OPEN-FILE REPORT

MOJAVE RIVER BASIN GROUND-WATER RECHARGE

with particular reference to

THE CALIFORNIA FLOODS OF JANUARY AND FEBRUARY 1969

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Menlo Park, California
1969

PREPARED IN COOPERATION WITH THE MOJAVE WATER AGENCY

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

MOJAVE RIVER BASIN GROUND-WATER RECHARGE WITH PARTICULAR REFERENCE TO THE CALIFORNIA FLOODS OF JANUARY AND FEBRUARY 1969

By

William F. Hardt

Prepared in cooperation with the
Mojave Water Agency

OPEN-FILE REPORT

7208-07

Menlo Park, California
December 17, 1969

MOJAVE RIVER BASIN GROUND-WATER RECHARGE WITH PARTICULAR REFERENCE TO THE CALIFORNIA FLOODS OF JANUARY AND FEBRUARY 1969

By William F. Hardt

ABSTRACT

The floods of January and February 1969 in the Mojave River basin caused about $6 to $12 million damage. In contrast to this heavy damage, the floods also produced substantial benefits in this water-deficient area as percolating floodwater recharged the underlying aquifer at no capital cost.

Aquifer recharge from March 1967 through March 1969 was about 300,000 acre-feet from surface flow in the Mojave River--flow that infiltrated the ground between The Forks and Afton Canyon. During that 25-month study period, consumptive use by phreatophytes and pumping of ground water adjacent to the river was about 190,000 acre-feet. Most of the recharge occurred during the 1969 floods. About 210,000 acre-feet of floodflow from January through March 1969 recharged the aquifer--the equivalent of about 2 years of normal water use in the basin.

The change in the quantity of ground water in storage for the basin during the study period was a net accretion of about 110,000 acre-feet, as determined from surface-water losses and from changes in ground-water level. The value of the water that recharged the basin sediments, on the basis of estimated cost of water from the California Aqueduct, was about $18 million for the 25-month period and $12 million for the 3-month flood period in 1969. Consideration might well be given to future artificial diversion of controlled floodflow to sparsely populated areas as an aid to enhancement of recharge to the basin.

Ground-water pumpage in the basin exceeds natural recharge from flow in the Mojave River. Floodflows are highly unpredictable and give only temporary relief to the long-term continuous lowering of water levels in the alluvial aquifer.

INTRODUCTION

The U.S. Geological Survey, in cooperation with the Mojave Water Agency, the Marine Corps Supply Center at Barstow, and George Air Force Base, has been making detailed geohydrologic studies of the Mojave River basin since the summer of 1966 for the purpose of aiding Federal, State, and local agencies in the better management of the water resources of the area. These studies have included the construction and use of an electrical analog model to help better understand the geohydrology of the basin.

During the 3-year period of the study, two major floods occurred, the first in January 1969 followed by a second in February 1969. According to the U.S. Army, Corps of Engineers, the flood caused an estimated $12 million maximum damage (oral commun., 1969) to roads, bridges, houses, railroads, and similar structures in the basin. Minimum damage was estimated to be $6 million. Despite the heavy damage, the floods produced a substantial beneficial effect on the local economy through recharge of ground water at no capital cost in this water-deficient area. Floodwater recharges the permeable alluvial aquifers, raises water levels, and thus helps the economy of the basin by increasing the quantity of water in storage and decreasing pumping lifts in wells. However, because ground-water pumpage exceeds the natural recharge, the floodwater recharge gives only temporary relief from the long-term continuous lowering of water levels in the alluvial aquifer.

As a part of the geohydrologic study of the area, the depth to water was measured in about 150 wells along and near the Mojave River in March 1967. Because of the heavy floods in January and February 1969 and their effect on recharging the basin, a special effort was made to remeasure the depth to water in the same wells. This was done during the period April 7-10, 1969. Those measurements provided an opportunity to determine the net change in ground-water storage for the 25-month period and particularly to examine the effects of the floods on the ground-water system.

