GEOHYDROLOGY AND POTENTIAL FOR ARTIFICIAL RECHARGE IN THE WESTERN PART OF THE U.S MARINE CORPS BASE, TWENTYNINE PALMS, CALIFORNIA, 1982-83

By J. P. Akers

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

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

Multiply	By	To obtain
acres	0.004047	km^2 (square kilometers)
acre-ft (acre-feet)	.001233	hm^3 (cubic hectometers)
ft (feet)	.3048	m (meters)
miles	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)
gal/min (gallons per minute)	.003785	m^3/min (cubic meters per minute)
(gal/min)/ft (gallons per minute per foot)	.01242	m^2/min (meters squared per minute)

Degrees Celsius are used in this report. To convert degrees Celsius (°C) to degrees Fahrenheit (°F), use the formula:

Temp °F = 1.8 temp °C + 32

Explanation of abbreviation:

mg/L = milligrams per liter

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ABSTRACT

A recent gravity survey indicates that sedimentary deposits in the Deadman Lake area of the Twentynine Palms Marine Corps Base, California, are as much as 10,500 feet thick. These deposits fill an ancient valley in the bedrock complex. This valley is alined east-west in the Surprise Spring area and north-south in the Deadman Lake area.

Water levels in the Ames Dry Lake area of the Surprise Spring subbasin have changed little between earliest measurements in 1952-53 and in 1982. Water levels in three Marine Corps Base supply wells in the same subbasin near Surprise Spring declined an average of 78 feet during the past 30 years. Water levels in the same timespan in Deadman subbasin and water quality in the base supply wells, drilled in 1952-53 and 1978, have remained virtually unchanged.

Ground water in storage, suitable for domestic use, in the top 200 feet of saturated sediments in Surprise Spring subbasin was estimated to be 810,000 acre-feet in the early 1950's. About 60,000 acre-feet of this has been removed, mostly for use at the Marine Corps Base, which leaves about 750,000 acre-feet of recoverable water of good quality still stored in the 200-foot interval considered. For planning purposes, it would be safe to use a conservative figure of 300,000 acre-feet for storage in the Deadman subbasin, which contains water having fluoride concentrations greater than the U.S. Environmental Protection Agency's standards for drinking water.

Three sites in the general area of the present well fields seem favorable for recharging the ground-water system in the Surprise Spring subbasin. Further exploration of these sites is suggested.

INTRODUCTION

The main facilities of the Twentynine Palms U.S. Marine Corps Base are about 130 miles east of Los Angeles and 5 miles north of the town of Twentynine Palms, Calif. (fig. 1). The Marine Corps Base covers about 1,000 mi^2, but the study area of this report includes about 210 mi^2 in the southwest corner of the base, and an indefinite area of about 165 mi^2 nearby, but outside the base boundary. The area adjacent to the base is rural and undeveloped; the base is undeveloped except for the main base facility, and is used principally for military exercises and training.

The geology of the area as simplified from Dibblee (1967a, b, c, and 1968) is shown in figure 1. The study area is a large sediment-filled valley surrounded by hills composed of igneous and metamorphic rock. The sedimentary deposits contain ground water that constitutes the main source of water supply for the base. Several large northwest-trending faults and numerous small ones cross the area.

The Emerson, Surprise Spring, and Mesquite faults act as ground-water barriers. Schaefer (1978) reported a 300-foot displacement in the water table at Surprise Spring along the Surprise Spring fault. These ground-water barriers have been used as boundaries for the ground-water basins and for three subbasins first described by F. S. Riley and G. F. Worts, Jr. (U.S. Geological Survey, written commun., 1953) and shown on plate 1. The Surprise Spring subbasin is bounded on the west by the Emerson fault and on the east by the Surprise Spring fault (fig. 1). The other subbasin boundaries are the virtually impermeable basement complex and the "transverse arch" described by Riley and Worts and shown in figure 1.

Purpose and Scope

This study is one of a series made by the U.S. Geological Survey in cooperation with the U.S. Marine Corps to define the geohydrology and to determine ground-water conditions at the Twentynine Palms Marine Corps Base.

The potable water supply for the Marine Corps Base is presently (1984) dependent on ground water pumped from the Surprise Spring subbasin. Water levels in base supply wells in this subbasin have declined a maximum of almost 100 feet between 1950 and 1982. Because of the water-level decline and a possible expansion of the base facilities, the Marine Corps, in cooperation with the Geological Survey, began the current study to determine the present ground-water conditions in the southwestern part of the base, and to determine the feasibility of recharging the basin using imported water.

This report summarizes the first phase of a two-phased study to be completed in 1986. The objectives of this first phase were to: (1) determine the thickness of the sedimentary deposits that contain virtually all the water within the study area, (2) determine the present (1982) ground-water levels, (3) refine previous estimates (Schaefer, 1978) of ground water in storage in the Surprise Spring and Deadman subbasins, (4) determine the water quality in accessible wells, (5) identify sites in the Surprise Spring subbasin that might be used for artificial recharge, and (6) suggest a program for testing the potential for artificial recharge at the sites selected.

