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APPRAISAL OF THE WATER RESOURCES OF

DEATH VALLEY, CALIFORNIA-NEVADA

By G. A. Miller

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CONVERSION FACTORS

English units are used in this report. For the benefit of readers who
prefer metric units, the conversion factors for the terms used herein
are listed below:

Multiply English unit	By	To obtain metric unit
acres	4.047×10^{-1}	hectares
acres/mi (acres per mile)	2.515×10^{-1}	hectares per kilometer
acre-ft (acre-feet)	1.233×10^{-3}	cubic hectometers
acre-ft/mi^2 (acre-feet per square mile)	4.763×10^{-3}	cubic hectometers per square kilometer
ft (feet)	3.048×10^{-1}	meters
ft^3/s (cubic feet per second)	2.832×10^{-2}	cubic meters per second
ft/mi (feet per mile)	1.894×10^{-1}	meters per kilometer
gal (gallons)	3.785	liters
gal/d (gallons per day)	3.785	liters per day
gal/min (gallons per minute)	6.309×10^{-2}	liters per second
gal/hr (gallons per hour)	1.052×10^{-3}	liters per second
(gal/min)/mi^2 (gallons per minute per square mile)	2.44×10^{-2}	liters per second per square kilometer
in (inches)	2.540×10	millimeters
mi (miles)	1.609	kilometers
mi^2 (square miles)	2.590	square kilometers

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ABSTRACT

Water supplies in Death Valley National Monument and vicinity are limited to ground-water sources, almost without exception. Most streams in the desert area flow only ephemerally, typically during flash floods. Ground water supports perennial flow over a few short reaches of some streams. There are several hundred fresh-water springs and seeps in the monument, but only a small percentage of these, including most of the large springs, are in areas of present or projected intensive use by man. Most springs are in mountainous areas; most visitor use of the monument is on the floor of Death Valley.

Ground water underlies the entire area, but its availability and suitability for use are greatly restricted by the chemical quality and to a lesser extent by the permeability of water-bearing materials.

The hydrologic system in Death Valley is probably in a steady-state condition--that is, recharge and discharge are equal, and net changes in the quantity of ground water in storage are not occurring. Recharge to ground water in the valley is derived from interbasin underflow and from local precipitation. The two sources may be of the same magnitude.

Ground water beneath the valley moves toward the lowest area, a 200-square-mile saltpan, much of which is underlain by rock salt and other saline minerals, probably to depths of hundreds of feet or even more than 1,000 feet. Some water discharges from the saltpan by evapotranspiration. Water beneath the valley floor, excluding the saltpan, typically contains between 3,000 and 5,000 milligrams per liter of dissolved solids. Water from most springs and seeps in the mountains contains a few hundred to several hundred milligrams per liter of dissolved solids. Water from large springs that probably discharge from interbasin flow systems typically contains between 500 and 1,000 milligrams per liter dissolved solids.

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Present sites of intensive use by man are supplied by springs, with the exception of the Stovepipe Wells Hotel area. Potential sources of supply for this area include (1) Emigrant Spring area, (2) Cottonwood Spring, and (3) northern Mesquite Flat.

Promising areas on the valley floor to explore for additional ground-water supplies are (1) the Eagle Borax Spring-Bennetts Well area, (2) near Midway Well and Triangle Spring, and (3) northern Mesquite Flat. Data indicate that ground water in these areas contains 500 to 1,500 milligrams per liter of dissolved solids and locally is under sufficient artesian pressure to flow from wells. Because of the paucity of subsurface hydrologic data, test drilling is necessary to appraise the ground-water resources of these areas.

Many springs at intermediate altitudes in the Panamint Range have been trampled and polluted by wild burros; the trampling tends to disperse the discharge at small springs and seeps, thus lessening available open water for wildlife.

INTRODUCTION

Purpose and Scope

During the early 1960's the National Park Service requested the U.S. Geological Survey to study, in a reconnaissance manner, the water resources of Death Valley National Monument (fig. 1). Visitor use of the monument had increased rapidly, and the Park Service needed information on water resources in order to properly develop and manage this desert area.

The scope of the work included the compilation of hydrologic maps, field canvass of selected wells and springs, study of the geohydrology at selected springs, collection of water samples for chemical analysis, operation of continuous water-level recorders on wells and springs, and augering of shallow test holes. Specific site studies requested by the Park Service also were made. The work was funded by the Western Service Center, National Park Service, San Francisco, Calif.

Most of the fieldwork concerned hydrologic features within Death Valley National Monument. Less attention was paid to details in the valley south and north of the monument boundaries.

In this report a general discussion of the geohydrology of the valley is followed by a more detailed description of the several hydrologic areas into which the valley was subdivided.
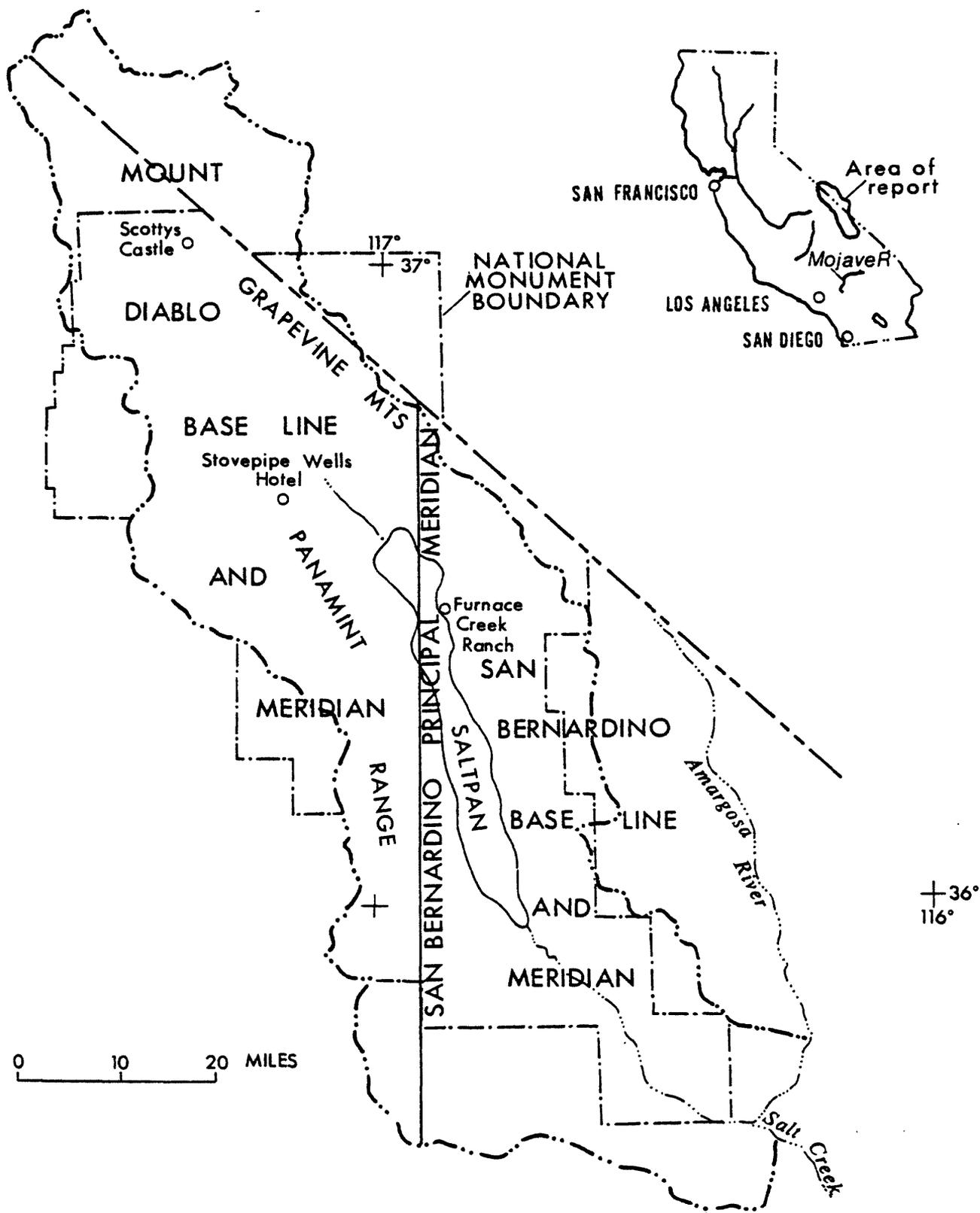
Figure 1.--Location of Death Valley National Monument. Also shown is
the line of origin for the major division of public lands.

Conclusions

The most important findings of the study are summarized below:

1. Ground water underlies the entire area, but its availability and suitability for use are greatly restricted by its chemical quality and to a lesser extent by the permeability of the water-bearing materials. Surface-water supplies are either nonexistent or unreliable, except in a few areas where perennial flow over short reaches is sustained by ground-water discharge.

2. The geographic distribution of fresh-water springs and ground water of good quality does not everywhere correspond to areas of present or projected intensive use.

3. Much of the total discharge from fresh-water springs is concentrated in three areas of high visitor use near Furnace Creek Ranch, near Scottys Castle, and at Park Village, about 3 mi northeast of the monument headquarters (fig. 2). The discharge in the first two areas exceeds present and projected needs in these areas.

4. Water quality is the most important factor limiting the development and use of water resources in the monument.

5. The ground water becomes a sodium chloride type as it moves toward and enters the saltpan.

6. The poor quality of water in the valley is almost entirely the result of natural chemical processes, whereby the water increases in dissolved solids both by prolonged contact and interaction with weathering rock materials and soluble minerals and by concentration of salts through evapotranspiration.

7. The ground-water system, as a whole, is probably in a steady-state condition, with respect to recharge, storage, and discharge.

8. Evidence suggests that in a few small remote areas recharge has diminished in recent decades; some springs have gone dry, and there are dead and dying phreatophytes. This probably is due to a general decline in rainfall since 1945.

9. Interbasin underflow from the northeast supplies much of the total flow from springs in the valley and much of the ground-water recharge. Minor quantities of ground water may enter the valley from basins to the west and northwest.

10. Many of the springs and seeps used by wildlife and man could be more reliable sources of water if they were developed properly and were protected from flash floods, from trampling and polluting by wild burros, and from evapotranspiration by phreatophytes.
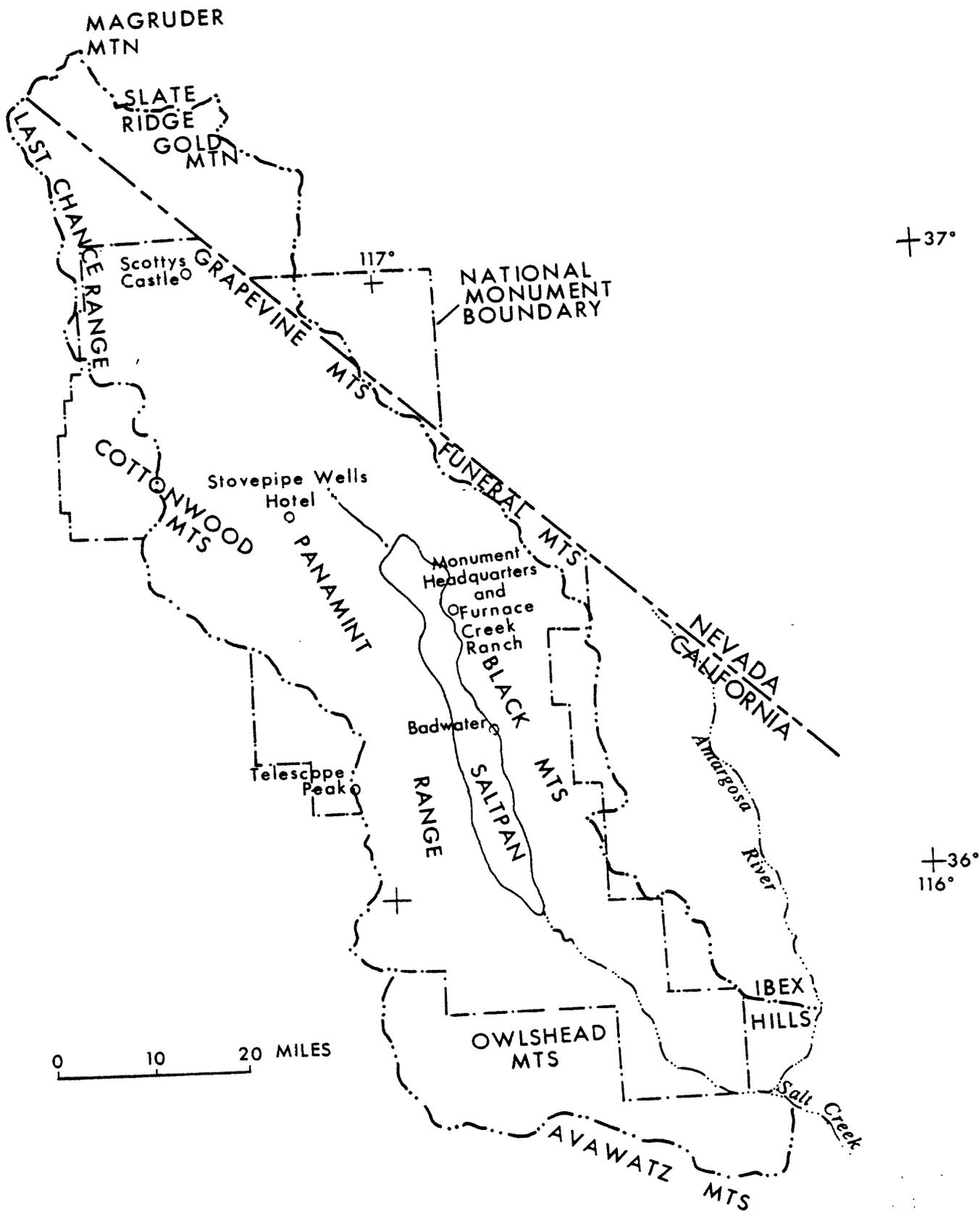
Figure 2.--Major geographic features.

11. The three most promising locations on the valley floor for developing additional ground-water supplies of usable quality are in (1) the Eagle Borax-Bennetts Well area (24N/1E), (2) the vicinity of Midway Well (14S/45E-18D1), and (3) the north edge of Mesquite Flat (14S/44E). Test drilling will be necessary in each area to adequately evaluate the ground-water supply.

12. Manmade and natural hydrologic stresses in and near the monument are causing and will continue to cause changes in water levels in wells, changes in discharge from springs, and changes in water quality. An adequate hydrologic monitoring program will be required to properly evaluate such changes.

Acknowledgments

Geography and Climate

Death Valley is a northwest-trending valley about 140 mi long at the southwest edge of the Great Basin in southeastern California. Part of the northeastern drainage boundary and part of the Death Valley National Monument extend into Nevada. The area studied encompasses about 4,400 mi^2. The valley is bounded on the east by the Black, Funeral, and Grapevine Mountains, and by Slate Ridge (fig. 2). The altitude of the crest of these mountains is generally 3,000 to 5,000 ft, with some peaks between 6,000 and 8,000 ft. On the south and west are the Avawatz and Owlshead Mountains, the Panamint Range, the Cottonwood Mountains, and the Last Chance Range. The altitude of the crest of these mountains is generally 4,000 to 9,000 ft. The highest peak in the area is Telescope Peak (11,049 ft) in the Panamint Range. This peak is about 15 mi west of Badwater, near where the valley floor is the lowest area (-282 ft) in the United States.

A 70-mi segment of the valley floor, from the middle of Mesquite Flat to just south of Confidence Hills, is below sea level. About 45 mi of this segment, from the south end of Salt Creek Hills to near Shore Line Butte, is below -200 ft and contains the monotonously flat saltpan.

During the summer much of the floor of Death Valley is hotter and drier than any other part of the United States. Records of the National Weather Service indicate the average annual precipitation at Furnace Creek Ranch is 1.8 in, and the daily high temperature during July and August commonly is above 120°F (49°C). An official air temperature of 134°F (56°C) was recorded at Furnace Creek Ranch, July 10, 1913 (Hunt and others, 1966, p. B5). At Badwater, 16 mi south of the ranch and 100 ft lower in altitude, maximum summer air temperatures are a few degrees higher than at Furnace Creek Ranch. Winter temperatures on the valley floor are mild. Table 1 shows average monthly temperature and precipitation at Furnace Creek Ranch.

In higher parts of both the Panamint Range and the Grapevine Mountains the climate is subalpine. Annual precipitation in Wildrose Canyon at altitudes between 4,000 ft and 9,000 ft averages 6-8 in. Much of the precipitation on high peaks is snow, and much of it evaporates rather than percolates into soil and rock. Summer temperatures in Wildrose Canyon at altitudes above 4,000 ft seldom exceed 90°F (32°C), and winter low temperatures of near 0°F (-18°C) occur.

The entire area is in the rain shadow of the Sierra Nevada, and the climate on the valley floor is strongly influenced by adiabatic processes as air masses move down the mountain slopes from the west.

TABLE 1.--*Average monthly temperature and precipitation at Furnace Creek Ranch*

[Data from publications of the National Weather Service]

	Temperature (°F)	Precipitation (inches)
January--	52.0	0.21
February---	58.2	.24
March--	67.3	.17
April--	77.0	.16
May--	85.1	.07
June---	93.9	.01
July---	101.6	.12
August---	99.1	.14
September--	90.0	.11
October--	77.0	.10
November---	61.5	.18
December---	53.1	.27
Average annual----------------------------------	76.3	1.78

The climate in some areas of the valley seems to be drier than in past decades, as evidenced by several recently dried springs and by dead or dying phreatophytes in some spring areas. For example, Park Service files indicate that several springs in Sheep Canyon, in the Black Mountains about 12 mi southeast of Badwater, were judged in 1939 as a "...watering place...used by Bighorn (sheep) from time immemorial." During the late 1950's, Drewes (1963, p. 4) noted those springs as "Small seeps [that] lie about 30 ft above the valley floor..." In April 1967 Chief Ranger Homer Leach and the author hiked down Sheep Canyon to canvass these springs. All were dry, and several dead cottonwood trees and dying mesquite clumps were noted.

Present and Potential Water Supply

The water supply in the valley is all from ground water, some of which originates locally from precipitation and some of which moves into the valley as underflow from basins on the north and east. With a few minor man-related exceptions, the hydrologic system seems to be about at equilibrium and the average supply available is about the same as it has been for many decades and perhaps centuries. Locally, intensive use of water by man has altered the flow system, but effects on the environment from such use are mainfest only in a few areas. For example, piping water from Texas Spring (27N/1E-23BS1) and from Travertine Springs (27N/1E-23,25,26S) for use on the alluvial fan downstream has resulted in local but intensive changes in the native vegetation in Furnace Creek Wash and at the downstream places of use. Similar changes have occurred at and below Nevares Spring and on a lesser scale at Scottys Castle, Emigrant Spring-Stovepipe Wells Hotel, and Wildrose Canyon.

Any planned extensive changes in the present pattern of use should take into account long-term effects that may arise as a result of altering the natural hydrologic regime.

Water for Man

The existing centers of water use primarily are Furnace Creek, the Stovepipe Wells Hotel area, Wildrose Canyon, Scottys Castle, and Park Village. There is a quantity of water (1,660 gal/min) available from Texas, Travertine, and Nevares (28N/1E-36GS1) Springs that seems to be stable.

At Stovepipe Wells Hotel, potable water was for many years trucked from a storage tank at Emigrant Ranger Station 9 mi southwest and 2,150 ft higher in altitude. The storage tank there is supplied by a buried pipeline from Emigrant Spring (17S/44E-27BS1), which is in Emigrant Canyon about 5 mi south of the ranger station at an altitude of about 3,800 ft. Flow from the spring probably averages 3 gal/min during the winter months, when demand is highest, and 2 gal/min during the summer. During 1973 the Park Service constructed an underground storage tank in the alluvial fan south of Stovepipe Wells Hotel and began trucking water to it from Nevares Spring for use in the area. At least five sources of potable water are available for use at the Stovepipe Wells Hotel area.

1. The local brackish (3,000 milligrams per liter dissolved solids) but abundant ground water that is presently being desalinized by a small installation.

2. Several springs within 2½ mi of Emigrant Spring that could be tapped to furnish, during the winter, as much as 15 gal/min of water containing 500 to 700 mg/L (milligrams per liter) dissolved solids. This water could be conveyed to the area of use by gravity pipeline.

3. Cottonwood Springs (16S/42E-25KS1), 14½ mi southwest of the hotel and at an altitude of about 3,600 ft. On April 28, 1968, this spring was flowing 73 gal/min and the water contained 330 mg/L dissolved solids. This spring probably could supply, by gravity pipeline, 25 to 75 gal/min during the winter.

4. Ground water less than 100 ft deep near the north end of Mesquite Flat and 12 mi northwest of the hotel, at a land-surface altitude of about 150 ft. This water contains 600 to 700 mg/L dissolved solids. The water-bearing properties, extent, and general water quality of the aquifer system are not well known, but it seems reasonable to expect that 50 gal/min of potable water could be obtained from this source.

5. Shallow ground water about 1 mi southeast of Triangle Spring (14S/44E-14ES1) and 8 mi northeast of Stovepipe Wells Hotel, where ample water for road construction was obtained during 1969 from a shallow sump dug into the alluvial-fan deposits at about sea level. More than 1 million gallons reportedly was pumped during a 1½-month period. The conductivity of the pumped water ranged from 1,750 to 1,950 μmho (micromhos), suggesting that the water contained 1,100 to 1,200 mg/L dissolved solids.

In Wildrose Canyon the supply from a spring half a mile upstream from the ranger station historically has been a reliable 5 to 9 gal/min of water containing 600 to 900 mg/L dissolved solids. This supply, with a proper storage facility, is adequate to supply several hundred campers, as well as the small National Park Service residence area.

At Scottys Castle the supply of about 200 gal/min from Stainingers Spring (11S/43E-5ES1) is adequate for foreseeable uses and could be increased by more intensive development at the spring to capture more of the underflow in the alluvium-filled wash. The water contains 400 to 600 mg/L dissolved solids. Additional supplies, perhaps another 200 gal/min, could be piped from Grapevine Springs (11S/42E-2,3,10S) without appreciably altering the hydrologic and ecologic system there. Water from this source contains 650 to 800 mg/L dissolved solids.

