GROUND-WATER CONDITIONS AND WELL YIELDS IN FRACTURED ROCKS, SOUTHWESTERN NEVADA COUNTY, CALIFORNIA

by R. W. Page, P. W. Anttila, K. L. Johnson, and M. J. Pierce

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CONVERSION FACTORS

For readers who may prefer to use International System of units (SI) 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	ha (hectares)
acre-ft (acre-feet)	.001233	hm^3 (cubic hectometers)
acre-ft/yr (acre-feet per year)	.001233	hm^3/a (cubic hectometers per year)
ft (feet)	.3048	m (meters)
ft/yr (feet per year)	.3048	m/a (meters per year)
gal/min (gallons per minute)	.003785	m^3/min (cubic meters per minute)
inches	25.4	mm (millimeters)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)
µmho/cm (micromhos per centimeter)	1.000	µS/cm (microsiemens per centimeter)

Degrees Fahrenheit is converted to degrees Celsius by using the formula

$$°C = (°F - 32)/1.8$$

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ABSTRACT

Ground-water conditions were studied in a 148-square-mile area in southwestern Nevada County, California, which lies in the foothills of the Sierra Nevada. There, the area is underlain chiefly by hard and dense metavolcanic and plutonic rocks of pre-Tertiary age.

Nevada County is experiencing a rapid growth in population, and ground water is being used to supply most of the new developments. Water systems in much of the area, however, are having difficulty in meeting the increased demand for water.

Ground water in this part of the county occurs chiefly in fractures in the hard rocks and moves through a zone that, in general, lies above a depth of about 215 feet and that is less than 200-feet thick.

Favorable sites for wells are those where saturated fractures occur in the hard rocks. These fractures probably trend northwestward or southwestward, and most probably occur above a depth of about 215 feet. Consequently, the deeper that wells have to be drilled to find water, the more likely that their yields will be small. Most wells in the study area average about 180 feet in depth and yield less than 18 gallons per minute.

INTRODUCTION

Nevada County, California, like other Sierran foothill counties, is undergoing a rapid growth in population. From 1970 to 1980, the population of the county increased 96 percent to a total of 51,645 (U.S. Bureau of Census, 1980). Not only is the population of the county growing rapidly, its growth is accelerating; between 1970 and 1975 population growth was 29 percent, between 1975 and 1980, it was 52 percent. However, between 1970 and 1980 the population of the incorporated community of Grass Valley, which lies partly within the study area (fig. 1), increased only 29 percent to a total of 6,630 (California State Census Data Center, written commun., 1981). Most of the growth in Nevada County, therefore, is occurring in the unincorporated areas.

In Nevada County, one of the major growth-related problems is the inability to meet the demand for water with the present water system. The deficiency in the water system results from a limited supply of surface water and an absence of an adequate aquifer for supplying large quantities of ground water. Nevertheless, in the study area, ground water is being used to supply domestic needs in most of the new developments.

Purpose and Scope

The purpose of this study is to provide information on ground water in the fractured rocks in the southwestern part of Nevada County, Calif. (fig. 1). The scope includes:

1. Describing the availability of ground water in the study area, and
2. Establishing, where possible, general guidelines for selecting suitable locations for future ground-water development.

The investigation was made by the U.S. Geological Survey in cooperation with Nevada County and Nevada Irrigation District.

Location and General Features

The southwestern part of Nevada County as referred to in this report comprises about 148 mi^2 in the northern foothill area of the Sierra Nevada (fig. 1). It is bounded on the north by California State Highway 20, on the east by State Highway 49, on the west by the Yuba County line, and on the south by Placer County and the Bear River. Part of the famed Mother Lode lies in this area.

Foothills in the area generally trend northwestward and have slopes ranging in value from about 5 to 30 percent. Small alluvium- or colluvium-filled valleys lie between the hills. Altitudes in the area range from about 200 ft in the southwestern part of the area to 2,631 ft at the top of Wolf Mountain (fig. 1).

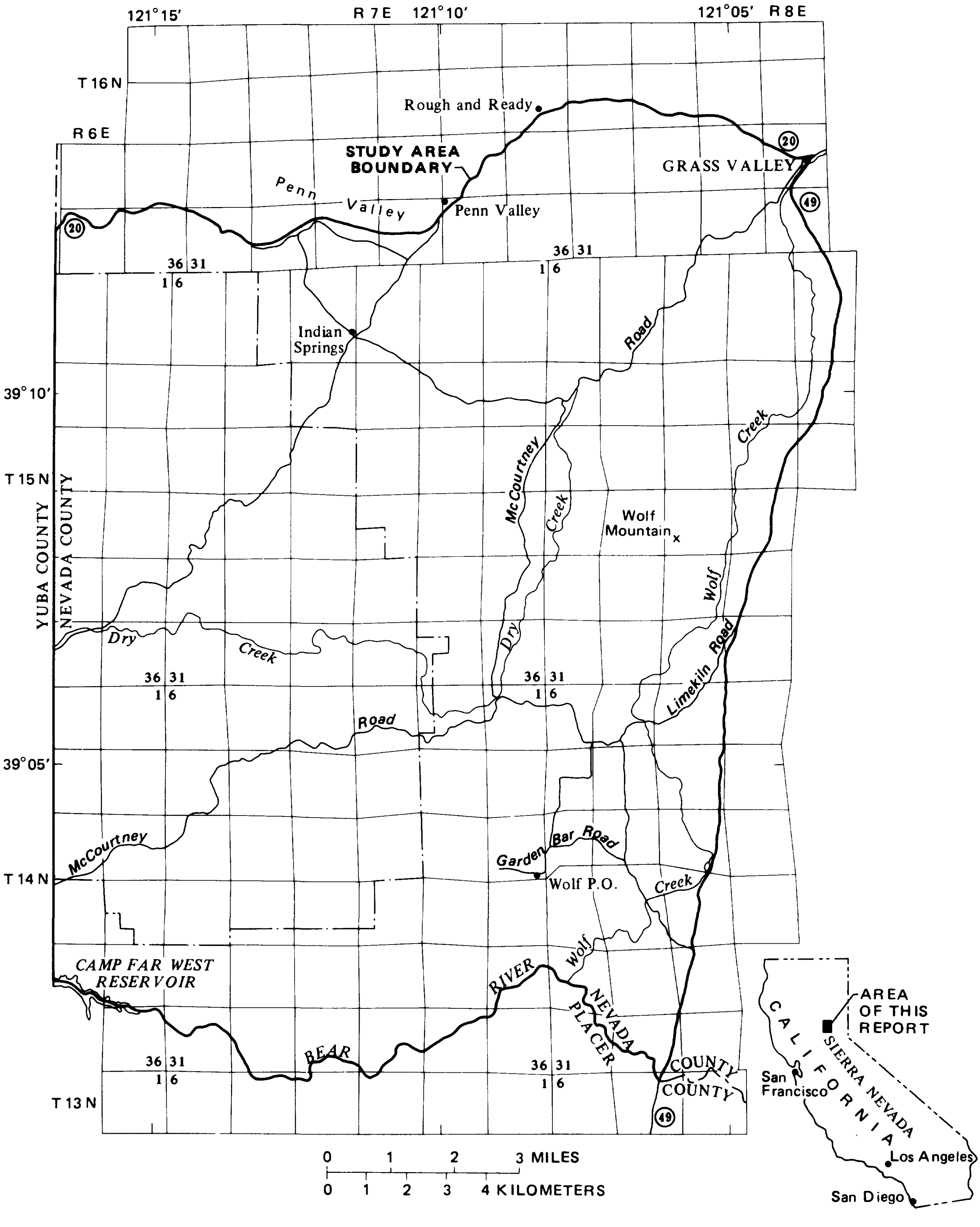


FIGURE 1. – Location of study area.

In the summer, the climate is characterized by low relative humidity, high temperature, and a small amount of precipitation; in winter it is characterized by higher humidity, lower temperature and larger amounts of precipitation. Grass Valley has a mean annual temperature of 55°F with summer highs in the high nineties or low one hundreds and winter lows occasionally dropping into the low twenties or high teens (U.S. National Oceanic and Atmospheric Admin., 1968-80). As a result of orographic effects, precipitation increases in an easterly direction and ranges from about 25 in/yr in the southwestern part of the study area to about 50 in/yr in the northeastern part (fig. 2). Almost 90 percent of the precipitation falls between November and April (U.S. National Oceanic and Atmospheric Admin., 1968-80), and most falls as rain with only occasional snow flurries at the higher altitudes.

Well-Numbering System

The well-numbering system used by the U.S. Geological Survey in California indicates the location of wells according to the rectangular system for the subdivision of public lands. For example, in the number 16N/7E-33J1, the part of the number preceding the slash indicates the township (T. 16 N.); the number after the slash, the range (R. 7 E.); the digits after the hyphen, the section (sec. 33); and the letter after the section number, the 40-acre subdivision of the section as indicated on the diagram below. Within each 40-acre tract the wells are numbered serially as indicated by the final digit of the well number. Thus, well 16N/7E-33J1 was the first well to be listed in the NE¼SE¼ sec. 33. For wells not field located by the Geological Survey, the final digit has been omitted, and where the 40-acre tract was not known, the letter was replaced by the letter Z. The entire study area is north and east of the Mount Diablo base line and meridian.

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

Origin of the Data

Planning for this study was begun in January 1980, and most of the fieldwork was completed by the autumn of that year. Some fieldwork was done in 1981 and 1982.

Fieldwork consisted of locating 226 wells and 20 springs, as well as visiting 13 surface-water sites. Wherever possible, data such as drillers' logs were correlated with well sites. In addition to the wells that were field located, 153 wells were office located using drillers' descriptions because access to certain parts of the area was denied, and it was felt that a larger data base would be more helpful in analyzing the occurrence of ground water and well yields. Descriptions on drillers' logs of the location of these wells were considered accurate enough to locate most of the wells to at least a 40-acre subdivision of a particular section.

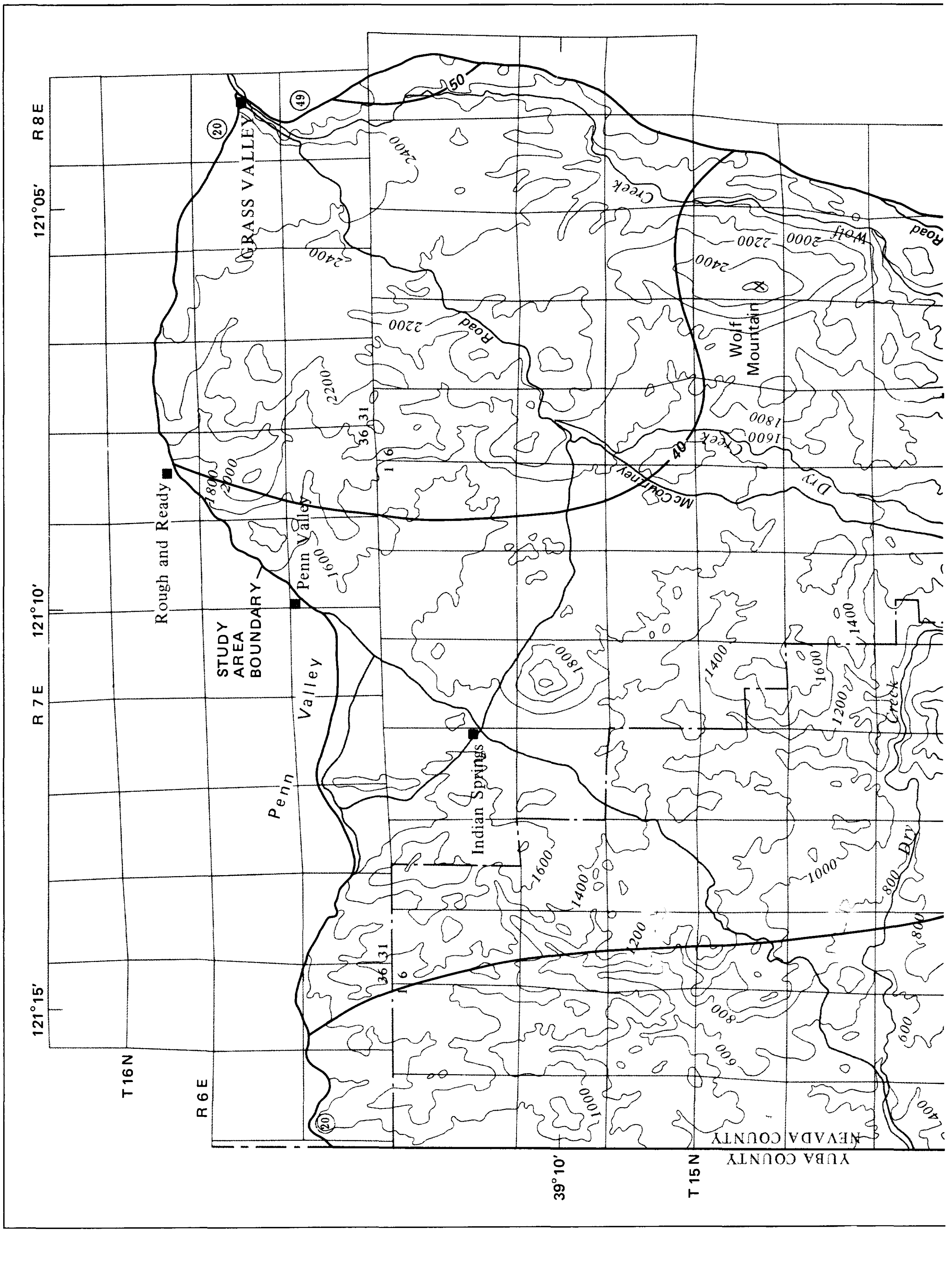
In addition to the well inventory, some geologic mapping was done in alluvium-filled valleys in the area. Also, aerial photographs were made and used to trace lineations and to locate springs.

