison of the analyses with drinking-water standards (U.S. Environmental Protection Agency, 1975; 1977) indicates that the water generally meets the standards. Analysis of only one sample exceeded the standard for nitrate concentration; the sample was collected from an irrigation well, 13N/11W-30A, south of Hopland. The high nitrate value may be related to the application of nitrate as fertilizer. Analyses of several samples exceed the standards set for iron and manganese. These standards are based on cosmetic and taste considerations. Both iron and manganese in sufficiently high concentrations can cause staining of plumbing fixtures and laundry and can give an unpleasant metallic taste to water. The iron and manganese are derived from solution of minerals in the rocks containing the ground water. The generally slightly acidic water (pH 6 to 7) increases the solubility of iron and manganese and accounts for the generally high concentrations of these two elements. As water is pumped from a well, changes in pH and dissolved-oxygen concentration can decrease the solubility of iron and manganese. The iron and manganese then begin to precipitate as hydrated mineral encrustations. Encrustation of pump parts, pipes, and well-casing perforations may be a problem in areas where iron and manganese are present in high concentrations.

Variations in chemical quality.--The composition of dissolved constituents in ground water is dependent on the history of the water prior to sampling. Geologic, hydrologic, and anthropogenic factors may influence the final composition.

Table 3.-- Chemical quality of ground water in Ukiah Valley

[EPA standard: National Interim Primary Drinking Water Regulation, U.S. Environmental Protection Agency, 1975; and National Secondary Drinking Water Regulations, U.S. Environmental Protection Agency, 1977]

	Number of analyses	Maximum	Minimum	Mean	EPA standard
Major constituents, in milligrams per liter					
Alkalinity as $CaCO_3$	20	330	68	147	--
Calcium	20	50	7.3	28.2	--
Chloride	20	31	3.4	10.4	250
Fluoride	20	.3	<.1	<.16	1.6
Magnesium	20	42	8.0	18.6	--
Nitrogen NO_2+NO_3 as N	20	11	.09	2.1	10
Potassium	20	1.6	.3	.88	--
Silica	20	36	1.4	19.4	--
Sodium	20	92	6.6	19.1	--
Sulfate	20	38	5.0	18.1	250
Sum of dissolved constituents	20	392	89.0	216	--
Minor constituents, in micrograms per liter					
Aluminum	9	<100	<100	<100	--
Arsenic	9	<1	<1	<1	50
Barium	9	230	52	112	1,000
Boron	26	8,700	20	1,012	--
Cadmium	9	<3.0	<1.0	<2.3	10
Chromium	9	<10	<10	<10	50
Copper	9	<30	<10	<23	1,000
Iron	20	8,100	9	820	300
Lead	9	<100	<1	<89	50
Manganese	20	1,300	<1	<186	50
Mercury	9	<.1	<.1	<.1	2
Nickel	9	<100	<100	<100	--
Zinc	9	70	<12	23.2	5,000

Geologic factors that influence the quality of water include geologic structures and variations in lithology. In the Ukiah Valley area, rocks rich in magnesium (such as serpentine) may be the source of the high magnesium concentrations in some samples.

Waters high in sodium and boron are found at some sites near faults. The source of the sodium and boron may be ground water rising from great depths along fault zones (Barnes, 1970). Carbon dioxide has been detected in some wells and was produced from wells in the past for a dry ice plant located 2 miles north of Hopland (Hubbard, 1943). The carbon dioxide, probably derived from metamorphism of carbonate sediments, moves up from depth along fault zones (Barnes, 1970).

Boron.--For 26 samples, boron ranged from 20 to 8,700 μg/L. Boron is an essential element for plant nutrition; however, the difference between required amounts and toxic amounts is very small. The sensitivity of crops to boron varies considerably, but generally concentrations less that 1,000 μg/L can be applied to crops without adverse effects. Because boron concentrations are known to exceed 5,000 μg/L in some locations and concentrations considerably less than this are toxic to some crops, chemical analysis for boron in irrigation water is advisable. Boron toxicity for most animals has not been established; however, toxic accumulations are unlikely because boron is rapidly eliminated by animals in urine (Gough and others, 1979).

Potential for contamination.--Ground water in Ukiah Valley is found at shallow depth. Therefore, it is subject to rapid recharge during the rainy season. Precipitation, applied water, or other liquids can rapidly percolate to the water table because of the shallow depth to the zone of saturation. This means spilled or discarded liquids or substances soluble in water may be carried into the ground-water reservoir within a period of days. The thinness of the unsaturated zone between land surface and the water table reduces the ability of this zone to inhibit movement of contaminants by the processes of adsorption, absorption, dispersion, and evaporation. The possibility of rapid traveltime from surface to reservoir also reduces the amount of time available to contain contaminants or to remove contaminated earth materials.

Minor incidents of ground-water contamination have occurred in Ukiah (J. Davis, Director of Environmental Health, written commun., 1985). These incidents have mostly involved gasoline leaks from buried storage tanks. However, in 1982 discharge of formaldehyde from an idle railroad tank car illegally released by vandals contaminated shallow wells in a small area near the southern end of the city. The formaldehyde also entered the Russian River, causing a temporary shutdown of some drinking-water supply wells in downstream communities. If this discharge had occurred farther from the river or in an area with poor surface drainage, a larger part of Ukiah's principal aquifer could have been affected.

The most sensitive areas to potential ground-water contamination are those underlain by permeable materials, such as sands and gravels in the Type I and II ground-water availability areas; areas with poor surface drainage; areas of excavation (for example, construction sites and gravel pits); areas where septic tanks provide sewage disposal; agricultural areas where the application of chemical fertilizers and pesticides may exceed the capacity of the soil and biota to inhibit and break down the chemicals; and areas close to pit wells, abandoned wells, or wells with no surface seals.

During the course of this study numerous well houses were found to serve also as storage sheds for fertilizers, pesticides, gasoline, oil, and other potential contaminants. This practice has the potential for causing localized ground-water contamination.

Little Lake Valley

Description of Area

Little Lake Valley, also known as Willits Valley, is located in the central part of the county about 25 miles north of Ukiah and lies immediately north of the drainage divide between the Eel and the Russian River basins (fig. 1). Several small streams, including Baechtel, Broaddus, Davis, Haehl, and Willits Creeks, flow through the valley and join in a marshy area near the north end (fig. 8). The marshy area is drained by Outlet Creek, a tributary of the main stem of the Eel River. The valley consists of an oblong-shaped flat floor measuring about 5 miles north to south and 2.5 miles west to east and an area of low hills encompassing an additional 5 mi^2 at the southern end of the valley. The average altitude of the the valley floor is approximately 1,350 feet above sea level.

Willits, the only town in the valley, had a population of 4,008 at the 1980 census. The community is served by a water system that obtains its supply from Morris Reservoir, which has a storage capacity of 835 acre-ft. The community has experienced water shortages during late summer during some years when the reservoir dropped to low levels. Ranches and residences outside the service area obtain water from individual wells and springs.

EXPLANATION FOR FIGURE 8

Qal	Alluvium	Holocene	Quaternary
QTc	Continental basin deposits	Pleistocene and Pliocene	Quaternary; Tertiary
		Unconformity	
TKJf	Franciscan Complex, undifferentiated		Tertiary, Cretaceous, and Jurassic

CONTACT – Dashed where approximately located

FAULT – Shows approximate location; dotted where concealed, queried where uncertain

A——A' LINE OF GEOLOGIC SECTION (See figure 9)

PETROLEUM EXPLORATION HOLE SITE

13B1 WELL AND NUMBER – Shows location of well used for geologic section, or mentioned specifically in section on "Water-Bearing Formations" in text

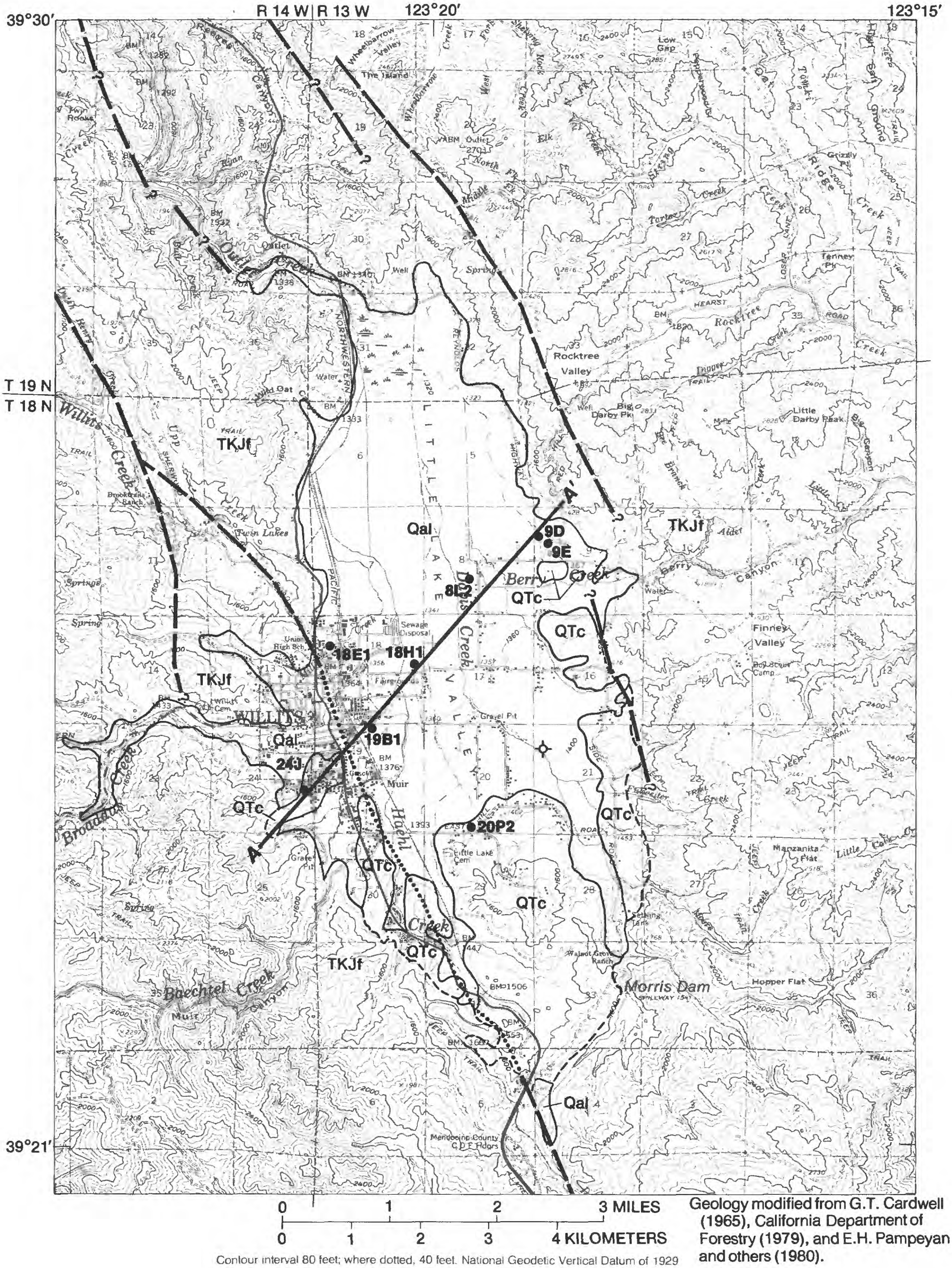


FIGURE 8. — Geology of Little Lake Valley.

Water-Bearing Formations

Valley fill occupies about 18 mi^2 and is subdivided into continental basin deposits and Holocene alluvium (fig. 8). A geologic section (fig. 9) along a line extending northeast across the central part of the valley shows the stratigraphic relation between units of fill.

The deepest water well for which records are available, 18N/13W-18E1 in the west-central part of the valley, has a total depth of 493 feet. The driller's log shows that this well penetrated 445 feet of fill before encountering the underlying basement rocks. Well 18N/13W-19B1 was drilled to a depth of 454 feet; the entire section penetrated was in valley fill. An abandoned gas exploration hole drilled 2,000 feet in sec. 21, T. 18 N., R. 13 W. penetrated about 1,000 feet of fill. This entire section of fill is saturated to within about 15 feet of the land surface; however, high salinities and small pockets of gas prevail below a poorly defined depth.

Continental basin deposits.--Continental basin deposits crop out discontinuously in an area of about 5 mi^2 along the east side, the southern end, and the southwestern part of the valley. The continental deposits extend across most of the remainder of the valley in the subsurface. Thickness ranges from zero at the valley margins to several hundred feet in the central part.

The basin deposits consist of poorly sorted gravel, sand, silt, and clay interbedded with beds of clay. The vertical distribution of poorly sorted units and clay beds varies markedly. Individual beds range in thickness from less than 1 foot to more than 100 feet. The permeability is very low because of the large fraction of fine-grained material occurring either as beds of clay or as filling between grains of coarser size. The small average grain size and general lack of cementing result in high porosity.

The widespread continental basin deposits are generally thick and have high porosity and low permeability. Although these deposits store a large volume of water, the low permeability greatly limits the yield of wells. Because of the interbedded, low-permeability clay units, ground water is present under confined or semiconfined conditions. Where confining pressures are great enough, wells drilled into these deposits flow at land surface. Although natural flows from wells generally do not exceed 2 gal/min, increased yields can be obtained by pumping.

Eleven wells that obtain water solely from the basin deposits and that have been tested for yield were inventoried. Yields range from less than 1 to 45 gal/min. Specific capacities of seven of the wells range from 0.07 to 2.5 (gal/min)/ft; specific capacities of five wells were less than 0.7 (gal/min)/ft. These data are based on short-term pumping tests that may overestimate potential long-term yields. Many well owners contacted during field surveys expressed the view that well yields have declined from initial production rates.

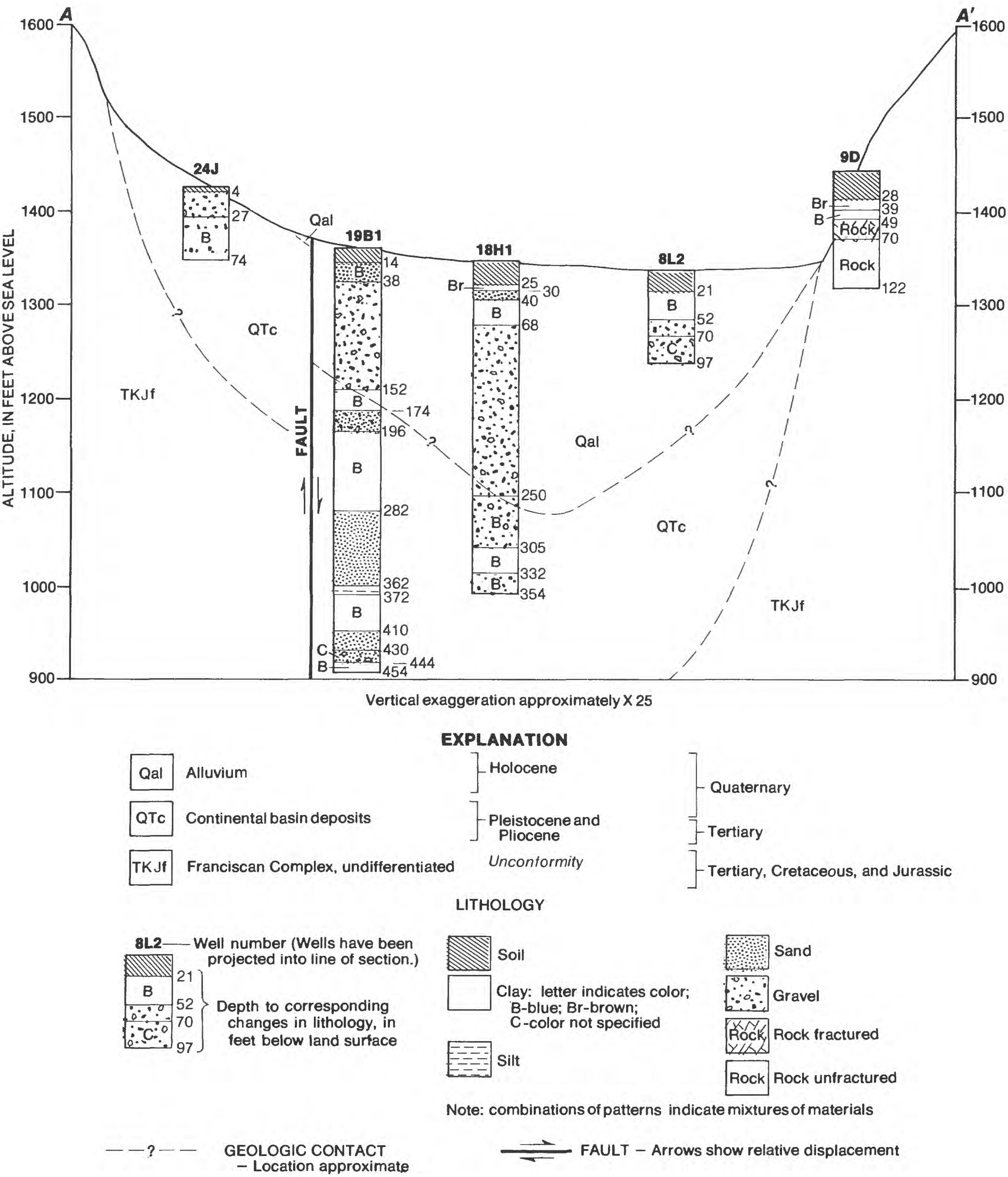


FIGURE 9. – Geologic section, Little Lake Valley. (Location shown in figure 8)

Added to these qualitative reports, the following measurements of flow from well 18N/13W-20P2 show a dramatic decline in yield:

Date	Flow rate (gal/min)
May 20, 1947---------	250
July 14, 1954--------	15
September 23, 1981---	.25

The current well owner reports that the flow rate does not change much during the year; therefore, seasonal variations do not account for this decline. Although the decline in yield may be due to encrustation or siltation clogging the well, the decline in yield may be evidence of long-term pressure reduction in confined permeable zones tapped by the well; the pressure reduction results from the low rate of recharge to these zones.

