UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

REGIONAL HYDROLOGY OF A PART OF SOUTHERN NEVADA:

A RECONNAISSANCE*

By

Thomas E. Eakin, Stuart L. Schoff, and Philip Cohen

July 1963

Report TEI-833

This report is preliminary
and has not been edited for
conformity with Geological
Survey format.

*Prepared on behalf of the
U.S. Atomic Energy Commission

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Washington 25, D. C.

July 17, 1963

Mr. James E. Reeves, Manager
Nevada Operations Office
U.S. Atomic Energy Commission
Post Office Box 1676
Las Vegas, Nevada

Dear Mr. Reeves:

Transmitted herewith are two copies of TEI-833, "Regional Hydrology of a Part of Southern Nevada: A Reconnaissance," by T. E. Eakin, S. L. Schoff, and Philip Cohen, 1963.

We plan to release this report to the public in the open files.

Sincerely yours,

Edwin B. Eckel. for

V. R. Wilmarth
Assistant Chief Geologist
for Engineering Geology

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REGIONAL HYDROLOGY OF A PART OF SOUTHERN NEVADA:

A reconnaissance

By

Thomas E. Eakin, Stuart L. Schoff, and Philip Cohen

ABSTRACT

The ground-water hydrology in a region of about 11,700 square miles encompassing the Nevada Test Site in southern Nevada is reviewed on the basis of data that are limited except at the Test Site. Only broad generalizations are possible. The direction of movement of the ground water is inferred from known and possible hydraulic gradients, relations of discharge to recharge of ground water, possible geologic conditions, and chemical character of ground water. These data suggest that the ground water moves generally southward or southwestward through the region but in a complex manner governed by differential primary and secondary permeabilities of Cenozoic volcanic and Paleozoic carbonate rocks and by multiple sources of recharge and discharge. The movement of ground water through the bedrock between basins, heretofore considered to be unlikely because the bedrock generally is of relatively low permeability, now seems to be a significant element in the hydrologic system. The Paleozoic carbonate rocks may be the principal media through which the interbasin movement takes place.

INTRODUCTION

This report summarizes the available hydrologic information for a part of Nevada surrounding the Nevada Test Site. It emphasizes the possibility that ground water may move from one basin to another, whereas the usual concept heretofore has been that the ground water of the region generally occurs in basins that are closed or nearly closed. The report suggests the possible direction, or directions, of movement of the ground water within the region.

The report was prepared to answer a request of the Board of Consultants to the U.S. Atomic Energy Commission for a resume of the regional hydrologic setting around the Nevada Test Site. It may provide the framework within which both present and future ground-water investigations in southern Nevada may be viewed in broad perspective. It is comparable in scope and treatment to reports on ground water scheduled for other parts of the region, which are to be released in the Ground-Water Resources Reconnaissance series of the Nevada Department of Conservation and Natural Resources.

Scope of report

This is a reconnaissance report presenting a synthesis of the hydrologic data currently available. These data for much of the region are sparse, but the collection of large quantities of additional data was not within the scope of the work. Data not published in other reports are given in the appendix of this report.

Location and area

The area discussed in this report is an arid, sparsely populated part of southern Nevada that lies just northeast of the California state line (fig. 1). It covers about 11,700 square miles in the Basin and Range physiographic province, and includes 20 intermontane basins and the ranges that bound them. The regional topography and principal geographic features are shown on figure 1. The intermontane basins considered in this report are delineated on figures 1-3.

The basin boundaries, in general, follow drainage divides, but at places are drawn arbitrarily to simplify estimating the recharge. Indian Spring and Three Lakes Valleys do not empty into Las Vegas Valley, but have playa lakes in their southern ends, into which runoff from the upper part of "Las Vegas Valley" drains, including runoff from the northeast flank of the Spring Mountains. If the boundaries of Indian Spring and Three Lakes Valleys were drawn strictly on drainage divides, these basins would extend to the crest of the mountains, and the recharge estimates for them should include some recharge on the northeast flank of the Spring Mountains. The question of how to divide this recharge area among Indian Spring, Three Lakes, and Las Vegas Valleys is not at present readily answerable. Hence, that part of the Las Vegas trough which belongs in the Indian Spring and Three Lakes drainages is here included in Las Vegas Valley.

This investigation

This investigation utilizes limited but representative data for developing a preliminary picture of regional ground-water relations. The underlying philosophy is that recharge and discharge in a basin will be equal if the hydraulic system is truly closed, but probably will be unequal if water enters or leaves by underflow. If discharge exceeds local recharge in a given basin, water must be entering the system from some other system. And if the water level of an adjacent basin is higher in altitude than the water level of the system being considered, the ground water may be able to move from the higher to the lower. Whether it moves in the obvious direction indicated by the foregoing criteria or takes an indirect route will depend on the character of the intervening bedrock and on the geologic structure. The chemical character of the ground water, dependent as it is on the rocks through which the water passes, gives qualitative clues to the probability of the suggested water movement.

Estimates of the natural recharge to and discharge from the different basins of the region have been made by a reconnaissance method used elsewhere in Nevada (Eakin and others, 1951, p. 79-80). Although crude and susceptible to great refinement, such estimates have proved to be a useful hydrologic tool.

The altitude of the water level in the different basins generally is taken to be the altitude of the lowest recorded static water level in a well. Additionally, altitudes of selected springs are used in Amargosa Desert and Las Vegas Valley.

The chemical analyses of water utilized in this study were made by the Quality of Water Branch, U.S. Geological Survey. They are shown together on a map for easy comparison.

AVAILABLE DATA

Three types of data have been used in preparing this report. These are well and spring records, chemical analyses of water, and geologic information. These data are not uniformly available in the region, as will be shown in paragraphs to follow.

The data are from published geological maps and reports, from TEI reports by the U.S. Geological Survey on various aspects of the hydrology of the Nevada Test Site, from reports of the Ground-Water Reconnaissance series of the Nevada Department of Conservation and Natural Resources, and from unpublished records in the files of the U.S. Geological Survey at Carson City and Mercury, Nev. Some of the unpublished records were collected for ground-water investigations under the Nevada State Cooperative program. Reports by Maxey and Jameson (1948) and by Malmberg (1961), although for areas outside the region considered here, have been used in evaluating broad regional aspects of the hydrology.