After the well inventory was completed, virtually all the well data were entered onto computer cards. Data for each well, where available, included location, altitude of the well site, rock type at well site, slope, topography, water level, type and depth of rocks in well, and depths of fractures.

GEOLOGY

Southwestern Nevada County lies on the gentle western slope of the tilted fault block that comprises the Sierra Nevada (Smith, 1964). The study area is underlain by mafic intrusive and metamorphic rocks of Paleozoic and (or) Mesozoic age; metavolcanic, epiclastic, and ultramafic rocks of Jurassic age; granitic rocks of Jurassic and Cretaceous age; pyroclastic rocks of Tertiary age, and alluvium and colluvium (not mapped) of Quaternary age (fig. 3).

Rocks in the area are hard and dense, except for alluvium, colluvium, and weathered portions of the older units. Metavolcanic rocks underlie the largest part of the area (fig. 3 and table 1) and are composed largely of mafic volcanic breccias and tuff (table 2). Breccia is a coarse-grained rock composed of angular rock fragments generally held together by a mineral cement; tuff is a consolidated clastic rock of volcanic origin. Granitic rocks are next in areal extent and are composed of quartz diorite and granodiorite. The granitic rocks are crystalline and are of igneous origin. Granitic and metamorphic rocks yield little, if any, water to wells unless they are fractured or weathered.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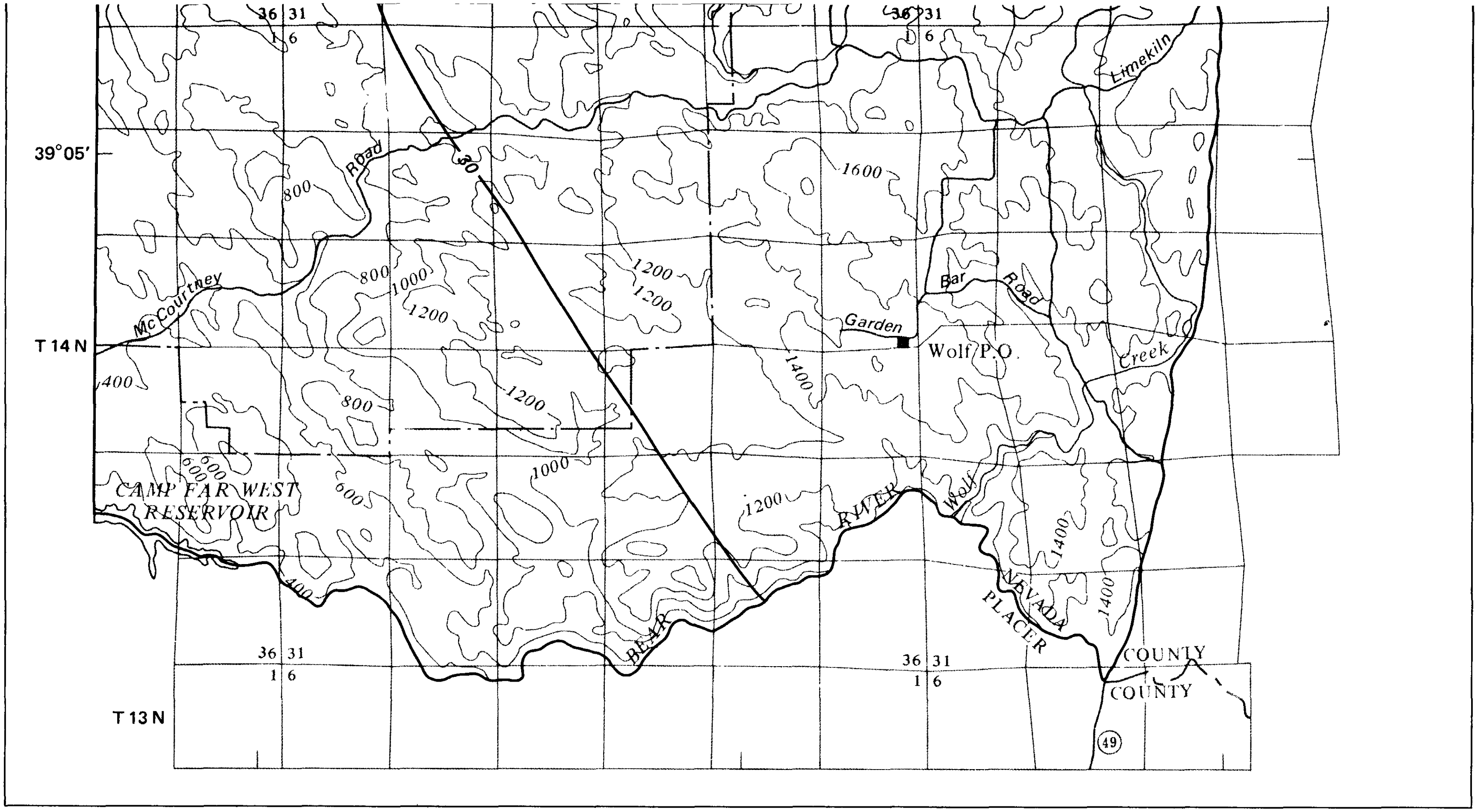
121°05'
121°10'
R 7 E
121°15'
T 16 N
R 6 E
GRASS VALLEY
Rough and Ready
Penn Valley
STUDY AREA BOUNDARY
Penn Valley
Indian Springs
Wolf Mountain
Wolf Creek
Dry Creek
McCourtney Road
Road
NEVADA COUNTY
YUBA COUNTY
39°10'
T 15 N



Base from U.S. Geological Survey
Grass Valley, 1:62,500, 1949; Smartville,
Camp Far West, 1:24,000, 1973

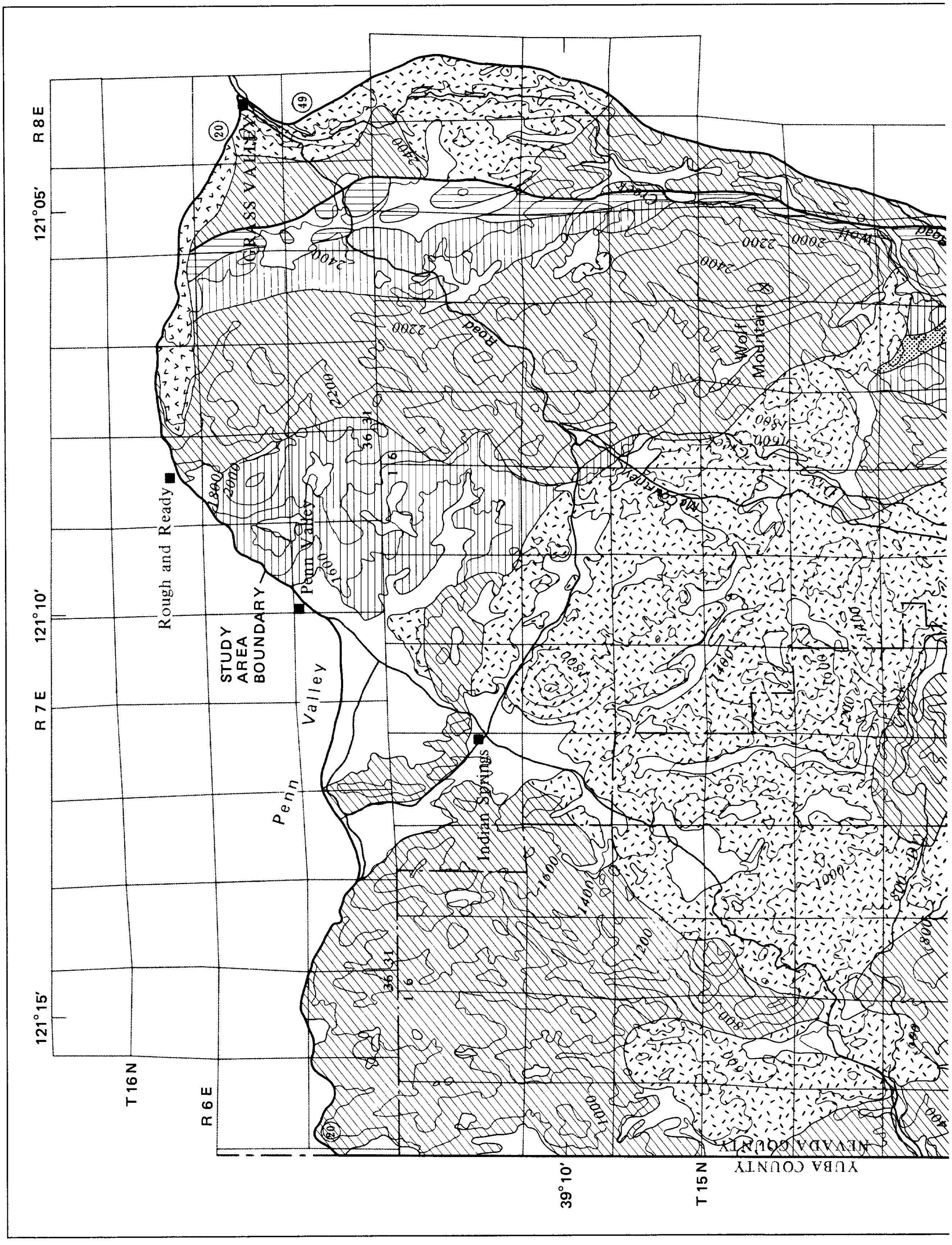
0 1 2 3 MILES
0 1 2 3 4 KILOMETERS

CONTOUR INTERVAL 200 FEET
National Geodetic Vertical Datum of 1929

EXPLANATION

—*30*— LINE OF EQUAL MEAN ANNUAL PRECIPITATION–
Interval 10 inches

FIGURE 2. – Mean annual precipitation, 1911–60 (from Rantz, 1969).



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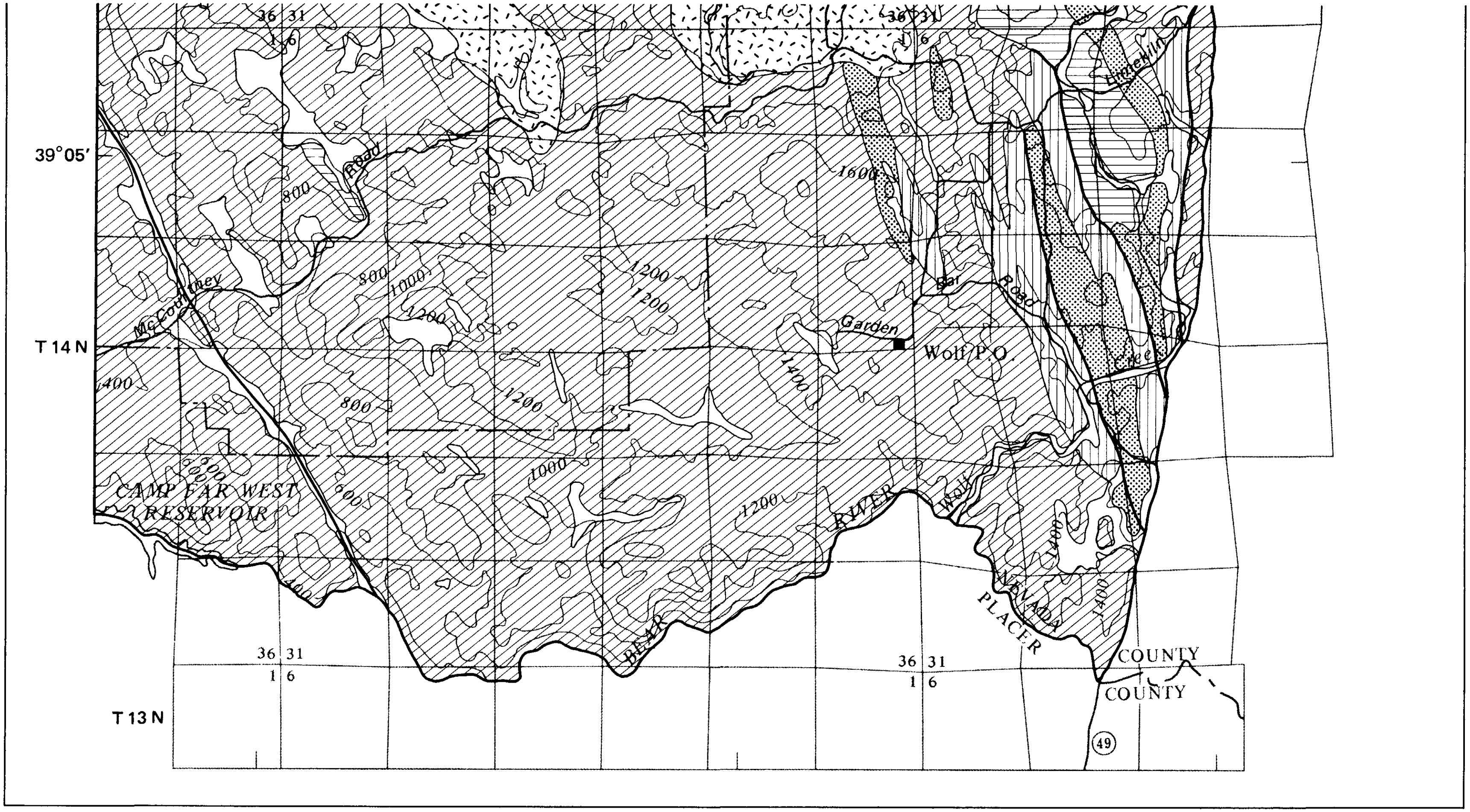