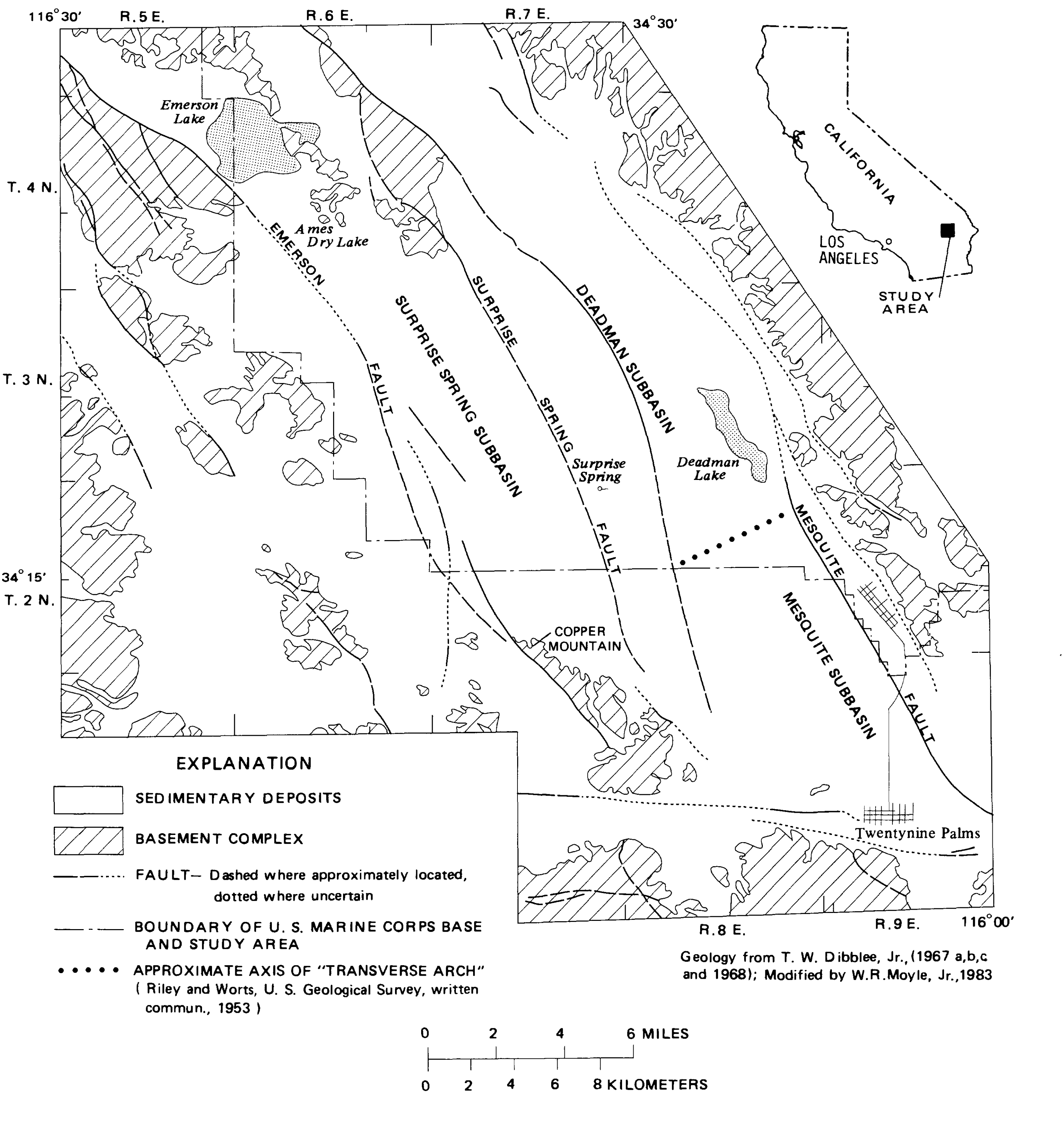


FIGURE 1.– Location of study area, subbasins, and generalized geology.

For phase 1, water levels were measured and water samples were collected for chemical analysis for all the accessible wells within the boundaries of the Marine Corps Base. A gravity survey made by Moyle (1984), also as part of the first phase, determined the thickness of sedimentary deposits in the area of the future ground-water model. This survey included sufficient gravity measurements to make profiles across areas where suspected ground-water recharge enters the study area from adjacent areas, and across the area of ground-water outflow. Thirteen two-dimensional profiles (Talwani, 1968) were made. Three sites that seem promising for infiltration of imported water were selected for detailed study.

The second phase will be to design a digital ground-water model of the study area. Part of the information obtained in the first phase of the study will be used for the model design.

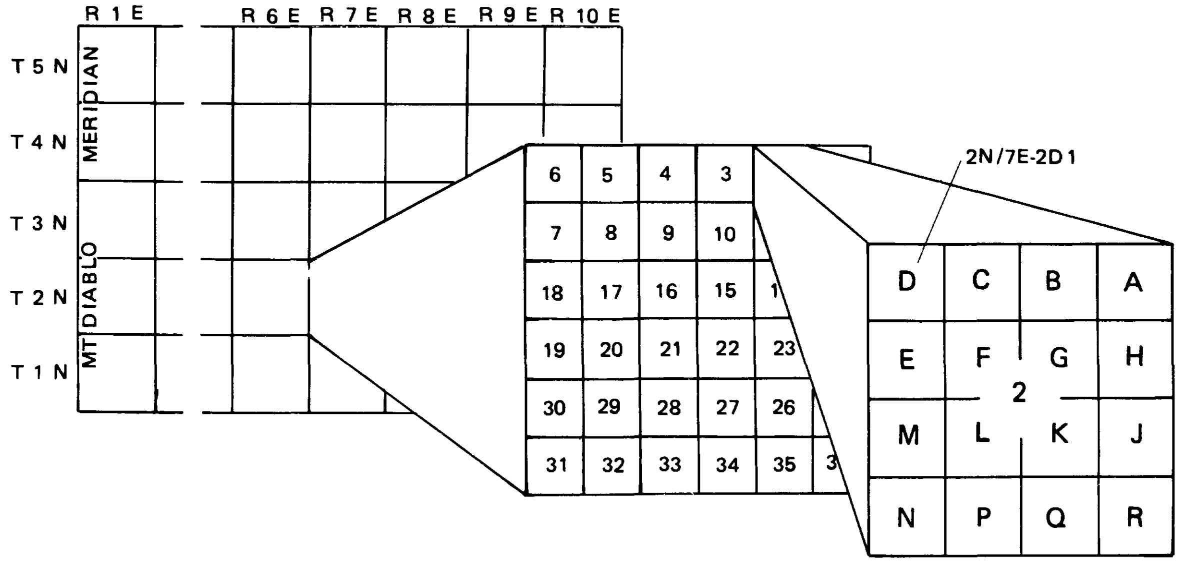
Previous Work and Acknowledgments

Previous studies by the Geological Survey, State agencies, and private consultants are listed in the reference section with those cited in this report. These reports contain various types of geological and hydrological data such as water-level measurements, quality of water, pumping tests on wells, annual pumpage by well, geologic maps, estimated annual recharge, aquifer characteristics, and methods for reducing gravity data. Each of these reports contributed to an overall understanding of the geologic and hydrologic framework of the subbasins and aided in the analysis of the gravity data.

