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GEOLOGICAL SURVEY

GROUND-WATER CONDITIONS AT BEALE AIR FORCE BASE AND VICINITY, CALIFORNIA

By R. W. Page

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CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For additional information write to:

District Chief
Water Resources Division
U.S. Geological Survey
345 Middlefield Rd.
Menlo Park, Calif. 94025

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[Plates are in pocket]

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For readers who may prefer to use metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Inch-pound	Multiply by	Metric
acre-ft (acre-foot)	0.001233	hm^3 (cubic hectometer)
acre-ft/d (acre foot per day)	.001233	hm^3/d (cubic hectometer per day)
acre-ft/yr (acre foot per year)	.001233	hm^3/yr (cubic hectometer per year)
ft (foot)	.3048	m (meter)
ft/d (foot per day)	.3048	m/d (meter per day)
ft^2/d (foot squared per day)	.0929	m^2/d (meter squared per day)
inch	25.4	mm (millimeter)
gal/min (gallon per minute)	.06309	L/s (liter per second)
(gal/min)/ft (gallon per minute per foot)	.207	(L/s)/m (liter per second per meter)
mi (mile)	1.609	km (kilometer)
mi^2 (square mile)	2.590	km^2 (square kilometer)

Degree Fahrenheit is converted to degree Celsius by using the formula

$$°C=5/9\ (°F-32).$$

Abbreviations used:

- mg/L - milligrams per liter
- μg/L - micrograms per liter
- μmho/cm - micromhos per centimeter

National Geodetic Vertical Datum of 1929 is a geodetic datum derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts and as such does not necessarily represent local mean sea level at any particular place. To establish a more precise nomenclature, the term "NGVD of 1929" is used in place of "Sea Level Datum of 1929" or "mean sea level."

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AND VICINITY, CALIFORNIA

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ABSTRACT

Ground-water conditions were studied in a 168-square-mile area between the Sierra Nevada and the Feather River in Yuba County, Calif. The area is in the eastern part of the Sacramento Valley and includes most of Beale Air Force Base. Source, occurrence, movement, and chemical quality of the ground water were evaluated, with particular emphasis on the 27 square miles of Beale Air Force Base that is west of the basement complex of the Sierra Nevada.

In the study area, ground water occurs in sedimentary and volcanic rocks of Tertiary and Quaternary age. The base of the fresh water is in the undifferentiated sedimentary rocks of Oligocene(?) and Eocene age that contain water of high dissolved-solids concentration.

The ground water occurs under unconfined conditions with local confinement due to lenses of clay and silt. Recharge to the aquifer in the area is principally from river infiltration. Recharge to the well field at Beale Air Force Base, although ultimately from the Yuba River, is principally by ground-water inflow from the north, northeast, and northwest and is estimated to be 4,000 acre-feet annually. Ground water moves from the rivers and the foothills of the Sierra Nevada toward a pumping depression south of the Air Force base and near the center of the study area.

Pumpage in the study area was estimated to be 129,000 acre-feet in 1975, of which 3,120 acre-feet was for the Air Force base. Outflow from the base well field is about 850 acre-feet annually. In the 1960's water levels in most parts of the study area declined less rapidly than in earlier years or became fairly stable. In the 1970's water levels at Beale Air Force Base declined only slightly. Spacing of wells on the base and rates of pumping are such that excessive pumping interference is avoided. Water quality throughout the study area is generally good. Dissolved-solids concentrations are 700 to 900 milligrams per liter in the undifferentiated sedimentary rocks beneath the base well field.

INTRODUCTION

Purpose and Scope

The U.S. Geological Survey was asked by the Air Force to make a study of ground-water conditions at the base. This report and an earlier data report have resulted from the study.

The purpose of the study was to appraise the ground-water resource in the vicinity of Beale Air Force Base with regard to source, occurrence, movement, and chemical quality. This information will be used in the long-term management of the water supply for the base.

The scope of the study included identifying zones of poor-quality water that could affect the base water supply and providing suggestions for changes in pumping, well construction, and well-site selection that would improve the reliability of the water supply.

Source material included drillers' logs, chemical analyses of ground water, water-level records, pumpage records, and previously published reports for the area.

Location and General Features

The study area comprises 168 mi^2 on the eastern side of the Sacramento Valley (fig. 1) and is mostly west of the basement complex of the Sierra Nevada of pre-Tertiary age (pl. 1).

Principal physiographic units in the study area are the dissected alluvial uplands west of the Sierra Nevada, the low alluvial plains and fans west of the Sierra Nevada, and the flood plains (Olmsted and Davis, 1961, p. 14-21, pl. 1). The dissected alluvial uplands consist of low hills and gently rolling country that merge with the foothills of the Sierra Nevada on the east and with the low alluvial plains of the eastern Sacramento Valley on the west. The low alluvial plains are nearly flat to slightly dissected where they merge with the dissected uplands on the east, and the flood plains border the streams that emerge from the Sierra Nevada. The flood plains lie at lower altitudes than the adjacent dissected uplands and the low alluvial plains (Olmsted and Davis, 1961, p. 19).

Most of the land around Beale Air Force Base is used for crops and pasture. The largest city in the study area is Olivehurst (pl. 1), which in 1970 had a population of 8,100 (U.S. Department of Commerce, 1971, p. 16). Water for crops and pastures is supplied mostly by about 470 irrigation wells. Water for Beale Air Force Base is supplied by nine wells located in the northwestern part of the base (pl. 1). Only the 27 mi^2 of Beale Air Force Base west of the basement complex was included in the study area; the total area of the base is 34 mi^2.

Boundaries of the study area were drawn on natural hydrologic boundaries, such as rivers, so that ground-water conditions at Beale Air Force Base could be appraised with regard to the regional hydrologic setting.

Summers are hot and dry, and winters are cool and moist (table 1).

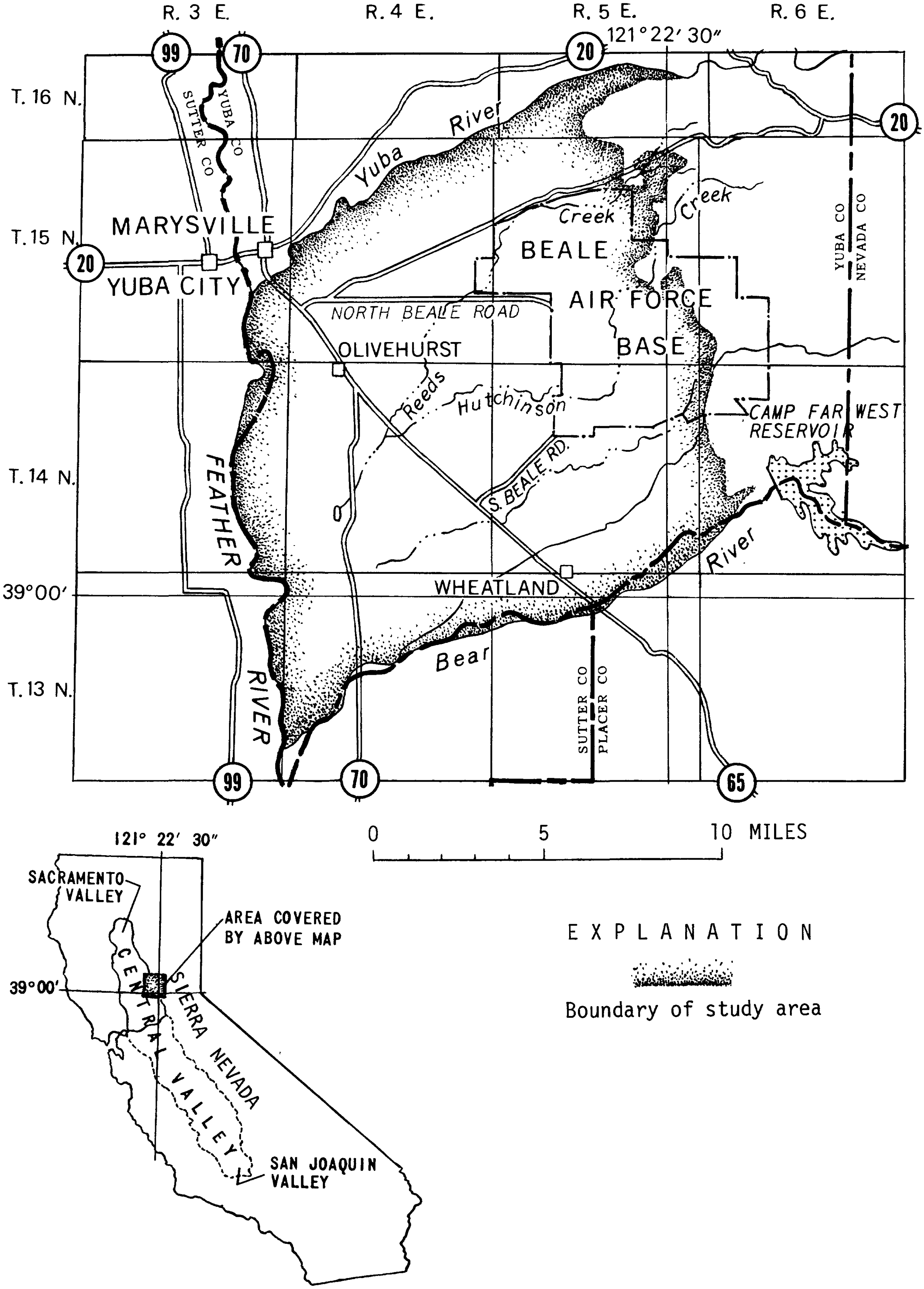

FIGURE 1.--Location of study area.

TABLE 1. - Humidity, temperature, and precipitation data, Beale Air Force Base

[Unpublished data, Beale Air Force Base, 1943-66]

Month	Mean relative humidity (percent) Hour 0400	Mean relative humidity (percent) Hour 1300	Mean temperature (°F) Maximum	Mean temperature (°F) Minimum	Mean precipitation (inches)
January	87	69	51	36	3.7
February	84	59	59	41	4.0
March	80	52	63	42	2.8
April	80	47	69	46	2.2
May	74	38	77	52	.7
June	67	31	89	59	.1
July	59	27	96	63	([1])
August	61	28	93	61	([1])
September	64	31	88	58	.4
October	69	39	78	52	2.2
November	79	55	63	43	3.1
December	85	70	53	38	2.3

[1]Less than 0.1 inch.

Previous Reports

Reports that contain geologic, hydrologic, and water-quality data for Beale Air Force Base and vicinity include:

Aetron and Hydrodevelopment, Inc. (1965), geologic sections and map, annotated electrical logs for three test holes at the base, general descriptions of lithologies to a depth of 1,675 ft, and a chemical analysis of water in the depth zone from 1,600 to 1,650 ft;

Aetron and Hydrodevelopment, Inc. (1966), electrical logs for three injection wells at the base, detailed geologist's logs from 220 to 1,304 ft, hydraulic conductivity and porosity data for lithologies in depth zone from 1,038 to 1,228 ft;

Berkstresser (1973), map showing altitude of base of fresh water, approximately 3,000 micromhos;

Bertoldi (1974), maps showing permeability of soils and barriers to vertical flow of water in soils;

California Department of Water Resources (1960), generalized geologic map, general description of ground water in Sacramento Valley, and chemical analyses of ground water in study area;

California Department of Water Resources (1978), descriptions of geologic units, ground-water pumpage, and ground water in storage; maps showing geology, well yields, and specific capacities, and diagrams showing ground-water pumpage and recharge.

Dewante and Stowell (1965), histories and descriptions of water wells at Beale Air Force Base, geologists' logs, results of pump tests, water levels, and chemical analyses of ground water;

Fogelman and Rockwell (1977), maps showing locations of wells, and tables of descriptions of wells and of chemical analyses of ground water;

Lofgren and Ireland (1973), maps showing water-level decline from 1912-13 to 1969 and average ground-water pumpage by township from 1966 to 1969;

Olmsted and Davis (1961), descriptions of geologic units, yields of wells, and storage capacities; maps showing geology, physiographic units, yield characteristics of wells, ground-water storage units, and altitude of base of fresh water; geologic sections; and tables of geologic units, yield characteristics of irrigation wells, and estimated ground-water storage capacity;

Page (1974), descriptions of post-Eocene continental deposits and maps showing the base and thickness of the post-Eocene deposits;

Rockwell (1978), maps showing locations of wells, and tables of descriptions of wells--the data report for the study area; and

U.S. Army Corps of Engineers (1966), descriptions, electrical logs, lithologic logs, and pump tests for Beale Air Force Base wells 15N/4E-24K1 and 15N/5E-19L1.

