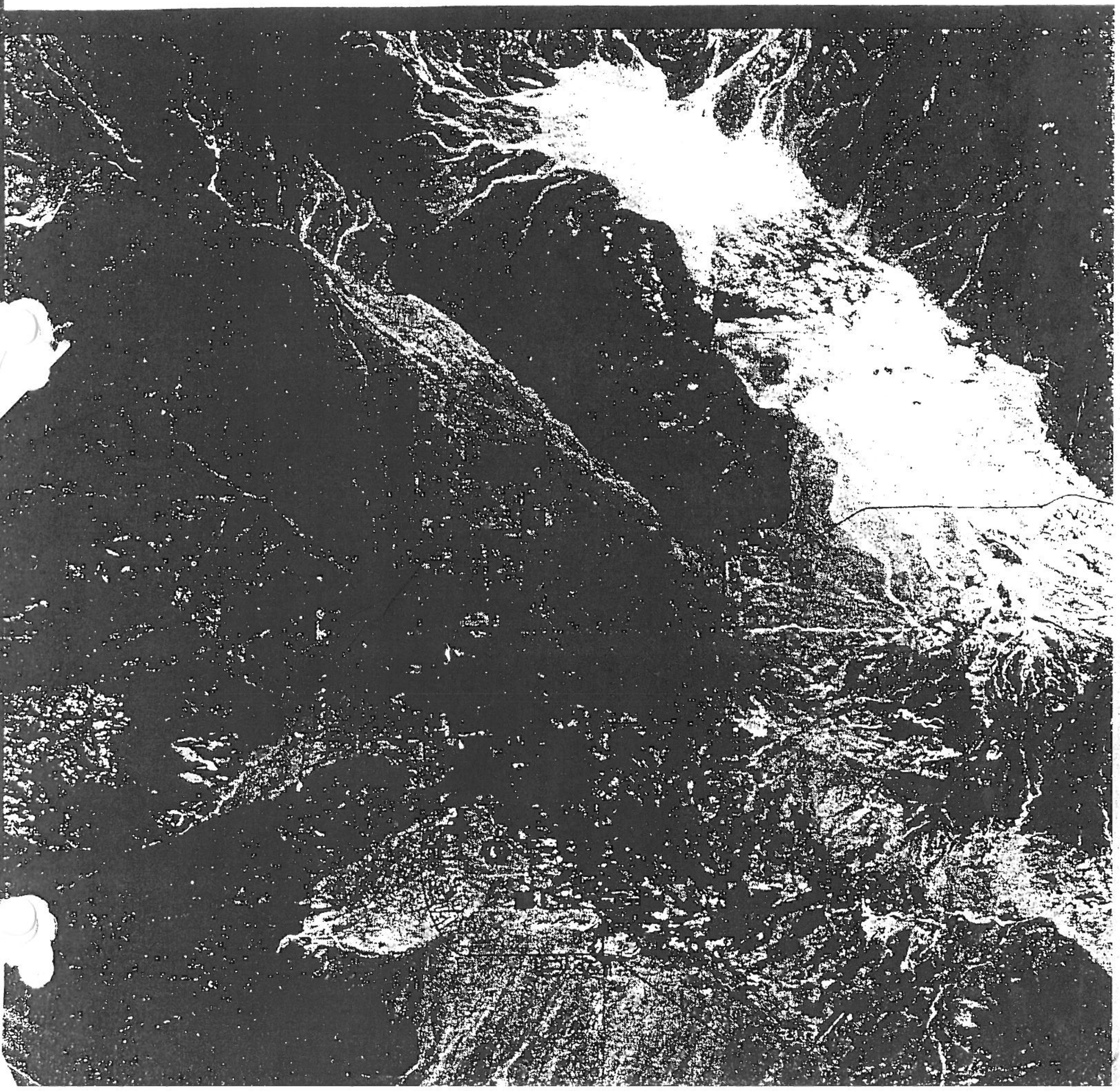
# WATER RESOURCES OF BORREGO VALLEY AND VICINITY, CALIFORNIA

## Phase 1--Definition of Geologic and Hydrologic Characteristics of Basin

U.S. GEOLOGICAL SURVEY
Open-File Report 82-855

#3

Prepared in cooperation with the COUNTY OF SAN DIEGO



## CONTENTS



## ILLUSTRATIONS

[Plates are in pocket]

TABLES

## CONVERSION FACTORS AND ABBREVIATIONS

For this report, both inch-pound and metric units have been used. The original units of measurement have been used in all cases so that no errors will be introduced because of conversion of units or in rounding. When the data are computerized and the model is constructed, the data can be published in any units desired.

| Multiply | By | To obtain |
|---|---|---|
| acres | 0.004047 | $km^2$ (square kilometers) |
| acre-ft (acre-feet) | 1233 | $m^3$ (cubic meters) |
| ft (feet) | 0.3048 | m (meters) |
| ft/d (feet per day) | 0.3048 | m/d (meters per day) |
| $ft^2/d$ (feet squared per day) | 0.0929 | $m^2/d$ (meters squared per day) |
| ft/mi (feet per mile) | 0.1894 | m/km (meters per kilometer) |
| gal/d (gallons per day) | 0.003785 | $m^3/d$ (cubic meters per day) |
| (gal/d)/ft (gallons per day per foot) | 0.01242 | $m^2/d$ (meters squared per day) |
| gal/min (gallons per minute) | 0.003785 | $m^3/min$ (cubic meters per minute) |
| (gal/min)/ft (gallons per minute per foot) | 0.2070 | (L/s)/m (liters per second per meter) |
| inches | 25.4 | mm (millimeters) |
| mi (miles) | 1.609 | km (kilometers) |
| ton/acre-ft (tons per acre-foot) | 735 | $Mg/hm^3$ (megagrams per cubic hectometer) |
| µmho/cm (micromhos per centimeter) | 1.00 | µS/cm (microsiemens per centimeter) |

Degrees Fahrenheit (°F) is converted to degrees Celsius (°C) by using the formula:

$$\text{Temp °C} = (\text{temp °F} - 32)/1.8.$$

Additional abbreviations used:
- (cm/s)/s, centimeter per second per second
- mGal, milligals
- mg/L, milligrams per liter
- µg/L, micrograms per liter
- $g/cm^3$, grams per cubic centimeter

## ALTITUDE DATUM

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

## TRADE NAMES

The use of brand names is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

WATER RESOURCES OF BORREGO VALLEY AND VICINITY, CALIFORNIA

Phase 1--Definition of Geologic and Hydrologic Characteristics of Basin

By W. R. Moyle, Jr.

ABSTRACT

This report includes information needed to build a digital hydrologic model of Borrego Valley. It includes sources and amounts of recharge water to the basin, areas of water withdrawal, total ground water in storage at steady-state conditions (1945), net ground-water depletion, grid network used to determine storage and depletion, total depth of alluvial fill, transmissivity, hydraulic conductivity and specific yield of aquifers, and thickness of individual aquifers.

At steady-state water-level conditions (1945) the Borrego Valley ground-water basin contained 5.5 million acre-feet of water. Between 1945 and 1980, 330,000 acre-feet of water were withdrawn from the basin in excess of recharge. Gravity data show that the thickness of alluvial fill ranges from 0 at the edges of the basin to about 2,450 feet at its deepest part. The alluvial fill is partly saturated and partly dry, depending on location. In some areas the water level is at or near land surface, whereas in other areas it is more than 400 feet below land surface. Between 1945 and 1980 water levels have declined locally as much as 100 feet, indicating that more water is being withdrawn than is being replenished.

Of prime importance to the population of Borrego Valley is the high nitrate ($NO_3$) water, more than 300 milligrams per liter, being produced from some wells. The recommended upper limit for nitrate in drinking water is 44 milligrams per liter. The source of high nitrate is septic tanks and leach fields, sewage-disposal systems, irrigation-return water, and decomposition of native vegetation. High nitrate in ground water generally stays near the water table and is picked up by wells having perforations above the pumping water level. Wells with perforations below the pumping water level generally contain low nitrate water.

# INTRODUCTION

## Location

Borrego Valley is in the northeastern part of San Diego County, Calif. (fig. 1 and pl. 1), about 130 miles southeast of Los Angeles and 50 miles northeast of San Diego. Access into Borrego Valley from the south is by State Highway 78 and from the east and west by San Diego County Highway 53. Numerous other paved and unpaved roads cross the valley.

## Purpose and Scope

This report was prepared by the U.S. Geological Survey, in cooperation with the county of San Diego, as a part of a larger study consisting of three phases. The purpose of this study, phase 1, is to collect and analyze geologic and hydrologic data needed to construct a digital ground-water model of Borrego Valley. Much geologic and hydrologic data for Borrego Valley were collected intermittently over the years by the U.S. Geological Survey, California Department of Water Resources, and National Oceanographic and Atmospheric Administration as a part of the continuing study of water resources of the arid areas of California. These earlier studies included information such as drillers' logs of wells, water-level measurements in wells, chemical analyses of water, results of aquifer tests in wells, geologic maps, streamflow measurements, and precipitation data. Despite this long history of data collection, in some areas of Borrego Valley no wells have been drilled, and no geologic or hydrologic data are available.

Long-range plans to assure an adequate water supply for Borrego Valley are being developed by the county of San Diego. In order to carry out these plans a knowledge of the hydrologic system is required. The data and interpretations presented in this report will serve as the initial input to a digital model of the ground-water basin. The model should help in (1) understanding the hydrologic system and (2) predicting the effects of various proposed water-management practices.

This report has two principal purposes: (1) To provide the necessary initial input to fulfill phase 1 of the overall study and (2) to document the initial input data for comparison with the final data. The development of a useful hydrologic model will undoubtedly necessitate the modification of some of the hydrologic inferences presented in this report.


FIGURE 1.--Study area.

The principal work to be accomplished during phase 1 is outlined below:

1. Select a grid network for use in determining basin storage during steady-state conditions (1945) and net change in storage between steady-state conditions and 1980.
2. Define the distribution of transmissivity of the basin.
3. Define geologic control such as basin boundaries, ground-water barriers, depth of basin, thickness of aquifers, and hydraulic conductivity of aquifers.
4. Determine historical ground-water pumpage with time, total ground water in storage of the basin under steady-state conditions, and depletion of ground-water storage between steady state (1945) and 1980.
5. Determine historical ground-water recharge to the basin.
6. Determine historical ground-water altitudes.
7. Determine the chemical quality of the surface and ground water and its relation to the geohydrologic framework.

For this report some of the estimates of the data components were made with a moderate amount of direct data, whereas others could be made only by extrapolation if data were not available. Despite these complications, the resulting geologic and hydrologic parameters are a reasonably valid representation of actual conditions, even though there may be some error in detail.

## Previous Work and Acknowledgments

The earliest unpublished map of the Borrego Valley area showing the locations of wells and springs was compiled in January 1905 from U.S. Surveys (1855-57) and personal surveys by C. S. Alverson (civil engineer) at a scale of 1:125,000. This hand-drawn map on linen shows the location of Borrego Springs, Price's Spring, and Clark well.