The continental basin deposits in most parts of the valley are capable of yielding a few gallons per minute, which is sufficient for domestic use. Higher yields may be found in some areas, but significant declines in yield may occur over a period of years.

Holocene alluvium.--Alluvial deposits of Holocene age cover most of the flat part of the valley floor, an area of about 13 mi^2. Over much of its areal extent, the alluvium overlies continental basin deposits (fig. 9).

The alluvium, composed of uncemented gravel, sand, silt, and clay, varies in thickness. The thickest sections are found in the area immediately south and east of the central part of Willits and are centered around well 18N/13W-18H1. A driller's log for this well shows that the well penetrates thick sections of gravel (fig. 9). The contact between alluvium and the underlying continental basin deposits cannot be determined precisely on driller's logs because of the similarity in the description of drill cuttings. However, the thickness of alluvium at well site 18H1 is about 250 feet; this probably is near the maximum thickness in the valley.

The alluvial deposits are high in porosity and permeability because of their coarse-grained composition and lack of cementation. The deposits are saturated below a depth that ranges from 5 to 20 feet in most locations. Where they are thin, such as around the margins of the valley and in the canyon bottoms of streams that drain the surrounding mountains, the deposits may be dry in late summer and early autumn.

The alluvium is the most productive aquifer in Little Lake Valley and is the only unit that can supply sufficient water for irrigation or municipal supply wells. Properly constructed wells in favorable areas can obtain up to 1,000 gal/min from the alluvium. Existing wells drilled 50 to 100 feet deep in most areas of the alluvium yield 20 gal/min or more. Specific capacities ranged from 0.3 to 83 (gal/min)/ft for 19 wells. Nine of these wells had specific capacities less than 1.0 (gal/min)/ft; only one well was greater than 11 (gal/min)/ft. The mean for 18 wells (the high value of 83 (gal/min)/ft not included) is 2.75 (gal/min)/ft.

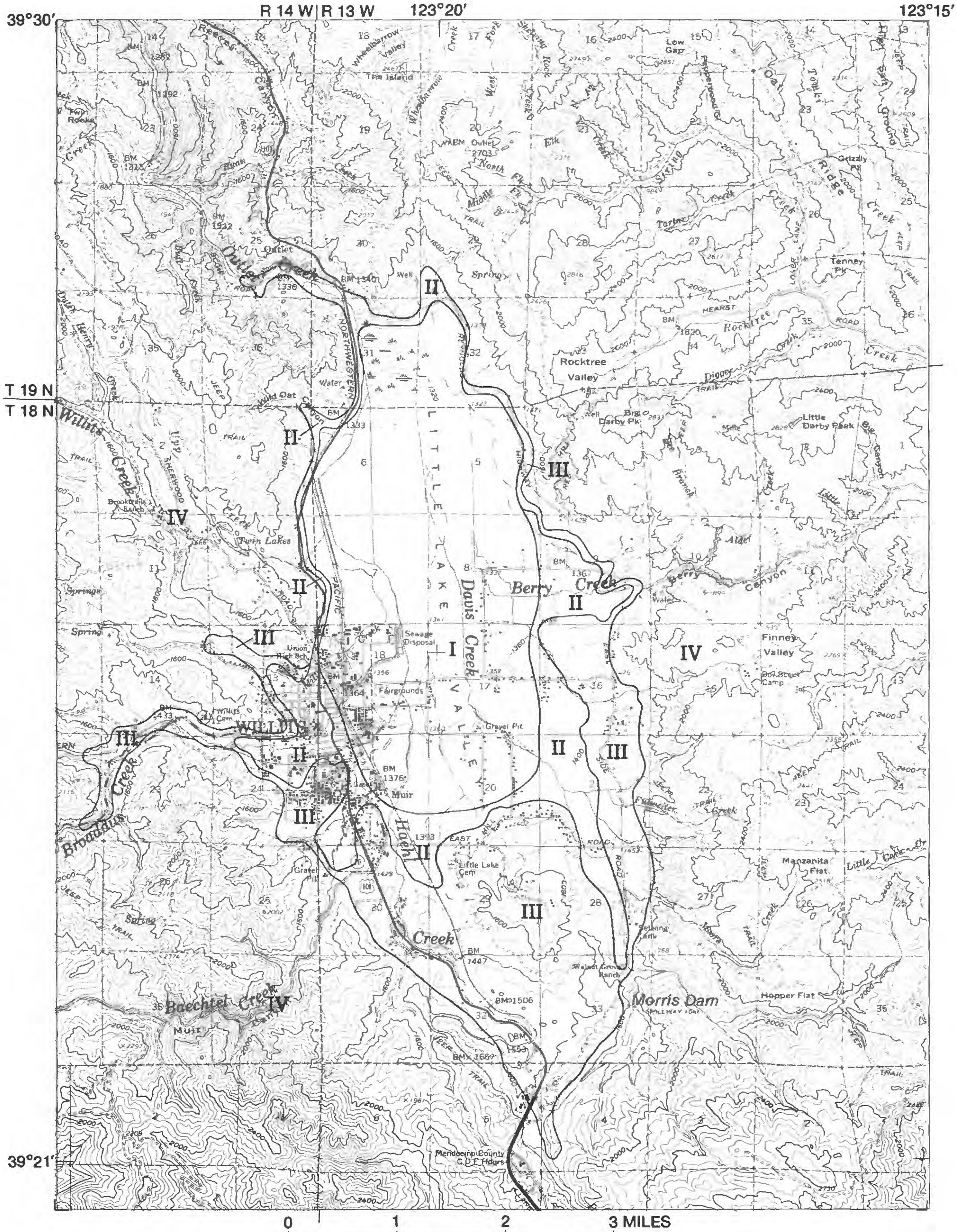
Ground-Water Availability

Ground-water availability in Little Lake Valley is classified into four categories: Types I, II, III, and IV (fig. 10). The most favorable area (Type I) for ground-water development is in the central part of the valley. The Type I area coincides with the flat valley floor and occupies about 7.5 mi^2; this area is underlain by thick valley fill and includes the thickest area of Holocene alluvium. Wells drilled in this area are assured of obtaining water sufficient in quantity for individual domestic supplies. In some places, especially along the axis of the valley and in the northern part, yields of 100 to 1,000 gal/min can be obtained from properly constructed wells.

The Type II area, in places, forms a narrow concentric band around the Type I area but extends into wider areas and further from the flat valley floor along the channels of Davis, Haehl, Broaddus, Baechtel, and Berry Creeks. The Type II area occupies about 3 mi^2 and is underlain by thin Holocene alluvium. Wells drilled in the Type II areas generally provide sufficient quantities of water for individual domestic wells. Well yields, however, generally do not exceed 10 gal/min for sustained pumping.

The Type III area occupies about 7 mi^2 around the margins of the southern one-half of the valley. An area of low hills at the south end of the valley, underlain by continental basin deposits, constitutes the main part of the Type III area. The fine-grained materials underlying the Type III area greatly restrict the quantity of water yielded to wells. Most wells drilled in this area provide only a few gallons per minute, and at some sites drilling for water may be unsuccessful.

The mountainous terrain surrounding the valley is classified Type IV. The Type IV area is mostly underlain by rocks of the Franciscan Complex. Well yields in Type IV areas vary widely depending on local rock type and degree of fracturing. Many dry holes have been drilled in the search for water in these areas; however, yields of up to 200 gal/min have been reported. Areas of good production are limited to widely spaced zones along faults and areas of highly fractured rock. Because significant quantities of water are available in small areas that are sparsely distributed among areas that are dry or of limited production capacity, careful site-specific studies are required to locate the best sites for drilling.



0 1 2 3 MILES
0 1 2 3 4 KILOMETERS

Contour interval 80 feet; where dotted, 40 feet. National Geodetic Vertical Datum of 1929

FIGURE 10. – Ground-water availability in Little Lake Valley.

EXPLANATION FOR FIGURE 10

MAP SYMBOL	GROUND WATER AVAILABILITY	WATER-BEARING UNITS
I	Ground water generally abundant. Production rate and supply sufficient for agricultural, industrial, municipal, and domestic uses.	All coarse-grained consolidated deposits of valley fill where thick and saturated. Any areas reported to have high-capacity wells.
II	Ground water generally available year-round at low production rates. Generally sufficient supply for domestic use; may provide adequate supply for irrigation or industrial use.	Margins of valley fill where partially saturated year-round, or areas where production is proven.
III	Ground water generally present, but production rates are extremely limited or ground water is only seasonally available; may provide sufficient supply for domestic use.	Areas where valley fill is thin, very fine grained, or cemented; or areas where water table seasonally drops below the fill. Includes some areas of shallow ground water, but very low permeability.
IV	Ground water generally not available in significant quantities. Where available, the occurrence is restricted to small areas lithologically or structurally favorable; may provide adequate supply for livestock or domestic use.	Franciscan Complex rocks comprising the mountainous terrain. Rocks are very fine grained or cemented.

Estimated Storage Capacity

The quantity of available ground water stored in the upper 100 feet of the most productive areas of valley fill (Type I) is estimated to be 35,000 acre-ft. This estimate was computed by determining the volume of saturated fill within 100 feet of the surface and multiplying the result by the estimated specific yield. The volume of saturated fill underlying the Type I area is about 430,000 acre-ft, based on an area of 7.5 mi^2 and a saturated thickness of 90 feet (water levels are about 10 feet below the land surface during the spring). This computed volume is probably within 10 percent of the actual value. The quantity of water that can be extracted from aquifer materials depends on the specific yield of the materials. The specific yield was estimated from lithologic observations at outcrops and from descriptions of materials on driller's reports. The average specific yield used for the storage-capacity computation was 8 percent. This estimated specific yield may be in error by about 25 percent. When the possible errors are considered, the storage capacity could range from 23,000 to 48,000 acre-ft.

Additional ground water is stored in aquifer materials underlying areas designated as Type II on the ground-water availability map. Estimated storage capacity in the upper 100 feet of Type II aquifer materials is 9,000 acre-ft, assuming an average specific yield of 5 percent.

No estimates were made of the storage capacity for Type III or IV areas because these areas have marginal capacities to yield water to wells.

The storage-capacity estimates for Type I and II areas include all available water regardless of quality. Chemical data for wells along the east side of the valley and in the north part indicate that some parts of the valley fill contain water with concentrations of chloride, boron, and dissolved solids that exceed the standards for some uses. Therefore, part of the quantity of water estimated in storage may not be usable for some purposes. Discussion of chemical quality in Little Lake Valley is covered in more detail in a later section of this report.

Water-Level Fluctuations

Water levels in wells in Little Lake Valley fluctuate principally in response to pumping and precipitation. Seasonal fluctuations result from seasonal variations in rainfall and pumping. Long-term changes may occur when the effects of pumping are not balanced by recharge from precipitation over a period of years.

Water-level records spanning 10 years or more are available for four wells in Little Lake Valley. Hydrographs for these wells show that the water level fluctuates about 10 to 15 feet seasonally (fig. 11). No significant long-term trends are evident from the records; water levels measured during the 1980's are nearly the same as levels measured during the 1950's. However, well 18E1 does show a slight water-level rise during 1959-73. The specific reason for this rise is not known, but it may relate to changes in local pumping. Because this is the deepest of these wells, it may respond more slowly than the shallow wells to seasonal variations in precipitation.

Variations in the quantity and distribution of precipitation cause some variability in the spring high water levels and autumn low water levels. Spring water levels measured during the drought of 1976 and 1977 (precipitation was 59 and 34 percent of normal, respectively) were lower than normal in the four hydrograph wells. Water levels rose to normal levels in three of the four wells by the end of the 1978 wet season (precipitation was 116 percent of normal during the 1978 rainfall season).

Comparison of precipitation records for stations in Little Lake Valley (California Department of Water Resources, 1981) with spring water-level measurements indicates that levels recover to normal if precipitation is at least 75 percent of normal during the preceding rainfall season. The available data for Little Lake Valley are not sufficient to ascertain if lesser amounts of precipitation would return water levels to normal; however, data from Ukiah Valley indicate that precipitation in excess of 60 percent of normal during the preceding season is enough to fully recharge the ground-water reservoir.