The contributions made by the many investigators cited or listed in the references is acknowledged. Both military and civilian personnel of the Public Works and Natural Resources Divisions, Twentynine Palms Marine Corps Base, contributed materially to the study. The contribution of Ralph Brown, Natural Resources Manager of the base, in coordinating access to the ranges on the base and in maintaining liaison between the U.S. Marine Corps and Geological Survey, is especially appreciated.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for subdivision of public land. For example, in the well number 2N/7E-2D1, that part of the number preceding the slash indicates the township, north or south (T. 2 N.); the number and letter following the slash indicates the range, east or west (R. 7 E.); the number following the hyphen indicates the section (sec. 2); the letter following the section number indicates the 40-acre subdivision of the section according to the lettered diagram below. The final digit is a serial number for wells in each 40-acre subdivision. Thus, well 2N/7E-2D1 is the first well to be listed in the NW¼NW¼ sec. 2, T. 2 N., R. 7 E. All wells in the study area are north and east of the San Bernardino baseline and meridian.



In addition, the U.S. Marine Corps has its own system for numbering supply wells and test wells. A cross index of Marine Corps well numbers and those used by the Geological Survey is shown in Schaefer (1978, table 1).

GEOHYDROLOGY

Gravity data from 495 sites were analyzed to obtain estimates of the thickness of the unconsolidated deposits that form the main aquifer.[1] Sedimentary deposits that overlie the basement complex range in thickness from less than 1 foot at the edge of the subbasins to a calculated maximum of 10,500 feet in the northeastern part of the study area. The configuration and altitude of the surface on the bedrock complex underlying the sedimentary deposits, as determined by subtracting the thickness of the alluvium from the land-surface altitude, is shown on plate 1.

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[1]Results of the gravity survey are summarized in a separate report by Moyle (1984). Gravity readings were made at most section corners (for altitude control) throughout the study area. The gravity data were analyzed and interpreted to obtain estimates of the thickness of the unconsolidated sedimentary deposits that form the main aquifer on the base. Where possible, thickness estimates based on the gravity interpretation were correlated with the thickness as determined from well logs.

The contours drawn, based on interpretation of the gravity data, on the basement complex surface indicate that in the western part of the study area sediments filled an east-trending "ancient valley." The axis of the filled valley in the Surprise Spring subbasin passes northwestward of Surprise Spring. Two tributary arms of the ancient valley, one between Giant Rock and Hidalgo Mountain, and another between Goat Mountain and Copper Mountain, are well-defined by the contours shown on plate 1. Another tributary arm extends northwest from Gypsum Ridge. The main valley is constricted by buried structural noses that extend southeast from Hidalgo Mountain and north-northwest from Copper Mountain. To the east, in the Deadman Lake area, this valley joins a deeper valley alined in a northwestward direction. A ridge that corresponds to the location of the "transverse arch" shown by Schaefer (1978, fig. 1) extends from the buried nose of Copper Mountain and separates the Deadman subbasin from the Mesquite subbasin.

These buried valleys have limited influence on the movement of ground water. Most of the ground water flows along paths that are subparallel to the buried valleys (pl. 2); but in places, such as over the buried nose of Copper Mountain, the flow paths seem to be unrelated to the course of the buried valley. The "transverse arch" has little influence on the movement of ground water.

GROUND WATER

Water Levels

Water levels were measured in wells on the Marine Corps Base (mostly in the Surprise Spring subbasin) during May and June 1982 (table 1 and pl. 2). The measurements indicate that since 1952-53, when measurements were made by F. S. Riley and G. F. Worts, Jr. (U.S. Geological Survey, written commun., 1953), water levels in wells in the Ames Dry Lake area (fig. 1 and pl. 2) have changed little. On the average, they rose slightly because pumping for irrigation in that area stopped in the early 1950's. However, in the same period water levels in three wells in the base well field near Surprise Spring (wells 2N/7E-2C1, 3A1, and 3B1) have declined an average of 78 feet. The maximum decline (in wells 2N/7E-2C1, 3B1) was slightly more than 97 feet.

Comparable water-level data for the Surprise Spring well field in the 7-year period from 1976 to 1982 when Schaefer (1978) made his study are not available because all the wells were pumping when he visited them. However, the water level in well 2N/7E-4H1 (pl. 2) about a mile west of the well field declined about 19 feet in the period 1952 to 1982. Water levels in the newer wells (3N/7E-28R1, 29G1, 29R1, and 32J1) declined an average of about 6 feet from 1978 to 1982. The maximum decline was 12 feet in well 3N/7E-28R1.