Hydrologic work in Borrego Valley was started by Gilbert E. Bailey prior to 1909. These data were later published by Mendenhall (1909) of the U.S. Geological Survey. Other early U.S. Geological Survey publications that contain hydrologic data for Borrego Valley are by Waring (1915) and Brown (1923), which include general data on watering places in and surrounding Borrego Valley. During the period 1920-45 few wells were drilled and little data were collected for the valley. In 1945, at the conclusion of World War II, Borrego Valley had an influx of people and new wells were drilled. In 1952, the U.S. Geological Survey in cooperation with the California Department of Water Resources began collecting data from Borrego Valley. These data and all well data known at that time were published by Burnham (1954). A reconnaissance geologic map of the Borrego Valley and a report tabulating the hydrologic data collected subsequent to the work of Burnham were published by Moyle (1968). Two reports by the U.S. Bureau of Reclamation (1968 and 1972) estimated recharge, recoverable water in storage, and average annual water-level decline in Borrego Valley.

The Geological Survey has also measured surface-water discharge on selected streams entering Borrego Valley between 1951 and the present (1980). These data are published in various water-supply papers and data reports listed in the references.

The geology of Borrego Valley was compiled by Moyle (1968) from unpublished mapping by T. W. Dibblee, Jr., E. R. Morley, and W. R. Moyle, Jr.

Data from previous studies and reports were freely used by the author in the preparation of this report along with data supplied by the many governmental agencies, ranchers, corporations, water companies, and individuals who live or work in Borrego Valley. Without their help this study would not have been possible.

## Well- and Spring-Numbering System

Wells are numbered according to their location in the rectangular system for subdivision of public land. That part of the number preceding the slash (as in 10S/6E-24K1) indicates the township (T. 10 S.); the number after the slash indicates the range (R. 6 E.); the number after the dash indicates the section (sec. 24); the letter after the section number indicates the 40-acre subdivision of the section according to the lettered diagram. The final digit is a serial number for wells in each 40-acre subdivision. Springs are numbered similarly to wells except an S is placed between the final letter and number as shown by the following spring number: 9S/5E-22KS1. The study area lies entirely in the southeast quadrant of the San Bernardino base line and meridian.

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

GEOGRAPHIC SETTING

## Description of Area

Borrego Valley (pl. 1) is bounded on the north by Coyote Mountain, on the south by the Vallecito Mountains (outside map area) and on the west by Hot Springs Mountain (outside map area). The northeast side of the valley is bounded by the Coyote Creek fault, the Borrego Badlands, Borrego Mountain, and some small hills.

The valley floor ranges in altitude from 400 to 1,200 feet, and the mountains on the west side of the valley attain an altitude of about 5,000 feet. Many intermittent streams enter Borrego Valley through canyons in the surrounding mountains on the west side of the valley. These streams supply most of the recharge to the ground water stored in the valley alluvium.

A striking physiographic feature of Borrego Valley is the Coyote Creek fault scarp which extends in a northwest direction through Coyote Creek canyon and along the base of Coyote Mountain, forming the east edge of Borrego Valley.

The land in the center of Borrego Valley is owned predominantly by corporations and individuals. Parts of the edge of the valley and the entire mountainous area surrounding the valley lie within the Anza-Borrego Desert State Park, which is owned by the State of California.

## Climate

The climate in Borrego Valley is arid. Average annual precipitation (pl. 2 and table 1) on the valley floor ranges from about 3 to 6 inches; in the mountains to the west it reaches a maximum of about 16 inches near the highest altitude (west of base map at Warner Springs). Most of the precipitation comes in the winter, but some thundershowers do occur infrequently in the summmer. The summers in Borrego Valley are generally hot, and temperatures of 110°F are not uncommon. Winters are cool, and temperatures occasionally are below freezing. During the spring and autumn the days are generally warm and the nights cool.

TABLE 1. - Annual precipitation at stations in Borrego Valley area

[Data from U.S. National Oceanic and Atmospheric Administration, (1965-80) and U.S. Weather Bureau (1878-1975)]

| Year | Annual precipitation, in inches | | | | | |
|---|---|---|---|---|---|---|
| | Borrego | Brawley | Warner Springs | Borrego Desert Park | Borrego Springs 3NNE | Brawley 2SW |
| 1907 | -- | -- | 18.39 | -- | -- | -- |
| 1908 | -- | -- | 15.05 | -- | -- | -- |
| 1909 | -- | 3.69 | 29.06 | -- | -- | -- |
| 1910 | -- | [1].69 | 11.33 | -- | -- | -- |
| 1911 | -- | [1]1.76 | 14.21 | -- | -- | -- |
| 1912 | -- | 1.55 | 17.05 | -- | -- | -- |
| 1913 | -- | 2.21 | 13.98 | -- | -- | -- |
| 1914 | -- | [1]2.94 | 19.09 | -- | -- | -- |
| 1915 | -- | [1]3.39 | 25.59 | -- | -- | -- |
| 1916 | -- | 2.84 | 25.73 | -- | -- | -- |
| 1917 | -- | 1.84 | 12.43 | -- | -- | -- |
| 1918 | -- | 1.94 | 16.26 | -- | -- | -- |
| 1919 | -- | 1.57 | 13.83 | -- | -- | -- |
| 1920 | -- | 4.17 | 13.61 | -- | -- | -- |
| 1921 | -- | 3.57 | 32.02 | -- | -- | -- |
| 1922 | -- | .73 | 22.28 | -- | -- | -- |
| 1923 | -- | 2.71 | 12.45 | -- | -- | -- |
| 1924 | -- | 1.23 | 8.89 | -- | -- | -- |
| 1925 | -- | 3.12 | 12.35 | -- | -- | -- |
| 1926 | -- | 6.23 | 24.27 | -- | -- | -- |
| 1927 | -- | 4.95 | 24.35 | -- | -- | -- |
| 1928 | -- | .45 | 8.42 | -- | -- | -- |
| 1929 | -- | .30 | 11.97 | -- | -- | -- |
| 1930 | -- | 2.03 | 19.66 | -- | -- | -- |
| 1931 | -- | 3.45 | 19.45 | -- | -- | -- |
| 1932 | -- | 5.69 | 22.64 | -- | -- | -- |
| 1933 | -- | 1.08 | 12.58 | -- | -- | -- |
| 1934 | -- | .11 | 12.12 | -- | -- | -- |
| 1935 | -- | 3.44 | 13.24 | -- | -- | -- |
| 1936 | -- | 1.10 | 20.31 | -- | -- | -- |
| 1937 | -- | .83 | 20.74 | -- | -- | -- |
| 1938 | -- | 2.59 | 23.67 | -- | -- | -- |
| 1939 | -- | 8.18 | 15.12 | -- | -- | -- |
| 1940 | -- | 3.18 | ([2]) | -- | -- | -- |
| 1941 | -- | 5.85 | 27.69 | -- | -- | -- |
| 1942 | -- | 1.34 | 9.29 | -- | -- | -- |
| 1943 | -- | 2.99 | 21.89 | -- | -- | -- |
| 1944 | [3]0.61 | 3.61 | 19.67 | -- | -- | -- |
| 1945 | 10.75 | 3.68 | 25.28 | -- | -- | -- |
| 1946 | 1.30 | .96 | 15.75 | -- | -- | -- |

See footnotes at end of table.

TABLE 1. - Annual precipitation at stations in Borrego Valley area--Continued

| Year | Annual precipitation, in inches | | | | | |
|---|---|---|---|---|---|---|
| | Borrego | Brawley | Warner Springs | Borrego Desert Park | Borrego Springs 3NNE | Brawley 2SW |
| 1947 | 4.92 | 0.85 | 7.33 | -- | -- | -- |
| 1948 | 4.12 | 1.48 | 10.60 | -- | -- | -- |
| 1949 | 2.59 | 2.60 | 13.92 | -- | -- | -- |
| 1950 | .68 | .21 | 10.22 | -- | -- | -- |
| 1951 | 4.75 | 3.60 | 19.21 | -- | -- | -- |
| 1952 | 6.26 | 1.39 | 20.31 | -- | -- | -- |
| 1953 | 1.06 | ([4]) | 7.35 | 1.35 | -- | -- |
| 1954 | -- | 1.46 | 14.56 | 5.21 | 3.54 | -- |
| 1955 | -- | 1.70 | [5]15.89 | 5.32 | 3.03 | -- |
| 1956 | -- | .09 | 6.35 | .65 | .13 | -- |
| 1957 | -- | 1.68 | 17.61 | 3.64 | 2.92 | -- |
| 1958 | -- | -- | 20.02 | 7.31 | 3.70 | 2.37 |
| 1959 | -- | -- | 11.77 | 6.31 | 3.96 | 1.95 |
| 1960 | -- | -- | 10.31 | 4.34 | 2.40 | 1.54 |
| 1961 | -- | -- | 5.00 | 2.29 | 1.33 | 1.47 |
| 1962 | -- | -- | 12.09 | 3.62 | 1.70 | 1.95 |
| 1963 | -- | -- | 15.18 | 6.85 | 5.85 | 2.39 |
| 1964 | -- | -- | 12.57 | 4.41 | 2.40 | .96 |
| 1965 | -- | -- | [5]23.99 | 8.04 | 4.64 | 3.37 |
| 1966 | -- | -- | 13.02 | 5.08 | 2.64 | 2.53 |
| 1967 | -- | -- | 17.59 | 5.91 | [3]1.02 | 5.49 |
| 1968 | -- | -- | 9.52 | 3.19 | -- | 1.85 |
| 1969 | -- | -- | 23.85 | 5.82 | -- | 2.93 |
| 1970 | -- | -- | 14.68 | 5.73 | -- | 1.98 |
| 1971 | -- | -- | 18.57 | 2.40 | -- | 1.62 |
| 1972 | -- | -- | 10.26 | 3.44 | -- | 2.13 |
| 1973 | -- | -- | [6]13.15 | 3.25 | -- | 1.66 |
| 1974 | -- | -- | [6]16.47 | 7.73 | -- | 2.47 |
| 1975 | -- | -- | 14.78 | 5.01 | -- | 1.40 |
| 1976 | -- | -- | 15.90 | 9.71 | -- | 7.12 |
| 1977 | -- | -- | 11.10 | 7.80 | -- | 6.12 |
| 1978 | -- | -- | ([2]) | 13.97 | -- | 4.74 |
| 1979 | -- | -- | ([2]) | 8.29 | -- | 3.65 |
| 1980 | -- | -- | ([2]) | 14.27 | -- | 4.91 |
| Total precipitation--- | 37.04 | 117.05 | 1,134.88 | 160.94 | 39.26 | 66.60 |
| Period of record---------- | 10 | 49 | 70 | 28 | 14 | 23 |
| Average------------ | 3.70 | 2.39 | 16.21 | 5.75 | 2.80 | 2.89 |

[1]Estimated from nearby station.
[2]No record.
[3]Partial record.
[4]Trace of precipitation.
[5]Water equivalent to snowfall wholly or partly estimated.
[6]Water is wholly or partly estimated.

# GEOLOGIC SETTING

## Geologic Formations

The geology of the Borrego, Carrizo, and San Felipe areas was mapped and published by the State of California in Bulletin 91-15 (Moyle, 1968). One-half the geologic map used in Bulletin 91-15 is included in this report as plate 1 to describe the geology of Borrego Valley. About 35 wells drilled between 1966 and 1980 have been added to update the map. The following geologic descriptions are quoted from Bulletin 91-15 with editorial comments in brackets.