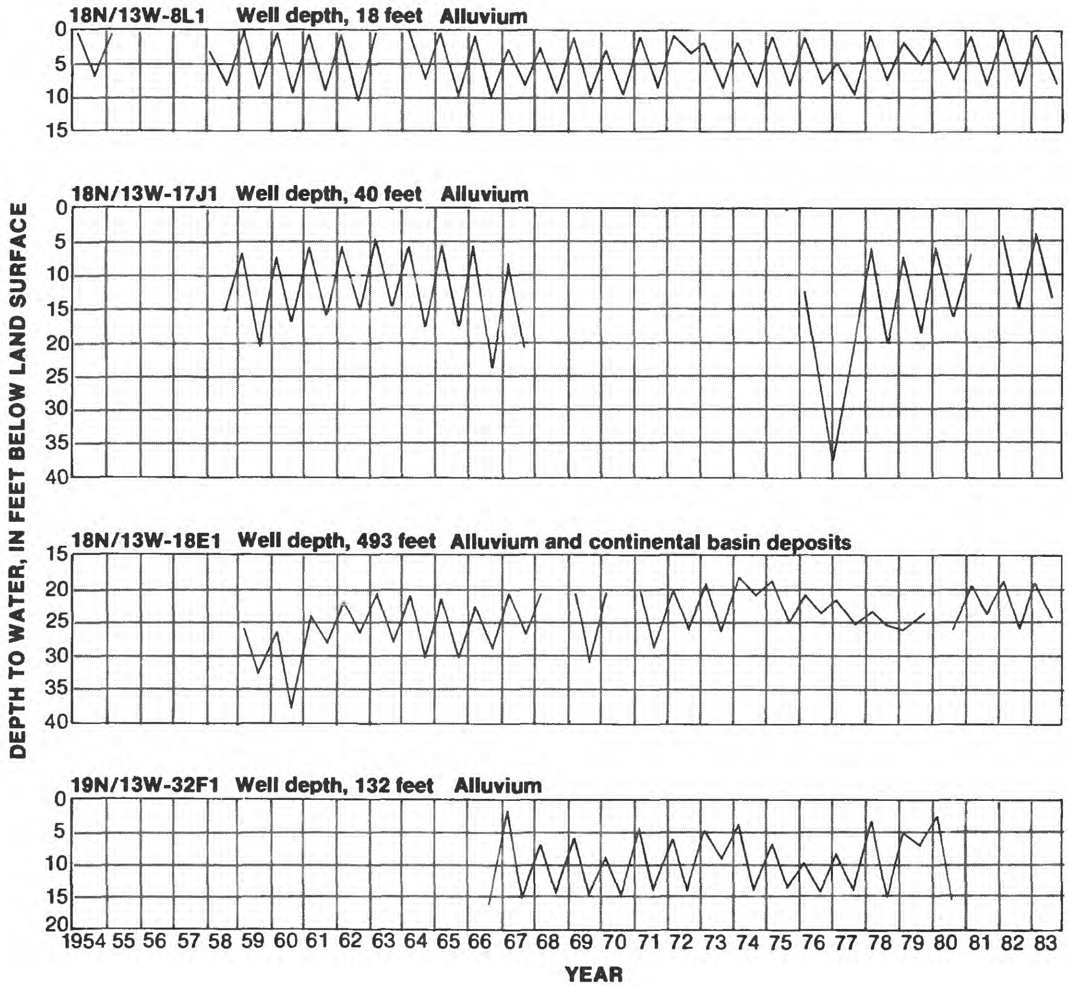


FIGURE 11. — Hydrographs for selected wells in Little Lake Valley. (Locations shown in figure 12)

Ground-Water Movement

The water-level contour map (fig. 12) shows the approximate altitude of the water table in the valley fill. Although the water-level measurements were made in wells of differing depths, the water-level contours are believed to closely approximate the altitude of the water table. The water-level measurements used to prepare the contour map were measured during September and October 1981, at a time when the water table was at its lowest level during the year.

The pattern of roughly concentric lines formed by the contours shows that ground water moves from the valley sides toward the center and from south to north. Ground water discharges in a large marshy area in the north end of the valley. A shallow lake covering several hundred acres forms in the marshy area during some winter seasons. The lake is filled in part by ground-water discharge and in part from surface water whose drainage from the valley is restricted by vegetation and a narrow stream channel. Water leaves the valley both as surface flow in Outlet Creek and as subsurface flow in the alluvium of the creek bed.

Recharge and Discharge

Recharge sources in Little Lake Valley include precipitation, surface-water infiltration, return flows from sewage and irrigation, and possibly upflow of ground water along fault zones. The main source of recharge is precipitation as rainfall. Recharge from direct infiltration of rainfall occurs over areas with permeable materials exposed at the surface; these are the areas underlain by Holocene alluvium (fig. 8). Where impermeable materials are exposed at the surface or lie at shallow depth, water from rainfall flows over the impermeable materials to contacts with permeable materials. The contact zones between Holocene alluvium and continental basin deposits are important recharge areas (fig. 8).

EXPLANATION FOR FIGURE 12

—*1340*—— WATER-LEVEL CONTOUR – Shows altitude of water table or potentiometric surface. Contour interval is 20 feet. Dashed where approximately located.

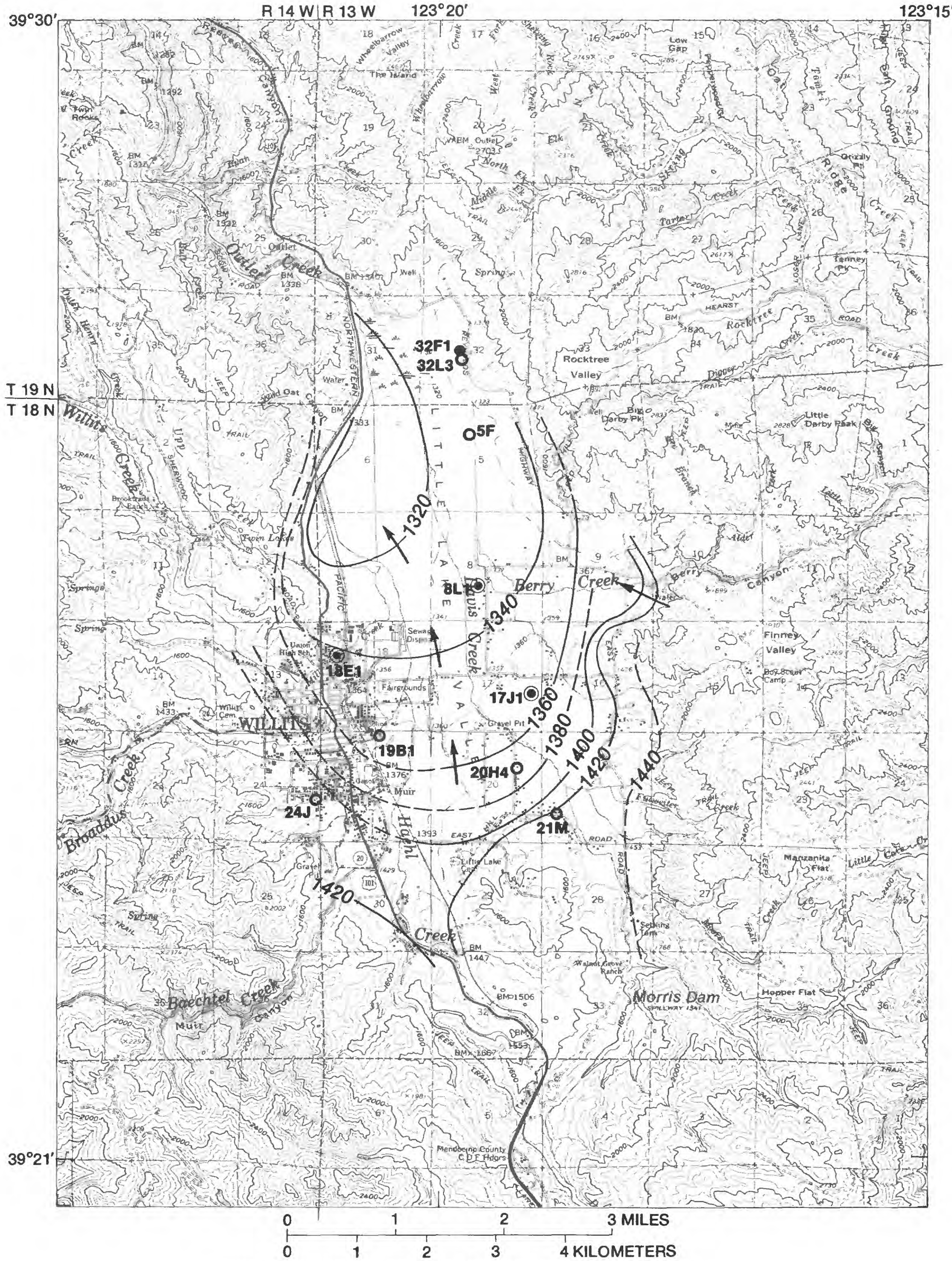
←—— APPROXIMATE DIRECTION OF GROUND-WATER MOVEMENT

WELL AND NUMBER

32F1 ● Well with hydrograph shown in figure 11

19B1 ○ Well included in proposed ground-water-level monitoring network

18E1 ◉ Well included in proposed ground-water-level monitoring network with hydrograph shown in figure 11



Contour interval 80 feet; where dotted, 40 feet. National Geodetic Vertical Datum of 1929

FIGURE 12. – Water-level contours in Little Lake Valley, September-October 1981, and location of wells for proposed ground-water-level monitoring network.

Surface water recharges the ground-water reservoir by infiltration along the channels of the several creeks draining into Little Lake Valley. Downward percolation of surface water impounded for livestock or irrigation also may recharge the ground-water reservoir.

Return flows from sewage-disposal facilities and excess irrigation water are minor sources of recharge. The city of Willits is served by a municipal sewage system that processes about 1 million gal/d. The treated waste water is used to irrigate local parks and pastureland or is discharged to Outlet Creek during the wet season. Rural areas of the valley rely on individual septic systems for sewage disposal. Part of the sewage from rural systems and part of the treated municipal sewage recharge the ground-water reservoir; part of each is lost by evaporation from the shallow soil zone.

The possibility of ground water moving upward from great depths along fault zones is supported by the high concentrations of sodium, chloride, and boron noted in water samples from some wells along the east side of the valley.

Sources of discharge in Little Lake Valley include evapotranspiration (ET), pumpage from wells, and discharge to streams. Total ET includes all the water transpired by plants (both crops and native vegetation) and evaporation from moist surfaces and water bodies. Total ET is difficult to quantify because the quantity of water transpired by native vegetation is not known. Although no estimate of the quantity of water consumed by ET is presented here, estimates of total pumpage and natural discharge to streams are given.

Irrigation is restricted to about 500 acres of pastureland, and the quantity of water pumped for irrigation is estimated to be about 1,000 acre-ft/yr. Residents of the city of Willits are supplied water from Morris Reservoir, and most of the remaining 4,000 residents in Little Lake Valley obtain water from individual domestic wells. Based on population and an estimated per capita use of 200 gal/d (California Department of Water Resources, 1983), total urban use is about 900 acre-ft/yr.

Ground-water discharge to streams during the dry period, May to October, is estimated to be about 2,000 acre-ft. This estimate is based on discharge measurements of Outlet Creek during periods of baseflow (Cardwell, 1965). The amount of ground water discharged to streams during the rainfall season, November to April, probably exceeds 2,000 acre-ft, but insufficient data are available to make a more accurate estimate.

Available Supply

Ground-water pumpage for all uses in Little Lake Valley is about 2,000 acre-ft/yr. An additional 2,000 acre-ft contributes to baseflow of streams during the dry season. The quantity of ground water discharged to streams during the rainy season is not known. During years when winter precipitation exceeds about 75 percent of normal, the ground-water reservoir is filled to capacity. Because the ground-water reservoir is refilled most years (as shown by water-level data), the quantity of ground water discharged as baseflow during the rainy season represents rejected potential recharge. This rejected recharge could be captured in part by lowering ground-water levels through increased pumpage.

The quantity of ground water lost from native vegetation through evapotranspiration is unknown. This quantity is probably quite significant because of the shallow water table and the considerable vegetation along streams. Part of the water consumed by evapotranspiration could be conserved by lowering ground-water levels. Any significant lowering of the water table probably would cause adverse effects on the native riparian vegetation.

The estimated 45,000 acre-ft of ground water available from Type I and II availability areas is many times greater than the estimated total of 4,000 acre-ft discharged to streams during the dry season and pumped for urban and agricultural uses. A significant additional unknown quantity of water is consumed by evapotranspiration from native vegetation.

Chemical Quality of Water

The chemical quality of water was analyzed from 20 samples collected from 17 wells in Little Lake Valley. The samples were analyzed at the U.S. Geological Survey's Central Laboratory in Arvada, Colorado. The relative abundance and actual concentrations of dissolved constituents vary significantly (fig. 13). The concentrations of 23 constituents are shown in table 4. Two distinct water types can be identified from these data: (1) Water in which calcium, magnesium, and bicarbonate are predominant and chloride and sodium are minor, and (2) water in which sodium and chloride are predominant and the dissolved-solids concentration is high relative to the first type. Water from wells 7A, 31P, and 5F, for example, is typical of bicarbonate-rich water. Water from well 9E is typical of sodium chloride water. Mixtures of these two waters probably account for intermediate variations observed in water from wells such as 9D, 9R, and 31G.

The chemical quality of the bicarbonate water is generally acceptable for domestic, agricultural, or industrial uses. The dissolved solids in this water range from less than 100 to about 350 mg/L. Concentrations of iron and manganese generally exceed the secondary maximum contaminant levels for drinking water (U.S. Environmental Protection Agency, 1977). However, this standard was set on the basis of consideration of taste and cosmetic factors (staining of laundry and plumbing fixtures); the standard is not based on detrimental health effects. None of the other constituents tested exceed the U.S. Environmental Protection Agency (EPA) standards.

The chemical quality of the sodium chloride water may be unacceptable for some uses. A gas exploration hole in sec. 21 produced water with a sodium chloride concentration of 1,064 mg/L from a depth zone of 930 to 986 feet. Well 18N/13W-9E, located in the northeast part of the valley and drilled to a depth of 128 feet, produced water with sodium and chloride concentrations of 510 and 770 mg/L, respectively, which is greater than three times the chloride concentration permissible under EPA standards. This sample also contained 1,710 mg/L dissolved solids. Mixtures of sodium chloride water and bicarbonate water result in water with intermediate concentrations of dissolved solids and chloride.

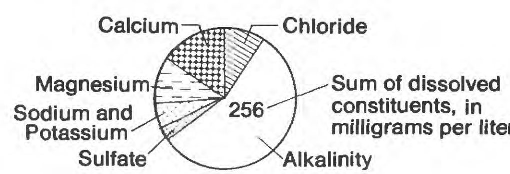
EXPLANATION FOR FIGURE 13

9R● WELL AND NUMBER

BORON CONCENTRATION --In micrograms per liter. Number in box Indicates specific concentration

40	0–500
970	501–1000
9100	> 1000'

CHEMICAL QUALITY DIAGRAM



Relative proportions of major dissolved constituents

0 100 200 300 400

MILLIGRAMS PER LITER

Diameter of circle proportional to dissolved-solids concentration. Circumference dashed where scale changed.

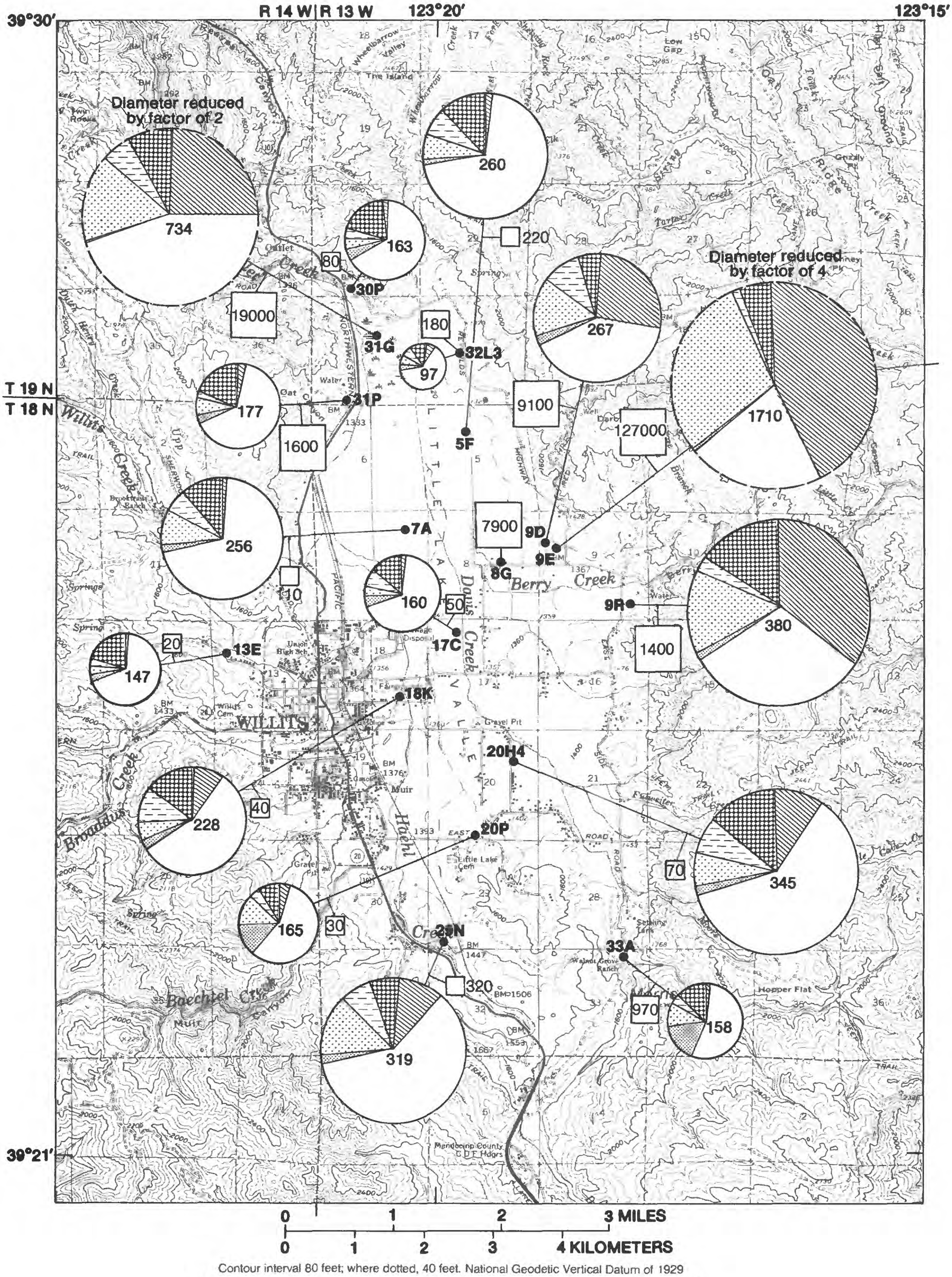


FIGURE 13. – Chemical quality of ground water, Little Lake Valley.