Well and spring data

Well records generally include location, depth to water, altitude, driller's logs, discharge, and hydraulic tests. The spring records include location, discharge, and related information. The well and spring records are not uniform; that is, not all items are recorded for every well or spring.

The well and spring records are relatively abundant for the Nevada Test Site (Yucca, Frenchman, and Jackass Flats) and vicinity, including parts of the Amargosa Desert. Wells are only moderately numerous in Sarcobatus Flat, Oasis, Ralston, and Stonecabin Valleys, and they are sparse in the rest of the region. There are none in Desert and Three Lakes Valleys and Crater Flat.

Chemical data

Chemical analyses have been made of many water samples from wells and springs in and near the Nevada Test Site. The analyses made to 1959 have been reported by Moore (1961, tables 3 and 5) and by Clebsch and Barker (1960, table 2). Analyses made since 1959 have been published in U.S. Geological Survey TEI reports on individual test wells by several different authors. The TEI reports are included in the list of references at the end of this report.

Several chemical analyses of water from wells and springs are available for Sarcobatus Flat and Oasis Valley (Malmberg and Eakin, 1962), Ralston and Stonecabin Valleys (Eakin, 1962), and the Amargosa Desert (Walker and Eakin, 1962). Elsewhere in the region of this report there are few analyses. The chemical analyses of water for Las Vegas and Pahrump Valleys, reported by Maxey and Jameson (1948), have been considered in the appraisal of regional relationships.

Geology and structure

Healey and Miller (1962, p. 7-10) have summarized the stratigraphy and structure of the Nevada Test Site and a large surrounding area. Their summary, although written for a somewhat smaller area than that covered in this report, is in terms general enough to be applicable. It is reproduced, with a few very minor changes, below.

> The region is characterized by structurally complex, thick deposits of sedimentary rocks of Precambrian and Paleozoic age, that are overlain in places by faulted volcanic and sedimentary rocks of Tertiary age. * * * The entire area is a sequence of basins and ranges.
>
> Some of the mountain ranges are composed of sedimentary rocks of Paleozoic age; others are composed of or capped by volcanic rocks of Tertiary age. The Funeral Mountains are unique in that they are made up predominantly of Precambrian rocks (Jennings, 1958). The range is composed of schist and gneiss with local occurrences of sedimentary rocks. Precambrian gneiss, schist and pegmatite (Cornwall and Kleinhampl, 1961) are also exposed at Bullfrog Hills west of Beatty.
>
> The Precambrian sequence includes rocks of two distinct lithologies. The older Precambrian rocks include * * * schist, gneiss, and pegmatite. The younger rocks are dominantly clastic with interbedded siltstone, carbonates, and some marble. These two rock types will hereafter be referred to as Precambrian crystalline and clastic rocks.
>
> The Paleozoic sequence at the Nevada Test Site includes rocks of Cambrian to Permian age. Earlier, Johnson and Hibbard (1957) thought that the total thickness of the Paleozoic sequence was at least 22,000 feet. Current geologic mapping, however, indicates that more than 28,000 feet of Paleozoic sedimentary rocks were deposited.
>
> Rocks of Cambrian age aggregate more than 11,000 feet in thickness. They consist of a lower half that is predominantly clastic and an upper half that is predominantly carbonate rock.
>
> Ordovician, Silurian, and Devonian beds aggregate approximately 6,500 feet in thickness. All three sequences are composed predominantly of limestone and dolomite with some quartzite and are herein grouped together because of their similar lithology.

> Rocks of Mississippian and Pennsylvanian age aggregate approximately 10,000 feet (Poole and others, 1961, p. D-110). The Mississippian sequence is predominantly clastic rock and the Pennsylvanian sequence is predominantly carbonate rock. Rocks of Permian age aggregate just over 1,000 feet in thickness and are predominantly carbonate rock.
>
> Three intrusive granitic bodies, probably Mesozoic in age, crop out * * * north of Yucca Valley and in Cactus Range.
>
> Tertiary rocks that include both sedimentary and volcanic materials overlie Paleozoic rocks in some of the ranges and all basins. The Tertiary section is mostly volcanic with minor amounts of sedimentary rocks in the lower part of the section. In places the alluvium is considered to be Tertiary in age. The volcanic rocks in much of the area consist of a series of welded and nonwelded ash-flow tuffs. * * * Flow rocks of basaltic, andesitic, and rhyodacitic composition also are present locally in considerable quantity. The total aggregate thickness of the Tertiary rocks is unknown, but it probably exceeds 10,000 feet.
>
> Quaternary alluvium generally lies directly on Tertiary volcanic beds although locally it rests on Paleozoic rocks. The maximum measured thickness of alluvium is 1,870 feet in south-central Yucca Valley where it is penetrated by a drill hole.
>
> The Paleozoic rocks were extensively thrust faulted, probably during the Late Cretaceous (Johnson and Hibbard, 1957, p. 378). Many normal faults displace both the Paleozoic sedimentary rocks and the Tertiary volcanic rocks. Vertical displacements on the normal faults range from a few feet to several thousands of feet.
>
> The Las Vegas Valley shear zone (Longwell, 1960) has had profound influence on the present structure of the southeast part of the region. This major shear zone may be traced 100 miles northwestward from Boulder City, Nev., to [the vicinity of Mercury]. East of Mercury, the mountain ranges trend east-west in sharp contrast to the north-south trend of the ranges farther north. The east-west trend is the result of right-lateral movement along the shear zone. Horizontal movement along the shear zone has been estimated at 25 miles by Longwell (1960) and 27 miles by B. C. Burchfiel (written commun., 1961).

Barnes (oral communication, 1963) subsequently has stated that the total stratigraphic thickness of Paleozoic rocks is about 35,000 feet, and that carbonate rocks make up about 18,000 feet.

Geologic and geophysical investigations of the Nevada Test Site are being made by the Geological Survey in behalf of the U.S. Atomic Energy Commission. The list of maps and reports resulting from this work is long and is growing longer. It need not be given in full at this point. Among the published reports are those by Johnson and Hibbard (1957), Hansen and Lemke (1958), Wilmarth and others (1959), Healey and Miller (1962), and Poole and others (1961). Other important papers are by Hewett (1931), Longwell (1936, 1945, 1960), and Nolan (1929). Geologic field investigations for doctoral theses, especially that of Burchfiel (1961), and the reconnaissance geologic maps of Clark County (Bowyer, Pompeyan, and Longwell, 1958), Lincoln County (Tschanz and Pompeyan, 1961), and northern Nye County (Kleinhampl and others), published or in preparation under a cooperative program of the State of Nevada and the U.S. Geological Survey, also provide useful geologic data.