"The geologic formations in the Borrego, Carrizo, and San Felipe Valley areas have dissimilar water-bearing characteristics, but, in general, the deposits of late Tertiary and Quaternary age are more permeable than the older rocks of pre-Tertiary and early Tertiary age. The Quaternary deposits generally underlie the valleys and contain much of the ground water stored in the area. Rocks of pre-Tertiary age form the mountains and hills, underlie the water-bearing deposits, and form the boundaries of the ground-water basin; these rocks are nearly impermeable but are important because the mountains and hills receive the major part of the precipitation within the drainage area. The runoff from the mountains and hills contributes most of the recharge to the ground-water body in the unconsolidated deposits.

"The oldest unit in the area is the basement complex composed of granite, schist, and gneiss, all of pre-Tertiary age. The basement complex is generally impermeable, but fractures and weathered zones yield small quantities of water to wells.

"The older continental rocks [Not found in Borrego Valley but may be at depth. These rocks have been described in logs of wells shown on plate 1 east of the study area], of Miocene age, are the Split Mountain Formation of Tarbet and Holman (1944) and the Fish Creek Gypsum of Dibblee (1954). The age of the Split Mountain Formation, originally considered Miocene(?) by Tarbet and Holman (1944), is now assigned to the Miocene because it underlies and overlies Miocene units. The Split Mountain Formation is composed of gray, granitic conglomerate; dioritic breccia; hard buff sandstone; and red, arkosic sandstone. The Fish Creek Gypsum, deposited mostly in playas, is composed of silt, clay, and white beds of gypsum and anhydrite. No wells penetrate this unit; it probably would not yield water of quantities usable for irrigation.

"The volcanic rocks [Not found in Borrego Valley but may be at depth], of Miocene age, consist entirely of the Alverson Andesite Lava of Dibblee (1954) which is dark-brown, andesitic lava. This unit overlies the Split Mountain Formation and underlies the Fish Creek Gypsum. No wells penetrate the volcanic rocks; they probably would not yield much water to wells.

"The marine rocks probably range in age from late Miocene to early Pliocene on the basis of fossil camel bones found embedded in oyster and mollusk shells in the NE¼ sec. 32, T. 11 S., R. 9 E. The age of the fossil was determined by the staff of the Los Angeles County Museum. Other fossils described by Hanna (1926) also indicate the same age range. The marine rocks include the Imperial Formation (Hanna, 1926), composed of gray to yellow claystone, buff sandstone, and oyster shells, other mollusks, and corals. Some deep oil test holes have been drilled into the marine deposits, but none are known to have produced large quantities of fresh water. [These rocks do not crop out in Borrego Valley but are identified at depth in well 10S/5E-25R1.]

"The younger continental deposits, of Pliocene and Pleistocene age, include the Canebrake Conglomerate of Dibblee (1954), the Palm Spring Formation (Woodring, 1931), the Borrego Formation of Tarbet and Holman (1944), and the Ocotillo Conglomerate of Dibblee (1954). The Canebrake Conglomerate is composed mainly of gray pebbles and cobbles. The Palm Spring Formation consists of arkosic sandstone and red clay. The Borrego Formation is composed of light-gray lacustrine claystone, siltstone, and minor amounts of buff sandstone. The Ocotillo Conglomerate is composed of gray conglomerate and fanglomerate. Many deep wells in Borrego Valley having large yields probably penetrate the upper part of this unit. Available data indicate that small to moderate (10-100 gal/min) quantities of water of good quality can probably be obtained from these deposits.

"The older alluvium, of Pleistocene age, underlies most of the valley floor and is overlain by a veneer of younger material. The older alluvium consists mainly of moderately sorted gravel, sand, silt, and clay. It is oxidized and generally unconsolidated, but in some places it is slightly cemented. This unit is permeable, extends below the water table in most areas, and, where saturated, yields water freely to wells. It is the principal water-bearing unit in the valley areas.

"The older fan deposits, of Pleistocene age, are composed of unconsolidated to moderately consolidated sand, gravel, and boulders derived from the granitic and metamorphic rocks. Where saturated, the deposits yield water to wells.

"The younger alluvium, of Recent [Holocene] age, consists of unconsolidated gravel, sand, silt, and clay. Deposition is taking place presently in the valley areas during times of infrequent precipitation. This unit is permeable and, where saturated, will yield some water to wells. It is thin, however, and usually is above the water table. Although it transmits water from the intermittent streams to the ground-water body, it is not an important water-bearing unit.

"The younger fan deposits, also of Recent [Holocene] age, consist of sand, gravel, and boulders derived from the local mountain areas. The deposits are generally very poorly sorted. This unit, generally above the regional water table, is not an important water-bearing unit.

"The playa deposits, of Recent [Holocene] age, are composed of clay with some sand and silt. Of the playas shown in figs. 2 and 3 only the Borrego Sink was a discharging playa in the recent past, having water levels at or near land surface. However, at the present time [1965 and 1980] water levels are below land surface. Where saturated, this unit yields some water to wells.

"The sand deposits, of Recent [Holocene] age, are composed of actively drifting fine to medium sand. In parts of the area this unit is saturated and yields small quantities of water, sometimes of inferior chemical quality.

"The lake deposits [Not in Borrego Valley but shown on pl. 1], of Recent [Holocene] age, are composed of alternating beds of sand and clay. These deposits presumably were laid down in ancient Lake Cahuilla which formerly covered a large part of Imperial and Coachella Valleys. Where saturated, this unit would probably yield moderate quantities of water to wells."

## Faulting

The geologic map (pl. 1) shows the location of many faults. The Coyote Creek fault is the most important fault with relation to the movement of ground water in Borrego Valley. This fault has ruptured several times in the recent past and has had numerous earthquakes associated with each rupture. The most recent large earthquake on the Coyote Creek fault occurred April 9, 1968, near Borrego Mountain. This earthquake had a magnitude of 6.4 on the Richter scale, a maximum horizontal (right lateral) surface displacement of 38 centimeters, and numerous aftershocks. Data for this earthquake were published by the U.S. Geological Survey (1972).

The Coyote Creek fault is probably a barrier to the movement of ground water. Water-level contours show that ground water flows parallel to the fault in most places during steady-state conditions, and there are abnormally high gradients across the fault, as is indicated by a few water levels measured in wells. Two common explanations for the barrier effect are fault gouge in the zone of rupture causing reduced permeability and sediments with different permeabilities, adjacent but on opposite sides of the fault, impeding the ground-water flow. A third possibility is that low-permeability sediment has silted in cracks along the fault. Following the Borrego Mountain earthquake, many large cracks as much as 2 feet in width were observed along the 17-mile-long fracture. In the following 2 years many of these fractures were being filled in by silt-laden water from flash floods that occur from precipitation in the mountains. This low-permeability silt could retard ground-water flow. There are no known documented examples of such barriers, but large, deep cracks have been described in numerous desert basins elsewhere (Holzer, 1977). The measured depth of one such crack was 25 meters, and the length 3.5 kilometers; some cracks have filled with sediment (Thomas L. Holzer, oral commun., 1982). In Borrego Valley there is evidence to support each of these explanations for the ground-water barrier along the Coyote Creek fault.

## Gravity Survey

Gravity surveys are useful in determining geologic structure and general shape of the surface of the basement complex beneath the alluvial basin. Gravity measurements can determine differences in acceleration of gravity caused by different densities of material beneath the surface of the earth. In general, a gravity low over an alluvial basin corresponds to a thick alluvial section. During this study gravity measurements were made at 223 stations throughout Borrego Valley in 1980 to determine the total thickness of the alluvial sediments. The instrument used for the measurements was a Worden gravity meter (No. 1083), which has a sensitivity of 0.02 mGal.

All gravity measurements were tied to a local base station (pl. 3, station 1) at BM-538 at the northwest corner of Palm Canyon Drive and Borrego Valley Road. This local base was established relative to the California Base Station Network by tying to the network base station at Ocotillo, California (station 339, Chapman, 1966, p. 33) and is also on the Woollard and Rose (1963) gravity datum.

After corrections were applied for tidal fluctuations and hand terrain to 2.29 km, the data were entered into the computer and corrected for latitude, altitude, free air, Bouguer effects, and terrain effects. A density of 2.67 $g/cm^3$ was used for the gravity reduction because this is the approximate density of the basement complex in the area and is "the average density of crustal rocks above sea level" (Nettleton, 1939). Computer terrain corrections were carried out from 2.29 to 90 km from each station using Plouff's (1966) program and previously digitized topography (Robbins and others, 1973).

To make all values positive, 1,000 mGal were added to all Bouguer anomaly values. Thus, for example, the true Bouguer anomaly corresponding to a value of 920 mGal on the contoured Bouguer gravity map is -80.

From the Bouguer gravity map, it was determined that a regional gradient of 35 mGal existed to the southeast across Borrego Valley. A regional gradient map was constructed and the regional dip was graphically subtracted from the complete Bouguer gravity map giving the resulting residual gravity map (pl. 3). Only the residual gravity map is published in this report.

The values shown on the residual gravity map range from 903 mGal on the edge of the valley at basement complex to 877 mGal (gravity station 3) at the deepest part of the basin near the Borrego Valley Airport.

Only two wells (10S/6E-7A1 and 9S/6E-31E1) have been reported as drilled to granitic rock in Borrego Valley. Granitic rock was found at 943 feet in well 10S/6E-7A1 and at 342 feet in well 9S/6E-31E1. Depths computed for these two wells on the basis of gravity measurements are 951 and 332 feet respectively, which are very close to the actual depth. Because of lack of density data at depth in the deepest part of the basin, the computed depth of 2,450 feet based on gravity measurements may show a slightly larger error than the depths calculated at the two wells.

## Geologic and Hydrologic Sections

Geologic and hydrologic sections (pl. 4) were constructed for Borrego Valley using data from drillers' logs and specific-capacity tests of wells, water-level measurements, depth interpretations from gravity profiles, and geologic mapping. Locations of the sections are shown on plate 1. Hydraulic conductivity and specific yield of the hydrologic units and their geologic map unit equivalents are shown in the insert on plate 4. Several of the geologic map units are considered as a single hydrologic unit because of similar hydrologic properties. Other geologic map units were separated into multiple hydrologic units because of dissimilar hydrologic properties. Aquifer thickness and hydraulic properties are discussed in more detail later in this section.

## Aquifer Thickness

Three aquifer-thickness maps (pl. 5) were constructed for the upper, middle, and lower aquifers for use in determining the volume of ground water in storage for the different aquifers. These maps show that the upper aquifer ranges in thickness from 0 to 1,000 feet, the middle aquifer 0 to 700 feet, and the lower aquifer 0 to 1,800 feet. The maximum thickness of each aquifer is in a different part of Borrego Valley. The maximum thickness of the upper aquifer is at the north end of the valley; the middle aquifer is thickest near the center of the valley adjacent to the Coyote Creek fault; and the lower aquifer is thickest in the south-central part of the valley.

## Aquifer Characteristics

The specific capacity of a well is the rate of discharge in gallons per minute per foot of drawdown. In section A-A' (pl. 4) a decrease in specific capacity of wells is apparent from northwest to southeast. When wells 10S/6E-5F1 and 12S/7E-4J1 are compared, both with approximately equal perforated intervals, the specific capacity drops from 92 to 2. This decline in specific capacity is due to the fact that well 10S/6E-5F1 is completed and perforated in the upper aquifer, whereas 12S/7E-4J1 is completed and perforated in the lower aquifer. This is an indication that the older sediments are more compact and therefore yield less water than the younger sediments.