Additional data were provided by the cities of Olivehurst and Wheatland, the Camp Far West Irrigation District, Plumas Mutual Water Co., and several agricultural and industrial firms in the area.

Well-Numbering System

The well-numbering system used by the Geological Survey in California indicates the location of wells according to the rectangular system for the subdivision for public lands. For example, in the number 15N/4E-24K1, the part of the number preceding the slash indicates the township (T. 15 N.); the number after the slash the range (R. 4 E.); the digits after the hyphen the section (sec. 24); 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 15N/4E-24K1 was the first well to be listed in NW¼SE¼ sec. 24. For wells not located in the field by the Geological Survey, the final digit has been omitted. 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

Table 2 shows the correlation between Beale Air Force Base well numbers and those of the Geological Survey.

TABLE 2. - Correlation of Beale Air Force Base and U.S. Geological Survey well numbers

Beale Air Force Base	U.S. Geological Survey
1	15N/4E-24R1
2	15N/4E-24R2
3	15N/5E-19F1
4	15N/4E-24H1
5	15N/4E-24G1
6	15N/4E-24B1
7	15N/4E-24A1
8	15N/5E-19L1
9	15N/4E-24K1

GEOLOGIC UNITS AND THEIR WATER-BEARING PROPERTIES

Geologic units that crop out in the study area include (1) basement complex of the Sierra Nevada of Paleozoic and Mesozoic age, (2) undifferentiated sedimentary rocks of Eocene and Oligocene(?) age, (3) volcanic rocks from the Sierra Nevada of Eocene(?) and Pliocene age, which include sedimentary rocks as described by Olmsted and Davis (1961, p. 58-67), (4) Laguna Formation and related continental deposits of Pliocene(?) and Pleistocene age, (5) Victor Formation and related deposits of Pleistocene age, and (6) river deposits of Holocene age (pl. 1). Fine-grained sedimentary rocks of Eocene and Oligocene(?) age do not crop out in the area, but are reached by water wells and test wells in the eastern part of the area (pl. 2). They probably are equivalent to the lower part of the undifferentiated sedimentary rocks of Olmsted and Davis, (1961, table 1).

The effective base of the usable ground water beneath Beale Air Force Base is at the contact between the undifferentiated sedimentary rocks and the underlying fine-grained sedimentary rocks (pl. 2). Near that contact, dissolved-solids concentrations in the water are estimated to be more than 700 mg/L. Near the western part of the study area, the effective base of the ground water is the bottom of the zone in which dissolved-solids concentrations are less than 2,000 mg/L. In that part of the study area, the bottom of the zone ranges in depth from about 650 ft to about 850 ft (Berkstresser, 1973).

Basement Complex of the Sierra Nevada

The basement complex of the Sierra Nevada consists of metamorphosed igneous and sedimentary rocks and of igneous rocks that have intruded the metamorphic rocks. It underlies all other rocks and deposits.

At Beale Air Force Base, the top of the basement complex slopes 2 to 6 degrees southwestward, and ranges in depth from 0 to about 1,400 ft (pl. 2, sec. A-A') (Aetron and Hydrodevelopment, Inc., 1965, geologic sections). In the extreme southwestern part of the study area, the depth to the basement complex is about 5,100 ft (Smith, 1964). In the study area, no water wells were found to reach the basement complex. Considering the rock types of the basement complex, water yielded to wells would probably be mostly from fractures, and then only in small quantities.

Fine-Grained Sedimentary Rocks and Undifferentiated Sedimentary Rocks

The fine-grained sedimentary rocks consist of clay, sandy clay, silty clay, sand, and claystone. The undifferentiated sedimentary rocks, as described by Olmsted and Davis (1961, p. 48-50, pl. 2), consist of marine, nonmarine, and deltaic sedimentary rocks of sand, clay, conglomerate, sandstone, tuff breccia, siltstone, and shale. As mentioned, the fine-grained sedimentary rocks probably are equivalent to the lower part of the undifferentiated sedimentary rocks of Olmsted and Davis (1961). The top of the fine-grained sedimentary rocks, where mapped, ranges in depth from at least 315 to 865 ft (pl. 2, sec. A-A').

A fine to medium marine sand of unknown age underlies the fine-grained sedimentary rocks (Aetron and Hydrodevelopment, Inc., 1965, p. 5-7). At well 14N/5E-18G, the water in that sand had a dissolved-solids concentration of 27,700 mg/L (Aetron and Hydrodevelopment, Inc., 1965, p. 13).

The undifferentiated sedimentary rocks that overlie the fine-grained sedimentary rocks dip gently southwestward (pl. 2, sec. A-A'). Where mapped, their top ranges in depth from 0 to about 455 ft, and they range in thickness from 0 to about 150 ft (pls. 1 and 2). Only a few water wells are known to reach the undifferentiated sedimentary rocks; of those wells, none pump exclusively from the sedimentary rocks.

Volcanic Rocks from the Sierra Nevada

The volcanic rocks from the Sierra Nevada consist of poorly- to well-consolidated fluviatile volcanic siltstone, sandstone, conglomerate, and shale, and volcanic breccia, tuff breccia, and tuff; they are predominantly andesitic and rhyolitic, and at Reeds Creek they are andesitic (Olmsted and Davis, 1961, p. 58-67). The contact between the volcanic rocks from the Sierra Nevada and the underlying sedimentary rocks is difficult to identify on drillers' logs and geologists' logs. For this study, identification of the contact was made on the basis of (1) a change from dark colors, associated with andesitic rocks, to lighter colors, (2) an occasional identification of volcanic and nonvolcanic rocks on the logs, and (3) an abrupt increase in the dissolved-solids concentration of the ground water, as indicated on electrical logs. The larger dissolved-solids concentration was interpreted as being associated with marine rocks of the underlying undifferentiated sedimentary rocks. In the middle and western parts of the study area, data were not adequate for picking the contact.

The volcanic rocks from the Sierra Nevada dip gently southwestward (pl. 2, sec. A-A'). Where mapped, the top of the volcanic rocks ranges in depth from 0 to 270 ft and their thickness from 0 to 325 ft (pls. 1 and 2).

Wells 13N/5E-4E1 and 14N/5E-17N1 probably yield water exclusively from the volcanic rocks from the Sierra Nevada (pl. 2, sec. A-A'; pl. 3); yields of those wells are 930 and 415 gal/min. Most of the wells at Beale Air Force Base are perforated in the volcanic rocks from the Sierra Nevada (pl. 2). Yields of those wells have ranged from 500 to 2,500 gal/min. During July 1975, yields ranged from 750 to 1,060 gal/min.

Laguna Formation and Related Continental Deposits

According to Olmsted and Davis (1961, p. 82-83), the Laguna Formation and related continental deposits include three geologic units mapped by Piper and others (1939, p. 49-61, pl. 1) in the Mokelumne area, a few miles south of Beale Air Force Base: Laguna Formation, gravel deposits of uncertain age, and Arroyo Seco Gravel. The Laguna Formation is a sequence of predominantly fine-grained, poorly bedded, somewhat compacted continental sedimentary deposits. The gravel deposits of uncertain age and the Arroyo Seco Gravel are coarse grained, poorly sorted, and form a discontinuous cap on the Laguna Formation and older formations. The units are mapped together for this study.

It is difficult to determine the subsurface contacts between the Laguna Formation and related continental deposits, the underlying volcanic rocks from the Sierra Nevada, and the overlying Victor Formation and related deposits (Olmsted and Davis, 1961, p. 83). Olmsted and Davis (1961, p. 83) arbitrarily considered the predominantly nonvolcanic sediments below depths of 50 to 150 ft, and above the largely andesitic detritus, to be the Laguna Formation. For this study, their criteria for mapping the contacts were followed wherever possible. Where they crop out (pl. 1), the Laguna Formation and related continental deposits approximate the boundaries of the dissected alluvial uplands west of the Sierra Nevada (Olmsted and Davis, 1961, pl. 1). Outcrops of the Laguna Formation and related continental deposits typically form rounded, low-lying hills (pls. 1 and 2).

The Laguna Formation and related continental deposits dip gently southwestward, as do the underlying and overlying deposits. Where mapped, the Laguna Formation and related continental deposits range in depth from 0 to 175 ft and in thickness from 0 to 180 ft (pls. 1 and 2).

Soils on the Laguna Formation and related continental deposits contain hardpan or other consolidated layers that restrict the vertical flow of water (Bertoldi, 1974, fig. 3). Hydraulic conductivity[1] in the layers ranges from 0 to 2 ft/d (Bertoldi, 1974, fig. 2).

Wells 14N/3E-13M1, 14N/5E-12N1, 15N/4E-10A1, 10M1, 14N3, 16H1, and 34E1 probably yield water mostly from the Laguna Formation and related continental deposits but some from the underlying volcanic rocks from the Sierra Nevada (pl. 2, sec. B-B'; pl. 3). In addition, well 15N/4E-10M1 probably yields some water from the undifferentiated sedimentary rocks. Yields to these wells are shown in the following table.

Yields to wells from the Laguna Formation and related continentel deposits and from the volcanic rocks from the Sierra Nevada

[Data from drillers' logs]

Well No.	Depth (ft)	Yield (gal/min)
14N/3E-13M1	700	4,200
14N/5E-12N1	249	100
15N/4E-10A1	375	3,700
15N/4E-10M1[1]	698	2,740
15N/4E-14N3	363	2,000
15N/4E-16H1	358	3,100
15N/4E-34E1	305	1,800

[1]Probably yields some water from the undifferentiated sedimentary rocks.

[1]The hydraulic conductivity of a medium is the volume of water, at the existing kinematic viscosity, that will move in unit time under a unit hydraulic gradient through a unit also measured at right angles to the direction of flow (Lohman and others, 1972, p. 4). In this report, hydraulic conductivity is expressed in cubic feet per day per square foot, which is reduced to feet per day.

Victor Formation and Related Deposits

According to Olmsted and Davis (1961, p. 93), the Victor Formation and related deposits include the Victor Formation of Piper and others (1939, p. 38-49, pl. 1) and unnamed equivalents of the Victor Formation north of the Mokelumne area. The Victor Formation and related deposits consist of a heterogeneous assemblage of silt, sand, gravel, and clay transported by shifting streams from the Sierra Nevada (Olmsted and Davis, 1961, p. 96). In addition, ill-defined tongues of sand and gravel, which underlie areas adjacent to the Feather and Yuba Rivers to depths of as much as 150 ft, represent channel deposits laid down by these streams (Olmsted and Davis, 1961, p. 96). Where they crop out (pl. 1), the Victor Formation and related deposits approximate the boundaries of the low alluvial plains and fans west of the Sierra Nevada (Olmsted and Davis, 1961, pl. 1).

The Victor Formation and related deposits dip gently southwestward. Where mapped, the Victor Formation and related deposits have their top at a depth of 0 to about 90 ft, and they range in thickness from 0 to 135 ft (pls. 1 and 2).

Soils on the Victor Formation and related deposits contain hardpan or other consolidated layers that restrict the vertical flow of water (Bertoldi, 1974, fig. 3). Hydraulic conductivity in the layers ranges from 0 to 2 ft/d (Bertoldi, 1974, fig. 2).

Wells 14N/3E-13G2 and 15N/4E-10R1 yield water from the Victor Formation and related deposits and from the underlying Laguna Formation and related continental deposits (pl. 3); yields to those wells are 2,150 and 2,100 gal/min. Wells 14N/4E-4N1 and 15N/4E-21D1 yield water exclusively from the Victor Formation and related deposits; yields to those wells are 1,000 and 1,600 gal/min. Further, Olmsted and Davis (1961, p. 99) indicated that the Victor Formation and related materials are among the most permeable deposits on the east side of the Sacramento Valley.

River Deposits

The river deposits consist of sand, gravel, silt, and minor amounts of clay. Outcrops approximate the boundaries of the Feather River flood plain and natural levees of the rivers and creeks in the study area (pl. 1) (Olmsted and Davis, 1961, pl. 1). In addition, well-defined tongues of sand and gravel underlie the present flood plains of the Bear, Feather, and Yuba Rivers (Olmsted and Davis, 1961, p. 110).

The lower boundary of the river deposits is difficult to determine from well-log data. For convenience, Olmsted and Davis (1961, p. 109) delineated the river deposits as the predominantly coarse-grained deposits at relatively shallow depth that seem to be hydraulically continuous with the deposits in present stream channels, flood plains, and natural levees. Their criteria were used, wherever possible, to map the river deposits.