REGIONAL HYDROLOGY

Ground water in the Basin and Range province has been regarded as occurring in many closed or partially closed basins that coincide, at least roughly, with topographic basins. Each closed basin, or group of partially closed basins, has its own water table and seems to be independent of the others. In these basins the ground water is recharged from precipitation, principally on the flanks of the enclosing mountains. The water moves into valley fill that occupies the lower part of the basins; it is discharged naturally by evapotranspiration.

The bedrock that forms the mountains and underlies the fill has been considered to be essentially impermeable and to constitute a barrier, preventing the movement of ground water from one basin to another.

The partially closed basins have topographic outlets through which the ground water may discharge by stream flow if the water table meets the land surface. If the water level is below the land surface but is in valley fill above the bedrock, the ground water may be discharged from the basin by underflow. If the water table is below the bedrock that underlies the fill, the ground water may be confined to the basin as effectively as if there were no topographic outlet. But the bedrock is not everywhere a barrier. Where it is permeable, it may permit the ground water to escape from a basin. Studies recently made at the Nevada Test Site (Winograd, 1962) and Death Valley (Hunt and Robinson, 1960) indicate that ground water does move between some basins.

Closed, partially closed (or partially open), and open basins occur in the region described in this report, and movement of ground water through the bedrock probably takes place between some of them.

Altitude of water table

The altitude of the lowest recorded water level in each basin is taken as the approximate altitude of the water table. Although some of the altitudes may be shown by future investigation to be neither precise nor representative, they cover so wide a range that they can hardly fail to indicate the direction the ground water must go if it moves at all. They range from about 5,300 feet above sea level in

Stonecabin Valley, at the north, to 1,960 feet in the southern part of the Amargosa Desert (table 1 and fig. 2). In broad regional terms, therefore, the direction of ground-water movement should be southward. The direction of movement in detail, as between adjacent basins, is less obvious than the direction of regional movement because the differences of water-table altitude between adjacent basins are less and because some of them may not be appropriate. The head in tuff at Yucca Flat, for example, is higher than that in underlying carbonate rocks, and it declines as wells are deepened (Winograd, 1962). Conceivably a revision of water-level data for some basins might reverse the difference in altitude and invalidate conclusions based on present limited data.

Recharge

The average annual recharge for the region is estimated to be nearly 60,000 acre-feet. About half of this amount is attributed to Ralston and Stonecabin Valleys, which are in the northern part of the region, and about 17,000 (29 percent) acre-feet is attributed to Stonewall Flat, Cactus Flat, and Kawich, Penoyer, and Desert Valleys (table 1). The remaining 10,000 or 11,000 acre-feet (18 percent) is distributed in the other valleys, which total about 5,000 square miles, or about 45 percent of the region. Estimates of recharge decreases markedly from north to south across the region (see fig. 2).

Discharge

Natural discharge of ground water within the region is accomplished mainly by evapotranspiration, underflow, or both. Discharge by surface flow occurs only at the south end of Amargosa Desert and is minor in amount.

The quantity of water discharged by evapotranspiration can be estimated from the areas occupied by phreatophyte vegetation, and this has been done for six basins (table 1). The estimates range from 2,000 acre-feet (Oasis Valley) to 24,000 acre-feet (Amargosa Desert). In the remaining basins, evapotranspiration from the ground-water reservoir does not occur. Whereas the estimates for recharge decrease from north to south across the region, the available estimates for discharge increase from north to south.

The quantities discharged by underflow are practically impossible to estimate without a great deal more subsurface information than is currently available. For this reason the natural discharge for about three-fourths of the basins in the region has not been estimated.

Close agreement between the estimates of ground-water recharge and discharge for this region would be surprising. This lack of agreement is somewhat indicative of the uncertainties in present knowledge of the system.

Discharge-recharge relations

The average annual discharge for Penoyer Valley, as estimated by Maxey and Eakin (1951, p. 156), is 3,500 acre-feet, nearly equal to the annual recharge as estimated for this report, 3,600 acre-feet per year. The valley, therefore, may have a closed, or nearly closed hydrologic system, provided that there is no unmeasured underground recharge that is matched by underground discharge.

The recharge estimates for Stonecabin and Ralston Valleys are 16,000 acre-feet each, greatly exceeding the natural discharge, which Eakin (1962) estimates as 2,000 and 2,500 acre-feet, respectively. An additional 150 acre-feet is estimated to be pumped from Ralston Valley for use in the city of Tonopah. The excess of recharge over discharge indicates that ground water leaves these basins by underflow, probably going to the west or southwest of Mud Lake.

The discharge by evapotranspiration in Sarcobatus Flat may be 3,000 acre-feet per year, or more than twice the estimated recharge from precipitation; in Oasis Valley 2,000 acre-feet per year, or eight times the estimated recharge from precipitation; and in the Amargosa Desert 24,000 acre-feet per year, or 240 times the recharge. These relations indicate that each of these valleys is receiving water from adjacent areas by underground routes.

Other basins having ground-water systems that probably are either open or are but partially closed are Kawich, Rock, and Indian Spring Valleys, Crater Flat, and Fortymile Canyon-Jackass Flats. The indications in most of these valleys are that the ground water is discharged by underflow but not necessarily through the bedrock.

Among the valleys possibly having discharge by interbasin movement of ground water through bedrock are Yucca, Frenchman, Cactus, Gold, and Stonewall Flats, and Emigrant Valley. The lowest known water levels in these valleys are too deep beneath the land surface for evapotranspiration to occur. Where recharge and discharge do not balance, therefore, the ground water must be presumed to move from basins of dominant recharge to basins of dominant discharge, and from higher to lower water tables.

Hydrogeochemistry

The available chemical analyses of ground water from the region are illustrated on figure 3 by Stiff diagrams (Stiff, 1951, p. 15). Analyses for some waters in the Pahrump and Las Vegas Valleys are included because they show a significant regional relationship. Analyses for most springs are excluded because many springs are fed from perched zones of saturation, and therefore have little relation to the regional movement of ground water.