In general, the lower aquifer is closer to land surface at the south end of Borrego Valley than at the north end; this is a reason why wells produce less water at the south end of the valley than at the north end.

If wells were drilled in each aquifer and perforated in only one aquifer at its maximum thickness, the upper aquifer well would have an estimated specific capacity of about 100 (gal/min)/ft of drawdown, the middle aquifer about 50 (gal/min)/ft of drawdown, and the lower aquifer about 10 (gal/min)/ft of drawdown.

TABLE 2. - Average specific yield to estimate total ground-water storage in the Borrego Valley

[From Thomasson and others, 1960, p. 286]

| Material | Specific yield (percent) |
| --- | --- |
| Gravel----------------------------------------------------------- | 25 |
| Sand, including sand and gravel, and gravel and sand----------- | 20 |
| Tight sand, hard sand, fine sand, sandstone, and related deposits---------------------------------------------------- | 10 |
| Clay and gravel, gravel and clay, cemented gravel, and related deposits---------------------------------------------------- | 5 |
| "Clay," silt, sandy clay, lava, and related fine-grained deposits---------------------------------------------------- | 3 |

## Specific Yield and Hydraulic Conductivity

Specific yield and hydraulic conductivity were estimated for each hydrologic unit by using grain size, degree of sorting, and amount of cementation and compaction of alluvial sediments as described in drillers' logs from wells. Thomasson, Olmsted, and LeRoux (1960) (table 2) list average specific-yield values that range from 3 percent for clay to 25 percent for gravel, and Lohman (1972) (table 3) lists average hydraulic conductivity values that range from 1 ft/d for clay to 1,000 ft/d for coarse gravel.

The table on plate 4 cross references geologic map units used on plate 1 and their hydrologic unit symbols with the hydraulic conductivity, specific yield, and hydrologic unit names used later in the text. The geologic units are divided into four hydrologic units on the basis of their capacity to transport and yield water. These four hydrologic units are referred to as the upper, middle, and lower aquifers, and the basement complex. The units are discussed from youngest to oldest or most to least water yielding.

The upper aquifer (Qa) is composed of alluvial and windblown deposits, all of Quaternary age. These deposits include the younger alluvium (Qya), younger fan deposits (Qyf), playa deposits (Qp), sand dunes (Qs), older alluvium (Qoa), and older fan deposits (Qof). Field observation and logs of wells that penetrate these deposits indicate that the grain size ranges from boulders to clay, medium sand being predominant. These deposits are assigned a hydraulic conductivity of 50 ft/d and a specific yield of 20 percent.

TABLE 3. - Average values of hydraulic conductivity of alluvial materials used in Borrego Valley, California

[From Lohman, 1972, p. 53]

| Material | Hydraulic conductivity (ft/d) |
|---|---|
| Gravel: | |
| Coarse | 1,000 |
| Medium | 950 |
| Fine | 900 |
| Sand: | |
| Gravel to very coarse | 800 |
| Very coarse | 700 |
| Very coarse to coarse | 500 |
| Coarse | 250 |
| Coarse to medium | 100 |
| Medium | 50 |
| Medium to fine | 30 |
| Fine | 15 |
| Fine to very fine | 5 |
| Very fine | 3 |
| Clay | 1 |

The middle aquifer (upper QTc) is composed of the upper part of the continental deposits. Well logs penetrating these deposits show they range in size from gravel to silt with moderate amounts of compaction and cementation. The predominant grain sizes range from medium sand to clay. These deposits are assigned a hydraulic conductivity of 5 ft/d and a specific yield of 10 percent.

The separation between the middle and lower aquifers is based on well-log descriptions of "hard, dry, red clays" that extend over the southern half of Borrego Valley at increasing depth to the north. Drillers' logs indicate sediments above the red clays are easy to drill, whereas those below the red clay are hard to drill.

The lower aquifer is composed of the lower part of the continental deposits and the marine rocks. The lower part of the continental deposits, highly compacted and cemented, is composed of sandstone, claystone, siltstone, and clay; the marine rocks are composed of sandstone, claystone, and beds of shells. Only one well (10S/5E-25R1) penetrates the marine rocks at depth in Borrego Valley. The lower aquifer is assigned a hydraulic conductivity of 1 ft/d and a specific yield of 5 percent.

The basement complex ranges from solid rock to fractured rock in fault zones. Only one well (11S/7E-36D1) in Borrego Valley is drilled entirely in a fault zone in basement complex. This well was drilled by the U.S. Geological Survey for a study of heat flow through the Earth's crust. This well yielded a small quantity of water when drilled, but because the well was constructed without a perforated casing a pump test could not be made. The assigned hydraulic conductivity of 0-0.1 ft/d and a specific yield of 0 to less than 1 percent is based on discussion with Jack Porter (U.S. Geological Survey) who was at the well when it was drilled.

## Transmissivity

Lines of equal transmissivity were compiled (pl. 6) using data from selected specific-capacity tests from wells in the Borrego Valley area. Two methods for determining transmissivity values were used in the Borrego area. The first, described by Lohman (1972, p. 52) was used to determine transmissivity in Borrego Valley proper and the second, described by Thomasson, Olmsted, and LeRoux (1960) was used to determine transmissivity beneath San Felipe Creek. The first method was used in Borrego Valley because multiple aquifers of varying thickness and hydraulic conductivities are present.

In Borrego Valley, the equation applied was:

$$T = \bar{K}b$$

where T is the total transmissivity for each aquifer, in feet squared per day,

$\bar{K}$ is the average hydraulic conductivity of the saturated thickness of each aquifer, in feet per day, and

b is the thickness of the saturated alluvium, in feet.

When the transmissivity was determined at well 10S/6E-7A1, it was determined that the water level was 307 feet below land surface and the depth to consolidated rock was 943 feet, giving a total saturated thickness of the upper aquifer of 636 feet. The middle and lower aquifers are not present at this location. The 636 feet thickness multiplied by a hydraulic conductivity of 50 ft/d equals a transmissivity of 34,026 $ft^2/d$.

The transmissivity of the saturated alluvium in Borrego Valley ranges from about 40,000 $ft^2/d$ in the northern part of the valley to about 0 $ft^2/d$ at the basin margins.

In San Felipe Creek, the equation applied was:

$$T = C_sB$$

where T is the transmissivity, in feet squared per day,

$C_s$ is the tested specific capacity of the well, in gallons per minute per foot of drawdown, and

B is a factor which was estimated to be 2000 in San Felipe Wash.

The specific capacity of well 12S/6E-18A1 is 1 (gal/min)/ft of drawdown. The factor (2000) used in San Felipe Wash was described by Thomasson, Olmsted, and LeRoux (1960, p. 222). They stated that the coefficient derived to estimate transmissivity from specific capacity ranged between 1500 and 2000 for Solano County, Calif., as well as in many other areas in California. Based on using the factor 2000, the transmissivity is 2000 (gal/d)/ft or 267 $ft^2/d$.

## MEASURED AND CALCULATED POTENTIAL RECHARGE

No attempt was made in this study to refine the estimates of the average annual recharge to the ground-water system in Borrego Valley made by earlier workers. Estimates by the U.S. Bureau of Reclamation (1968), based on various approaches, range from about 5,000 to 11,000 acre-ft/yr; Charles F. Lough, San Diego County Planning Department (written communication, 1974) estimated about 3,300 acre-ft/yr.

The quantities from the sources of potential recharge described below are probably most but not all of the potential recharge to Borrego Valley. Other, less significant, sources may be indicated by the steady-state simulation in the modeling phase to follow this study.

## Ground-Water Inflow from San Felipe Creek

San Felipe Creek has the thickest saturated alluvial sediments of any channel entering Borrego Valley from the west side of the basin; therefore, it probably contributes the largest amount of ground-water inflow. Ground-water inflow to Borrego was calculated for San Felipe Creek in T. 12 S., R. 6 E., sec. 17 through section G-G' (pls. 1 and 7) from the equation:

$$Q = TIW$$

where Q is ground-water inflow, in gallons per day,
T is transmissivity, in gallons per day per foot,
I is gradient, in feet per mile, and
W is width of the aquifer at the water table, in miles.

The transmissivity at well 12S/6E-18A1 is 2,000 (gal/d)/ft, the gradient of the water table between 12S/6E-17C2 and 18A1 is 50.7 ft/mi, and the width of the aquifer at the water table is 0.28 mi. The total ground water underflow calculated at section G-G' is 31.8 acre-ft/yr.

Most other channels entering Borrego Valley from the west contain very little alluvial sediments and do not contribute appreciable amounts of ground-water inflow to the basin. The one exception is Coyote Creek (pl. 1). However, a high spot in the bedrock at Santa Catarina Spring brings all underflow to the surface and all recharge enters the valley as surface-water flow.

## Surface-Water Inflow

Three continuous water-stage recorders (pl. 7 and table 4) are presently (1980) being operated on streams entering Borrego Valley. The stations on Borrego Palm and Coyote Creeks have been in operation since 1951, and the station on San Felipe Creek has been in operation since 1959. In addition, two staff gages on Yaqui Pass and one on Pinyon Wash measured peak flow between 1960 and 1969. Approximately 65 percent of the surface-water inflow to Borrego Valley comes from the Coyote Creek drainage; most of the rest of the surface-water inflow (35 percent) is distributed between Borrego Palm Canyon and San Felipe Creek. Most of the other stream channels produce very little runoff or recharge to Borrego Valley.

Most of the streamflow occurs as intermittent runoff in the winter. Little correlation exists between stream runoff and precipitation data from sparsely located rain gages. Rainfall at the Borrego Desert Park gage during 1980 was about three times the average, while the discharge measured at the gage on San Felipe Creek for the same time period was greater than the total recorded for the previous 21 years. Surface-water inflow during 1980 totaled 21,720 acre-ft, which is the highest yearly total of record.