In addition to determination of the net change in ground-water storage resulting from the floods, a separate analysis was made of the surface-water flows utilizing the records for six gaging stations along the Mojave River. Losses between gaging stations provided data as to how much water was going into storage. Surface-water records and water-level measurements at many wells along the river permit analysis of the surface water-ground water relations for a time period before and after this major flood. Data of this type suitable for a regional recharge study are not always available.

LOCATION AND NATURE OF THE AREA

The Mojave River basin is in the arid Mojave Desert region of southern California and is about 80 miles northeast of Los Angeles (fig. 1). Annual precipitation in the area measured at Victorville and Barstow averaged 4.97 and 4.16 inches, respectively, for the period 1939-68. The basin is an alluviated plain that slopes gently northeastward. A tremendous quantity of ground water is stored in the alluvial sediments underlying the plain. Surrounding the plain and forming the boundary of the ground-water basin are numerous mountains (fig. 1) formed of mainly non-water-bearing crystalline and metamorphic rocks. The study area is about 1,400 square miles in extent, ranges from The Forks to Afton Canyon, and includes Harper, Coyote, and Troy playa lakes. Most of the basin is undeveloped, except for the irrigable lands and centers of population adjacent to the Mojave River. The water supply is obtained primarily by pumping from wells that tap the large ground-water reservoir. The reservoir is recharged by infiltration of streamflow from the Mojave River, which is the main stream traversing the area. During the period November-April, most of the precipitation and runoff occurs in the headwaters of the basin in the San Bernardino Mountains and is the source of streamflow in the Mojave River. Annual precipitation in the high mountainous area averages about 40 inches.

Deep Creek and West Fork Mojave River drain the San Bernardino Mountains, headwaters of the Mojave River basin, and join at The Forks to form the Mojave River. Below The Forks the stream enters the relatively flat desert alluvial basin. The gradient of the Mojave River is 15-20 feet per mile. Tributary washes with gradients of 50-100 feet per mile are common on the sides of the valley. Total surface-water inflow to the basin is measured by two gaging stations near The Forks (fig. 1). The outflow from the basin is measured by a gaging station in Afton Canyon, about 100 miles downstream from The Forks. Intermediate gaging stations are at Victorville, Wild Crossing, and Barstow (fig. 1).

DETERMINATION OF AQUIFER RECHARGE

Surface-Water Loss Method

The period March 1967 through March 1969 was selected as the study period for direct correlation of recharge determined from streamflow records and water-level change in the aquifer. Surface-water flow during this 25-month period was much greater than the long-term average, principally because of the floods of January and February 1969. During the correlation period, about 75 percent of the inflow and 99 percent of the outflow occurred from January to March 1969. About 60 percent of the inflow during the period was discharged from Deep Creek and 40 percent from West Fork Mojave River with the increased percentage of flow from Deep Creek coming primarily in January. The records indicate that, for the 25-month period, nearly 375,000 acre-feet of water entered the Mojave River at The Forks and about 70,000 acre-feet left the basin at Afton Canyon (table 1). The long-term average (1931-65) inflow at The Forks was nearly 56,000 acre-feet per year, and outflow at Afton Canyon was about 8,800 acre-feet per year. The outflow includes some ground water discharged to the stream a few miles upstream from the gaging station. Table 1 shows that little flow occurred at Wild Crossing except during flood periods. Thus, recharge to the lower basin occurs only during periods of high flow in the upper part of the basin.

The difference between inflow and outflow, about 300,000 acre-feet, was mostly recharged to the basin. However, some of the water was used by phreatophytes, was pumped, or was evaporated. The remainder reflects a net increase in the quantity of ground water in storage. Most of this recharge to the ground-water system was the result of the floods of January 18-26 and February 4-18 and 22-26, 1969. During the 3-month period January through March 1969, inflow to the basin was about 279,000 acre-feet and outflow was about 69,000 acre-feet (table 1). A large percentage of this surface-water loss of 210,000 acre-feet entered the ground and recharged the ground-water basin. Because the floods occurred during the winter, the quantity of water withdrawn by pumping (particularly for irrigation) was at a minimum, water use by dormant phreatophytes and other plantlife was minor, and evaporation was low.