Table 4.-- Chemical quality of ground water in Little Lake Valley

[EPA standard: National Interim Primary Drinking Water Regulation, U.S. Environmental Protection Agency, 1975; and National Secondary Drinking Water Regulations, U.S. Environmental Protection Agency, 1977]

	Number of analyses	Maximum	Minimum	Mean	EPA standard
Major constituents, in milligrams per liter					
Alkalinity as $CaCO_3$	17	380	67	170	--
Calcium	17	89	11	37	--
Chloride	17	770	2.9	80	250
Fluoride	17	3.4	.1	.35	1.8
Magnesium	17	39	4.9	17	--
Nitrogen NO_2+NO_3 as N	17	7.2	0	.7	10
Potassium	17	2.9	.5	1.2	--
Silica	17	57	11	28	--
Sodium	17	510	6.0	58	--
Sulfate	17	24	5.0	7.5	250
Sum of dissolved constituents	16	1,710	97	340	--
Minor constituents, in micrograms per liter					
Aluminum	8	<100	<100	<100	--
Arsenic	8	16	1.0	4.1	50
Barium	8	500	40	185	1,000
Boron	20	127,000	20	8,600	--
Cadmium	8	<30	<1.0	<5.6	10
Chromium	8	<10	<10	<10	50
Copper	8	40	<10	<24	1,000
Iron	18	16,000	<10	<2,250	300
Lead	8	<100	0	<88	50
Manganese	17	1,700	3.0	528	50
Mercury	8	1.8	<.1	<.58	2
Nickel	8	<100	<100	<100	--
Zinc	8	150	5.0	37	5,000

Boron.--Boron was analyzed in 20 samples; concentrations ranged from 20 to 127,000 µg/L. EPA has set no standard for this element. Boron is known to be required by plants in small amounts but is toxic to plants at higher concentrations. The sensitivity of crops to boron varies considerably, but water with concentrations of less than 1,000 µg/L generally may be applied to crops without adverse effects. Boron concentrations exceeded 2,000 µg/L in 4 of 20 samples; the 4 samples were taken from wells located in the north and northeast parts of the valley. The boron may originate from water moving up from great depth along the fault zone located along the east and northeast sides of the valley (fig. 8).

Because ground water contains high concentrations of boron in some parts of the valley, it would be advisable to analyze for boron concentrations in water from newly drilled wells before applying the water to crops.

Gases.--Both flammable and nonflammable gases have been reported in wells, primarily in the central and eastern parts of the valley. Samples of gas collected from five wells and analyzed by the Research Branch of the Pacific Gas & Electric Co. (J. Kiely, written commun., 1979) indicate that the gas consists of varying mixtures of carbon dioxide, oxygen, argon, nitrogen, and methane. The methane is not present in commercial concentrations but has been used in the past by some local residents for heating (Carpenter and Millberry, 1914). The methane probably originates from decomposition of organic matter contained in the sediments of the continental basin deposits.

The presence of gas in water generally would pose no problems. If considerable gas were present, provisions for venting the wells might be needed. Caution to avoid ignition of the flammable gas should be considered.

Potential for contamination.--Because ground water generally is found at shallow depths in Little Lake Valley, the potential for contamination is high. Liquid contaminants or those soluble in water could pass quickly through permeable alluvial materials, especially during the rainy season.

Cases of minor contamination have been reported (J. Davis, Director, Mendocino County Division of Environmental Health, written commun., 1985). Most of these cases involved leakage of gasoline from underground storage tanks.

Laytonville Valley

Description of Area

Laytonville Valley is located in the northern part of the county about 40 miles north of Ukiah (fig. 1). The valley floor occupies about 7 mi^2 and is drained to the north by Ten Mile Creek and to the south by Long Valley Creek. Both streams are part of the Eel River drainage.

The town of Laytonville, in the northeastern part of the valley, is the only community in the area. The town is served by a community water system that obtains its supply from one well located in the central part of the valley. Outlying residences and farms rely on individual wells for water.

Water-Bearing Formations

Valley fill, which has been subdivided into continental terrace deposits and Holocene alluvium, occupies about 6 mi^2 in the main part of the valley (fig. 14). In addition, isolated patches of continental terrace deposits and alluvium are present northwest and southwest of the main part of the valley and cover a cumulative total of about 5 mi^2. These thin patches probably do not contain appreciable quantities of ground water.

EXPLANATION FOR FIGURE 14

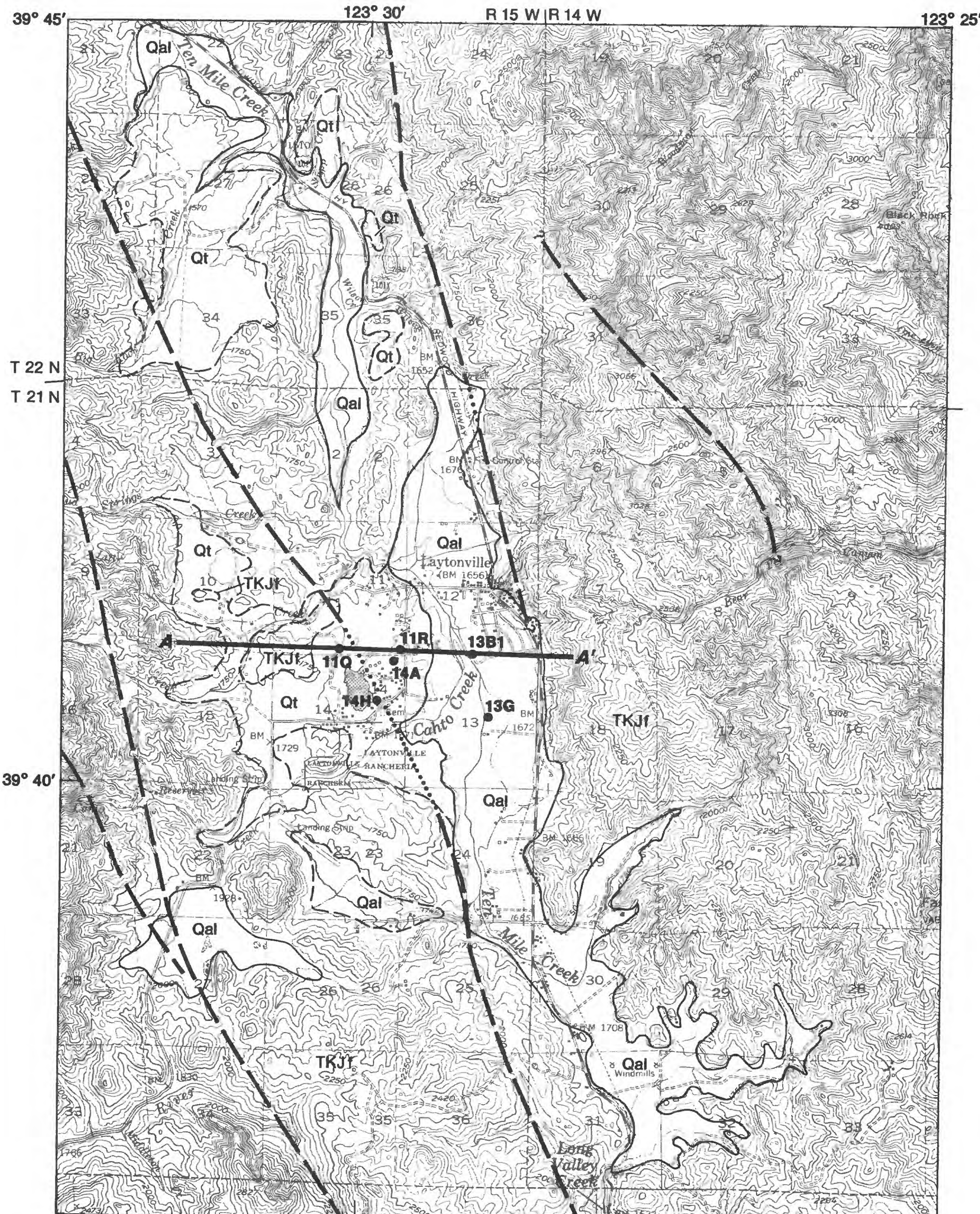
Qal	Alluvium	Holocene	Quaternary
Qt	Continental terrace deposits	Pleistocene and Pliocene	Tertiary
		Unconformity	
TKJf	Franciscan Complex, undifferentiated		Tertiary, Cretaceous, and Jurassic

CONTACT – Dashed where approximately located

FAULT – Shows approximate location; dotted where concealed, queried where uncertain

A——A' LINE OF GEOLOGIC SECTION (See figure 15)

13B1 WELL AND NUMBER – Shows location of well used for geologic section or mentioned specifically in section on "Water-Bearing Formations" in text



0 1 2 3 MILES

0 1 2 3 4 KILOMETERS

Contour interval 50 feet. National Geodetic Vertical Datum of 1929

Geology modified from G.T. Cardwell (1965), California Department of Forestry (1979), and E.H. Pampeyan and others (1980).

FIGURE 14. – Geology of Laytonville Valley area.

Continental terrace deposits.--The continental terrace deposits, exposed over an area 2 to 3 mi^2 west and northwest of the main part of the valley, are composed of gravel, sand, silt, and clay. The deposits are weakly cemented in places and strongly dissected by streams over the area of exposure. The terrace deposits are the remnants of older alluvium that filled the prehistoric valley to an unknown depth before being partially removed by erosion. These deposits underlie most of the valley and are covered by Holocene alluvium where not exposed at the surface (fig. 15).

Where exposed at the surface, the terrace deposits are probably no more than 50 feet thick, but where covered by Holocene alluvium, the deposits attain a thickness of about 200 feet. In the subsurface, the contact between the terrace deposits and Holocene alluvium usually cannot be discerned because of the similarity of descriptions given on drillers' logs. The only difference in lithology is the partial cementing of some beds in the terrace deposits.

The water-yielding potential of this unit is limited by the reduction in permeability due to cementation and by its thinness except where covered by Holocene alluvium. Wells completed in places where the terrace deposits are less than about 15 feet thick and where there is no overlying alluvium commonly go dry during autumn. More commonly the terrace deposits are partially saturated all year and can provide enough water to supply domestic wells. Well 21N/15W-14H (fig. 14), drilled to a depth of 50 feet close to the edge of a small lake that recharges the deposits, has a reported yield of 25 gal/min and a specific capacity of 1.47 (gal/min)/ft. Well 21N/15W-14A, 49 feet deep and about 0.25 mile from the lake, has a reported yield of 10 gal/min and a specific capacity of 0.29 (gal/min)/ft. These two wells show the variability of yield in the terrace deposits.

EXPLANATION FOR FIGURE 15

DESCRIPTION OF GEOLOGIC UNITS

Qal — Alluvium — Holocene — Quaternary

Qt — Continental terrace deposits — Pleistocene and Pliocene — Tertiary

Unconformity

TKJf — Franciscan Complex, undifferentiated — Tertiary, Cretaceous, and Jurassic

— — ? — — GEOLOGIC CONTACT — Location approximate

FAULT — Arrows show relative displacement

DESCRIPTION OF LITHOLOGY

11R — Well number (Wells have been projected into line of section.)

Y / B / B / B / Rock — 20, 30, 50, 65, 76 — Depth to corresponding changes in lithology, in feet below land surface

Soil

B — Clay: letter indicates color; B-blue; Br-brown; Y-yellow

Silt

Sand

Gravel

Sh — Shale

Rock — Rock fractured

Rock — Rock unspecified type

Note: combinations of patterns indicate mixtures of materials

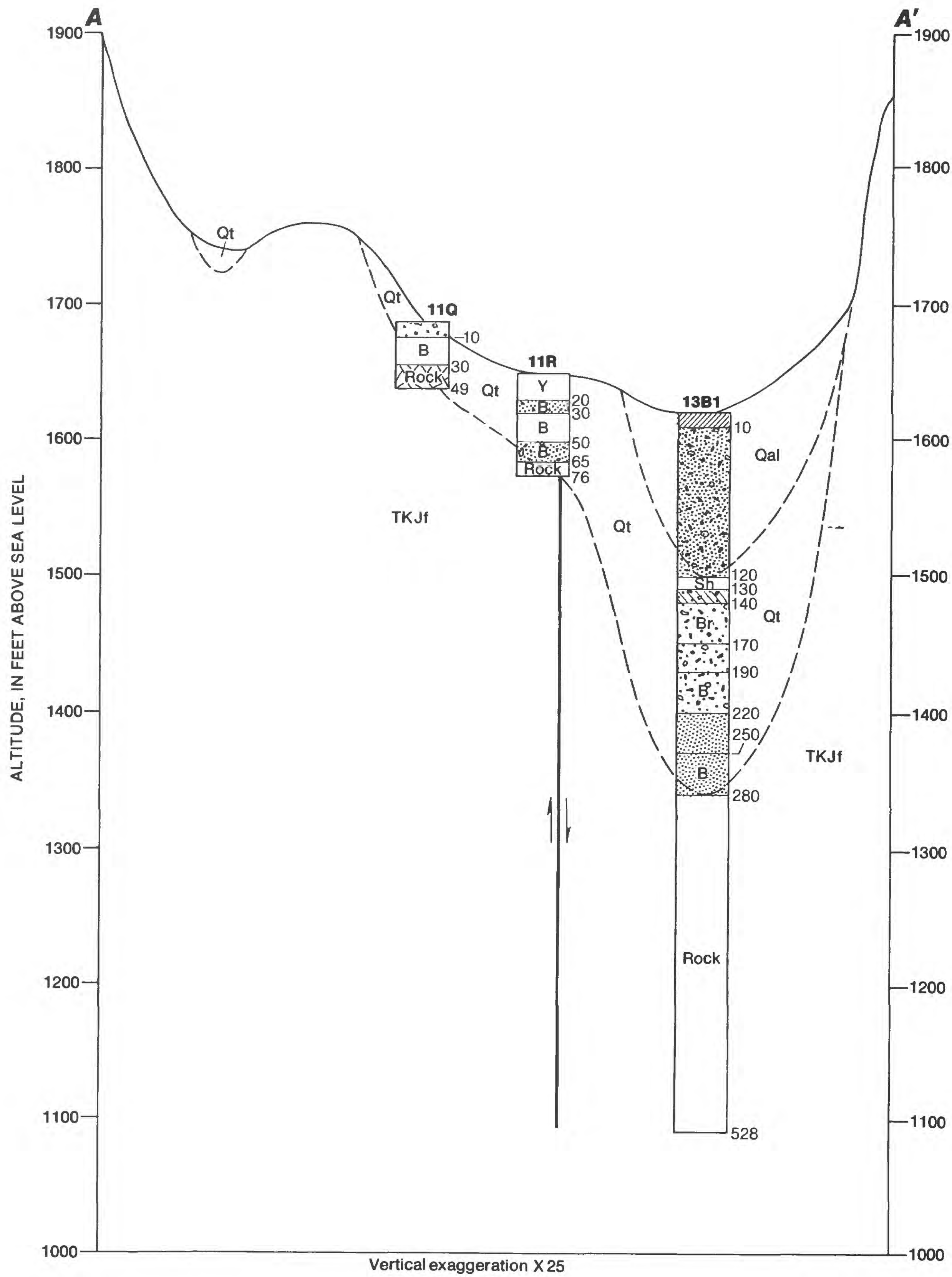


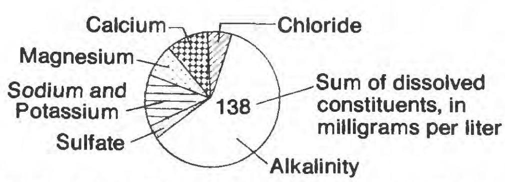
FIGURE 15. — Geologic section, Laytonville Valley.