Base from U.S. Geological Survey
Grass Valley, 1:62,500, 1949; Smartville,
Camp Far West, 1:24,000, 1973

Geology compiled and modified by M.J. Pierce, 1984, from Waldemar Lindgren and H.W. Turner (1895), California Division of Mines and Geology (1962), C.W. Jennings and others (1975), and L.D. Clark (1976). Alluvium mapped by W.R. Moyle, Jr., (1981)

0 1 2 3 MILES

0 1 2 3 4 KILOMETERS

CONTOUR INTERVAL 200 FEET
National Geodetic Vertical Datum of 1929

FIGURE 3.– Generalized geologic map of southwestern Nevada County.
(Explanation follows on page 10)

EXPLANATION FOR FIGURE 3

CORRELATION OF MAP UNITS

Qal	Holocene and Pleistocene (?)	QUATERNARY
Tv	Pliocene	TERTIARY
unconformity		
KJg		CRETACEOUS AND JURASSIC
Ju		JURASSIC
Je		JURASSIC
Jv		JURASSIC
MzPz		MESOZOIC AND (OR) PALEOZOIC

DESCRIPTION OF MAP UNITS

Qal	ALLUVIUM
Tv	PYROCLASTIC ROCKS
unconformity	
KJg	GRANITIC ROCKS
Ju	ULTRAMAFIC ROCKS
Je	EPICLASTIC ROCKS
Jv	METAVOLCANIC ROCKS
MzPz	MAFIC INTRUSIVE AND METAMORPHIC ROCKS

EXPLANATION

CONTACT

FAULT

TABLE 1. - Area of rock type as percentage of study area

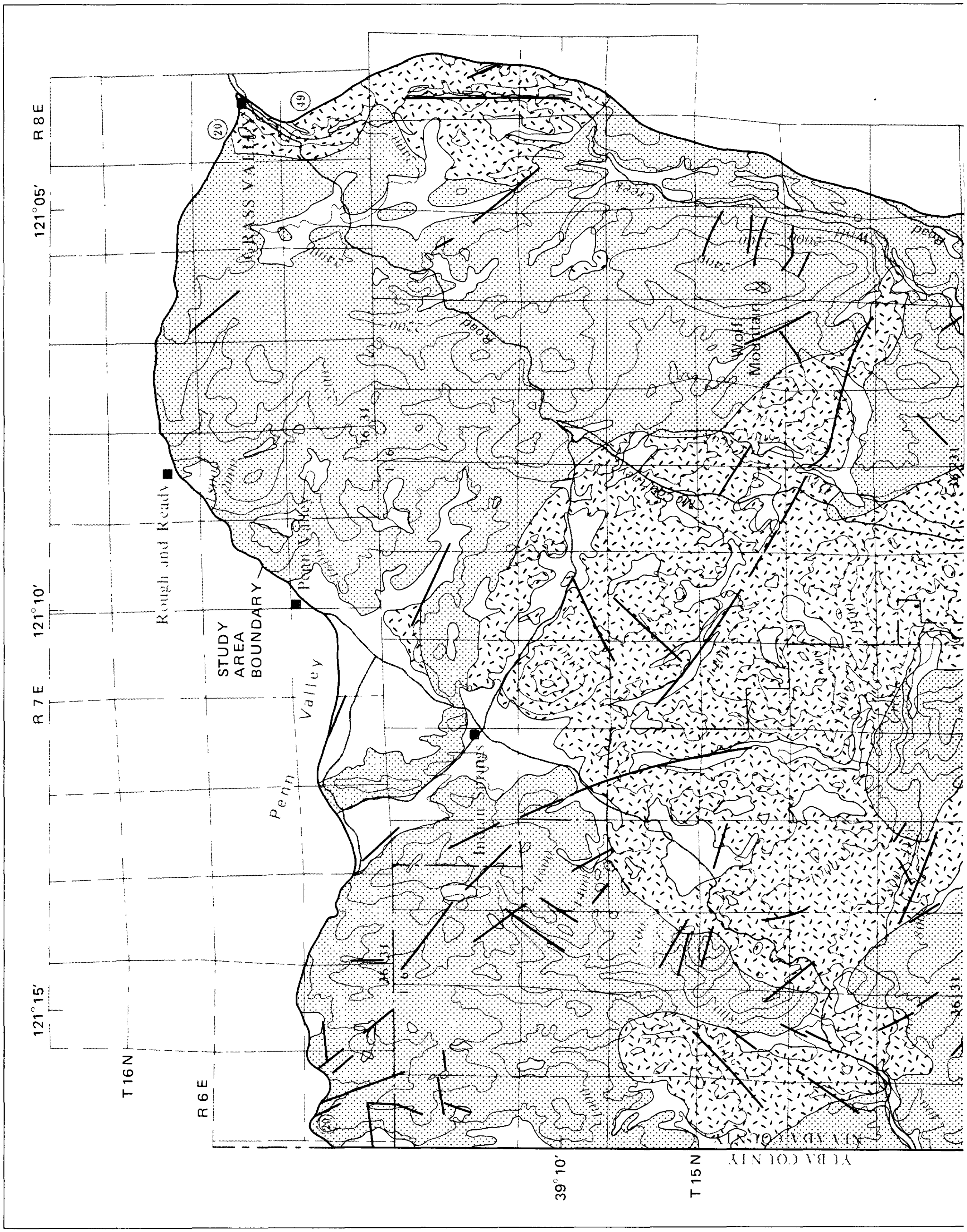
Rock type and map symbol	Area (mi^2)	Percentage of study area
Alluvium (Qal)	16.3	11
Pyroclastic (Tv)	1.5	1
Granitic (KJg)	29.6	20
Ultramafic (Ju)	3.0	2
Epiclastic (Je)	8.9	6
Metavolcanic (Jv)	84.4	57
Mafic intrusive and metamorphic (MzPz)	4.4	3
Total	[1]148	100

[1]Rounded to nearest square mile.

Colluvium, which was not mapped for this report, covers many of the hillslopes in the area and is composed chiefly of clay and silt and some sand. As indicated by drillers' logs, it is generally less than 20 ft thick and is generally not saturated. Alluvium of Holocene and Pleistocene (?) age occurs in the valleys of the area and is composed chiefly of clay, silt, and some thin beds of sand and gravel; some of this sediment is probably colluvium that has washed down from the hills. The alluvium is not thick. For example, the alluvium in Penn Valley, together with material described as decomposed granite, has a mean thickness of about 25 ft.

A major fault occurs in the eastern part of the area and another in the southwestern part (fig. 3). They are probably steeply east-dipping reverse faults (Clark, 1976, pl. 1).

Lineations of undetermined type trend in northwestward and southwestward directions (fig. 4); the northwestward trend parallels that of the fault in the southwestern part of the area. Lineations in the granitic rocks have virtually the same trends as those in the nongranitic rocks. Some lineations cross the contact between those rock types, indicating that at least some of the lineations in the nongranitic rocks were formed after the younger, granitic rocks were in place. Although the lineations were clearly indicated on aerial photographs, they were difficult to detect in the field. Consequently, their type, fracture or foliation, was not determined, but those lineations that cross the contact between rock types probably have origins different from that of any foliations that occur in the nongranitic metamorphic rocks in the area.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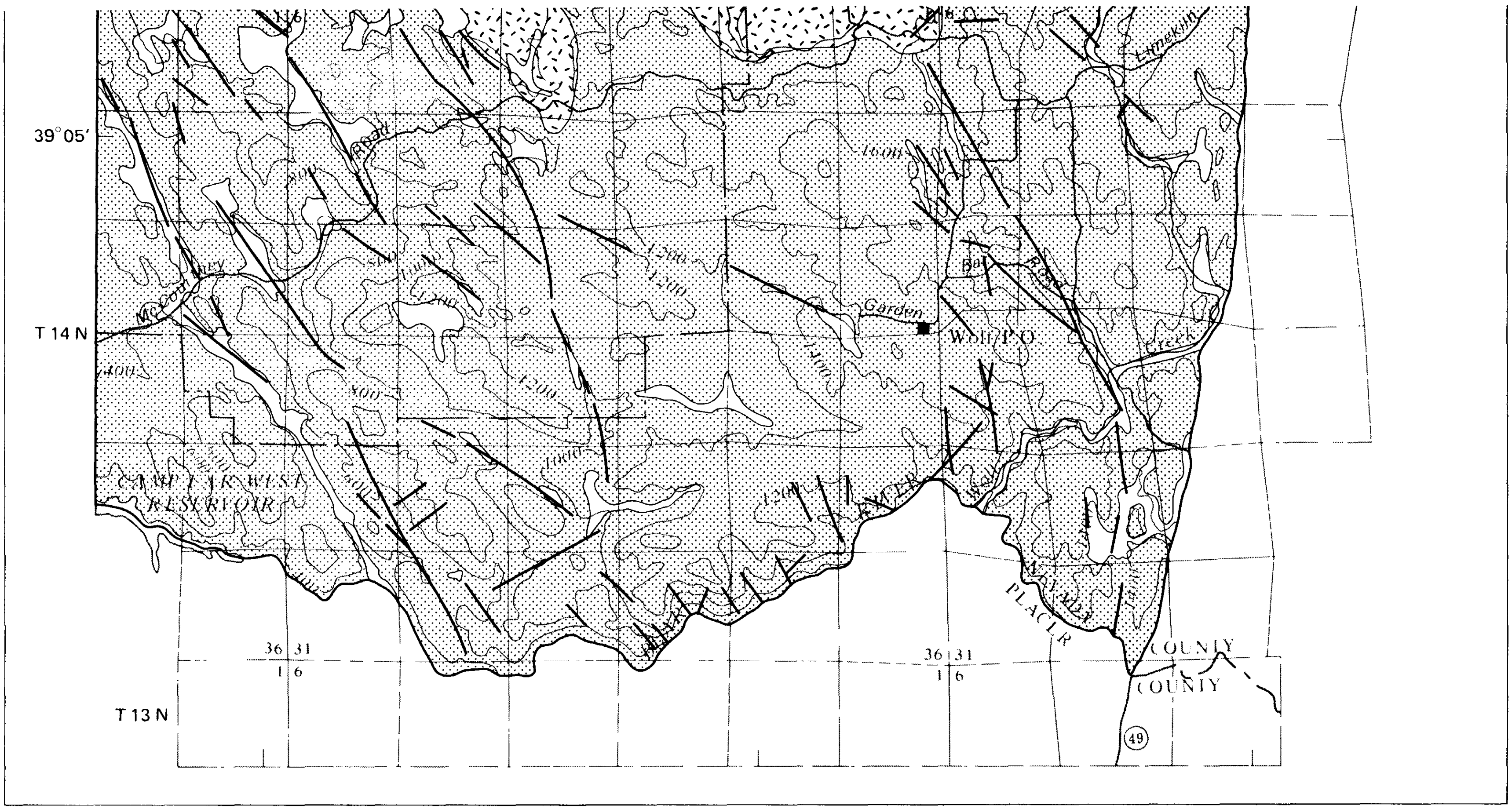

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0 1 2 3 MILES
0 1 2 3 4 KILOMETERS
CONTOUR INTERVAL 200 FEET
National Geodetic Vertical Datum of 1929

Lineations compiled by K.L. Johnson,
U.S. Geological Survey, 1981

MODIFIED MAP UNITS

- ALLUVIUM
- GRANITIC-TYPE ROCKS
- NON-GRANITIC-TYPE ROCKS

EXPLANATION

- CONTACT
- LINEATION

FIGURE 4. — Lineations and modified rock types.