Along the Yuba River near Marysville, a top zone of sand and gravel extends to about 100 ft below land surface, but the base of the coarse-grained deposits is somewhat shallower to the northeast (Olmsted and Davis, 1961, p. 112). Near the confluence of the Bear and Feather Rivers, wells tap coarse-grained deposits that have a base from 130 to 140 ft below land surface, but Olmsted and Davis (1961, p. 112) stated that those deposits probably belong to the Victor Formation. The river deposits, where mapped for this study, range in thickness from 0 to 90 ft (pls. 1 and 2).

Soils on the river deposits generally are not barriers to the vertical flow of water (Bertoldi, 1974, fig. 3). Hydraulic conductivities in the soil layers range from 2 to 10 ft/d; along the Yuba River near Hammonton and the Bear River near Wheatland, hydraulic conductivities in the soil layers are greater than 20 ft/d (Bertoldi, 1974, fig. 2).

Data are not available to determine the yields of wells in the river deposits, but Olmsted and Davis (1961, p. 114, pl. 2) indicated that the river deposits are highly permeable.

HYDROLOGY

Occurrence and Movement of Ground Water

Ground water in the study area occurs in undifferentiated sedimentary rocks, volcanic rocks from the Sierra Nevada, the Laguna Formation and related continental deposits, the Victor Formation and related deposits, and in river deposits. Because these geologic units are both lenticular and gradational in texture, the details of ground-water occurrence differ from place to place. During periods of pumping, drawdowns vary from place to place, probably because of the numerous lenses of fine-grained material which partly confine the water and prevent uniform vertical movement through the aquifer. Partial confinement probably occurs beneath Beale Air Force Base where beds of fine-grained material, of unknown areal extent, occur virtually throughout the water-bearing section (table 3). In general, though, nonpumping water levels in nearby wells of different depths are nearly the same, and ground water in the study area is considered to occur under unconfined conditions, with local confinement due to lenses of clay and silt.

TABLE 3. - Log of Beale Air Force Base well 15N/5E-19L1 and estimated values of hydraulic conductivity and transmissivity

15N/5E-19L1. Altitude 86 ft. Drilled by Beylik in 1966.
14-inch casing perforated 93-105 ft, 129-237 ft, 285-297 ft.

Material	Thickness (ft)	Depth (ft)	Hydraulic conductivity (ft/d)	Transmissivity (ft^2/d)
Gravel, clayey, sandy, brown, moist[1]	27	27		
Sand, gravelly, clayey, brown, moist[1]	8	35		
Clay, sandy, brown to tan, firm[1]	15	50		
Sandstone, silty; fine sand, light brown, slightly cemented[1]	13	63		
Sandstone, greenish black, slightly to moderately cemented	20	83	40	800
Siltstone and sandstone, tan to gray, interbedded	10	93	8	80
Clay, reddish brown, stiff[1]	9	102		
Sandstone, yellow-brown, slightly cemented	6	108	40	240
Sand, silt, and clay, blue-green interbedded, moderately cemented[1]	17	125		
Claystone, light-brown, stiff, waxy luster[1]	4	129		
Sandstone, gray to brown, well cemented	31	160	13	403
Gravel, sandy, dark green to gray, slightly cemented, contains some sandstone interbeds, contains gravel and cobbles to 8 inches	39	199	107	4,173
Clay, tan, stiff[1]	3	202		
Gravel, sandy, as at 160 ft	44	246	107	4,708
Sand, fine, greenish-gray, poorly cemented	14	260	8	112
Sand and fine gravel, brown and white	6	266	107	642
Clay, gray and blue-green, contains scattered gravel[1]	27	293		
Gravel, sandy, bluish, lightly cemented	13	306	107	1,391
Clay, blue, fat contains scattered gravel[1]	41	347		
Clay, gray-green, moderately plastic[1]	13	360		
Clay, dark brown, moderately plastic, contains scattered thin lenses of sand and gravel[1]	45	405		
			Total transmissivity =	12,500

[1]Hydraulic conductivity not estimated.

Because ground water moves from areas of high to low head (the height of the water level referenced to National Geodetic Vertical Datum of 1929), and, in general, normal to lines of equal head, the direction of ground-water movement can be determined from a water-level contour map (pl. 3). In March 1976, ground water moved generally from the foothills of the Sierra Nevada and from the rivers toward a pumping depression in secs. 1 and 12, T. 14 N., R. 4 E., and secs. 6 and 7, T. 14 N., R. 5 E. Locally, ground water moves as indicated in plate 3.

Aquifer Hydraulics

Because the emphasis of this study is on ground-water conditions at Beale Air Force Base, transmissivity[2] and storage coefficient[3] were estimated only for the rocks and deposits beneath the base. Two methods were used to estimate transmissivity. For the first method, transmissivity was estimated by multiplying specific capacity[4] by 1,700. This method was used by Thomasson and others (1960, p. 220-222) in Solano County, Calif. The transmissivity values obtained by applying that factor to seven wells on the base (two wells were not tested) ranged from 5,000 ft^2/d to 12,700 ft^2/d. Specific capacity for some wells, however, were not considered valid for calculating transmissivity because their small values indicated large drawdowns due to well-entrance losses. The calculation assumes that entrance losses in the wells are minor. Specific-capacity tests for five wells were made by Dewante and Stowell (1965) after those wells had been in service for over 20 years. Values at those wells were much smaller than those obtained during development of wells 15N/4E-24K1 and 15N/5E-19L1 in 1966. For example, the specific capacity of well 15N/4E-24R2 was 22 (gal/min)/ft, whereas the specific capacity of well 15N/5E-19L1 was 45 (gal/min)/ft.

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[2]Transmissivity is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman and others, 1972, p. 13). In this report, transmissivity is expressed in cubic feet per day per foot, which is reduced to feet squared per day.

[3]The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (Lohman and others, 1972, p. 13).

[4]The specific capacity of a well is the discharge per foot of drawdown. The specific capacity of a well that yields 750 gal/min with 10 ft of drawdown is 75 (gal/min)/ft.

Because the specific-capacity tests for wells 15N/4E-24K1 and 15N/5E-19L1 were made at a time when those wells were being developed and well-entrance losses were probably small, the specific-capacity values were assumed to be more valid for estimating transmissivity than the specific-capacity values of the other wells for which development data were not available. The specific capacity of well 15N/4E-24B1 was also considered to be valid for estimating transmissivity because its specific capacity of 47 (gal/min)/ft was comparable to that of wells 15N/5E-19L1 and 15N/4E-24K1. Using the specific-capacity values of those three wells, computed transmissivity values ranged from about 10,200 to 12,700 ft^2/d; the mean was about 11,200 ft^2/d.

A second method used to estimate transmissivity was to assign estimated values of hydraulic conductivity to the various lithologies indicated on the logs of eight wells. The log of well 15N/4E-24H1 was not used because it yielded a transmissivity value of 132,000 ft^2/d, which was considered to be excessively large. Values for hydraulic conductivity were assigned by using individual judgment and data from Johnson (1963, table 4), Johnson and others (1968, table 5), and Morris and Johnson (1967, tables 3-6 and 12). Values of hydraulic conductivity were not assigned to the upper 50-60 ft of material noted on a log, because water levels in wells on the base generally are below that depth. Also, values of hydraulic conductivity were not assigned to fine-grained materials such as clay and claystone, because those values were considered to be too small to account for very much of the water yielded to wells (Morris and Johnson, 1967, tables 6 and 12). An example of the computation is given in table 3. Using the data from eight geologists' logs, estimated transmissivity values ranged from 7,400 to 14,700 ft^2/d (table 4); the mean was about 12,000 ft^2/d.

TABLE 4. - Depths of eight wells and estimated transmissivity values at Beale Air Force Base

[Specific capacity: n.e., not used for estimating transmissivity because of small value]

Well No.	Depth (ft)	Estimated transmissivity (ft^2/d)	
		Geologists' logs	From specific capacity
15N/4E-24A1	300	7,400	n.e.
15N/4E-24B1	313	13,100	10,700
15N/4E-24G1	299	12,300	n.e.
15N/4E-24K1	370	9,400	12,700
15N/4E-24R1	296	12,700	n.e.
15N/4E-24R2	326	14,000	n.e.
15N/5E-19F1	264	14,700	n.e.
15N/5E-19L1	405	12,500	10,200

Using the information from these two methods, a final estimated transmissivity of 12,000 ft^2/d was assigned. This value is a mean of all values shown in table 4. The estimated transmissivity of 12,000 ft^2/d was used to compute ground-water inflow and outflow. This transmissivity value seems reasonable, considering that by using 12,000 ft^2/d the ground-water inflow approximately equals ground-water outflow plus pumpage, and water levels at the base have been about the same from spring 1971 to spring 1976 (see p. 18).

The first estimates of storage coefficient were made by using data from logs of eight wells on the base and assuming unconfined conditions. In an unconfined aquifer the storage coefficient is virtually equal to the specific yield.[5] Values of specific yield assigned to the various groups of materials noted on the logs were those used by Olmsted and Davis (1961, p. 150) in the Sacramento Valley. Using those values, the estimated specific yield of materials in approximately the upper 300 ft of saturated deposits beneath the base ranged in value from 6.7 to 13.0 percent (table 5); the mean was about 11 percent (storage coefficient of 0.11).

Because water in the aquifer may be confined at times when it is restricted by an overlying fine-grained bed, estimates of the storage coefficient under confined conditions were made by using a technique described by Lohman (1972, p. 53), in which the storage coefficient for confined aquifers, divided by the aquifer thickness, is assumed to equal 0.000001. Assuming 300 ft of saturated section to be under confined conditions, the storage coefficient would be 0.0003. It should be noted that the duration of confinement, once a well begins to pump, is unknown because the areal extent of any confining bed is unknown (see p. 11).

TABLE 5. - Estimated specific yield of rocks and deposits beneath Beale Air Force Base

Well No.	Estimated specific yield (percent)	Well No.	Estimated specific yield (percent)
15N/4E-24A1	9.5	15N/4E-24R1	12.9
15N/4E-24B1	11.9	15N/4E-24R2	12.6
15N/4E-24G1	11.3	15N/5E-19F1	13.0
15N/4E-24K1	6.7	15N/5E-19L1	8.5

[5]Specific yield of a rock or soil is the ratio of the volume of water which the rock or soil, after being saturated, will yield by gravity to the volume of the rock or soil (Lohman and others, 1972, p. 12).

Recharge

Recharge to the aquifer in the study area is principally by loss of water from the rivers to the aquifer, as indicated by water-level contours (pl. 3). Recharge may also occur by seepage from precipitation, from intermittent creeks, and from surface water applied to irrigated fields, although data are not available to substantiate this.

Recharge to the well field at Beale Air Force Base, although ultimately from the Yuba River, is principally by ground-water inflow from the north, northeast, and northwest (pl. 3). The volume rate of ground water moving through the aquifer toward the well field was computed by using the equation Q = TIL, where Q equals the volume rate at which water moves across a section; T, the transmissivity; I, the hydraulic gradient; and L, the length of the cross section. Transmissivity was estimated by using specific-capacity tests, and geologists' logs (see p. 13-15). Hydraulic gradient was determined from the contours of the water surface of the unconfined aquifer, and the length of segment A-A' was measured on the map (pl. 3). On this basis the ground-water inflow across segment A-A' into the well field at Beale Air Force Base is about 11.0 acre-ft/d or 4,000 acre-ft/yr.

Discharge

Discharge from the aquifer in the study area is principally by pumping. Water-level contours for March 1976 (pl. 3) indicate that no water leaves the study area as ground-water outflow. For the period 1966-71 and for 1975, ground-water pumpage in the study area ranged from 96,000 to 129,000 acre-ft/yr (table 6). Discharge from the well field at Beale Air Force Base is by pumping and by ground-water outflow to the south, southeast, and southwest and generally toward a pumping depression in the NE¼ T. 14 N., R. 4 E. and the NW¼ T. 14 N., R. 5 E. (pl. 3). This depression has been caused principally by the distribution and pumping of wells in the area and their distance from a recharge source (table 6, and Rockwell, 1978). For the period 1960-75, ground-water pumpage at Beale Air Force Base ranged from 1,370 to 4,240 acre-ft/yr (table 7). Most of the pumping at Beale Air Force Base occurs from May through September (table 8).

