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A Regional Interbasin Groundwater System in the White River Area, Southeastern Nevada[1]

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Abstract. A regional interbasin groundwater system including thirteen valleys in southeastern Nevada is generally identified on the basis of preliminary appraisals of the distribution and quantities of the estimated groundwater recharge and discharge within the region, the uniformity of discharge of the principal springs, the compatibility of the potential hydraulic gradient with regional groundwater movement, the relative hydrologic properties of the major rock groups in the region, and, to a limited extent, the chemical character of water issuing from the principal springs. The principal findings are: (1) Paleozoic carbonate rocks are the principal means of transmitting groundwater in the interbasin regional system—the regional transmissibility provisionally is estimated to be about 200,000 gal/day/ft; (2) estimates of recharge and discharge show wide discrepancies in individual valleys, but hydrologic balance with recharge and discharge estimates of about 100,000 acre-ft/yr obtains within the thirteen-valley region; and (3) the discharge of the Muddy River Springs, the lowest of the three principal spring groups, is shown to be highly uniform, which is consistent with their being supplied from a large regional groundwater system. The relation between this regional system and others in eastern and southern Nevada is now under study by the Geological Survey. (Key words: Hydrologic systems; hydrology (limestone); springs; groundwater)

INTRODUCTION

Reconnaissance appraisals of the groundwater resources of various valleys in Nevada have been made for several years. One of the assumptions on which these studies originally were predicated was the generally accepted concept that most hydrologic systems were more or less co-extensive with the topographically closed basins in the Basin and Range province. As studies for various areas were completed, it became evident that groundwater systems in certain valleys of eastern and southern Nevada extended beyond the limits of the particular valley. Some valleys have a much larger spring discharge than could be sustained by local recharge, and other valleys have deep water levels that preclude an annual groundwater discharge by evapotranspiration comparable with probable local recharge. If these observations are correct, a multivalley regional groundwater system is required to satisfy the general hydrologic equation that inflow equals outflow.

This report describes the general features of a regional groundwater system in a part of the Basin and Range province in southeastern Nevada. Although the scope of the report is limited by the reconnaissance nature of the investigations on which it is based, virtually all components of the hydrologic system are evaluated.

Location and extent of the region. The region discussed includes the area within the drainage divides of six valleys drained by the White River in Pleistocene time and seven adjacent but topographically separated valleys. It is in southeastern Nevada and lies within lat 36°40′ and 41°10′N and long. 114°30′ and 115°45′W. It includes parts of Clark, Elko, Lincoln, Nye, and White Pine counties (Figure 1). From its north end in southern Elko County, the region extends southward to include the upper Moapa Valley, a distance of about 240 miles. Its maximum width is about 70 miles near lat 38°N. The region includes an area of about 7700 square miles.

Topographic setting. Figure 2 shows the locations of the principal valleys and ranges in the region. Of the thirteen valleys, Long, Jakes, Cave, Dry Lake, and Delamar valleys are topographically closed. Garden Valley surfici-

[1] Publication authorized by the Director, U. S. Geological Survey.

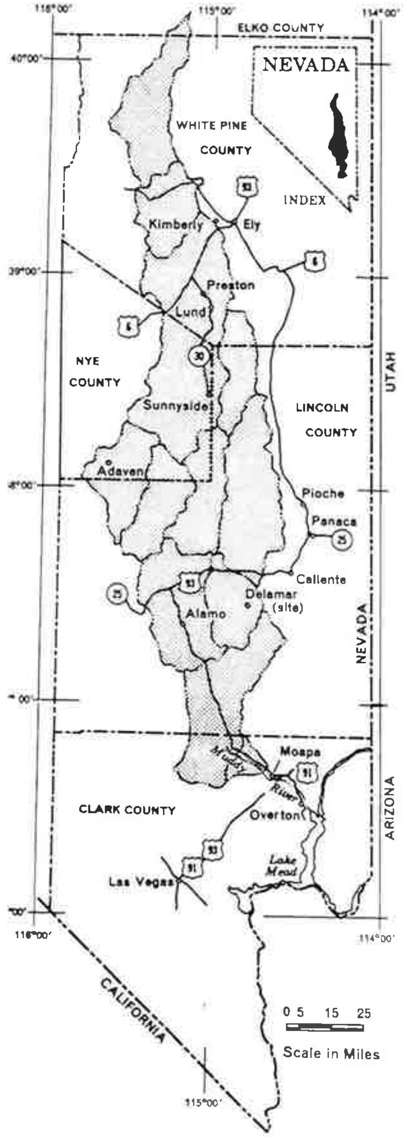

Fig. 1. Location of regional interbasin groundwater system described in this report.

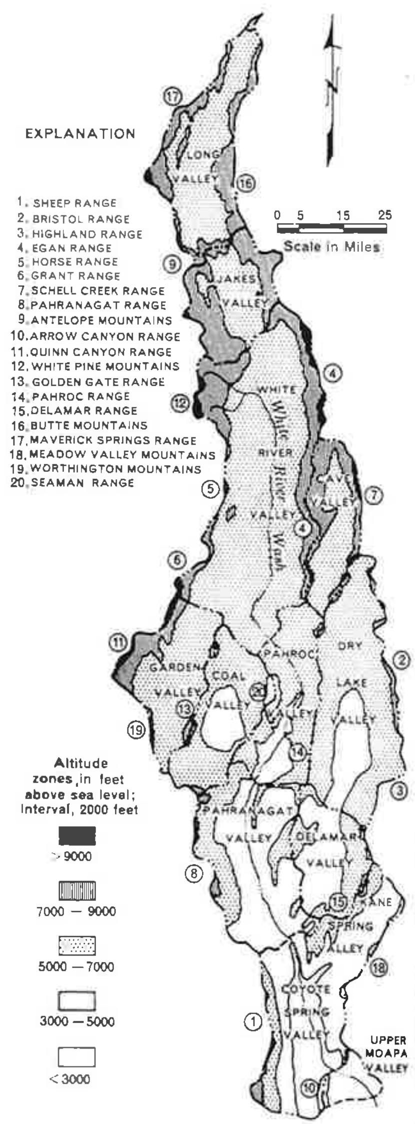

Fig. 2. General topography of the area of this report.

ally may drain into Coal Valley but together they form a topographically closed unit. The remaining six valleys were drained by the Pleistocene White River, then a tributary to the Colorado River system. The six valleys are White River, Pahroc, Pahranagat, Kane Spring, Coyote Spring, and upper Moapa.

This region of mountains and valleys generally has a southward gradient (Figure 2). Along the White River Wash the altitude decreases from about 5500 feet in the latitude of Lund to about 1800 feet in the vicinity of the Muddy River Springs in a channel distance of about 175 miles. The average gradient along the Wash is about 21 feet per mile. The White River Wash forms an axial topographic low between Garden and Coal valleys on the west and Cave, Dry Lake, and Delamar valleys on the east.

The mountains generally are 2000 to 4000 feet higher than the floors of the adjacent valley (Figure 2). The crests of the ranges commonly exceed 8000 feet above sea level and locally exceed 10,000 feet in the north part of the area. In the south part of the area the crests of the ranges exceed 8000 feet above sea level only locally and commonly are less than 7000 feet in altitude.

THE REGIONAL GROUNDWATER SYSTEM

The regional groundwater system includes both the rocks and the groundwater of the defined area. It includes the areas of recharge and discharge, storage and transmission of water, and geologic units that control the occurrence and movement of water. Semiperched groundwater in the mountains and in the valley fill of at least some valleys contributes to the regional system but is not emphasized herein.

The identification of this regional groundwater system is based upon (1) the relative hydrologic properties of the major rock groups in the area of consideration; (2) the regional movement of groundwater as inferred from potential hydraulic gradients; (3) the relative distribution and quantities of the estimated recharge and discharge; (4) the relative uniformity and long-term fluctuation of the discharge of the principal springs; and (5) the chemical quality of the water discharged from the principal springs. Much of the available data pertinent to the analysis is included in Tables 1, 4, 5, and 6 and on Figures 4 and 6. These elements are discussed in the following sections.

Geologic setting. The rocks provide the framework in which groundwater occurs and moves. Groundwater may occur in interstitial openings, in fractures, or in solution openings in the rocks. The openings may have been formed at the time the rocks were deposited or at a subsequent time by fracturing, weathering, or solution. The distribution and nature of these openings may relate generally to other physical and chemical characteristics of formations or groups of rocks. Thus, the general nature and distribution of the rocks in the region permit some inferences regarding the occurrence and movement of groundwater.