TABLE 2. - Generalized section of the geologic units and their water-bearing properties

Era	Period	Epoch	Rock type and map symbol	Lithologic characteristics	Water-bearing properties
CENOZOIC	QUATERNARY	Holocene and Pleistocene (?)	Alluvium (Qal)	Clay, silt, sand, and gravel; includes colluvium.	Water storage and yield are limited; few wells obtain water from the alluvium.
	TERTIARY	Pliocene	Pyroclastic rocks (Tv)	Andesitic tuff and breccia	In the study area, saturated fractures yield most of the water to wells; storage capacity and yields decrease with depth.
MESOZOIC	CRETACEOUS AND JURASSIC		Granitic rocks (KJg)	Mostly quartz diorite or grandiorite, in many places the granitic and older rocks are weathered and (or) are overlain by thin deposits of colluvium.	
	JURASSIC		Ultramafic rocks (Ju)	Mostly serpentine. Includes some peridotite, dunite, and intrusive rocks.	
			Epiclastic rocks (Je)	Dark-gray slate with some inter-bedded conglomerate, thin-bedded chert.	
			Metavolcanic rocks (Jv)	Chiefly mafic volcanic breccia and tuff. Includes pillow lava near the Bear River.	
MESOZOIC AND (OR) PALEOZOIC			Mafic intrusive and metamorphic rocks (MzPz)	Gabbroic and dioritic rocks and amphibolite. In part intrusive and in part the products of regional and contact metamorphism.	

HYDROLOGY

Ground water is being used to supply most of the domestic water for new developments in the study area. Surface water is available in limited amounts to some parts of the area, but a costly program would be needed before much more surface water could be delivered. According to R. G. Singleton (Nevada Irrigation District, oral commun., 1981) many of the canal and treatment facilities in the area are operating at or near capacity.

Surface Water

The three main streams in the study area are Bear River, Wolf Creek, and Dry Creek (fig. 1). Bear River and Wolf Creek flow into the area from the east; Dry Creek originates in the area. None of the streams in the study area are gaged.

About 21,000 acre-feet of surface water is delivered annually to the area by the Nevada Irrigation District through a system of canals, ditches, and natural drainages chiefly from diversions of streams outside the area (R. G. Singleton, oral and written commun., 1981). Some water is diverted from Wolf Creek. Most of the water is used for irrigation. About 300 acre-ft/yr is delivered for domestic use through treatment facilities. The city of Grass Valley relies on a municipal supply of treated surface water.

Ground Water

Ground-water Use

Ground-water use in the study area was determined by calculating domestic and irrigation water needs and then subtracting the amount of surface water delivered by the Nevada Irrigation District (table 3). Estimated applied water, as shown on table 3, was determined by multiplying a given crop acreage (California Dept. Water Resources, written commun., 1978) by a unit factor appropriate to that crop (table 4).

Ground water, therefore, supplies about 90 percent of the domestic water that is used in the study area and about 5 percent of the irrigation water (table 3).

TABLE 3. - Estimated annual ground-water use

Domestic use[1]

1980 housing units	Housing units served by Nevada Irrigation District	Housing units using ground water	Unit use[2] (acre-ft/yr)	Domestic ground-water use (acre-ft/yr)
2,770	300	2,470	1.0	2,470

Irrigation use

Estimated applied water (acre-ft/yr)	Water delivered by Nevada Irrigation District (acre-ft/yr)	Irrigation ground-water use (acre-ft/yr)
21,840	21,000	840

Total ground-water use

Domestic use	Irrigation use	Total use
2,470	840	3,310

[1]Does not include city of Grass Valley.
[2]George Sato (California Department of Water Resources, oral commun., 1980)

TABLE 4. - Estimated applied-irrigation water

Crop type	Acres	Unit applied water (ft/yr)[1]	Applied water (acre-ft/yr)
Pasture ---------------	6,174	3.5	21,609
Truck crops -----------	43	1.6	69
Deciduous fruits and nuts ----------------	43	1.9	82
Vineyards -------------	7	2.4	17
Miscellaneous ---------	18	3.5	63
Total ---------------	6,285		21,840

[1]George Sato (California Department of Water Resources, oral commun., 1981).

Recharge and Discharge

Estimating quantities of ground-water recharge and discharge was beyond the scope of this report. In this section, recharge and discharge are discussed in only a general way.

Recharge occurs through infiltration from precipitation, streams, and drainages. Recharge also occurs as part of the losses from the unlined ditches of the Nevada Irrigation District. Those losses may be as large as 20 to 30 percent (R. G. Singleton, oral commun., 1981). In addition, some recharge occurs from septic-tank effluent and probably from irrigation return. Most of the recharge moves through fractures in the hard rock of the area; some recharge moves through the alluvium.

Ground-water discharge in the area occurs as ground-water pumpage, which amounts to about 3,300 acre-ft/yr (table 3). Springs also account for discharge in the area, although the quantity was not estimated. In addition, some of the native vegetation probably gets water from saturated fractures and transpires part of it to the atmosphere. Mr. J. H. Loveall (resident, oral commun., 1980) said that springs started flowing in areas of his property where oak trees had been removed.

Chemical Quality

Ground-water samples were not collected for this study. The California Department of Water Resources (1974), however, reported that ground water in the study area is chiefly a calcium-bicarbonate type water.[1] The mean pH of 22 water samples measured by the Department of Water Resources (1974) was 6.6, indicating a pH that is in the normal range for ground water (Hem, 1970, p. 93); mean specific conductance of the water samples was 283 μmho/cm, indicating a water with a generally small dissolved-solids concentration.

Occurrence and Movement

In the study area, ground water occurs chiefly in the fractures of the hard rock. Very little ground water occurs in the alluvium and colluvium of the area.

In Penn Valley (fig. 3), which is the largest valley in the area, the alluvium and the decomposed granite range in thickness from less than 5 ft to about 50 ft (fig. 4 and table 5). As indicated on drillers' logs, ground water was found chiefly at the contact between the alluvium, or the decomposed granite, and the underlying hard rock (table 5). Furthermore, the alluvium in this area is composed largely of silt and clay with only a few beds of sand and gravel. Consequently, where saturated, the transmissivity of the alluvium would be generally small, and yields to wells would be low.

A characteristic feature of hard rocks is that with depth, fractures become fewer and smaller. As a result, yields to wells in hard-rock areas generally decline with increasing well depths (table 6). Some of the wells indicated on table 6 as penetrating unfractured zones undoubtedly penetrated small fracture zones that were not recorded while drilling. Nevertheless, the data indicate that those wells recorded as penetrating fracture zones and with depths greater than about 100 ft have larger yields than those wells where fracture zones were not recorded. Below a depth of about 215 ft, however, the difference in yield probably is not significant.

In an attempt to locate fracture zones, aerial photographs were used to detect lineations in the hard rock. Wells in which fracture zones were noted were plotted on a map in order to determine if those fractures were associated with the lineations (fig. 5). Finally, color infrared aerial photographs were used to locate springs or seeps. The infrared photographs were taken in July 1980 so that the live, healthy vegetation surrounding the springs could be distinguished from dry areas.

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[1]Calcium bicarbonate designates a water type in which calcium constitutes 50 percent or more of the cations and bicarbonates constitutes 50 percent or more of the anions, in milliequivalents per liter (Piper, Garrett, and others, 1953, p. 26).

$$\text{Milliequivalents per liter} = \frac{\text{Concentration in milligrams per liter}}{\text{Molecular weight/valence}}$$

TABLE 5. - Data from wells drilled in alluvium as recorded on driller's logs

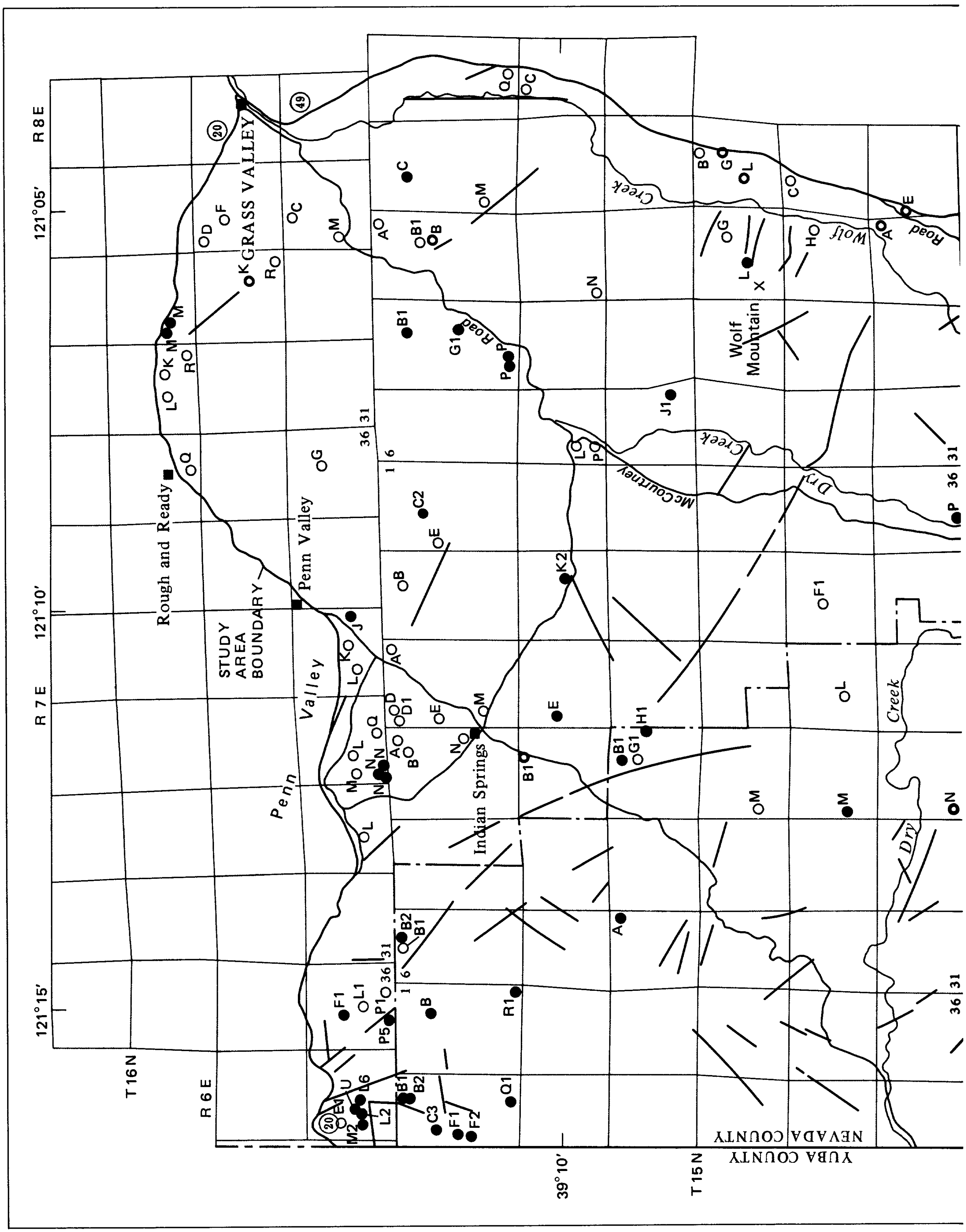
Well No.	Depth of well (ft)	Yield (gal/min)	Depth to water (ft)	Thickness of alluvium plus decomposed granite (ft)	Underlying rock type
15N/7E-3A	70	60	20	20	Fractured granite
-3A	60	40	25	35	Do.
-3C2	77	[1]300	51	--	Do.
-3D	95	60	20	20	Fractured granite
-4A	195	8	45	25	Do.
-4B	45	60	20	20	Do.
-4Z	95	5	30	30	Do.
-4Z	70	40	25	25	Do.
-9B1	275	2.2	5	1	Do.
-9G1	67	120	30	5	Lava
-16G1	205	15	11	18	Fractured granite
16N/7E-33K	60	60	20	50	Fractured granite
-33Q	80	60	20	30	Do.
-33Q	120	4	20	20	Do.
-33Q	100	35	30	11	Granite
-34K	380	2	35	7	Do.
-34L	95	45	40	35	Fractured granite
-36G	60	60	40	40	Do.
16N/8E-29R	105	40	65	50	Do.

[1]Yield from at least two fracture zones.