TABLE 6. - Estimated ground-water pumpage, in acre-feet, Beale Air Force Base and vicinity, 1966-71, 1975[1]

Township/ range	1966	1967	1968	1969	1970	1971	1975
13N/4E	13,600	11,200	14,800	18,900	18,300	16,900	16,700
13N/5E	6,300	5,000	5,900	6,500	8,100	7,400	6,200
14N/3E	8,100	6,700	6,800	7,100	7,000	7,300	10,900
14N/4E	40,800	32,000	39,400	33,000	36,300	31,200	40,500
14N/5E	20,600	16,600	22,200	22,200	22,900	22,100	26,100
15N/4E	28,900	22,000	27,400	26,400	22,000	20,700	27,100
15N/5E	1,900	2,400	2,100	1,500	1,000	1,000	1,700
Total[2]	120,000	96,000	119,000	116,000	116,000	107,000	129,000

[1]Pumpage data not available, 1972-74.
[2]Rounded to nearest 1,000 acre-ft.

TABLE 7. - Ground-water pumpage, in acre-feet, at Beale Air Force Base, 1960-75

Year	Pumpage	Year	Pumpage
1960	1,370	1968	4,240
1961	1,980	1969	4,110
1962	2,510	1970	3,860
1963	2,300	1971	3,510
1964	2,500	1972	3,480
1965	2,710	1973	3,560
1966	3,230	1974	3,100
1967	3,450	1975	3,120

TABLE 8.- Monthly ground-water pumpage, in acre-feet, at Beale Air Force Base, 1975

Month	Pumpage	Month	Pumpage
January	120	July	520
February	110	August	470
March	150	September	350
April	130	October	190
May	350	November	130
June	480	December	120

Ground-water outflow from the base well field was computed by using the equation Q = TIL. The estimated ground-water outflow moving across segment B-B' (pl. 3) and away from the well field is 2.3 acre-ft/d, or about 850 acre-ft/yr. The estimated values for ground-water inflow and outflow seem reasonable, considering that the difference between ground-water inflow and outflow nearly equals pumpage at the base (see table below) and that water levels at the base were about the same for spring 1975 and spring 1976 (figs. 6 and 7), indicating little net removal of water from storage. Water levels at the base were about the same from spring 1971 to spring 1976, thus indicating a balance between ground-water discharge and ground-water recharge during this period.

Ground-water inflow (acre-ft/yr)	Ground-water outflow (acre-ft/yr)	Difference inflow-outflow (acre-ft/yr)	Pumpage (acre-ft/yr)
4,000	850	3,150	3,120

Interference Among Wells at Beale Air Force Base

Mutual drawdown effects, or interference, among wells at Beale Air Force Base were calculated in order to determine if excessive interference was occurring at any well because of spacing of wells or current rates of pumping. Interference can be calculated, at least theoretically, by means of the Theis formula (Ferris and others, 1962, p. 76). Information required for the calculation consists of aquifer transmissivity, aquifer storage coefficient, period of pumping, and well-discharge rates. At the Air Force base an average transmissivity of 12,000 ft^2/d, storage coefficients of 0.11 and 0.0003, pumping periods of 35 years for 6 wells and 10 years for 3 wells, and average pumping rates derived from 7 years of record were used. The 35- and 10-year pumping periods reflect the actual periods of use of the base wells. Other factors that might contribute to well interference, such as hydrologic boundaries and wells pumped outside the base, were not considered.

Because it is not known how long confined conditions existed while wells at the base were being pumped, one set of calculations was made as though confined conditions existed throughout the entire pumping period. Such calculations yield a theoretical maximum limit of interference at a well. Because only partial confinement exists at the base, interference at a well would be less than the calculated maximum. Under unconfined conditions, calculation of interference yield values approaching a theoretical minimum limit. Interference at the wells is somewhere between that calculated for confined conditions and that for unconfined conditions. Refinement of interference values would require intensive aquifer testing. Results of the calculations are given in table 9. For each well the interference is the sum of the drawdown effects caused by pumping the other wells.

The foregoing calculations are useful in evaluating the present spacing of wells. Inasmuch as the interference is virtually the same in all the existing wells, at the current rates of pumping the wells seem to be adequately spaced. Less interference would require greater spacing or reduced pumping.

TABLE 9. - Total theoretical interference, in feet, caused by wells 15N/4E-24A1, B1, G1, H1, R1, and R2 being pumped for 35 years and wells 15N/4E-24K1, 15N/5E-19F1, and 15N/5E-19L1 being pumped for 10 years

Well No.	Transmissivity (12,000 ft^2/d) Unconfined storage coefficient (0.11)	Confined storage coefficient (0.0003)
15N/4E-24A1	13	26
15N/4E-24B1	14	28
15N/4E-24G1	15	31
15N/4E-24H1	15	26
15N/4E-24R1	14	29
15N/4E-24R2	13	28
15N/4E-24K1	15	30
15N/5E-19F1	13	28
15N/5E-19L1	14	28

Water-Level Fluctuations

Long- and short-term trends in the available ground-water supply in the study area are indicated by hydrographs showing monthly and semiannual measurements of water levels in wells (figs. 2-7). A change in the rate of decline or rise in water level indicates a change in discharge or recharge. A decline in water level indicates that water has been taken from storage; a rise indicates that water has been added to storage. If no net change occurs in water level from one year to the next, discharge for that period is equal to recharge.

In the 1960's water levels in most parts of the study area declined less rapidly than in earlier years or became fairly stable. In the 1970's water levels at Beale Air Force Base declined only slightly. Examples of water-level trends in the study area are given below.

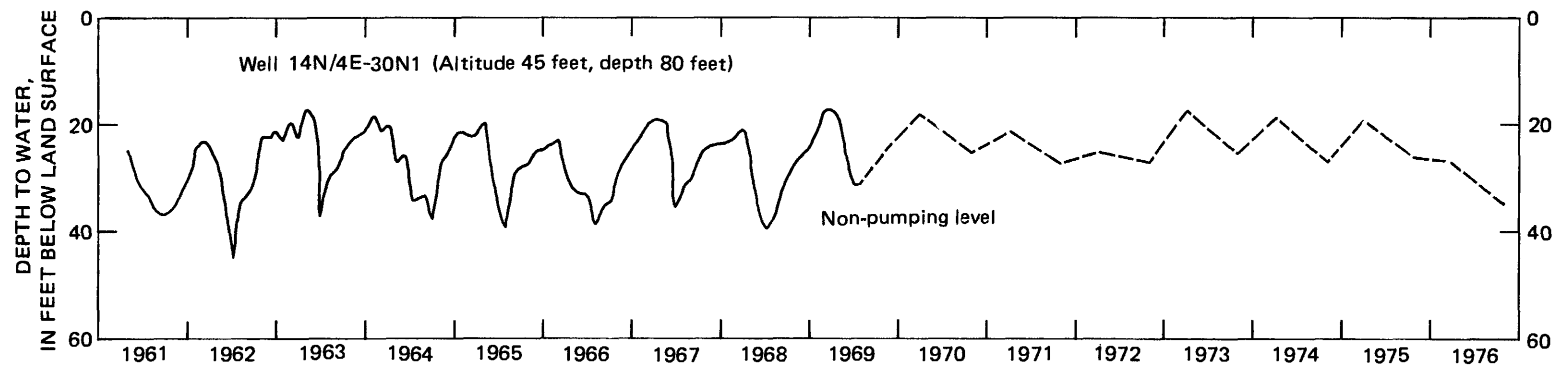
At Beale Air Force Base, water levels declined as much as 80 ft from 1912 to 1969 (Lofgren and Ireland, 1973, fig. 3). From 1945 to 1964, water levels declined about 40 ft (fig. 6). From 1964 to 1971, water levels in well 15N/4E-24A1 declined about 17 ft; since 1971, water levels in that well have declined only sightly (fig. 6). Water levels in well 15N/4E-24R1 show a similar trend (fig. 7).

In the southwestern part of the study area, there was virtually no net decline from 1961 to late 1975 (fig. 2). From late 1975 to late 1976, water levels declined about 9 ft. Prior to that period the largest net change in water level from one year to the next was about 8 ft and occurred from early 1972 to early 1973 and again from early 1975 to early 1976.

In the south-central part of the study area, water levels declined about 46 ft from 1948 to 1964 (fig. 3). Since 1964, water levels have had little net change.

In the northwestern part of the study area near Olivehurst, water levels declined about 20 ft from 1948 to 1962 (fig. 4). From 1962 to 1976, water levels declined about only 8 ft. Near the Yuba River, water levels have shown little change, except between 1957 and 1966 when they declined about 13 ft (fig. 5).

Annual trends show that water levels generally rise during autumn and winter, when the demand for water is at a minimum, and decline during spring and summer, when the demand is at a maximum. Thus, maximum decline of water level in the study area and at Beale Air Force Base may occur anytime from July to September, but is most often in August (figs. 2-7).



Hydrograph by R. W. Page, 1977. Data from California Department of Water Resources, 1966–74, 1976 and unpublished data

FIGURE 2.--Water-level fluctuations in well 14N/4E-30N1.