TABLE 4. - Annual streamflow, in acre-feet, at surface-water gaging stations in the Borrego Valley area

| Calendar year | Surface-water gaging stations | | | | | |
|---|---|---|---|---|---|---|
| | San Felipe 10255700 | Borrego Palm 10255810 | Coyote 10255800 | Yaqui Pass No. 1[1] 10255820 | Yaqui Pass No. 2[1] 10255825 | Pinyon Wash 10255730 |
| 1951 | -- | 273 | 2,410 | -- | -- | -- |
| 1952 | -- | 981 | 2,330 | -- | -- | -- |
| 1953 | -- | 238 | 1,650 | -- | -- | -- |
| 1954 | -- | 303 | 1,820 | -- | -- | -- |
| 1955 | -- | 357 | 1,730 | -- | -- | -- |
| 1956 | -- | 225 | 1,520 | -- | -- | -- |
| 1957 | -- | 152 | 1,420 | -- | -- | -- |
| 1958 | -- | 718 | 1,860 | -- | -- | -- |
| 1959 | 241 | 139 | 1,500 | -- | -- | -- |
| 1960 | 217 | 149 | 1,490 | <1 | <1 | 0 |
| 1961 | 164 | 38 | 1,440 | <1 | <1 | -- |
| 1962 | 165 | 128 | 1,020 | <1 | <1 | 0 |
| 1963 | 138 | 59 | 1,320 | <1 | <1 | -- |
| 1964 | 128 | 115 | 1,100 | <2 | <1 | 0 |
| 1965 | 123 | 174 | 1,580 | <1 | 0 | 0 |
| 1966 | 291 | 266 | 1,190 | <1 | <1 | <1 |
| 1967 | 406 | 115 | 1,140 | 0 | 0 | 0 |
| 1968 | 93 | 122 | 888 | <1 | <1 | 0 |
| 1969 | 246 | 716 | 963 | 0 | 0 | <2 |
| 1970 | 184 | 127 | 1,110 | -- | -- | -- |
| 1971 | 113 | 55 | 908 | -- | -- | -- |
| 1972 | 65 | 9 | 980 | -- | -- | -- |
| 1973 | 90 | 258 | 412 | -- | -- | -- |
| 1974 | 102 | 47 | 1,110 | -- | -- | -- |
| 1975 | 87 | 65 | 353 | -- | -- | -- |
| 1976 | 149 | 97 | 448 | -- | -- | -- |
| 1977 | 108 | 312 | 1,450 | -- | -- | -- |
| 1978 | 763 | 770 | 1,810 | -- | -- | -- |
| 1979 | 426 | 2,460 | 2,390 | -- | -- | -- |
| 1980 | 4,820 | 5,640 | 11,260 | -- | -- | -- |
| Total for period of record------- | 9,119 | 15,108 | 50,602 | -- | -- | -- |
| Years of record---------- | 22 | 30 | 30 | -- | -- | -- |
| Average-------- | 414.5 | 503.6 | 1,686 | -- | -- | -- |
| Percentage of inflow[2]------- | 15.9 | 19.3 | 64.7 | -- | -- | -- |

[1]Computed annual surface-water flow from peak discharge measurements made on staff gages.

[2]Percentage of inflow of station compared with other stations.

# BASIN DEVELOPMENT

## Historical Land Use and Water Development (1909-80)

### 1909

Mendenhall (1909) reported on desert watering places in southeastern California and southwestern Nevada to aid desert travelers. He described Borrego Springs and a nearby abandoned cabin but did not mention that any people lived in the valley at that time. The only reported use of water was by mesquite trees and other native vegetation in the area.

### 1917-18

Brown (1923) visted Borrego Valley in the winter of 1917-18. He described three flowing wells, one non-flowing well, Borrego Springs, and several acres of marsh surrounding the Borrego Sink. He also indicated that several homesteaders had taken up land claims in Borrego Valley mainly for grazing cattle.

### 1926-27

During 1926-27 approximately 40 acres of dates were planted in Borrego Valley. About 20 acres were planted in T. 11 S., R. 6 E., sec. 4 and owned by R. F. Ensign. Another 20 acres of dates were planted on the Ensign Ranch in T. 11 S., R. 6 E., sec. 9. The first harvest from these date groves was in 1939. These trees are still growing but have not been trimmed for some time and were not harvested in 1980.

### 1946

In March 1946 Taylor and Taylor, Engineers (written commun., 1946) of Los Angeles, produced a map showing that 36 wells had been drilled in Borrego Valley.

### 1951

A map produced by the DiGeorgio Corp. (written commun., June 1951), shows that vineyards covered 1,020 acres and asparagus 40 acres of its property.

### 1952-53

Burnham (1954) visited Borrego Valley intermittenly between 1952 and 1953 to collect various geological and hydrological data. In the process, Geological Survey personnel visited 133 wells in Borrego Valley, which indicates that about 100 wells had been drilled between 1946 and 1953 throughout the valley.

## 1954-55

Areal photographs were taken over Borrego and Clark Lake Valleys by the U.S. Navy (COP) in April 1954 and July 1955. These photographs were used to determine irrigated acreage (pl. 8A). Irrigated acreage in Borrego Valley was 4,730 acres in 1954 and 4,710 in 1955. The decline in irrigated acreage between 1954 and 1955 was due to cessation of irrigation on the three small plots shown on plate 8A in T. 9 S., R. 6 E., sec. 31 and T. 10 S., R. 6 E., sec. 6. These three plots were irrigated with surface water diverted from Coyote Creek by way of a small, unlined canal. Irrigated acreage in Clark Lake Valley was 70 acres for both 1954 and 1955 in T. 10 S., R. 7 E., sec. 19.

## 1964

Areal photographs taken over Borrego Valley in October 1964 show that the irrigated acreage had declined to 2,550 acres. Clark Lake Valley had no irrigation in 1964.

## 1965

The U.S. Bureau of Reclamation (1968) reported about 2,000 acres of crops were irrigated in 1965. This report contains a map showing the location of the irrigated areas; however, the types of crops were not indicated. The report also stated that the population of Borrego Valley in 1965 was 1,300 people.

## 1980

During 1980, an attempt was made to determine all land and water use for Borrego and Clark Lake Valleys. Irrigated land totals 2,175 acres, which does not include native vegetation.

The permanent population of Clark Lake Valley is less than 10 people, and the total water use is estimated to be less than 25 acre-ft/yr.

Borrego Valley land use is shown on plate 8B; water use is given in tables 5 and 6. Plate 8B shows irrigated areas by crop type, location of State Park Campgrounds, sewage-disposal sites, and areas of native vegetation. The native vegetation surrounding the Borrego Sink uses an estimated 1,220 acre-ft of water each year, which is almost half the amount of water entering Borrego Valley from streams on the west side.

TABLE 5. - Population of Borrego Valley and water use in 1980

| | Population | Water use (acre-ft/yr) |
|---|---|---|
| Borrego Telephone Directory (Adults) | 1,798 | -- |
| Borrego Pre-School (under 5 years of age) | 13 | -- |
| Borrego Elementary School | 166 | -- |
| Borrego High School | 154 | -- |
| Total permanent population | 2,131 | 298 |
| Borrego Palm Canyon Campground, 117 campsites | [1]81,601 | 31 |
| Horse Camp, 10 campsites, 40 horse corral | [1,2]7,300 | 2.2 |
| Tamarisk Grove Campground, 25 campsites | [1,2]18,250 | 2.8 |
| Total use | | 334 |

[1]Total campers using facilities during 1980 on daily basis (M. H. Getty, Area Manager, Anza-Borrego Desert State Park, oral commun., 1981).
[2]Estimated (M. H. Getty, Area Manager, Anza-Borrego Desert State Park, oral commun., 1981).

TABLE 6. - Water use in Borrego Valley during 1980

| Type water use | Number of acres irrigated | Consumptive water use per acre (acre-ft) | Water used (acre-ft) |
|---|---|---|---|
| Population (permanent and transient) | | (125 [gal/d]/ person) | 334 |
| Citrus | 940 | 3.26 | 3,064 |
| Grass (pasture) | 425 | 4 | 1,700 |
| Alfalfa | 140 | 6.19 | 867 |
| Tomatoes (hot house) | 10 | 2 | 20 |
| Tree farm[1] | 390 | 2 | 780 |
| Grass (golf course) | 270 | 7 | 1,890 |
| Mesquite and tamarisk trees (native vegetation) | 4,510 | [2]2.7 | 1,218 |
| Grapes (dead) | 655 | [3]0 | 0 |
| Date palm | 40 | 40 | 0 |
| Total water use (rounded) | | | 9,870 |

[1]Tree farms are predominantly palm trees, but also include other ornamental trees such as olive.
[2]Trees cover about 10 percent of ground in 4,510 acres, or 2.7 acre-ft/yr times 10 percent.
[3]Grapes not irrigated since 1966.
[4]Not irrigated in 1980.

## Population of Borrego Valley and Water Use in 1980

Table 5 shows the number of people residing in Borrego Valley and the number of visitors to the State Park Campgrounds. The 1980 census, in its preliminary figures, lists 1,408 residents for Borrego Valley; however, the total population estimated in table 5 is somewhat higher. This discrepancy occurs probably because many of the residents in Borrego Valley are retired, travel during the hot summer months, and may not have been home during the census. The total water use by the permanent and transient population of Borrego Valley was about 334 acre-ft in 1980, based on an estimated per capita water use of 125 gallons of water per day per person for 1980. Water-company data show that the per capita water use in Borrego Valley for 1961 was about 93 gallons per day per person. Per capita water use has increased with time because homes are being built larger than in the past and have dishwashers, air conditioning, large lawns, and other amenities.

Table 6 and plate 8B show the consumption of water for all purposes. About 9,900 acre-ft of water was consumptively used during 1980 in Borrego Valley.

## Consumptive Use of Water by Type of Crop

Each crop type consumptively uses a different amount of water depending upon the climate and where the crop is grown. Table 6 shows the consumptive use of water by various crops based on average values published for other areas with similar climatic conditions by Erie, French, and Harris (1965), Blaney and Harris (1951), and Blaney (1951). Some crops, such as pasture grass, were averaged (4 acre-ft/yr) because more than one type of grass was present. These grasses consumptively use between 2.7 to 6.4 acre-ft/yr.

# BASIN GROUND-WATER STORAGE AND NET DEPLETION

A grid network based on the rectangular system for the subdivision of public lands was used in determining the ground-water storage at steady-state conditions and the depletion between steady state (1945) and 1980. Values were calculated for each section within the basin boundary shown on plate 5. The sum of the storage and depletion for each section equals the totals for the basin. Figure 2 shows a schematic diagram of information used to estimate total storage and depletion. In addition, information is needed as to when the ground water acted in a natural or steady-state condition (pl. 9A) and when man's activities began to affect the ground-water levels. Hydrographs of wells (pl. 10) in Borrego Valley indicate that water levels did not decline until after World War II and that steady-state conditions probably existed prior to 1945.