A number of geologic studies in parts of the area of this report have been made. For present purposes, the reconnaissance geologic map of Lincoln County [*Tschanz and Pampeyan*, 1961], the reconnaissance geologic map of Clark County [*Bowyer et al.* 1958], the general geologic map accompanying the guidebook to the geology of east-central Nevada [*Boettcher and Sloan*, 1960] for White Pine and parts of northeastern Nye counties, and unpublished information from F. J. Kleinhampl for segments of the region in northeastern Nye County have been most useful with reference to the areal geology of the region. For the White Pine County part of the region many of the papers in the guidebook to the geology of east-central Nevada [*Boettcher and Sloan*, 1960] are of much value.

Although not known to crop out within the area of this report, Precambrian rocks are exposed in the northern Egan Range east of Long Valley, in the Schell Creek Range [*Young*, 1960], along the east side of Cave Valley and northward, and in the Mormon Mountains [*Tschanz and Pampeyan*, 1961] east of Coyote Spring Valley and may be inferred to underlie all the region of this report.

A thick section of Paleozoic rocks was deposited throughout and beyond the area. Locally, the stratigraphic thickness of the Paleozoic rocks exceeds 30,000 feet [*Kellog*, 1963, p. 685]. Clastic rocks occur principally in the upper and lower parts of the section. Carbonate rocks, which comprise more than half of the section, are generally found in the central part of the Paleozoic section.

Lower Triassic marine deposits are noted by

EXPLANATION

Valley fill

Principally clay, silt, sand, and gravel; locally may include fresh-water limestone or evaporite; consolidated to unconsolidated. Deposited under subaerial, stream or lacustrine environments. Lower Tertiary deposits involved in deformation; upper Tertiary and Quaternary deposits moderately deformed, locally. Sand and gravel deposited in stream channels and alluvial fans transmit water freely; fine-grained deposits, where saturated, transmit water slowly but contain a large volume of water in storage

TERTIARY AND QUATERNARY

Volcanic rocks

Principally volcanic tuff and welded tuff or ignimbrite, but include other volcanic rock types and locally sedimentary deposits. Generally transmits water slowly, but locally highly fractured welded tuff may yield water readily. In mountains differential transmissibility, bedding planes, or fracture systems result in semiperched ground water which supplies many small springs. Where saturated transmits water slowly but contain a large volume of water in storage

TERTIARY

Paleozoic rocks undivided

Principally limestone and dolomite. Secondary fracture or solution openings result in transmission of substantial quantities of water, at least locally. In gross where saturated, store a large volume of water. Principal regional aquifer.

Include some shale, sandstone, and quartzite which generally act as a barrier to ground-water movement. Locally, however, fractured or weathered zones transmit some water

PALEOZOIC

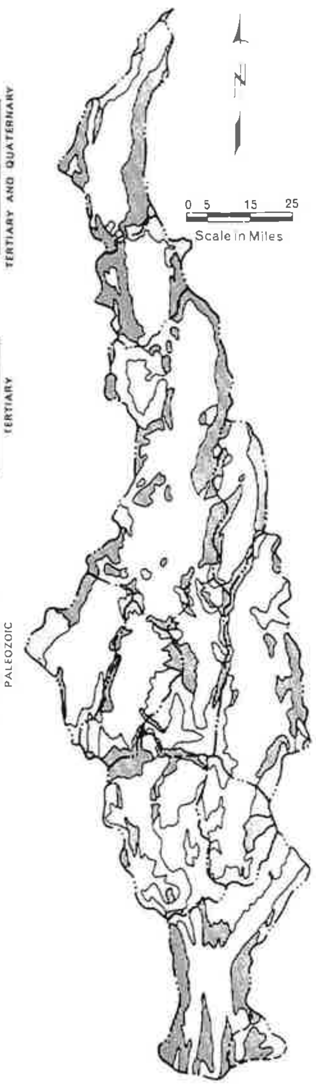

Fig. 3. Generalized geology of the region. Adapted from *Bowyer et al.* [1959] for Clark County; *Tschanz and Pampeyan* [1961] for Lincoln County; F. Kleinhampl (private communication, 1963) for parts of Nye County; and *Boettcher and Sloan* [1960] for remaining area.

EXPLANATION

Area of evapotranspiration of ground water

4600

Playa and approximate altitude, in feet, above sea level

Lund Spring (5595)

Data point, name, and approximate altitude of water level above sea level

30

Data point and serial number. Points described below include name or well number followed by depth to water and by altitude of water level. For oil tests, only total depth (T.D.) of well given

1.—Well 21N/59-18d2; 88; 6000
2.—Well 21N/58-33b1; 68; 6000
3.—Well 20N/58-14a1; 117; 6000
4.—Oil test, Summit Springs Unit no. 1; T.D. 11453
5.—Illipah Creek
6.—Oil test, Hayden Creek Unit no. 1; T.D. 5117
7.—Well 14N/61-10c1; 280; 5780
8.—Ellison Creek
9.—White River
10.—Oil test, County Line Unit no. 1; T.D. 4850
11.—Emigrant Springs; 5415
12.—Morman Spring; 5300
13.—Butterfield and Flag Springs; 5275
14.—Well 5N/60-25a1; 25; 5100
15.—Well 8N/64-30c1; 331; 5800
16.—Well 5N/64-14a1; 214 (dry); < 5385
17.—Well 3N/64-20b1; 317; 4820
18.—Well 2N/64-3b1; 664; 4350
19.—Well 1N/64-24a1; 398; 4300
20.—Well 4N/61-36c1; 90; 4970
21.—Well 3N/62-8c1; 217; 4835
22.—Well 3N/62-35b1; 252; 4770
23.—Well 2N/63-31b1; 800 (dry); < 4125
24.—Well 2S/61-23d1; 302 (dry); <3900
25.—Well 2N/59-22b1; 250 (dry); < 4775
26.—Well 4N/59-6d1; 9; 5340
27.—Well 3N/58-15b1; 235; 5040
28.—Well 3N/57-16c1; 33; 6150
29.—Well 1S/57-3a1; 570; 5020
30.—Well 6S/63-12a1; 900 (dry); <3700
31.—Well 4S/61-15b1; 670; 3700
32.—Well 5S/60-6c1; 380; 4025
33.—Well 3S/60-24d1; 187; 3815
34.—Well 4S/60-2a1; 105; 3870
35.—Hiko Spring, altitude 3890
36.—Crystal Springs, altitude 3805
37.—Ash Springs, altitude 3610
38.—Upper Pahranagat Lake
39.—Maynard Lake
40.—Well 10S/62-14a1; 416; 2175
41.—Coyote Spring, altitude 2575
42.—Well 13S/63-25a1; 330; 1875

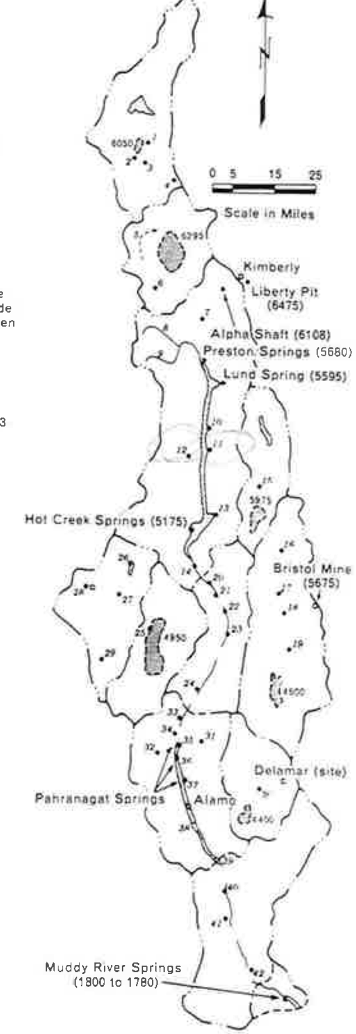

Fig. 4. Location points of selected data in the area of this report.