In addition to the areas of present and projected significant use discussed above, potable ground water occurs at shallow depths under artesian head in the Eagle Borax-Bennetts Well area (24N/1E), and probably in a similar manner beneath a 10-15 mi strip along the west side road between Bennetts Well and Tule Spring. Water from several wells and test holes in this strip contains 360 to 670 mg/L dissolved solids. Recharge to the area is such that 50-100 gal/min probably could be developed without significant ecologic or hydrologic effects on the discharge area.

Water for Wildlife

Widespread springs and seeps in the more habitable parts of Death Valley have provided a generally adequate supply of water for wildlife. During dry periods, as ephemeral springs and seeps go dry, much animal life moves to areas of more permanent water.

Proper development could maintain flow from many of the springs and seeps that now go dry during prolonged droughts, in particular those where lush growths of phreatophytes indicate perennially saturated ground at shallow depths. Because the typical water needs of wildlife at a spring are small, requiring a reliable supply of 5 to 6 gal/hr at most, development techniques should consider the following: (1) Outflow to whatever drinking facility is used should be restricted to the minimum quantity needed, so as not to deplete ground-water storage; (2) flow should be conveyed to a suitable storage and drinking facility; (3) the entire system should be so constructed that it will be protected from damage by freezing, vandalism, floods, and from trampling and contamination by wild burros.

The burro population in the monument aggravates the problem of maintaining perennial flow in open channels and storage in pools at small springs and seeps. Widespread trampling and the resultant puddling of the discharge area diffuses the small quantity of discharge over a large area, thereby increasing evaporation and seepage in areas away from the orifice and reducing the availability of open water for drinking. Such effects were noted at several springs and seeps during this study. Burros also have contaminated the water supply at many outlets with fecal matter and urine. This has happened at most springs in the Hunter Mountain, Wildrose, Emigrant, and Anvil Spring Canyon areas.

Springs, Seeps, and Wells

Current Situation

Welles and Welles (1959) compiled data for 320 springs and seeps, 40 wells, and 20 miscellaneous water-related items in the monument. During the present study, 150 wells were canvassed in the monument, including 50 test holes that were augered or drilled, and data were obtained from various sources on another 40 wells. Concurrently, 230 springs were canvassed in the monument, and data were obtained on 50 others. In addition, 40 springs, seeps, and wells were canvassed outside the monument but within Death Valley. All the above are given in round numbers.

Most of the springs and seeps are in the mountains, and most discharge less than 1 gal/min. The open water and associated vegetation at the widely distributed springs are important to the wildlife ecology of the monument. Man's long-term use of springs for water supply has been concentrated near Furnace Creek Ranch and at Stovepipe Wells Hotel (which uses water from Emigrant Spring), Wildrose Canyon, and Scottys Castle. In addition, miners, hikers, and campers utilize springs throughout the monument.

Seventy percent of the springs are at altitudes above 3,000 ft and more than half are above 4,000 ft. This largely reflects the relation of precipitation and ground-water recharge to altitude and the lessened evapotranspiration at higher altitudes.

Of the approximately 40 wells in the valley listed by Welles and Welles (1959), most are now either dry or destroyed. Many of the wells were dug during the early mining and exploration days of the late 1800's and early 1900's.

Data on wells and springs collected during this study are in the files of the U.S. Geological Survey. The ones described in the text are located in figure 3.

Numbering System for Wells and Springs

Wells and springs in California and Nevada are assigned numbers according to their location in the rectangular system for subdivision of public land. In most unsurveyed areas, protraction diagrams furnished by the U.S. Bureau of Land Management were available to assist in assigning numbers.

The study area lies partly in the northeast quadrant of the San Bernardino base line and meridian and partly in the southeast quadrant of the Mount Diablo base line and meridian (fig. 1).

Examples:

<div align="center">California well 15S/42E-32C2</div>

15S is township; 42E is range; 32 is section; C is 40-acre subdivision of section. The 2 indicates that this is the second well recorded in the 40-acre tract. If this were a spring instead of a well, an S would be inserted before the final digit. Where half-townships exist, such as T. 22½ N.in the Black Mountains, the sections are included in the next township north by adding 36 to the original number.

<div align="center">Nevada well 7S/40E-27ca1</div>

Same system as for California, except that the quarter-sections are labeled abcd and the 40-acre tracts abcd on each quarter-section.

California Well   Nevada Well
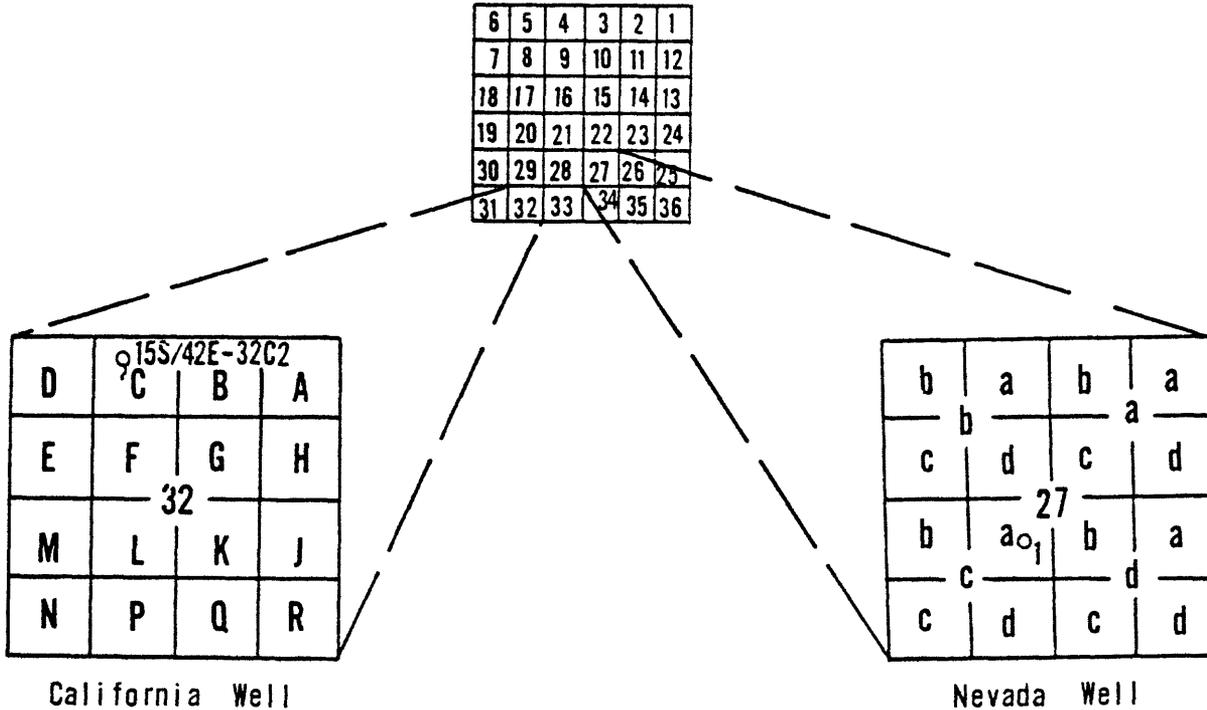
Where a Z has been substituted for the letter designating the 40-acre tract, the Z indicates that the well is plotted from unverified location descriptions; the indicated sites of such wells were visited, but no evidence of a well could be found.

Other well and spring numbers have been assigned by Mendenhall (1909), Welles and Welles (1959), and Mr. R. W. Hunter (for springs in the Hunter Mountain area). These have subsequently been renumbered according to the above described system.

The Geological Survey's nationwide system of numbering wells and springs, based on the latitude and longitude of the site, is used in the Survey data files on each well and spring.

Surface-water sampling and flow-measurement sites are numbered by the system used in California, except that the final serial digit is omitted.

Previous Investigations

A large number of reports relating to the geology and water resources of Death Valley have been published. Several of them are cited herein and others are included in the list of selected references. The most useful reports for the readers and workers interested in the sources and availability of ground water are by Hunt and others (1966) and by Pistrang and Kunkel (1964). The first report describes the desert environment in considerable detail but concentrates also on definition of the rock types and evaluation of spring discharge and quality. A large part of the report is a treatment of the geochemistry of the saltpan.

The report by Pistrang and Kunkel deals with a 6- by 8-mi area encompassing Furnace Creek Wash where several important springs are located.

GEOHYDROLOGY OF THE MONUMENT

Death Valley is an elongate closed desert basin where the only outlet for surface runoff and ground-water flow is by evaporation. Most of the valley floor is underlain by unconsolidated to semiconsolidated sediments of Cenozoic age, which may be as much as several thousand feet thick. The surrounding mountains are made up largely of rocks ranging in age from Precambrian to Tertiary.

Surface water enters the valley floor from canyons in the surrounding mountains, from Salt Creek (north), and from the south via the Amargosa River and Salt Creek (south). There are two Salt Creeks in Death Valley; one at the south end flows northwestward and joins the Amargosa River, and one near Stovepipe Wells drains southeastward into the saltpan. In this report they are denoted Salt Creek (south) and Salt Creek (north). Ground-water discharge from the saltpan has several sources: Recharge that originates in the valley from seepage during flash floods; seepage and underflow from the Amargosa River, Salt Creek (south), and the Mojave River system; interbasin underflow from the Sarcobatus Flat-Amargosa Desert areas; and possibly minor quantities of underflow from basins on the north and west.

Geology

The valley is bounded by block-faulted mountain masses that are made up principally of folded and faulted rocks of Precambrian Y and Z ages and Paleozoic age[1]. The valley fill, of Cenozoic age, is made up in large part of detritus from these rocks.

For a more comprehensive discussion of the geologic features of the area, the reader is referred to work by Hunt and Mabey (1966), Drewes (1963), McAllister (1952, 1970), and Reynolds (1966). Published maps by Jennings (1958), Jennings and others (1962), and Strand (1967) present the areal geology of the Death Valley region (fig. 4).

Stratigraphy and Water-Bearing Character of the Rocks

The oldest rocks exposed in the valley are a crystalline basement complex, which consists of gneiss and schist of sedimentary and igneous origins, and other metamorphosed igneous rocks, all of Precambrian (probably Precambrian Y) age. These rocks are widely exposed in the central and southern Black Mountains and crop out locally in the Avawatz Mountains, Owlshead Mountains, and the Panamint Range. The basement rocks contain small quantities of water in near-surface weathered zones and in altered and crushed zones associated with faults and fractures. These features are not widespread and the quantity of ground water contained in these rocks, per unit volume of rock, is probably less than in any other rock type in the valley.

Overlying the basement complex is a thick sequence (10,000 ft) of metamorphosed sedimentary rocks of Precambrian Z age. The rocks, chiefly shale and carbonate, have been extensively folded and faulted. They crop out over wide areas in the southern Black Mountains, Avawatz Mountains, northern Funeral Mountains, and various parts of the Panamint Range. They also crop out in the northern Owlshead Mountains and on Slate Ridge.

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[1]Precambrian Y includes rocks from about 800 million to 1,600 million years old. Precambrian Z includes rocks from about 570 million to 800 million years old.

MARIPOSA SHEET (Strand, 1967) --covers
the area between latitudes 37° and
38° and longitudes 117° 10' and 120°

117°   116°
                                                          37°

DEATH VALLEY SHEET (Jennings, 1958)

                                                          36°

TRONA SHEET (Jennings and others, 1962)--
covers the area between latitudes 35° and
36° and longitudes 116° and 118°
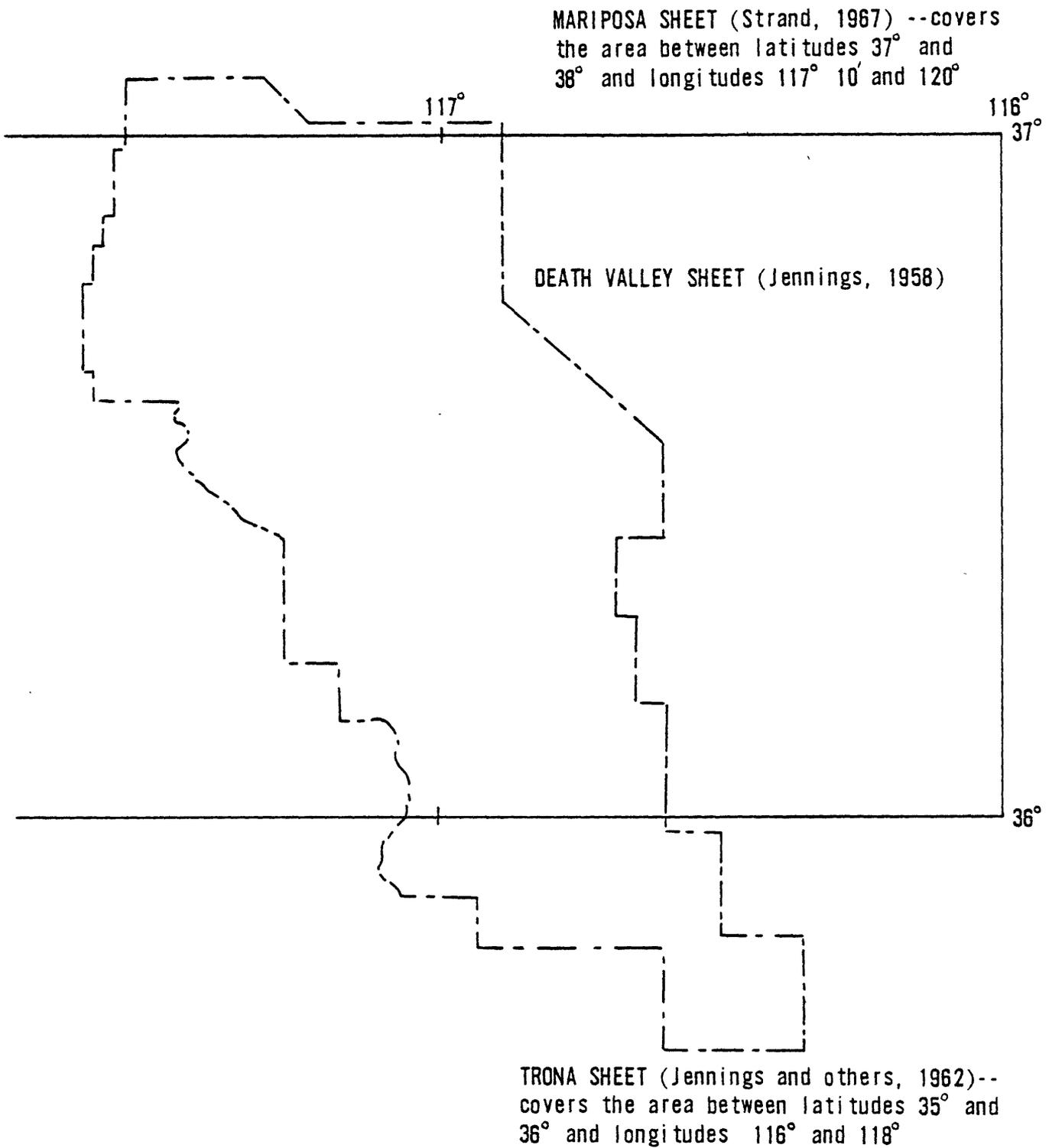
Figure 4.--Death Valley National Monument coverage by
published geologic maps.

The Precambrian rocks are probably part of a large interbasin aquifer system that extends northward and eastward from Death Valley. Saratoga and Keane Wonder (15S/46E-1RS1) Springs issue from these rocks and probably discharge water from this system. Ground water occurs in these rocks in fractures and solution openings and is more abundant than in the crystalline basement but probably less abundant than in the overlying sedimentary rocks of Paleozoic age.

Sedimentary and metamorphic rocks of Paleozoic age crop out in most of the mountain areas. They consist in large part of limestone, dolomite, sandstone (now largely quartzite), and shale. These rocks are intensively folded and faulted, and the brittle carbonate and quartzite layers are highly fractured. Locally, the fractures in carbonate rocks have been enlarged by the dissolving action of water. The carbonate rocks, and to a lesser degree the fractured quartzite, make up the most important part of a large interbasin flow system (Winograd, 1971; Winograd and Thordarson, 1975) that extends northward and eastward into Nevada. In the Panamint Range and Grapevine Mountains many springs issue from faulted and fractured zones in these rocks. Locally, as in the northern Cottonwood Mountains and Last Chance Range, large areas of outcrop at high altitudes are almost devoid of springs, probably because fractures and solution openings allow recharge to move readily downward and laterally into Death Valley as ground-water flow.

Fractured quartzitic strata, widespread in the mountain areas, are a potentially productive aquifer for wells. This rock is strong enough to maintain open fractures at great depths, and its chemically inert nature and low solubility generally prevent fractures from being filled with secondary minerals that would reduce the permeability. A test well (16S/44E-12N1) about 2 mi south of Stovepipe Wells Hotel, drilled with air percussion tools, penetrated several hundred feet of highly fractured quartzite above the water table. The rock was judged to be capable of yielding several hundred gallons per minute if saturated.

Shale of Paleozoic age typically is dense and minutely fractured, but the fractures are generally not open or interconnected and this type of rock commonly forms barriers to the movement of ground water. Locally, limy shale layers contain open fractures and constitute the aquifer system for several small springs.

Granitic rocks of Mesozoic age crop out in most of the mountain ranges, and sedimentary and volcanic rocks of Triassic age crop out in a small area near Butte Valley. The Triassic rocks are similar in hydrologic nature to the Precambrian Z and Paleozoic rocks. The granitic rocks, some of which are of early Tertiary age, are similar in hydrologic nature to the rocks of Precambrian Y age. Many small springs issue from weathered and fractured zones in granitic rocks on Hunter Mountain and Magruder Mountain.

Rocks of Tertiary age are sedimentary and volcanic in origin and include soft sandstone, mudstone, conglomerate, impure limestone, shale, evaporites, tuff, rhyolite, and related rocks. All have been folded and faulted, but to a lesser degree than the older rocks. These materials vary widely in their hydrologic properties. The volcanic rocks are for the most part above the water table, but fractures and rubbly flow boundaries in them form highly permeable zones. The shale, mudstone, and evaporite deposits, although locally highly porous, are only slightly permeable, and the sandstone and fanglomerate are little more so.

Alluvial-fan deposits compose most of the material of Quaternary age peripheral to the valley floor. Older fan deposits of Pleistocene age occur in most interstream areas on the fans, and younger fan deposits occupy active washes and fan channels. The fan material consists chiefly of gravel, sand, and silt; boulders are common locally. These clastic materials range from well-sorted stream-channel gravel to poorly sorted mudflow deposits. The older fan deposits generally are more indurated and less permeable than the younger fan deposits, and outcrops typically are darkly colored with desert varnish. Most of the younger fan deposits are above the water table; however, they provide the major pathway for recharge to the underlying strata by seepage during floodflow.

Salt-impregnated deposits of silt, sand, and clay occur around the edge of much of the saltpan. These alluvial materials contain abundant carbonate and sulfate salts that have accumulated by evaporation from the capillary fringe above the shallow water table and as salt deposited in a Holocene lake that filled the valley to a depth of about 30 ft (Hunt and Mabey, 1966, p. A79-83).

Evaporite deposits of impure rock salt (sodium chloride) cover much of the saltpan (Hunt and others, 1966). The salt surface ranges in texture from very rough and jagged where it is almost pure sodium chloride to smooth where impure and silty. The saltpan, fed by capillary movement from below, nearly everywhere discharges ground water by evaporation.

Dune sand and playa (lake) deposits of silty clay, which occur in few areas, are mostly above the water table.

Structure

The effects of geologic structure on the hydrology of Death Valley are principally those related to (1) large-scale folding and block faulting which formed sedimentary basins now filled with clastic material and which contain most of the ground water in the valley; (2) faulting and intense folding that fractured the hard limestone, dolomite, and quartzite, so as to greatly increase the permeability of these rocks; and (3) faulting and folding that resulted in hydrologic barriers to the movement of ground water, thus causing many springs to issue in faulted areas; specific examples are cited elsewhere in the text.

Most of the folding and faulting of the thick section of Precambrian and Paleozoic sedimentary rocks occurred during late Mesozoic and early Tertiary time.

Most rocks of Tertiary age in the valley have been folded and faulted, especially along the northern Death Valley-Furnace Creek fault zone.

Locally, the deposits of Quaternary age, in particular the alluvial fan deposits along the northern Death Valley-Furnace Creek fault zone and the fans in the southern part of the Panamint Range, have been gently folded and faulted.

Drainage Relations

About 4,000 mi^2 drains directly into Death Valley. In addition, the Amargosa River drains almost 3,500 mi^2 north and east of the valley, and Salt Creek (south) drains about 1,500 mi^2. During part of the Pleistocene Epoch, the Mojave River (12,800 mi^2 of drainage) flowed into Death Valley by way of Silver Lake, and the Owens River may have emptied into the valley by way of Searles Lake and Panamint Valley through Wingate Wash (Gale, 1914; Snyder and others, 1964).

In addition to surface drainage into the valley, underflow of ground water from the north and east originates in areas that probably aggregate several thousand--possibly more than ten thousand--square miles in Nevada (Winograd, 1971, p. 27). Underflow from the Mojave River system probably enters the valley via Salt Creek (south) (Hunt and others, 1966). Some underflow probably enters the valley from small closed basins that total 20 to 30 mi^2 in the southern Cottonwood Mountains. Thus, the saltpan appears to be the ultimate sump or discharge area for some of the water that falls as precipitation on many thousands of square miles that lie on all sides of Death Valley.

The major surface drainages are the Amargosa River at the south end of the valley and Salt Creek (north)-Death Valley Wash at the north end. Both are ephemeral desert streams that flow only during infrequent floods, except for short perennial reaches fed by ground water. Floods on the Amargosa River periodically have filled many square miles of the saltpan to depths of a foot or more during the past few decades.