Holocene alluvium.--Deposits of Holocene alluvium entirely blanket the main part of the valley floor, an area about 4 mi^2. The alluvium overlies continental terrace deposits in the central part of the valley (fig. 15). To the north and south, the alluvium is probably resting on rocks of the Franciscan Complex with no terrace deposits between.

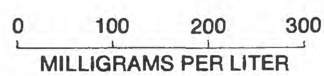
The alluvium is composed of gravel-, sand-, silt-, and clay-sized particles that are uncemented and only slightly compacted. Thickness ranges from zero along margins of the valley to about 150 feet in the central part. The distinction between Holocene alluvium and the underlying terrace deposits is commonly difficult to determine on drillers' logs because of lithologic similarity. The main difference is that the alluvium lacks cementation and is less compacted than the terrace materials.

EXPLANATION FOR FIGURE 16

CHEMICAL QUALITY DIAGRAM



Relative proportions of major dissolved constituents



Diameter of circle proportional to dissolved- solids concentration.

WELL AND NUMBER

• 24P

MAP SYMBOL	GROUND WATER AVAILABILITY	WATER-BEARING UNITS
I	Ground water generally abundant. Production rate and supply sufficient for agricultural, industrial, municipal, and domestic uses.	All coarse-grained consolidated deposits of valley fill where thick and saturated. Any areas reported to have high-capacity wells.
II	Ground water generally available year-round at low production rates. Generally sufficient supply for domestic use; may provide adequate supply for irrigation or industrial use.	Margins of valley fill where partially saturated year-round, or areas where production is proven.
III	Ground water generally present, but production rates are extremely limited or ground water is only seasonally available; may provide sufficient supply for domestic use.	Areas where valley fill is thin, very fine grained, or cemented; or areas where water table seasonally drops below the fill. Includes some areas of shallow ground water, but very low permeability.
IV	Ground water generally not available in significant quantities. Where available, the occurrence is restricted to small areas lithologically or structurally favorable; may provide adequate supply for livestock or domestic use.	Franciscan Complex rocks comprising the mountainous terrain. Rocks are very fine grained or cemented.

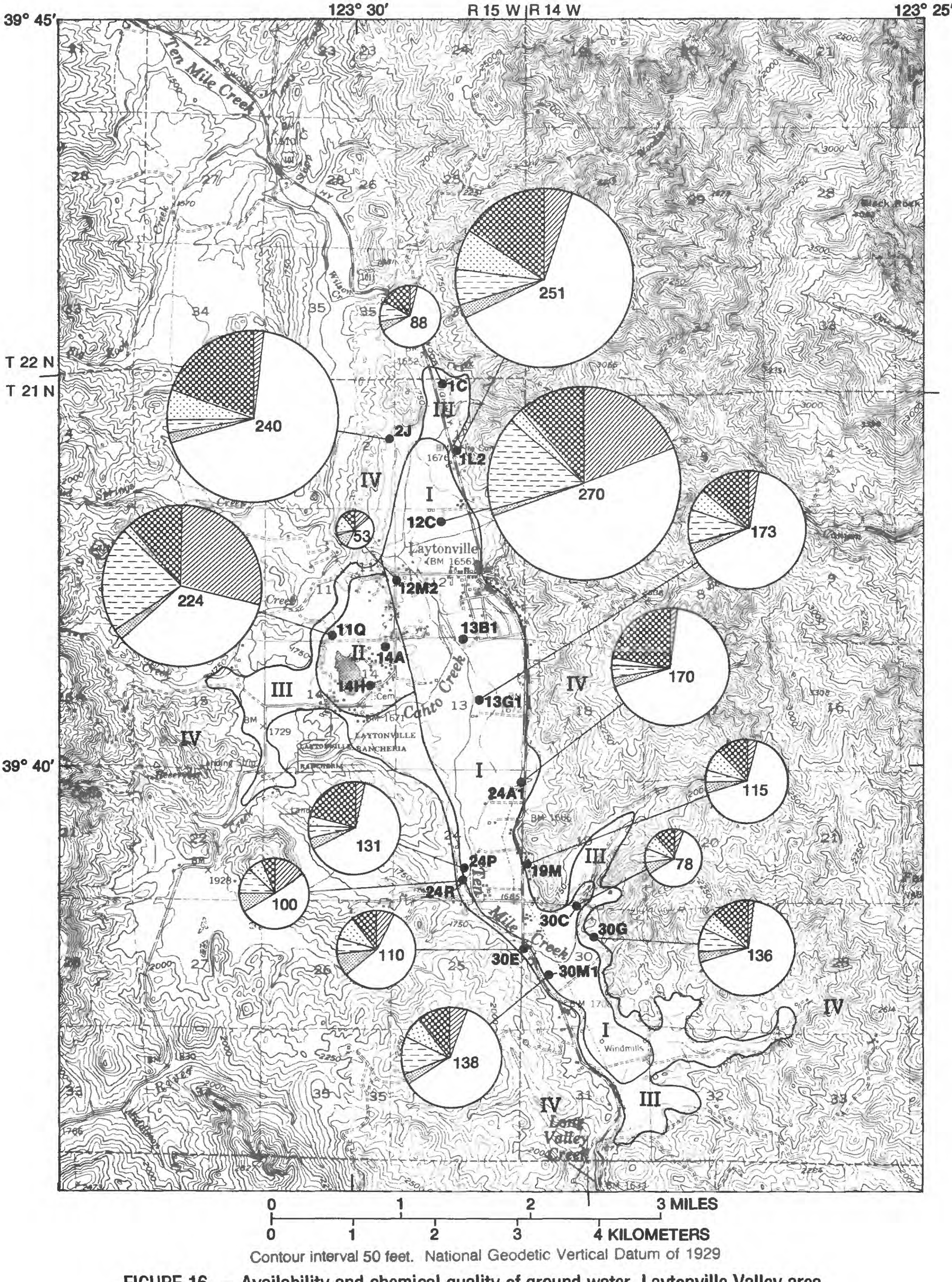


FIGURE 16. — Availability and chemical quality of ground water, Laytonville Valley area.

The alluvial materials are highly permeable and are generally saturated below a depth of 10 to 20 feet. The high permeability, combined with the thick zone of saturation, makes the alluvium a productive aquifer. Wells drilled in the central part of the valley near its axis can provide adequate yields for municipal and irrigation wells. Yields of several hundred gallons per minute have been obtained from wells drilled in favorable areas. Well 21N/15W-13B1 (fig. 16), the supply well for Laytonville's community water system, produced 700 gal/min with about 18 feet of drawdown during a 60-hour pump test shortly after drilling was completed in June 1951. This well was originally drilled to a depth of 528 feet, but has subsequently silted-in to a depth of about 480 feet. The well penetrates about 130 feet of Holocene alluvium and 150 feet of terrace deposits before encountering rocks of the Franciscan Complex at a depth of 280 feet. Most of the water is pumped from the alluvium, but an undetermined quantity comes from the terrace materials and Franciscan rocks. During 1981, this well was being pumped at a rate of about 275 gal/min with a pumping level of about 37 feet in August. Well 21N/15W-13G1 was drillled 423 feet deep in July 1951; a pump test run at that time produced 575 gal/min with 27 feet of drawdown. This well penetrates about 80 feet of alluvium, 60 feet of terrace materials, and 283 feet of rocks of the Franciscan Complex. During 1981, this well was being pumped at 130 gal/min to irrigate pasturelands. The long-term sustained maximum pumping rates for these two wells are not known. The figures cited here, however, indicate that at pumping rates in excess of 100 gal/min, the permeable alluvial materials are not appreciably dewatered. Well yields near the valley margins generally are considerably less than those described here.

For 17 wells obtaining most or all their water from the alluvium, yields range from 7 to 700 gal/min. Specific capacity for 11 wells (that have enough data to compute) ranges from 0.21 to 450 (gal/min)/ft. Two wells have specific capacities less than 1.0 (gal/min)/ft, six wells range between 1 and 7 (gal/min)/ft, and three exceed 10 (gal/min)/ft.

Ground-Water Availability

Ground-water availability in the Laytonville Valley area is classified into four categories: Type I, II, III, and IV (fig. 16). The most favorable area for ground-water production (Type I) extends nearly the entire length of the valley floor, includes about 3 mi^2, and is underlain by Holocene alluvium. Wells drilled in this area can be expected to provide sufficient water for domestic supplies; wells near the valley axis can provide up to several hundred gallons per minute.

The Type II area occupies about 0.6 mi^2 in the western part of the valley and is underlain by terrace deposits as much as 50 feet thick. Wells in this area generally can provide sufficient water for individual domestic supplies but not enough water for community water systems or irrigation.

The Type III areas include a total of about 2 mi^2 and are underlain by thin alluvium or terrace deposits. Wells drilled in Type III areas may provide enough water for individual domestic supplies; however, some wells may go dry during late summer or autumn.

The Type IV area, which includes all the mountainous terrain surrounding the valley, is underlain mostly by rocks of the Franciscan Complex. Well yields in the Type IV area vary widely depending on rock type and geologic structures. Where fractured hard rocks are present, well yields of up to a few hundred gallons per minute may be obtained. Generally, however, yields will be much less, and many sites will be dry. Areas of higher yields are of local areal extent and are widely spaced between areas that are either dry or of very low production capacity. When drilling for water in the Type IV area, careful detailed study of the specific site is necessary to determine the potential for water production.

Estimated Storage Capacity

The quantity of available ground water stored in the upper 100 feet of the most productive areas of valley fill (Type I, fig. 16) is estimated to be about 14,000 acre-ft. This estimate was computed by determining the volume of saturated fill and multiplying this value by the estimated specific yield. Considering the possible errors in estimating the saturated volume and estimated specific yield, the storage capacity could actually range from 9,300 to 17,300 acre-ft.

Additional ground water is available from areas classified as Type II, III, and IV availability. Type II and III areas probably contain an additional 2,000 to 3,000 acre-ft of ground-water storage. The Type IV area contains an undetermined additional quantity; ground-water storage cannot be estimated for this area because of the difficulty in estimating specific yield. The Type IV area is underlain by bedrock of the Franciscan Complex. Many existing wells drilled near the margins of valley fill or in the hills bounding the valley obtain part or all of their yield from fractured sections of the bedrock. Yields from these wells vary widely depending on local conditions.

Water-Level Fluctuations

The water levels in wells in the Laytonville Valley area fluctuate seasonally over a range of about 10 to 15 feet. The water levels are highest in early spring after the ground-water basin has received the bulk of recharge from precipitation. Water levels are generally 10 feet or less below land surface during the seasonal high. Pumping from wells and natural discharge of ground water cause the seasonal decline.

Records of water levels extending over periods of 10 or more years are available for four wells in the valley (fig. 17). Hydrographs for these wells show no significant long-term changes. Water levels measured during the 1980's are similar to those measured during 1960-70. Some differences in the high or low levels from year to year may be seen in the record. These differences are related primarily to the variations in total annual precipitation (California Department of Water Resources, 1981), the distribution of precipitation over time, and the timing of the water-level measurement relative to recent precipitation events.

The most notable deviation from the normal seasonal fluctuations is seen in the records for the drought years of 1976 and 1977. Records of rainfall at Laytonville are incomplete for 1976, but other stations in the county received 60 percent or less of normal rainfall. For 1977, the Laytonville station recorded 45 percent of normal rainfall. The spring high water levels for 1977 in all four hydrograph wells show that the recovery for this period was well below normal. The low water-level measurements made during autumn of 1977 are conspicuously lower than normal in wells 21N/15W-12M2 and 24A1. By spring of 1978, the water levels in all four wells had recovered to normal. Rainfall records for the Laytonville station are incomplete for water-year 1978, but rainfall is estimated to have been 30 percent above normal.

The four hydrographs show that following 2 consecutive years when precipitation was less than 60 percent of normal, water levels recovered to normal after one rainfall season of 30-percent above-normal precipitation. The actual quantity of rainfall during the rainy season, October to April, necessary to fully recharge the reservoir from a low level following a drought (similar to that of 1976-77) may be less than 30 percent above normal, but the available records are not complete enough to determine the minimum quantity required.

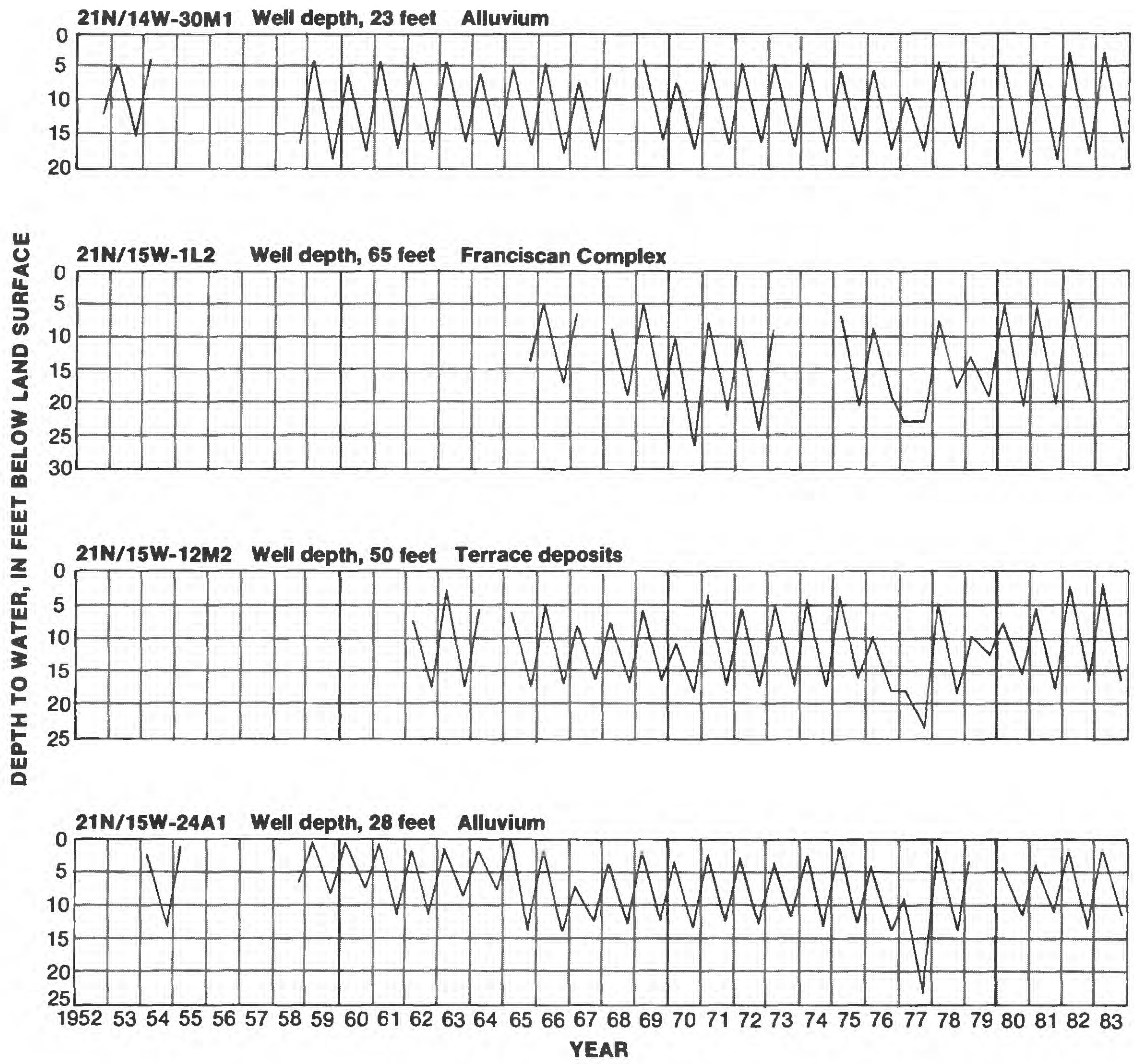


FIGURE 17. — Hydrographs for selected wells in Laytonville Valley. (Well locations shown in figure 18)

Ground-Water Movement

The water-level contour map (fig. 18) shows the approximate altitude of the water table in the valley fill and the approximate direction of ground-water movement. The contours show the water table during January 1982, a time of year when the water table was nearest land surface.