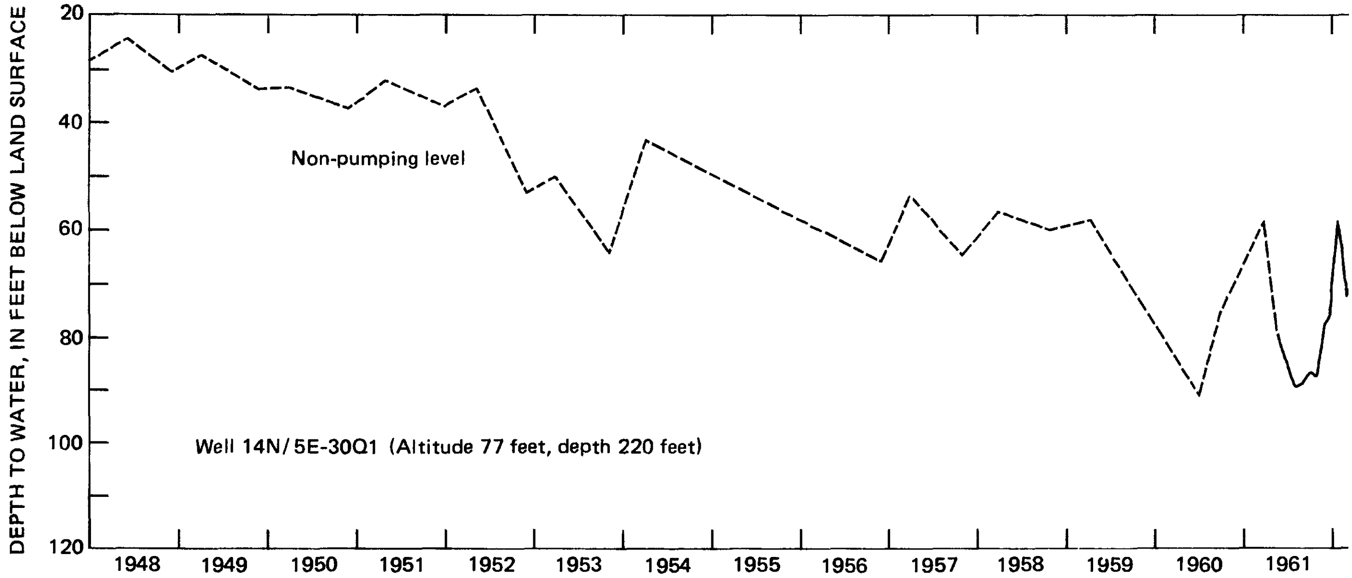


FIGURE 3.--Water-level fluctuations

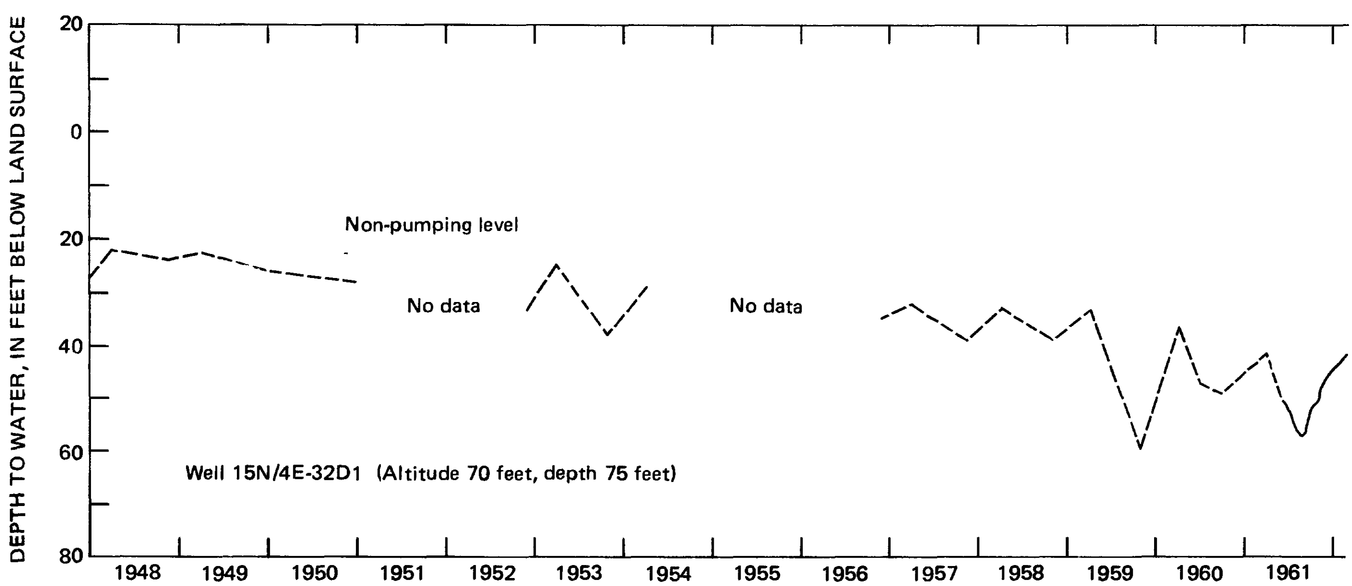
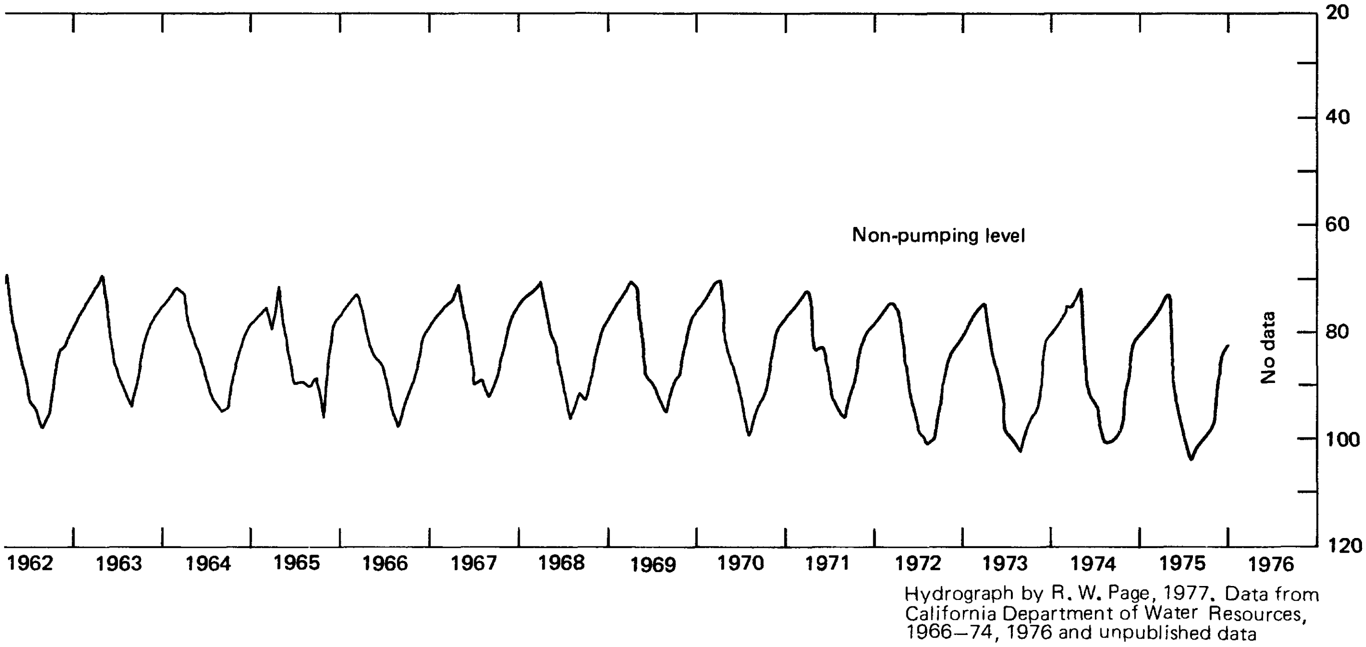
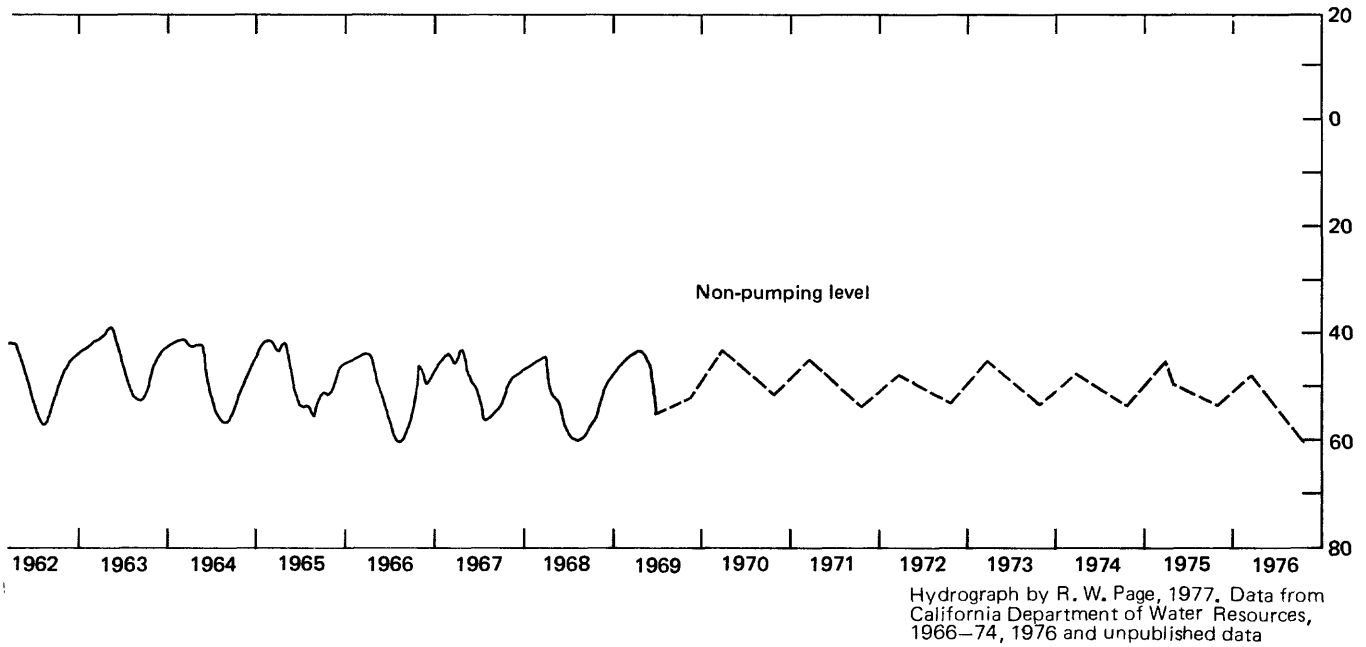


FIGURE 4.--Water-level fluctuations



in well 14N/5E-30Q1.



in well 15N/4E-32D1.