Peak discharges for the January and February 1969 floods were about one-half those for the March 1938 flood (table 2), although the total quantity of water coming into the basin in 1969 was greater because of the longer duration of flow. In 1938 February-May inflow to the basin at The Forks was about 172,000 acre-feet of water compared with the nearly 333,000 acre-feet of water in January-May 1969. Figure 2 shows photographs of the Mojave River at flood stage near Hesperia, Victorville, Wild Crossing, and Barstow. The photographs were made by the Geological Survey in January and February 1969.

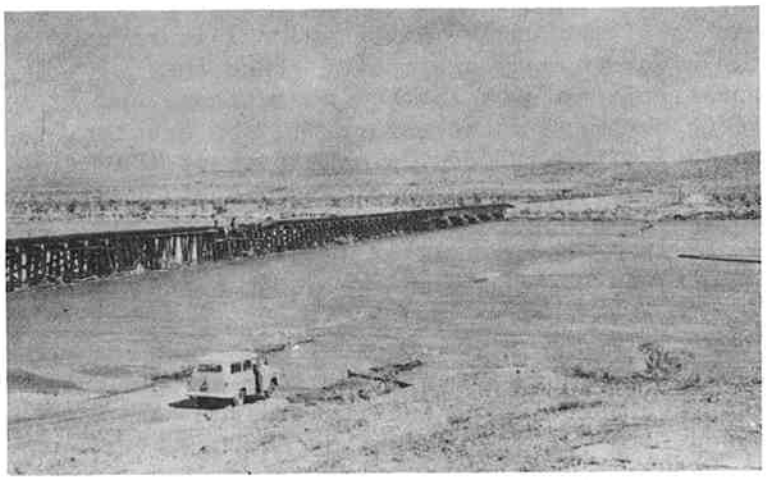
TABLE 1.--*Mojave River flow at gaging stations, March 1967 through March 1969 (acre-feet)*

Date	(1) 10-2605 Deep Creek near Hesperia	(2) 10-2610 West Fork Mojave River near Hesperia	(3) The Forks (1) + (2)	(4) 10-2615 Mojave River at lower narrows near Victorville[1]	(5) 10-2619 Mojave River at Wild Crossing	(6) 10-2625 Mojave River at Barstow	(7) 10-2630 Mojave River at Afton[1]
1967							
March	8,170	9,000	17,170	8,060	5,280	233	48
April	15,280	14,040	29,320	20,340	16,000	240	54
May	11,480	5,870	17,350	11,890	6,280	43	15
June	2,780	1,760	4,540	1,240	0	0	1
July	941	28	969	956	8	1	192
August	466	0	466	720	0	0	0
September	500	0	500	928	0	14	124
October	536	0	536	1,230	0	0	16
November	2,140	1,250	3,390	2,070	6	0	67
December	2,060	1,510	3,570	2,570	0	0	89
1968							
January	1,870	1,080	2,950	2,550	0	0	49
February	3,230	1,430	4,660	2,300	0	0	48
March	3,080	1,600	4,680	1,850	0	0	40
April	2,160	686	2,846	1,540	0	0	23
May	1,040	0	1,040	1,130	0	0	26
June	414	0	414	1,020	0	0	1
July	228	0	228	735	0	0	0
August	170	0	170	811	7	0	0
September	134	0	134	988	0	0	0
October[2]	257	0	257	1,330	0	0	0
November[2]	468	0	468	1,350	0	0	0
December[2]	377	0	377	1,910	0	0	27
1969							
January[2]	71,980	32,840	104,820	74,770	57,460	45,960	21,310
February[2]	64,990	64,380	129,370	111,160	93,580	70,890	39,180
March[2]	28,430	15,834	44,384	53,970	48,070	14,640	8,670
Totals:							
March 1967-69	223,181	151,308	374,609	307,418	226,691	132,021	69,980
January-March 1969	165,400	113,054	278,454	239,900	199,110	131,490	69,160

[1]Includes ground-water discharge where figure is greater than that for preceding station.
[2]Provisional records--subject to revision.