TABLE 6. - Mean yields from wells by depth in fractured and unfractured rocks

Depth of wells (ft)	Number of wells	Mean yield[1] from wells with recorded fractures (gal/min)	Number of wells	Mean yield[1] from wells without recorded fractures (gal/min)
≦ 50	4	31	2	20
> 50 ≦ 100	23	31	17	31
> 100 ≦ 150	22	25	22	15
> 150 ≦ 215	25	25	21	10
> 215	18	7	33	5

[1]Analysis restricted to wells yielding ≦ 60 gal/min; only six wells in the study area had reported yields > 60 gal/min.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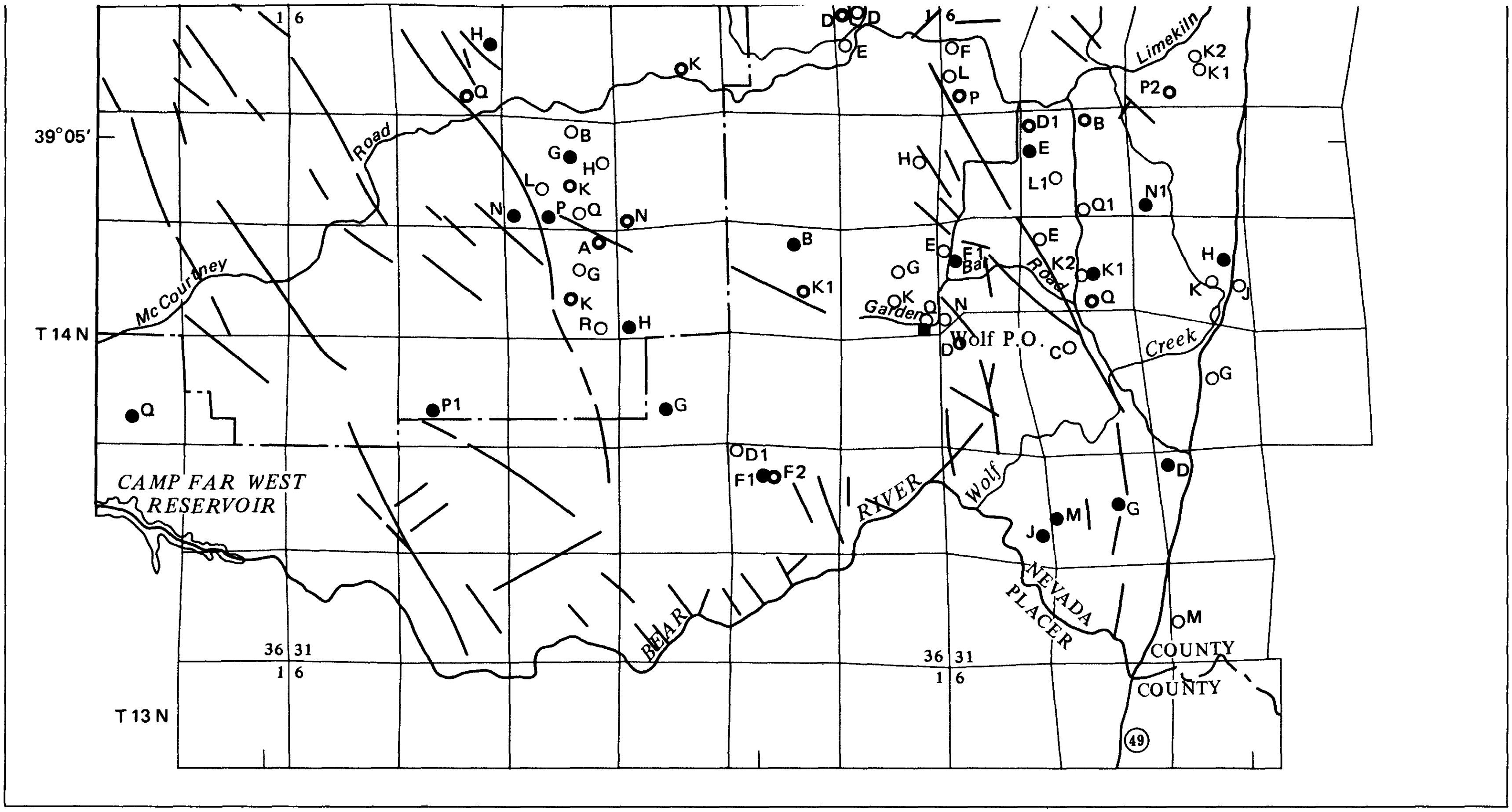

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0 1 2 3 MILES
0 1 2 3 4 KILOMETERS

Lineations compiled by K.L. Johnson,
U.S. Geological Survey, 1981

EXPLANATION

WELL SITE AND NUMBER

○G1 Well depth less than 215 feet; reported by drillers to penetrate fractured rock

oD1 Well depth greater than 215 feet; penetrates fractured rock

●H1 Well depth greater than 215 feet; does not penetrate fractured rock

—— LINEATION

FIGURE 5. – Lineations and wells.

Springs in the area may lie along zones of saturated fractures, or they may lie along contacts between different rock types. Because many of the springs were difficult to reach or access was denied, their type was not determined. Spring locations and lineations are shown in figure 6.

Although some springs and some wells that penetrate fractures are grouped around the lineations, many are not (figs. 5 and 6). Furthermore, several wells that are deeper than 215 ft and do not penetrate fractures are near lineations (fig. 5). In some areas, fractures seem to be local in occurrence as indicated by pairs of nearby wells. For example, well 14N/8E-17K1 was reported as not penetrating fractures, but nearby well 17K2 was reported as penetrating fractures; similarly, well 14N/7E-25F1 does not penetrate fractures, but well 25F2 does (fig. 5). With the limited available data, a relation between saturated fracture zones and lineations cannot be made. It is worth noting, however, that the lineation near Indian Springs in the northwestern corner of the study area (fig. 6) has springs occurring along it and that this lineation crosses the contact between granitic rocks and nongranitic rocks (fig. 4); it probably is a fracture zone (see p. 11). Lineations probably indicate trends in foliations and fracture zones. Thus, most fracture zones in the study area probably trend in a northwestward or southwestward direction.

Ground water in the study area moves primarily through the fractures in the hard rock, with some water probably moving along the contact between the thin layers of alluvium, colluvium, or decomposed granite and the hard rock. In general, the movement of ground water parallels the land surface because water moves from areas of higher altitude toward areas of lower altitude (fig. 7). In this respect, topographic ridges in the area define ground-water divides; that is, ground water moves downslope from the ridges and not through them. Similarly, valleys in the area probably define ground-water sinks, although depths to water in areas where land slopes are less than 5 percent are not much less than those areas where slopes are greater than 5 percent (table 7).

Considering that the depth to water in most wells is more than 15 ft (fig. 7 and table 8) and that fractures are probably few and small below a depth of about 215 ft, as indicated by yields to wells (fig. 8 and table 6), it can be concluded that most ground water in the study area occurs in fractures above a depth of about 215 ft and moves through a zone that is generally less than 200-ft thick.

Water in this thin zone of fractured rock, which is overlain in places by only thin layers of alluvium or colluvium, is subject to contamination because recharge water generally will not be effectively filtered before it reaches the underlying fractures.

TABLE 7. - Land slope and depth to water

Number of samples	Land slope[1] (percent)	Mean depth to water[2] (ft)
48	≦ 5	45
214	> 5 ≦ 16	60
42	> 16	53

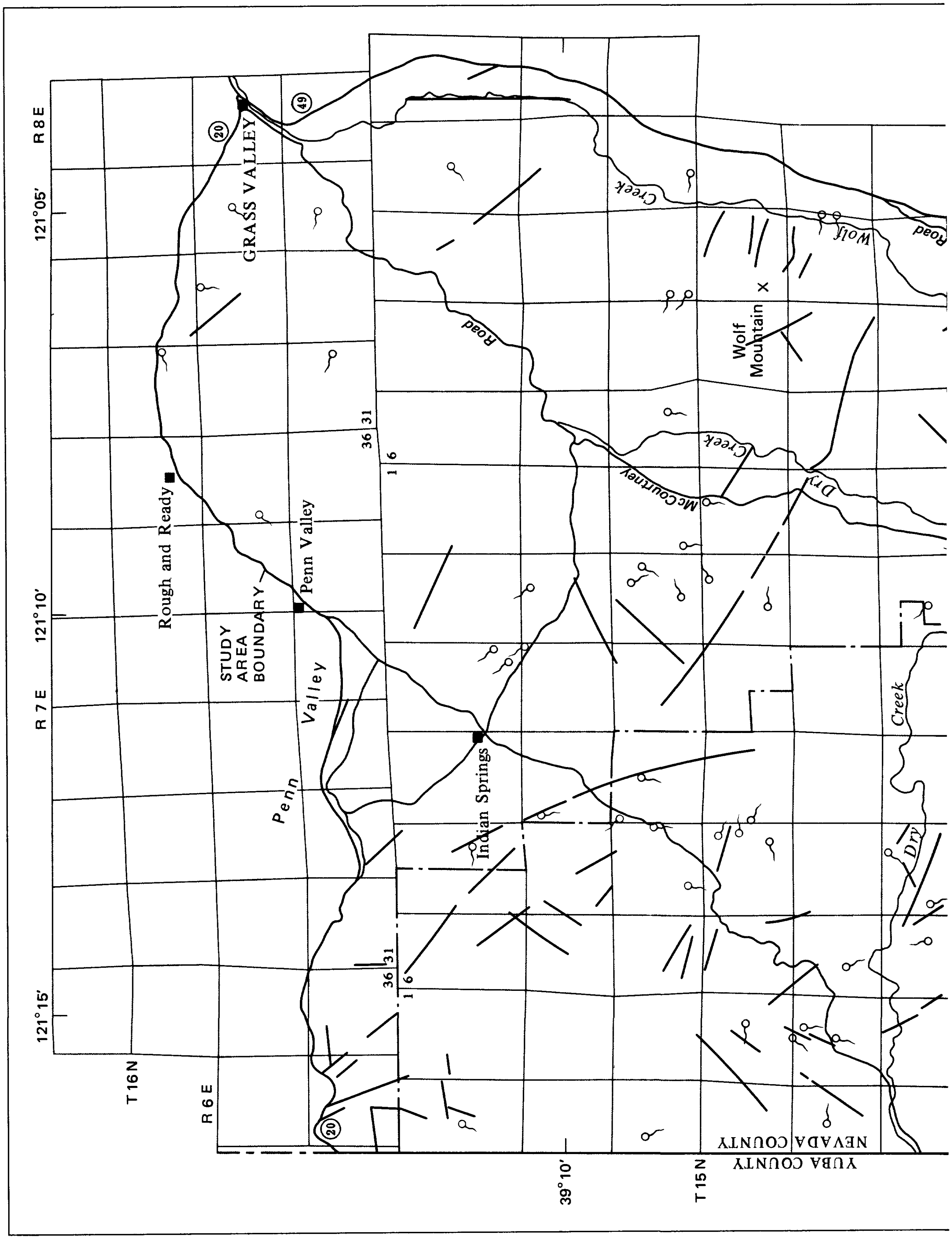
[1]Slope was calculated for each well site and is equal to vertical distance divided by horizontal distance and multiplied by 100.

[2]Taken chiefly from drillers' logs.

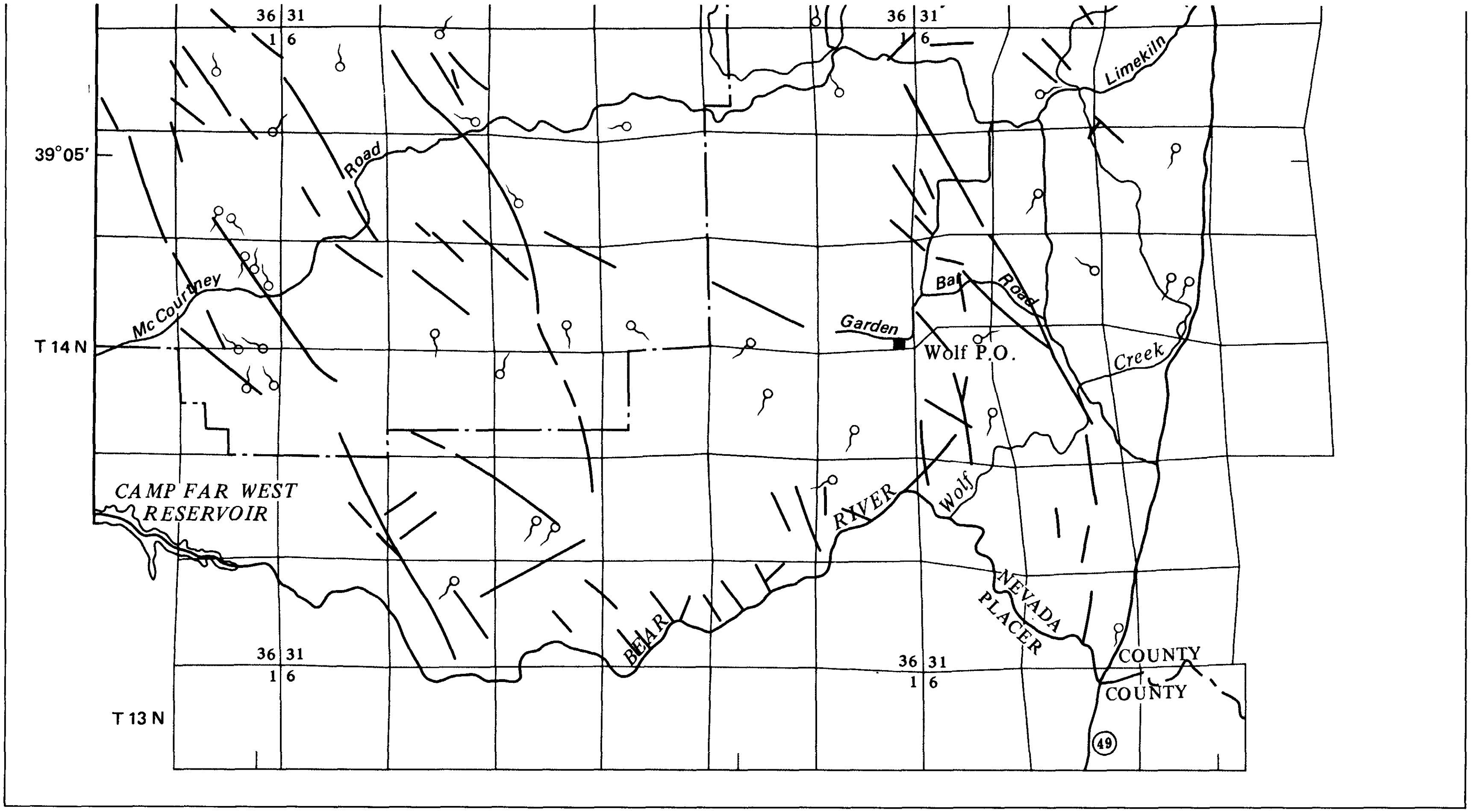
TABLE 8. - Mean depth to water by well depth

Range of well depth (ft)	Number of wells	Mean depth to water[1] (ft)
≦ 50	3	23
> 50 ≦ 100	40	36
> 100 ≦ 150	38	68
> 150 ≦ 215	36	77
> 215	36	131

[1]Taken chiefly from drillers' logs.