With few exceptions, streams and washes in the valley flow only after unusually heavy rains. The coarse bed material in almost all stream channels that debouch from the mountains attests to flows of high velocity and energy. During the course of the investigation several flash floods occurred that are worthy of note. In July 1968 a storm in Grapevine Canyon caused a peak discharge of about 700 ft^3/s below Scottys Castle. During the same month a flash flood in Furnace Creek Wash, originating as an intense thunderstorm almost entirely in the Ryan-Dantes View area, flowed at a peak between 7,000 and 10,000 ft^3/s near Zabriskie Point and destroyed or damaged several miles of Highway 190. This flood appreciably deepened the channel of the wash near its diversion into Gower Gulch at Zabriskie Point (Troxel, 1974; Dzurisin, 1975) and deposited a large quantity of debris in the valley.

An extensive storm occurred in the Tucki Mountain-Pinto Peak area in February 1969, resulting in several miles of destroyed or damaged road between Emigrant Ranger Station and Harrisburg Flats. Cones of debris from tributaries to Emigrant Canyon that were 5-10 ft high blocked the highway at many places. Recharge from this storm to the alluvium in Emigrant Canyon caused a spring with an initial flow of about 450 gal/min (1 ft^3/s) to appear in the wash near Upper Emigrant Spring (17S/44E-27KS1). This spring flowed for about a month.

On June 1, 1972, a summer thunderstorm about 2 mi wide crossed the large alluvial fan at the mouth of Cottonwood Canyon from southwest to northeast and caused peak flows of about 30 ft^3/s in many of the shallow washes on the fan. Several times during the late 1960's and early 1970's the road through Titus Canyon was closed because of flood damage.

These and similar unpredictable storms have sculptured many of the details of the modern landscape and provided much of the ground-water recharge to the valley.

Salt Creek (north) is the most notable flowing stream in the valley. Ground water discharges to the surface in a marshy area upstream from Salt Creek Hills and results in 0.1 to 1 ft^3/s of base flow where Salt Creek (north) crosses uplifted beds of siltstone and shale.

Ground Water

Occurrence and Movement

Ground water in appreciable quantities occurs beneath most of Death Valley and the surrounding mountains, but the ready availability and utility of the water varies widely from place to place. With some important exceptions, there is a general inverse relation between the age of water-bearing rocks and their water-bearing capability. For example, the crystalline basement rocks of Precambrian Y age contain less water and are less permeable than the younger sedimentary rocks of Precambrian Z age, which in turn contain less water and are less permeable than the sedimentary rocks of the Paleozoic Era. The detrital sedimentary rocks and other deposits of Tertiary age are generally much more porous than older rocks, but in turn they are less porous than most deposits of Quaternary age. An exception to the above generalizations is the intrusive granitic rock of the late Mesozoic Era and Tertiary Period, which is hydrologically similar to the crystalline basement of Precambrian Y age. An important exception is the carbonate rock of late Precambrian and Paleozoic age with its fracture zones and solution features. Such openings, although they typically constitute a minor percentage of the total void space in the rock body, commonly provide a ready passageway for movement of large volumes of water under a low hydraulic gradient.

Ground water in Death Valley moves toward the valley floor, and beneath the floor toward the saltpan. The movement may be locally impeded or enhanced by faults; fault planes in unconsolidated materials typically form barriers to movement, whereas faults in consolidated rocks commonly form highly permeable zones. Uplifted beds of shale and mudstone, such as at Valley Spring and at Salt Creek (north), locally cause ground water to discharge at the land surface. Lateral changes in the lithology of water-bearing strata also affect the movement of ground water; the permeable coarse-grained alluvial fan deposits near the mountains grade into silt and clay near the edge of the saltpan, thus ponding the ground water and causing discharge in several areas by springs, phreatophytes, and evaporation.

Recharge

Interbasin flow of ground water and seepage from stream channels during floods are by far the dominant sources of recharge. Direct infiltration of precipitation probably is a rare event in the alluvial part of the valley because the combination of low annual precipitation and high temperature results in large deficiencies in soil moisture. Infiltration probably occurs in fractured rocks in the mountain areas during intense or prolonged storms and during periods of snowmelt (Eakin, 1966, p. 263).

Sparse historical data suggest that water levels in wells and discharge from most springs have not changed appreciably, and thus for the period of record the long-term recharge seems to equal discharge.

Data and methodology are available on which to base a crude estimate of recharge (excepting underflow) in desert areas similar to Death Valley. Eakin and Maxey (1951) developed an empirical method of estimating recharge in eastern Nevada, which was later applied to the nearby Amargosa Desert by Walker and Eakin (1963) and to Clayton Valley-Stonewall Flat by Rush (1968). Rantz and Eakin (1971, p. 86) summarized this "first-approximation" method. The basis of the method is the concept that precipitation increases with increasing altitude, that some percentage of precipitation becomes ground-water recharge, that this percentage increases with increasing precipitation, and that in the Basin and Range province the higher mountains are consolidated rock that promotes runoff and the valleys are alluvium that absorbs streamflow. The distribution of phreatophytes along the toes of the alluvial fans on the west side of the saltpan (see figs. 5 and 9), which reflects to some degree the availability of incoming fresh ground water, suggests that these general assumptions are valid in Death Valley, and it also suggests that little recharge to ground water occurs where watersheds do not extend above 6,000 ft in altitude.

Utilizing the method referred to above, the areas of altitude zones at 1,000-ft intervals above 6,000 ft within the valley drainage basin, excluding the Amargosa drainage basin outside Death Valley, were used to compute recharge, as shown in table 2. The average annual recharge thus derived is estimated to be 8,000 acre-ft. The applicability of this method to Death Valley was checked by using estimates of ground-water discharge to the saltpan from part of the Panamint Range. Hunt, Robinson, Bowles, and Washburn (1966, table 25) estimated that springs and seeps in the Bennetts Well-Tule Spring area (25N/1E-24), which is downgradient from the highest part of the Panamint Range, discharge about 570 acre-ft annually. Using the area-altitude method described above, the annual recharge from this part of the range is estimated to be 1,000 acre-ft. Hunt, Robinson, Bowles, and Washburn (1966, table 25) also estimated that the total ground-water discharge along the west side of the valley, excluding about 10 mi at the north end, is about 4,700 acre-ft annually, most of which is from 8,500 acres of mudflats. Recharge from this part of the Panamint Range is estimated to be only 2,700 acre-ft annually, using the area-altitude method.

Another crude check was made in the Hunter Mountain area, where ground-water outflow is concentrated at Cottonwood Springs (16S/42E-25KS1). The average annual recharge in the local drainage basin, using the area-altitude method, is estimated to be 200 acre-ft, whereas the total discharge at the spring and by phreatophytes is estimated to be 80 acre-ft annually.
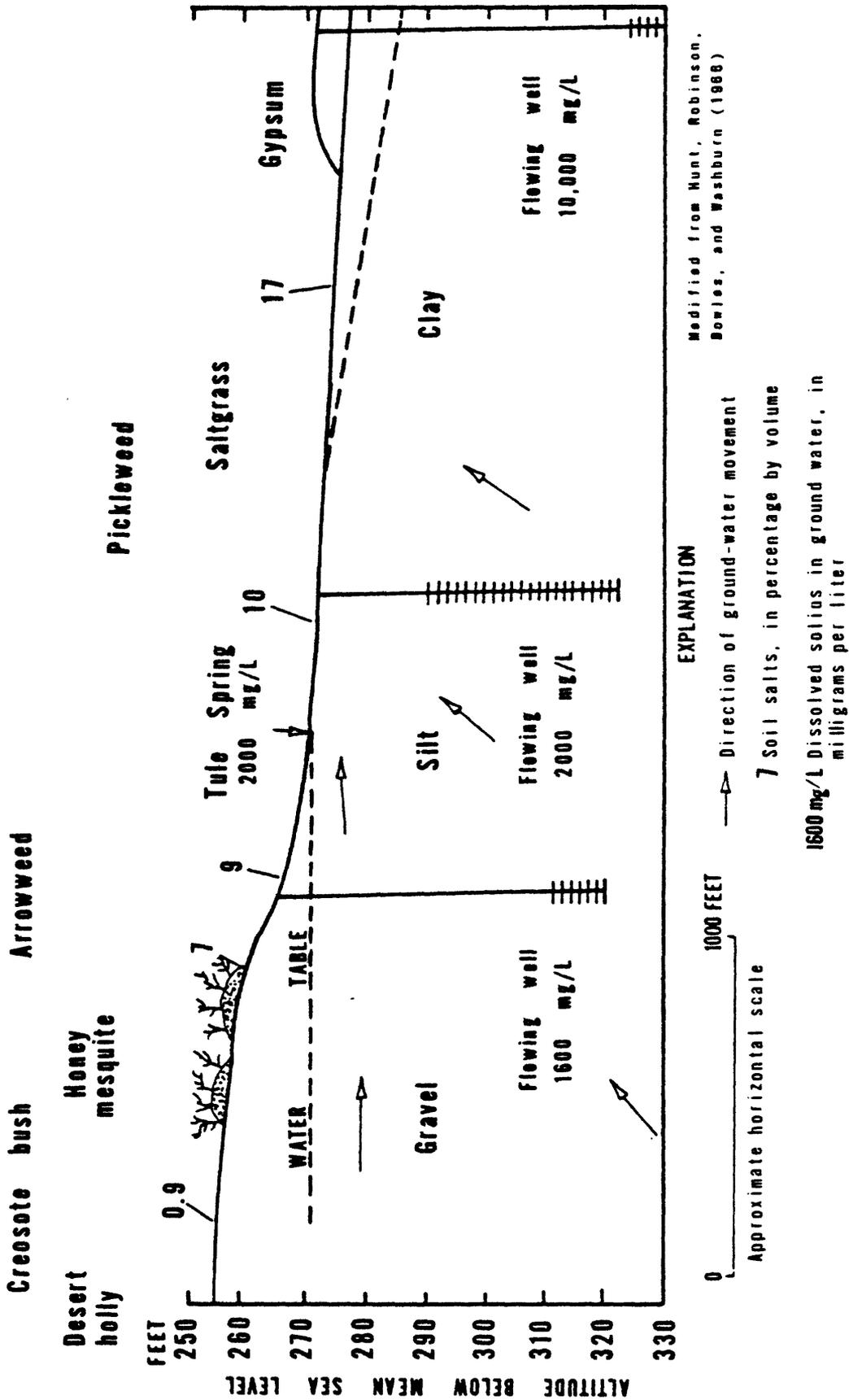
Figure 5.--Diagrammatic section showing ground-water flow system and distribution of dissolved solids and vegetation at Tule Spring.

TABLE 2.--*Estimated ground-water recharge from precipitation,
Death Valley, Calif.*

Altitude zone		Annual precipitation		Assumed average annual recharge		
Feet	Approximate square miles	Estimated range (inches)	Assumed annual average (feet)	Percentage of precipitation	Feet	Acre-feet (rounded)
Constants from Rantz and Eakin (1971, p. 86)						
Below 6,000	--	<8	Variable	Negligible	--	--
6,000- 7,000	150	8-12	0.83	3	0.025	2,400
7,000- 8,000	65	12-15	1.12	7	.078	3,200
8,000- 9,000	10	15-20	1.46	15	.22	1,400
9,000-10,000	3	>20	1.75	25	.44	840
>10,000	<1	>20	1.75	25	.44	200
Total (rounded)						8,000
Constants from Rush (1968, table 5)						
Below 6,000	--	--	--	--	--	--
6,000-7,000	150	<8	.5	Minor	--	--
7,000-8,000	65	8-12	.8	3	.024	1,000
Above 8,000	14	>12	1.1	7	.077	690
Total (rounded)						1,700

These large discrepancies in the estimates of recharge and discharge are not readily explained; however, several factors may contribute to them:

1. The drainage areas are small compared to those used to develop the area-altitude method, and thus wide variations may exist (Rantz and Eakin, 1971, p. 86) when applied to small areas.

2. The drainage slopes cited above face north and east, and thus evaporation probably is below average.

3. Uncertainties in the estimates of discharge may account for some of the discrepancies.

4. The last example (Cottonwood Springs) is well above the valley floor, and thus subject to lower temperatures and less evapotranspiration than lower areas.

5. Some ground water may move eastward through the Panamint Range and thus add to the discharge along the saltpan. Recharge enters Death Valley as interbasin flow of ground water from areas on the north and east (Hunt and others, 1966, p. B-27, 28; Winograd, 1971; Winograd and Thordarson, 1975) and probably in small quantities from the west.

6. The constants used (Rantz and Eakin, 1971, p. 86) probably need adjustment for use in Death Valley; thus, the above figures should be considered only as crude estimates. For example, Rush (1968, table 5) estimated that in Oriental Wash and in Grapevine Canyon only 3 percent of the precipitation that falls between 7,000 and 8,000 ft altitude becomes recharge; that amount of precipitation is less than shown in table 2. Applying Rush's figures (table 2), the average annual recharge from local precipitation can be estimated to be less than 2,000 acre-ft, as compared to 8,000 acre-ft by using data from Rantz and Eakin.

7. The several thousand square miles below an altitude of 6,000 ft may contribute some recharge (Crippen, 1965, p. E17), and this will slightly raise the estimates shown in table 2.

8. Data collected in the Wildrose Canyon area for several years suggest that the relation of average precipitation to altitude may not be as straightforward as shown in table 2. Incomplete data from six precipitation stations there at altitudes ranging from about 4,300 to 9,900 ft suggest that the average annual precipitation rises from about 6.5 in at 4,300 ft to a maximum of 8.6 in at 7,200 ft, then seems to decline to about 6.5 in at 9,900 ft. If such meteorological patterns are representative of the high areas of the entire valley, then the constants for average precipitation used in table 2 are much too high.

9. Finally, the Eakin and Maxey method and its variants are simplistic; they do not consider critical factors such as rock type, permeability of weathered mantle and soil, permeability of stream-channel deposits where recharge occurs during runoff, soil-moisture conditions at the time of precipitation, and slope.

A detailed estimate of total recharge to and discharge from the valley is beyond the scope of this report. The above discussion merely gives some indication of the uncertainties involved in such a study.

Seepage from and underflow beneath the Amargosa River channel adds recharge to the south end of the valley. Surface flow in the river channel into the valley is intermittent and occurs mostly during the winter months, typically at rates of a few cubic feet per second except during large floods. These low flows move down the valley several miles to the vicinity of Saratoga Spring (18N/5E-2ES1,2) in a sandy channel which is 20-30 ft above the water table. The low seepage rate may be caused by calichelike deposits underlying the channel bottom. During the 1969 water year the peak flow at the gage at Tecopa, about 15 mi upstream from the valley, was about 5,000 ft^3/s, and the total flow was 6,650 acre-ft. Mean annual flow past this gage is about 1,800 acre-ft, of which probably half or less becomes recharge to ground water in Death Valley.

Discharge

Discharge of water from Death Valley is entirely by evapotranspiration.
Hunt, Robinson, Bowles, and Washburn (1966, p. B37-38) estimated that the
annual discharge of ground water from most of the valley floor was nearly
13,000 acre-ft. Additional discharge by evapotranspiration takes place at
springs and seeps in the mountains and upstream from the areas considered by
Hunt, Robinson, Bowles, and Washburn. For example, evapotranspiration by
phreatophytes and from open water surfaces is about 200 acre-ft annually
at Saratoga Spring (Kunkel, 1966) and 30 acre-ft annually at Cottonwood
Springs (Miller, 1970). Annual evaporation from the several hundred small
springs and seeps in the entire area probably exceeds 1,000 acre-ft. Annual
evapotranspiration from the moist vegetated areas at Valley Spring
(19N/4E-24FS1), near Midway Well (14S/45E-18D1), and at Grapevine Springs
(11S/42E-2,3,10S) is estimated to be 100, 300, and 700 acre-ft, respectively.
Evapotranspiration is 3,000 to 5,000 acre-ft annually from the marsh that
feeds Salt Creek (north). From the large area of scattered mesquite and
other phreatophytes in Mesquite Flat (excluding the area near Midway Well),
the evapotranspiration is probably another few thousand acre-feet annually.

From the foregoing, 20,000-25,000 acre-ft is a crude estimate of ground-
water discharge from the entire valley. This ranges from 2 to 10 times as
much as the estimated recharge, and much of the discrepancy may be attributed
to interbasin flow of ground water, largely from the north and east.

Interbasin Flow of Ground Water into Death Valley

Several large springs along the east side of Death Valley appear to be
discharging from a large interbasin flow system that extends many miles to
the north and east (Winograd, 1971; Winograd and Thordarson, 1975; Hunt and
others, 1966, p. 25-28). These springs, which are discussed below, are, from
south to north, Saratoga, Travertine, Texas, Nevares, Keane Wonder,
Stainingers (at Scottys Castle), and Grapevine (table 4). Most of these
springs occur near the contact of alluvial deposits and consolidated rocks;
three discharge along major faults.

Interbasin flow of ground water in the southern part of the Basin and
Range province has been discussed by several workers, including Eakin (1966);
Eakin and Moore (1964); Eakin and Winograd (1965); Grove and others (1969);
Hunt and Robinson (1960); Hunt and others (1966); Loeltz (1960); Maxey (1968);
Maxey and Mifflin (1966); Pistrang and Kunkel (1964); Walker and Eakin (1963);
Winograd (1962, 1971); and Winograd and Thordarson (1975). All reported

certain indirect or direct lines of evidence for interbasin flow. These and other lines of evidence noted in Death Valley are summarized as follows: (1) Little or no fluctuation in the discharge rates of major springs, (2) a near-constant ground-water temperature between 6 and 15 degrees (Celsius) higher than the mean annual air temperature, (3) little or no discernible change in water chemistry with time, (4) discharge that is many times larger than may reasonably be expected from the size of the surface drainage area and nature of the climate, (5) the presence of fractured carbonate rocks and quartzite several thousand feet thick upgradient from some springs and between the springs and adjacent ground-water systems, and (6) water levels, in adjacent upgradient basins, that are several hundred to a thousand feet above the altitudes of springs.

Water chemistry may, in some instances, offer limited evidence of interbasin flow (Hunt and others, 1966, p. B40); however, for the postulated flow system between Sarcobatus Flat-Amargosa Desert and Death Valley two unknown factors, or at least uncertainties, limit the use of water quality as evidence: (1) The source of samples of water in the upgradient areas is limited to existing wells that generally tap only the alluvial fill and probably are not representative of water in the underlying carbonate-rock aquifer, which may carry most of the underflow, and (2) long travel paths and presumably accompanying long residence time in contact with the rocks between the supposed source and the springs could change the water chemistry by such mechanisms as mineral weathering, ion exchange, and inflow of water of unknown quantity and quality from other sources. Preliminary carbon-14 data obtained by I. J. Winograd (oral commun., 1975) suggest that water presently discharging from Texas-Travertine-Nevares Springs (28N/1E-27) may have been in transit for as long as 10,000 years.

At all the springs in Death Valley mentioned above, data indicate that most or all the above criteria or characteristics of interbasin flow prevail. The data also strongly suggest, in fact almost require, that the water at these springs is derived from outside the immediate drainage area.

The lines of evidence mentioned earlier, either singly or in combination, are not conclusive proof of interbasin flow, and with few exceptions, water-level and hydraulic data are not available to prove that a hydraulic continuum exists between basins. All except the line of evidence in item (4)--discharge versus drainage area--may characterize a spring discharging from a single large, deep ground-water basin with coincidental surface drainage, and item (4) is perhaps the least amenable to quantitative definition. Most discharge values attributed by previous workers to interbasin flow are many times as large per unit of catchment size, as the discharge of springs in the same area, which are almost certainly discharge points for local aquifers, based on their geologic setting and hydraulic characteristics.

Saratoga Spring.--Saratoga Spring (18N/5E-2ES1,2) may be a point of
discharge for interbasin flow, probably from the Shoshone-Tecopa area,
although some of the water may be derived locally from underflow beneath the
nearby Amargosa River. The water temperature at the spring, as measured six
times between 1908 and 1967 ranged from 28° to 29°C, which is probably 6° to
8° warmer than the mean annual air temperature. Discharge from the main
spring ranges from 76 to 80 gal/min, based on 12 measurements during the
period April 1967-November 1968 and on continuously recorded flow during part
of this period. During this time the monthly flow in the Amargosa River at
the Tecopa gage (25 mi upstream from Saratoga Spring) ranged from no flow in
August 1967 and September 1968 to 390 acre-ft during February 1968. Judging
from the record at Tecopa, floodflow in the river and concomitant ground-
water recharge probably occurred in the alluvium-filled valley a quarter of a
mile south of the spring three or four times during the period of measurements
at the spring, but no fluctuations in spring discharge were noted nor did
chemical quality vary significantly.

The geohydrologic setting at Saratoga Spring suggests that ground water
moves, at depths as much as a few thousand feet, through folded and faulted
sedimentary rocks of Precambrian Z age from a large ground-water basin in
the Shoshone-Tecopa area about 15 mi northeast of the spring and discharges
at a fault zone along the west side of the Saratoga Hills. Limited data
indicate that the ground-water levels near Tecopa are about 1,200 ft higher
than at Saratoga Spring. Additional but inconclusive evidence that much of
the flow at Saratoga Spring is derived from underflow from the northeast is
provided by the chemical nature of the water. The water from Saratoga Spring
most closely resembles that from the Tecopa area, allowing for near-surface
cooling and for increases in several constituents during the postulated 15 mi
of travel through fractured carbonate, shale, quartzite, and other types of
rocks. This evidence is certainly not conclusive or unambiguous; however,
the hydrologic setting and constancy of both flow and chemistry with time are
compelling evidence for interbasin flow to Saratoga Spring.