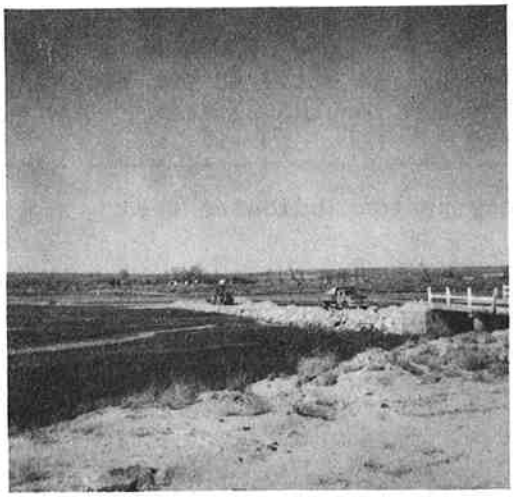
TABLE 2.--*Peak discharges in Mojave River, 1932-69*

Station No.	Stream gaging station	Period of record	Drainage area (sq miles)	Peak discharge in cubic feet per second	
				Date	Discharge
10-2605	Deep Creek near Hesperia	1904-22 1929-69	136	Feb. 9, 1932	7,900
				Feb. 14, 1937	6,800
				Mar. 2, 1938	46,600
				Jan. 23, 1943	19,000
				Nov. 22, 1965	21,700
				Dec. 29, 1965	20,800
				Jan. 25, 1969	23,000
				Feb. 25, 1969	17,600
10-2610	West Fork Mojave River near Hesperia	1904-22 1929-69	74.6	Feb. 8, 1932	8,500
				Mar. 13, 1937	4,100
				Mar. 2, 1938	26,100
				Jan. 23, 1943	23,000
				Nov. 22, 1965	8,420
				Dec. 29, 1965	21,200
				Jan. 25, 1969	13,200
				Feb. 25, 1969	20,000
10-2615	Mojave River at lower narrows near Victorville	1899-1906 1930-69	514	Feb. 9, 1932	12,500
				Feb. 14, 1937	8,880
				Mar. 2, 1938	70,600
				Jan. 23, 1943	32,000
				Nov. 23, 1965	17,100
				Dec. 30, 1965	32,800
				Jan. 25, 1969	33,800
				Feb. 25, 1969	34,500
10-2625	Mojave River at Barstow	1930-69	1,290	Feb. 9, 1932	8,300
				Feb. 15, 1937	6,000
				Mar. 3, 1938	64,300
				Jan. 23, 1943	26,000
				Nov. 23, 1965	4,600
				Dec. 30, 1965	8,970
				Jan. 25, 1969	29,000
				Feb. 25, 1969	30,000
10-2630	Mojave River at Afton	1929-32 1952-69	2,120	Feb. 10, 1932	3,550
				Nov. 23, 1965	8
				Dec. 31, 1965	4,150
				Jan. 26, 1969	18,000
				Feb. 26, 1969	16,400