Stokes [1960, Figure 2] near Currie, Nevada, and near Wah Wah, Utah, about 70 miles north and 90 miles southeast of Ely, respectively. *Nolan et al.* [1956, pp. 68–70] described the nonmarine Newark Canyon Formation of Early Cretaceous age, which occurs in the vicinity of Eureka, Nevada, 70 miles west of Ely. To the southeast in northwest Arizona and adjacent areas, substantial sections of Mesozoic rocks occur. *Stokes* [1960, p. 121] indicates that southeastern Nevada was generally above sea level for most of Mesozoic time. At least in late Mesozoic time, parts of the area were being eroded and had exterior drainage.

Nonmarine sedimentary rocks of Eocene age in and adjacent to the White River Valley have been described by *Winfrey* [1960], who named them the Sheep Pass Formation. Their aggregate thickness is 3220 feet. As tentatively outlined [*Winfrey*, 1960, Figure 3], the basin in which they were deposited extended from about T5N to T11N in the southern White River Valley and from Cave Valley on the east to beyond the White Pine Mountains on the west. Contemporaneous deposits have not been described elsewhere in the region, although the Horse Spring Formation of Eocene (?) age in the Muddy Mountains, south of Coyote Spring Valley, may be equivalent in age [*Winfrey*, 1960, p. 133].

During middle Tertiary time an extensive and thick section of volcanic rocks was laid down in eastern Nevada. *Cook* [1960, Figure 1] indicates that an extensive ignimbrite province included much of the area of this report. To some extent nonmarine sediments, such as the lacustrine limestone and cobble conglomerate in the Pahroc Range reported by *Tschanz* [1960, p. 204], are interbedded locally with the volcanic rocks. The thickness of the volcanic rocks varies substantially from place to place, but *Dolgoff* [1963, p. 878] estimates a thickness of over 3000 feet for the volcanic sequence in the Pahranagat area.

Continental deposits overlie the Tertiary volcanic rocks in the present valleys. Commonly these are fine grained lacustrine or playa deposits that grade laterally to coarser fractions toward the source areas in the mountains. The Muddy Creek Formation of Pliocene (?) age [*Longwell*, 1928, pp. 90–96] is partly exhumed in Moapa Valley. *Longwell* [1928, p. 94] suggested that a thickness of 1700 feet for the Muddy Creek Formation was not excessive in the central part of the basin. Somewhat similar fine grained deposits are exposed along parts of the White River Channel. Their maximum thickness is not known. In White River Valley the County Line oil test (point 10, Figure 4) penetrated 1475 feet of 'valley fill' as reported by *McJannett and Clark* [1960*a*, p. 245], who infer that part of this valley fill is of Pliocene (?) age. Obviously, as the deposits were laid down in basins or valleys, the thickness should be variable, ranging from a feather edge at the margins to a substantial thickness in the central parts of the valleys.

Quaternary deposits include gravel, sand, silt, and clay laid down in stream-channel, alluvial-fan, and playa environments. White River, when it was a through-flowing stream in late Pleistocene time, probably removed more material than it deposited in the lower parts of the valleys in which it flowed. The depth and extent of dissection are greatest in the southern or downstream valleys.

Most of the mining districts have areas of exposed intrusive rocks, and *Bauer et al.* [1960, p. 223] discuss some of the intrusive rocks in the Robinson Mining District west of Ely. *Adair and Stringham* [1960, Figure 1] show the location of five intrusive igneous bodies or dike groups adjacent to the White River Valley. Two areas are in the White Pine Mountains, and three areas are in the Egan Range.

The rocks have been faulted, fractured, and displaced in a complex way and in varying degrees within the region during several periods of structural activity.

Occurrence of groundwater. For the purposes of this report the several stratigraphic units discussed briefly in the previous section can be grouped broadly on the basis of apparent gross hydraulic properties.

Three groups are shown on Figure 3. The relative hydraulic properties are noted in the explanation. Not shown are Precambrian and intrusive rocks that have negligible fracture permeability. These rocks probably provide a lower limit to groundwater circulation, not otherwise limited, at depth. Where these rocks are exposed and are continuous with depth, they also should form a barrier to the lateral movement of groundwater.

Fracture and solution openings in the Paleozoic carbonate rocks locally store and transmit substantial quantities of groundwater. The great thickness of Paleozoic carbonate rocks in this region tends to favor a regional hydraulic continuity, even though the Paleozoic rocks have been subjected to several periods of substantial faulting.

The occurrence of groundwater in carbonate rocks is demonstrated by the widespread distribution of many large springs associated with Paleozoic carbonate rocks throughout eastern Nevada. For example, most of the flow of Crystal Springs in Pahranagat Valley (Figure 4) issues in the bottom of pools and adjacent seeps from valley fill. However, part of the flow of Crystal Springs issues directly from carbonate rocks, which are exposed and also underlie the adjacent valley fill. The other principal springs, such as Ash and Hiko springs in Pahranagat Valley, the large springs in upper Moapa Valley, and Hot Creek, Mormon, and Lund springs in White River Valley, issue from points at or near contacts with carbonate rocks and valley fill.

Groundwater occurs in carbonate rocks at depth, as in the Deep Ruth, Kelinske, and Starpointer shafts in the Robinson Mining District (L. Green and M. Dale, oral communication, 1964). These shafts are about 1 mile east of Liberty pit, shown on Figure 4. Groundwater also occurs in carbonate rocks in the Bristol Mine in the Bristol Range (Paul Gemmill, private communication, 1964). Fresh water was reported [*McJannett and Clark*, 1960*b*, p. 249] in 'cavernous zones' of the Joana Limestone (Lower Mississippian) at depths of 4058 to 4097 feet below land surface in the Hayden Creek oil test (data point 6, Figure 4). This interval is roughly 3000 feet lower than the floor of Jakes Valley, which is about 5 miles northeast of the test well.

The clastic rocks included in the Paleozoic group in Figure 3 tend to act as barriers to groundwater movement compared with carbonate rocks. However, fractured clastic rocks do store and transmit some groundwater at least locally, as in the Pioche district.

The older Tertiary sedimentary rocks, such as the Sheep Pass Formation of *Winfrey* [1960], are generally consolidated and are believed to have little primary permeability. Locally they are faulted, which may provide secondary fractures through which some water may be transmitted to springs, such as in T11N, R62E in the Egan Range where that formation is exposed. Where such rocks underlie the valley floor and are saturated, they may contain a considerable volume of groundwater in storage, even though the average permeability is small.

The Tertiary volcanic rocks generally have low permeability. These rocks ordinarily are rather fine grained, and the extent to which they may transmit groundwater is possibly controlled by the degree to which closely spaced fractures occur in them. Where these rocks are welded or more or less glassy, fractures may be somewhat open and locally transmit groundwater freely. A well north of Lathrop Wells in southern Nevada is known to be capable of producing several hundred gallons of water per minute from the welded tuff (Winograd, private communication, 1963). Commonly, however, semiperched groundwater in fracture systems in the Tertiary volcanic rocks supplies the water for numerous small springs in the mountains, such as those in the southern Butte Mountains, in the Quinn Canyon Range along the west side of Garden Valley, and in the Delamar Range along the northwest side of Kane Spring Valley. Where these rocks are beneath the valleys and are saturated, substantial quantities of groundwater may be stored in them. The extent to which they may transmit groundwater is rather a function of the cross-sectional area through which the water may move and the hydraulic gradient than of the unit permeability, which generally is very low.

The partly consolidated or cemented fine-grained valley fill of Pliocene(?) and Pleistocene age generally yields water slowly. However, Coyote Spring in Coyote Spring Valley yields a modest supply of water, at one time nearly half a cubic foot per second, from a combined development of a tunnel and several wells in fine-grained valley-fill deposits. Brownie Spring in Pahranagat Valley yields about 1 cubic foot per second from a tunnel in consolidated conglomerate. Where saturated, the fine-grain valley fill is capable of storing large quantities of water. The unconsolidated sand and gravel deposits of the younger valley fill and in alluvial fans are capable of transmitting water freely. The sand and gravel deposits of the younger valley fill commonly have the highest unit permeability of any unconsolidated deposits in the region. The large-capacity irrigation wells in the White River, Pahranagat, and upper Moapa valleys are developed in these deposits.