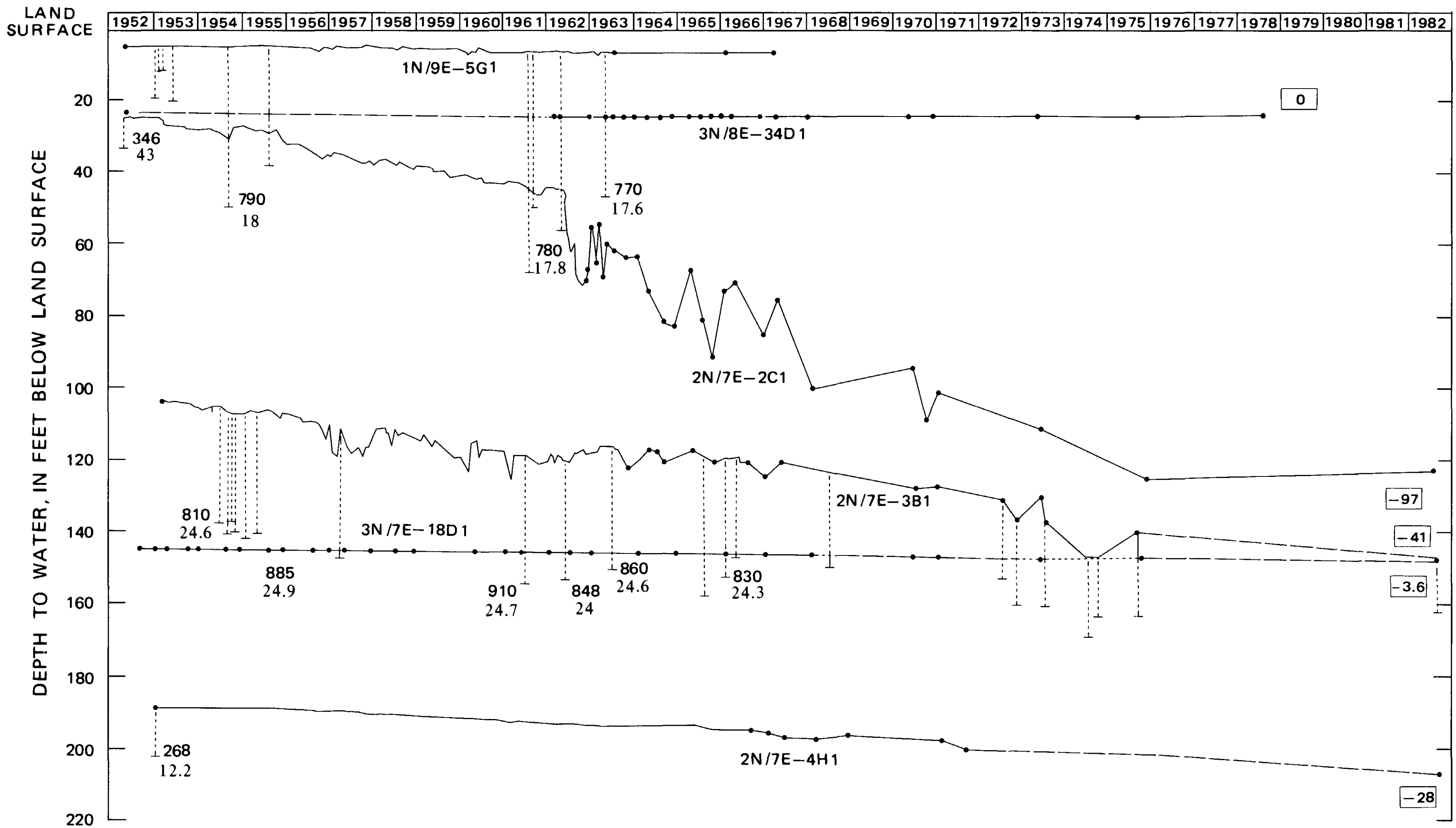
The water level in well 3N/8E-29L1 in the Deadman subbasin has remained virtually unchanged (perhaps it has declined about 1 foot) in the 30 years between 1952 and 1982, as it has in well 3N/7E-36G1 during the period 1978-82. Water levels in the Deadman subbasin are stable because the wells in that area are seldom pumped. Hydrographs of selected wells are shown in figure 2.

TABLE 1.--Water levels and well conditions in Twentynine Palms Marine Corps Base, May and June 1982

[LSD, Land-surface datum. Locations of wells shown on plate 2]

Well number	Depth (feet)	1982 water level below LSD (feet)	Intermediate measurement		Earliest measurement		Water-level change (feet)	Years of record	Remarks
			Date	Water level below LSD (feet)	Date	Water level below LSD (feet)			
2N/7E-2C1		122.83			03-24-52	25.58	-97	30	
2D1	532	137.69			12-03-68	102.53	-35	14	
3A1	560	151.41			05-02-53	54.63	-97	29	
3B1		163.06			01-10-53	104.22	-41	29	
3E1	570	215.6			12-11-68	153.31	-62	14	
4H1	485	207.25			10-02-52	188.72	-19	30	
14K1	[1]333	Dry	03-19-80	356.72	10-02-52	334.1	-22	28	Water level declined 22 feet between 1952 and 1980.
18N1	241.5	Dry							
2N/8E-11B1		([2])	04-26-52	35.52					Well destroyed in 1960.
13A1		([2])	08-27-75	91.12	05-08-52	95.22	+4	23	A 4-foot rise in water level between 1952 and 1975.
3N/6E-3N1		([2])							
4L1		([2])							
4L2	[1]51.5	Dry	11-11-60	77.01	05-08-52	80.05	+3	8	A 3-foot rise in water level between 1952 and 1960.
4P1	12.2	Dry							
4P2		([2])	02-19-76	75.75					Single measurement.
4P3		([2])							
6N1	126.5	Dry							
3N/7E-13N1	[1]185.5	Dry	10-17-55	189.39	10-28-52	189.5	0	3	
18D1	151	149.4	06-07-82	149.40	07-08-52	145.75	-4	30	
20C1	[1,3]148.5	Dry			02-19-76	189.72			
28R1	[4]605	291.49			06-25-78	279	-12	4	
29G1	348.5	251.5			12-08-75	248	-3	7	
29R1	[4]604	275.71			08-03-78	270.6	-5	4	
31E1	[1]249.5	Dry	07-08-52	249.96	10-22-75	250.2	0	23	
32J1	[4]600	309.35			09-16-78	305.4	-4	4	
34D1					03-02-76	257			
35P1	7.4	Dry	05-04-61	15.18	12-14-51	[5]+3.98	-19	10	
35P2	[4]609	136.65			06-07-61	43.13	-93	21	
36G1	387	280.43			01-16-68	280	0	12	
36K1	[1]268.3	Dry	04-10-73	286	01-10-68	285.5	0	5	
3N/8E-17L1	489.5	48.1			07-09-52	46.87	-1	30	
29C1			04-26-79	88.61	09-10-52	87.51	-1	27	
29L1	[3]600	103.11	04-30-53	102.03			-1	29	
33B1		([2])	04-10-73	43.85	05-28-52	42.94	-1	21	
34D1			04-10-73	24.33	04-26-52	23.96	0	21	
4N/5E-13R1		Dry	05-22-58	39.99	11-01-53	40.1	0	5	
4N/6E-18L1	52.2	39.66			03-02-76	46.8	+7	6	
22M1	20	Dry							
27C1	[1]2	Dry	06-23-54	59.29	01-29-53	59.28	0	1½	
27C2	2.9	Dry							
27D1	78	69.65			05-08-52	68.47	-1	30	
27F1	72.5	61.66			05-08-52	70.55	+9	30	
27M1		84.92			01-29-53	83.88	-1	29	
28R1	101.5	100.25			05-08-53	100.13	0	29	
32B1	[1]4.5	Dry			03-02-76	77			
34E1	107.5	99.33			01-23-75	98.42	-1	7	
5N/6E-31N1		([2])							

[1]Casing probably obstructed.
[2]Well destroyed.
[3]Drilled in 1975 to 606 feet.
[4]Reported.
[5]Flowing.