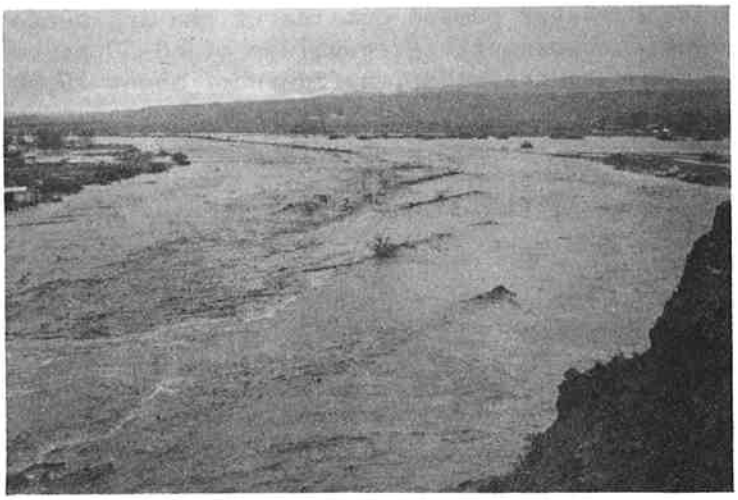


Four miles east of Hesperia at railroad bridge, February 26. Site is about 6 miles downstream from the gaging stations at The Forks. Downstream flow to left.

Looking downstream from old highway (State 18) bridge, upper narrows at Victorville, January 25, at peak flow of 33,800 cubic feet per second.



Wild Crossing, February 12. Flow to right, road beyond bridge washed out, gaging station on bridge.



Looking upstream (west) from hill at gaging station, U.S. Highway 91 bridge at Barstow February 27.

FIGURE 2.--Mojave River during January and February 1969 floods.

A virtue of the floods in the Mojave River basin, in contrast to the damage potential, is their ability to recharge aquifers in the area downstream from Helendale, and particularly in the Barstow urban area. Low flow in the Mojave River has little chance to pass downstream because of the porous material in the river channel, water loss to phreatophytes, and upstream pumping. Flow in the downstream reaches of the Mojave River channel is related to antecedent moisture content of the river-channel sediments. Once the channel has been wetted, a subsequent flood can move farther downstream, and recharge potential is increased, although damage to structures may be greater. This sequence was illustrated in the 1969 winter floods. The effect of the January storm and flood was subdued by the dryness of the river channel, whereas the February floodflows occurred in a wetted channel. Consequently, outflow at Afton Canyon in February was about twice that of January, although the rainfall in the San Bernardino Mountains was about the same for both months.

During the 25-month period March 1967 through March 1969, some of the approximately 300,000 acre-feet of surface water which infiltrated the basin was consumed by phreatophytes or pumped from wells. Studies by the U.S. Bureau of Reclamation (1967) indicated that about 17,000 acre-feet of water was consumed by phreatophytes in 1967. In earlier years water use by phreatophytes was probably higher. The California Department of Water Resources (1967) indicated a larger figure, based on reconnaissance studies. For purposes of this report, 20,000 acre-feet per year is assumed to have been consumed by phreatophytes.

Pumpage in the basin was determined from detailed studies for the period 1951-65 by a consulting engineering company (Dibble, 1967). Pumpage estimates for the basin, excluding the Harper Lake area, were 189,000 acre-feet in 1964 and 183,000 acre-feet in 1965. Annual pumpage for the period 1966-69 is unknown, but was probably comparable to that during the period 1964-65. Most of the water is pumped from wells in or adjacent to the Mojave River channel. Omitting water pumped outside of the influence of the Mojave River channel and assuming consumptive-use values of 40-50 percent for water pumped from wells adjacent to the river, a figure of about 75,000 acre-feet is obtained for net withdrawal of water annually from the ground-water system for the period 1966-69.