The contours are approximately concentric with the outline of the valley floor and indicate that ground water moves from the valley margins toward the center. Ground water discharges to Ten Mile Creek and leaves the valley as surface flow. Water levels measured during summer and autumn show that, although water levels are lower than in winter, the same concentric pattern of contours is maintained, and ground water moves from the valley margins toward the center. Locally, the water table may be depressed in the vicinity of the larger capacity wells (such as well 13B1) that pump a few hundred gallons per minute on a sustained basis.

Recharge and Discharge

Sources of recharge for the ground-water reservoir include precipitation, surface-water infiltration, return flow from sewage and irrigation, and possibly ground-water inflow from outside the basin. Mean annual precipitation at Laytonville is 56.02 inches. Precipitation is the main source of recharge to the ground-water system. Where precipitation falls directly on permeable valley fill, it can percolate downward and recharge the ground-water reservoir. Where precipitation falls on impermeable materials that compose the hills around the valley, the water moves downslope in countless rills and small channels or within the thin cover of soil. When this flow of surface water crosses the contact between the impermeable materials of the hillsides and the permeable valley fill, it can percolate downward to recharge the ground-water reservoir.

Surface water infiltrating through permeable channel materials is another important source of recharge. During periods of high streamflow, the ground-water reservoir is recharged by infiltration of surface water along the valley margins where streams cross the contact between rocks of the Franciscan Complex and the more permeable valley fill. Near the center of the valley, ground water discharges to Ten Mile Creek.

EXPLANATION FOR FIGURE 18

—*1640*— WATER-LEVEL CONTOUR--Shows altitude of water table. Contour interval 10 and 20 feet. Datum is sea level.

←— APPROXIMATE DIRECTION OF GROUND-WATER MOVEMENT

WELL AND NUMBER

12M2 ● Well with hydrograph in figure 17 and in proposed ground-water-level monitoring network

30G ○ Well in proposed ground-water-level monitoring network

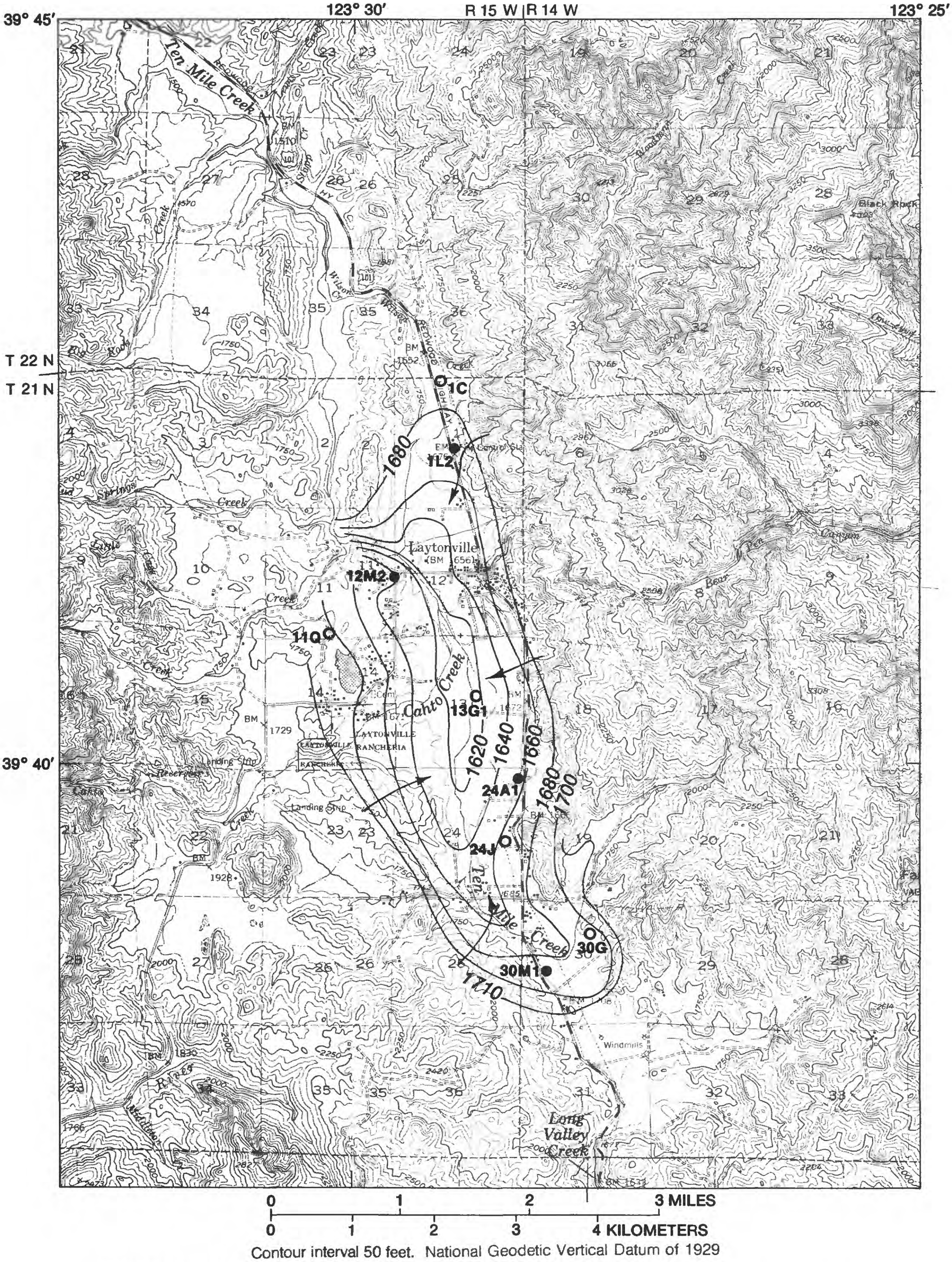


FIGURE 18. – Water-level contours, Laytonville Valley area, January 1982, and location of wells for proposed ground-water-level monitoring network.

The quantity of recharge gained from infiltration of excess irrigation and sewage is small compared to recharge from other sources. Recharge from upflow of ground water along fault zones may occur in places.

Sources of ground-water discharge include pumping from wells, discharge to springs, leakage to streams, and evapotranspiration. Pumpage from wells provides water for the municipal-water system, for individual domestic systems, and for irrigation. Total pumpage is estimated at less than 1,000 acre-ft/yr, based on per capita water use and crop requirements. The amount of discharge from the other sources listed above is not known but probably exceeds the amount pumped from wells.

Available Supply

The estimated 16,000 acre-ft of ground water in storage beneath the areas designated as Type I, II, and III availability (fig. 16) is more than 10 times the quantity of ground water pumped annually from the valley. However, the quantity of ground water lost to evapotranspiration, discharge to springs, and discharge to stream channels (baseflow) is also significant. Increasing ground-water extractions through pumping could reduce the amount of water lost to these sources. The reduction of baseflow in streams or the lowering of the water table by increasing well production could cause adverse changes in native vegetation along streams or in marshy areas and could adversely affect the fauna inhabiting these areas.

Taken as a whole, the valley has abundant ground-water resources; however, the distribution is not uniform. In the part of the valley shown as Type I availability (fig. 16), ground water is abundant, and high water-table conditions are more of a problem than is limited supply. In the areas shown as Type II and III availability, ground-water levels are generally shallow, but the thinness of the saturated valley fill limits the total quantity of ground water available.

Chemical Quality of Water

Chemical analyses were performed on 15 ground-water samples collected during September 1981. The relative abundances and actual concentrations of major dissolved constituents at different sites in the valley show some variations (fig. 16). The ranges of values for 13 constituents are shown in table 5.

In general, the chemical quality of water is acceptable for most uses. For most of the analyses, the concentration of dissolved solids is less than 200 mg/L; the only four greater range from 224 to 270 mg/L. Only iron and manganese are found in concentrations that exceed drinking-water standards (U.S. Environmental Protection Agency, 1975; 1977). The recommended limits set for these two constituents are based on cosmetic considerations. At levels above the recommended maximum, iron and manganese may cause a degradation in taste of water and may cause staining of laundry and porcelain fixtures.

Table 5.-- Chemical quality of ground water in Laytonville Valley area

[EPA standard: National Interim Primary Drinking Water Regulation, U.S. Environmental Protection Agency, 1975; and National Secondary Drinking Water Regulations, U.S. Environmental Protection Agency, 1977]

	Number of analyses	Maximum	Minimum	Mean	EPA standard
Major constituents, in milligrams per liter					
Alkalinity as $CaCO_3$	15	200	18.0	100	--
Calcium	15	58	3.5	24.7	--
Chloride	15	67	2.8	10.1	250
Fluoride	15	.40	.1	.17	1.8
Magnesium	15	19	2.1	9.27	--
Nitrogen NO_2+NO_3 as N	15	.72	.1	.25	10
Potassium	15	1.8	.2	.85	--
Silica	15	39	15	23.1	--
Sodium	15	50	4.2	12	--
Sulfate	15	11	5	5.53	250
Sum of dissolved constituents	15	251	53	149	--
Minor constituents, in micrograms per liter					
Boron	15	420	0	48.7	--
Iron	15	20,000	10	1,764	300
Manganese	15	1,200	200	145	50

On the basis of the relative abundances of major dissolved constituents, two chemical types of water are found. The most prevalent water type is higher in alkalinity and calcium and lower in sodium and chloride. The second type of water is relatively higher in sodium and chloride. Mixtures of these two waters may be found at some of the sample sites.

The variations in concentration of dissolved solids may be related to proximity of the sample location to local recharge sources. The occurrence of sodium chloride water is probably related to the faults transecting the area. The chloride-rich waters may originate at depth through progressive metamorphism of the sedimentary rocks that make up the reservoir (White, 1965); the deep water moves upward along fault zones and mixes with water in the valley fill.

Potential for contamination.--Ground water is found at shallow depths throughout the valley. Because the ground-water reservoir is not protected by a thick cover of soil or rock, contaminants spilled on the land surface or leaking at shallow depth have the potential of reaching the reservoir. Ground-water levels rise to within a few feet of the land surface during the rainy season. Septic systems located in areas of high water levels may be flooded, which may allow mixing of ground water with sewage.

Leggett Area

Description of Area

The Leggett area includes the communities of Leggett and South Leggett and is located in the northwest part of the county along the South Fork of the Eel River (fig. 1). This area is occupied by a few hundred residents living in Leggett and South Leggett and in the hills surrounding these communities. No community water system exists in this area; instead, residents and businesses obtain water from individual wells, springs, or surface-water sources.

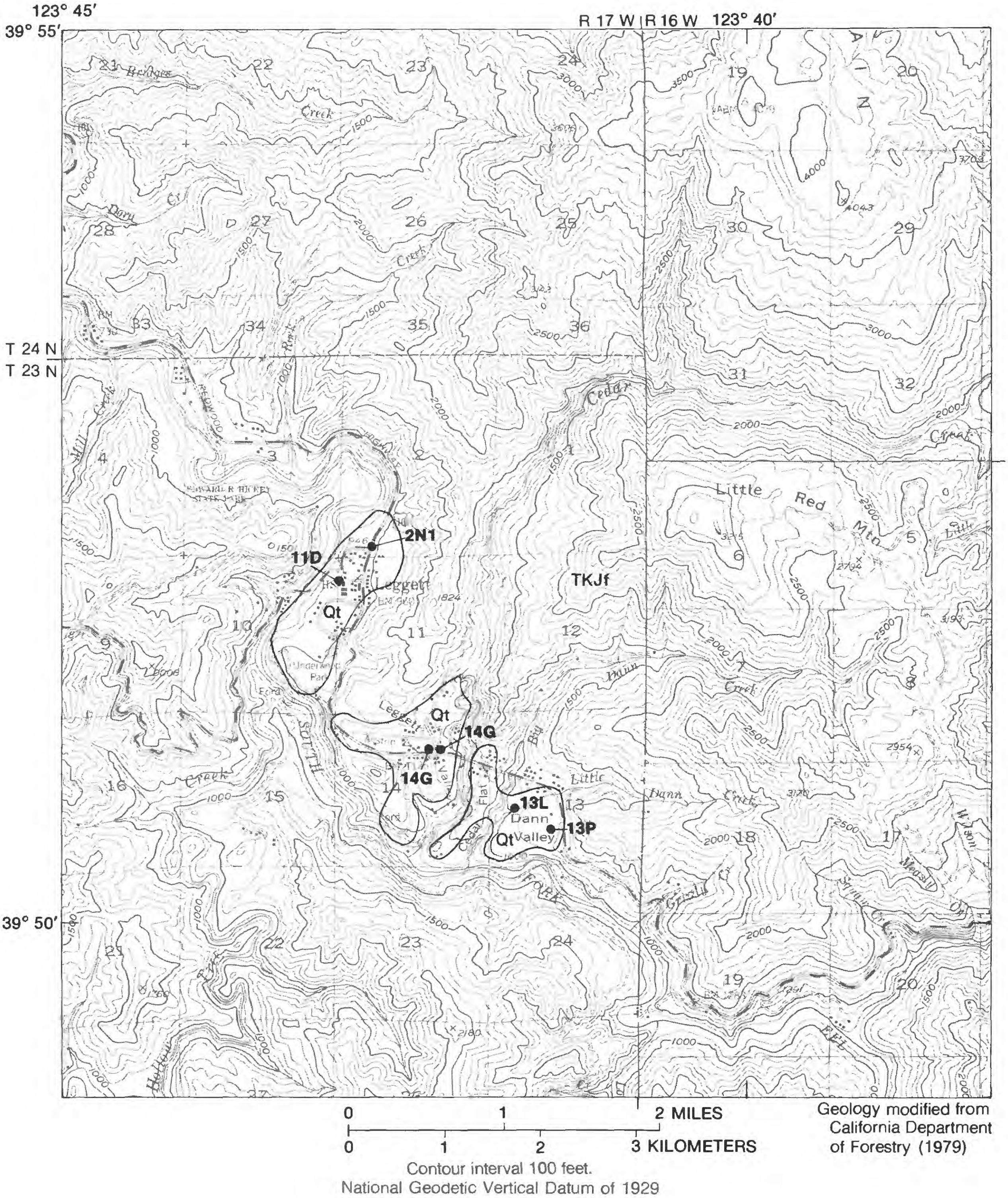
Water-Bearing Formations

Ground water is contained in fractured rocks of the Franciscan Complex and in the overlying continental terrace deposits. Rocks of the Franciscan Complex are mostly consolidated sandstone and mudstone. These rocks have very low primary permeability and, where unfractured, contain little water. Water can be obtained from the Franciscan rocks where fracturing has created secondary permeability. Areas where the Franciscan is fractured and will yield water to wells are generally of limited extent.