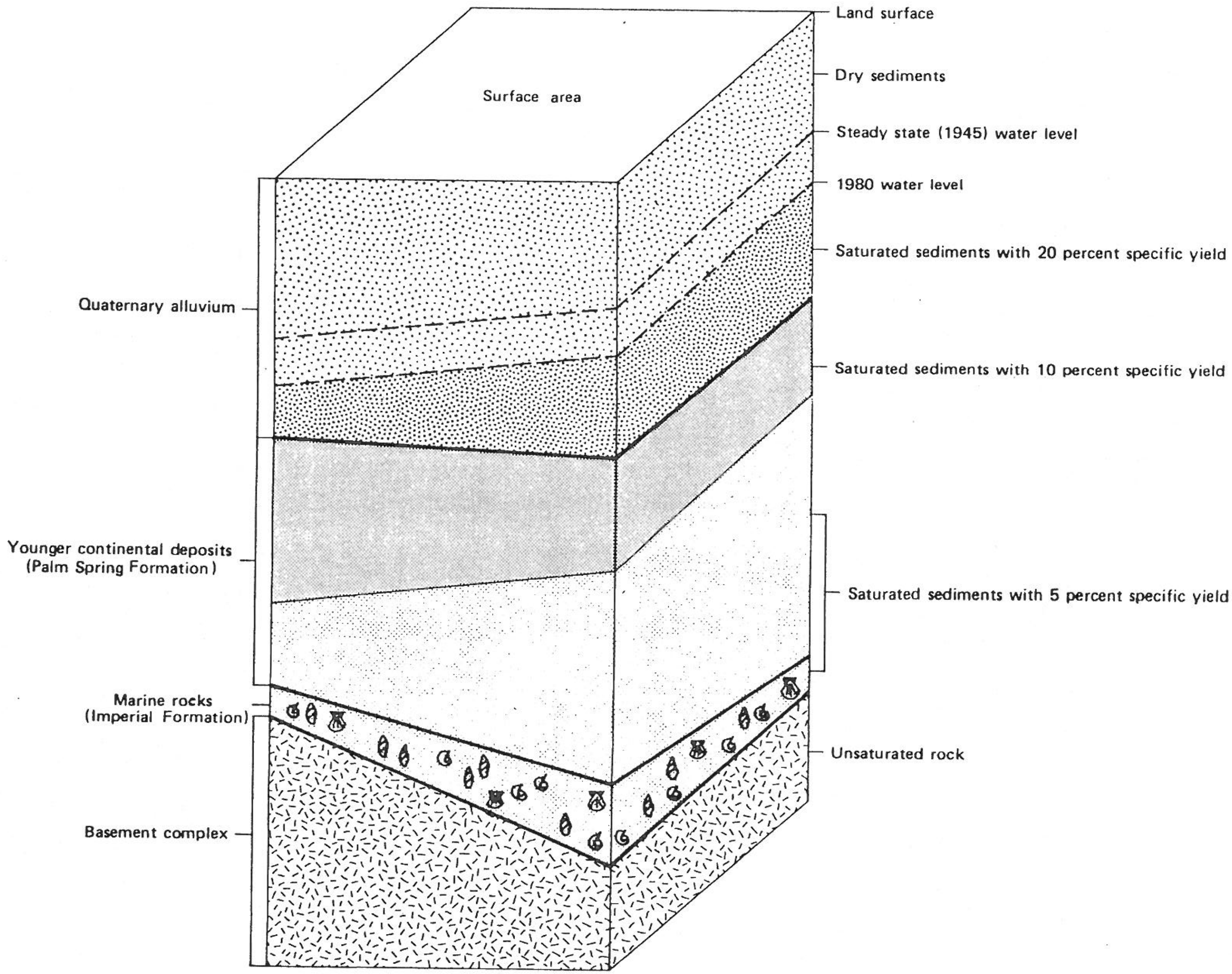



FIGURE 2.--Schematic diagram showing geologic formations, hydrologic units, specific yield, and relative positions of 1945 and 1980 water levels.

Water levels in some wells in the northern and central parts of Borrego Valley declined in the period between 1950 and 1953. Some wells in the southern end of the valley did not decline until about 1970. Water-level measurements (Burnham, 1954) were used to construct a contour map (pl. 9B) for 1952-53. This map shows numerous pumping depressions in the water table. Two other contour maps were made from measurements made in 1965 (Moyle, 1968) and 1980 (Supplemental Data A). These contour maps (pl. 9C and 9D) indicate that the water table has declined with time. These four water-level contour maps are important and will be used later to verify results from the model.

Plates 11A and 11B show water-level change in Borrego and Clark Lake Valleys for 1953-65 and 1965-80. These maps show that water levels declined more in Borrego Valley during 1953-65 than during 1965-80. The land-use maps also show a greater amount of land under irrigation in 1953-65 than 1965-80 (pl. 8). Although the water levels declined less during 1965-80, the decline indicates that more water was being pumped from storage and consumptively used than the amount of recharge available to Borrego Valley from all sources for the same time periods.

Using graphical subtraction between steady-state (1945) and 1980, the net water-level decline can be determined for Borrego and Clark Lake Valleys. Plate 11C shows a maximum water-level decline of 100 feet in one area within Borrego Valley and 30 feet in Clark Lake Valley adjacent to the Coyote Creek fault.

The total amount of water in storage in Borrego Valley was about 5.5 million acre-ft prior to 1945, and the net depletion that has occurred between steady-state (1945) and 1980 is about 330,000 acre-ft.

## WATER QUALITY IN BORREGO VALLEY AND VICINITY

### General Information

Water samples from individual wells (Supplemental Data B) show that some constituents are above the recommended limit set by the U.S. Environmental Protection Agency (National Academy of Sciences, National Academy of Engineering, 1973) for drinking and irrigation water. The recommended upper limits for drinking water are sodium, 250 mg/L; sulfate, 250 mg/L; chloride, 250 mg/L; nitrate 44 mg/L (nitrogen, 10 mg/L); and iron 0.3 mg/L. Concentrations of boron in irrigation water of about 1 mg/L may be of concern to farmers. Small amounts (less than 1 mg/L) of boron are essential to plant growth; however, larger amounts may be harmful or toxic depending on the type of plant and amount of boron.

Concentrations of dissolved solids in ground water from Borrego Valley and vicinity range from less than 200 mg/L to almost 3,000 mg/L (Moyle, 1968, table 3; Supplemental Data B in this report), and is generally excellent to poor for domestic use. The Environmental Protection Agency (National Academy of Sciences, National Academy of Engineering, 1973) recommends an upper limit of 500 mg/L dissolved solids in water for human consumption. Water having higher dissolved solids can be used where 500 mg/L water is unavailable depending upon the individual constituents in the water. Some plants, cattle, mining, and industrial operations can tolerate higher dissolved solids.

Sites where water-quality samples were collected in Borrego Valley area during 1980 are shown on plate 12 and the analyses are listed in Supplemental Data B.

## Source of Nitrogen in Ground Water

Nitrogen (N) is the individual constituent in ground water in Borrego Valley of most concern to residents. Some laboratory analyses report nitrogen (N)[1]; others report nitrate ($NO_3$). According to the Environmental Protection Agency (National Academy of Sciences, National Academy of Engineering, 1973, p. 73) "high concentrations of nitrate (44 mg/L $NO_3$ or greater) in drinking water may cause infantile methemoglobinemia, especially in infants under 3 months of age. The development of methemoglobinemia is dependent upon the bacterial conversion of the relatively innocuous nitrate ($NO_3$) to nitrite ($NO_2$). Nitrite absorbed into the bloodstream converts hemoglobin to methemoglobin. The altered pigment can then no longer transport oxygen, and the clinical effect of methemoglobinemia is that of oxygen deprivation or suffocation."

Nitrate ($NO_3$) in water samples analyzed from Borrego Valley over the years ranged from 0 to more than 300 mg/L. Concentrations of nitrate in the same wells sampled periodically have fluctuated with time. Well 10S/6E-15D1 (fig. 3) was sampled 22 times between 1950 and 1979 for nitrate ($NO_3$). Nitrate values in water from this well ranged from 2 to 213 mg/L. The reason for the fluctuation in nitrate levels with time is probably contamination from septic tanks, irrigation return, well construction, and frequency and size of floods entering Borrego Valley from adjacent stream channels. Large floods sometimes inundate the sewage-dumping area in T. 10 S., R. 6 E., sec. 36. Small floods do not reach this area.

Data are presently not available to determine the areal extent of nitrate or if the nitrate concentration in water at or near the water table is increasing or decreasing with time. To collect and analyze high-nitrate water, wells must be constructed with perforations at the water table, but production wells normally are not. When water levels in wells decline to the point where the perforations are exposed at the water table, they produce high nitrate water. These wells are usually destroyed, and new wells are drilled at the same locations with deeper perforations to produce low nitrate water.

Figure 3 shows the perforated interval of the casing in well 10S/6E-15D1, the static and pumping water levels in the well during pumping tests, the pumping rate in gallons per minute, and nitrate ($NO_3$) concentrations in the water for various times.

The nitrate pollution in Borrego Valley comes from:

1. Individual septic tanks and leach lines.
2. Effluent from sewage-disposal systems.
3. Irrigation-return water containing fertilizer.
4. Decomposition of native vegetation.

---

[1]To convert N (nitrate-nitrogen) to $NO_3$ (nitrate) multiply by 4.427.

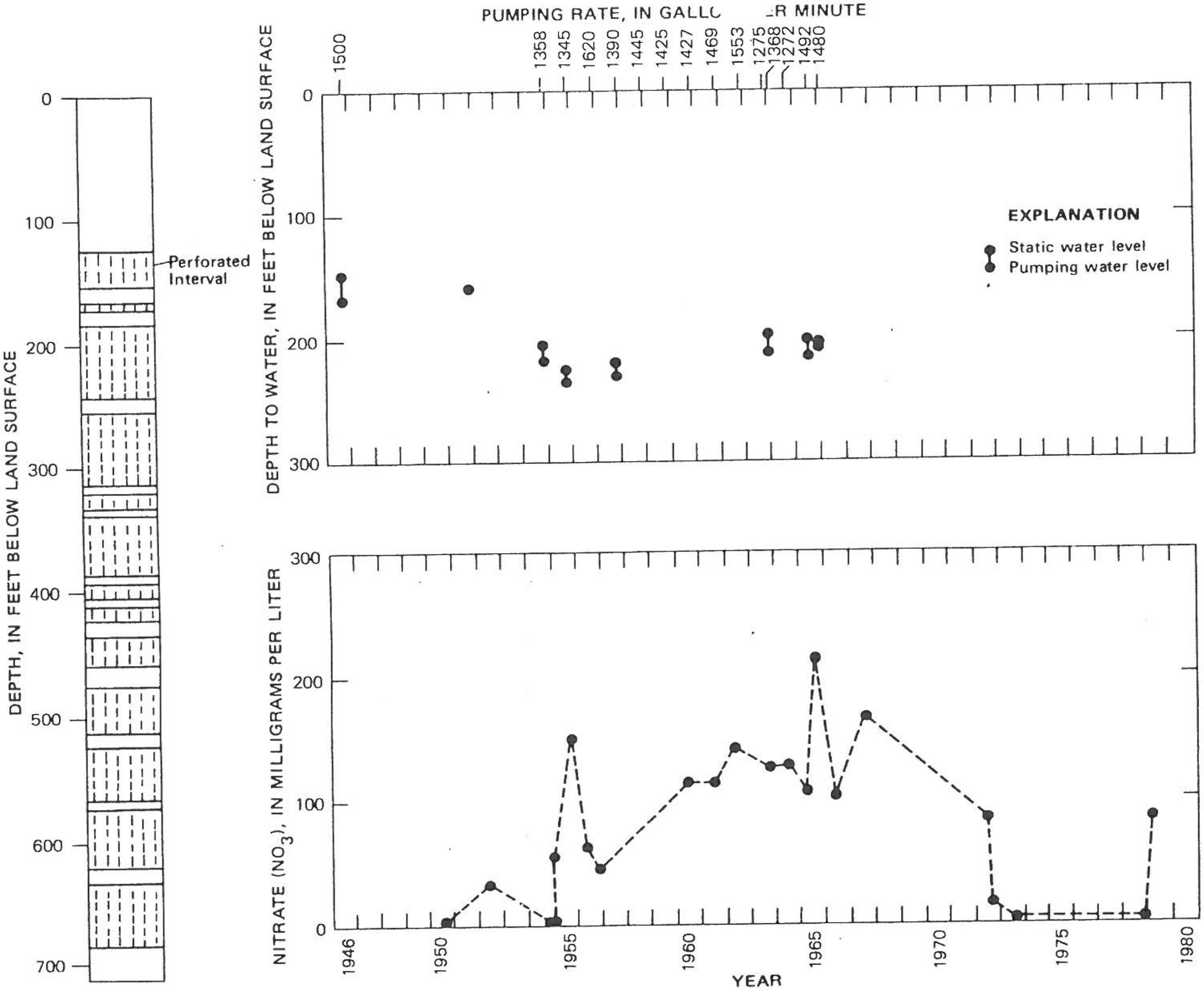



FIGURE 3.--Perforated interval, pumping rate, depth to water, and nitrate concentration of water in well 10S/6E-15D1.