The two principal types of water found in this region are sodium bicarbonate and calcium-magnesium bicarbonate. The sodium-bicarbonate water seems to be related to aquifers in tuff or in alluvium containing fragmental tuff. The calcium-magnesium bicarbonate water appears to be related to aquifers in limestone and dolomite, or to alluvium containing detrital limestone and dolomite.

The sodium-bicarbonate ("tuff") waters are found along the west side of the region (Cactus and Sarcobatus Flats, Oasis Valley, and northwestern Amargosa Desert) and in the central part of the region (Nevada Test Site and Emigrant Valley). The calcium-magnesium bicarbonate ("limestone and dolomite") waters occur in Pahrump and Las Vegas Valleys, and in three wells of the Nevada Test Site that tap limestone or dolomite.

In addition, there are several intermediate analyses that may be regarded as altered. These are sodium-calcium-magnesium bicarbonate waters. They could be waters from tuff that have traveled long enough and far enough through limestone or dolomite to pick up significant amounts of calcium and magnesium; or they could be waters from limestone or dolomite to which some water from tuff has been added, or in which ion exchange has occurred. The altered waters seem to be most numerous in the southern part of the Amargosa Desert, but appearances may be deceptive. Possibly the altered waters are just as numerous in parts of the region for which chemical analyses are now very sparse.

Part of the sodium-bicarbonate ("tuff") waters and the altered waters now found in the southern Amargosa Desert could have moved to the Amargosa basin from localities to the north or northeast. Waters from the Nevada Test Site (Yucca, Frenchman, and Jackass Flats), for example, are now believed to move downward through alluvium and tuff into carbonate rocks of Paleozoic age and thence laterally southward or southwestward (Winograd, 1962). In this travel these waters could become altered.

The calcium-magnesium bicarbonate waters of the Pahrump and Las Vegas Valleys probably have not come from the northwest; rather, they are derived from the Spring Mountains, where Paleozoic carbonate rocks occur. They probably have not been in contact with tuff. The drainage divide that separates Pahrump and Las Vegas Valleys from the southeastern end of the Amargosa Desert marks a pronounced change in the chemical character of the ground water. Most of the waters northwest of the divide contain considerable sodium; those shown on fig. 3 southeast of the divide contain but little.

The calcium and magnesium in ground water may be exchanged for sodium if the water comes in contact with rocks containing exchangeable sodium, but sodium, once dissolved in water, generally remains in the water. The calcium-magnesium bicarbonate waters of Pahrump and Las Vegas Valleys therefore cannot have passed extensively through the tuffaceous aquifers or have come from the Amargosa Desert. If they had done so, they would contain more sodium. Only if they had traveled principally through limestone or dolomite, or detritus thereof, with little or no contact with tuff or "tuff" water, could they have the observed chemical composition. Although some of the waters from carbonate-rock aquifers in wells within or adjacent to the Nevada Test Site contain enough sodium to be classed as altered (nos. 73-66, 75-73, and 79-69), even these waters can hardly be reaching Las Vegas Valley in quantity. Not only do they contain too much sodium, but their average total solids--470 ppm--is more than twice the average total solids for four water from Las Vegas Valley (215 ppm, nos. 66-77, 65-76, 66-75, and 66-79). Substantial dilution would be required, in addition to selective elimination of sodium, to make them resemble those waters. Elsewhere in this report it will be shown that the configuration of the water table also precludes movement of ground water southeastward into Las Vegas Valley.

Age of ground water

The length of time that water has been underground may help to set limits on the rate of movement of the water. Known both as "age" and as "residence time," this may be determined for periods up to 50 or 75 years by measuring the tritium content of the water; and for periods in thousands of years, by measuring C^{14}. The C^{14} method is still in an experimental stage.

Clebsch (1961, p. C-122-125) reported the residence times of nine water samples from the Nevada Test Site and vicinity, based on tritium. Only two of these were less than 50 years. The two samples were from perched ground water, and probably were collected not far from the recharge area. The others, collected from wells that probably extend below the regional water table, suggest that the water had taken at least 50 years to reach the places where the samples were collected.

Experiments with the C^{14} method may show the age of the ground water to be several thousand years.

Direction of ground-water movement

The inferred directions of ground-water movement between the basins of the region, and the information on which they are based, are summarized in table 1. The indicated directions are those in which it appears to be possible for the water to go, without proof that the water actually is moving away from any particular valley. Proof that movement takes place depends on the relation of discharge to recharge,

Table 1.--Probable direction of interbasin movement of ground water from basins in a part of southern Nevada, based on estimates of average annual recharge and discharge, potential hydraulic gradient, geology and structure, and water chemistry.

Basin name	Area (square miles)	Estimated annual recharge from precipitation (acre-feet)	Estimated annual discharge (acre-feet)	Principal means of discharge 1/	Minimum depth to water (feet)	Lowest known water level in valley			Principal direction of underflow based on:		Chemistry of water	
						Depth below land surface (feet)	Altitude (feet)	Water in: a, alluvium c, carbonate rocks v, volcanic rocks	Potential hydraulic gradients (compass direction)	Geology and structure (compass direction)	Water type	Compatibility with probable water movement
Amargosa Desert	1,350	< 100	24,000± 2/	ET	0-5	75	1,960	a	S or W	S	Altered	Yes
Cactus Flat	700	4,000	--	U	110	443	5,057(?)	a	W or S	W or S	$NaHCO_3$	(?)
Crater Flat	210	< 100	--	U	253	253	2,360(?)	v(?)	S(?)	S	(?)	(?)
Desert Valley	1,000	2,800	(?)	(?)	(?)	(?)	(?)	(?)	(?)	(?)	(?)	(?)
40-mile-Jackass Flat	500	1,300	--	U	747	747	2,387	v	S	S(?)	$NaHCO_3$	Yes
Frenchman Flat	450	< 100	--	U	683	1,103	2,381	c	SW	SW or S(?)	Altered	(?)
Gold Flat	730	1,600	--	U	230	250	4,885(?)	a	S or E	(?)	(?)	(?)
Emigrant Valley	630	2,500	--	U	107	896	3,541	a, v(?)	S	S(?)	$NaHCO_3$	Yes
Indian Spring Valley	360	< 100	--	U	650(?)	650(?)	2,420(?)	a(?)	(?)	(?)	$CaHCO_3$	(?)
Kawich Valley	380	3,500	--	U	--	660(?)	<4,860±	a, (v?)	(?)	N	(?)	(?)
Mud Lake	200	< 100	--	U	---	--	4,950 3/	a	S or W	S or W	(?)	(?)
Oasis Valley	490	250	2,000	ET	0-5	--	3,300 4/	a	SW	SW	$NaHCO_3$	Yes
Penoyer Valley	715	3,600	3,500(?)	ET	19	--	4,750±	a	Closed or S	Closed(?)	(?)	(?)
Ralston Valley	770	16,000	2,500	ET	5-10	377	4,996	a, (v?)	S	S	$Ca(HCO_3)_2$	(?)
Rock Valley	85	< 100	--	U	---	675	2,378	(?)	SW(?)	SW	(?)	(?)
Sarcobatus Flat	760	1,200	3,000	ET	0-5	3/	4,000±	a	SW	Closed or SW	Altered	(?)
Stonecabin Valley	800	16,000	2,000	ET	0-5	107	5,300	a, (v?)	S	S	(?)	(?)
Stonewall Flat	890	3,000	--	U	100(?)	275±	4,300±	a	S	S	Altered	(?)
Three Lakes Valley	370	1,900	--	U	301(?)	301(?)	2,764(?)	a(?)	(?)	(?)	(?)	(?)
Yucca Flat	300	400	--	U	670	1,539	2,382	c	S	SW	$NaHCO_3$	Yes
Total (rounded)	11,700	59,000										