Groundwater movement. The hydraulic gradients between springs and selected wells, and, more generally, the regional topographic

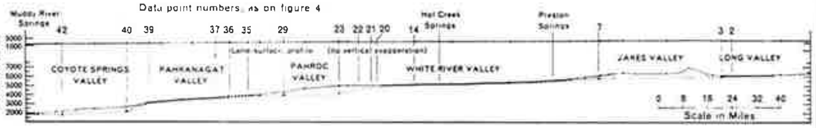

Fig. 5. Diagrammatic profile showing relation of water level to land surface along longitudinal axis of the area.

gradient, indicate the general direction of potential lateral groundwater movement in the regional system. Actual movement is dependent upon the hydraulic conductivity of the rocks.

The principal springs, which are the major points of discharge from the regional system, are on or adjacent to the White River Wash, and the altitudes of their orifices decrease southward. Thus, in White River Valley, Preston Big Spring issues at an altitude of 5680 feet above sea level and Hot Creek Springs, about 40 miles south, issues at an altitude of 5175 feet above sea level (Figure 4). In Pahranagat Valley from north to south, Hiko, Crystal, and Ash Springs issue at altitudes of about 3890, 3805, and 3610 feet, respectively. In upper Moapa Valley, the closely grouped Muddy River Springs issue between altitudes of 1800 and 1780 ft.

Compared with the low parts of adjacent topographically closed valleys of the regional groundwater system, the White River Wash is generally considerably lower at equivalent latitudes (Figure 4). The playa of Cave Valley is about 5975 feet above sea level. Due west in White River Valley the Wash altitude is less than 5200 feet. In Coal Valley the playa is at an altitude of about 4950 feet, whereas due east the White River Wash altitude is about 4800 feet. In Dry Lake Valley the playa altitude is slightly less than 4600 feet. At the latitude of the central part of that playa, the White River Wash is about 440 feet. The Delamar Valley playa is about 4400 feet above sea level, and upper Pahranagat Lake due west is about 1000 feet lower.

In all the above valleys plus Garden Valley, which surficially drains to Coal Valley, water levels are several hundred feet or more below the respective playas. Representative known, reported, or inferred low water-level altitudes for Cave, Dry Lake, Delamar, Garden, and Coal valleys, respectively, are 5800, 4300, 3700 ?), 5020, and less than 4775 feet (points 15, 19, 30, 29, and 25 on Figure 4). The altitudes of these water levels are higher than known or inferred altitudes of water levels along White River Wash at or south of the equivalent latitudes. Most of these water levels are considered to represent semiperched groundwater in valley fill. As such, it is inferred that water levels in the carbonate rocks underlying the several wells would be at somewhat lower altitudes. Even so, the potential gradient and movement from the adjacent valleys apparently is toward the trough occupied by the White River Wash.

For Jakes and Long valleys, lying north of White River Valley, the valley floors are at altitudes of 6295 and 6050 feet, respectively, and are higher than White River Valley. The lowest known water-level altitude beneath the playa of Long Valley is about 6000 feet, and in Jakes Valley the water level is unknown but is estimated to be as much as 400 feet below the playa surface. A potential though low southward gradient through the carbonate rocks toward White River Valley apparently exists, as the altitude of the water level in a well (point 7, Figure 5) in northern White River Valley is about 5780 feet and at Preston Springs, about 12 miles farther south, is about 5680 feet.

Outcrops of Paleozoic carbonate rocks at or adjacent to most of the springs are at altitudes lower than other Paleozoic carbonate rocks at or north of the latitude of the respective outcrops within this region. For example, in White River Valley the carbonate-rock outcrops adjacent to Lund Spring (Figures 3 and 4) are at a lower altitude than other carbonate-rock outcrops at or north of that latitude in White River, Jakes, or Long valleys. The carbonate-rock outcrops from which Hot Creek Springs issue are also at lower altitudes than any others at or north of that latitude in White River, Jakes, Long, and Cave valleys.

Similarly, the Paleozoic carbonate rocks from which Crystal Springs issues in Pahranagat

Valley are at a lower altitude than other outcrops of carbonate rocks north of that latitude. This same relation applies to the Paleozoic carbonate rocks exposed adjacent to the Muddy River Springs. This repetitive association of large springs with areas of topographically low outcrops of Paleozoic carbonate rocks demonstrates their close association and supports the inference of the regional movement of groundwater.

The regional potential groundwater surface is not everywhere defined by a smooth surface. On the contrary, limited data suggest that the water surfaces have local hydraulic discontinuities resulting from barrier effects or from other causes.

The profile in Figure 5 shows the land-surface and water-level altitudes along the approximate longitudinal axis of the region. It follows the general alignment of the White River wash southward from the latitude of Preston Springs. The upper line of the profile shows land surface with the vertical and horizontal scales the same, to illustrate the small proportion of relief in the region as a whole. The lower profile shows the land surface and water levels at a vertical exaggeration 10 times the horizontal scale for the purpose of more readily showing the local divergence of water level from land surface. As can be seen from the lower profile, the water-level gradient is near and parallel to the land-surface gradient in the White River, Pahranagat, and upper Moapa valleys, the areas of principal spring discharge. Elsewhere, the gradient locally may be steeper than the land surface, as is indicated in the north end of Pahroc and Coyote Springs valleys, and in other sections the gradient is less than that of the land surface, as in the central and southern parts of Pahroc and Coyote Spring valleys.

At the north end of Pahroc Valley and the south end of White River Valley the depth to water in the valley fill along White River Wash in 4 wells (points 20, 21, 22, and 23, Figure 4) increases progressively from about 90, to 217, to 252, and to more than 800 feet below land surface. The land-surface gradient in this segment of the wash is about 14 feet per mile, and the distances between the wells are 3, 4.5, and 6 miles, respectively. Thus, the indicated water-level gradient between the upstream pair of wells (points 20 and 21) is about 56 feet per mile, between the middle pair of wells (points 21 and 22) is nearly 22 feet per mile, and between the downstream pair of wells (points 22 and 23) is over 100 feet per mile. Several miles northwest of the upstream well (point 20) the water-level gradient is parallel to and within about 10 feet of land surface. The steepening of the water-level gradient in the valley fill in this section of the White River Wash is inferred to reflect a relatively abrupt change of head in the groundwater in the underlying carbonate rocks. This change or difference in head may be associated with faulting in the carbonate rocks, which results in a barrier effect to the movment of groundwater across the fault, or with an increase in the relative capacity to transmit water in the Paleozoic carbonate rocks downstream from this section.

A somewhat similar discordance in altitude of water levels occurs in the valley fill southward from Maynard Lake (point 39, Figure 4). The reported depth to water in the well (point 40) in northern Coyote Spring Valley was 416 feet, or at an altitude of 2175 feet. The well is about 8 miles south of Maynard Lake. The indicated water-level gradient between Maynard Lake and the well is about 117 feet per mile. This gradient too is considered to reflect a relatively steep apparent water-level gradient of the groundwater in the underlying Paleozoic carbonate rocks in the vicinity of Maynard Lake gap. The most likely cause here is a barrier effect resulting from faulting in the vicinity of the Maynard Lake gap. *Tschanz and Pampeyan* [1961] show a prominent fault complex crossing White River Wash just south of Maynard Lake, which could provide the necessary local barrier effect to southward groundwater movement.

In central Pahroc Valley, the well (point 23) was dry at a depth of 800 feet, or at about an altitude of 4125 feet, as noted above; the altitude of Hiko Spring, 31 miles southwest along the Wash, is about 3890 feet. The indicated gradient is less than 8 feet per mile. However, the water-level altitude in the carbonate rocks is probably somewhat lower than in the overlying valley fill in the vicinity of the well. Thus, the inferred water-level gradient in the carbonate rocks between these two points may be even less than the above indicated gradient of 8 feet per mile.

In Coyote Spring Valley, the indicated hydraulic gradient between the two wells (points 40 and 42) is about 13.5 feet per mile. This lower gradient is in contrast with the steep gradient near the north end of the valley, as was also the case in Pahroc Valley. Between the southern well (point 42) and Muddy River Springs the difference in altitude of water level is about 75 feet in a distance of about 10 miles. The apparent gradient is about 7.5 feet per mile. Again the inference is that the water-level gradient in the underlying carbonate rocks is probably somewhat less than that in the valley fill for most of the length of the valley. The above information suggests that a general gradient in the carbonate rocks in this region may be less than 8 feet per mile. Thus, the relative altitudes of the principal springs, wells in key locations, and regional topography support the inference of regional groundwater gradient to the south.