A simplified water budget for the 25-month study period indicates the following:

Recharge from river channel and overbank flooding		300,000 acre-feet
Water removed from basin by:		
Phreatophytes, 20,000 x 2	40,000	
Ground-water pumpage, 75,000 x 2	150,000	
		190,000
Net accretion to basin as a result of Mojave River flow		110,000 acre-feet

Analysis of the flow in the Mojave River for the period March 1967 through March 1969 indicates that enough water was recharged to the ground-water system to supply normal water needs for 3 years under present (1969) water use. The recharge to the aquifer near the river from the floods of January and February 1969 alone was equivalent to about a 2-year supply. Obviously, some areas were helped more than others. The area between Hinkley and Barstow was one of those helped most by the floods. Prior to excess flow in the river, this area had the largest water-level declines in the basin with little replenishment because of its location in the lower part of the basin away from the San Bernardino Mountains. Ground-water pumpage in this area has been large for many years owing to extensive agricultural development. In recent years pumpage was reduced because of the inability to obtain adequate volumes of water from the aquifer in some places. The water-level declines had resulted in a reduction of more than 50 percent in the saturated thickness of the aquifer east of Hinkley.

Recharge in the area in 1969 was substantial as documented by water-level changes. On February 25, 1969, the river overflowed its bank about 3 miles north of Hodge and created a new channel a quarter of a mile to a mile north of the previous channel, and some flow passed north of the gaging station at U.S. Highway 91 bridge at Barstow. The overflow channel washed out the Atchison, Topeka and Santa Fe Railway tracks causing a train derailment with resultant large economic loss (oral commun., D. Inman, 1969). Hydrologically, this overflow had a beneficial effect because the new channel increased the area for recharge to the aquifer. In the future, consideration could be given to artificial diversion of controlled floodflows to sparsely settled areas as an aid to recharge to the basin.

Ground-Water-Level Change Method

Net change in storage for the period March 1967 through March 1969 was also computed by plotting the water-level change in more than 150 wells and contouring the rises as shown in figure 1. Most of the wells are adjacent to the river. The volume of ground-water storage change was determined by planimetering the areas between contours and multiplying by appropriate values for increase in saturated thickness. This figure, in acre-feet, was multiplied by the estimated specific yield of the aquifer. The specific yields of the aquifer used in the computations ranged from 20 to 25 percent in the river channel and from 12 to 15 percent in areas adjacent to the river. The greatest rises in water levels were in the river channel northeast of Hesperia, between Hodge and Barstow, and along the east side of Waterman fault near Daggett. A major rise in water levels also occurred on the upstream side of the Calico-Newberry fault because of its barrier effect to ground-water flow.

The changes in ground-water levels, particularly those caused by the 1969 flood, are shown by the hydrographs for two wells for the period 1966-69 (fig. 3). The water level in the well in sec. 12, T. 3 N., R. 4 W., in the Upper Mojave basin, about half a mile west of the river and 5 miles southeast of Hesperia, reflects annual recharge in the vicinity of The Forks near the headwaters of the desert basin. The water level is low about December of each year and rises to a high in the spring as a result of recharge from winter runoff. The water level declines during the summer because ground-water pumping is at a maximum and streamflow is at a minimum. As a result of the January and February 1969 floods, the water level in the well rose until about August 1, 1969, to a level that was the highest recorded since 1966.

The Lower Mojave basin receives little recharge from the Mojave River except in times of flood or high flows of long duration. A hydrograph (fig. 3) of a well in sec. 13, T. 9 N., R. 1 E., 12 miles east of Barstow (50 miles downstream from The Forks) and about half a mile south of the river, shows the beneficial effects of the winter 1969 flood to the ground-water system in this area. The water level rose because of flood recharge until June 2, 1969, to a level equivalent to that 3 years earlier, and then again started a downward trend.

The increase in the quantity of ground water in storage, computed by the ground-water-level change method, represents a net accretion to the ground-water system of about 105,000 acre-feet for the 25-month study period, mostly as a result of the floods in January and February 1969. This recharge is in excess of net pumpage, use by phreatophytes, and other evapotranspiration for the study period. In the Upper Mojave basin between The Forks and Victorville, the increase in storage was about 30,000 acre-feet; between Victorville and Hodge, about 10,000 acre-feet; between Hodge and Waterman fault, about 50,000 acre-feet; and between Waterman fault and Calico-Newberry fault, about 15,000 acre-feet. Recharge in the area between the Calico-Newberry fault and Afton Canyon was probably minimal as water levels are always near the land surface because of ground-water discharge in the area near Camp Cady. In the reach from Camp Cady east to Afton Canyon, the permeable alluvial channel is narrow with little room for additional ground-water storage. The area along this stretch of the river has not had much development, and there are few wells and very few water-level data.