LAND SURFACE
DEPTH TO WATER, IN FEET BELOW LAND SURFACE
20
40
60
80
100
120
140
160
180
200
220
1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982
1N/9E-5G1
3N/8E-34D1
2N/7E-2C1
2N/7E-3B1
3N/7E-18D1
2N/7E-4H1
346
43
790
18
780
17.8
770
17.6
810
24.6
885
24.9
910
24.7
848
24
860
24.6
830
24.3
268
12.2
0
-97
-41
-3.6
-28

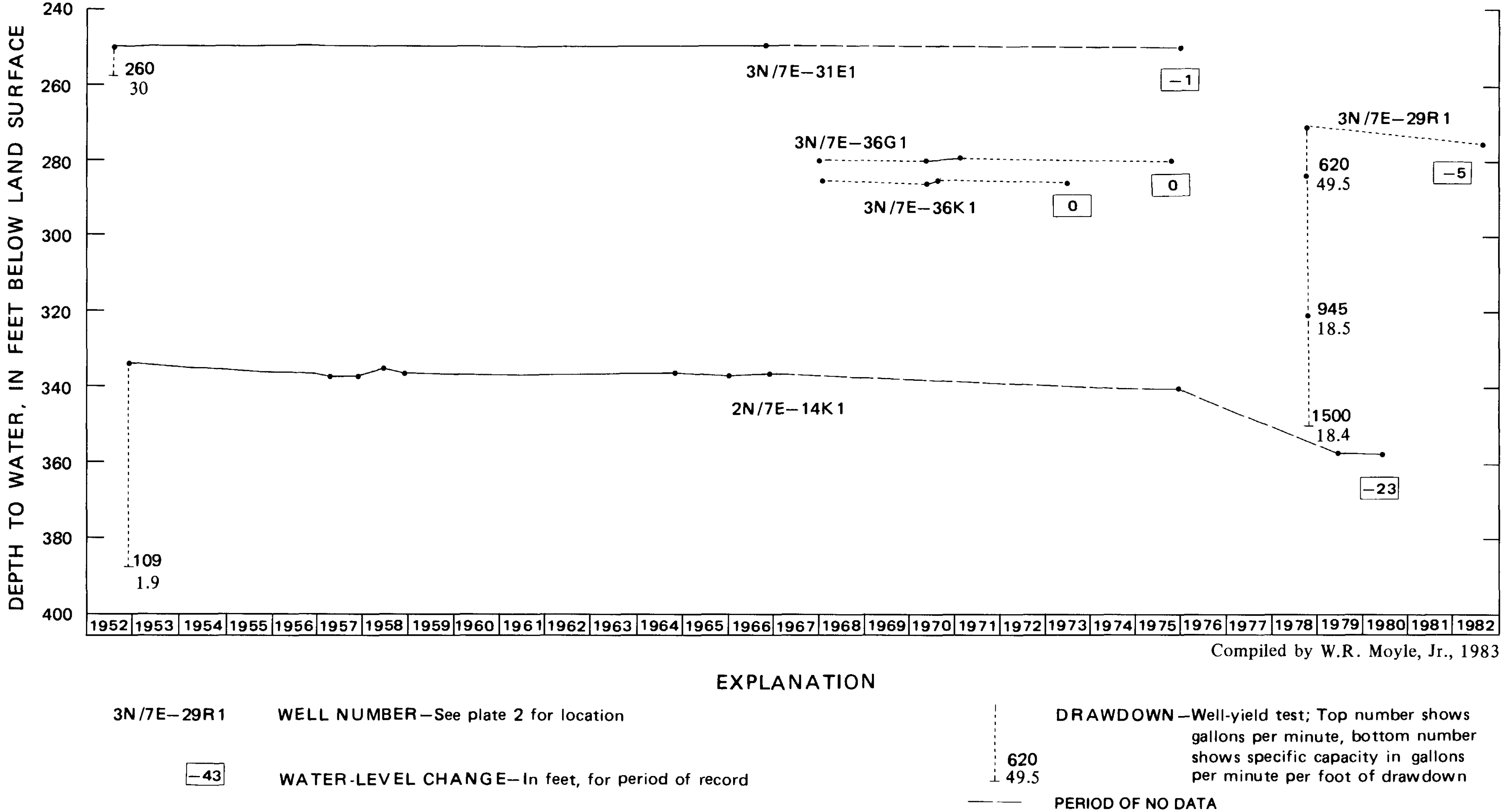


FIGURE 2.— Hydrographs and data on yield of selected wells, 1952–82.

There are few water-level data adjacent to the Deadman subbasin immediately east of the Surprise Spring fault. However, the altitude of the water level in well 3N/7E-36G1 (pl. 2) about 1 mile east of the fault, was 1,830 feet above sea level in August 1982, and in well 3N/7E-35P2, about 0.3 mile west of the fault, it was 2,134 feet above sea level--a difference of about 300 feet. The steep eastward gradient between these two wells reflects the low permeability of the Surprise Spring fault zone. Even with the 100-foot water-level decline in the base well field, the general gradient is still toward the east, from the Surprise Spring subbasin to the Deadman subbasin. The eastward gradient keeps the water in the Deadman subbasin from moving into the base well field. The general direction of ground-water movement in summer 1982 is shown on plate 2.

Quality of Water

Water samples collected for chemical analyses between 1953 and 1978, when most of the base supply wells were drilled, and in 1982 (table 2) indicate that there has been no significant water-quality change in the supply wells since they were drilled. Water from all the supply wells in the Surprise Spring subbasin is of excellent quality. The concentration of boron has increased somewhat, but is still within acceptable limits for drinking water and for watering plants. The dissolved-solids concentration varies slightly from well to well and among sampling periods. These slight changes may reflect differences in analytical precision, or they may be real and reflect movement of water of slightly different composition toward the wells because of lowered water levels from pumping.