1/ ET - By evapotranspiration; U - By underflow.

2/ Includes annual discharge of about 18,000 acre-feet from springs whose source is considered to be to a large extent in the Spring Mountains, east of the area.

3/ Altitude in reference to playa.

4/ Altitude in reference to land-surface.

which for many basins is not know at present. In general, it is easier to say that the ground water cannot move from a specific basin to another than to say that it does so move. It cannot, for example, move from the basin having the lower water-table altitude to the basin having the higher water-table altitude, but it may move in the opposite direction. The data presented on preceding pages are essentially in agreement, as follows:

1. Regionally, the available water-table altitudes indicate that the ground water should move southward toward the Amargosa Desert, if it moves at all.

2. The recharge-discharge relations indicate that ground water does move toward the Amargosa Desert, although they do not prove that water from Ralston and Stonecabin Valleys travels all the way to that desert.

3. The hydrogeochemical data are compatible with this indicated regional ground-water movement, but do not prove that it occurs. The hydrogeochemical data do show, however, that ground water of the region probably does not escape into the Pahrump and Las Vegas Valleys.

Local modifications of the regional direction of ground-water movement probably are numerous. These modifications may be due to natural ground-water discharge to localities outside the region, (out of Ralston and Stonecabin Valleys), recharge that creates areas of high water table (water-table divides), and geologic controls on the permeability of the rocks.

Nevada Test Site in the regional system

The potential water-table gradients of table 1 and figure 2 suggest that ground water may be able to move into the Nevada Test Site from the northwest, north, or northeast, and may move out to the southwest. The lowest known water levels in Penoyer, Emigrant, and Kawich Valleys, and Gold Flat are 1,100 to 2,500 feet higher than water levels in the valleys of the Nevada Test Site. Geologic conditions seem to favor underflow from the northeast, that is, from Emigrant Valley, rather than from the north or northwest. Water from Emigrant Valley might move through Paleozoic carbonate rocks, or possibly through Tertiary volcanic rocks. Hydrogeochemical data, available for Emigrant Valley but not for the other three valleys to the north, are compatible as far as they go. Waters from three wells in the central part of Emigrant Valley are of the sodium bicarbonate type, similar to waters from aquifers in tuff within the Nevada Test Site.

The movement of ground water away from the Nevada Test Site necessarily must be toward localities of natural discharge at altitudes below the water tables of the Test Site. Only three such localities are known. The nearest is Ash Meadows in the southern end of the Amargosa Desert, about 35 miles south-southwest of Yucca Flat. The others are Muddy River springs in Moapa Valley, more than 60 miles to the east, and southeastern Las Vegas Valley, some 60 miles southeast. The Amargosa Desert seems to be a possible destination for the ground water of the Nevada Test Site. The other two localities do not.

The hydraulic gradient between the Yucca-Frenchman Flats area and the Amargosa Desert cannot be precisely determined at this time. Heads of the springs in the Amargosa area, or abnormally high heads in several wells 5 to 6 miles south of Lathrop Wells, could be used to indicate gradients. These would suggest a gradient of less than a foot per mile between the Yucca-Frenchman Flats area and the Amargosa Desert. However, these heads probably are influenced by the movement of ground water from the direction of the Spring Mountains, and thus they may imply a lower gradient from the Yucca-Frenchman Flat direction than is actually the case. The actual gradient distribution depends in part upon the position of the flow line of ground water moving from the Yucca-Frenchman Flat area to the Amargosa Desert. The position of this line at entry into the Amargosa Desert is strongly dependent upon the extent to which the head in the carbonate rocks is controlled by ground water recharged from the Spring Mountains. If that recharge has only small or negligible effect on the head in the carbonate rocks northeast of the Amargosa Spring area, the flow line of ground water coming from Yucca and Frenchman Flats may pass through the spring area. However, if that recharge builds up the head substantially, the flow line would be shifted northwestward, possibly into the Lathrop Wells area.

The quantity of ground water discharged from the Amargosa Desert by evapotranspiration and by springs (table 1) is roughly 240 times larger than can be reasonably accounted for by recharge from precipitation within the Amargosa Desert as shown on figure 2. It is practically required, therefore, that several outside sources, most likely to the north, northeast, and east, contribute to the water supply. Loeltz (1961) suggested that much of the water discharged in the springs is supplied by recharge in the Spring Mountains to the east.

The contribution of ground water derived from precipitation within Yucca and Frenchman Flats is but a small fraction of the estimated total discharge from the Amargosa Desert. The estimates of annual recharge in Yucca and Frenchman Flats are 400 and less than 100 acre-feet, respectively. If all this water were to be discharged in the Amargosa Desert, it would amount to about 2 percent of the total ground water discharged there. The Jackass Flats-Fortymile Canyon basin, on a similar basis, would contribute about 5½ percent, and the total from the Nevada Test Site would be only 7½ percent.