Sewage disposal in Borrego Valley is predominantly by individual septic tanks and leach fields. One small sewage-treatment plant in the northeast corner of sec. 9, T. 11 S., R. 6 E. (pl. 8) services the homes surrounding the Club Circle Golf Course (formerly Ensign Ranch). The volume of sewage treated in this plant is small. Only 12 homes were serviced by this plant from October through December 1980, according to records in the file of the California State Water Quality Control Board. Plans are presently in progress for a new 25,000 gal/d sewage-disposal plant north of the town of Borrego Springs. Phase one of this plant was scheduled to be in operation near the end of 1981.

Septic tanks at individual homes are cleaned out periodically by commerical companies using vacuum trucks to haul away the sewage sludge. Data in the California State Water Quality Control Board's files indicate that 75,000 gallons of sludge was removed from various septic tanks in Borrego Valley between October 15, 1980, and January 1, 1981, and was deposited at a dump site in the SE¼ of sec. 36, T. 10 S., R. 6 E. A sample of sewage was collected from this dump site November 21, 1980. Tables 7 and 8 show the results of this analysis.

Solid waste (trash) is trucked to the dump site in T. 11 S., R. 7 E., sec. 6 (pl. 8) and buried or burned.

High nitrate water is conducted from the land surface to the water table and generally stays within a few feet below the water table. Wells constructed with perforations above the water table, as well as wells that are in areas where declining water levels have exposed the perforations above the water table show signs of high nitrate values at various times. Similar observations of high nitrate near the water table have been made by Klein and Bradford (1979) in the Redlands area.

Several wells that contained high nitrate water have been destroyed by their owners; well 10S/6E-29K1 was destroyed by pulling the casing out of the ground and backfilling the hole. Water from 29K1 contained 30 mg/L $NO_3$ in 1952. A new well (10S/6E-29K2) was drilled about 50 feet east of 29K1. The new well was constructed with deeper perforations and has 3.5 mg/L $NO_3$ (0.8 mg/L N) (Supplemental Data B).

Floods entering Borrego Valley from the surrounding mountains also contribute to the amount and concentration of nitrate in the ground water. Small floods help transport the nitrate from land surface to the water table, as do the large floods, but the large floods may help dilute the available nitrate.

With periodic nitrate analysis of water from irrigation wells, some farmers could take advantage of the high nitrate for use on crops such as citrus trees that can tolerate high concentrations of nitrate. This would also help remove nitrate from the aquifer and lower the pollution. Water companies or farmers that raise grapes, which are less tolerant to nitrate, may wish not to use high nitrate water. Wells can be constructed with perforations some distance below the expected pumping water level to prevent high nitrate water from entering the wells. If low nitrate water is desired, wells should be constructed so that the perforations remain below the pumping water level in the well for the expected life of the well.

Water-quality samples collected from streams and wells along the west side of Borrego Valley show no evidence of high-nitrate water entering the valley from adjacent areas.

TABLE 7. - Analysis of sewage from dump site in T. 10 S., R. 6 E., sec. 36

| Constituent | Concentration (mg/L) |
|---|---|
| Total organic carbon | 3,200 |
| Chemical oxygen demand (COD)[1] | 20,800 |
| Total nitrogen[1] | 580 |
| Total phosphorus | 250 |

[1]Analyzed as bottom material (U.S. Geological Survey Laboratory, Denver, Colo.).

TABLE 8. - Semiquantitative analysis of selected metals in sewage collected from dump site in T. 10 S., R. 6 E., sec. 36

[Sample required digestion prior to analysis; (>) "greater-than" symbol indicates element exceeded the upper limit of detection; (<) "less-than" symbol indicates element is below limit of detection]

| Element | Concentration (µg/L) | Element | Concentration (µg/L) |
|---|---|---|---|
| Aluminum | >10,000 | Magnesium | 10 |
| Barium | 1,000 | Manganese | 500 |
| Beryllium | <1 | Molybdenum | 300 |
| Bismuth | <1,000 | Nickel | <50 |
| Boron | 100 | Potassium | 0 |
| Cadmium | 30 | Silica | 50 |
| Calcium | 100 | Silver | <10 |
| Chromium | <50 | Sodium | 50 |
| Cobalt | 300 | Strontium | 500 |
| Copper | 3,000 | Tin | 700 |
| Gallium | 50 | Titanium | 1,000 |
| Germanium | 100 | Vanadium | 300 |
| Iron | >10,000 | Zinc | 5,000 |
| Lead | 1,000 | Zirconium | <5 |
| Lithium | 30 | | |

## NEED FOR ADDITIONAL DATA

Additional data are needed in the area near Borrego Spring and along the Coyote Creek fault. Two test holes drilled on opposite sides of the Coyote Creek fault would help to determine the water-level decline in Borrego Valley and whether the fault acts as a ground-water barrier. A 2-inch auger hole 17 feet deep was dug at Borrego Spring during this study in an effort to measure the water level in this area. The hole was dry, indicating the water-level decline has been greater than 17 feet since 1909 when the spring was flowing.

The few data available on the vertical separation of heads in the various aquifers indicate that under present conditions of stress there is little head difference. However, future changes in pumping stress patterns or simulated stress in the digital model to be constructed may indicate head differences that could be defined by test drilling.

## SUMMARY AND CONCLUSIONS

This report includes information needed to build a digital hydrologic model of Borrego Valley. It includes sources and amounts of recharge water to the basin, areas of withdrawal, a grid network used to estimate the total recoverable ground water in storage and total ground-water depletion, total depth of alluvial fill, transmissivity, hydraulic conductivity and specific yield of aquifers, and thickness of individual aquifers.

The results of this study show that at steady-state conditions (1945) the basin contained 5.5 million acre-ft of water. Between 1945 and 1980 water levels in wells have declined as much as 100 feet locally and water withdrawn from the basin exceeded recharge by 330,000 acre-ft. Interpretation of the gravity data shows that the thickness of alluvial fill in the basin ranges from 0 feet at the edges of the basin to about 2,450 feet at its deepest part. Part of this alluvial fill is saturated, and part is dry, depending on location. In some areas the water level is at or near land surface, whereas in other areas it is more than 400 feet below land surface.

In Borrego Valley some water could be salvaged that is presently being lost. During large floods, water passes through Borrego by way of San Felipe Creek. Dams on the larger creeks could hold all or part of this water until it could be recharged into the ground-water basin. In addition, some of the native vegetation that uses about half the natural basin recharge could be removed. Studies would be needed to determine the ecological and other effects of such removals.

The chemical quality of water was also investigated during this study. Of prime concern to the population of Borrego Valley is high nitrate ($NO_3$) water in some wells. Some wells produce water with concentrations of nitrate greater than 300 mg/L. The Environmental Protection Agency recommends that the upper limit for nitrate in drinking water be 44 mg/L (National Academy of Sciences, National Academy of Engineering, 1973). High nitrate can cause infantile methemoglobinemia especially in infants under 3 months of age. The sources of high nitrate are septic tanks and leach fields, sewage-disposal systems, irrigation return water containing fertilizer, and decomposition of native vegetation. When conducted to the water table, high-nitrate water generally stays in the uppermost part of the saturated zone and enters wells with perforations above the pumping water level. Wells with perforations below the pumping water level generally produce water with lower concentrations of nitrate.

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# GEOLOGIC AND HYDROLOGIC TERMS

Complete Bouguer: A gravity anomaly calculated by allowing for the attraction effects of topography, latitude, altitude, and curvature but not for that of isostatic compensation.

Consumptive use: The difference between the total quantity of water withdrawn from a source for use and the quantity of water returned to the source. It includes mainly water transpired by plants and evaporated from the soil.

Gal: The gravity unit most commonly used in gravity surveys to measure field strength. Named after Galileo, it is equivalent to an acceleration of one centimeter per second per second. A milligal is 0.001 Gal.

Hydraulic conductivity: The rate of flow of water in feet per day under a unit hydraulic gradient, at the prevailing temperature.

Hydraulic gradient: The rate of change of static head per unit of distance in a given direction.

Net depletion: The progressive loss of water from the ground-water reservoir at a rate greater than that of replenishment.

Precipitation: The discharge of water (as rain, snow, sleet, or hail) from the atmosphere upon the Earth's surface. It is measured as a liquid regardless of the form in which it originally occurred.

Rock density: The mass divided by the volume of a rock is the density. It is generally stated in grams per cubic centimeter.

Specific capacity: The rate of discharge of a water well per unit of draw-down, commonly expressed in gallons per minute per foot.

Specific yield: The ratio of the volume of water a given mass of saturated rock will yield by gravity to the volume of that mass. The ratio is stated as a percent.

Transmissivity: The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width, under a unit hydraulic gradient. Units are given in feet squared per day.

SUPPLEMENTAL DATA A: Water-level measurements in wells during 1980

| Well or spring No. | Water level (feet below land surface) | Remarks |
| --- | --- | --- |
| 9S/5E-5DS1 | 0 | |
| 22KS1 | 0 | |
| 9S/6E-31E1 | 277.30 | |
| 36A1 | 17.67 | |
| 9S/7E-32A1 | 17.25 | |
| 10S/5E-25R1 | 260.97 | |
| 36A1 | 243.98 | |
| 10S/6E-1A1 | 18.18 | |
| 7A1 | 305.76 | |
| 8B1 | 288.09 | |
| 8L2 | 270 | |
| 10M1 | 214.18 | |
| 14G1 | 141.03 | |
| 15D2 | 200.82 | |
| 17J2 | 221.65 | |
| 17K2 | 211.62 | |
| 17L1 | 221.96 | |
| 19J1 | 163.56 | |
| 19R1 | 152.5 | |
| 21A1 | 177.73 | |
| 21B1 | 184.62 | |
| 21C1 | -- | Dry at 178.5 ft (total depth). |
| 21E1 | 175.94 | |
| 21F1 | 172.40 | |
| 22B2 | -- | Dry at 128 ft (total depth). |
| 23M1 | 128.39 | |
| 23M2 | 127.75 | |
| 24C1 | 135.06 | |
| 24K2 | 93.54 | |
| 24L1 | 123.32 | |
| 25R1 | 89.32 | |
| 26P1 | -- | Dry at 58.0 ft (total depth). |
| 26P2 | -- | Dry at 70.8 ft (total depth). |
| 28D1 | 147.40 | |
| 28E1 | 139.47 | |

SUPPLEMENTAL DATA A: Water-level measurements in wells during 1980--Continued

| Well or spring No. | Water level (feet below land surface) | Remarks |
| --- | --- | --- |
| 10S/6E-29B1 | 196 | |
| 29K2 | 139 | |
| 29M1 | 138.67 | |
| 32R1 | 115.53 | |
| 33D1 | 118.19 | |
| 33F1 | 116.19 | |
| 34D1 | 89.98 | |
| 34K1 | 72.58 | |
| 35N1 | 55.1 | |
| 36Q1 | 71.79 | |
| 10S/7E-5D1 | 20.48 | |
| 5D2 | 26.13 | |
| 30F1 | 121.89 | |
| 11S/6E-1C1 | 59 | |
| 3C1 | 62.71 | |
| 3E1 | -- | Dry at 54 ft (total depth). |
| 3M3 | -- | Dry at 59.3 ft (total depth). |
| 3N1 | -- | Dry at 46 ft (total depth). |
| 3N2 | -- | Dry at 36 ft (total depth). |
| 3N3 | -- | Dry at 52 ft (total depth). |
| 3N4 | 53.10 | |
| 4A3 | 83.98 | Intermittent pumping. |
| 4D1 | 90.74 | |
| 4F1 | 79.84 | |
| 4M1 | -- | 80 ft to obstruction, dry. |
| 4P1 | -- | 90 ft to obstruction, dry. |
| 5P1 | 152.82 | |
| 7K2 | 266.25 | |
| 8H1 | 152.41 | |
| 10D3 | 57.59 | |
| 10M2 | 67.86 | |
| 10N1 | 74.41 | |
| 11D2 | 64.49 | |
| 11M1 | 40.42 | |
| 14C2 | 38.62 | |