The chemical composition of water in an unused well (4N/6E-27F1, table 2) changed considerably between 1953 and 1982. The sodium concentration increased from 790 to 1,500 mg/L; chloride increased from 88 to 120 mg/L; and dissolved solids increased from 1,860 to 3,420 mg/L. The reason for this change is unknown, but may be related to the presence or absence of water in Ames Dry Lake, which is adjacent to this well--relatively fresh surface water may have entered the well to reduce the dissolved-solids concentration prior to the first sampling. The fluoride concentration of water in Deadman subbasin exceeds the U.S. Environmental Agency's (1977) standards for drinking water.

Estimated Ground-Water Storage

Refining the estimate of ground-water storage made by F. S. Riley and G. F. Worts, Jr. (U.S. Geological Survey, written commun., 1953) and by Schaefer (1978) required a gravity survey in areas both within and on the outside periphery of the base to determine the saturated thickness of the main aquifer. Gravity surveys measure differences in the attraction of gravity at the Earth's surface caused by differences in density of materials forming the Earth. In general, a gravity low corresponds to a section of thick sedimentary deposits and a gravity high corresponds to a thin section of sedimentary deposits. The saturated thickness was determined by subtracting the altitude of the bedrock surface underlying the sedimentary deposits (pl. 1) from the altitude of the water table (pl. 2). The saturated volume was computed for each 640-acre section and totaled. The total volume of saturated sediments, multiplied by the specific yield of the alluvium, gives the estimated storage. The specific yield is the ratio of (1) the volume of water that will drain by gravity from the aquifer to (2) the total saturated volume of the aquifer, expressed as a percentage.

The saturated thickness of the sedimentary deposits in the Surprise Spring subbasin indicated by the gravity survey and the water levels, ranges from about 400 to 700 feet near the southern boundary of the base to about 1,800 feet near the Emerson fault in sec. 1, T. 2 N., R. 6 E., and in sec. 10, T. 3 N., R. 6 E. In general, the saturated thickness in the base well-field area, ranges from about 1,000 feet near Surprise Spring to about 1,700 feet near well 3N/7E-29R1.

Not all the water in the saturated zone in the Surprise Spring subbasin is suitable for use as a water supply for the base, and not all that is suitable can be recovered. Water from several of the wells in the Ames Dry Lake and Emerson Lake areas contains dissolved-solids concentrations or individual constituents in excess of drinking water standards.

Therefore, in estimating the storage of water of good quality in Surprise Spring subbasin, the area of poor-quality water near Ames Dry Lake and Emerson Lake is excluded. Also, it is assumed that it is technically (if not economically) feasible to extract the ground water stored only in the upper 200 feet of the saturated thickness. The sedimentary deposits in the sub-basin, except perhaps some of the area near Hidalgo Mountain and in parts of sections 14 and 15, T. 2 N., R. 7 E., along the southern boundary of the base have a saturated thickness of at least 200 feet. The area used for computing storage, as outlined on plate 1, contains about 29,000 acres. Recent calculations by W. R. Moyle, Jr. (U.S. Geological Survey, written commun., 1983), indicate that the specific yield of the aquifer in the Surprise Spring subbasin is about 14 percent. Using these assumptions, an estimated 810,000 acre-ft of potentially extractible ground water of quality suitable for the base supply was stored in the 200-foot interval below the water table in Surprise Spring subbasin before pumping began.

TABLE 2.--Selected chemical

[Constituents in milligrams per liter except iron and boron
specific conductance, in micromhos per

State well No.	Date of collection	Specific conduct- ance	pH	Water temper- ature	Hard- ness as $CaCO_3$	Hard- ness noncar- bonate	Calcium (Ca)	Magne- sium (Mg)	Sodium (Na)	Per- cent sodium
2N/7E-2D1	2-18-76	275	8.4	31.0	20	0	7.9	0	48	80
	8-31-82	248	9.0	32.5	10	0	4.0	.03	50	90
2N/7E-3A1	2-24-53	--	8.8	29.2	26	--	9	1.0	[1]44	78
	3-01-66	271	7.7	26.7	29	0	11	.4	45	76
	2-18-76	265	8.3	28.0	29	0	11	.4	45	75
2N/7E-3B1	1-15-53	311	8.4	28.0	38	--	9	1.0	[1]44	72
	3-03-66	293	8.0	26.5	29	0	11	.4	48	77
	2-18-76	290	8.4	28.0	28	0	11	.2	48	75
	8-31-82	298	8.8	27.5	26	0	10	.22	49	79
2N/7E-3E1	2-18-76	300	9.1	29.0	9	0	3.4	.2	58	91
	8-31-82	310	8.7	28.5	18	0	7.1	.1	17	85
2N/7E-4H1	9-30-52	--	8.5	26.5	35	--	12	1.0	[1]43	73
	2-18-76	225	8.8	23.5	15	0	5.5	.4	40	81
	1-09-82	211	8.9	25.5	10	0	3.9	.03	40	87
3N/7E-29R1	8-31-82	353	8.7	26.5	50	0	19	.56	45	65
3N/7E-35P2	3-03-66	249	8.4	29.0	10	0	4.0	0	49	90
	8-31-82	263	9.1	29.5	--	--	5.4	.01	52	--
3N/7E-36G1	1-16-68	517	7.9	23.5	16	0	5.8	.2	106	93
	1-09-82	416	10.7	28.5	--	--	10	.01	64	--
4N/6E-18L1	8-31-82	24,600	9.6	23.0	150	0	14	27.0	6,900	99
4N/6E-27F1	1-29-53	3,170	9.7	--	10	--	[4]4	--	790	99
	8-30-82	5,250	8.9	22.5	--	0	1.1	.8	1,500	99
4N/6E-34E1	2-19-76	1,380	7.6	20.0	410	370	130	21	93	36
	8-31-82	1,260	8.0	22.5	380	340	120	19	87	33

[1]Includes potassium
[2]Computed from laboratory alkalinity
[3]Residue on evaporation
[4]Includes magnesium

analyses of water from wells

in micrograms per liter; water temperature, in degrees Celsius; centimeter at 25°C; percent sodium, and pH]

Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids residue	Dissolved nitrite plus nitrate as N (NO_2+NO_3)	Boron (B)	Iron (Fe)
4.9	83	9.0	24	16	0.7	18	175	1.3	70	120
1.7	[2]90	--	23	10	.7	21	[3]161	1.3	160	<3
--	68	5	29	18	.9	24	185	--	60	100
2.0	81	0	29	18	.9	19	174	--	0	10
2.8	81	0	33	21	.8	17	176	1.2	60	80
--	68	5	29	18	.9	21	--	--	60	100
2.2	76	0	31	23	.6	18	185	--	0	10
4.5	74	2	34	26	.6	16	184	1.2	40	0
2.2	[2]81	--	34	21	.6	17	[3]179	1.2	170	4
2.7	79	6	34	21	.4	16	185	.88	50	10
1.8	[2]89	--	34	22	.4	17	185	1.0	50	<3
--	76	1	39	15	.7	25	164	--	100	0
4.4	58	7	24	17	.9	12	141	.02	60	130
2.1	[2]67	--	21	13	.7	14	128	.10	170	150
2.3	[2]98	--	31	21	.7	21	[3]197	1.8	210	3
1.4	79	4	19	14	.9	19	163	--	0	10
1.6	[2]79	--	28	14	.8	19	--	1.2	180	3
1.8	140	110	64	33	9.6	21	311	1.1	50	50
2.3	[2]80	--	24	42	6.9	--	--	.10	630	44
23	[2]4,416	--	2,400	6,300	37	11	17,900	.1	19,000	150
4.9	568	421	173	88	100	--	1,860	--	--	--
16	[2]3,355	--	19	120	84	3.2	3,420	.18	22,000	1,200
3.8	53	0	100	350	.4	6	731	.08	50	10
--	[2]45	--	61	330	.5	9	654	<.10	170	960

Schaefer (1978) estimated that cumulative pumpage to December 1975 was about 42,000 acre-ft. Records of metered pumpage kept by the Public Works Department, Twentynine Palms Marine Corps Base, indicate that about 17,000 acre-ft was pumped for use at the base between January 1, 1976, and December 31, 1982 (table 3). Counting a small quantity pumped outside the Marine Corps Base, cumulative pumpage from the Surprise Spring subbasin through 1982 was about 60,000 acre-ft. Subtracting the cumulative pumpage from the original storage, and assuming no recharge, there still is about 750,000 acre-ft of potentially recoverable water stored in the subbasin. This agrees fairly well with Schaefer's (1978) estimate of 600,000 acre-feet.

TABLE 3.--Annual pumpage, in acre-feet, from supply wells in Surprise Spring subbasin, 1976-82

Year	Pumpage	Remarks
1976	2,615	Pumpage for January estimated at 100 acre-feet
1977	2,057	--
1978	2,222	--
1979	2,868	--
1980	2,781	--
1981	2,500	Pumpage for May estimated at 93 acre-feet
1982	2,221	Pumpage for October estimated at 200 acre-feet

Walter Hofmann, (U.S. Geological Survey, written commun., 1952), estimated the average annual runoff of Pipes Wash at "The Windmill" (sec. 2, T. 1 N., R. 5 E.) upstream from Landers (pl. 1) at about 2,000 acre-ft, plus or minus 50 percent. The underflow of Pipes Wash at the same location was estimated by Lewis (1972) at about 500 acre-ft/yr. Neither Hofmann nor Lewis estimated what part, if any, of the runoff and underflow reaches Surprise Spring subbasin to become recharge. However, preliminary studies by W. R. Moyle, Jr. (U.S. Geological Survey, oral commun., 1983) of the recharge area suggest that Lewis' estimate is probably closer to the actual value. Studies in the modeling phase, to follow this present study, probably will give a better indication of the magnitude of recharge. However, natural recharge to the Surprise Spring subbasin is small compared to the ground-water storage in the subbasin which, at present (1984), is the only dependable water supply for the base.

A greater volume of water is stored in the saturated sediments below the 200-foot interval that was used in estimating storage discussed above. In places in the central part of the Surprise Spring subbasin, the saturated thickness of the sediments is more than 1,000 feet. According to Schaefer (1978, p. 11), the quality of water at depths of 230 and 600 feet in well 3N/7E-20C1 (19A1 of Schaefer, 1978) is virtually the same. This would indicate that the water is of good quality to a depth of at least 600 feet. If we consider the next 400 feet below the 200-foot interval already estimated, and assume water of good quality and a lower specific yield of 10 percent, an additional 980,000 acre-ft of good quality water is stored in Surprise Spring subbasin. This figure accounts for areas within the 400-foot zone considered where the saturated thickness is less than 400 feet because of irregularities on the buried surface of the basement complex.

This latter figure is presented only to give some indication of the quantity of water stored in the subbasin. The water stored in the zone from 200 to 600 feet below the water table probably is not extractible under present economic conditions. Large extractions from that zone could reverse the hydraulic gradient in that area, and water of poorer quality might be induced to move in from the Deadman subbasin or from the Emerson and Ames Dry Lakes area.

The quantity of water of poor quality stored in the sediments of the Emerson-Ames Dry Lakes area is estimated to be 160,000 acre-ft. This represents the total saturated thickness and assumes a specific yield of 10 percent. Some of the shallower water (less than 100-feet depth) in the Ames Dry Lake area was used for irrigation in the early 1950's. However, the water at depths between 100 to 150 feet contains high sodium, fluoride, boron, and dissolved solids as indicated by water from well 4N/6E-27F1 (table 2). The water in the Emerson-Ames Dry Lakes area, although not of drinking water quality, might have some use other than for public supply and irrigation.

Ground-water level and other data are insufficient for determining the saturated volume of the sedimentary deposits (and hence, the storage) in Deadman subbasin. However, results of the gravity survey indicate that Deadman subbasin is underlain by a thick section (several hundred to several thousand feet) of sediment. The saturated thickness is probably much more than the 100 feet used by F. S. Riley and G. F. Worts, Jr. (U.S. Geological Survey, written commun., 1953) for estimating a usable storage of 290,000 acre-ft. For planning purposes, a rounded figure of 300,000 acre-ft of recoverable storage in Deadman subbasin may be used. However, this water does not meet the U.S. Environmental Protection Agency's (1977) standards for drinking water because of high fluoride concentrations. Also, gypsum (calcium sulfate) is known to be present in the sediments that form the Mud Hills and Gypsum Ridge (pl. 1). Because gypsum is soluable in water, heavy pumping in the Deadman subbasin south of these areas could induce southward movement of water containing high sulfate concentrations.