The influence of the stratigraphy and the geologic structure on the possible movement of ground water from the Nevada Test Site to the Amargosa Desert is obscure because the structure is complex. Numerous faults, both thrust and high-angle, have broken the Paleozoic sedimentary rocks and overlying Tertiary tuffs into myriads of fault blocks. Yet, the ground water seems to move from one block to another within the Test Site. The available water-table altitudes for wells in the three basins of the Test Site are enough alike so that hydraulic connection between the basins, not separation, seems probable. Not all the faults are barriers that prevent ground-water movement, even if some are. Possibly the biggest potential structural obstacle to ground-water movement is a major shear zone that has been postulated as trending northwest along the northeastern side of the Amargosa

Desert (Burchfiel, 1961). Ground water leaving the Jackass Flats-Fortymile Canyon area would have to cross this shear zone. The hydraulic effect of the shear zone is not known, but the presently available data on water levels and on water chemistry, although too sparse to be conclusive, do not indicate that the shear zone is a hydraulic barrier in this area.

Muddy River springs, the more distant of the other two suggested discharge areas, are about 650 feet lower in altitude than the ground-water levels of the Nevada Test Site, but a hydraulic connection between the two localities is dubious. Ground water from Yucca and Frenchman Flats at the Test Site would have to cross the structural trend of several mountain ranges, among them Spotted, Pintwater, and Sheep, if it were to issue at the Muddy River springs. Furthermore, the recharge in these mountains should tend to maintain ground-water divides above the water table at the Test Site. Hence, movement eastward to the Muddy River springs is unlikely. Furthermore, the water from Muddy River springs is a calcium-magnesium bicarbonate type of low total concentration, not likely to have originated within the Nevada Test Site.

Las Vegas Valley also is an unlikely discharge area for the ground water from the Nevada Test Site, even though the water levels in the discharge area southeast of Las Vegas are about 700 feet lower than at the Test Site. This indicated difference in altitude fails to take into account the water levels at intermediate locations, which are higher than those at the Test Site--about 60 feet higher at Tule Spring, only

11 miles northwest of Las Vegas and about 360 feet higher in well 66-75, a few miles east of Mercury. But high intervening water levels are not all. The chemical character of the ground water in the northwestern part of Las Vegas Valley, as shown in another section of this report, also suggests that the ground water from the Nevada Test Site does not move into Las Vegas Valley in large quantities. Additionally, much of the recharge to Las Vegas Valley is supplied from precipitation in the Spring Mountains, and this recharge could maintain a ground-water divide between Frenchman Flat in the Nevada Test Site and Las Vegas Valley. The estimates of recharge and discharge for Las Vegas Valley are in close agreement (Malmberg, 1961), making it probable that there is little or no underflow into the valley.

FURTHER INVESTIGATIONS

Data from the hydrologic studies at and near the Nevada Test Site seem to be adequate for outlining the principal features of the hydraulic system as it relates to the movement of water away from the Nevada Test Site, although many details remain obscure. The data may be lacking in some respects, but requirements for additional data should be considered carefully in relation to their cost.

The source--i.e., recharge area--and quantity of the ground water reaching the Nevada Test Site are perhaps less important to the Atomic Energy Commission than is the destination of the water that leaves. The recharge aspect of the hydrologic cycle is both difficult and expensive to appraise, and thus far has not beenattacked in earnest. Yet ultimately it must be appraised if the regional hydrology is to be understood.

Although the concentration of hydrologic data for the Nevada Test Site is not likely to be equalled elsewhere in the region unless an equally compelling need and strong sponsorship appear, it is worthwhile to suggest here the kinds of information and types of study that are needed.

Hydrology

Hydrologic data are scarce to lacking in much of the region. Depth to static water level, altitude of water level, head relations between aquifers, changes in head with depth, permeabilities of aquifers and aquicludes, recharge and discharge relations, and knowledge of the chemical character of water are needed to show whether the regional system broadly outlined in this report is valid, and to fill in the details not touched on here. The movement of ground water between basins, which is suggested in this and two previous papers, should be rigorously verified basin by basin. The age ("residence time") might be determined for a carefully chosen suite of samples if the experiments currently being made on a few water samples from the Nevada Test Site show the C^{14} method to be promising.

Geology

Additional geologic study is needed if the movement of ground water between basins is to be better understood. Such movement is postulated in this paper largely on the basis of hydrologic data, because detailed geologic data directly applicable to hydrologic problems are not generally available to show whether movement between basins is possible. The principal geologic features of the region are known, but important details are lacking. The following lines of investigation could prove fruitful.

1. Study of the geologic history, including the structural history, of the rocks of Paleozoic age may show how secondary permeability was developed in the carbonate rocks fracturing and solution. Such study may indicate how the distribution of secondary permeability relates to the transmission of ground water. The effect of faults in interrupting fracture and solution systems would be part of this study.

2. Field and laboratory studies of the solubility of the Paleozoic carbonate rocks may show which of these rocks are likely to be aquifers and which are not. Solution openings in Paleozoic rocks are known to occur in a number of areas adjacent to the region considered here. Solution openings locally transmit water to many springs in Nevada and also may be important in transmitting ground water at depth.

3. Identification of the surface of the "basement complex," that is, the surface below which ground water circulation is negligible. This surface may roughly coincide with the bottom of the Paleozoic

carbonate rocks that are a part of the regional hydrologic system. Undoubtedly this surface differs in altitude greatly from place to place. Where the surface is above the regional water level, the basement would impede, or deflect the movement of ground water. The recognition of such conditions would greatly improve the understanding of the movement of ground water in this region.

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APPENDIX

Basic data

Most of the available records of wells and springs, and the chemical analyses of water for the region, have been published in previous reports. The first table below indicates which report or reports to consult for data on each of the basins. Records of the test wells drilled under the hydrologic program for the Nevada Test Site, and analyses of water from them, have not previously been brought together, although part of these data have been published in TEI reports on individual test wells. These and similar data for four valleys of the northern part of the region are summarized in the second and third tables following.