Recharge of groundwater. Table 1 summarizes the estimates of recharge to and of discharge from the groundwater system. These estimates were derived mainly in the reports referred to in the table.

Precipitation provides the principal source of water for recharge to the regional groundwater system. The direct measurement of recharge is not feasible, nor perhaps even possible, over an area of any great size. However, the general relationships that potential recharge increases with increased precipitation and that precipitation generally increases with altitude have been used to make estimates of long-term average annual recharge. The average annual recharge to groundwater from precipitation in a valley has been estimated empirically for the reconnaissance investigations by a technique that seemingly produces reasonable estimates for most areas of Nevada. Briefly, precipitation zones indicated by *Hardman and Mason* [1949, p. 10] are taken to be approximately represented by altitude zones on the 1:250,000-scale topographic maps. The successively higher zones have higher average annual precipitation and accordingly are considered to have a higher percentage of the precipitation recharging the groundwater reservoir. The values generally assumed are shown in Table 2.

Obviously, recharge is not uniformly distributed either over the area or in time. However, average precipitation is greatest in the mountainous areas at altitudes of 7000 feet and higher. Much of the precipitation in the mountains occurs as snow, which accumulates during the winter and melts in the spring. This process is favorable for accomplishing recharge. In general, then, most of the recharge from precipitation is probably centered in and adjacent to the several principal mountain ranges.

The general relations of increased precipitation with altitude and the seasonal distribution of precipitation are shown by the average monthly and annual precipitation for Kimberly, Adaven, Alamo, and Overton (Table 3). Station locations are shown on Figure 1.

Winter precipitation usually results from general storms that originate in the north Pacific. Summer precipitation occurs as high-intensity showers resulting mainly from southeast storms and local convectional storms. This relationship results in a pattern in which most of the precipitation occurs during the winter half of the year but with a secondary summer maximum in July and August. The summer maximum tends to be more pronounced in the southern part of the region.

The distribution of water runoff from the mountains also permits some inferences of the distribution and manner of recharge to the groundwater system. For mountain areas of otherwise similar characteristics, proportionally large runoff suggests little recharge by deep infiltration in bedrock in the mountains, and small runoff suggests proportionally large recharge by deep infiltration in the bedrock. Also, substantial runoff from the mountains suggests that recharge by infiltration from streamflow on the valley fill may be significant.

Records are not available to demonstrate the magnitude and distribution of streamflow throughout this region, but a general description of the streamflow conditions provides illustrative support.

The present-day White River is a headwater remnant of the ancestral White River (Figures 1 and 4). The White River formerly was a throughflowing stream that surficially drained the White River, Pahroc, Pahranagat, Coyote Spring, Kane Spring, and upper Moapa valleys to the Colorado River. It was a prominent stream as late as late Pleistocene time. Probably, too, in extremely rare and most favorable con-

TABLE 1. Summary of Hydrologic Information Relative to the Regional Groundwater System

Valley or Area (1)	Area, mi² (2)	Estimated Average Annual Recharge from Precipitation, acre-ft (3)	Estimated Average Annual Discharge of Groundwater by Evapotranspiration, acre-ft (4)	Estimated Discharge from Principal Springs, acre-ft (5)	Probable Principal Means of Discharge U–Underflow Sp–Springs ET–Evapotranspiration (6)	Lowest Water Level: Location and Reported Depth below Land Surface, ft (7)	Lowest Water Level: Approximate Altitude Above Sea Level (8)	Lowest Water Level: Water in A–alluvium T–Tertiary Volcanics (9)	References (10)
Cave Valley	365	14,000	Few 100		U	8N, 64-30c1 330	5,800	A(?)	*Eakin* [1962, pp. 2, 12, 13, 14]
Coal Valley	455	2,000	Minor		U	2N/59-22b1 250 (dry)	<4,750	A(?)	*Eakin* [1963*b*, pp. 14, 18, 19]
Coyote Spring and Kane Spring valleys	950	2,600	Few 100		U	13S, 63-25a1 332	1,875	A(?)	*Eakin* [1964, pp. 20, 22, 25]
Delamar Valley	385	1,000	Minor		U	6S, 63-12a1 900	3,700	A–T(?)	*Eakin* [1963*a*, pp. 13, 17, 18]
Dry Lake Valley	900	5,000	Minor		U	2N, 64-3b1 664	4,350	A–T(?)	*Eakin* [1963*a*, pp. 13, 17, 18]
Garden Valley	490	10,000	2,000		U	1S, 57-2a1 570	5,020	A–T(?)	*Eakin* [1963*b*, pp. 14, 18, 19]
Jakes Valley	430	17,000	Minor		U	...	?	...	Columns 2 and 3 computed in same manner as for other valleys. Value in column 3 is based on topographic maps now available and differs somewhat from value given by *Maxey and Eakin* [1949, p. 41]
Long Valley	650	10,000	2,200		U	21N, 58-35b1	6,000	A	*Eakin* [1961, pp. 22, 23, 31, Fig. 2]
Upper Moapa Valley (Muddy River Springs)	75	Minor	2,300	*36,000	Sp, ET	River	1,660	A	*Eakin* [1964, pp. 4, 6, 22, 24]
Pahranagat Valley	790	1,800	25,000	†25,000	ET, Sp	Maynard Lake <5	3,115	A	*Eakin* [1963*c*, pp. 18, 20]
Pahroc Valley	510	2,200	Minor		U	2S/61-23d1 350	3,950	A–T(?)	*Eakin* [1963*c*, pp. 13, 19, 21, Fig. 3]
White River Valley	1,620	38,000	34,000	‡37,000	ET, U	5N, 60-25a1 25	5,100	A	*Maxey and Eakin* [1949, pp. 12, 41, 44]. Estimates in columns 3 and 5 differ slightly from Maxey and Eakin figures, owing to minor differences in computations.
Totals (rounded)	7,670	101,000	‡65,000	98,000					

* Average of about 33,700 acre-ft occurs as flow in Muddy River; remainder of about 2,300 acre-ft is consumed locally by evapotranspiration.
† Nearly all subsequently consumed by evapotranspiration within valley.
‡ Includes about 5,000 acre-ft of evapotranspiration of groundwater largely unrelated to major spring discharge.

TABLE 2. Assumed Values for Precipitation and Per Cent Recharge for Several Altitude Zones in Area of This Report

Precipitation Zone, in.	Altitude Zone, ft	Assumed Average Annual Precipitation, ft	Assumed Average Annual Recharge to Groundwater, % of average precipitation
Less than 8	below 6000	variable	negligible
8 to 12	6000 to 7000	0.83	3
12 to 15	7000 to 8000	1.12	7
15 to 20	8000 to 9000	1.46	15
More than 20	more than 9000	1.75	25

litions, through streamflow may have occurred since Pleistocene time. The position of the ancestral White River is marked by a wash or trench along the topographical axis of the White River, Pahroc, Pahranagat, Coyote Spring, and upper Moapa valleys. The wash is ncised from a few to several hundred feet below the adjacent valley surfaces. Perennial flow presently occurs only from the White Pine Mountains and downstream from the principal springs in the White River, Pahranagat, and Moapa valleys. The principal present-day flow occurs in the downstream part of the ancestral river. Here Muddy River flows from Muddy River Springs near the head of Moapa Valley through Moapa Valley to Lake Mead (Figure 1). Otherwise, flow occurs along limited sections of the wash only after high-intensity storms or very favorable snowmelt conditions.

The present-day White River and its principal tributary, Ellison Creek, drain a part of the east side of the White Pine Mountains. The White River flows from these mountains at a point about 5 miles northwest of Preston Springs. During periods of high flow or when evapotranspiration is at a minimum, the streamflow may extend to the south end of White River Valley, a distance of about 50 miles, in part sustained by flow from the several springs along the floor of the valley. However, during much of the year streamflow from the mountains is small and is dissipated by diversion for irrigation and evapotranspiration before it reaches the Nye County line. At times of minimum streamflow the channel may be dry only a short distance downstream from where the stream leaves the mountains. The streamflow reportedly [*Maxey and Eakin*, 1949, p. 15] has been as much as 75 cfs (cubic feet per second) during the spring freshet, although commonly the streamflow is about 2 cfs during the summer season in the vicinity of Preston. *Maxey and Eakin* [1949, Table 1] list a number of measurements on the White River, made during the period 1908–1943.