Travertine, Texas, and Nevares Springs.--The source of water for these
large springs (28N/1E-27) discharging 1,190, 210, and 260 gal/min,
respectively in January 1977, near Furnace Creek was discussed by several
workers, including Hunt and Robinson (1960); Pistrang and Kunkel (1964);
Hunt, Robinson, Bowles, and Washburn (1966); Winograd (1971); Winograd and
Friedman (1973); Winograd and Thordarson (1975); and J. P. Akers (written
commun., 1974). With the exception of Pistrang and Kunkel (1964, p. 20),
these investigators concluded that the source of water discharged by these
springs is the large basins north and east of Death Valley. Pistrang and
Kunkel argued (1964, p. 20) that "...there appears to be sufficient recharge
from this source [precipitation in the local Furnace Creek drainage]...to
explain all measured ground-water discharge in the area." Several lines of
evidence from subsequently developed data almost preclude a local origin for
most or even any appreciable quantity of the water discharging from these
springs. The evidence is summarized as follows:

1. Using methods discussed earlier for estimating recharge in the general area (Eakin and Maxey, 1951; Rantz and Eakin, 1971) and precipitation data and estimates by Hunt, Robinson, Bowles, and Washburn (1966, figs. 3 and 4), it is apparent that little recharge occurs from precipitation in the Furnace Creek watershed, because of the low altitude and low precipitation in the drainage basin.

2. In order to increase the possible drainage area to Travertine and Texas Springs (27N/1E), Pistrang and Kunkel (1964, p. 20) tentatively assumed that underflow from the upper reaches of Furnace Creek Wash, upstream from Zabriskie Point where dry shale is exposed in the floor of the wash, moves "...entirely in the cracks and fissures or along faults and bedding planes of the lacustrine deposits of Tertiary age." About 8 mi upstream from Zabriskie Point and 2,000 ft higher in altitude, and presumably upgradient (Pistrang and Kunkel, 1964, p. 20) from the spring, data from test drilling and from dewatering an open-pit borate mine 2 mi northwest of Ryan indicate that several impure limestone beds in the lacustrine sequence referred to above are highly permeable but that the permeability is localized. Of greater significance, however, is the fact that these beds at the open-pit mine contain highly mineralized water with a substantial percentage of boron. It is reasonable to conclude that the chemical quality of water from Travertine and Texas Springs would be vastly different if the discharge contained a significant quantity of this water.

3. Furthermore, the rate of discharge at these springs is remarkably constant, even following flash floods in Furnace Creek Wash. During the period from April 10, 1968, to August 10, 1971, continuous recorders were operated on an 18-in rectangular weir at Texas Spring and on test well 27N/1E-24E1, located between Travertine and Texas Springs. On July 8, 1968, a thunderstorm centered near Dantes View produced a flash flood in Furnace Creek Wash with an estimated peak flow of 7,000 to 10,000 ft^3/s (E. G. Pearson, written commun., 1968). Local residents reported that the flood was one of the most damaging in memory. Such an unusual event should have affected the ground-water system at the springs if local recharge makes up a significant part of the flow. There was no change in water level in the test well attributable to the flood. Discharge from the spring remained almost constant, and no change related to the flood could be detected from the recorder charts or from subsequent measurements. Figure 6 shows a continuous record of flow at Texas Spring from April 30, 1968, to November 16, 1968. The envelope of daily fluctuations, shown on the chart, probably reflects the effects of barometric fluctuations on the aquifer feeding the spring and diurnal temperature fluctuations acting on the springhouse that supported the recorder above the concrete weir box.

DISCHARGE AT TEXAS SPRING, APRIL 30 TO NOVEMBER 16,1968
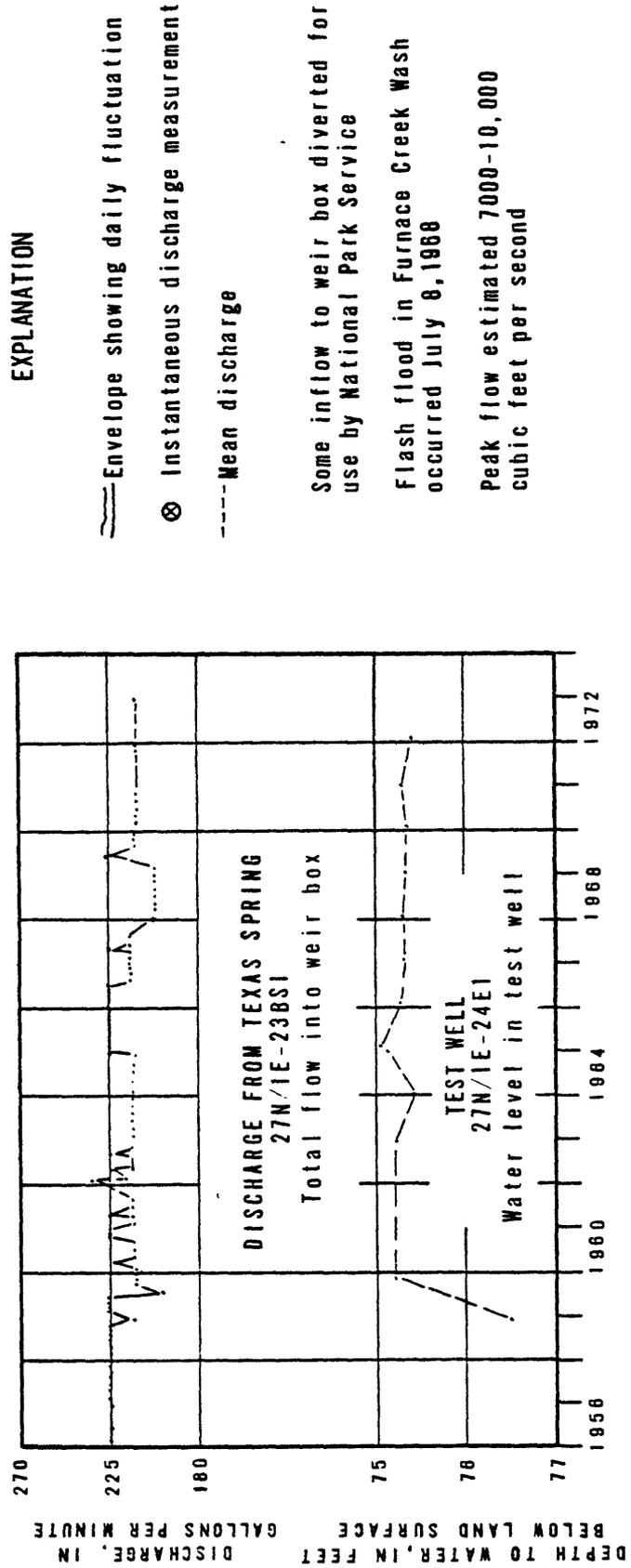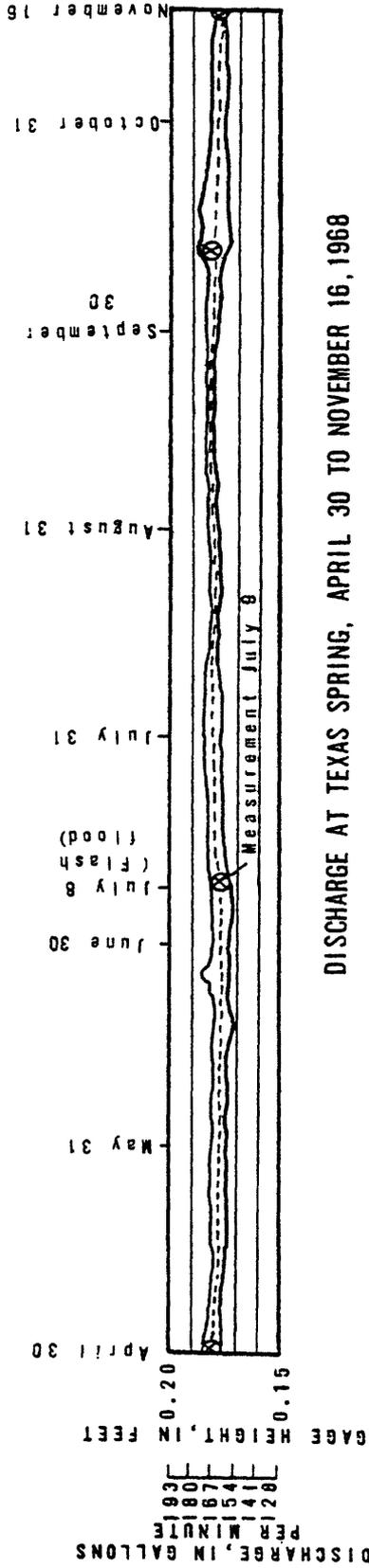
EXPLANATION

Envelope showing daily fluctuation

⊗ Instantaneous discharge measurement

---Mean discharge

Some inflow to weir box diverted for use by National Park Service

Flash flood in Furnace Creek Wash occurred July 8,1968

Peak flow estimated 7000-10,000 cubic feet per second

DISCHARGE FROM TEXAS SPRING
27N/1E-23BS1
Total flow into weir box

TEST WELL
27N/1E-24E1
Water level in test well

Figure 6.--Hydrographs of Texas Spring and test well 27N/1E-24E1.

The short-term fluctuations in discharge at Travertine Springs (27N/1E-23RS1, 25DS1,2, and 26AS1-7) are greater than at Texas Spring (27N/1E-23BS1) (Pistrang and Kunkel, 1964). This may be attributed in part to variations in the condition and efficiency of the complex collector system of ditches that conveys the flow from 10 springs (Pistrang and Kunkel, 1964, p. 26) to the measuring point (a flume in Furnace Creek Wash) and in part to variation in evapotranspiration losses in the collector area. The combined flow from the springs averaged 850 gal/min during the period 1956-72, with no apparent long-term trend away from this average.

Data for South Travertine Spring (27N/1E-26BS1), which flows from a manmade sump in the alluvium in Furnace Creek Wash, show rises in discharge for short periods in response to flash floods in the wash, then rapid declines. A short distance upstream from the spring, at Zabriskie Point, the entire section of alluvium in Furnace Creek Wash is dry, as shown where the base of the alluvium rests on shale and siltstone beds at the point where the Wash has been directed into Gower Gulch. The source of most of the water at this spring is the same as that at Texas and Travertine Springs.

4. Similar drainages in the National Monument having springs in the downstream reaches do not produce nearly the quantity of ground water as the springs in Furnace Creek Wash. For example, Willow Spring (23N/3E-54JS1), in the Black Mountains about 30 mi south of Furnace Creek, discharges at a bedrock narrows downstream from the alluvial part of Gold Valley. The valley is a 19-mi^2 alluvium-floored mountain drainage basin underlain by crystalline bedrock (Drewes, 1963, pl. 1) of low permeability. Altitudes range from 2,700 ft at the spring to 5,000-5,500 ft along most of the drainage divide. The climate is similar to that of the upper reaches of Furnace Creek, and the geohydrology suggests that little or no ground water leaves the basin except as discharge at the spring. The discharge at Willow Spring, based on 14 instantaneous-discharge measurements from March 1967 through January 1971 and including about a year of near-continuous record, was distinctly seasonal in character and ranged from 2 to 20 gal/min. The estimated average discharge was 10 gal/min, or about 0.5 (gal/min)/mi^2, which is slightly less than 1 acre-ft/mi^2 per year.

This rate is less than a hundredth that postulated by Pistrang and Kunkel (1964, p. 20) as being available from precipitation in the Funeral Mountains tributary to Furnace Creek. Thus, the approximately 1,660 gal/min of discharge at Travertine, Texas, and Nevares Springs (28N/1E-27) (Pistrang and Kunkel, 1964, table 4) must originate outside Death Valley.

The geologic structure and hydrologic properties of rocks in the Travertine-Texas-Nevares Springs area (McAllister, 1970; Pistrang and Kunkel, 1964) appear to set some recognizable limits on the nearby flow paths of ground water. Figure 7 shows that the permeable alluvial deposits in the Texas Spring syncline (Hunt and Mabey, 1966, p. A60) are in contact at the surface with carbonate rocks of Paleozoic age (a probable interbasin aquifer) only between Echo Canyon and a northeast-trending fault about 2 mi to the southeast. Geologic sections across the syncline (McAllister, 1970) indicate that shale of the Pliocene Furnace Creek Formation lies below the permeable alluvial deposits and may effectively retard upward movement of water. The
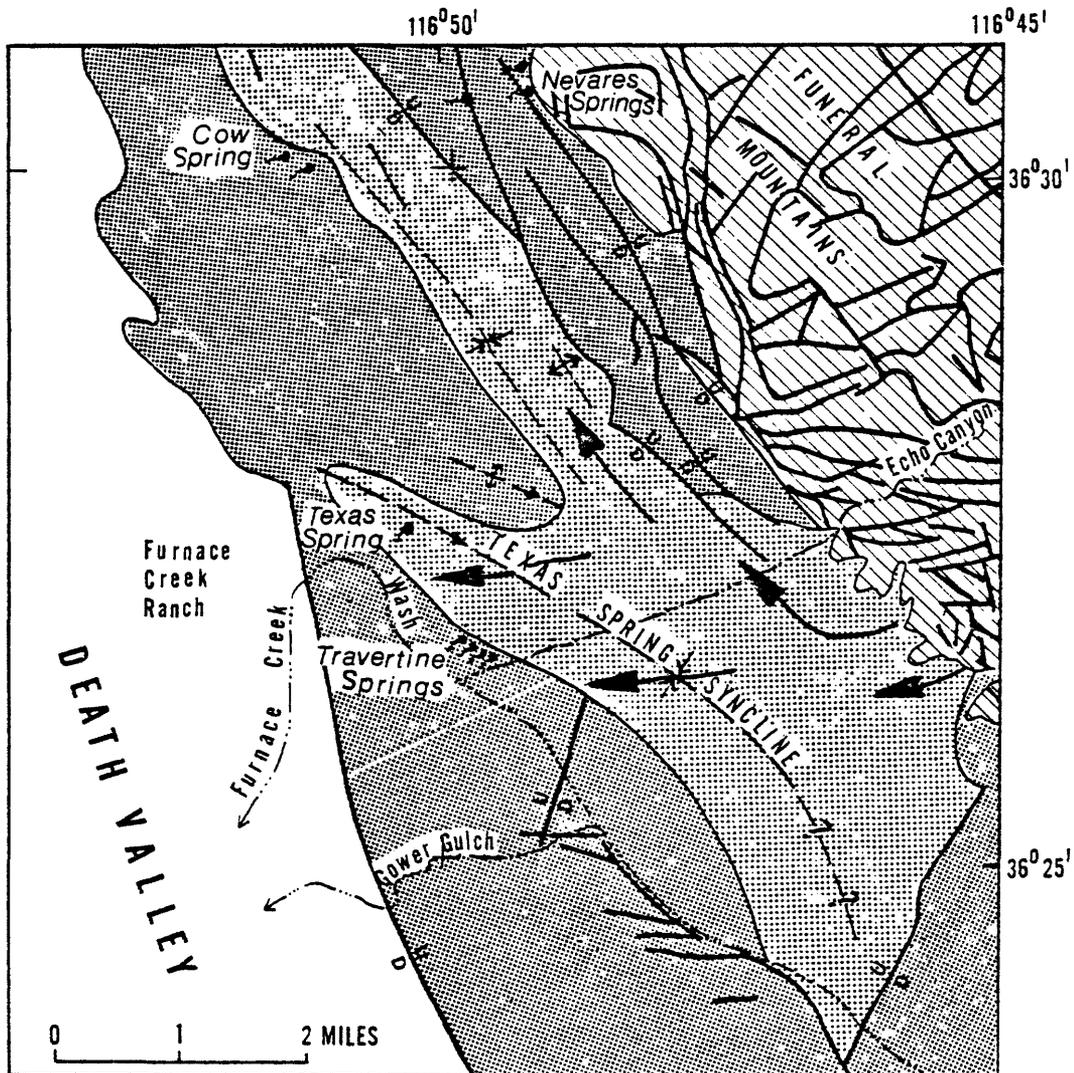
EXPLANATION

Geology after Pistrang
and Kunkel (1964) and
McAllister (1970)

ALLUVIUM AND SALINE DEPOSITS ON
FLOOR OF DEATH VALLEY

FANGLOMERATE AND FAN DEPOSITS--
Moderately to highly permeable

SHALE AND MUDSTONE--Slightly
permeable to almost impermeable

LIMESTONE, DOLOMITE, AND
QUARTZITE--Solution features
and fractures; locally highly
permeable

CONTACT
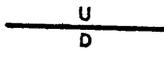
FAULT--U,upthrown side;
D, downthrown side

ANTICLINE--Showing trace of
crestal plane and direction
of plunge. Dashed where
approximately located
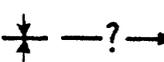
SYNCLINE--Showing trace of
trough plane and direction
of plunge. Dashed where
approximately located.
Queried where doubtful

SPRING

POSTULATED GENERAL DIRECTION
OF GROUND-WATER FLOW

Figure 7.--Generalized geohydrology of the Furnace Creek area, showing
postulated movement of ground water from the Funeral Mountains to
major springs.

most logical pathway for ground water from the east to enter the alluvial deposits in the syncline seems to be through the 2-mi gap mentioned earlier, then westward toward the springs. Some water may move northwestward and emerge at Cow Spring (27N/1E-3AS1) and at the saltpan. The major springs are at an altitude of 380-400 ft and the alluvium-carbonate rock contact is at 1,600-1,800 ft. The water level in test well 27N/1E-24E1 is at an altitude of 413 ft, which suggests that the ground-water gradient is not steep across the syncline. No data are available on the nature of the entry of water into the syncline. Several test holes 100 ft or less in depth are needed north and east of the springs to better delineate the pattern of flow.

Keane Wonder Spring.--This spring (15S/46E-1RS1) issues from somewhat metamorphosed sedimentary rocks of Precambrian age along the Keane Wonder fault, about 12 mi northwest of Nevares Spring (28N/1E-36GS1). The spring site is near the south end of a large mound-like mass of gray to tan travertine that marks old discharge sites. The historically consistent rate of flow (25-30 gal/min) based on a few measurements, the above-normal temperature (32.8°C), and the high discharge rate compared with the few square miles of drainage all point to other than a local source for the water, probably from the north and east beneath the Amargosa Desert.

Stainingers Spring (11S/43E-5ES1) and Grapevine Springs (11S/42E-2,3,10S).-- These springs probably derive much of their water from the Sarcobatus Flat area, by underflow through alluvium, volcanic rocks, and carbonate rocks. Water-level data from wells in Bonnie Claire Flat northeast of the springs suggest that the hydraulic gradient there is southwestward toward Death Valley at 7 to 10 ft/mi, but the water level at the springs is a few hundred feet lower than in the nearest well in southern Bonnie Claire Flat. The wells are drilled into alluvium and probably penetrate the underlying volcanic rocks.

Long-term discharge measurements are not available at Stainingers Spring, which supplies water to Scottys Castle, or at Grapevine Springs. At Stainingers Spring, a measurement of 187 gal/min was reported in 1924, 180 gal/min was measured in 1958, and about 200 gal/min was reported by Rush (1968, p. 32). On January 14, 1971, the author measured 188 gal/min, using flume and volumetric measurements at several distributary points in the water system. This suggests that discharge probably has remained fairly constant. Data from Ludwig (1958) suggest that the flow increases following rainstorms but quickly diminishes to the above rate. Water temperature at the spring was 26°C on January 14, 1971, which is perhaps 6° to 8°C warmer than the mean annual air temperature. The drainage area in Grapevine Canyon above Stainingers Spring (altitude 3,220 ft) comprises about 22 mi^2 of alluvial fan and volcanic terrane, all below an altitude of 6,000 ft; less than 0.5 mi^2 is above 5,000 ft. Thus the drainage area is all lower in altitude than the most significant water-productive zones outlined by Rantz and Eakin (1971). Rush (1968, p. 22) estimated that the recharge by precipitation in Grapevine Canyon amounts to 50 acre-ft annually, which is about one-sixth of the annual discharge from the spring. In order to sustain a flow of 190 gal/min the annual recharge would have to be 14 acre-ft/mi^2, more than 10 times the recharge rate estimated previously for a similar drainage in Gold Valley.

Grapevine Springs, located near the northern boundary of the monument, consists of a dozen or more springs and seeps that, in the aggregate, discharge more than 1 ft^3/s of water ranging in temperature from 22°C to 38.5°C. The total discharge from the area includes evapotranspiration from about 150 acres of phreatophytes (mostly mesquite) and moist ground, which together is equivalent to about 100 acres of 100-percent cover by phreatophytes. The springs issue from travertine deposits built up to form an elongated topographic bench along the east side of the northern Death Valley-Furnace Creek fault zone at an altitude between 2,700 and 2,800 ft. The travertine appears to overlie carbonate rocks of Paleozoic age which, along with volcanic rocks of Tertiary age, probably transmit water from the Sarcobatus Flat area through the same aquifer system that feeds Stainingers Spring. The surface drainage area above the springs is about 13 mi^2, all at altitudes below 6,000 ft, which seems far inadequate to account for the quantity of discharge.

No historical data are available on the consistency of the water chemistry, but the geologic setting, above-normal temperature, and small drainage basin for the magnitude of the discharge suggest an interbasin source for this water.

Water Quality

The quality of the water beneath the floor of Death Valley is the most critical limitation on widespread utilization of ground water in the monument. Water from most of the springs in the mountains is of usable quality, generally less than 1,000 mg/L dissolved solids and commonly less than 500 mg/L. In contrast, water beneath the valley floor (excluding beneath the saltpan where near-saturated brines occur) from the south end of the valley northward to and including most of Mesquite Flat commonly contains 3,000 to 5,000 mg/L dissolved solids. A few exceptions are areas where appreciable recharge of water of better quality enters the valley, such as at Furnace Creek and along the toes of the alluvial fans downstream from the highest parts of the Panamint Range and southern Grapevine Mountains.

As ground water nears the saltpan it rises toward the surface and evaporates. As evaporation proceeds, dissolved solids are concentrated to the point where certain minerals precipitate. Under these conditions, calcium and magnesium carbonates and gypsum are least soluble. Hence, these minerals are precipitated around the periphery of the saltpan, and the brine remaining is enriched in sodium chloride. Thus, from the periphery toward the center of the saltpan, the brine shifts toward a sodium chloride type, regardless of the original composition of the source ground water (Hunt and others, 1966).

Chemical analyses of the water in the Death Valley National Monument (table 3) show the variations in type and quality from place to place. Repeated analyses over a long period, show that, at least at Saratoga Spring, little change in water quality takes place with time.