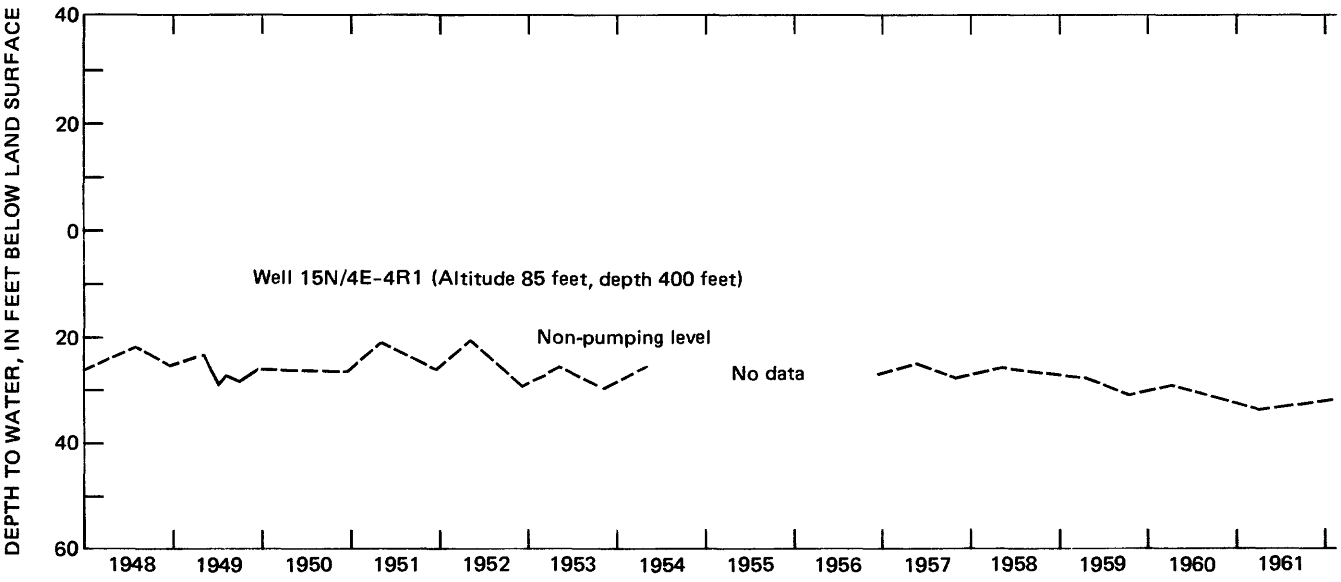


FIGURE 5.--Water-level fluctuation

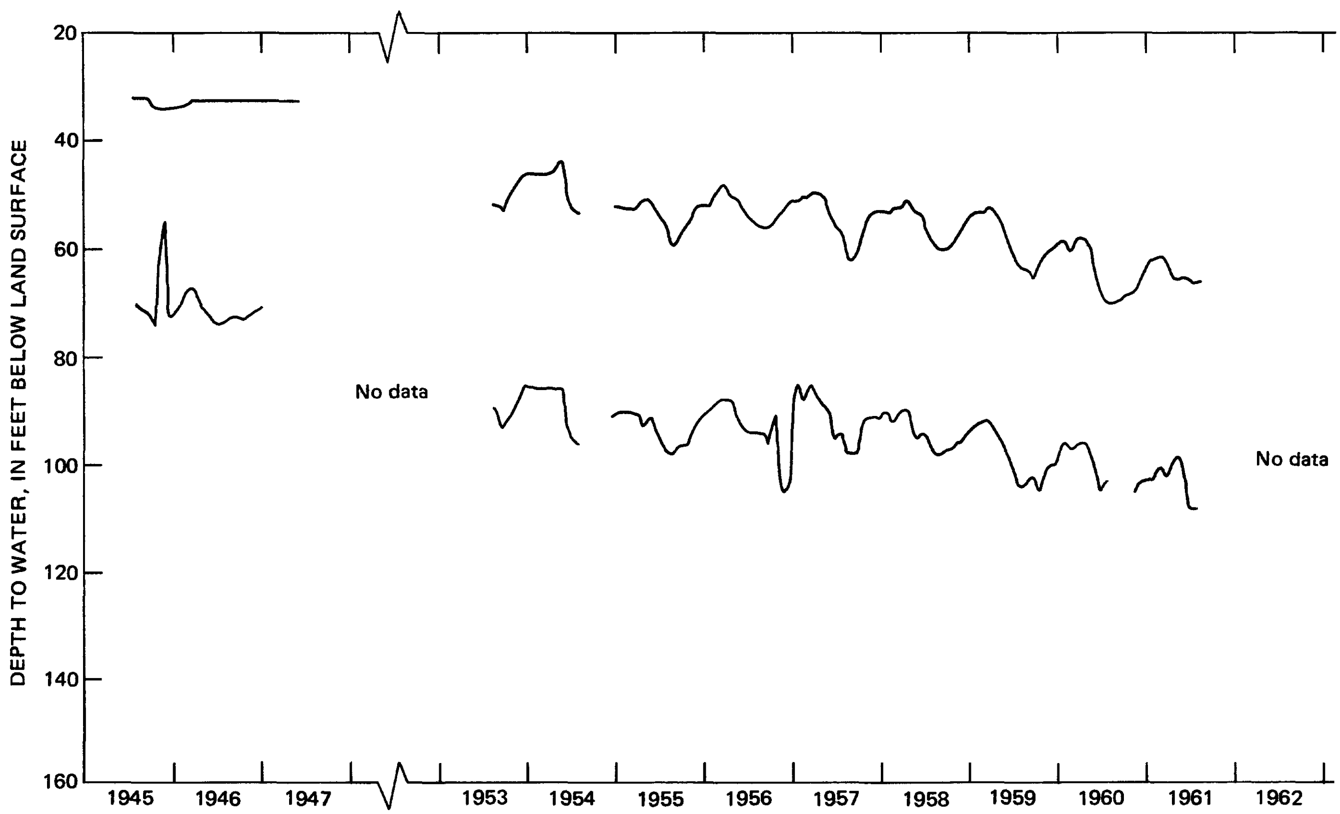
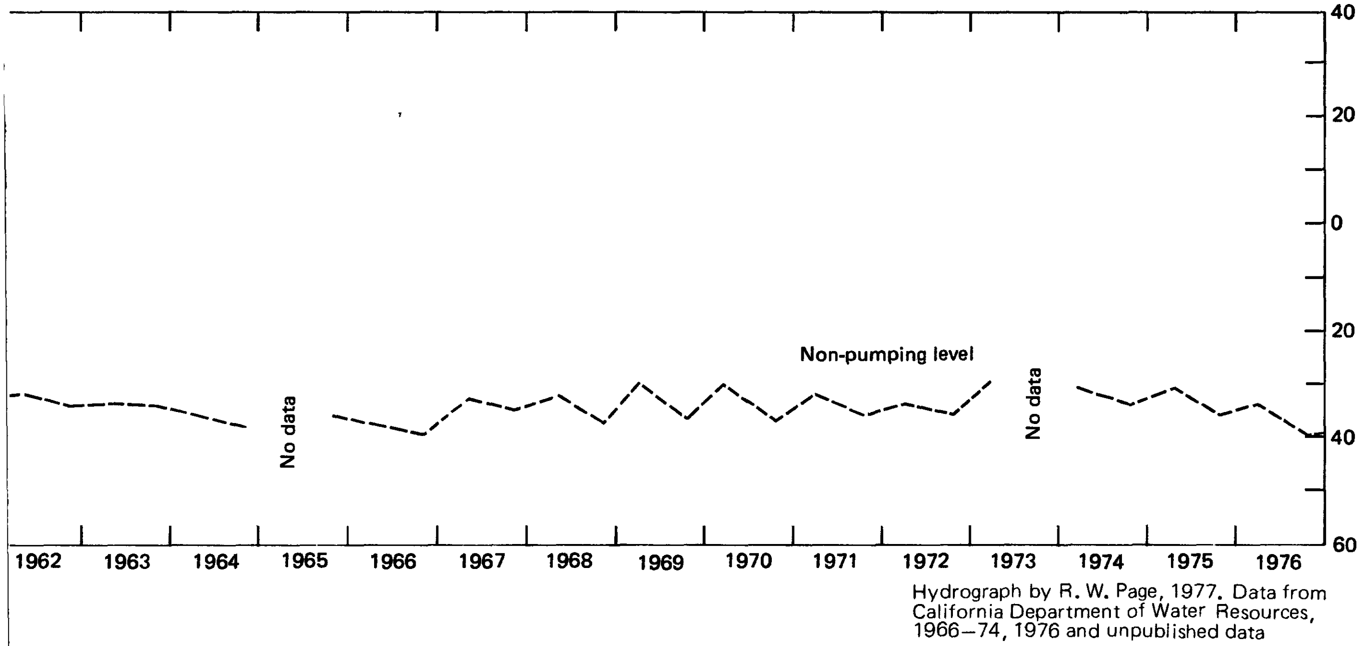
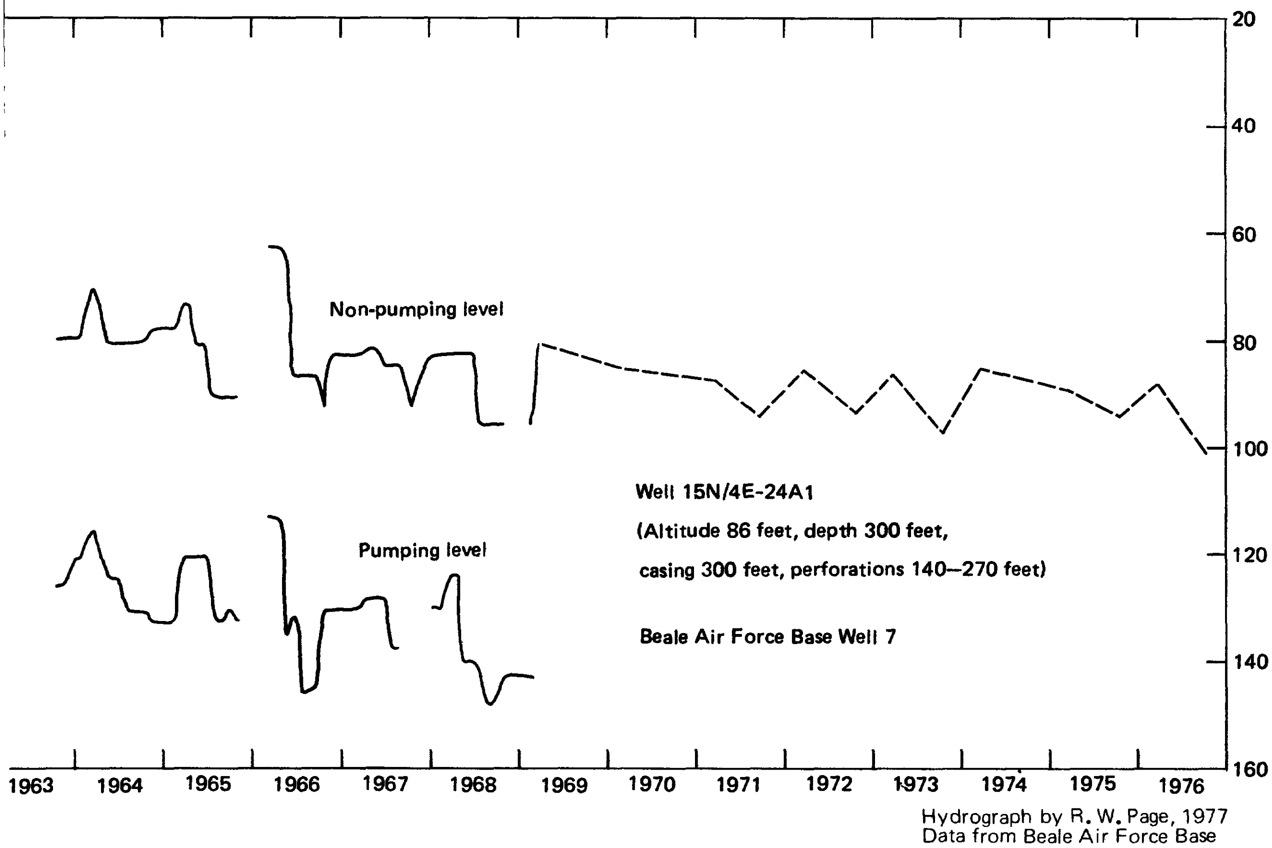


FIGURE 6.--Water-level fluctuations



in well 15N/4E-4R1.



in well 15N/4E24A1.

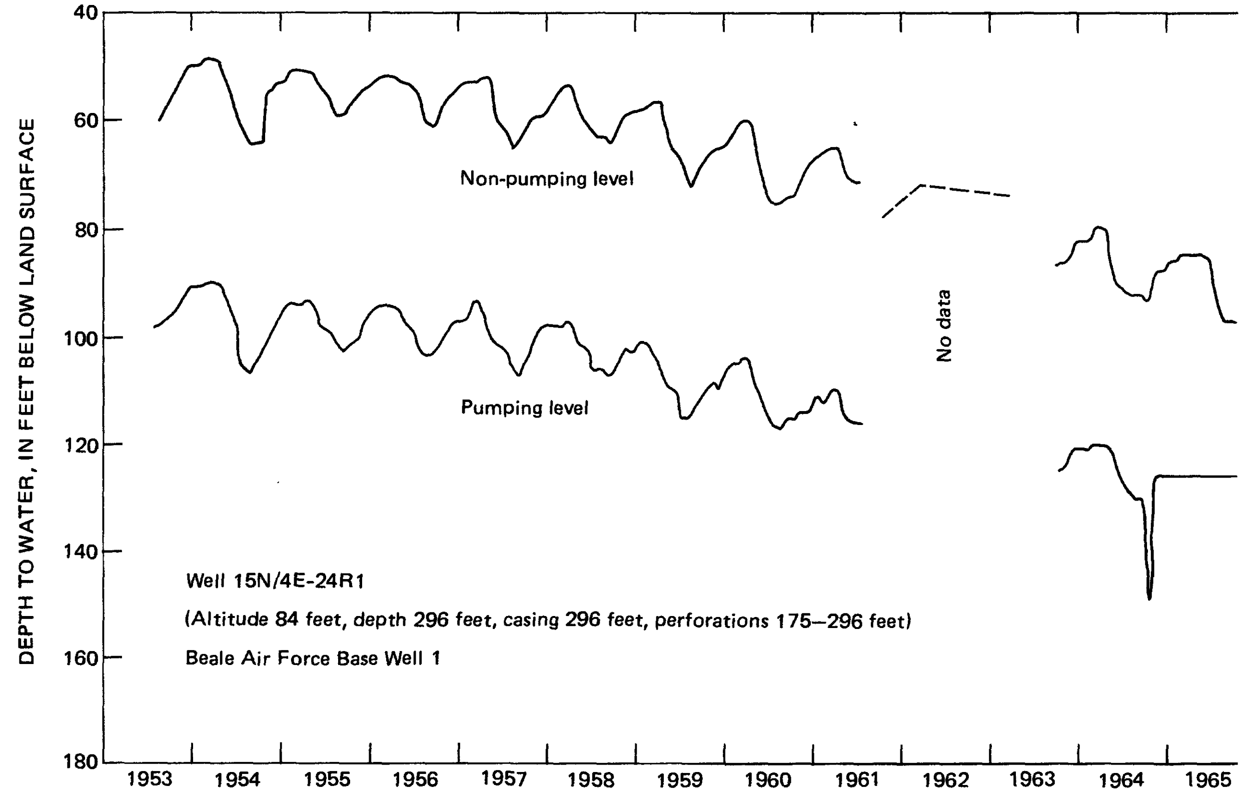


FIGURE 7.--Water-level fluctuations

GROUND-WATER QUALITY

The chemical quality of water yielded to wells was studied to identify zones of poor-quality water that could affect utilization of the ground-water reservoir.

Terms used to describe chemical types of water in this report follow Piper, Garrett, and others (1953, p. 26), as in the following examples:

1. Calcium bicarbonate designates a water type in which calcium constitutes 50 percent or more of the cations and bicarbonate constitutes 50 percent or more of the anions, in milliequivalents per liter.[6]
2. Sodium calcium bicarbonate designates a water type in which sodium and calcium are first and second in order of abundance of the cations, but neither is 50 percent or more of the total cations.
3. Sodium chloride bicarbonate designates a water type in which chloride and bicarbonate are first and second in order of abundance of the anions, but neither is 50 percent or more of the total anions.