R 8 E
121°05'
121°10'
R 7 E
121°15'
T 16 N
R 6 E
GRASS VALLEY
49
20
Rough and Ready
Penn Valley
STUDY AREA BOUNDARY
Penn Valley
Indian Springs
Road
Creek
Wolf
Road
Wolf Mountain
McCourtney
Creek
Dry
Creek
Dry
36
31
1
6
NEVADA COUNTY
YUBA COUNTY
39°10'
T 15 N



Base from U.S. Geological Survey
Grass Valley, 1:62,500, 1949; Smartville,
Camp Far West, 1:24,000, 1973

0 1 2 3 MILES
0 1 2 3 4 KILOMETERS

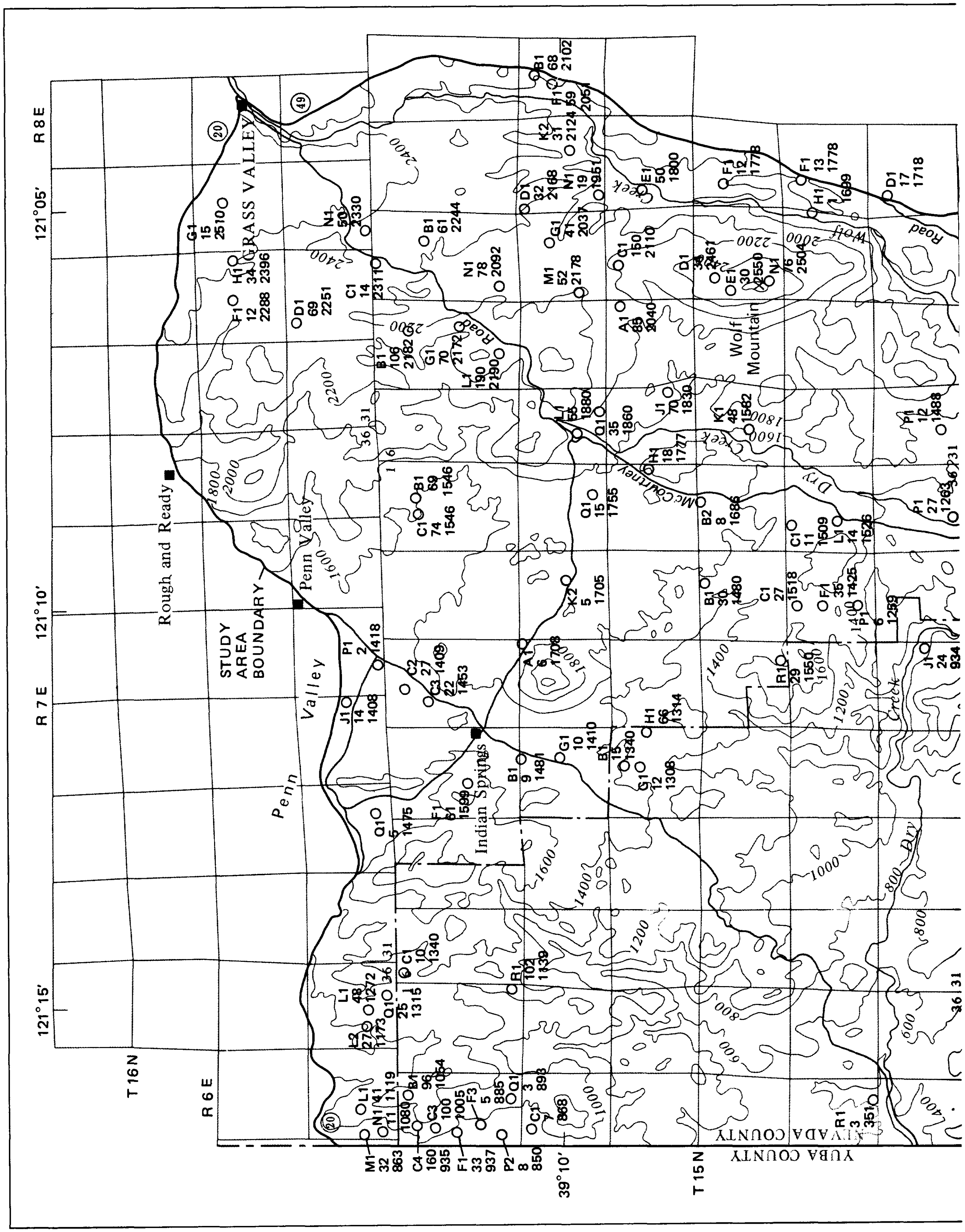
Lineations complied by K.L. Johnson,
U.S. Geological Survey, 1981

EXPLANATION

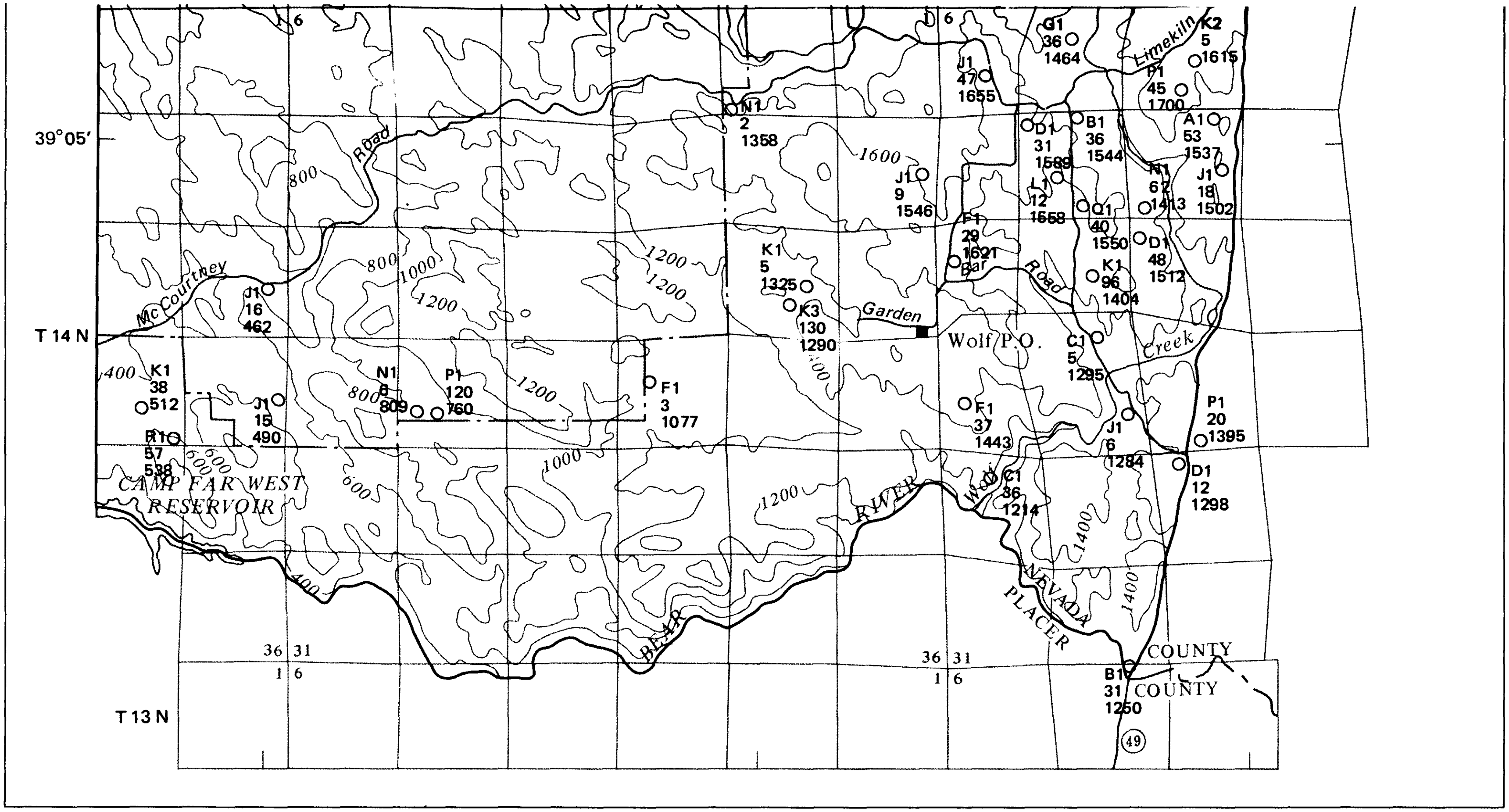
SPRING

LINEATION

FIGURE 6. – Lineations and springs.



R 8 E
R 7 E
R 6 E
T 16 N
T 15 N
121°05′
121°10′
121°15′
39°10′
GRASS VALLEY
Rough and Ready
STUDY AREA BOUNDARY
Penn Valley
Penn Valley
Indian Springs
Wolf Mountain
Wolf Creek
McCourtney Road
Dry Creek
NEVADA COUNTY
YUBA COUNTY



Base from U.S. Geological Survey
Grass Valley, 1:62,500, 1949; Smartville,
Camp Far West, 1:24,000, 1973

0 1 2 3 MILES

0 1 2 3 4 KILOMETERS

CONTOUR INTERVAL 200 FEET
National Geodetic Vertical Datum of 1929

EXPLANATION

C1 ○ 14 2311 — WELL SITE—Top number is well number. Middle number is depth to water, in feet below land surface. Bottom number is altitude of water, in feet

FIGURE 7. – Depth to and altitude of water in wells, May–October 1980.