POTENTIAL SITES FOR ARTIFICIAL RECHARGE

Based on the geometry of the sediment-filled valley (pl. 1), thickness of the sediment, direction of ground-water movement, high specific capacity of the production wells, type of sediments described in the well logs, permeable surficial materials, location of pumping depressions, and accessibility to the probable location of imported water--the hachured areas shown on plate 2 seem the most suitable for percolation of imported water. However, local conditions at any individual site within these areas could preclude final selection of the site for percolation operations.

Most of the surficial material in the Surprise Spring subbasin is permeable, windblown sand several feet thick. Lithologies of wells and exposures of the sedimentary deposits indicate that the sediments consist largely of lenticular beds of gravel, sand, silt, and clay. Most well logs indicate that sand and gravel dominate. However, the sediments also contain fairly extensive beds of caliche at various depths throughout the subbasin. A prominent bed of caliche-cemented gravel and sand near the surface surrounds the site of the now-dry Surprise Spring. This bed is traceable for several hundred yards along the channel of Surprise Spring Wash, and historically may have acted to confine water in a shallow artesian zone that supplied water to a well that once flowed at Surprise Spring (F. S. Riley and G. F. Worts, U.S. Geological Survey, written commun., 1952).

The surficial windblown sand and the gravel and sand beds in the alluvium probably will readily accept recharge water. Any deposits of caliche, silt, or clay, if present below an infiltration pond, would impede or prevent the infiltration of water. However, water percolated directly into a thick gravel or sand bed to a depth beyond the zone affected by evapotranspiration, probably in time, would move around or through the more impermeable beds to the water table.

Lithologic logs of test wells (2N/7E-2C1, 2N/7E-14K1, and 2N/7E-4H1, plate 2) show that these wells intersected micaceous clay beds at depths of 325, 388, and 155 feet, respectively, that imparted a milky appearance to the water. The clay bed in test well 2N/7E-14K1 apparently acted as a confining layer above which water rose in the well 84 feet. However, these beds are all at depths of more than 750 feet and would not substantially affect artificial recharge into the unsaturated water-table zone.

The newer Marine Corps base supply wells 3N/7E-28R1, 29R1, 31E1, and 32J1, drilled in 1952, are all fairly productive wells that have specific capacities that range from 18 to 30 (gal/min)/ft of drawdown. The yield of these wells indicates that they tap fairly permeable materials. Wells 3N/7E-31E1 and 32J1, have the highest specific capacity of this group, and are alined along the main ground-water flow path in the water-level troughs indicated by the contours on plate 2. Any water percolated between these wells, or in the potential recharge areas indicated in plate 2, would move toward the base supply wells in both the old and new well fields.

Specific capacities of wells south of Surprise Spring Wash are comparatively low (generally less than 2 (gal/min)/ft drawdown). This indicates low permeabilities and probably precludes using the area south of Surprise Spring Wash for efficient artificial recharge.

Three areas seem favorable for further exploration as potential recharge sites (pl. 2). These are area 1 in sec. 31 and 32 between wells 3N/7E-31E1 and 32J1, area 2 in Surprise Spring Wash north of well 2N/7E-4H1, and area 3 in the wash just southwest of well 3N/7E-20C1.

Well 3N/7E-31E1 near area 1 penetrated a 39-foot-thick sand bed between depths of 5 and 44 feet, but it also penetrated several silty and sandy clay beds between depths of 44 and 210 feet. Water percolating into the shallow sand beds should ultimately reach the water table, even though the clay beds would slow the percolation rate. Water for testing a recharge pit in this area probably could be pumped from base supply well 3N/7E-32J1, or from well 3N/7E-31E1 if it were cleaned out. Well 3N/7E-31E1 was dry in May 1982 at a depth of 249.5 feet, at which point the well was obstructed. The depth when the well was drilled in 1952 was 430 feet and the water level was 249.8 feet. The well yielded 262 gal/min with 8.6 feet of drawdown.

Area 2 is along the Surprise Spring Wash a few yards north of well 2N/7E-4H1. This location is in the area affected by the cone of drawdown caused by pumping the base supply wells. Recharge water reaching the water table in this area would immediately retard the rate of drawdown near the old well field.

The lithologic log of well 2N/7E-4H1 does not show any clayey materials that would retard recharge. However, a caliche bed is exposed in the wash, and as described above, seems to be fairly widespread in the Surprise Spring area. The distribution and thickness of the caliche can be determined by drilling or augering before a test percolation pond is built. It would be necessary to bottom such a pond below the caliche, should the caliche be present at the proposed site. If there is no caliche below Surprise Spring Wash, it may be possible to utilize the natural channel for infiltrating the imported water. The water could be released in the channel and spread by check dams. Water for use for a percolation test in this area probably could be pumped from well 2N/7E-3E1, which is about 0.50 mile to the east, or from the base supply wells about a mile to the east.

The well log of test hole 3N/7E-20C1 (19A1 of Schaefer, 1978) near area 3 indicates very coarse sand and "some rock" to a depth of 109 feet; very coarse sand and "some silt and rock" between 109 and 260 feet; and sand, silt, clay, and "rock" between 260 feet and the bottom of the hole at 606 feet. This suggests that water percolated at area 3 would move downward readily. It may be feasible to release water directly into the drainage in this area to effect recharge. There is no nearby source of water for testing at this site.

Test drilling will be necessary to determine local conditions at each of the potential recharge areas described above. Three or four holes will be necessary at each site to determine the local vertical and horizontal distribution of any clay beds that might hinder percolation. If the local strata do not contain clay or caliche, pits could be constructed for percolation tests. The test holes can be cased with plastic tubing and left for observation wells (should recharge be attempted) and to determine if the water is reaching the water table.

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