Most of the streams having sufficient flow to be utilized for irrigation head in the ranges bordering the west side of Jakes, White River, and Garden valleys. The streamflow is derived largely from the seasonal snow accumulation. Peak flow occurs with the spring runoff, and low flow is partly supplied from small mountain springs.

Throughout the area streamflow may occur for short periods after high-intensity storms, most of which probably occur during the summer months. On the whole all streamflow is dissipated within the area by evaporation, transpiration, and recharge, except for minor amounts generated by high-intensity storms either in Coyote Spring or Kane Spring valleys, which occasionally results in runoff through Arrow Canyon into the Muddy River in upper Moapa Valley.

TABLE 3. Average Monthly and Annual Precipitation for Adaven, Alamo, Kimberly, and Overton, Nevada, for Period of Record

Station	Period of Record	Altitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Adaven	1919–1962	6250	1.32	1.48	1.46	1.01	0.81	0.43	0.86	1.20	0.50	1.02	0.84	1.20	12.19
Alamo	1922–1960	3610	0.62	0.66	0.70	0.58	0.47	0.16	0.67	0.72	0.26	0.56	0.43	0.51	6.34
Kimberly	1931–1958	7230	1.55	1.50	1.55	1.32	1.32	0.66	0.90	0.83	0.68	0.89	0.84	1.51	13.30
Overton	1910–1962	1220	0.51	0.48	0.41	0.24	0.15	0.05	0.20	0.38	0.29	0.17	0.41	0.60	4.22

The nature of the bedrock in the mountains apparently affects the runoff in the area. Locally, the Paleozoic carbonate rocks, which transmit water readily, seemingly receive recharge from precipitation that otherwise would become runoff in the mountain canyons. Thus, Illipah Creek (point 5, Figure 4) seems to be smaller than one might expect from the altitude and area of its drainage basin. Perhaps a more surprising example is the near lack of perennial runoff into the valley for the well-watered Egan Range.

The distribution of present-day perennial and seasonal runoff is closely associated with the distribution of the higher mountain ranges and generally supports the concept that the greater average precipitation is associated with the higher mountain ranges.

Average annual runoff from the mountains of the region is estimated to be about 80,000 acre-feet, as computed by the altitude-runoff method described by *Riggs and Moore* [1965]. Of this amount, about 70% is estimated to be generated in the northern half of the region. Thus, the distribution of runoff indicates that the northern part of the area is relatively well watered. This indication in turn suggests that the potential for recharge from streamflow also is relatively favorable in the northern part of the region.

Discharge of groundwater. The principal natural discharge of groundwater is from the three groups of springs in the White River, Pahranagat, and upper Moapa valleys. The discharge of the springs in the White River and Pahranagat valleys subsequently is lost from those valleys, largely by evapotranspiration, including the water utilized for irrigation. In upper Moapa Valley most of the spring discharge leaves the valley as streamflow in the Muddy River. The combined average discharge of these three groups of springs is estimated to be about 98,000 acre-feet a year (Table 1). Additionally, discharge of groundwater by evapotranspiration in the other valleys, which is not associated with the principal springs, is estimated to be nearly 5000 acre-feet a year and largely occurs in Long, Garden, and Cave valleys.

The springs of the three groups generally are known to have relatively uniform flow. Some variation of flow undoubtedly occurs, but the occasional measurements of discharge made at most of the springs are not adequate to define minor variations. In White River Valley, the Preston Springs–principally Big, Arnoldson, Cold, and Nicholas–have been measured at regular weekly intervals sufficiently to demonstrate a relatively constant flow characteristic. Preston Big Spring (discharge about 8.5 cfs) has been measured at about weekly intervals during the periods March to August 1936, September to November 1948, April to November during 1949, 1950, and 1951, and from May to September 1952. Arnoldson Springs (discharge about 3.5 cfs) and Nicholas Springs (discharge about 3.0 cfs) have been measured at about weekly intervals from September 1948 to September 1952. These records indicate that the minimum discharge is only about 10% less than the maximum.

Arnoldson, Nicholas, and Cold springs also were measured at about weekly intervals from March to August 1936. These measurements also indicated nearly constant flow. During this period the flows of Arnoldson (3.8 cfs) and Nicholas (2.7 cfs) springs were somewhat different than the flows during the later period of measurement, apparently the result of changing the outlet level of one of the springs. However, the combined flow of the two springs for both periods was almost identical. These data suggest a highly uniform flow of the springs. The best record to indicate the long-term spring-flow characteristics, however, is the gaging record of the Muddy River near Moapa. The gaging station is within 2 miles of the Muddy River springs, which supply most of the flow of the Muddy River. With appropriate adjustments, that record can be used to represent the discharge of the springs.

The streamflow of the Muddy River, near Moapa, has been recorded for the periods July 1913 to September 1915, May 1916 to September 1918, June 1928 to October 1931, April to July 1932, and from October 1944 to the present. The streamflow record at this station represents the actual discharge of the springs, except as follows: (1) streamflow at the station may be higher than spring discharge during periods of local runoff, particularly from high-intensity rains within the immediate drainage area; and (2) streamflow at the station is lower than spring discharge when water is diverted above the gaging station for irrigation, and when evapotranspiration between the station and the springs depletes the flow at the gaging station site.

A partial adjustment for the effect of overland runoff, during the period 1944–1962, was made by *Eakin* [1964, p. 23]. This adjustment resulted in a residual flow that, in effect, was entirely derived from spring discharge. The mean, median, and adjusted mean monthly and annual discharges for 25 complete water years of record through 1962 are given in Table 4.

Recently *Eakin and Moore* [1964] further analyzed the record of discharge of the Muddy River to evaluate the characteristics of the flow of the springs supplying the river. Corrections for evapotranspiration losses between the springs and gaging station virtually eliminated the seasonal variation shown by the month-to-month variations of mean streamflow at the gaging station. January characteristically is the month having the minimum average temperature and rate of evapotranspiration. Accordingly, the mean annual discharge of the springs supplying Muddy River is thus closely represented by the mean January discharge (49.8 cfs) recorded at the gaging station.

The analysis indicated a high degree of uniformity of spring discharge. The minimum annual mean discharge was about 90% of the maximum year. However, the small range in annual mean discharge apparently is significant in that the variations appear to be orderly and to occur, with considerable time lag, in response to variations in precipitation and consequent recharge. Both the high degree of uniformit of discharge and the small variations in annual mean discharge are compatible with the expected character of discharge from a regional groundwater system.

Relation of estimated groundwater recharge to discharge. The estimates of recharge to and discharge from the regional system shown in Table 1 agree closely for the region as a whole: the estimated recharge is 104,000 acre-feet a year, and the estimated discharge is 103,000 acre-feet a year. The estimates are considered reasonable and represent the magnitude of water naturally entering and leaving the regional system. The close agreement in the numerical values is considered to be coincidental rather than to indicate a high order of accuracy in the estimating techniques.

Although the regional estimates agree closely, there is wide divergence in the estimates for particular valleys. For example, in the White River and upper Moapa valleys the estimates of spring discharge are 37,000 and 36,000 acre-fee respectively. The estimate of recharge (38,(acre-feet) from precipitation within the su ficial drainage area of White River Valley approximates the estimate for spring discharge, but the estimated recharge from precipitation in the local drainage area of upper Moapa Valley is negligible.

Figure 6 shows the distribution of the estimated recharge to and discharge from the regional groundwater system and a generalized representation of the regional flow system. From the figure it is seen that about 78% of the recharge is estimated to occur in the 4 northern valleys, and about 62% of the discharge is estimated to be from the springs in

TABLE 4. Monthly Discharge of Muddy River, near Moapa, for 25-year Period Ending September 30, 1962

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Year
25-year mean	46.1	48.7	49.5	49.8	49.7	48.1	46.8	45.0	43.2	43.4	44.2	44.4	46.5
25-year median	46.5	48.0	49.3	49.3	49.2	47.6	46.5	45.4	43.4	43.9	43.3	44.4	46.7
Mean adjusted for effect of local surface-water runoff	46.0	48.2	49.5	49.8	49.4	48.0	46.8	44.9	43.2	43.0	53.5	44.4	46.