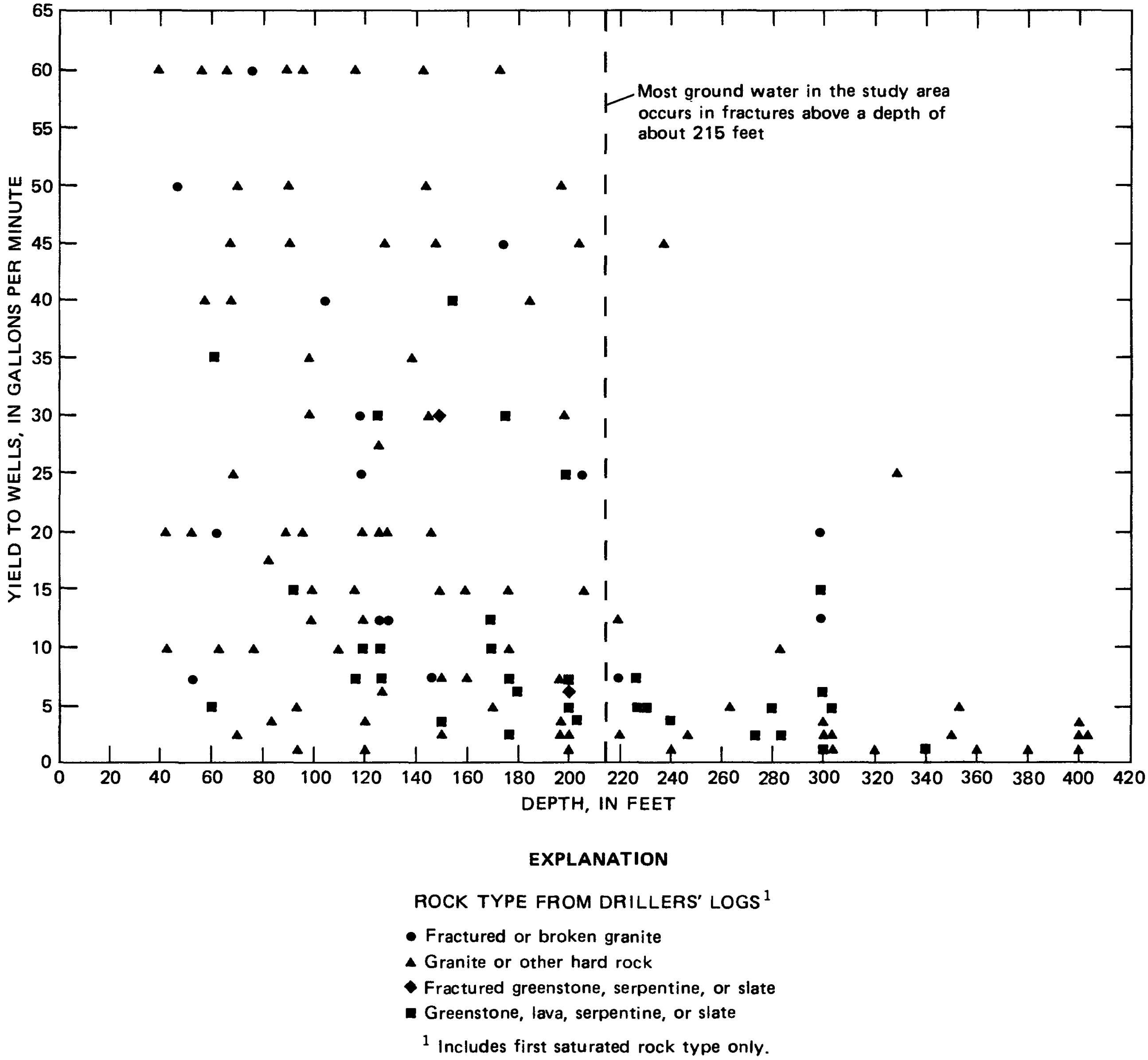


FIGURE 8. – Yield of water to wells drilled in selected rock types versus depth.

Evaluation of Well Sites

As a part of this study, an attempt was made to determine whether or not any particular geohydrologic or topographic condition or combination of conditions could be used as indicators for locating favorable well sites with respect to yield. Conditions that were considered included depth to water, depth of well, rock type at site, slope at site, thickness of soil, and topographic type. Topographic type was assigned a numerical value based on a system used by LeGrand (1967, p. 2) where small values were assigned to steep ridges and slopes and larger values were assigned to valley bottoms and catchment areas. Rock types were assigned random numerical values.

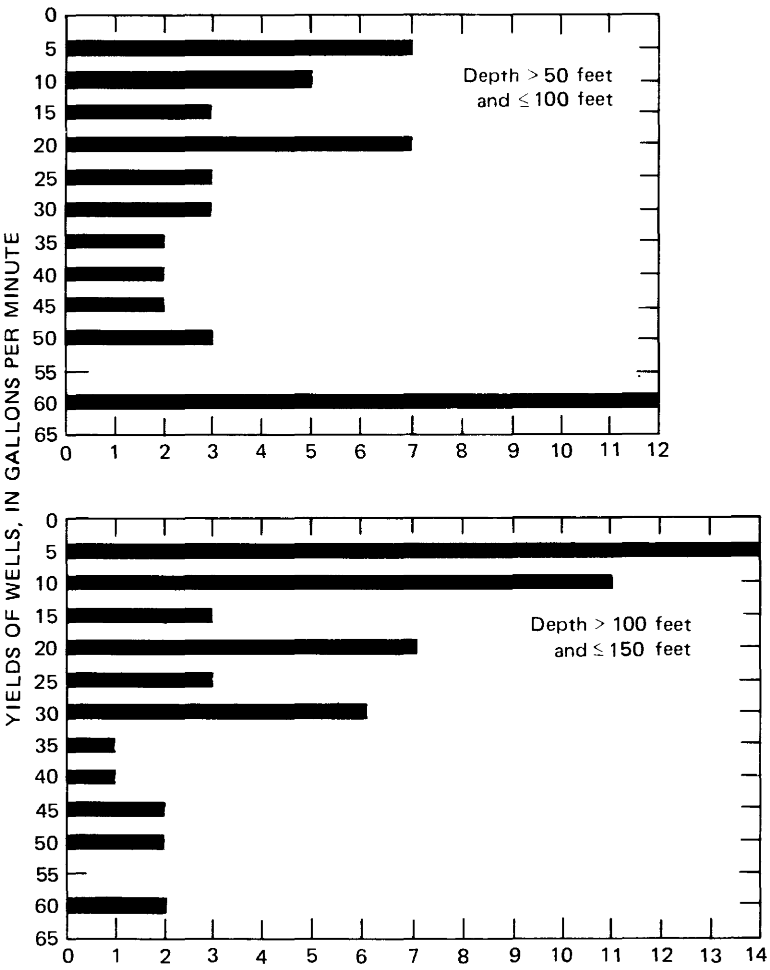
Plots of well yields against virtually all these conditions were widely scattered, indicating very little correlation between yield and a particular condition. Stepwise multiple regression analyses were made in an attempt to determine a relation between yield and geohydrologic and topographic conditions. In the stepwise analysis, conditions are added one by one to the regression model. Results of the analysis showed no significant relations between yield and any one or any combination of conditions.

It should be noted that a study of hard-rock areas in Georgia, in which lithology, structure, and yield were analyzed by multiple regression, also did not find any significant relations (C. W. Cressler, U.S. Geological Survey, written commun., 1983). An indicator of the goodness of fit of a regression is the computed R-square (R^2) value, where R^2 ranges from 0 to 1. The higher the R^2 value, the better the regression fit. Computed R^2 for regressions between yield and depth, which was the best one variable condition in all the regressions, was 0.2.

A plot of yield versus depth, however, indicated a rather abrupt decrease in well yields at a depth of about 215 ft (fig. 8). Furthermore, plots of yield in depth intervals of about 50 ft indicated that yields decrease with depth (figs. 9 and 10). For example, for well depths from 50 to 100 ft, about 14 percent of the wells tested by drillers yielded about 5 gal/min or less; from 100 to 150 ft, about 27 percent of the wells yielded about 5 gal/min or less; from 150 to 215 ft, about 48 percent of the wells yielded about 5 gal/min or less; and for well depths greater than 215 ft, about 75 percent of the wells yielded about 5 gal/min or less (figs. 9-11). For well depths from 0 to 50 ft, one well of only four tested yielded about 5 gal/min or less. Probably this decrease in yield with depth was because saturated fractures were not found at shallower depths (see below).

Yields indicated in figures 9 and 10 are shown as 60 gal/min or less because only six wells in the area were reported as yielding more than 60 gal/min. Mean yield to wells, as derived from drillers' logs, is about 18 gal/min; median yield is about 10 gal/min. Most drillers' logs, however, did not indicate the length of the pump test or water-level drawdown. If the tests were of short duration, the reported yield would tend to be too large. Furthermore, about 40 percent of the wells used in this study had no data on yield, and some of those wells were probably dry. Three wells used in this study were reported as having no yield. Thus, the mean yield of 18 gal/min is probably high for an area average.

Most of the wells in the area are drilled to depths of about 200 ft or less (fig. 12). Mean depth of wells is about 180 ft; median depth is about 130 ft. As indicated on drillers' logs, some wells are drilled deeper because, in general, water was not found in sufficient quantities at shallower depths (table 8). Also wells were drilled to deeper depths because saturated fractures probably were not found at shallow depths. Twenty-nine percent of the 379 wells used in this study were reported as penetrating saturated fractures. Thirteen wells penetrated more than one set of fractures. Of all the reported saturated fractures, 84 percent occurred above a depth of 150 ft (table 9).

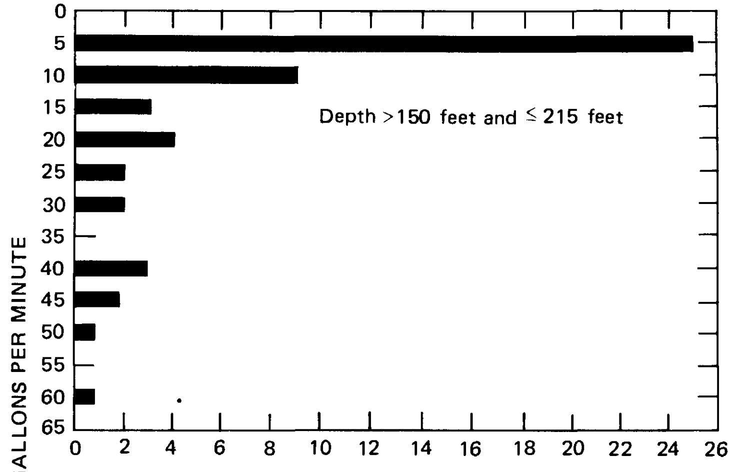


FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
7	7	14.29	14.29
5	12	10.20	24.49
3	15	6.12	30.61
7	22	14.29	44.90
3	25	6.12	51.02
3	28	6.12	57.14
2	30	4.08	61.22
2	32	4.08	65.31
2	34	4.08	69.39
3	37	6.12	75.51
0	37	0.00	75.51
12	49	24.49	100.00

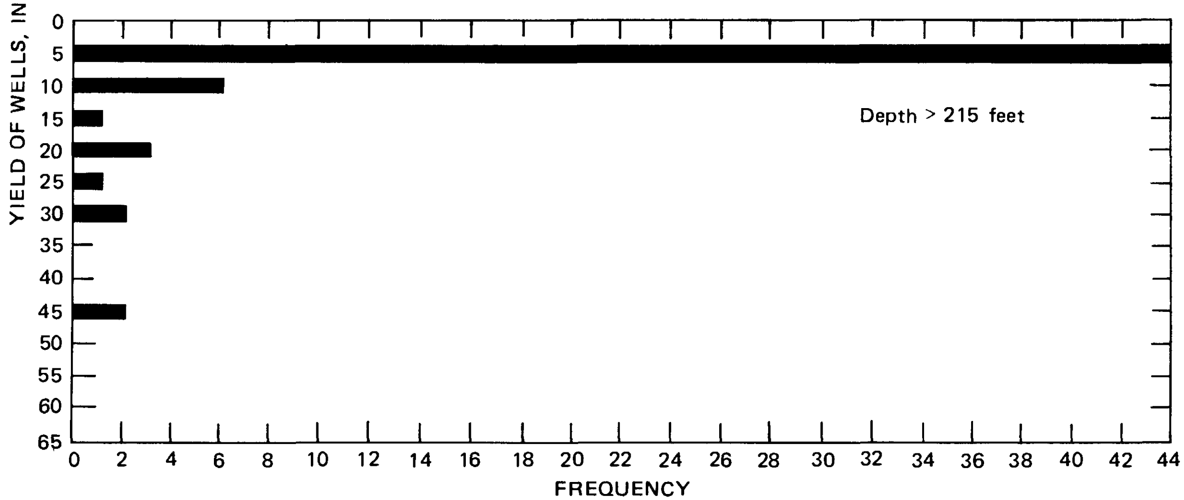
FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
14	14	26.92	26.92
11	25	21.15	48.09
3	28	5.77	53.85
7	35	13.46	67.31
3	38	5.77	73.08
6	44	11.54	84.62
1	45	1.92	86.54
1	46	1.92	88.46
2	48	3.85	92.31
2	50	3.85	96.15
0	50	0.00	96.15
2	52	3.85	100.00

FIGURE 9. – Frequency of well yields by depth, 50 to 100 and 100 to 150 feet.

Table 10 summarizes well yields with regard to slope and topographic site. Some of the wells indicated on the table were started in alluvium. Four of the wells started in alluvium had yields in the 30 to 40 gal/min range, and six of the wells had yields in the 50 to 60 gal/min range; virtually all these wells are in low-lying Penn Valley. As mentioned, yields there are mostly from fractured rock (table 5). Investigators of other hard-rock areas, namely in Georgia, have found that valleys generally are areas of concentrated fracture development relative to other topographic types (C. W. Cressler, U.S. Geological Survey, written commun., 1983). Except for Penn Valley, however, few data were available concerning well yields and fractures in local valleys.



FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
25	25	48.08	48.08
9	34	17.31	65.38
3	37	5.77	71.15
4	41	7.69	78.85
2	43	3.85	82.69
2	45	3.85	86.54
0	45	0.00	86.54
3	48	5.77	92.31
2	50	3.85	96.15
1	51	1.92	98.08
0	51	0.00	98.08
1	52	1.92	100.00



44	44	74.58	74.58
6	50	10.17	84.75
1	51	1.69	86.44
3	54	5.08	91.53
1	55	1.69	93.22
2	57	3.39	96.61
0	57	0.00	96.61
0	57	0.00	96.61
2	59	3.39	100.00
0	59	0.00	100.00
0	59	0.00	100.00
0	59	0.00	100.00

FIGURE 10. – Frequency of well yields by depth, 150 to 215 feet and greater than 215 feet.