The effective base of the ground-water reservoir is the base of the undifferentiated sedimentary rocks. At Beale Air Force Base the base of these rocks ranges in depth from at least 315 ft to about 525 ft (pl. 2). Water in

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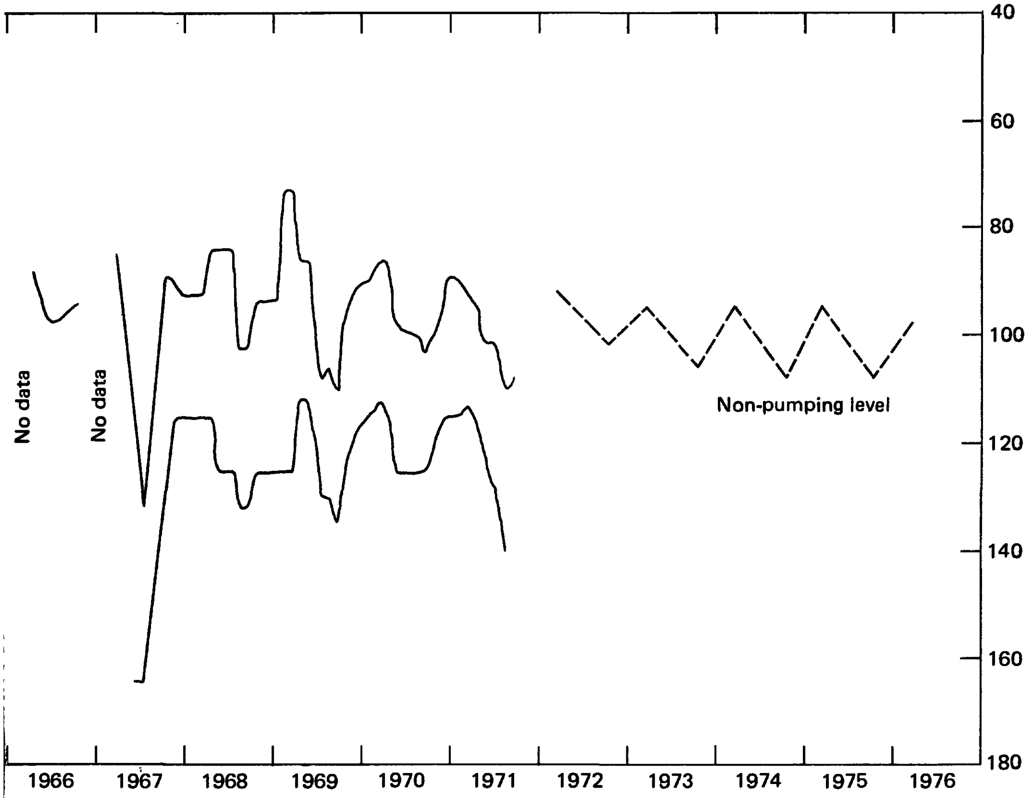
[6]Milliequivalents per liter = $\frac{\text{concentrations in milligrams per liter}}{\text{molecular weight/valence}}$



Hydrograph by R. W. Page, 1977
Data from Beale Air Force Base

in well 15N/4E-24R1.

the undifferentiated sedimentary rocks and the underlying fine-grained sedimentary rocks has a larger dissolved-solids concentration than the water in the overlying rocks and deposits. At the base well field, water in the zone from 295 to 345 ft has a dissolved-solids concentration of 700 to 900 mg/L, based on estimates from the electrical log of well 15N/5E-19L1. South of the well field, dissolved-solids concentrations of water were estimated to be between 1,000 and 2,000 mg/L, based on electrical logs of wells 14N/5E-5R and 15N/5E-32R (pl. 2). Well 14N/5E-21A1, drilled to a depth of 548 ft, yielded water with a dissolved-solids concentration of 1,800 mg/L and a chloride concentration of 775 mg/L (Olmsted and Davis, 1961, p. 51).

Dissolved-solids concentrations have increased in water from seven of the nine supply wells at Beale Air Force Base (table 10). At least some of this increase probably results from deeper water of high dissolved-solids concentration entering the well field in response to reduced head in the upper zones.

Fogelman and Rockwell (1977, fig. 6) show that most of the water yielded to wells in the study area is either a calcium-magnesium or magnesium-calcium bicarbonate type of water. At Beale Air Force Base, well 15N/4E-24A1 yields a sodium-calcium chloride type, and wells 15N/4E-24H1, 15N/4E-24R1, 15N/4E-24R2, and 15N/5E-19F1 yield a sodium-calcium bicarbonate type. Outside the base, well 13N/5E-4E1 yields a sodium-bicarbonate chloride type of water; well 14N/5E-16P1 yields a calcium-magnesium chloride type; and well 14N/5E-22M2 yields a sodium-calcium chloride type.

TABLE 10. - Chemical analyses of water

[All analyses by U.S.

Well No.	Date of sample	Depth (ft)	Geologic section	Specific conductance (µmho/cm at 25°C)	pH (units)	Temperature (°C)	Hardness (Ca,Mg) (mg/L)	Calcium (Ca) (mg/L)	Magnesium (Mg) (mg/L)	Sodium (Na) (mg/L)
15N/4E-24A1	11-06-62	300	--	236	7.3	--	68	14	8.0	22
	11-14-67			464	7.4	--	105	24	11	50
	11-07-75			809	7.4	22	190	45	20	61
15N/4E-24B1	11-11-61	313	--	192	7.6	--	69	15	7.7	13
	11-03-69			197	7.9	--	69	14	8.3	13
	11-13-75			232	7.9	20	84	18	9.6	13
15N/4E-24G1	11-21-61	299	--	184	7.4	--	68	14	8.0	10
	11-03-69			186	7.6	--	71	12	10	11
	11-18-75			194	7.6	21	74	14	9.6	10
15N/4E-24H1	11-11-61	300	A-A'	369	7.7	--	83	18	9.2	38
	11-03-69			298	7.6	--	76	16	8.6	29
	11-07-75			304	7.8	21.6	81	18	8.7	23
15N/4E-24R1	11-21-61	294	B-B'	257	7.4	--	64	13	7.7	25
	10-28-68			215	6.8	--	57	10	7.0	23
	9-05-74			301	7.2	20	93	19	11	22
15N/4E-24R2	11-11-61	326	B-B'	192	7.6	--	69	15	7.7	13
	11-14-67			147	7.1	--	50	9.6	6.5	10
	11-07-75			299	7.4	23	72	15	8.5	33
15N/4E-24K1	10-28-68	[1]370	B-B'	297	7.3	--	86	18	10	25
	11-10-75			250	7.6	22	90	18	11	14
15N/5E-19F1	11-14-67	264	A-A'	169	7.6	--	52	11	6.0	14
	11-07-75			186	8.0	21.6	53	11	6.2	14
15N/5E-19L1	10-28-68	[2]405	--	165	7.0	--	53	9.6	7.0	13
	11-13-75			176	7.7	20	57	11	7.1	13

[1]Cement grout from 354 to 370 ft.
[2]Cement grout from 325 to 405 ft.

from supply wells at Beale Air Force Base

[...Geological Survey]

Percent sodium	Potassium (K) (mg/L)	Bicarbonate (HCO_3) (mg/L)	Sulfate (SO_4) (mg/L)	Chloride (Cl) (mg/L)	Fluoride (F) (mg/L)	Silica (SiO_2) (mg/L)	Dissolved solids, residue at 180°C. (mg/L)	Dissolved solids, sum (mg/L)	Dissolved nitrate (N) (mg/L)	Total nitrite plus nitrate (N) (mg/L)	Iron (Fe) (µg/L)	Manganese (Mn) (µg/L)
41	1.5	82	5.0	28	0.2	43	161	166	4.0	--	0	--
50	1.7	84	1.0	103	.3	40	298	272	.1	--	10	--
40	2.6	75	--	210	.1	43	493	--	--	0	0	40
29	1.4	94	0	15	.2	47	138	145	.1	--	40	--
29	1.4	96	1.0	13	.1	39	136	137	0	--	--	--
25	1.7	107	--	19	.1	45	163	--	--	0.06	140	140
24	1.4	92	1.0	12	.2	50	139	142	.1	--	30	--
25	.9	100	5.0	5.6	.2	42	130	136	0	--	--	--
22	.9	113	--	6.1	.1	43	144	--	--	0	280	260
49	1.9	86	6.0	67	.2	54	238	237	.1	--	40	--
45	2.0	79	6.0	51	.3	54	208	206	0	--	--	--
38	1.8	86	.3	45	.1	58	212	198	--	.02	0	200
45	1.6	80	6.0	3.6	.3	73	199	203	1.0	--	20	--
47	1.8	81	5.4	20	.2	67	177	177	2.4	--	--	--
33	1.9	92	8.1	42	.1	49	214	199	--	.02	10	0
29	1.4	94	0	15	.2	47	138	145	.1	--	40	--
30	1.0	74	6.0	4.6	.3	55	127	131	2.0	--	0	--
49	2.0	88	--	45	.1	61	216	--	--	.09	0	70
38	2.3	94	1.0	44	0	51	206	198	.3	--	--	--
25	1.3	114	--	21	.1	45	169	--	--	0	190	610
36	1.3	77	6.0	11	.3	53	141	142	.9	--	10	--
36	1.4	74	8.0	14	.2	56	160	147	--	0	0	100
34	1.8	76	6.8	6.0	.2	66	148	152	4.1	--	--	--
32	1.7	74	4.0	7.3	.2	65	165	154	--	1.80	10	10

TABLE 11. - Chemical analyses of water from selected wells in the study area outside Beale Air Force Base

[All analyses by U.S. Geological Survey]

Well No.	Date of sample	Depth (ft)	Geologic section	Specific conductance (µmho/cm at 25°C)	pH (units)	Temperature (°C)	Hardness (Ca,Mg) (mg/L)	Calcium (Ca) (mg/L)	Magnesium (Mg) (mg/L)	Sodium (Na) (mg/L)	Percent sodium	Potassium (K) (mg/L)	Bicarbonate (HCO_3) (mg/L)	Sulfate (SO_4) (mg/L)	Chloride (Cl) (mg/L)	Fluoride (F) (mg/L)	Silica (SiO_2) (mg/L)	Dissolved solids, residue at 180°C. (mg/L)	Dissolved solids, sum (mg/L)	Dissolved nitrate (N) (mg/L)	Total nitrite plus nitrate (N) (mg/L)	Iron (Fe) (µg/L)	Manganese (Mn) (µg/L)
13N/4E-20B3	8-09-76	--	--	470	7.7	18.5	230	56	22	21	16	4.0	226	81	12	0.1	36	345	344	--	0.31	0	390
13N/5E- 4E1	8-05-76	300	B-B'	440	7.2	19.5	62	19	3.6	71	68	--	128	27	67	--	--	312	--	--	.71	--	--
14N/4E- 9F2	8-12-76	320	A-A'	238	7.4	21.5	90	18	11	17	29	1.9	93	7.2	30	.2	55	178	187	--	0	0	200
13R3	8-12-76	355	--	199	7.1	21.0	72	14	9.0	13	27	--	88	6.9	17	--	--	177	--	--	.90	--	--
32F1	8-12-76	75	--	373	7.3	20.5	180	33	23	19	19	--	220	9.5	14	--	--	258	--	--	1.6	--	--
14N/5E- 7L1	8-16-76	220	--	183	7.3	20.0	77	16	9.1	12	25	--	86	6.0	13	--	--	178	--	--	1.2	--	--
12N1	8-16-76	249	--	254	7.0	21.0	130	27	14	13	18	.7	154	10	11	.1	25	170	177	--	.15	10	30
15C1	8-16-76	650	B-B'	222	7.1	20.0	86	19	9.4	15	28	--	76	12	23	--	--	190	--	--	1.2	--	--
16P1	8-16-76	230	--	1,120	7.3	19.0	420	100	42	39	17	2.7	85	29	280	.1	64	712	599	--	.83	0	0
22M2	8-16-76	500	B-B'	431	7.4	19.5	120	33	9.0	48	44	--	105	14	97	--	--	342	--	--	1.7	--	--
14N/5E-32R3	8-16-76	278	B-B'	234	7.3	18.5	110	21	14	15	23	--	114	9.0	22	--	--	205	--	--	2.8	--	--
15N/4E-24E1	8-17-76	165	--	926	6.9	19.0	420	83	51	16	--	--	104	40	90	--	--	686	--	--	60	--	--
33H2	8-17-76	300	A-A'	199	7.5	20.5	85	16	11	11	21	--	114	4.6	12	--	--	141	--	--	.16	--	--

Water from wells at Beale Air Force Base and from most wells in the study area generally is of good chemical quality. Some mineral constituents in the water from some wells, however, exceed the limits recommended by the National Academy of Sciences, National Academy of Engineering (1973, p. 54-93). Water from well 14N/5E-16P1 exceeds the recommended limit for chloride by 30 mg/L (table 11), although the limit of 250 mg/L (table 12) was set because of taste preferences and not because such concentrations are toxic. Water from wells 13N/4E-20B3, 14N/4E-9F2, 15N/4E-24B1, 15N/4E-24G1, 15N/4E-24R2, 15N/4E-24K1, and 15N/5E-19F1 exceed the recommended limit for manganese. Dissolved manganese is objectionable in water because it affects taste, stains plumbing fixtures, spots laundered clothes, and accumulates as deposits in distribution systems. Water from well 15N/4E-24E1 exceeds the recommended limit for nitrate-nitrogen[7] by 50 mg/L. Dissolved nitrate-nitrogen at concentrations larger than 10 mg/L has caused adverse physiological effects in infants.