Continental terrace deposits crop out over an area totaling about 1.2 mi^2 and underlie three areas separated from one another by rocks of the Franciscan Complex (fig. 19). The deposits contain boulders, gravel, and sand embedded in a silt and clay matrix. The maximum thickness is about 50 feet and in most areas is probably 30 feet or less. Ground-water levels in the deposits vary with location and with the seasons. After receiving recharge from winter rainfall, water levels are generally 10 feet or less below land surface. In late summer, water levels drop 10 feet or more in response to pumping and natural discharge.

Because the terrace deposits contain considerable fine-grained material, the permeability is low. Wells tapping the terraces generally yield 5 to 10 gal/min or less. The small areal extent of the terraces and their thinness greatly restrict the amount of water stored. The total quantity of ground water available from the terraces is estimated at 1,000 to 2,000 acre-ft. Rainfall in this area is sufficient in most years to fully recharge the terraces.

Yields and water levels in wells tapping rocks of the Franciscan Complex vary more than those for wells drilled in terrace deposits. Yields range from less than one to several tens of gallons per minute. Water levels range from near the land surface to 50 feet or more below the surface.



EXPLANATION

Quaternary (Pleistocene)	Qt	Continental terrace deposits – Loosely cemented gravel, sand, silt, and clay
Tertiary, Cretaceous, and Jurassic	TKJf	Franciscan Complex – Consolidated sandstone, shale, limestone, chert, and metamorphic rocks

——— GEOLOGIC CONTACT

•13P WELL AND NUMBER – Chemical sample included in table 6.

FIGURE 19. – Geology of the Leggett area.

Chemical Quality of Water

Ground water in the Leggett area can be classified generally as calcium magnesium bicarbonate, based on the prevalence of major dissolved constituents. The ranges of values for major dissolved constituents in samples from six wells are listed in table 6. Except for iron and manganese, none of the dissolved constituents exceed the drinking-water standards (U.S. Environmental Protection Agency, 1975; 1977). High concentrations of iron and manganese can cause encrustation and plugging of well perforations and pipes. In addition, at concentrations above the EPA standards, iron and manganese can give an unpleasant taste to drinking water and can cause staining of porcelain fixtures or laundry.

Table 6.-- Chemical quality of ground water in Leggett area

[EPA standard: National Interim Primary Drinking Water Regulation, U.S. Environmental Protection Agency, 1975; and National Secondary Drinking Water Regulations, U.S. Environmental Protection Agency, 1977]

	Number of analyses	Maximum	Minimum	Mean	EPA standard
Major constituents, in milligrams per liter					
Alkalinity as $CaCO_3$------------	6	340	98.0	184	--
Calcium-----------------------	6	44	10	24	--
Chloride----------------------	6	38	3.4	17	250
Fluoride----------------------	6	0.2	0	.07	1.8
Magnesium---------------------	6	50	3.6	28	--
Nitrogen NO_2+NO_3 as N----------	6	.01	0	.03	10
Potassium---------------------	6	1.1	.3	.8	--
Silica------------------------	6	46	13	28	--
Sodium------------------------	6	37	7.3	18	--
Sulfate-----------------------	6	5	<5	<5	250
Sum of dissolved constituents--	6	425	149	231	--
Minor constituents, in micrograms per liter					
Boron-------------------------	6	1,500	80	467	--
Iron--------------------------	6	4,600	10	1,302	300
Manganese---------------------	6	880	27	396	50

The Mountainous Areas

Description of Area

Mendocino County is dominated by mountainous topography. Except for the hills immediately adjacent to the populated inland valleys, the mountainous areas of the county are sparsely settled. Because of the lack of development and the large variations in ground-water potential in the mountainous areas, only a general discussion of ground-water conditions is presented here.

The mountainous topography results from the uplift and erosion of consolidated rocks, which are almost exclusively of the Franciscan Complex. The Franciscan Complex, with minor patches of rock in the Great Valley sequence and Tertiary sedimentary rocks, makes up the basement rocks and crops out over about 95 percent of the county.

Ground-water conditions in the basement rocks vary greatly from conditions in the valley fill. The differences in ground-water conditions result from differences in lithology, structural deformation, and topography. Basement rocks include a wide variety of lithologic types: sandstone, graywacke, siltstone, mudstone, limestone, chert, greenstone, serpentine, and others. These rock types result from the lithification of sediments deposited millions of years ago in deep ocean basins and from major structural deformation of the Earth's crust.

The structural disruption that uplifted the flat-lying sedimentary rocks to form mountainous terrain also caused pervasive shearing along zones a few feet to several miles in width. The intense shearing pulverized consolidated rocks in these zones producing fine-grained, clayey material.

The mountainous area, then, consists of boulder- to huge slab-sized masses of various sedimentary and metamorphic rocks interleaved with the clayey materials of large-scale shear zones and slide masses.

Water-Bearing Characteristics of the Basement Rocks

The porosity and permeability of the basement rocks differ greatly from those of the valley fill. Ground water in the valley fill can be likened to the water contained in a saturated sandbox; ground water in the basement rocks can be compared to the water contained in the cracks of fractured concrete. The valley fill consists largely of uncemented (locally loosely cemented) gravel, sand, silt, and clay and has primary porosity and permeability; that is, the void spaces between grains contain ground water. Porosity and permeability in the basement rocks is almost exclusively of secondary origin. Because of great geologic age and varied geologic history, the spaces between grains in the basement rocks are largely filled by the mineral cements of calcium carbonate, silica, and iron oxides. The structural deformation of the basement rocks has produced secondary porosity and permeability by fracturing. In general, the porosity and permeability of secondary origin in the basement rocks is much lower that the porosity and permeability of primary origin in the valley fill.

In addition to having generally lower porosity and permeability than the valley fill, the basement rocks show greater variability in these properties. Wells drilled close to one another in the mountainous terrain may encounter rocks of greatly differing permeability. The wells may be drilled into rocks of the same composition but, because of a difference in degree of fracturing, large differences may result in permeability and, consequently, well yield. On the other hand, nearby wells may encounter entirely different rock types due to the great lithologic heterogeneity of basement rocks. Rock type exerts controls on the development of secondary permeability. Well-bedded sedimentary rocks such as graywacke, siltstone, and chert occur within the basement rocks. The bedding planes are planes of weakness along which fracturing and slipping may occur as the basement rocks undergo deformation. In some rock types that are soluble in water, such as limestone or dolomite, secondary permeability develops where water dissolves parts of the rock. In shear zones, where intense deformation has shattered and ground rocks into clay-sized material, permeability is greatly reduced because of fine-grain size and because fractures do not remain open.

Ground-Water Movement

The paths along which ground water moves through the consolidated basement rocks are fractures and other features of secondary permeability. Where unfractured, the consolidated rocks are virtually impermeable; ground water is almost entirely contained in the fractures and can move only along these planes. Ground water in some fractures is present under confined conditions. Wells drilled into such fractures will flow at land surface, where hydraulic pressure is sufficient.

Sources of ground water in the basement rocks include recharge from precipitation, upflow of ground water from deep sources, and possible connate ground water (water trapped in sediments during deposition). Recharge from precipitation is an important source of ground water in the basement rocks. The relatively low permeability of the basement rocks results in high surface runoff from the mountains. However, the abundant precipitation and heavy vegetation lead to saturation of the soil zone each year. Water moves through the forest litter and thin soil and percolates to fractures in the basement rocks.

Water, long out of contact with the atmosphere, may be present deep within the basement rocks. Such water may be moving along the major fault zones marginal to the inland valleys and may be the source of sodium chloride waters noted in some water samples (White, 1965).

The heterogeneity of the basement rocks results in large variations in water levels in neighboring wells. Wells drilled close together but tapping different fracture systems may show large variations in seasonal water-level fluctuations and well yield. The variations result from differences in position of the well site relative to recharge and discharge points and the number and position of fractures penetrated by each well.

Chemical Quality of Water

The chemical quality of ground water in the basement rocks varies considerably. Part of the variability can be attributed to the source of water. Wells tapping shallow fractured zones in basement rocks often pump water that recharged the system only a short time ago. Because of the short contact time of water with rock, only minor concentrations of dissolved minerals are found in the water. For example, chemical data for two shallow wells near Willits, tapping basement rocks, show that dissolved solids are present in concentrations of 147 and 270 mg/L. The water in both wells is slightly alkaline, and calcium and bicarbonate are the dominant dissolved constituents.

Water pumped from wells tapping deep fracture zones may be highly mineralized. The high concentration of dissolved constituents may be related to original mineralization in connate water, to the long contact time of water with rock, or to higher temperatures at depth.

Water sampled from a well tapping basement rocks near a fault zone east of Willits contained 380 mg/L dissolved solids and had a strong smell of sulfur. This water contained sodium and chloride concentrations about equal to calcium and bicarbonate concentrations.

Vichy Springs, about 3 miles east of Ukiah, consists of a group of springs that issue from basement rocks. Water from these springs contains up to 4,600 mg/L dissolved solids. The water is high in sodium bicarbonate and contains up to 2,000 mg/L dissolved carbon dioxide (Waring, 1915).

Choices for Development of Ground-Water Supply

Ground water in the mountainous areas is not uniformly distributed. Close examination of the geology, surface-water drainage, topography, and other factors is needed in order to select the best well site for a particular locality.

Two distinct types of sites can be identified on the basis of lithology: sites underlain by coherent rock and sites underlain by sheared rock consisting of blocks of rock within a mud matrix. In areas with large masses of coherent rock, zones with the most intense fracturing will provide the best sites for well development. In sheared areas, where fine-grained uncemented materials predominate, the best well sites are generally in topographic lows.

The locations of springs and seeps, and the presence of phreatophytes (Meinzer, 1927) can be useful in determining the best sites for well drilling. Proximity to local sources of recharge, such as ponds or streams, is another important factor.

In addition to site selection, the type of well construction is an important consideration. Most wells are drilled vertically downward into the soil and rocks; wells drilled horizontally or at an angle from vertical are another option. In areas where water is being developed from fractured rock, horizontal drilling commonly is successful in following productive fracture zones. Part of the difference in success between vertical and horizontal drilling may relate to the tendency of fractures to close up at depth due to increased pressure from overlying rocks (lithostatic pressure). In vertical drilling, lithostatic pressure increases with depth, and fractures are forced shut. In horizontal drilling, lithostatic pressures do not increase to the same extent and, therefore, open fractures may be intercepted for greater distances along the well bore.

In shear zones where fractured coherent rocks are subordinate to the mud matrix, ground water is released slowly to wells from the fine-grained materials. One effective approach for a water supply in these areas is to drill large-diameter wells (greater than about 36 inches) and to use a gravel pack from shallow depth to the bottom of the well. This maximizes the open area over which the slow release of ground water can occur. Many wells that provide adequate domestic water supplies have been constructed by excavating a large pit about 15 feet deep with a backhoe. The pit was then backfilled with gravel around a section of perforated well casing. Wells constructed in this fashion are subject to potential contamination from surface water entering the well. Diversion of surface water away from the well site would help prevent contamination.

GROUND-WATER-LEVEL MONITORING NETWORK

Ground water is a valuable resource in Mendocino County. In rural areas, ground water is the main source of water for domestic supplies. Municipal and community water systems depend on ground water in many areas. Ground water is also used in agriculture to augment surface-water supplies.

The quantity of ground water in storage at any time varies in response to recharge, natural discharge, and pumpage from wells. The quantity of ground water in storage may decrease if pumpage exceeds recharge by a significant factor.

One means of keeping track of the quantity of ground water in storage and the variations in storage over time is to measure the water levels in selected wells. By monitoring water levels, plans can be made to implement appropriate changes in the way the resource is being used before major problems arise.

Proposed Network

A network of wells has been selected to monitor the quantity of ground water in storage in each of the main ground-water basins--Ukiah, Little Lake, and Laytonville Valleys (table 7). The locations of monitor wells are shown for Ukiah Valley on plate 3, for Little Lake Valley in figure 12, and for the Laytonville Valley area in figure 18. Monitoring ground-water storage in the mountainous parts of the county is not practical because these areas are hydrologically diverse, and numerous discontinuities exist. Furthermore, ground-water utilization is scant in the mountainous areas, whereas in the main valleys, ground-water utilization is more intense.

Each well in the proposed network should be measured in early spring and again in early autumn. In this way a measure of annual recharge could be provided, and knowledge of the basin's annual low water level could be determined.

In order to interpret the data collected at a particular well site, sufficient information concerning the construction of the well is needed. The following information is considered important to aid in the interpretation of water-level data: (1) Total well depth, (2) well diameter, (3) zones of perforations or openings, (4) finish (type of well construction), (5) depth of well seals, and (6) lithologic log. Information of water use, production rate, and method of drilling also may be helpful. Most of the wells selected for this proposed network have the key items of information available (table 7). Some wells with incomplete records of well construction are included in this network because long-term records of water levels in these wells are available from the California Department of Water Resources. These long-term records are valuable for assessing long-term changes; therefore, continuation of water-level measurements is warranted at these sites.

As conditions change in a ground-water basin, the network should change to effectively monitor the system and provide information on ground-water conditions. More wells or increased frequency of measurements may be required to adequately monitor the basin if pumpage increases. Additional wells may be required for monitoring in areas of new development.

Table 7.--Construction data and years of available record for proposed water-level-monitoring network wells

[ft, feet; in., inches. Finish: F, gravel pack with perforations; P, perforated or slotted; R, rock lined. Water level records available for years shown: Measurement and records by D, California Department of Water Resources; U, U.S. Geological Survey records; O, owner]

Well No.	Latitude north (degrees minutes seconds)	Longitude west (degrees minutes seconds)	Well depth (ft)	Casing diameter (in.)	Depth interval of openings (ft)	Finish	Depth of seal (ft)	Lithologic log available	Water-level records available
Ukiah Valley (well locations are shown on plate 3									
13N/11W-18E1	385917	1230704	52	12	--	-	--	No	1953-84 D
-19P	385756	1230644	44	12	13-42	F	12	Yes	1981-82 U
-21L	385814	1230428	441	12	242-441	F	12	Yes	1981-82 U
14N/12W-5K1	390600	1231217	94	8	69-94	P	0	Yes	1973-84 D
-26F2	390248	1230857	40	8	20-40	F	10	Yes	1973-84 D
15N/12W-8L1	391025	1231234	62	12	--	-	--	No	1951-84 D
-20R	390829	1231149	213	16	50-200	F	0	Yes	1970-84 O
-27F	390808	1231006	202	12	61-203	F	18	Yes	1981-82 U
-34Q1	390635	1230959	112	8	0-111	F	0	Yes	1973-84 D
16N/12W-7A	391544	1231336	165	6	79-157	F	19	Yes	1981-82 U
-9E	391537	1231209	53	18	36-53	F	15	Yes	1981-82 U
-16N2	391410	1231205	274	8	94-274	F	35	Yes	1973-84 D
-32R	391114	1231218	68	12	--	-	--	Yes	1981-82 U
17N/12W-28M1	391745	1231214	73	8	--	-	--	No	1973-84 D
-29P	391739	1231308	101	8	23-101	F	15	Yes	1981-82 U
Little Lake Valley (well locations are shown in figure 12)									
18N/13W-5F	392644	1231944	150	12	50-150	F	10	Yes	1981-82 U
-8L1	392530	1231933	18	48	--	-	0	No	1953-84 D
-17J1	392437	1231902	40	12	23-39	P	0	Yes	1958-84 D
-18E1	392459	1232103	493	12	--	-	--	Yes	1958-84 D
-19B1	392418	1232039	260	12	170-260	F	0	Yes	1981-82 U
-20H4	392404	1231912	26	36	--	R	0	No	1979-84 D
-21M	392343	1231848	71	8	21-71	F	--	Yes	1981-82 U
18N/14W-24J	392348	1232115	74	8	34-74	F	20	Yes	--
19N/13W-32L3	392720	1231945	120	6	80-120	F	20	Yes	1978-84 D
Laytonville Valley (well locations are shown in figure 18)									
21N/14W-30G	393850	1232756	84	6	54-84	F	20	Yes	1981-82 U
-30M1	393834	1232815	23	60	19-23	P	0	Yes	1953-84 D
21N/15W-1C	394235	1232917	150	8	20-58	F	20	Yes	1981-82 U
-1L2	394208	1232907	62	8	--	-	--	No	1953-84 D
-11Q	394051	1233011	49	18	22-49	F	19	Yes	1981-82 U
-12M2	394114	1232938	50	20	--	-	--	No	1962-84 D
-13G1	394025	1232855	423	10	20-423	F	--	Yes	1981-82 U
-24A1	393954	1232832	28	48	--	R	0	No	1952-84 D
-24J	393927	1232838	53	8	15-53	F	--	Yes	1981-82 U

SUMMARY AND CONCLUSIONS

Within the study area, ground water is found in two distinct geologic settings: (1) interior valleys underlain by relatively thick deposits of valley fill, and (2) the mountainous areas underlain by consolidated rocks of the Franciscan Complex.