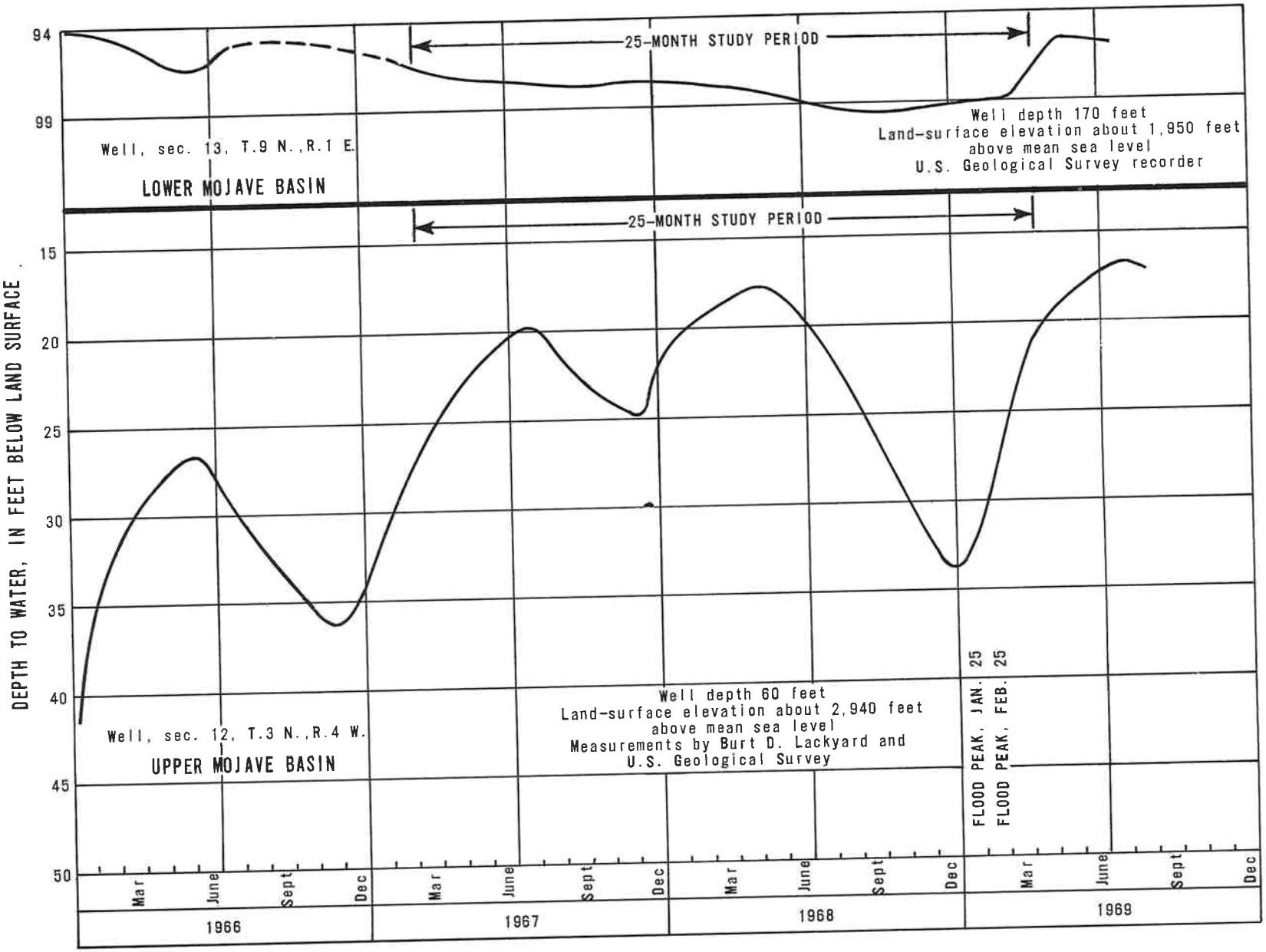


FIGURE 3.--Hydrographs for two wells in the Mojave River basin, 1966-69.