TABLE 3.—*Chemical analyses of water in*

[Constituents in milligrams per liter, except iron and boron in micrograms per liter; Analyst: DWR, California Department of Water Resources;

Identification No.	Source	Date	Temperature	Silica (SiO₂)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO₃)
							Water in the Saratoga Spring-Tecopa area (from			
18N/5E-2ES1	Saratoga Spring (concrete springhouse)	9- 8-17	--	70	170	31	36	(994)		410
	do.	3-31-55	--	41	50	33	36	989	40	428
	do.	12-31-64	28	41	--	34	35	990	32	416
	do.	4- 8-67	29	39	0	34	21	1,000	40	435
18N/5E-2ES2	Saratoga Spring (pool)	4-27-32	28.5	38	--	35	38	942	32	430
	do.	12-22-55	28	44	30	33	34	970	30	420
	do.	4-26-67	29	37	0	40	40	980	26	420
18N/7E-30FS1	Salt Spring (Discharge: 22 gal/min)	4-25-67	19	--	--	177	169	2,030	56	534
19N/6E-19N1	(Depth: 268 ft)	3-17-67	30.5	42	30	27	10	1,360	7.8	694
21N/7E-28P1	Flowing well (Depth: 200± ft)	4- 8-67	49	85	100	2.0	.0	900	17	595
21N/7E-33PS1	Tecopa Hot Spring (Discharge: 180 gal/min)	11-16-64	43	8.9	.0	6.0	.0	815	17	640
							Ground water from			
16S/42E-18RS1	Jackass Spring, east slope of Hunter Mountain	4-23-68	10	45	<30	86	22	49	1.2	460
22S/47E-19QS1	Galena Canyon ⎫ South	6-23-70	--	21	--	23	40	27	2.6	180
23S/45E-23QS1	Greater View ⎬ Panamint Spring ⎭ Range	4-27-67	14.5	25	--	55	7.2	38	4.3	200
21N/4E-11MS1	Rhodes Spring ⎫ Black	3-23-70	17	30	--	45	18	160	5.5	360
23N/3E-54JS1	Willow Spring area ⎭ Mountains	1-12-66	20	--	--	60	14	67	5	360
							Ground water from			
13S/45E-4LS1	Klare Spring, Grapevine Mountains	11-17-68	22.5	20	20	44	24	130	4.9	360
16S/45E-29DS1	Tucki Spring, Tucki Mountain	2-11-71	8	10	--	18	26	27	5.1	160
20S/45E-4LS1	Hummingbird Spring, Panamint Range	6-18-70	14.5	19	--	66	14	14	3.6	160
							Ground water from			
11S/43E-18ES2	Surprise Springs, North Grapevine Mountains	1-21-67	20	64	--	7.3	1.3	150	7.6	230
23S/46E-33DS1	Squaw Spring, South Panamint Range	5-15-67	22	72	10	17	7.8	27	10	100
23N/3E-37QS1	Hidden Spring ⎫ Black	4- 7-67	13	59	200	5.7	1.2	50	5.0	110
25N/2E-13GS1	Lemonade Spring ⎭ Mountains	11-18-68	12	57	--	2.2	2.1	180	7.4	260
							Ground water from			
18N/3E-22CS1	Owl Hole Spring, Owlshead Mountains	3-16-67	14	--	--	40	11	590	10	140
26N/2E-5Q1	Borate Mine, Furnace Creek (Depth: 50 ft)	1- 7-72	14	12	20	350	87	990	7.5	460
							Ground water from			
9S/41E-7RS1	Sand Spring, North Death Valley	1-29-59	11	46	570	26	.0	250	1.4	54
14S/45E-18D2	Test well at Midway Well (Depth: 97 ft)	5-10-72	30	33	30	120	49	190	20	740
14S/45E-30BS1	Palm Tree Spring, Mesquite Flat	5-15-74	18.5	37	100	58	65	340	23	670
14S/45E-30B6	Test well south of Triangle Spring (Depth: 59 ft)	4-28-68	26.5	24	<30	37	59	360	21	420

'eath Valley National Monument and vicinity

	Sulfate (SO₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO₃)	Dissolved solids	Hardness as calcium carbonate		Percent sodium	Boron	Specific conductance	pH	Analyst
						Ca,Mg	Noncarbonate					
ded and faulted Precambrian sedimentary rocks)												
..	1,040	657	--	1.7	3,100	225	--	--	--	--	--	USGS
	1,030	680	2.8	3.4	3,080	229	0	88	9,500	4,680	7.8	USGS
	1,040	690	--	5.1	3,080	228	0	88	9,600	4,680	7.9	USGS
	1,040	650	2.4	3.4	3,050	172	0	91	9,600	4,720	8.0	USGS
	1,020	702	--	9.9	3,040	240	--	88	10,000	4,650	8.2	USDA
	1,040	680	2.2	4.7	3,080	222	--	89	--	4,640	8.1	USGS
	1,010	690	2.5	2.9	3,040	265	0	88	9,600	4,700	7.9	USGS
-	912	2,870	8.1	3.1	6,700	1,135	697	--	7,500	10,100	7.7	DWR
	1,290	775	6.0	5.9	3,900	108	0	96	14,000	5,880	8.5	USGS .
	590	540	3.0	.0	2,500	5	0	99	9,100	3,900	8.8	USGS
	540	462	3.8	.0	2,300	15	0	98	8,600	3,480	8.6	USGS
stalline bedrock												
.	8.0	18	.3	0	459	310	--	26	230	712	8.2	USGS
.	42	50	1.7	19	314	220	76	32	551	220	8.1	USGS
.	38	27	.6	14	305	160	--	32	200	478	8.0	USGS
.	200	30	2.6	.4	667	190	--	65	1,400	1,010	7.8	USGS
.	88	57	.5	1	365	210	--	--	780	729	7.8	DWR
estone and dolomite												
.	140	31	5.0	.6	572	300	--	57	420	880	7.8	USGS
.	34	26	0	--	224	150	23	27	410	415	8.2	USGS
.	110	5.0	.2	.1	307	220	92	12	20	480	8.2	USGS
canic rock												
.	93	46	1.9	1.7	484	24	--	91	1.0	710	7.9	USGS
.	16	24	.2	4.7	229	74	--	40	200	308	6.9	USGS
.	21	15	.6	.6	212	19	--	81	300	265	7.8	USGS
.	79	64	.8	13	533	14	--	94	1,300	797	7.1	USGS
ustrine deposits												
.	660	430	5.2	24	1,960	140	--	--	3,960	3,060	8.5	DWR
.	2,900	220	1.1	.6	5,390	1,200	860	63	590,000	5,830	8.0	USGS
dstone and conglomerate												
.	480	32	10	.2	869	65	21	89	640	1,240	6.6	USGS
.	240	73	1.3	.9	1,090	500	--	44	1,300	1,690	6.9	USGS
.	360	210	1.5	2.2	1,430	410	--	63	3,200	2,210	8.1	USGS
.	360	280	1.5	.0	1,360	340	--	68	4,600	2,180	8.3	USGS

TABLE 3.--*Chemical analyses of water in Death*

Identification No.	Source	Date	Temperature	Silica (SiO$_2$)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO$_3$)
										Ground water from
16S/43E-20FS1	Spring in Cottonwood Canyon	4-28-68	--	46	<30	61	23	52	2.7	350
17S/44E-27BS1	Emigrant Spring, Panamint Range	12-10-59	14.5	23	--	28	20	28	2.7	180
26N/2E-13FS1	Navel Spring, Furnace Creek	5-16-74	23	18	250	30	11	160	8.4	300
										Ground water from
15S/44E-4Q1	Test well on Cottonwood Fan (Depth: 92 ft)	5- 7-72	30	70	60	100	61	550	61	520
15S/44E-33B1	Test well on Cottonwood Fan (Depth: 78 ft)	4-30-68	30.5	48	<30	150	66	830	62	480
15S/44E-36K1	Stovepipe Wells Hotel (Depth: 80 ft)	3-21-67	29	82	10	170	250	2,660	170	360
15S/45E-1SD1	Stovepipe Wells (Depth unknown)	4- 9-52	--	--	--	16	38	600	--	760
18N/5E-14J1	South Death Valley (Depth: 67 ft)	5- 2-68	26	--	--	130	110	1,380	52	190
										Ground water near the
23N/1E-35Z1	Mesquite Well (Depth: 10 ft)	4-22-32	15	37	--	430	320	2,050	92	320
24N/1E-15DS1	Eagle Borax Spring	11- -54	--	42	--	610	270	760	28	320
24N/1E-15F1	Artesian test well at Eagle Borax Spring (Depth: 50 ft)	5-17-74	28.5	28	50	63	35	110	7.5	110
24N/1E-27D1	Test well near Bennetts Well (Depth: 32 ft)	4-27-68	29.5	--	--	48	78	74	4	130
24N/2E-4BS1	Badwater Spring	1-30-59	11.5	26	16,000	830	95	8,050	330	110
25N/1E-33F2	Artesian test well at Tule Spring (Depth: 52 ft)	3-22-70	21	21	--	75	40	250	7.0	130
										Ground water from
24N/2E-6Z1	Test well near Badwater (Depth: 32 ft)	1914	--	--	--	200	140	105,900	3,700	--
25N/1E-33H1	Test well 0.4 mi east of Tule Spring (Depth: 52 ft)	3-12-70	27.5	--	--	14	13	2,400	470	790
										Surface
14S/44E-32M	Flash flood, Cottonwood Fan (Discharge: 2 ft^3/s)	6- 1-72	20	9.1	310	15	3.7	98	12	110
15S/44E-4N	Flash flood, Cottonwood Fan (Discharge: 5 ft^3/s)	6- 1-72	20	3.3	70	8.2	1.3	15	4.9	55
18N/6E-12M	Amargosa River at Highway 127 (Discharge: 0.6 ft^3/s)	3-21-67	14.5	22	120	22	56	1,070	49	910
										Summary of water quality
--	Furnace Creek Ranch (Travertine and Texas Springs)	--	31	25-40	--	30	20	150	10-15	330
--	National Park Service living area (Nevares Springs)	--	38	--	--	40	20-30	140-250	15	300-400
--	Stovepipe Wells Hotel nonculinary water (wells)	--	29.5	80	10-100	110-170	130-250	1,300-2,600	80-170	350-550
--	Emigrant Ranger Station (Emigrant Spring)	--	--	--	--	30-50	20-40	30	2	100-300
--	Wildrose Ranger Station (Spring 19S/44E-23KS4)	--	20	--	30	85	30	30	5	125
--	Grapevine Ranger Station (Surprise Springs)	--	20	64	--	7	1	150	8	230
--	Scottys Castle (Stainingers Spring)	--	26.5	--	10	5	1	140	7	210

Valley National Monument and vicinity--Continued

Carbonate (CO₃)	Sulfate (SO₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO₃)	Dissolved solids	Hardness as calcium carbonate		Percent sodium	Boron	Specific conductance	pH	Analyst
						Ca,Mg	Noncarbonate					
fanglomerate deposits												
--	16	34	0.6	0	409	250	--	31	410	652	8.2	USGS
0	23	26	.25	10	312	160	S	28	240	431	7.7	DWR
--	100	76	2.0	31	590	120	--	73	3,200	1,030	8.2	USGS
alluvial fans												
--	420	660	4.2	.9	2,190	500	71	67	3,600	3,640	7.5	USGS
--	440	1,200	3.6	.0	3,080	660	260	71	6,800	5,110	7.6	USGS
--	1,700	3,900	1.0	30	9,170	1,400	1,200	96	24,000	14,400	7.4	USGS
--	460	290	1.1	--	2,250	--	--	--	4,200	3,640	8.1	DWR
--	760	2,000	4.8	3.5	4,760	770	--	78	9,000	7,360	7.6	DWR
edge of the saltpan												
--	610	4,400	--	.6	8,160	--	--	64	6,700	14,000	7.6	USDA
--	1,400	1,800	1.2	.7	5,130	2,600	--	38	4,400	7,730	7.1	USGS
--	170	200	.4	.2	673	500	210	44	580	1,190	7.9	USGS
--	180	43	.8	0	495	190	--	--	680	692	7.5	DWR
--	2,800	11,400	9.8	0	23,600	2,500	2,400	86	344,000	35,000	7.5	USGS
--	250	400	.3	.0	1,100	350	250	60	1,300	1,840	7.4	USGS
the saltpan												
--	22,600	150,000	--	--	285,000	1,060	--	98	--	--	--	USGS
--	470	3,600	5.4	.00	--	--	--	--	--	12,100	8.1	DWR
water												
--	36	110	2.1	9.3	349	53	--	76	1,100	612	7.1	USGS
--	8.7	9.1	.3	5.3	83	26	--	50	240	148	7.4	USGS
96	1,010	500	5.3	1.3	3,290	285	--	87	11,000	4,870	8.6	USGS
at major points of use												
0	160	50-50	3-4	0-4	600-700	160	--	65	0-2,000	1,000	7.5-8.5	--
0-10	170-300	30-80	3-4	0-2	600-900	200	--	65	1,000	1,500	8	--
0	700-1,700	2,000-4,000	1-2.5	5-30	3,000-9,000	800-1,500	--	80	10,000-30,000	5,000-15,000	7.5	--
0	20	20	.3	5-10	250-300	160	--	30	250	400-500	7.5-8.5	--
0	260	10-20	1	0-1	500-600	340	--	15	--	800-900	7.5	--
0	90	50	2	2	500	25	--	90	1,000	700	8	--
--	90	50	2	2	400	15	--	90	500	660	8	--

Ground water in crystalline bedrock terranes such as occurs in the Black Mountains, the southern Panamints, Hunter Mountain, and in the northernmost part of the valley, typically is a calcium-sodium bicarbonate type, is moderately hard, and contains 300 to 500 mg/L dissolved solids. The largest supplies of water readily available from the crystalline rocks are at Cottonwood Springs (16S/42E-25KS1) in the Hunter Mountain area, Willow Spring (23N/3E-54JS1) in Gold Valley, and Willow Spring (23S/46E-30LS1) in Butte Valley.

Ground water from springs that appear to discharge from local hydrologic systems in limestone and dolomite of Precambrian Z and Paleozoic age varies widely in chemical makeup. The major anion generally is bicarbonate, and calcium, magnesium or rarely sodium may be the major cation. The water typically is hard and contains 200 to 500 mg/L or more dissolved solids. The carbonate rocks commonly contain secondary minerals as the result of metamorphism and introduced vein material, which may account for the varied water chemistry.

Ground water in volcanic rocks of Tertiary and Quaternary age typically contains 200 to 500 mg/L of dissolved solids, and the predominant ions are sodium and bicarbonate. The water is soft, possibly attributable to ion exchange in tuffaceous material.

Most lacustrine rocks of Tertiary age contain ground water that is high in dissolved solids. The predominant ions typically are sodium and sulfate, and the water commonly contains several hundred milligrams per liter of chloride and is high in fluoride and boron.

Ground water in sandstone and conglomerate of Tertiary age varies considerably in its dissolved constituents; typically it contains from several hundred to a few thousand milligrams per liter dissolved solids, and the predominant ions are sodium and bicarbonate. The concentration of fluoride commonly exceeds 1 mg/L, and the water is hard.

Several springs issue from semiconsolidated fanglomerate of Tertiary and (or) Quarternary age. Water from these deposits generally contains between 200 and 1,000 mg/L dissolved solids, the water is soft to moderately hard, and its dissolved constituents reflect somewhat the principal type of rock in the fanglomerate. The predominant anions generally are bicarbonate and sulfate, and the predominant cations generally are calcium and sodium.

Ground water in alluvial fans of Quaternary age in central and southern Death Valley typically contains a few thousand milligrams per liter dissolved solids. Limited data suggest that much of the ground water in fan deposits north of Mesquite Flat and east of the higher part of the Panamint Range contains 500 to 800 mg/L dissolved solids. The predominant ions in the poor-quality water in alluvial fans are almost invariably sodium and chloride, and sulfate and bicarbonate are commonly present in concentrations of several hundred milligrams per liter each. The water is hard, and much of it contains several milligrams per liter of fluoride and boron. The predominant ions in the better quality water in the alluvial fans typically are sodium and bicarbonate; in some areas sodium and sulfate or chloride are predominant.

Ground water in alluvial deposits around the edge of the saltpan is highly variable in quality, depending largely on the local rate of recharge by fresh water, the presence of saline deposits, and the effects of evapotranspiration. For example, on the west side of the saltpan, water from Eagle Borax Spring, which discharges into a swampy area of dense phreatophytes, contains about 5,000 mg/L dissolved solids. A nearby test well, 50 ft deep, encountered artesian (flowing) water containing less than 700 mg/L dissolved solids. The water from the spring, of sodium chloride type, is hard and contains several milligrams per liter of fluoride and boron. The better water, such as from test holes at Bennetts Well and near Eagle Borax Spring, contains 500-700 mg/L dissolved solids, is hard, and contains sodium, sulfate, and chloride as the major ions.

Much of the saltpan contains ground water that is at or near saturation with sodium, chloride, and sulfate.

The quality of surface water during local storm runoff into the valley is highly variable, depending in large part on the solubility of surface material over which flow occurs. Most of the stormflow in the Amargosa River originates outside Death Valley and contains 5,000 to 30,000 mg/L dissolved solids (Hunt and others, 1966, fig. 50).

Two samples of surface flow were collected June 1, 1972, during runoff from a summer thunderstorm on the Cottonwood Canyon alluvial fan. The water, which had travelled half a mile to a mile across the fan before being sampled, was surprisingly fresh. Flow of about 5 ft^3/s in a channel contained only 83 mg/L dissolved solids; a flow of 2 ft^3/s in a channel a few miles away contained 349 mg/L dissolved solids. The major ions in both samples were sodium, bicarbonate, and chloride. (See "Surface water" in table 3).

A summary of the quality of water supplies at the major points of use by man in the valley is included in table 3. The overall quality, in terms of dissolved solids, is equal to or better than that of the supplies available to many users in the southwestern United States.

HYDROLOGIC AREAS

For discussion in this report, the monument was subdivided into eight areas (fig. 8), each being relatively homogeneous in its hydrologic regime. For each area the geology and the occurrence, movement, quality, and availability of water are discussed, and needs for additional data are pointed out.
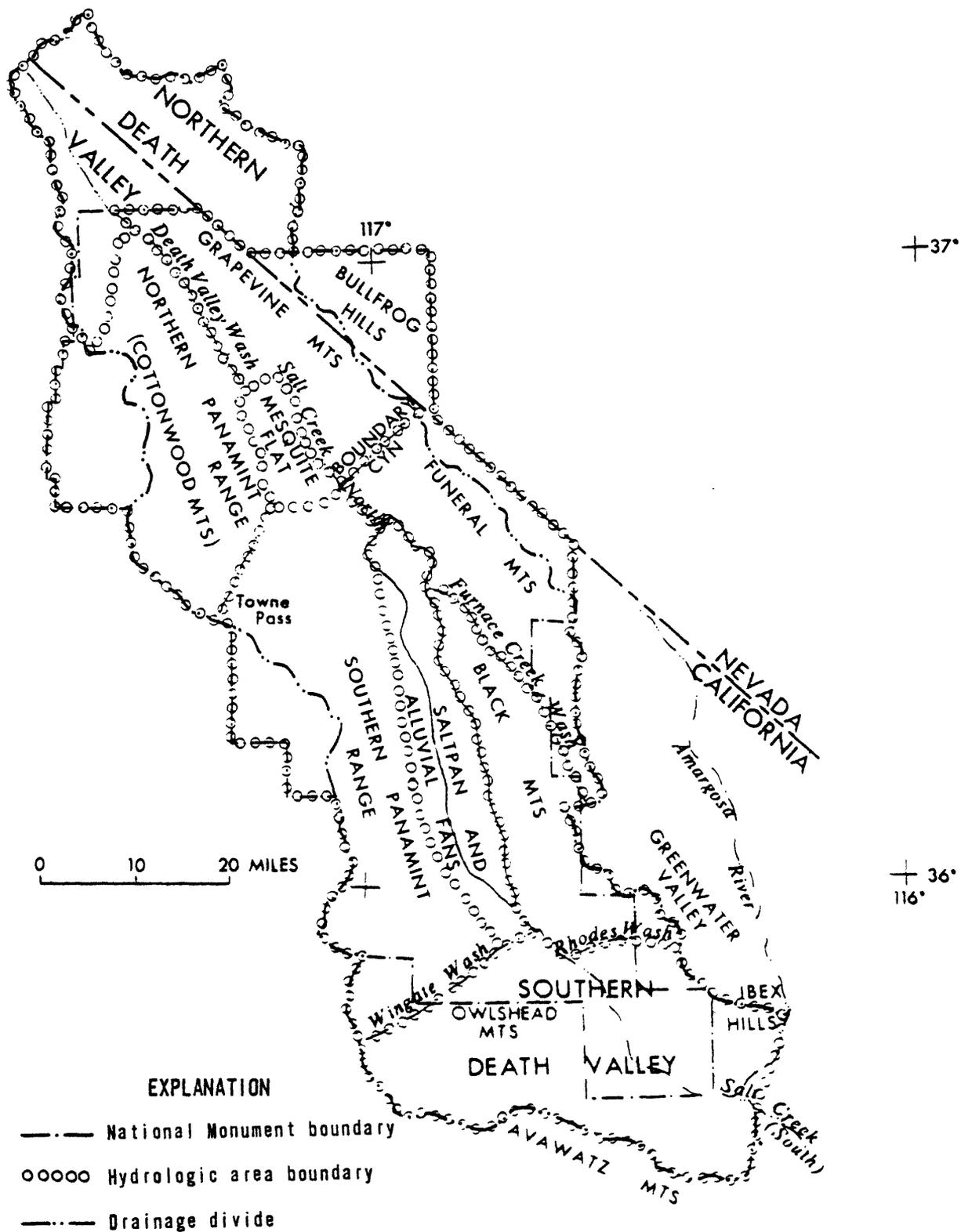
Figure 8.--Hydrologic areas discussed in report.