SUPPLEMENTAL DATA A: Water-level measurements in wells during 1980--Continued

| Well or spring No. | Water level (feet below land surface) | Remarks |
|---|---|---|
| 11S/6E-14D3 | 41.55 | |
| 15E4 | 67.44 | |
| 15G1 | 65.08 | |
| 16K1 | 110.00 | |
| 16M1 | 173.92 | |
| 18R1 | 325.28 | |
| 22A2 | 77.52 | |
| 22D1 | 131.22 | |
| 23E1 | 109.01 | |
| 23J1 | 52.61 | |
| 25A1 | 48.65 | |
| 25C1 | 94.96 | |
| 34A1 | -- | Dry at 441.6 ft (total depth). |
| 11S/7E-29C1 | 77.28 | |
| 30G1 | 64.5 | |
| 30G2 | 78.39 | |
| 30G4 | 79.72 | |
| 30K1 | 72.82 | |
| 30K3 | 78.08 | |
| 32Q1 | 196.83 | |
| 12S/7E-4J1 | 266.47 | |

710
197
513

## SUPPLEMENTAL DATA B: Chemical analyses of w

[Values are in milligrams per l

| Local Identifier | Date of sample | Specific conductance (µmho /cm at 25°C) | pH (units) | Water temperature (°C) | Hardness, as $CACO_3$ | Hardness, noncarbonate | Dissolved calcium | Dissolved magnesium | Dissolved sodium | Sodium percent | Sodium adsorption ratio | D so po s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coyote Creek near Borrego Springs | 11-04-80 | 1,305 | 8.2 | 20.0 | 440 | 270 | 130 | 29 | 110 | 34 | 2.3 | 1 |
| Palm Canyon Creek near Borrego | 11-05-80 | 574 | 8.3 | 15.0 | 190 | 45 | 50 | 17 | 37 | 28 | 1.2 | |
| 9S/6E-31E1 | 11-04-80 | 1,021 | 7.9 | 27.0 | 300 | 150 | 90 | 19 | 91 | 38 | 2.3 | 1 |
| 9S/7E-28N2 | 11-06-80 | 1,195 | 8.9 | 24.5 | 15 | 0 | 5.2 | .6 | 230 | 95 | 25 | |
| 10S/5E-25R1 | 11-20-80 | 693 | 7.6 | 21.0 | 220 | 83 | 58 | 19 | 47 | 31 | 1.4 | |
| 10S/6E-5F1 | 11-07-80 | 1,129 | 7.9 | 22.5 | 360 | 190 | 110 | 20 | 100 | 37 | 2.3 | 1 |
| | 11-20-80 | 1,095 | 7.7 | 24.0 | 300 | 120 | 92 | 18 | 99 | 41 | 2.5 | 1 |
| 10S/6E-7A1 | 11-20-80 | 1,100 | 8.0 | 25.0 | 320 | 140 | 100 | 18 | 110 | 42 | 2.7 | |
| 10S/6E-10M1 | 11-20-80 | 1,400 | 7.7 | 19.0 | 340 | 220 | 110 | 15 | 140 | 47 | 3.3 | 1 |
| 10S/6E-14G1 | 11-06-80 | 1,235 | 8.9 | 29.0 | 170 | 150 | 61 | 4.4 | 190 | 69 | 6.3 | |
| 10S/6E-16E1 | 11-20-80 | 1,125 | 7.7 | 27.0 | 310 | 150 | 99 | 16 | 110 | 42 | 2.7 | 1 |
| 10S/6E-18R1 | 11-19-80 | 990 | 7.7 | 33.0 | 110 | 62 | 44 | .9 | 150 | 72 | 6.1 | 1 |
| 10S/6E-24K2 | 11-06-80 | 1,460 | 7.8 | 29.0 | 250 | 220 | 93 | 3.3 | 210 | 64 | 5.8 | 1 |
| 10S/6E-29K2 | 11-19-80 | 550 | 7.9 | 28.0 | 87 | 13 | 30 | 3.0 | 70 | 62 | 3.3 | |
| 10S/6E-34D1 | 11-20-80 | 1,800 | 7.7 | 22.0 | 430 | 340 | 140 | 19 | 180 | 47 | 3.8 | 1 |
| 10S/6E-36Q1 | 12-03-80 | 815 | 7.7 | 27.5 | 94 | 46 | 33 | 2.8 | 130 | 74 | 5.8 | |
| 10S/7E-30F1 | 11-06-80 | 1,770 | 8.6 | 27.5 | 220 | 180 | 86 | 1.5 | 280 | 72 | 8.2 | 1 |
| 11S/6E-1C1 | 11-06-80 | 1,130 | 7.9 | 27.5 | 54 | 0 | 14 | 4.6 | 200 | 83 | 12 | 3 |
| 11S/6E-3D3 | 11-20-80 | 925 | 7.9 | 24.0 | 310 | 180 | 98 | 17 | 71 | 32 | 1.7 | |
| 11S/6E-7K3 | 11-19-80 | 750 | 7.7 | 27.0 | 96 | 0 | 33 | 3.2 | 120 | 72 | 5.3 | |
| 11S/6E-9B1 | 12-03-80 | 1,750 | 7.7 | 23.0 | 350 | 110 | 98 | 25 | 250 | 60 | 5.8 | |
| 11S/6E-11D1 | 12-03-80 | 490 | 8.6 | 28.5 | 57 | 8 | 20 | 1.7 | 76 | 73 | 4.4 | |
| 11S/6E-18R1 | 12-03-80 | 1,130 | 7.7 | 16.0 | 230 | 92 | 73 | 12 | 120 | 52 | 3.4 | |
| 11S/6E-23E1 | 11-05-80 | 972 | 8.0 | 26.0 | 160 | 54 | 53 | 7.8 | 130 | 62 | 4.4 | |
| 11S/7E-30G4 | 11-05-80 | 1,840 | 8.0 | 27.0 | 460 | 410 | 150 | 20 | 230 | 52 | 4.7 | |
| 11S/7E-32Q1 | 11-05-80 | 615 | 9.3 | 27.0 | 25 | 0 | 9.6 | .3 | 110 | 88 | 9.5 | |
| 12S/6E-17C3 | 11-05-80 | 3,230 | 7.7 | 21.5 | 1,100 | 960 | 300 | 96 | 340 | 39 | 4.4 | 2 |

water from wells and streams collected in 1980

li+er; except where noted]

| Dissolved potassium | Alkalinity | Dissolved sulfate | Dissolved chloride | Dissolved fluoride | Dissolved silica | Dissolved solids, sum of constituents | Dissolved nitrogen, $NO_2+NO_3$ as N | Dissolved phosphorus, orthophosphate | Dissolved boron (μg/L) | Dissolved iron (μg/L) | Total arsenic (μg/L) | Dissolved solids (ton/acre-ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 170 | 430 | 78 | 1.5 | 35 | 930 | 0.35 | 0.09 | 250 | 40 | 1 | 1.26 |
| 6.2 | 150 | 100 | 30 | .4 | 42 | 373 | .02 | .21 | 40 | 70 | 1 | .51 |
| 11 | 150 | 270 | 66 | .8 | 29 | 669 | .52 | .03 | 170 | 10 | 0 | .91 |
| 9.9 | 120 | .1 | 290 | .1 | 1.9 | 611 | .00 | .00 | 1,400 | 20 | 1 | .83 |
| 7.2 | 140 | 130 | 43 | .3 | 35 | 425 | .19 | .03 | 60 | 420 | 1 | .58 |
| 11 | 170 | 310 | 70 | .9 | 27 | 757 | 1.2 | .00 | 190 | 10 | 1 | 1.03 |
| 10 | 180 | 240 | 68 | 1.0 | 25 | 664 | .67 | .06 | 230 | 20 | 1 | .90 |
| 9.8 | 180 | 250 | 81 | .9 | 25 | 708 | 1.1 | .06 | 280 | <10 | 1 | .96 |
| 10 | 120 | 370 | 99 | .7 | 20 | 850 | 2.8 | .03 | 270 | 20 | 1 | 1.16 |
| 9.2 | 25 | 450 | 82 | .5 | 4.6 | 817 | .00 | .00 | 230 | 30 | 0 | 1.11 |
| 10 | 160 | 310 | 72 | .6 | 25 | 745 | .95 | .03 | 230 | 1,300 | 1 | 1.01 |
| 10 | 52 | 320 | 61 | .5 | 14 | 634 | .43 | .03 | 290 | 10 | 1 | .86 |
| 12 | 23 | 380 | 220 | .5 | 14 | 947 | .00 | .00 | 290 | <10 | 1 | 1.29 |
| 5.9 | 74 | 120 | 31 | .2 | 19 | 327 | .80 | .03 | 70 | 20 | 3 | .44 |
| 10 | 89 | 360 | 210 | .2 | 23 | 1,130 | 30 | .03 | 120 | 20 | 0 | 1.54 |
| 5.7 | 48 | 220 | 62 | .8 | 9.0 | 493 | .11 | .06 | 210 | 30 | 4 | .67 |
| 10 | 38 | 420 | 270 | .7 | 13 | 1,100 | .04 | .00 | 150 | 40 | 2 | 1.50 |
| 30 | 360 | 4.2 | 150 | .4 | 3.4 | 624 | .07 | .00 | 290 | 30 | 0 | .85 |
| 5.0 | 130 | 160 | 140 | .2 | 30 | 605 | 1.3 | .00 | 80 | 50 | 0 | .82 |
| 4.8 | 110 | 110 | 100 | 1.4 | 26 | 468 | .69 | .03 | 190 | 10 | 2 | .64 |
| 6.8 | 240 | 350 | 200 | .7 | 64 | 1,150 | 1.3 | .00 | 360 | 150 | 2 | 1.56 |
|  | 49 | 130 | 33 | .9 | 17 | 312 | .08 | .06 | 150 | 20 | 7 | .42 |
|  | 140 | 28 | 210 | .5 | 26 | 608 | 11 | .03 | 210 | 10 | 0 | .83 |
| 6.8 | 110 | 110 | 170 | .4 | 22 | 572 | 1.2 | .00 | 220 | 10 | 2 | .78 |
| 9.6 | 52 | 560 | 240 | .2 | 17 | 1,260 | 1.1 | .00 | 110 | <10 | 1 | 1.71 |
| 6.7 | 29 | 100 | 83 | .3 | 12 | 369 | 6.7 | .00 | 70 | 20 | 1 | .50 |
| 20 | 180 | 1,200 | 340 | .5 | 36 | 2,440 | .13 | .00 | 130 | 40 | 1 | 3.32 |