Sources of hydrologic and hydrogeochemical data

Basin	None	Nev. State Eng. W. R. Bull.			Nev. Dept. Cons. Recon. Rept.			U.S. Geological Survey TEI Report									
		5	12	18	10	12	14	358 (1)	763 (2)	781	788 (1)	800	803	804 (1)	808	818	This
Ralston Valley						X											
Stonecabin Valley						X											
Stonewall Flat																	X
Cactus Flat																	X
Gold Flat																	X
Kawich Valley			(1)							(1)							
Penoyer Valley			(1)														X
Emigrant Valley										X							
Desert Valley	X																
Mud Lake						X											
Sarcobatus Flat					X												
Oasis Valley					X												
Yucca Flat								X	X	X	X	X	X	X	X	X	X
Frenchman Flat										X	X			X			X
Three Lakes Valley	X																
Indian Springs Valley		X															
Crater Flat	X																
Jackass F.-Fortymile C.										X				X			X
Rock Valley																	X
Amargosa Desert							X			X							
Las Vegas Valley		X		X						X							X
Pahrump Valley		X															

(1) Well information only.

(2) Chemical data only.

Partial record of wells

S - Stock
I - Irrigation
PS - Public supply
C - Construction
Ind - Industrial
X - Exploration
T - Turbine pump
E - Electric power
W - Windmill
G - Gasoline engine
R - Reported
M - Measured

Number	Location	Owner	Depth (feet)	Diameter (inches)	Use	Equipped	Measured or reported	Date of measurement	Measuring point	Depth to water below M.P. (feet)	M.P. above L.S.D. (feet)	Land surface altitude above sea level (feet) (approx)	Temperature (° F)	Remarks
66-75	Las Vegas Valley	USAEC	1,490	8 5/8-7 5/8	X	None	M	9-13-62	Land surface	734	----	3,479	78	Aquif., Paleoz. carb. rk.
67-68	Amargosa basin	USAEC	1,953	10 3/4	C	T, E	M	7-20-62	----do----------	784	----	3,154	92	Do
68-60	Rock Valley	USAEC	916	7	X	None	M	10- 2-62	----do----------	675	----	3,053	--	Aquif., Paleoz. rk.
73-66	Rock Valley	USAEC	3,400	8 5/8	X	None	M	10-25-61	----do----------	[a] 80	----	4,142	92	Aquif., Tert. tuff
								8-11-62	----do----------	1,735	----	--do--	144	Aquif., Paleoz. carb. rk.
74-58	Jackass Flats	USAEC	3,490	13 7/8-7 5/8	X	None	M	1- 1-63	----do----------	926	----	3,318	87	Aquif., Tert. tuff
75-73	Frenchman Flat	USAEC	1,853	7 5/8	X	None	M	5- 9-62	----do----------	1,103	----	3,484	98	Aquif., Paleoz. carb. rk.
79-69	Yucca Flat	USAEC	1,701	10 3/4	C	T, E	M	9-13-61	----do----------	1,539	----	3,921	98	Do
81-69	Yucca Flat	USAEC	1,675	10 3/4	X	None	M	5-16-61	----do----------	1,511	----	3,929	78	Aquif., Tert. tuff
83-68	Yucca Flat	USAEC	1,870	10 3/4	Ind	T, E	M	9-21-60	Top of casing	1,605	1.5	4,006	79	Aquif., alluvium
84-67	Yucca Flat	USAEC	1,950	10 3/4	X	None	M	12-31-60	Land surface	1,733	----	4,150	78	Aquif., Paleoz. rk.
84-69	Yucca Flat	USAEC	2,639	10 3/4-2 7/8	X	None	M	7-31-60	----do----------	[a]1,721	----	4,173	--	Aquif., Tert. tuff
								11-20-62	----do----------	1,783	----	--do--		Aquif., Paleoz. carb. rk.
85-67	Yucca Flat	USAEC	3,028	6 1/8	X	None	---	--------	----------------	1,740±	----	4,155	--	Do
87-60	Fortymile Canyon	USAEC	5,489	11 3/4-7 5/8	X	None	M	1- 1-63	----do----------	[a]1,064	----	5,695	--	Aquif., Tert. tuff
87-62	Fortymile Canyon	USAEC	4,206	11 3/4-8 5/8	X	None	M	9- -60	----do----------	[a]412	----	6,156	60	Aquif., Tert. tuff
								8-11-62	----do----------	1,971	----	--do--	87	Aquif., Paleoz. carb. rk.
88-66	Yucca Flat	USAEC	3,422	8 5/8-6 5/8	PS	T, E	M	3-28-61	----do----------	[a]1,915	----	4,470	87	Aquif., Tert. tuff
								3-20-62	----do----------	2,056	----	--do--	93	Aquif., Paleoz. carb. rk.
89-68	Yucca Flat	USAEC	6,001	11-7	X	None	M	3- 8-62	----do----------	669	----	4,586	95	Aquif., Paleoz. rk.

[a] First water-level measurement; head declined as well was deepened, indicating that water in Tertiary tuff is semiperched with respect to Paleozoic aquifer.

Partial record of wells--Continued

Number	Location	Owner	Depth (feet)	Diameter (inches)	Use	Equipped	Measured or reported	Date of measurement	Measuring point	Depth to water below M.P. (feet)	M.P. above L.S.D. (feet)	Land surface altitude above sea level (feet) (approx)	Temperature (° F)	Remarks
97-50	Gold Flat	Wilson Stewart	225	--	S	----	------	--------	----------------	------	-------	5,240	------	
97-52	Gold Flat	J. J. Casey	290	6	S	----	R	5- -47	----------------	230	-------	5,195	65	
98-35	Stonewall Flat	Unknown	325	6	S	W	R	--------	Top of casing	285	2.6	4,650±	------	
98-55A	Gold Flat	J. J. Casey	400	6	---	----	R	11- 7-49	----------------	250	-------	5,135	50	
98-55B	Gold Flat	Jim Daniels	530	8	S	----	R	4-30-50	----------------	475	-------	-----	55	Location uncertain
100-34	Stonewall Flat	Margie Guyott	604	16	PS	----	R	9-10-58	----------------	365	-------	4,678	60	
101-43	Stonewall Flat	J. M. Daniels	100±	--	---	W	---	--------	----------------	----	-------	-----	-----	Location uncertain
103-41	Stonewall Flat	Unknown	----	--	---	----	R	--------	----------------	110±	-------	4,685	-----	Report by Ball, USGS Bull. 308, p. 83
108-74	Penoyer Valley	Unknown	20	8	S	W	R	5- 5-48	Top of casing	14.75	-4.0	4,770	-----	
110-47A	Cactus Flat	U.S. Government	525	8	I	----	R	8-27-56	----------------	443	-------	-----	-----	
110-47B	Cactus Flat	U.S. Government	536	8	C	----	R	7- 2-59	----------------	353	-------	-----	-----	
111-51	Cactus Flat	J. J. Casey	418	6	S	G	---	11- 9-56	----------------	----	-------	5,610	-----	Cannot measure
112-47	Cactus Flat	U.S. Government	250	8	C	---	R	6-10-59	----------------	108.7	-------	-----	-----	
114-44	Cactus Flat	J. J. Casey	117	--	S	W	R	5-26-56	----------------	90	0.0	5,295	-----	
115-47	Cactus Flat	J. J. Casey	----	14	S	W	M	5-22-56	Top of concrete curb	107.1	5.0	5,400	-----	
116-45	Cactus Flat	J. J. Casey	184	6	S	W	M	5-22-56	Top of pump pipe	134.64	4.7	5,380	-----	
117-49	Cactus Flat	J. J. Casey	-----	--	---	----	---	--------	----------------	------	-----	5,475	-----	Abandoned