Southern Death Valley

The southern Death Valley hydrologic area includes the valley floor, the north slope of the Avawatz Mountains, the Owlshead Mountains, the Black Mountains south of Rhodes Wash, and the Ibex Hills. Much of the valley floor here appears to be underlain by several hundred feet of alluvial sand, silt, and gravel of Quaternary age. Shale, siltstone, and evaporite deposits of Tertiary age crop out locally. The largest outcrop is a belt of folded evaporite-bearing beds north of the Avawatz Mountains along the southern part of the valley floor. The belt is about 9 mi long. Rock salt and associated saline deposits of Tertiary age crop out in this belt and may underlie much of the valley floor. The beds are well exposed in Salt Basin, about 4 mi south of Saratoga Spring. Gravelly and bouldery alluvial-fan deposits mantle much of the slope between the valley and the mountain fronts. As noted by Mendenhall (1909), these fan deposits are exceptionally bouldery along the north slopes of the Avawatz Mountains. The fans derived from granitic rocks in the Owlshead Mountains are much less bouldery. Fan deposits in major washes locally are thin; a dry test hole in Buckwheat Wash was bottomed in consolidated carbonate rocks at a depth of 31 ft. Granitic rocks probably underlie much of the fan deposits on the north slope of the Avawatz Mountains.

The Amargosa River enters the area from the northeast and drains the valley toward the saltpan on the northwest (fig. 8). Perennial flow occurs in the river in a short reach below Valley Spring (19N/4E-24S1). A perennial flow of brackish water in Salt Creek (south) enters the area from the southeast but sinks into the alluvium a short distance downstream from a granitic bedrock gorge.

Ground water moves into the valley from the surrounding mountains and alluvial fans, as underflow beneath the Amargosa River, and probably as interbasin underflow from the north. The water then moves northwestward down the valley toward the saltpan. The water table is near the surface from Saratoga Spring to below Valley Spring, and considerable evapotranspiration occurs in this reach where salt-crusted, puffy, efflorescent ground and phreatophytes are common. Details of the flow system are not well known; however, the gradient appears to range from about 10 ft/mi north of the Confidence Hills to at least 20 ft/mi near Valley Spring.

All ground water sampled in the valley floor in southern Death Valley contains more than 3,000 mg/L dissolved solids, and the major ions are sodium, chloride, and sulfate. Water from most springs in the Avawatz Mountains contains a few hundred to several hundred milligrams per liter dissolved solids; the predominant ions typically are sodium, bicarbonate, and sulfate. Calcium, magnesium, and sulfate are the predominant ions in water from several springs. Massive beds of rock salt and other evaporites probably contribute salt to the local ground water. Water from a test hole 67 ft deep (18N/5E-14J1), about 2 mi northeast of and apparently downgradient from Salt Basin, contained 4,760 mg/L dissolved solids; the major ions were sodium and chloride.

Rhodes Wash, near Rhodes Spring (21N/4E-11MS1) and Bradbury Well (21N/4E-15R1), appears to be one of the more promising areas for developing a potable ground-water supply in southern Death Valley. On January 13, 1967, and March 23, 1970, Rhodes Spring was flowing about 6 gal/hr from a sump in gneissic bedrock. During a flow test, the water level in the spring was drawn down 2 ft, and the level recovered at a rate that indicated a capacity of half a gallon per minute. The water, sampled at the end of the drawdown period, contained 667 mg/L dissolved solids, and the predominant ions were sodium and bicarbonate (table 3). An earlier sample (January 13, 1967) contained only 490 mg/L dissolved solids. The quality of this water makes it useful for many purposes, although the concentration of fluoride (2.6 mg/L) is above the limit recommended by the U.S. Environmental Protection Agency (1972).

Bradbury Well is in weathered crystalline rock on a highly fractured east-trending fault zone. The well is partially filled with debris and was dry at a depth of 10 ft on January 13, 1967. A test hole (21N/4E-15R2) about 25 ft northeast of Bradbury Well was augered to a depth of 27 ft. The water level was about 12 ft below land surface in this well February 20, 1969. The specific conductance of the water was 1,500 micromhos, which suggests that the concentration of dissolved solids was about 1,000 mg/L. A sample of water from Bradbury Well, taken in 1932, contained 1,018 mg/L dissolved solids, and the predominant ions were sodium, sulfate, and bicarbonate.

Black Mountains

The Black Mountains hydrologic area includes the Black Mountains between Rhodes Wash and Furnace Creek Wash. The topographic divide is almost everywhere near the east side of the area, and nearly all the area drains directly westward into Death Valley.

Most of the mountain mass is crystalline bedrock, chiefly gneiss of Precambrian age and quartz monzonite of Cretaceous or early Tertiary age. Volcanic rocks of Tertiary age blanket much of the northern and eastern parts of the mountains, and sedimentary rocks of Tertiary age crop out in the northern part of the area. Alluvial deposits of Tertiary and Quaternary age occur in some of the high mountain valleys, notably Rhodes Wash, Gold Valley, and Copper Canyon. Intensely faulted sedimentary rocks of Precambrian Z and Cambrian age crop out in an east-west belt along the south edge of the area (Noble, 1941). The western front of the mountains typically is marked by steep slopes related to fault scarps of the Death Valley and Amargosa fault zones (Hunt and Mabey, 1966).

Perennial streamflow in the Black Mountains occurs only in a short reach of a bedrock gorge downstream from Willow Spring in Gold Valley. Runoff during infrequent flash floods from the steep mountain front into Death Valley has built up short, steep alluvial fans and cones of boulders and bouldery mudflow material between much of the mountain front and the saltpan.

Several small seeps and springs discharge ground water into small manmade or natural pools that provide water for wildlife. Average annual precipitation is slight in the high mountains, perhaps 3 or 4 in, and recharge to ground water occurs as seepage through alluvial channels during infrequent flash floods.

Because of the widespread and almost impermeable crystalline bedrock, the ground-water divide probably coincides with the topographic divide, and most ground water moves toward Death Valley.

Water from the springs and seeps contains 300 to almost 1,000 mg/L dissolved solids, and the major ions typically are sodium and bicarbonate.

Virgin Spring (21N/4E-6AS1), Hidden Spring (23N/3E-37QS1), spring 22N/3E-34DS1 in Scottys Canyon, and Lemonade Spring (25N/2E-13GS1) probably flow perennially, although the flow from each is a small fraction of a gallon per minute during much of the year. Willow Spring in Gold Valley is the largest spring in the area, the flow averaging 10 gal/min during much of the period 1967-72.

Several seeps and springs in Sheep Canyon reported to be flowing during the 1940's and 1950's were dry when examined April 6, 1967, and they appeared to have been dry for many years. Locally in the canyon, some of the mesquite clumps and other phreatophytes (phragmites and arrowweed) seemed to be growing vigorously, indicating that ground water is near the surface. Several cottonwood trees were dead or distressed, probably as a result of a lowered water table. All phreatophytes are on the north side of the steep canyon wall, and many seemed to be rooted in weathered crystalline bedrock several feet above the alluvium-filled channel. These sites probably are good prospects for developing small water supplies for wildlife by drilling near-horizontal holes into the bedrock of the north wall of the canyon.

Recharge during flash floods that reach the alluvial fans near the saltpan may result in local lenses of fresh ground water floating on the near-saturated, heavier brines beneath the valley floor. The most likely place for this to occur is beneath the coalescing fans at the mouths of Sheep Canyon and Willow Creek and the fan at the mouth of Copper Canyon.

Funeral Mountains

This hydrologic area includes the Funeral Mountains, the alluvial fans extending from them into Death Valley, and part of the alluvial valley east of the mountains (fig. 8).

Folded and faulted sedimentary rocks of Precambrian Z and Cambrian ages form the central and northern parts of the Funeral Mountains. The rocks there become more metamorphosed, and progressively older rocks are exposed, from the central Funeral Mountains to the north end. The degree of metamorphism ranges from phyllitic phases in the south to rocks of the amphibolite phase that contain staurolite, garnet, muscovite, and kyanite in the Chloride Cliff-Monarch Canyon area (Troxel, 1974). This results in a general decrease in porosity and probably in permeability in these rocks from south to north. Dolomite, limestone, and quartzite of Paleozoic age make up the southern part of the Funeral Mountains south of the latitude of Nevares Peak. These rocks are folded and broken by many north- and northeast-trending faults.

Sedimentary rocks of Tertiary age, mostly mudstone, shale, sandstone, and conglomerate, crop out at several places on the westward-sloping alluvial apron of the Funeral Mountains. A thin mantle of alluvial-fan deposits of Holocene age. overlies these rocks. The fan deposits consist, in large part, of channel deposits composed of discontinuous beds of sandy gravel and poorly sorted mudflow material.

Ground water occurs in fractures and solution openings in the rocks of Precambrian and Paleozoic age. The carbonate rocks probably are the most permeable of the consolidated rocks in the area (Winograd and Friedman, 1972, p. 3693, 3704; Winograd and Thordarson, 1975; Maxey, 1968, p. 16) and are considered to be part of an aquifer system through which water moves from the Amargosa Desert to discharge at several large springs near Furnace Creek and at Keane Wonder Spring (15S/46E-1RS1). Some of this underflow probably continues westward and finally discharges at marshy areas along the edge of the saltpan between Furnace Creek Wash and Salt Creek Hills. The occurrence and movement of ground water at Travertine, Texas, and Nevares Springs have been greatly altered by manmade diversions, whereby most of the flow, which formerly seeped into alluvial deposits below the springs and then moved toward the valley, is now piped downslope a few miles for use.

Little local recharge occurs; small springs near Indian Pass, in Monarch Canyon, and at Navel Spring (18S/2E-13FS1) seem to be fed by local recharge. They discharge at higher altitudes than the water level in wells across the mountains in the Amargosa Desert. Some reportedly go dry at times, and at some the discharge rate reportedly increases greatly following rainstorms. Local recharge by seepage of floodwater to the alluvium in the lower reaches of Furnace Creek and to the large alluvial fan at Furnace Creek Ranch has been drastically diminished during the past few decades because of a manmade diversion of Furnace Creek Wash into Gower Gulch at Zabriskie Point (Troxel, 1974). This diversion also caused great changes in the erosional-depositional regime of the channels.

The large springs in this area, all considered to be a part of an interbasin underflow system, were discussed earlier in this report.

The quality of ground water, as measured by the concentration of dissolved solids, varies widely, from about 600 mg/L at Keane (30N/1E-7AS1), Travertine, Texas, Nevares, and Navel Springs to about 1,500 mg/L at the springs in the canyon east of Indian Pass, and to about 3,000 mg/L at Keane Wonder Spring. The predominant ions in water from most springs are sodium, bicarbonate, and sulfate. Fluoride exceeds 2 mg/L in many of the springs.

Most springs in the area that are near roads or mines have been developed by man to some degree. The large springs near Furnace Creek have elaborate collection facilities and several miles of pipeline to convey water to points of use. Some of the remote springs in the canyon east of Indian Pass reportedly flow intermittently; however, clumps of mesquite and tamarisk reportedly grow at the springs and indicate that a perennial supply of ground water exists at shallow depths. This probably could be developed as a reliable water supply for wildlife.

Grapevine Mountains

This area includes the Grapevine Mountains between Daylight Pass and the north boundary of the monument, the part of the monument in Nevada (including the Bullfrog Hills), and the alluvial fans extending into Death Valley Wash.

The southern and central parts of the Grapevine Mountains are underlain chiefly by intensely folded and faulted sedimentary rocks of Paleozoic age. Limestone, dolomite, quartzite, and siltstone are the common types of rocks (Reynolds, 1966). Similar rocks crop out in a small area between Grapevine Springs and the northern boundary of the area. Basaltic volcanic rocks of Tertiary age cover much of the northern Grapevine Mountains, and sedimentary and volcanic rocks, in large part tuffaceous beds of Tertiary age, overlie the Paleozoic rocks of the mountain core along much of the eastern flank of the mountains.

The Bullfrog Hills are made up largely of scattered, resistant outcrops of volcanic rocks of Tertiary age and a few exposures of sedimentary rocks of Paleozoic age and crystalline rocks of Precambrian age. Apparently thin alluvial-fan deposits of Quaternary age lie between the hills. Somewhat thicker alluvial-fan deposits occur in a broad area at the north end of the Amargosa Desert between the Bullfrog Hills and the Grapevine Mountains and at the south end of Sarcobatus Flat.

Thin alluvial-fan deposits of Quaternary age overlie and partly cover folded and faulted sedimentary rocks of Tertiary age in small areas west of the mountain front. Near Mesquite Spring (11S/42E-27RS1), shale and siltstone of Tertiary age crop out in low hills near Death Valley Wash. Folded and faulted fanglomerate of Tertiary and Quaternary age crops out in the west-central foothills of the Grapevine Mountains.

Ground water occurs in fractures and solution openings in the sedimentary rocks of Paleozoic age. These rocks are almost everywhere intensely folded and locally are faulted into coarse breccia zones. The Paleozoic rocks probably transmit ground water through the Grapevine Mountains from Sarcobatus Flat, and perhaps from the Amargosa Desert, to Death Valley. Also, several small springs discharge from apparently perched ground-water bodies in these rocks along the western slope of the mountains.

Water occurs both in fractures and in intergranular spaces in rocks of Tertiary age and in fractures and interflow zones of the volcanic rocks. The sedimentary rocks of Tertiary age that crop out along the east flank of the mountains contain beds of shaly siltstone and volcanic tuff. These beds are tilted generally eastward. To the depth that they extend, they may retard the flow of ground water into the underlying Paleozoic rocks from the alluvium-filled Amargosa Desert. Sedimentary rocks of Tertiary age that crop out along the west flank of the mountains consist for the most part of silty sandstone and mudstone that contain water in the interstices. Numerous small springs and seeps discharge from these beds.

Alluvium of Quaternary age is an important aquifer in the Amargosa Desert, in Sarcobatus Flat, and probably in Death Valley Wash. Alluvium-filled channels in the Bullfrog Hills and in the mountains transmit recharge to the underlying rocks during periods of runoff.

The chemical quality of the water from small springs and seeps in the mountains is generally good when compared with other desert areas. The concentration of dissolved solids, based on chemical analyses and as estimated from specific conductance, is as low as 150 mg/L in several springs and is less than 500 mg/L in most springs. Sodium and bicarbonate are the predominant ions, and the concentration of fluoride commonly is between 2 and 5 mg/L.

Dissolved solids range from about 400 to 700 mg/L in the large springs at Scottys Castle (Grapevine Springs) and at Mesquite Spring. Sodium, bicarbonate, and sulfate are the most abundant ions in the water.

Many of the small springs and seeps reportedly go dry during the summer months and during prolonged dry periods. Their reliability as a source of water for wildlife could be improved by proper development and by reduction in the density of phreatophytes.

Northern Death Valley

The Northern Death Valley hydrologic area encompasses the valley floor north of the monument boundary and the Death Valley drainage of the Gold Mountain and Slate Ridge highlands to the east, Magruder Mountain to the north, and the Last Chance Range and Dry Mountain on the west.

Sedimentary rocks of Precambrian age crop out on Magruder Mountain and in small areas on Gold Mountain and Slate Ridge. These rocks consist of limestone, siltstone, dolomite, and quartzite, all intensely folded and faulted. Some are metamorphosed locally. Sedimentary rocks of Paleozoic age, chiefly carbonate rocks and quartzite, crop out along the east side of the Northern Death Valley-Furnace Creek fault zone at and north of Grapevine Springs and on Magruder Mountain and form most of the Last Chance Range and Dry Mountain. Granitic rocks of Mesozoic age crop out in Oriental Wash and underlie much of the foothill area between Magruder Mountain and Death Valley. Rhyolitic ash flows, indurated tuff, and basalt, all of Tertiary age, form the foothills south of Gold Mountain, and similar rocks occur locally in the Last Chance Range. Sedimentary rocks and other deposits of Tertiary age, mostly shale and mudstone, crop out in a few places in the Last Chance Range. Most of the valley floor is covered with alluvial-fan deposits of sand and gravel of Quaternary age, which probably overlie sedimentary deposits of Tertiary age. Several narrow, elongate hills of shale and mudstone of Cenozoic age occur along the Northern Death Valley-Furnace Creek fault zone between Little Sand Spring and the north end of the valley, and lacustrine beds and volcanic ejecta of Quaternary age occur in the valley floor at the south edge of the area near Ubehebe Crater.

Sedimentary rocks of Precambrian and Paleozoic age contain ground water in fractures in siltstone, shale, and quartzite and in solution features in carbonate rocks. Several springs issue from siltstone and shale beds along faults on the southern slope of Magruder Mountain. Last Chance Spring (8S/39E-2KS1) flows several gallons per minute from fractured limestone in a fault zone on the east slope of Last Chance Mountain; however, it and a smaller nearby spring are the only springs known in the Death Valley drainage of the Last Chance Range and Dry Mountain. This is unusual when compared with other nearby mountain ranges, considering that the altitude of much of the crest of the range is between 6,000 and 7,000 ft. The faulted and fractured carbonate rocks that underlie the range apparently are highly permeable and rapidly conduct recharge from flood runoff downward, where it moves by underflow into the alluvium-filled valley.

Similarly, no springs occur in the large area of highly permeable volcanic rocks of Tertiary age southwest of Gold Mountain. Sand Spring (9S/41E-7RS1) and Little Sand Spring issue from soft sedimentary rocks of Cenozoic age along the Northern Death Valley-Furnace Creek fault zone.

Ground water moves generally from areas of recharge in the mountains toward the valley floor, then southeastward down the valley, probably through alluvial-fan deposits and underlying sedimentary rocks of Tertiary age. This pattern of movement is deduced largely from the general physiographic, hydrologic, and geologic features in the area; few wells and springs exist in the valley to substantiate details of ground-water movement. The geohydrologic setting at Sand Spring and Grapevine Springs in the northern Grapevine Mountains area suggests that the Northern Death Valley-Furnace Creek fault zone is a barrier to the movement of ground water, with much higher ground-water levels on the northeast side of the fault. Sand Spring and Little Sand Spring are at an altitude between 60 and 80 ft above the dry course of Death Valley Wash half a mile to the west, and the Grapevine Springs discharge is about 600 ft in altitude above the wash. No data are available on the depth to ground water beneath the wash, so the total difference in water level across the fault is not known.

Water in springs that issue from granitic rocks is of good to excellent quality; the concentration of dissolved solids in most of the springs, based largely on specific conductance of the water, ranges from about 200 to 400 mg/L. Water from most springs that issue from sedimentary rocks of Precambrian and Paleozoic age and volcanic rocks of Tertiary age contains 200 to 300 mg/L dissolved solids, and water from sedimentary rocks of Cenozoic age at Sand Spring and Little Sand Spring contains 650 to 850 mg/L dissolved solids. The major ions in water from these two springs are sodium and sulfate. A few wells and springs in canyons on the southern slope of Magruder Mountain are in thin alluvial deposits of sand and gravel of Quaternary age. Water from these contains about 300 mg/L dissolved solids. At most wells and springs in the area, there is evidence of development by man for stock and mining uses.

Cottonwood Mountains

The Cottonwood Mountains hydrologic area includes the northern Panamint Range from Towne Pass on the south to Tin Mountain on the north. It extends westward to the monument boundary and includes Ubehebe Peak and Racetrack Valley. The eastern boundary is Death Valley Wash and the west edge of Mesquite Flat.

The northern three-fourths of the Cottonwood Mountains is precipitous terrain underlain by fractured and folded sedimentary rocks of Paleozoic age. These rocks consist chiefly of limestone, dolomite, and shale. Locally, about 4 mi southeast of Tin Mountain, they are intruded by small bodies of igneous rock. Most of the southwestern part of the area consists of steeply rolling slopes underlain by weathered granitic rocks, mostly quartz monzonite of Mesozoic age, which is in sharp intrusive contact with the Paleozoic rocks.

The southernmost part, between Panamint Butte and Towne Pass, consists of steep, rugged terrain carved into sedimentary rocks of Paleozoic age that are locally overlain by basalt flows of Quaternary age. Alluvium of Quaternary age floors several intermontane valleys in the southwestern part of the area, notably Racetrack Valley, Sand Flat, Ulida Flat, Hidden Valley, and an area in the valley of Cottonwood Canyon above Cottonwood Springs. All but the last mentioned of these valleys are closed topographic basins. Alluvial-fan deposits of Quaternary age extend into Death Valley from the mountain front. The largest fan, which covers almost 20 mi^2, extends into the valley from the mouth of Cottonwood Canyon.

About 10 small springs and seeps issue from Paleozoic rocks in the northern three-fourths of the mountain range. Several flow perennially and make up the total water supply for about 200 mi^2 of bighorn sheep range. Dozens of small springs and seeps issue from the fractured and weathered granitic rocks in the southern part of the area that is east of Hunter Mountain. Feral burros, a few wild horses, and deer utilize these springs. Cottonwood Springs, one of the largest springs in the monument, flows from alluvium at a granitic bedrock narrows in Cottonwood Canyon.

Ground water flows generally eastward toward Death Valley from areas of recharge in the mountains. Ground-water flow toward the valley is also probable from some or all of the closed basins mentioned above. Ground water does not discharge at the surface from any of these closed basins, and an almost continuous belt of nearly impermeable granitic rock lies west of the basins. At the north end of Racetrack Valley, however, inconclusive evidence from the geologic setting and from a deep well drilled for mineral exploration suggests that some ground water there may move toward the west and discharge into Saline Valley.

Water from several springs that issue from sedimentary rocks of Paleozoic age generally contains 500 to 1,200 mg/L dissolved solids, and the predominant ions are calcium, magnesium, and sulfate. Ground water from seeps and springs in the granitic rocks contains 250 to 400 mg/L dissolved solids, and the major ions are calcium, sodium, and bicarbonate. Ground water in several test holes near the toes of alluvial fans that extend into central and southern Mesquite Flat contains a few thousand milligrams per liter dissolved solids. Sodium and chloride typically are the major ions. Ground water in these fan deposits probably is of better quality beneath the higher parts of the fans near the mountain front.