The mountainous areas make up about 95 percent of the study area, and the six principal interior valleys make up most of the remainder. The interior valleys include Anderson, Laytonville, Little Lake, Potter, Round, and Ukiah Valleys. Ground-water conditions in Round Valley were described in an earlier report (Muir and Webster, 1977). Anderson Valley is being studied by the California Department of Water Resources. Ground-water conditions in Laytonville, Little Lake, and Ukiah Valleys, and the Leggett area are described in this report.

Ground-water availability in each valley is classified into four categories: Type I (most productive), Type II, Type III, and Type IV (least productive).

Type I areas include the central parts of each valley underlain by thick deposits of Holocene alluvium. Type II areas are peripheral to Type I areas and include continental terrace deposits or thin sections of alluvium. Land area, storage capacity, and range of expected well yields are shown for Type I and II areas in Laytonville, Little Lake, and Ukiah Valleys in table 8.

Table 8.-- Land area, storage capacity, and expected well yields in Laytonville, Little Lake, and Ukiah Valleys

[mi^2, square miles; acre-ft, acre-feet; gal/min, gallons per minute]

Valley	Type I areas (most productive)			Type II areas (next most productive)			Water use[2] (acre-ft)
	Area (mi^2)	Storage capacity[1] (acre-ft)	Expected well yields (gal/min)	Area (mi^2)	Storage capacity[1] (acre-ft)	Expected well yields (gal/min)	
Laytonville--	3.0	14,000	50-1,000	0.6	2,000	1-25	1,000
Little Lake--	7.5	35,000	50-1,000	3.0	9,000	1-25	[3]2,000
Ukiah--------	20.0	90,000	50-1,000	19.0	45,000	1-25	41,000

[1]Estimated ground water stored in upper 100 feet of aquifer.
[2]Water for agricultural and urban use.
[3]Does not include water used from Morris Reservoir.

Type III areas are generally along valley margins in areas underlain by thin sections of alluvium or continental terrace deposits and areas with thick sections of continental basin deposits. These materials have a low capacity to yield water to wells; however, quantities of water sufficient to meet the demands of individual homes can be obtained in Type III areas.

Type IV areas generally do not contain abundant ground water, and dry holes are common. The great variability in ground-water potential in these areas requires specific onsite examination in order to select the most favorable drilling sites.

Areas of recharge to aquifers include the permeable materials on valley floors, strips of land along stream channels, and zones along contacts between impermeable and permeable geologic units. If these areas are protected from major modification (paving, building, gravel removal, etc.), continued recharge will resupply ground-water reservoirs.

Historic water-level data from the 1950's to 1984 indicate that no significant lowering of water levels has occurred in Laytonville, Little Lake, or Ukiah Valleys. In each valley water levels fluctuate seasonally over a range of 5 to 15 feet in response to precipitation and ground-water use. During drought years, water levels may remain low; however, the ground-water reservoirs are fully recharged by early spring in years when precipitation equals or exceeds about 60 to 70 percent of normal.

The chemical quality of water in the three valleys is generally acceptable for drinking water supplies, irrigation, and industrial use. Concentrations of dissolved iron and manganese commonly exceed drinking-water standards throughout Mendocino County; while undesirable, this does not seriously diminish the utility of the water for most uses.

High concentrations of boron (greater than 5 mg/L) are found in water from some wells in Little Lake and Ukiah Valleys. In some wells, the boron concentration is well above the tolerance level of many crops. Although restricted to localized areas, the high levels of boron probably constitute the most significant chemical-quality problem in Little Lake and Ukiah Valleys.

Potential for contamination of ground-water resources in the main valley areas emphasized in the study exists primarily because of the shallow depth to the water table. The greatest potential for contamination includes areas underlain by permeable materials, areas with poor surface drainage, excavation sites, areas where septic tanks are in use, and some agricultural areas where fertilizers or pesticides are applied heavily.

Ground water obtained from wells drilled in the fault zones along valley margins or from wells drilled to depths exceeding 100 to 200 feet may produce highly mineralized water (dissolved constituents greater than 1,000 mg/L). Water from the wells may contain high concentrations of sodium and chloride, and the wells may produce gas (carbon dioxide and methane).

In the Leggett area, moderately permeable terrace deposits underlie about 1.2 mi^2 and store an estimated 1,000 to 2,000 acre-ft of ground water. Because of the thinness and restricted areal extent of the terrace deposits, many wells in the Leggett area obtain part or all of their water from consolidated rocks of the Franciscan Complex.

Ground-water conditions in the mountainous areas are difficult to characterize because of the heterogeneity and the wide variation in permeability of rocks. Two distinct areas can be identified: (1) areas underlain by coherent sedimentary rocks, and (2) areas underlain by clay-size materials enclosing blocks of various rock types.

In the areas underlain by coherent sedimentary rocks, ground water can be obtained in localized areas from wells that intercept water moving through extensively fractured zones. The fractured zones with potential for ground-water production are generally widely separated by unproductive zones. Site-specific studies are needed to determine the most favorable locations for drilling.

In the areas of shear zones where large blocks of rock are contained in a matrix of clay-size material, ground water is yielded very slowly to wells. In such areas, ground-water resources commonly will be insufficient even to meet the domestic water demand of individual residences.

Ground water is an important resource for Mendocino County. In order to determine the quantity in storage, a ground-water-level monitoring network is proposed, consisting of 15 wells in Ukiah Valley and 9 wells each in Little Lake and Laytonville Valleys. The monitoring would consist of measuring water levels in each of the wells twice each year.

Further studies of ground-water resources in the county would be useful. Test drilling and aquifer testing in the thick alluvial areas of Laytonville, Little Lake, and Ukiah Valleys could provide the basis for better estimates of storage capacity, maximum well production, and the effects of pumping on neighboring wells. Additional water sampling could better define areas and depths where water high in boron, sodium, or chloride is present. Also, experimentation with different well-construction techniques could help to maximize well yields in the mountainous areas.

REFERENCES CITED

Akers, J.P., 1966, Domestic water supply for the Hopland Indian Rancheria, Mendocino County, California: U.S. Geological Survey open-file report, 10 p.

Bailey, E.H., Blake, M.C., Jr., and Jones, D.L., 1970, On-land Mesozoic oceanic crust in California Coast Ranges: U.S. Geological Survey Professional Paper 700-C, p. 70-81.

Barnes, Ivan, 1970, Metamorphic waters from the Pacific tectonic belt of the west coast of the United States: Science, v. 168, p. 973-975.

Blake, M.C., Jr., Campbell, R.H., Dibblee, T.W., Jr., Howell, D.G., Nilsen, T.H., Normark, W.R., Vedder, J.C., and Silver, E.H., 1978, Neogene basin formation in relation to plate-tectonic evolution of San Andreas fault system, California: American Association of Petroleum Geologists Bulletin, v. 62, no. 3, p. 344-372.

Blake, M.C., Jr., and Jones, D.L., 1981, The Franciscan assemblage and related rocks in Northern California: A reinterpretation, _in_ Ernst, W.G., ed., The geotectonic development of California: New Jersey, Prentice-Hall Inc., p. 307-328.

Brown, R.D., Jr., and Wolfe, E.W., 1973, Map showing recently active breaks along the San Andreas fault between Point Delgada and Bolinas Bay, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-692, 2 sheets, 1:24,000.

California Department of Forestry, 1979, Geologic maps of Mendocino County-Branscomb, Hopland, Laytonville, Leggett, Potter Valley, Ukiah, Willits: 15-minute quadrangles, 1:62,000, unpublished.

California Department of Water Resources, 1958, Recommended water well construction and sealing standards, Mendocino County: Bulletin 62, 169 p.

-----1975, Vegetative water use in California, 1974: Bulletin 113-3, 104 p.

-----1977, Russian River service area--present and projected relation of water use to demand: Draft report, January 1977, Central District, 139 p.

-----1980, 1979 land use survey, Russian River Hydrographic Unit: unpublished data.

-----1981, California rainfall summary--monthly total precipitation 1849-1980: 43 p.

-----1982, Mendocino County coastal ground-water study: 86 p.

-----1983, Urban water use in California: Bulletin 166-3, October 1983, 239 p.

-----1985, Town of Mendocino ground-water study: 71 p.

California Division of Mines and Geology, 1960, Geologic map of California: Ukiah sheet, 1:250,000.

-----1982, Geologic map of California: Santa Rosa sheet, 1:250,000.

Cardwell, G.T., 1965, Geology and ground water in Russian River valley areas, and in Round, Laytonville, and Little Lake Valleys, Sonoma and Mendocino Counties, California: U.S. Geological Survey Water-Supply Paper 1548, 154 p.

Carpenter, A.D., and Millberry, P.H., 1914, History of Mendocino and Lake Counties, California: Los Angeles, Calif., Historic Record Co., 1045 p.

Fox, K.F., Jr., 1983a, Melanges and their bearing on late Mesozoic and Tertiary subduction and interplate translation at the west edge of the North American plate: U.S. Geological Survey Professional Paper 1198, 40 p.

-----1983b, Tectonic setting of late Miocene, Pliocene, and Pleistocene rocks in part of the Coast Ranges north of San Francisco, California: U.S. Geological Survey Professional Paper 1239, 33 p.

Gough, L.P., Shacklette, H.T., and Case, A.A., 1979, Element concentrations toxic to plants, animals, and man: U.S. Geological Survey Bulletin 1466, 80 p.

Hsu, K.J., 1968, Principles of melanges and their bearing on the Franciscan-Knoxville paradox: Geological Society of America Bulletin, v. 79, p. 1063-1074.

Hubbard, H.G., 1943, Carbon dioxide gas occurrences in Mendocino and northern Sonoma Counties: California Division of Mines and Geology Report 39, p. 301-309.

Maxwell, J.C., 1974, Anatomy of an orogen: Geological Society of America Bulletin, v. 85, p. 1195-1204.

McLaughlin, R.J., and Nilsen, T.H., 1982, Neogene nonmarine sedimentation and tectonics in small pull-apart basins of the San Andreas fault system, Sonoma County, California: Sedimentology, v. 29, no. 6, p. 865-876.

Meinzer, O.E., 1927, Plants as indicators of ground water: U.S. Geological Survey Water-Supply Paper 577, 95 p.

Muir, K.S., and Webster, D.A., 1977, Geohydrology of part of the Round Valley Indian Reservation, Mendocino County, California: U.S. Geological Survey Water-Resources Investigations 77-22, 40 p.

Orchard, D.M., 1979, Geology of the Robinson Creek-Ukiah area, northern Coast Ranges, California: Austin, University of Texas, M.S. Thesis, 89 p.

Pampeyan, E.H., Harsh, P.W., and Coakley, J.M., 1980, Preliminary map showing recently active breaks along the Maacama fault zone between Hopland and Laytonville, Mendocino County, California: U.S. Geological Survey Open-File Report 80-662, 32 p., 10 sheets.

Rantz, S.E., 1968, Average annual precipitation and runoff in north coastal California: U.S. Geological Survey Hydrologic Investigations Atlas HA-298, 4 p., 1 sheet.

Simon, R.B., Pampeyan, E.H., and Stover, C.W., 1978, The Willits, California, magnitude 4.8 earthquake of November 22, 1977: U.S. Geological Survey Open-File Report 78-1075, 24 p.

U.S. Environmental Protection Agency, 1975, National interim primary drinking water regulations: Federal Register, v. 40, no. 248, Wednesday, December 24, 1975, Part IV, p. 59566-59587.

-----1977, National secondary drinking water regulations: Federal Register, v. 42, no. 62, Thursday, March 31, 1977, Part I, p. 17143-17147.

Waring, G.H., 1915, Springs of California: U.S. Geological Survey Water-Supply Paper 338, 410 p.

White, D.E., 1965, Saline waters of sedimentary rocks, in Fluids in subsurface environments--a symposium: American Association of Petroleum Geologists, Memoir No. 4, p. 342-366.

GLOSSARY

Aquifer: A body of rock or unconsolidated earth materials that contains sufficient saturated permeable material to yield usable quantities of water to wells.

Basement rocks: In this report, refers to all rocks of pre-Pliocene age. This grouping includes primarily rocks of the Franciscan Complex and the Great Valley sequence. These rocks are consolidated and mostly well cemented but also include the clayey matrix material, widely distributed in shear zones.

Cement: Mineral material, usually chemically precipitated, that fills the pore spaces of sedimentary rocks and binds individual grains together.

Clay: In this report, used in reference to particle size. Any particle less than 0.00015 inch or 0.004 millimeter in diameter.

Confined water: Ground water that is under pressure sufficient to cause it to rise above the level at which it was first encountered in the well.

Evapotranspiration: A compound word for the water lost through vaporization from soil and water surfaces and the water consumed by plants.

Ground water: Underground water (or subsurface water) that is found within the saturated zone.

Ground-water reservoir: An aquifer (or group of interconnected aquifers) with specific boundaries that hydrologically separate it from aquifers in neighboring areas.

Head: In this report, used synonymously with total head. Includes elevation head and pressure head; for nonflowing wells is equal to the difference between altitude of the measuring point and the depth to water.

Lithology: Description of rocks in terms of mineralogy, origin, history, and physical properties.

Permeability: Synonymous with hydraulic conductivity. A measure of the capacity of an aquifer to transmit water. It is related to porosity and the size, shape, and interconnection between pore spaces and other openings in the aquifer.

Porosity: The ratio of openings (voids) to the total volume of soil or rock expressed as a decimal fraction or as a percentage.

Potentiometric surface: A surface which represents the static head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells. Where the head varies appreciably with depth in the aquifer, a potentiometric surface is meaningful only if it describes the static head along a particular specified surface or stratum in that aquifer. More than one potentiometric surface is then required to describe the distribution of head. The water table is a particular potentiometric surface (Lohman, 1972).

Specific capacity: A measure of well productivity, it is the yield per unit of drawdown expressed as gallons per minute per foot of drawdown.

Specific yield: The quantity of water that a unit volume of material will yield when drained by gravity, expressed as a decimal fraction or as a percentage.

Storage capacity: The total amount of ground water that could be pumped from a reservoir regardless of quality or economic cost.

Water table: The level at which water stands in wells that are drilled just deep enough to hold standing water. Deeper wells will have water levels below the water table in areas of downflow and levels above the water table in areas of upflow. (See also Potentiometric surface.)

Further explanation of terms and discussion of hydrologic principles can be found in one of many basic hydrology texts. The following U.S. Geological Survey publications provide informative discussions of basic principles:

Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, by R.C. Heath, 1983 (2d printing, 1984), 84 p.

Definitions of selected ground-water terms--revisions and conceptual refinements: U.S. Geological Survey Water-Supply Paper 1988, by S.W. Lohman, 1972, 21 p.

Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 1473, by J.D. Hem, 1970, 2d ed., 363 p.

Outline of ground-water hydrology with definitions: U.S. Geological Survey Water-Supply Paper 494, by O.E. Meinzer, 1923, 71 p.