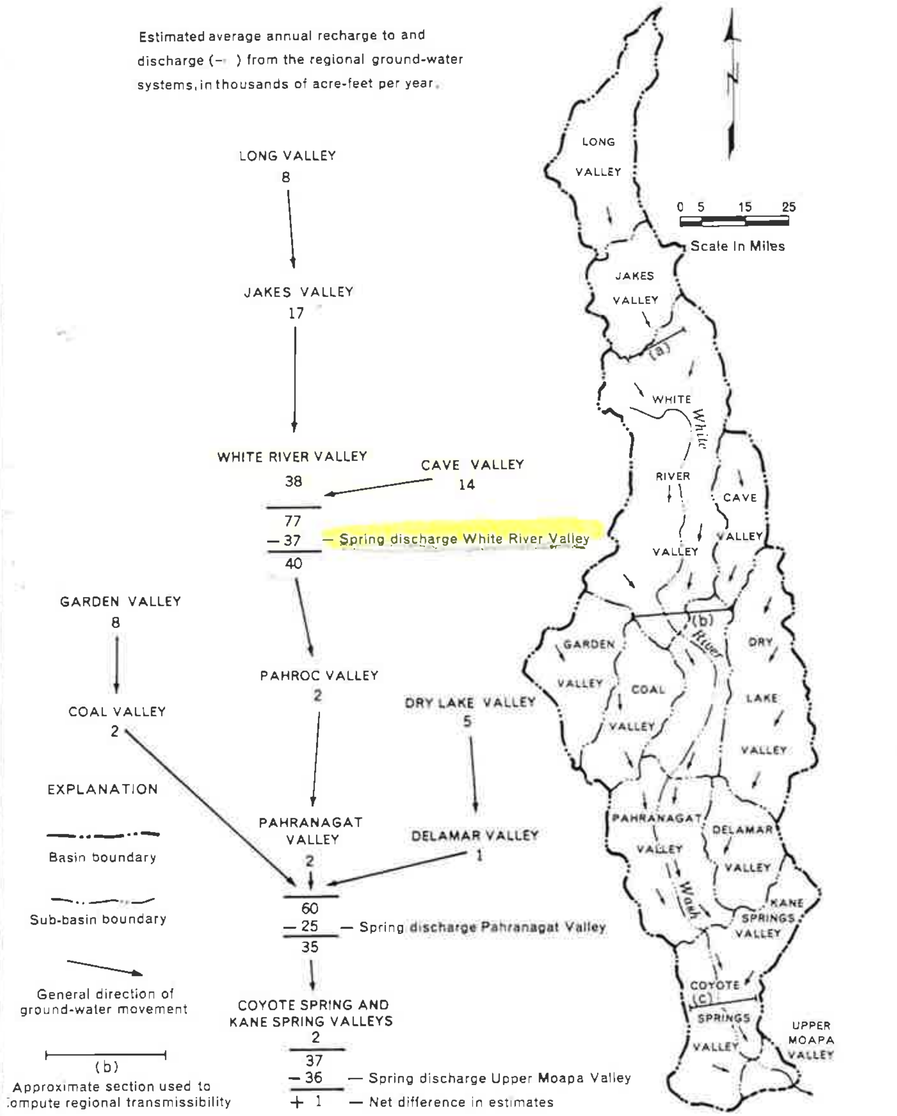

Fig. 6. Generalized flow pattern and estimated average annual recharge to and discharge from the regional groundwater system.

the Pahranagat and upper Moapa valleys in the southern part of the region.

Thus, the general balance between the overall estimates of recharge and discharge suggests a regional system within the 13-valley area. Further, the gross distribution of recharge and discharge infers a generally southward movement compatible with the regional movement indicated by the potential hydraulic gradient discussed in the previous section.

Regional transmissibility of the Paleozoic carbonate rocks. Transmissibility, one of the hydraulic properties of an aquifer, is usually determined by pumping tests under controlled conditions. Values so obtained are then used to compute the quantity of groundwater flow through a specified segment of aquifer. Wells are not available in this region to obtain transmissibility data of the carbonate rocks.

However, the generalized flow pattern and natural recharge-discharge relations shown on Figure 6, together with the hydraulic gradients discussed in the previous section on movement and generally shown in the profile on Figure 5, can be used to estimate the regional transmissibility of the Paleozoic carbonate rocks. The formula used is

$$T = Q/0.00112\, IW \qquad (1)$$

where T is the transmissibility in gal/day/ft; Q is the underflow in acre-feet per year; I is the hydraulic gradient in feet per mile; W is the effective width of the aquifer in miles, through which southward flow occurs; and the constant 0.00112 is a factor to convert gallons per day to acre-feet per year.

Three general sections were selected to estimate transmissibility: (1) a section near the north end of White River Valley through which most of the underflow occurs from Long and Jakes valleys; (2) a section near the south end of White River Valley through which most of the underflow occurs from White River and Cave valleys; and (3) a section in central Coyote Spring Valley through which most of the underflow occurs from Pahranagat and Delamar valleys. Gradients used are the indicated regional minimums, as discussed in the section on groundwater movement. Locally, actual gradients may be only a foot or two per mile or as much as several hundred feet per mile where controlled by barriers.

The estimated transmissibilities for the three sections were computed by using equation 1 and the values are listed in Table 5. These values suggest that a first approximation of the regional transmissibility of the Paleozoic carbonate rocks is on the order of 200,000 gal/day/ft. The value is not large considering the substantial thickness of the Paleozoic carbonate rocks. However, as the actual transmission of groundwater in the carbonate rocks is localized largely in fracture or solution zones, local transmissibility values undoubtedly are much higher, perhaps 10 times or more, than the indicated average regional value. On the other hand, large areas of carbonate rocks that have little or no fracturing and solution openings transmit very small amounts of water.

Chemical quality of water in the regional system. The chemical character of groundwater in part reflects an interaction between the water and the rocks through which it passes. Chemical analyses of water from several of the principal springs in the region are listed in Table 6. As these springs represent most of the discharge for the regional system, chemical constituents are a composite of the variations and concentrations that ordinarily may be found in the system. Locally, higher or lower concentrations of individual constituents and total dissolved constituents undoubtedly occur.

The water from the springs in the White River and Pahranagat valleys characteristically is a calcium-magnesium bicarbonate type, and the dissolved-solids concentration ranges from 246 to 343 ppm (parts per million). Water from the Muddy River Springs in upper Moapa Valley has about twice the dissolved-solids concentration (614 and 620 ppm) and is of a mixed type.

In a complex hydrologic system with many

TABLE 5. Three Estimates of Transmissibility in the Regional Groundwater System

Section	Underflow (Q) from Figure 2, acre-ft/yr	Estimated Effective Width (W), mi	Computed Gradient, ft/mi	Estimated Transmissibility, gpd/ft
(a)	25,000	15	6.4	230,000
(b)	40,000	25	8	180,000
(c)	35,000	15	8	260,000

TABLE 6. Chemical Analyses for Selected Springs in the Regional Groundwater System (in ppm)
(Analyses by U. S. Geological Survey)

†Springs	Date of Collection	Temperature, °F	SiO_2	Fe	Ca	Mg	Na	K	*HCO_3	SO_4	Cl	F	NO_3	B	Dissolved Solids (sum of determined constituents)	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific Conductance, μmhos at 25°C	pH
White River Valley																			
Preston Big	6–23–62	61	20	0.01	43	22	1	3.2	193	39	15	0.4	3.0	0.1	254	196	38	417	7.9
Lund	6–23–62	65	11	...	56	25	0.5	0.8	281	11	8.0	0.1	3.0	0.0	257	242	12	438	8.0
Lund	4–16–63	59	12	0.01	48	28	3.8	1.0	275	12	2.8	0.1	3.2	0.1	246	235	9	408	8.1
Butterfield	5–27–49	...	46	...	40	23	2.0	...	178	27	18	...	...	...	283	194	...	...	...
Hot Creek	6–23–62	88	28	...	60	22	29	5.3	288	45	8.9	1.0	0.4	0.0	342	238	2	540	8.0
Hot Creek	4–16–63	80	28	0.01	60	24	24	5.1	300	43	9.0	1.0	0.6	0.1	343	248	2	548	7.6
Pahranagat Valley																			
Hiko	3–10–62	80	33	...	44	23	29	7.2	260	36	11	0.5	1.2	0.1	313	206	0	494	8.0
Crystal	4–15–63	81	28	0.00	45	23	23	5.2	272	27	8.0	0.5	1.1	0.2	295	209	0	484	8.0
Ash	3– 9–62	88	31	...	39	18	32	6.8	231	34	9.7	0.5	1.2	0.1	286	172	0	443	8.1
Upper Moapa Valley																			
‡Warm	4–15–63	90	31	0.00	65	28	99	10	288	171	60	2.4	2.3	0.3	614	279	43	985	7.7
‡Iverson's	9–12–63	89	29	0.00	70	26	101	11	274	179	64	2.3	2.2	0.3	620	280	55	964	7.5
Muddy River gaging station near Moapa	3– 9–62	71	32	...	71	33	125	14	303	216	75	2.4	1.5	0.4	719	313	65	1,090	8.2

* CO_3 reported as 0 in all analyses except that for Butterfield Springs.
† See Figure 5 for location.
‡ Part of Muddy River Springs.

and precipitation and resultant groundwater recharge alone may be insufficient to maintain a hydraulic divide in these sections. The effectiveness of these divides cannot be determined at this time. However, the prominent structural trends parallel to these ranges probably act as barriers or partial barriers to groundwater movement across those alignments. Provisionally, then, it is assumed that the principal structural trends are sufficient to maintain hydraulic divides in these mountains.