During two pack trips made to investigate springs in the Cottonwood Canyon-Marble Canyon drainages in the Hunter Mountain area early in 1968, no live bighorn sheep were seen in this well-watered area. Several dozen burros were seen, and most springs and seeps were trampled and contaminated by burro fecal matter so that the water was discolored and malodorous; the water from most springs and seeps was judged unsafe for drinking and unsuitable for obtaining a representative sample for chemical analysis.

Southern Panamint Range

This hydrologic area includes the rugged Panamint Range between Tucki Mountain and Towne Pass on the north and Wingate Wash on the south. The area extends westward to the monument boundary, which coincides with the mountain crest in the south-central part of the range and includes some areas at high altitude in the northern part that drain into Panamint Valley. The southern Panamints make up the highest mountain mass in the area.

Sedimentary rocks of Precambrian Z and Paleozoic age form most of the mountain mass. These rocks consist chiefly of dolomite, limestone, quartzite, and shale, all intensely folded and faulted. The Precambrian rocks are progressively more metamorphosed from south to north. Sedimentary and volcanic rocks of Mesozoic age crop out in a small area east of Butte Valley. Granitic rocks of Mesozoic age occur as intrusive masses in Butte Valley, Anvil Spring Canyon, and Warm Spring Canyon. Intrusive rocks of Tertiary age occur in Hanaupah Canyon, and the granite at Skidoo is Tertiary or Mesozoic in age. Granitic basement may underlie most of the range at shallow depths (Hunt and Mabey, 1966, p. 139-141). A thick pile of volcanic rocks of Tertiary age, for the most part rhyolite and basalt flows, agglomerate, and tuff, form most of the range south of Anvil Spring Canyon. Fanglomerate deposits of Tertiary and Quarternary ages, with interbedded volcanic rocks, form a dissected highland southwest of Tucki Mountain that culminates in Pinto Peak (altitude 7,510 ft). Volcanic rocks compose most of these deposits in the northwestern part of the highland. Lava flows and volcanic ash occur at the base of the fanglomerate south of Emigrant Spring, lying unconformably on folded sedimentary rocks of Precambrian or Paleozoic age. Bouldery alluvial deposits of Quaternary age occur in stream channels and in broad valleys in Anvil Spring and Wildrose Canyons. Sandy alluvial deposits floor the intermontane valleys in Harrisburg Flats, White Sage Flat, and Butte Valley.

Numerous springs, among them the largest in the range, issue from fractured sedimentary rocks of Precambrian and Paleozoic age. Hunt, Robinson, Bowles, and Washburn (1966, p. 29) noted that most of the springs in the Panamint Range discharge along low-angle faults. Several springs occur in fractured and weathered granitic rocks and near their contact with sedimentary rocks in Hanaupah Canyon (20S/47E). In Butte Valley (23S/46E) several small springs issue from weathered and fractured granitic rocks. About a dozen springs and seeps flow from fanglomerate and interbedded volcanic rocks near Emigrant Spring, north of Pinto Peak. Most are near the base of the deposit, where volcanic rocks and ash apparently form an almost impermeable layer that impedes downward movement of ground water into the underlying older sedimentary rocks, thus forming a perched ground-water body.

Several springs occur where the cross-sectional area of alluvial deposits in canyons is reduced at bedrock narrows. Willow Spring (23S/46E-30CS1) in Butte Valley and the spring at Wildrose Ranger Station occur at such constrictions, and each flows several gallons per minute throughout the year. Mesquite Spring (21N/1E-7CS1) in Anvil Spring Canyon is at a channel constriction in granitic bedrock. The spring reportedly has been dry for several years, but a heavy growth of mesquite along the channel at the site attests to the presence of shallow ground water.

The movement of ground water in the Panamint Range is not well understood. Along the eastern slope of the mountains water probably moves toward Death Valley, entering the extensive alluvial fan deposits and eventually discharging at the saltpan. Most of the ground water beneath the western slope of the range probably moves toward Panamint Valley. At Wildrose Canyon, however, and perhaps in other areas on the western slope, some ground water may move eastward, down-dip in the sedimentary rocks, and into Death Valley. The outflow of spring 19S/44E-23KS4 that supplies Wildrose Ranger Station (altitude 4,000 ft) is 6-9 gal/min. This 10-15 acre-ft per year discharge is about the same yield per square mile as from the 24-mi^2 drainage in Gold Valley in the Black Mountains. The latter drainage is in the rain shadow of the Panamints, the altitude is lower, and presumably the precipitation is much less. James J. French (written commun., 1963) noted this small flow at Wildrose in relation to the geohydrologic setting and postulated that appreciable ground-water recharge in the canyon moves eastward under the mountains and discharges into Death Valley.

Several small springs and seeps at an altitude of 4,300-4,500 ft at the northeastern base of Manly Peak discharge less than 1 gal/min each which infiltrates into alluvial-fan deposits. This water and other local recharge apparently moves eastward across Butte Valley for about 1 mi to reappear at Willow Spring (altitude about 3,600 ft) which typically flows several gallons per minute at a granitic bedrock narrows at the toe of the alluvial-fan deposits. Discharge from Willow Spring infiltrates into the alluvium in Anvil Spring Canyon within a short reach and moves eastward toward Death Valley. Farther downstream at a bedrock narrows, ground water is again near the surface at Mesquite Spring (dry). This general pattern of movement is typical over most of the Panamint Range, whereby many springs occur at high altitudes and the water flows for short reaches and seeps into the ground, sometimes reappearing downstream at hydrologic constrictions and eventually discharging at the saltpan.

About a dozen small springs and seeps with an aggregate flow of perhaps 10-15 gal/min issue from fanglomerate and associated volcanic rocks of Tertiary and Quarternary age in the Emigrant Spring-Pinto Peak area. Most of them occur near the base of the unit where lava, tuff, and ash form an almost impermeable layer that retards downward flow into the underlying older rocks. Much of the discharge is consumed by phreatophytes at the springs. Some infiltrates into alluvium-filled washes and then downward into fractured and faulted older rocks where presumably the water moves northward and eastward toward Death Valley.

Most ground water in the southern Panamint Range contains less than 500 mg/L dissolved solids. Water from a few springs contains about 700 mg/L dissolved solids. Water from springs that issue from carbonate rocks of Precambrian and Paleozoic age generally contains 300 to 500 mg/L dissolved solids. A few large springs that flow from these rocks contain 150 to 200 mg/L dissolved solids. Calcium and bicarbonate commonly are the predominant ions, and magnesium and sulfate are abundant.

Ground water from springs in granitic rocks near the north base of Manly Peak typically contains 200-300 mg/L dissolved solids, and calcium, sodium, and bicarbonate are the major ions. The concentrations of chloride and sulfate typically are 20-30 and 30-40 mg/L. A sample of water from Willow Spring in Butte Valley, which presumably receives much of its recharge from the Manly Peak area, contained 475 mg/L dissolved solids, and calcium, magnesium, and sulfate were the major ions. The water contained 35 mg/L chloride and 205 mg/L sulfate. The significant increase in sulfate may be caused by the addition of sulfate from oxidizing sulfide minerals buried beneath alluvial-fan deposits upgradient from Willow Spring. Several iron-oxide-stained fractures that crop out in zones of altered rock on Manly Peak have been prospected.

Water from springs that issue from volcanic rocks of Tertiary age in the Panamint Range generally contains 200-300 mg/L dissolved solids. Sodium and bicarbonate are the major ions.

Springs in fanglomerate deposits in the Pinto Peak area typically contain 250 to 550 mg/L dissolved solids, and calcium, sodium, and bicarbonate are the predominant ions.

Most springs in the alluvium contain 500 to 800 mg/L dissolved solids, and the major ions are calcium, sulfate, and bicarbonate.

Many of the more easily accessible springs have been developed for uses such as mining and domestic water supplies. Some of the developments are in disrepair and have been abandoned for many years, and heavy use by feral burros has damaged spring boxes and other works. Trampling and fecal matter, related to use by burros, has polluted dozens of springs in the Butte Valley-Anvil Spring Canyon and Wildrose Canyon-Pinto Peak areas.

Mesquite Flat

Mesquite Flat lies north of Tucki Mountain between the Cottonwood and Grapevine Mountains. Most of the flat lies between altitudes of -100 ft and +100 ft. Death Valley Wash enters the flat from the north, and Salt Creek (north) drains the flat southward to the saltpan. Much of the flat is a monotonously smooth alluvial plain 6-8 mi wide by about 15 mi long and surrounded by alluvial fans rising from its edge toward the mountains. Drifting sand dunes cover about 10 mi^2 of the southern part of the flat and a

few square miles of the northwestern part. A thin blanket of drifting, windblown sand covers much of the rest of the flat. Ground water occurs at depths ranging from 5 to 30 ft beneath much of the flat, and mesquite and other phreatophytes grow in scattered clumps over much of the area. Mesquite typically grows around the edges of the flat. Arrowweed and other salt-tolerant species are more common in the central and southern parts where the ground water becomes progressively more saline as it moves toward the saltpan.

Deposits of Cenozoic age that are estimated from gravity data to be as much as 2 mi thick underlie part of the flat (Hunt and Mabey, 1966, p. A107). These deposits probably are mostly alluvial and lacustrine in origin and may resemble the beds of conglomerate, sandstone, mudstone, and shale that crop out in a discontinuous belt along the east side of the Northern Death Valley-Furnace Creek fault zone and in the Salt Creek Hills. Several lakes have formed and evaporated during the geologic history of Death Valley, leaving extensive playa and lacustrine deposits, some of which contain evaporite deposits of readily soluble salts (Hunt and Mabey, 1966, p. 59-62, 79-83). Thus it seems reasonable to assume that such deposits make up part of the thick sedimentary fill beneath the flat.

Several square miles in the northwestern part of the flat are underlain by flat-lying beds of white, soft, impure, lacustrine limestone, probably of Quaternary age. Drifting sand, sand dunes, thinly layered mudflow deposits, and sandy alluvium, all of Quaternary age, mantle the rest of the flat. These deposits intertongue with gravelly alluvial-fan deposits of Quaternary age along the edge of the flat.

Scant data are available on the water-bearing characteristics of the aquifers in this area. Water wells at Stovepipe Wells Hotel yield 20-30 gal/min. Well 16S/44E-12N1, drilled by the Park Service to a depth of 702 ft into carbonate rocks during 1971, yielded 10 gal/min with 80 ft of drawdown. Well 16S/44E-1C1 was drilled to a depth of 315 ft in alluvial-fan deposits by the Park Service in 1973 to supply water for a small desalination plant. It yielded 72 gal/min with 14 ft of drawdown.

Flash floods from the nearby mountains debouch onto the alluvial fans around the flat, often several times a year. These local floods, and floods in Death Valley Wash that originate north of the flat, lose water by seepage into flood-channel deposits and are a source of ground-water recharge. Other sources, which may be more significant, are underflow from rocks of Paleozoic age in the Cottonwood Mountains (Miller, 1970, p. 11), underflow from the north through alluvial deposits beneath Death Valley Wash, and underflow from the east. The latter two sources are probably made up of water derived from local recharge and water that has moved beneath the mountains as underflow from Sarcobatus Flat and perhaps the northern part of the Amargosa Desert.

Total recharge to the flat, as judged from the outflow at Salt Creek (north), from discharge by a large area of phreatophytes, and from the several square miles of puffy efflorescent ground, may be in the 5 to 30 ft^3/s range.

There is a large quantity of ground water beneath the flat and in the adjacent alluvial-fan deposits. The hydrologic setting and data from several shallow test holes and a few water wells indicate that ground water moves generally southeastward beneath the flat, under a gradient of 10-12 ft/mi. A few miles upstream from the Salt Creek Hills, near California Highway 190, the water table is almost at the ground surface, and a large marshy area that heads a short distance downstream from the highway feeds Salt Creek (north). This marshy area is the result of what appears to be discharge of most of the ground water moving through Mesquite Flat. Ground water probably occurs at shallow depths under confined (artesian) conditions beneath much of the southeastern part of the flat, and the general geohydrologic setting suggests that confined conditions occur at greater depths under most of the flat.

Ground water occurs locally under confined conditions at shallow depths in the northeastern part of the flat east of the Northern Death Valley-Furnace Creek fault zone. At Midway Well a test hole (14S/45E-18D2) 97 ft deep and screened from 95 to 97 ft flowed from the top of the 2-in casing which is 3 ft above land surface. Pressure measurements on the capped well indicate that the hydrostatic level is about 15 ft above land surface. In contrast, the depth to water in Midway Well (9 ft deep, about 50 ft to the north and at the same altitude) was about 6 ft below land surface, indicating a head difference in the aquifer system of about 20 ft in a vertical depth of less than 90 ft.

The chemical quality of ground water is poor beneath most of Mesquite Flat. Samples from wells typically contain more than 3,000 mg/L dissolved solids. Sodium, chloride, and locally bicarbonate are the major ions in water from most sources in the flat. The concentration of fluoride exceeds 1 mg/L in most wells. Water from one test hole (14S/44E-6L1), about 1½ mi west of Death Valley Wash near the north edge of the flat, contained only 632 mg/L dissolved solids. The major ions in the water are sodium and bicarbonate, but the water contained 8 mg/L fluoride. Water from the artesian test well at Midway Well (mentioned above) contains about 1,500 mg/L dissolved solids. Sodium, bicarbonate, and sulfate are the predominant ions.

As water moves southeastward beneath the flat toward Salt Creek (north) the concentration of dissolved solids and the percentage of sodium and chloride increases. Two samples from Salt Creek (north) contained 12,000 and 23,000 mg/L dissolved solids. The progressive increase in dissolved solids is manifest in the type of vegetation. Mesquite, which can tolerate ground water containing as much as 5,000 mg/L dissolved solids (Hunt and others, 1966, p. 22), is prevalent in the northern three-fourths of the flat. Near California Highway 190, mesquite gives way to arrowweed which tolerates ground water containing as much as 20,000 mg/L dissolved solids (Hunt and others, 1966). Pickleweed, which grows where ground water contains as much as 60,000 mg/L dissolved solids, is prevalent in the marshy area that feeds Salt Creek (north).

Additional test holes are needed in the northern part of Mesquite Flat to understand better the occurrence and availability of the relatively good water there. A test hole 500-1,000 ft deep, with piezometers installed in several depth zones as indicated by logging the hole, would provide more information on the depth of occurrence of potable water, as well as the nature of the flow system. In addition, several shallow holes about 100 ft deep in the northeast corner of the flat will be necessary to understand better the occurrence and quality of confined water so that the water resources in this area can be adequately evaluated.

The Saltpan and Adjacent Alluvial Fans

The saltpan covers more than 200 mi^2 of the valley floor, all of it below sea level, between Salt Creek Hills on the north and near the mouth of Wingate Wash on the south. The surface material of the central part of the pan is high in sodium chloride; locally, as at Devils Golf Course, it is hard, rough, rock salt. At many places near the edge of the pan the sodium chloride grades progressively fanward into sulfate and carbonate salts. Deposits of silt and sand that are impregnated with salt cover much of the north and south ends of the pan. Little is known of material that underlies the salt. The total thickness of alluvial fill beneath the pan may be as much as 8,000 ft, and locally the more salty sequence of beds is as much as 1,000 ft thick (Hunt and others, 1966, p. 13, 42, and 43).

Steep alluvial fans of boulders, gravel, and mudflow material slope into the valley from the Black Mountains and intertongue with finer-grained sediments beneath the saltpan. In the central and northern parts of the area these fans typically are 0.5 to 1 mi long from apex to toe, and they slope panward at 500 or more feet per mile. Some of the steep fans south of Mormon Point resemble talus cones or rock-avalanche deposits. In contrast, the fans that head in the Panamint Range generally extend 3-6 mi into the valley and slope at no more than 450 ft/mi. This asymmetry between the fans on either side of the valley is due to tilting of the valley floor to the east as the fans were deposited, thus crowding the saltpan next to the Black Mountains (Hunt and Mabey, 1966).

The Black Mountains and Funeral Mountains yield little runoff and, therefore, little recharge to the fans in Death Valley. This is most clearly evidenced by the near absence of phreatophytes along the toes of the fans where major drainages reach the saltpan. In contrast, appreciable runoff and concomitant recharge originate in the higher parts of the Panamint Range. Phreatophytes, mostly mesquite, are common along the toes of the fans between Trail Canyon and Salt Well, a distance of 20 mi. The abundance of phreatophytes here correlates well with the crest altitude of the mountains (fig. 9). Hunt and others (1966, table 25) estimated that more than 6 ft^3/s (2,700 gal/min) of ground water discharges as evapotranspiration along the toes of the Panamint fans and the nearby edge of the saltpan.
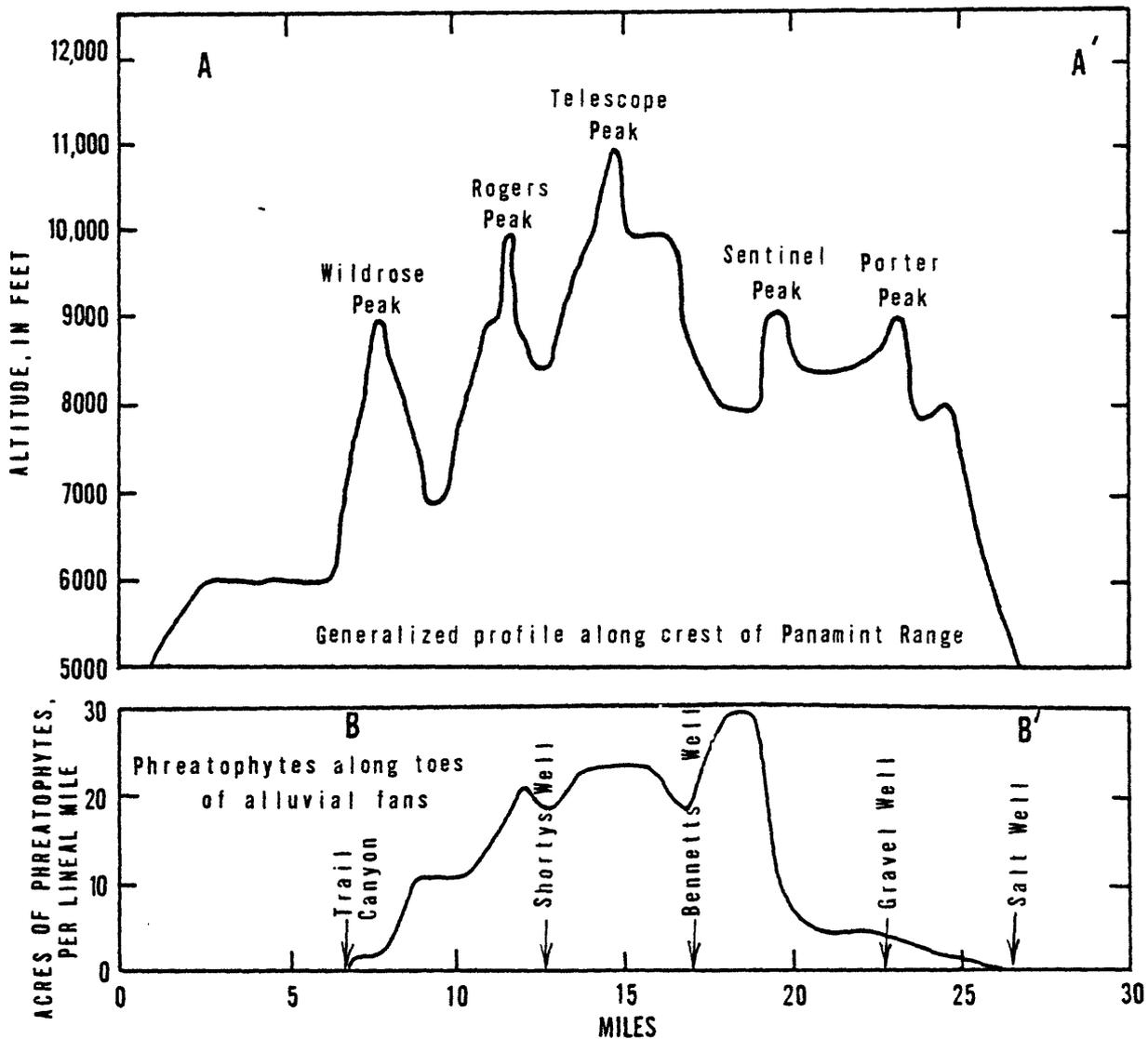
Figure 9.--Diagrammatic sketches showing crestal altitude of the
Panamint Range (A-A') and occurrence of phreatophytes along
toes of alluvial fans at the east base of the range (B-B').
See figure 3 for location of sketches.

The underflow system into the saltpan probably is complex, because of intertonguing of strata deposited in fans and in the saltpan and because of the hydraulics of the fresh water-salt water system. Shallow test wells near Tule Spring (fig. 5) and near Eagle Borax Spring encountered progressively higher heads and progressively fresher water with depth; water flowed from test wells about 50 ft deep that tap these strata at these sites. The freshening with depth in these shallow holes probably is related to near-surface buildup of salt as a result of transpiration from deep-rooted phreatophytes and evaporation from the capillary fringe.

The more dense salt water beneath the saltpan probably extends mountainward beneath the fans as a wedge, with fresh water above it. The depth to salt water and the slope of the fresh water-salt water wedge, as well as the slope of the water table, are not known. The wedge of fresh water floats on the heavier salt water, and its position, shape, and depth along the edge of the saltpan are determined largely by the quantity of inflowing fresh water. Thus, near Eagle Borax Spring where the inflow is great the wedge of fresh water probably extends eastward for a short distance beneath the saltpan while at Salt Wells where the inflow is less the wedge may roughly coincide with the edge of the pan. Intertonguing of highly permeable fan deposits and much less permeable saltpan deposits complicates the location and shape of the wedge.

Ground water in the flowing test hole near Eagle Borax Spring (24N/1E-15DS1) contains about 670 mg/L dissolved solids, and the major ions are sodium, chloride, and sulfate. Water from Bennetts Well (24N/1E-27F1,2) and from nearby shallow test holes contains 400-500 mg/L dissolved solids. The six major ions in available analyses from these wells are nearly equal in concentration but tend toward sodium and sulfate dominance.