Chemical analyses of water by the U.S. Geological Survey
(except analyses 23164 and 430652)
(in parts per million, except as indicated)

	66-75	67-68	73-66	73-66
Lab. no.	4941	4888	4234	4866
Basin	Indian Spr.	Mercury	Rock	Rock
Depth (feet)	1,500	1,953	1,700	3,400
Water-bearing fm.1/	Carb. rk.	Carb. rk.	Tuff	Carb. rk.
Temperature ($^{\circ}$F)	78	92	72	148
Silica (SiO_2)	20	21	32	31
Aluminum (Al)	.12	.03	.4	.00
Iron (Fe)	.03	.03	.15	1.2
Manganese (Mn)		.00	.00	.00
Calcium (Ca)	34	47	13	68
Magnesium (Mg)	17	21	1.0	30
Sodium (Na)	13	37	99	63
Potassium (K)	2.5	5.2	6.4	9.6
Lithium (Li)	.03	.00	-----	.11
Bicarbonate (HCO_3)	197	256	199	278
Carbonate (CO_3)	0	0	-----	0
Sulfate (SO_4)	17	53	34	181
Chloride (Cl)	6.1	16	32	11
Fluoride (F)	.0	.9	.4	2.4
Nitrate (NO_3)	4.7	1.2	11	.0
Phosphate (PO_4)	.00	.16	.26	.00
Residue on evap.	225	330	330	536
Hardness - total	155	204	37	293
Non-carbonate	0	0	0	65
Specif. cond. (μmhos at 25° C)	337	544	492	751
pH	7.5	7.1	7.3	7.3

Chemical analyses of water by the U.S. Geological Survey
(except analyses 23164 and 430652)
(in parts per million, except as indicated)--Continued

	75-73	79-69	83-68	84-67
Lab. no.	4843	4667	4810	4103
Basin	Frenchman	Yucca	Yucca	Yucca
Depth (feet)	1,860	1,700	1,870	1,950
Water-bearing fm.1/	Carb. rk.	Carb. rk.	Alluv.	Tuff & carb. rk.
Temperature (° F)	100	97	81	-----
Silica (SiO_2)	24	30	81	18
Aluminum (Al)	.03	.00	.08	.4
Iron (Fe)	.00	.00	.00	.03
Manganese (Mn)	----	.00	----	.00
Calcium (Ca)	51	70	22	17
Magnesium (Mg)	21	19	7.4	10
Sodium (Na)	83	130	53	107
Potassium (K)	7.6	12	8.8	14
Lithium (Li)	.12	.35	.02	----
Bicarbonate (HCO_3)	328	560	206	274
Carbonate (CO_3)	0	0	0	0
Sulfate (SO_4)	84	75	21	71
Chloride (Cl)	23	23	6.5	20
Fluoride (F)	1.5	.3	.5	1.6
Nitrate (NO_3)	.9	.1	4.9	4.2
Phosphate (PO_4)	.00	.00	.00	.38
Residue on evap.	444	633	296	343
Hardness - total	214	253	82	84
Non-carbonate	0	0	0	0
Specif. cond. (µmhos at 25° C)	710	1,050	382	486
pH	7.3	7.2	8.0	7.8

Chemical analyses of water by the U.S. Geological Survey
(except analyses 23164 and 430652)
(in parts per million, except as indicated)--Continued

	89-68	98-35	107-74	110-47A
Lab. no.	4757	23164	40589	430652
Basin	Yucca	Stonewall	Penoyer	Cactus
Depth (feet)	6,001	325	200+	525
Water-bearing fm.1/	Carb. rk. and qzt.	Alluv.	-----	Alluv.
Temperature (° F)	95	65	60	-----
Silica (SiO_2)	17	-----	83	30.0
Aluminum (Al)	.0	-----	-----	-----
Iron (Fe)	.0	Neg.	-----	-----
Manganese (Mn)	.0	-----	-----	-----
Calcium (Ca)	41	34	42	2.4
Magnesium (Mg)	13	13	2.8	0.5
Sodium (Na)	96	63	30	79.6
Potassium (K)	15		11	-----
Lithium (Li)	.17	-----	-----	-----
Bicarbonate (HCO_3)	384	249	1.30	119.6
Carbonate (CO_3)	0	-----	-----	21.6
Sulfate (SO_4)	54	19.	41	26.3
Chloride (Cl)	11	34.	8.8	14.0
Fluoride (F)	1.1	.6	.6	1.1
Nitrate (NO_3)	.2	Neg.	1.3	-----
Phosphate (PO_4)	.0	-----	-----	-----
Residue on evap.	431	399	-----	-----
Hardness- total	156	136	116	-----
Non-carbonate	0	0	0	-----
Specif. cond. (µmhos at 25° C)	720	-----	371	16.7
pH	7.8	8.4	7.7	8.9

1/ Abbreviations: Carb. rk., carbonate rock of Paleozoic age; Alluv., alluvium of Quaternary and possibly in part Tertiary age; qzt, quartzite of Paleozoic age. Tuff is of Tertiary age.