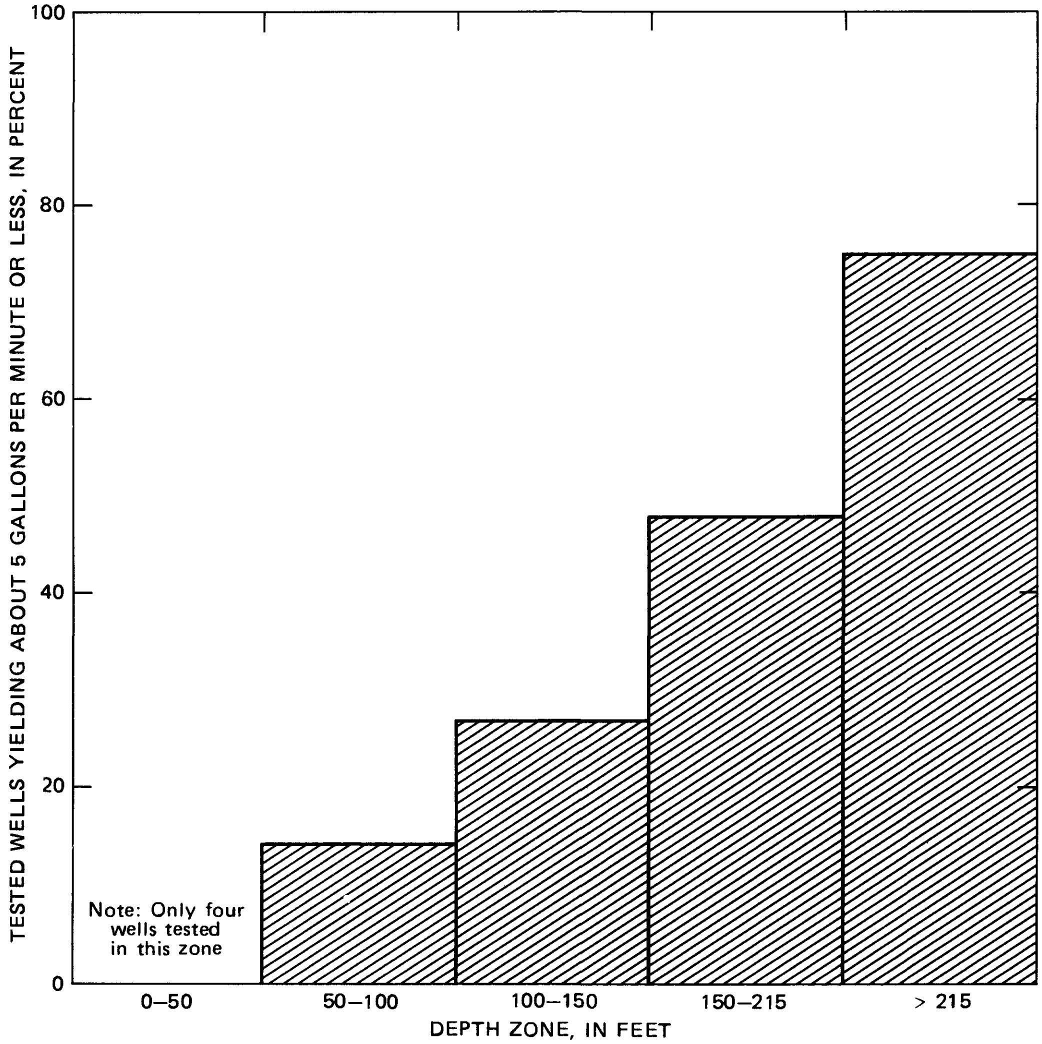
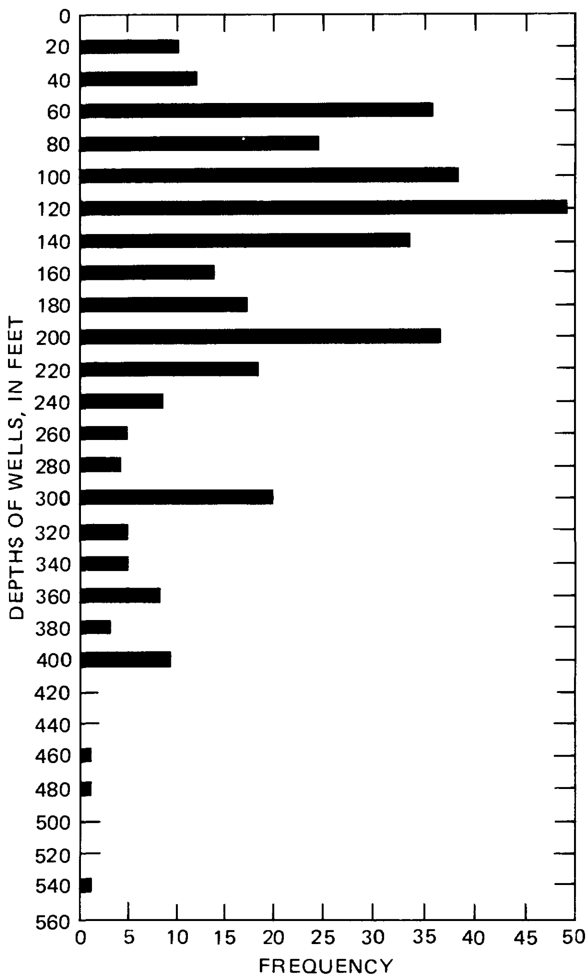


FIGURE 11. – Depth zones and wells yielding about 5 gallons per minute or less.

Most of the wells in the study area are drilled into metavolcanic rocks, and most future wells probably will be drilled into these rocks, because they underlie the largest part of the area (fig. 3 and table 1). Granitic rocks are next in terms of area and probable future well sites. In this study, however, only 18 wells were definitely identified as yielding water from that type of rock (table 11).

It is difficult to compare yields among the various rock types because the data are skewed and the number of samples for each rock type are unequal. Nevertheless, yields to wells from the various types of hard rocks in the area are fairly equal. One exception occurs for a small number of wells drilled into granitic rocks in the 50- to 100-feet depth range. Reported yields from these wells were larger than reported yields from other rock types (table 11).



FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
10	10	2.80	2.80
12	22	3.36	6.16
36	58	10.08	16.25
24	82	6.72	22.97
38	120	10.64	33.61
49	169	13.73	47.34
33	202	9.24	56.58
14	216	3.92	60.50
17	233	4.76	65.27
36	269	10.08	75.35
18	287	5.04	80.39
8	295	2.24	82.63
5	300	1.40	84.03
4	304	1.12	85.15
20	324	5.60	90.76
5	329	1.40	92.16
5	334	1.40	93.56
8	342	2.24	95.80
3	345	0.84	96.64
9	354	2.52	99.16
0	354	0.00	99.16
0	354	0.00	99.16
1	355	0.28	99.44
1	356	0.28	99.72
0	356	0.00	99.72
0	356	0.00	99.72
1	357	0.28	100.00

FIGURE 12. – Depths of wells.

Although regression analyses did not indicate an optimum set of conditions with regard to well yield, the most favorable sites are located where saturated fractures occur in the hard rocks. Drillers' logs indicate that a number of saturated fractures underlie Penn Valley (table 5), and other studys of hard rock indicate that concentrated fracture development occurs in valleys (see above). In the study area, fractures probably trend northwestward or southwestward, and most of them probably occur above a depth of about 215 ft. Consequently, the deeper that wells have to be drilled to find water, the more likely that the yield will be small (figs. 9-11).

TABLE 9. - Saturated fracture zones by well depth, as indicated on drillers' logs

Range of well depth (ft)	Number of saturated fracture zones	Saturated fracture zones (percent)
< 50	29	23
> 50 ≦ 100	49	40
> 100 ≦ 150	26	21
> 150 ≦ 215	11	9
> 215	9	7

TABLE 10. - Yields of wells by slope and topographic site

Yield (gal/min)	Number of wells	Mean slope (percent)	Mean value of topographic site
≦ 5	73	11.6	7.3
> 5 ≦ 10	38	10.8	7.8
> 10 ≦ 20	41	9.0	8.0
> 20 ≦ 30	22	10.3	7.8
> 30 ≦ 40	9	6.2	10.4
> 40 ≦ 50	15	10.7	7.3
> 50 ≦ 60	16	10.0	8.6

TABLE 11. - Mean yield to wells by rock type and depth

Number of wells	Mean yield (gal/min)	Range of depth (ft)
	Granitic rock	
5	43	> 50 ≦ 100
6	21	> 100 ≦ 150
4	15	> 150 ≦ 215
3	6	> 215
Total 18	--	---
	Ultramafic rock	
3	16	> 50 ≦ 100
2	28	> 100 ≦ 150
2	14	> 150 ≦ 215
4	5	> 215
Total 11	--	---
	Metavolcanic rock	
11	21	> 50 ≦ 100
13	29	> 100 ≦ 150
25	13	> 150 ≦ 215
32	6	> 215
Total 81	--	---
	Mafic intrusive and metavolcanic rock	
1	20	< 50
8	34	> 50 ≦ 100
9	20	> 100 ≦ 150
6	12	> 150 ≦ 215
8	8	> 215
Total 32	--	---

FUTURE STUDIES

Many of the standard approaches used to calculate ground-water recharge, discharge, and storage are not applicable to the fractured, hard-rock aquifers of the Sierra Nevada foothills. Aquifer characteristics of igneous and metamorphic rocks are determined by their fracture systems, which in turn are dependent on rock type, method of emplacement, and structural history. Locally, controlled pump tests could be helpful for locating wells with larger than average yields. In turn, these tests could be evaluated for common factors of rock type, structure, and topography, for possible establishment of general guidelines for other well sites. Such a testing procedure increased the probability of selecting sites of maximum yields in other hard-rock areas (C. W. Cressler, written commun., 1983).

A regional study to quantify recharge, discharge, and storage for the Sierran foothills is not realistic because of large variations in rock types and precipitation. A suggested approach is to make intensive studies in several small (2 to 10 mi^2) watersheds. Ideally, study watersheds would be distributed geographically across the State in crystalline-rock areas where a growth in population is occurring or is projected to occur. The geographic distribution would allow for geologic and climatic variations. Study watersheds would be carefully selected to provide an optimum amount of information that can be extrapolated to other areas.

Ideally, the duration of an intensive watershed study would be of sufficient time to define the effect of annual variation in precipitation on recharge, discharge, and evapotranspiration. One or two initial watershed studies are suggested that would serve as prototypes to refine methodology and data collection. Thus, the scope of the initial studies could consist of an extensive data set of many geologic, environmental, and hydrologic variables. The following is a list of some suggested variables:

A. Geology
   1. Detailed geologic map
   2. Density, depth, and patterns of fractures
   3. Soil types
   4. Soil moisture and tension
   5. Downhole geophysical logs
B. Climate and Environment
   1. Precipitation
   2. Temperature
   3. Vegetation types and density
C. Hydrology
   1. Surface-water runoff
   2. Ground-water levels
   3. Tests for aquifer characteristics
   4. Water quality of surface and ground water
   5. Subsurface tracer studies
   6. Evapotranspiration

Collecting these data would in turn help to (1) evaluate ground-water storage capacity in hard-rock environments, (2) quantify penetration of rain and snowmelt over long periods of time and under special conditions, such as a drought, and (3) develop models for testing wells yields in hard-rock terranes under a variety of climatic conditions.

SUMMARY AND CONCLUSIONS

This report presents the results of a ground-water investigation of a 148 mi^2 area in southwestern Nevada County. The need for the study was prompted by the area's rapid growth in population and resulting land development, both of which are largely dependent upon ground water for water supplies. Annual ground-water use was estimated to be 2,470 acre-ft/yr for domestic needs and 840 acre-ft/yr for irrigation. The scope of the study was limited to a description of the availability of ground water and an attempt to establish general guidelines for selecting suitable locations for future ground-water development.

Metavolcanic rocks underlie 57 percent of the study area and granitic rocks underlie 20 percent of the area. Alluvium and colluvium, which underlie 11 percent of the area, occur in the valleys of the area; they are generally less than 50 ft thick and in general are not sources of ground water.

Most of the ground water occurs in fractures in the hard rocks above depths of about 215 ft and moves through a zone that is generally less than 200-ft thick. Yields to wells decrease with depth, and in general an abrupt decrease in yields occurs below depths of about 215 ft. Mean depth of wells is about 180 ft, and most wells are drilled to depths of 200 ft or less. Mean yield to wells, as derived from drillers' logs, is about 18 gal/min. This yield is probably too large for an average because some of the pumping tests may have been too short and because some of the wells that had no data were probably dry.

Multiple regression analyses between yield and various geohydrologic and topographic characteristics showed no significant relation. Studies are proposed for selected small watersheds to refine the general findings of this study with respect to well yields in hard-rock environments.

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