COMPARISON OF METHODS

The results of computations of net recharge to the Mojave River ground-water basin from March 1967 through March 1969 by evaluation of net change in storage determined from water-level changes and water losses between the gaging stations at The Forks and at Afton Canyon were comparable; the values were within 5 percent after accounting for water consumed by phreatophytes and ground-water pumping. These calculations of recharge are only estimates because water movement is a dynamic process and the quantity of water in transit, either in the unsaturated or saturated zone of the aquifer, can be substantial. For example, some surface water enters the unsaturated zone above the water table, moves slowly downward, and, particularly where water levels are deep beneath the land surface, is unaccounted for in a water-level measuring program until months afterward. In much of the area, water levels were still rising at the end of the study period, so the estimate of total recharge to the basin by the floods is low. However, the water-level measuring program could not have been delayed any longer because of the beginning of large-scale pumping for agriculture. This pumping of unknown quantities of ground water causes cones of depression in the water table and would have complicated analysis of recharge by use of the water-level method.

Floods are generally recognized as a destructive process, but in water-deficient areas, such as the Mojave Desert, floods are also of great economic value. Man presently has little control over the weather, and, until weather modification becomes a reality, man's environment is bent by Mother Nature. Occasional floods are the principal source of recharge to the large ground-water reservoir in the Mojave basin; but floodflow cannot be relied on and gives only temporary relief to the long-term lowering of water levels in the alluvial aquifer.

ECONOMIC BENEFITS OF RIVER RECHARGE

The beneficial economic effects of the floods in terms of water stored in the ground for future use were substantial. The cost of water from the California Aqueduct at the turnout for the Mojave basin area is nearly $60 per acre-foot (oral commun., Mojave Water Agency, 1969). Thus, in the 2-year period (March 1967 through March 1969) water with a value of about $18 million was added to the ground-water system. The value of the recharge from floodwater for only the 3-month period, January through March 1969, was about $12 million, assuming complete recovery. Conveyance costs are added to the price of the water if it must be transported by manmade structures. This is significant in the lower half of the Mojave River basin where the cost of imported aqueduct water may be about $90 per acre-foot (oral commun., Mojave Water Agency, 1969). As an example, recharge between Hodge and Barstow for the water-deficient Hinkley area would be enhanced by a manmade conveyance, because the river in this reach is dry most of the time. The water loss between Wild Crossing and Barstow gaging stations from January through March 1969 was about 68,000 acre-feet. Thus, the cost including conveyance, of this naturally supplied water would have been about $6 million, if it had to be transported by methods other than in the natural channel of the Mojave River.

SELECTED REFERENCES

California Department of Water Resources, 1967, Mojave River ground water basins investigation: California Dept. Water Resources, Bull. no. 84, 151 p.

Dibble, E. F., 1967, Mojave Water Agency, Water production verification program: E. F. Dibble, Redlands, Calif., 39 p.

Hedman, E. R., and Pearson, E. G., 1966, Floods of November and December 1965 in southern California: U.S. Geol. Survey open-file rept., 90 p.

U.S. Bureau of Reclamation, 1967, Summary of phreatophyte ground water use study along the Mojave River: U.S. Bur. Reclamation, San Bernardino, 12 p.

Waananen, A. O., 1969, Floods of January and February 1969 in central and southern California: U.S. Geol. Survey open-file rept., 233 p.

GPO 978-430