A test well near Bennetts Well between 500 and 1,000 ft in depth would provide needed information on the flow system and chemical quality of the ground water, as well as the magnitude and availability of the fresh-water resources there. Several shallow (100 ft ±) holes are needed along the toes of the fans between Gravel Well (23N/1E-23E1) and Tule Spring (25N/1E-33FS1) to better define the occurrence and availability of fresh water in this area.

WELL AND SPRING MONITORING

Hydrologic monitoring in Death Valley, of the ground water in particular, should be based on (1) obtaining general background or baseline information on the natural variations with time over the entire area, and (2) detecting, identifying, and understanding changes that take place in areas known to be or anticipated to be affected by man. Where changes occur during the course of monitoring, cause-effect relations can be more thoroughly understood, and, as a rule, problems related to such changes can be dealt with at an early stage.

Several wells and springs throughout the valley should be measured periodically and a few measured continuously with recorders for a short time to develop baseline data against which future changes can be compared. After a period of 2-5 years, data evaluation could reduce the frequency of measurements at many sites, probably by a factor of 2 to 5. Springs and wells that might be included in this program are listed in tables 4 and 5 and shown in figure 3. The wells and springs in these tables are considered to fulfill only minimum requirements for monitoring. If they were evenly distributed, they would represent roughly one data point for each 100 mi^2 of the area. The U.S. Geological Survey stream gage on the Amargosa River at Tecopa and the discontinued station in Wildrose Canyon provide additional baseline data.

Manmade changes in the hydrologic system are presently occurring at places of use, as in the Stovepipe Wells Hotel area, at Furnace Creek, at Wildrose Canyon, at Emigrant Spring, and at Scottys Castle. The monitoring at these places could include periodic photographic coverage (Malde, 1973) from fixed stations and from aircraft so as to better identify and evaluate any surface changes that may accompany the diversion of water for man's use.

Water quality may change in response to use by man; however, the changes are apt to occur more slowly than hydraulic (water-level or spring-discharge) changes. To help detect these slower changes, an initial chemical analysis of the water at each suggested monitoring site listed in tables 4 and 5 should be made, followed by periodic field measurements of temperature, pH, and specific conductance at the springs and at flowing or pumped wells. Chemical analyses should be repeated every 5 years, or more frequently if significant changes are detected from the field measurements of water level, spring discharge, temperature, pH, or specific conductance.

If the results of the monitoring are reviewed as the data are collected, adjustments can be made in the program to keep it abreast of changes.

TABLE 4.--Data for selected springs in Death Valley National Monument and vicinity .

Spring name and No.	Flow, in gallons per minute	Date	Dissolved solids, in milligrams per liter (approximate)	Specific conductance, in micromhos (approximate)	Suitable for monitoring (*) and suggested frequency, in times per year	Remarks
Sheep Creek 17N/6E-5QS1	10	4-25-67	800	1,200	*3	
Saratoga 18N/5E-2ES1,2	75	4-27-67	3,100	4,700	*3	Combined flow of two springs from large pool.
Rhodes 21N/4E-11MS1	.1	3-23-70	500-700	750-1,000	*3	Perched spring in southern Black Mountains.
Willow (Gold Valley) 23N/3E-54JS1	10	4-15-69	800	1,200	*3	Flow varies between 2 and 20 gallons per minute.
Eagle Borax 24N/1E-15DS1	300	--	1,600	2,500	--	
Tule 25N/1E-33FS1	0	5-16-67	2,000	3,000	--	
Texas 27N/1E-23BS1	210	12-08-76	600	1,000	*3	Discharge is from interbasin flow.
Travertine 27N/1E-23,25, 26S	700	1-06-77	600	1,000	*3	Discharge is from interbasin flow. Aggregate of several springs.
South Travertine 27N/1E-26BS1	490	1-06-77	640	1,020	*3	Discharge is from interbasin flow.
Unnamed 28N/1E-36FS1	40	1-07-77	550	850	--	Near Nevares Springs.

TABLE 4.--Data for selected springs in Death Valley National Monument and vicinity--Continued

Spring name and No.	Flow, in gallons per minute	Date	Dissolved solids, in milligrams per liter (approximate)	Specific conductance, in micromhos (approximate)	Suitable for monitoring (*) and suggested frequency, in times per year	Remarks
Nevares 28N/1E-36GS1	220	1-07-77	630	1,000	*Continuous	Discharge is from interbasin flow. Aggregate of several springs.
Unnamed 7S/40E-15adS1	.2	--	300	500	*3	Upgradient from Roosevelt Well in Magruder Mountain area, Nevada.
Sand 9S/41E-7RS1	.4	5-01-68	850	1,300	*3	Northern headwaters of Death Valley.
Grapevine 11S/42E-2,3, 10S	450	--	650-800	1,000-1,200	--	Numerous outlets. Flow given is aggregate.
Mesquite 11S/42E-27RS1	9	--	900	1,300	*3	Largest spring in floor of northern Death Valley.
Stainingers 11S/43E-5ES1	200	--	480	730	*Continuous	Supplies Scottys Castle; probably interbasin flow.
Surprise 11S/43E-18ES1,2	5	--	480	700	*3	Supplies Grapevine Ranger Station. Perched water in volcanic rocks.
Brier 11S/44E-32bcS1	1	--	200	320	*3	
Quartz 13S/41E-26MS1	.02	2-14-67	480	800	*3	Important to bighorn sheep habitat.
Klare 13S/45E-4LS1	1.5	11-17-68	.570	880	*3	
Goldbelt 15S/42E-32CS2	.3	5-20-71	150-250	250-400	*3	

TABLE 4.—Data for selected springs in Death Valley National Monument and vicinity—Continued

Spring name and No.	Flow, in gallons per minute	Date	Dissolved solids, in milligrams per liter (approximate)	Specific conductance, in micromhos (approximate)	Suitable for monitoring (*) and suggested frequency, in times per year	Remarks
Keane Wonder 15S/46E-1RS1	30	11-17-68	3,100	4,500	*3	
Jackass 16S/42E-18RS1	3.1	4-23-68	--	--	--	
Cottonwood 16S/42E-25KS1	73	4-24-68	350	520	*1	
Tucki 16S/45E-29DS1	10	6-10-57	--	--	--	
Emigrant 17S/44E-27BS1	1.9	11-09-71	350	550	*6	
Upper Emigrant 17S/44E-27KS1	.8	11-09-71	530	850	*6	
Wildrose 19S/44E-21RS1	7.6	1-05-72	500	800	*Continuous	Supplies ranger station.
Greater View 23S/45E-23QS1	.3	4-27-67	350	520	--	At Russell Camp.
Willow (Butte Valley) 23S/46E-30CS1	6.7	4-28-67	320	500	*3	
Squaw 23S/46E-33DS1	2.1	5-15-67	350	540	--	

TABLE 5.—Data for selected wells in Death Valley National Monument and vicinity

Well No.	Depth, in feet	Depth to water, in feet	Date	Dissolved solids, in milligrams per liter (approximate)	Specific conductance, in micromhos (approximate)	Suitable for monitoring (*) and suggested frequency, in times per year	Remarks
18N/5E-14J1	67	32.0	4-27-68	4,800	7,400	*3	
19N/6E-19N1	268	257.3	2-17-67	3,900	5,900	*3	Upgradient from Saratoga Springs. No pumping in area.
20N/4E-9K1	73	57.0	4-27-68	3,900	5,900	*3	In underflow section along Amargosa River to south end of saltpan.
21N/3E-28B1	275	160	--	6,500	9,800	*3	Do.
21N/4E-15R2	27	12	2-20-69	1,000	1,500	*3	Test well in fracture zone at Bradbury Well.
22N/1E-12D1 (Salt Well)	50	5	--	6,000	9,500	*3	In recharge area from southern Panamint Range.
23N/1E-23E1 (Gravel Well)	20	17	--	2,000	3,300	*Continuous	Do.
24N/1E-4F1 (Shortys Well)	19	2.2	5-16-67	550	850	*3	Do.
24N/1E-15E1	50	0	--	670	1,200	*3	Flowing and nonflowing piezometers in same borehole.
24N/1E-15E2	18	6	--	--	--	*3	Do.
24N/1E-27D1	32	18.0	4-27-68	500	700	*3	In fresh-water area near edge of saltpan.
24N/1E-27D2	93	17	--	400	500	*3	Do.

TABLE 5.--Data for selected wells in Death Valley National Monument and vicinity--Continued

Well No.	Depth, in feet	Depth to water, in feet	Date	Dissolved solids, in milligrams per liter (approximate)	Specific conductance, in micromhos (approximate)	Suitable for monitoring (*) and suggested frequency, in times per year	Remarks
24N/1E-27F1 (Bennetts Well)	12	7	--	390	580	*3	In fresh-water area near edge of saltpan.
24N/1E-27F2 (Bennetts Well)	18	9.2	5-19-71	--	--	*3	Do.
25N/1E-28E1	23	14.5	11-20-68	2,000	3,100	*3	
25N/1E-28M1	22	10.7	11-20-68	2,100	3,300	*3	
25N/1E-33F1	11	7	--	--	--	*3	Flowing and nonflowing piezometers in same borehole.
25N/1E-33F2	52	0	--	1,000	1,800	*3	Do.
25N/1E-33F3	29	1	--	--	--	*3	Do.
27N/1E-16R1	200	38	5-10-71	1,300	2,100	*3	Test well on Furnace Creek fan.
27N/1E-24E1	250	74.5	12-08-76	570	950	*3	Test well on Furnace Creek syncline.
27N/4E-26B1	--	25	--	--	--	*6	In Amargosa Desert northeast of Furnace Creek.
27N/4E-27B2	--	45	--	600	940	*6	Do.
28N/1E-36G3	20	1.5	1-07-77	--	--	--	

TABLE 5.--*Data for selected wells in Death Valley National Monument and vicinity*--Continued

Well No.	Depth, in feet	Depth to water, in feet	Date	Dissolved solids, in milligrams per liter (approximate)	Specific conductance, in micromhos (approximate)	Suitable for monitoring (*) and suggested frequency, in times per year	Remarks
7S/40E-27ca1 (Roosevelt Well)	--	75	--	320	500	*3	In Nevada.
8S/43E-23bb1	--	45	--	--	--	*6	Upgradient from Stainingers and Grapevine Springs.
10S/42E-2cd1	310	270	--	460	690	*6	Do.
14S/43E-24F1, 14S/44E-31G1, 14S/44E-32Q1,2, 15S/44E-4Q1,2, 15S/44E-16J1, 15S/44E-33B1, and 15S/44E-34D1	10-92	--	--	3,000-5,000	4,500-9,000	*3	Test wells on Cottonwood fan, upgradient from area of pumping at Stovepipe Wells Hotel.
14S/44E-6L1	97	90	--	630	1,000	*3	Taps fresh water in northern Mesquite Flat.
14S/45E-18D1 (Midway Well)	9	8	--	1,400	2,100	*3	
14S/45E-18D2	97	+15 (flowing)	--	1,100	1,700	*3	Flowing test well.
14S/45E-30B1	63	4.8	4-28-68	1,300	2,000	--	
14S/47E-24d1	--	255	--	--	--	*6	In Amargosa Desert (Nevada) northeast of Furnace Creek.
14S/48E-32a1	--	220	--	--	--	*6	Do.

TABLE 5.--*Data for selected wells in Death Valley National Monument and vicinity*--Continued

Well No.	Depth, in feet	Depth to water, in feet	Date	Dissolved solids, in milligrams per liter (approximate)	Specific conductance, in micromhos (approximate)	Suitable for monitoring (*) and suggested frequency, in times per year	Remarks
15S/44E-36K1	80	50	1966	9,000	24,000	---	At airstrip.
15S/44E-36K2	50	39.3	1-10-67	Salty	--	--	Do.
15S/44E-36M1-P1 and 15S/45E-32L1	--	20-120	--	3,000-9,000	>4,000	*6	Test wells in pumping depression at Stovepipe Wells Hotel.
16S/44E-1C1	315	--	--	--	--	--	72-gallons per minute yield.
16S/44E-12N1	702	--	--	--	--	--	10-gallons per minute yield.
16S/48E-15a1	--	100	--	250	380	*6	In Amargosa Desert (Nevada) northeast of Furnace Creek.
16S/48E-18b1	--	90	--	--	--	*6	Do.
19S/44E-23K1	27	24	--	500	800	*6	Test well in Wildrose Canyon.

SELECTED REFERENCES

Bader, J. S., 1969, California district manual, water-well and spring
    numbering: U.S. Geol. Survey open-file rept., 9 p.
Ball, S. H., 1907, A geologic reconnaissance in southwestern Nevada and
    eastern California: U.S. Geol. Survey Bull. 308, 218 p.
Clopine, G. A., and Horne, J. D., The natural environment of Death Valley:
    Riverside, Univ. of Calif. Ext., 14 p.
Cohen, Philip, 1962, Source of sulfate in ground water of the Truckee Meadows
    area, Nevada: U.S. Geol. Survey Prof. Paper 450-C, p. C131-C132.
Crippen, J. R., 1965, Natural water loss and recoverable water in mountain
    basins of southern Calif.: U.S. Geol. Survey Prof. Paper 417-E,
    p. E1-E24.
Croft, M. G., 1964, Results of drilling test well 27N/1E-16R1 near Furnace
    Creek Ranch in Death Valley National Monument, California: U.S. Geol.
    Survey open-file rept., 5 p.
Drewes, Harald, 1963, Geology of the Funeral Peak quadrangle, California, on
    the east flank of Death Valley: U.S. Geol. Survey Prof. Paper 413, 78 p.
Dzurisin, Daniel, 1975, Channel responses to artificial stream capture, Death
    Valley, California: Geology, v. 3, no. 6, p. 309-312.
Eakin, T. E., 1966, A regional interbasin ground-water system in the White
    River area, southeastern Nevada: Water Resources Research, v. 2, no. 2,
    p. 251-272.
Eakin, T. E., and Maxey, G. B., 1951, Ground water in Clover and Independence
    Valleys, Elko County, Nevada, in Contributions to the hydrology of
    eastern Nevada: Nevada Dept. Conserv. and Nat. Resources, Water
    Resources Bull. 12, 171 p.
Eakin, T. E., and Moore, D. O., 1964, Uniformity of discharge of Muddy River
    Springs, southeastern Nevada, and relation to interbasin movement of
    ground water: U.S. Geol. Survey Prof. Paper 501-D, p. D171-D176.
Eakin, T. E., Schoff, S. L., and Cohen, Philip, 1963, Regional hydrology of a
    part of southern Nevada: A reconnaissance: U.S. Geol. Survey TEI-833,
    40 p.
Eakin, T. E., and Winograd, I. J., 1965, Interbasin movement of ground water
    in south-central Nevada—some implications, in Abstracts for 1964: Geol.
    Soc. America Spec. Paper 82, p. 52.
Engineering-Science, Inc., 1960, Report on quantities of spring waters
    available at Lower Ranch, Grapevine Canyon, Scottys Castle, Death Valley,
    California: Arcadia, Calif., Engineering Consultant's rept., 9 p.
Gale, H. S., 1914, Prospecting for potash in Death Valley, California:
    U.S. Geol. Survey Bull. 540-N, p. 407-415.
Greene, G. W., and Hunt, C. B., 1960, Observations of current tilting of the
    earth's surface in the Death Valley, California, area: U.S. Geol. Survey
    Prof. Paper 400-B, p. B275-B276.
Grove, D. B., Rubin, Meyer, Hanshaw, B. B., and Beetem, W. A., 1969, Carbon-14
    dates of ground water from a Paleozoic carbonate aquifer, south-central
    Nevada: U.S. Geol. Survey Prof. Paper 650-C, p. C215-C218.
Hunt, C. B., And Mabey, D. R., 1966, Stratigraphy and structure, Death Valley,
    California: U.S. Geol. Survey Prof. Paper 494-A, 162 p.

Hunt, C. B., and Robinson, T. W., 1960, Possible interbasin circulation of
    ground water in the southern part of the Great Basin: U.S. Geol. Survey
    Prof. Paper 400-B, p. B273-B274.
Hunt, C. B., Robinson, T. W., Bowles, W. A., and Washburn, A. L., 1966,
    Hydrologic basin, Death Valley, California: U.S. Geol. Survey Prof.
    Paper 494-B, 138 p.
Jennings, C. W., 1958, Geologic map of California--Death Valley Sheet:
    California Div. Mines.
Jennings, C. W., Burnett, J. L., and Troxel, B. W., 1962, Geologic map of
    California--Trona Sheet: California Div. Mines.
Johnson, E. A., 1971, Geology of a part of the southeastern site of the
    Cottonwood Mountains, Death Valley, California: Houston, Texas, Rice
    Univ. unpub. Ph. D. thesis, 81 p.
Kunkel, Fred, 1963, A brief summary of ground water in the Furnace Creek Wash
    area, Death Valley National Monument, California: U.S. Geol. Survey
    open-file rept., 9 p.
Kunkel, Fred, 1966, A geohydrologic reconnaissance of the Saratoga Spring
    area, Death Valley National Monument, California: U.S. Geol. Survey
    open-file rept., 27 p.
Loeltz, O. J., 1960, Source of water issuing from springs in Ash Meadow
    Valley, Nye County, Nevada [abs.]: Geol. Soc. America Bull., v. 71,
    p. 1917-1918.
Ludwig, H. F., 1958, Report on quantities of spring waters available at
    Scottys Castle, Death Valley: Engineering Consultants rept.
Malde, H. E., 1973, Geologic bench marks by terrestrial photography: U.S.
    Geol. Survey Jour. Research, v. 1, no. 2, p. 193-205.
Maxey, G. B., 1968, Hydrogeology of desert basins: Ground Water, v. 6, no. 5,
    p. 10-22.
Maxey, G. B., and Mifflin, M. D., 1966, Occurrence and movement of ground
    water in carbonate rocks of Nevada: Natl. Speleol. Soc. Bull. v. 28,
    no. 3, p. 141-157.
McAllister, J. F., 1952, Rocks and structure of the Quartz Spring area,
    northern Panamint Range, California: California Dept. Nat. Res., Div.
    Mines Special Rept. 25, 38 p.
_____1970, Geology of the Furnace Creek borate area, Death Valley, California:
    California Div. Mines and Geology Map Sheet, MS14.
Mendenhall, W. C., 1909, Some desert watering places in southeastern
    California and southwestern Nevada: U.S. Geol. Survey Water-Supply Paper
    224, 98 p.
Miller, G. A., 1970, Data on water resources of the Hunter Mountain area,
    Death Valley National Monument, California: U.S. Geol. Survey open-file
    rept., 22 p.
Noble, L. F., 1941, Structural features of the Virgin Spring area, California:
    Geol. Soc. America Bull., v. 52, no. 7, p. 941-999.
Pistrang, M. A., and Kunkel, Fred, 1964, A brief geologic and hydrologic
    reconnaissance of the Furnace Creek Wash area, Death Valley National
    Monument, California: U.S. Geol. Survey Water-Supply Paper 1779-Y, 35 p.
Rantz, S. E., and Eakin, T. E., 1971, A summary of methods for the collection
    and analysis of basic hydrologic data for arid regions: U.S. Geol.
    Survey open-file rept., 125 p.

Reynolds, M. W., 1966, Structure of the southern Grapevine Mountains, Death Valley, California [abs.]: Geol. Soc. America Spec. Paper 87, p. 226-227.

Robinson, T. W., 1952, Investigation of the water resources of the Nevares property in Death Valley National Monument, California: U.S. Geol. Survey open-file rept., 21 p.

_____1957, Determination of the flow of Saratoga Spring in Death Valley National Monument, California: U.S. Geol. Survey open-file rept., 19 p.

Rush, F. E., 1968, Water resources appraisal of Clayton Valley-Stonewall Flat area, Nevada and California: Nevada Dept. Conserv. and Nat. Resources, Reconn. Ser. rept. no. 45, 54 p.

Snyder, C. T., Hardman, George, and Zdenek, F. F., 1964, Pleistocene lakes of the Great Basin: U.S. Geol. Survey Misc. Geol. Inv. Map I-416.

Strand, R. G., 1967, Geologic map of California--Mariposa Sheet: California Div. Mines.

Troxel, B. W., 1974, Man-made diversion on Furnace Creek Wash, Zabriskie Point, Death Valley, California, in California Geology: California Div. Mines and Geol., v. 27, no. 10, p. 219-223.

U.S. Environmental Protection Agency, Environmental Studies Board, 1972, Water quality criteria 1972--a report of the Committee on Water Quality Criteria: Washington, U.S. Govt. Printing Office, 594 p.

U.S. Public Health Service, 1962, Drinking water standards, 1962: Pub. 956, 61 p.

Walker, G. E., and Eakin, T. E., 1963, Geology and ground water of Amargosa Desert, Nevada-California: Nevada Dept. Conserv. and Nat. Resources, Reconn. Ser. rept. 14, 45 p.

Ward, F. N., Nakagawa, H. M., and Hunt, C. B., 1960, Geochemical investigation of molybdenum at Nevares Spring in Death Valley, California: U.S. Geol. Survey Prof. Paper 400-B, p. B454-B456.

Welles, R. E., and Welles, F. B., 1959, Preliminary study of wildlife water sources in Death Valley National Monument: Report prepared under Natl. Park Service contract 14-10-434-375.

Winograd, I. J., 1962, Interbasin movement of ground water at the Nevada test site, Nevada: U.S. Geol. Survey Prof. Paper 450-C, p. C108-C111.

_____1971, Origin of major springs in the Amargosa Desert of Nevada and Death Valley, California: Arizona Univ., Dept. of Geosciences unpub. Ph. D. theses, 170 p.

Winograd, I. J., and Friedman, Irving, 1972, Deuterium as a tracer of regional ground-water flow, southern Great Basin, Nevada and California: Geol. Soc. America Bull. v. 83, no. 12, p. 3691-3708.

Winograd, I. J., and Thordarson, William, 1975, Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California, with special reference to the Nevada test site: U.S. Geol. Survey, Prof. Paper 712-C, 126 p.

Wright, L. A., 1968, Talc deposits of the southern Death Valley-Kingston Range region, California: California Div. Mines and Geol. Spec. Rept. 95, 79 p.