TABLE 12. - Some quality standards for drinking water

[National Academy of Sciences, National Academy of Engineering, 1973, p. 56, 61, 64, 66, 69-71, 73, 86, 89, 93]

Constituent[1]	Maximum concentration (mg/L)
Arsenic	0.1
Chloride	250
Copper	1
Fluoride[2]	1.6
Iron	.3
Lead	.05
Manganese	.05
Nitrate-nitrogen	10
Selenium	.01
Sulfate	250
Zinc	5

[1] Not a complete list.

[2] Based on average maximum daily air temperature of 74°F at Beale Air Force Base between 1943 and 1966 (unpublished data, Beale Air Force Base, 1943-66).

[7]Hem (1970, p. 180) indicated that nitrate-nitrogen seems to be the only form of nitrogen of significance in the ground water.

Although the National Academy of Sciences and National Academy of Engineering quality standards do not specify a limit on the hardness of water, hardness in excess of 120 mg/L (as $CaCO_3$) is objectionable because it causes scaling (Sawyer, 1960, p. 233). In the study area, hardness in places exceeds 120 mg/L (tables 10 and 11).

SUMMARY AND CONCLUSIONS

The findings and conclusions of this study that are pertinent to the ground-water supply of Beale Air Force Base are listed below.

1. Long-term trends indicate that in past years water levels at Beale Air Force Base were declining; from spring 1971 to spring 1976, however, water levels in wells at the base showed little net change, indicating that the amount of water pumped from wells was generally balanced by ground-water inflow and that little net change occurred in ground-water storage.

2. Water from wells at the base generally is of good chemical quality, but wells 15N/4E-24B1, 15N/4E-24G1, 15N/4E-24H1, 15N/4E-24R2, 15N/4E-24K1, and 15N/5E-19L1 exceed the recommended limit for manganese.

3. The theoretical interference among the wells at the base is virtually uniform, indicating that spacing of wells and current pumping rates in the well field do not contribute to excessive interference in any one well. Theoretical interference in wells at the base ranged from 13 to 15 ft for unconfined conditions and from 26 to 31 ft for confined conditions. Total interference at a given well probably is between the interference computed for unconfined conditions and that for confined conditions.

4. Water-level decline at the base has increased hydraulic gradients near the base well field and thus increased ground-water inflow to the well field.

5. Principal recharge to the well field at the base is by ground-water inflow from the north, northeast, and northwest. The inflow in 1975 was estimated to be 4,000 acre-ft/yr.

6. Discharge from the well field at the base is by pumping and ground-water outflow. Pumpage in 1975 was 3,120 acre-ft; ground-water outflow in 1975 was estimated to be 850 acre-ft/yr in 1975.

7. The effective base of the ground-water reservoir beneath Beale Air Force Base is the base of the undifferentiated sedimentary rocks, which, where mapped, ranges in depth from at least 315 ft to about 525 ft.

8. Most of the water yielded to wells at the base comes from the volcanic rocks from the Sierra Nevada.

9. Water in the undifferentiated sedimentary rocks at the base well field is estimated to have a dissolved-solids concentration of 700 to 900 mg/L. Water in the undifferentiated sedimentary rocks in the southern part of the base near wells 14N/5E-5R and 15N/5E-32R is estimated to have a dissolved-solids concentration between 1,000 and 2,000 mg/L.

10. The fresh-water section near well 14N/5E-5R, in the southwestern part of the base, is about 400 ft thick.

RECOMMENDATIONS

In 1966, when wells 15N/4E-24K1 and 15N/5E-19L1 were being developed, the specific capacities of the wells, 56 and 45 (gal/min)/ft, were about double that of any other well at the base, except for well 15N/4E-24B1. The larger specific capacities of the two newer wells indicate that the specific capacities of the other wells at the base might be increased, and the pumping drawdown in those wells thereby decreased. The following program is recommended:

1. Test the specific capacity of all wells in the base well field.

2. Select a well with a small specific capacity, 20-30 (gal/min)/ft of drawdown for rehabilitation.

3. After the selected well has been rehabilitated, test its specific capacity again.

4. If the specific capacity of that well is improved, rehabilitate other wells with small specific capacities.

Before rehabilitating any well, however, the selected contractor should know all the specifics of its design in order to ensure that the proper method of rehabilitation is used and that the well will not be damaged.

For the long-range reliability of the water supply at Beale Air Force Base, the following recommendations are made:

1. Pump wells at or below their current rate, because recharge has about equaled discharge in recent years, and water levels declined only slightly in the period 1971-76.

2. If more water is needed at the base, wells drilled in the northeastern part of the well field, as near as possible to the Yuba River, would probably yield adequate supplies. New wells could also be drilled in the northwestern and southwestern part of the well field, but they would be subject to interference from wells pumping outside the base.

3. Drill a well deep enough in the well field for the chemical quality of water in the underlying undifferentiated sedimentary rocks to be determined.

4. If the water in the undifferentiated sedimentary rocks does not contain harmful chemical constituents, consider mixing that water with fresh water from existing wells or desalinizing it for use at the base.

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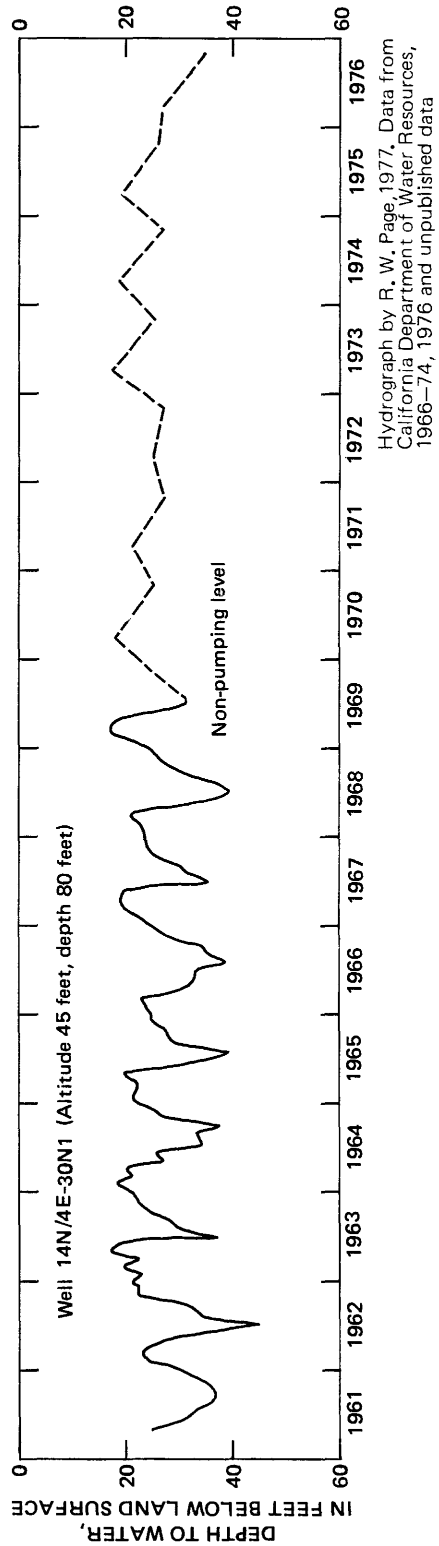

FIGURE 2.--Water-level fluctuations in well 14N/4E-30N1.

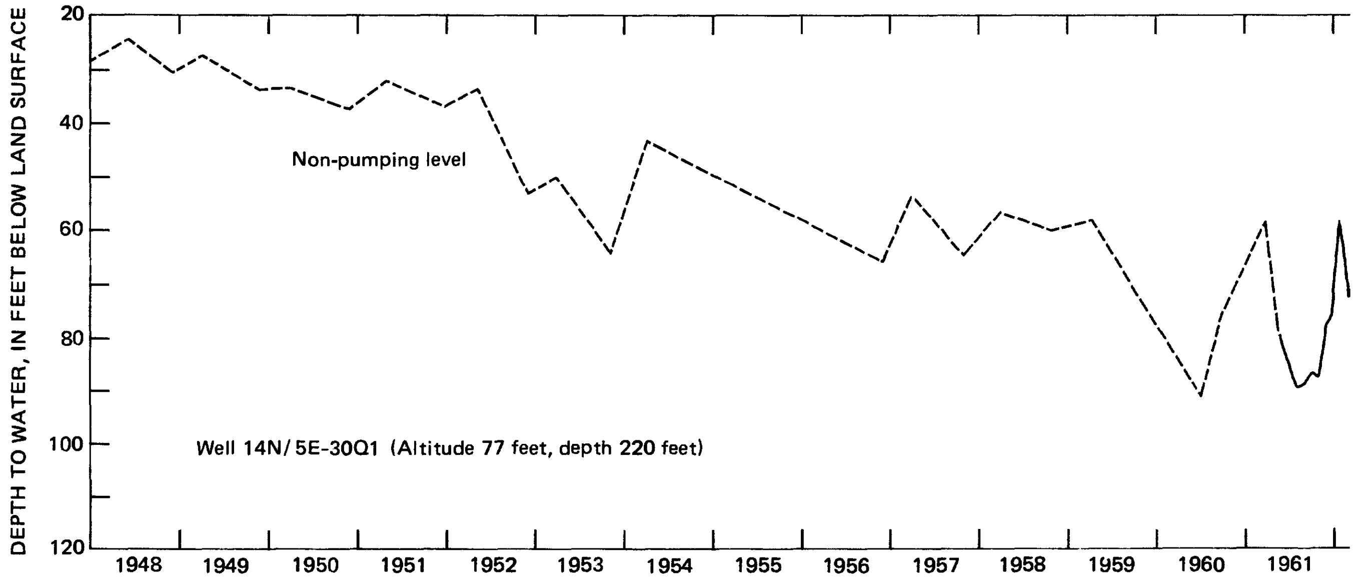

FIGURE 3.--Water-level fluctuations

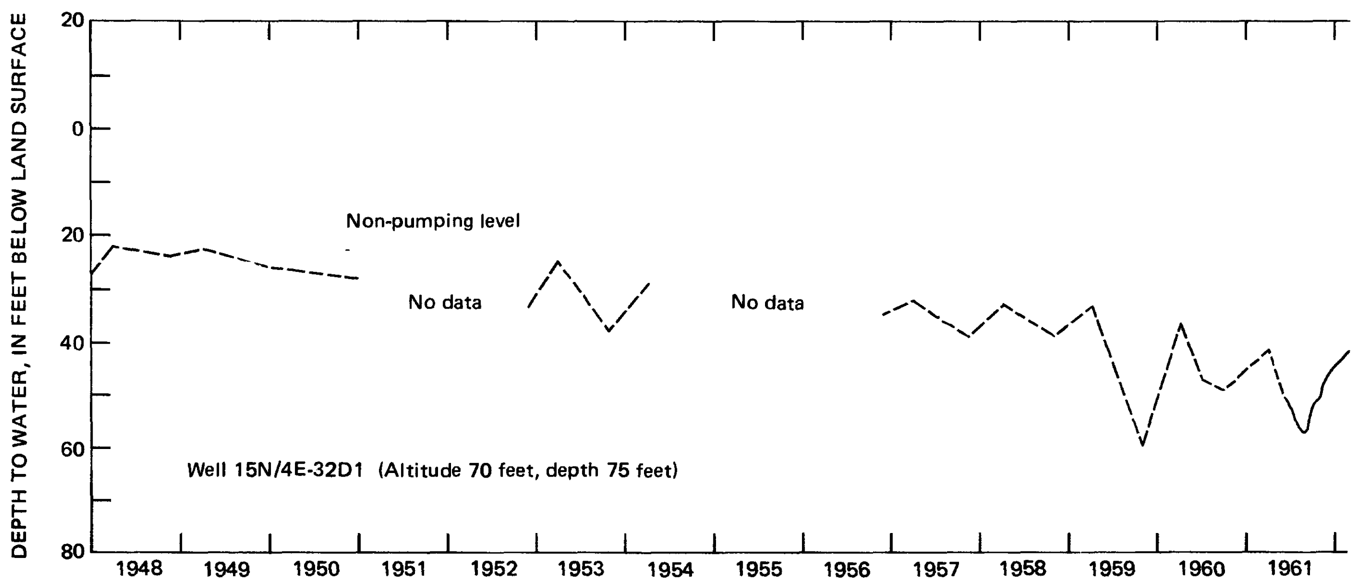

FIGURE 4.--Water-level fluctuations