Very little recharge occurs in the low Meadow Valley Mountains. The degree of influence of these mountains on groundwater movement in the carbonate rocks in this area is not known but might very well be almost negligible. Groundwater in the carbonate rocks occurs at higher altitudes, both in the region of this report and northeastward in the Meadow Valley area. However, in the Meadow Valley area the estimates of recharge from precipitation and discharge by evapotranspiration are in relative agreement [*Rush*, 1964, pp. 20–24]. This agreement suggests that if the Meadow Valley area contributes groundwater that ultimately discharges from the Muddy River Springs, then the quantity is only a small proportion of the total discharge of the springs.

In contrast, the combined estimated recharge from precipitation in the area considered to be supplying this regional groundwater system is in reasonable agreement with estimates of discharge from the springs only if the Muddy River Springs are included with those in Pahranagat and White River valleys. For the present, then, information favors the theory that most of the water supplying Muddy River Springs is derived from within the boundaries of the regional groundwater system as described in this report.

CLOSING STATEMENT

The regional interbasin groundwater system here described reasonably explains several otherwise anomalous occurrences of large natural spring discharge in 'dry' areas and of very deep water levels in valleys where at least limited natural discharge of groundwater by evapotranspiration ordinarily would be expected. The identification of this regional system is provisional in that it is based largely on indirect methods and limited data. However, the gross nature of the regional system is conside[illegible] be valid.

Other regional or multivalley groundw[illegible] systems potentially may occur elsewhere in [illegible] Basin and Range province, especially within [illegible] principal area of carbonate deposition in P[illegible] zoic time, which is the area sometimes refe[illegible] to as the Paleozoic miogeosynclinal are[illegible] eastern and southern Nevada, parts of we[illegible] Utah, and possibly in southern Idaho.

West of the area of this report, inte[illegible] studies are being completed on interbasin m[illegible] ment in Paleozoic carbonate rocks in and [illegible] jacent to the Nevada Test Site by the Geo[illegible] cal Survey. Further, additional data are b[illegible] obtained relating to the location and exte[illegible] regional groundwater systems, in conju[illegible] with the regular investigations under th[illegible] operative program of the Geological Surv[illegible] Nevada.

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This paper is a product of the reconnais[illegible] project conducted as a part of the general [illegible] gram of water-resources investigations in Nev[illegible] by the U. S. Geological Survey, in cooper[illegible] with the Nevada Department of Conservation [illegible] Natural Resources.

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interrelated subsystems, the causes of many of the chemical variations of the groundwater naturally would be obscure. However, the analyses of water from springs in the White River Valley show a reasonable uniformity of composition for water that probably has been derived from nearby areas and has moved largely through carbonate rocks, but which includes some water that has moved partly in volcanic and sedimentary rocks. If the hypothesis of the regional system is approximately correct, most of the water supplying the springs in Pahranagat Valley should be derived from a considerable distance beyond the immediate surface drainage area; that is, several tens of miles at least. The concentration of water from these springs might remain relatively low if the water moved almost entirely in carbonate rocks. The analyses of water from Hiko, Crystal, and Ash springs shown in Table 6 are indeed low, ranging from 286 to 313 ppm of dissolved solids.

The dissolved-solids concentration of the water from two of the springs in upper Moapa Valley is about 2 times that of the other two groups of springs. Much of the increase is due to an increase in sodium, sulfate, and chloride ions. Calcium is moderately higher, but magnesium is nearly constant in the water from all the springs. This general increase in concentration is more or less to be expected for water issuing from a position in the regional system relatively removed from most areas of discharge. The moderate degree of concentration suggests that circulation in the regional system is comparatively active.

Boundaries of the regional groundwater system. In the preceding discussion the general boundary of the White River regional system has been represented as being approximately coincident with the outer topographic divides of the appropriate valleys. In basin and range hydrology, mountains usually are assumed to be hydraulic barriers. Ordinarily few data are available to demonstrate this assumption as a fact, but one or more of several factors provide the basis for this generally correct assumption. These factors include the following:

1. The consolidated bedrock forming the mountains is virtually impermeable. Secondary openings due to surficial fracturing or weathering, which rarely extend to depths of more than a few hundred feet, may transmit ground water, but the lateral movement of water closel conforms to the general slope of the land su face.

2. The major structural trend commonly about parallel to the principal topographic ax of the range. Ordinarily, faults and structur alignments tend to act as barriers to ground water movement across or at right angles t them.

3. The mountains characteristically receiv much greater average precipitation than do th adjacent valleys; greater precipitation provid a greater potential for recharge. If greater r charge occurs per unit area, other things bein equal, a hydraulic high (or divide) will b maintained between the areas of lesser or m recharge.

4. Surface water divides are coincident wit the topographic divides, which suggests that th groundwater divide is also aligned with th topographic divide.

The position of the hydraulic boundary of th regional groundwater system is indicated a only a few locations. For example, in the Ega Range, the water-level altitude in the we (point 7, Figure 4) 12 miles north of Presto Springs in White River Valley is about 578 feet. Northeastward about 11 miles, the water level altitude in the Alpha Shaft is reported t be 6108 feet [*Maxey and Eakin*, 1949, p. 41] Eastward about half a mile, the water-lev altitude in the Liberty Pit is maintained b pumping at an altitude of about 6475 fee Drill holes on the east side of Liberty Pit ar reported to have water-level altitudes rangin from about 6860 to 6960 feet. Groundwater i carbonate rocks was encountered in the nearb Deep Ruth and Kelinske shafts. About 2 mil east the water-level altitude in the Kimberl Pit is somewhat below 6600 feet, and adjace altitudes in drill holes range from about 661 to 6822 feet. The above-water-level informatio for the Robinson mining district area was r ported by L. Green and M. Dale of the Kenne cott Copper Company (private communicatio 1964). About 3½ miles southeast of the Kim berly Pit, Murry Springs, which provide th municipal water supply for the City of Ely issue at an altitude of about 6600 feet. Finally several miles east in the floor of Steptoe Valley

he water level is within a few feet of land rface, which is at an altitude of about 6375 et. This mountain area is geologically and ructurally complex, and water levels have en affected somewhat by mining operations. owever, the generalized information indicates at a hydraulic divide is several hundred feet gher than the water level in either White iver or Steptoe valleys and is within perhaps mile of the topographic divide.

Limited water-level information also indi- ated the position of the hydraulic divide at the orth end of the Bristol Range. The water-level ltitude at a well (point 17, Figure 4) in Dry ake Valley is about 4820 feet; about 8 miles st the water-level altitude in the Bristol Mine, s reported (oral communication, 1964) by Paul emmill (formerly of Combined Metals Re- uction Company), is about 5675 feet. Still rther east in the next valley, about 4 miles ortheast of Bristol Mine, the water-level alti- ude in a well is about 5610 [*Rush*, 1964, Table 5]. Groundwater in the Bristol Mine occurs in aleozoic carbonate rocks, and, according to emmill, the level apparently fluctuates to some xtent with variations in recharge. The ground- ater encountered in the wells is in valley fill nd may be under a higher head than in the nderlying carbonate rocks. Nevertheless, the ater-level altitude in the Bristol Mine indi- ates a hydraulic divide close to the topographic ivide in the Bristol Range.

The Pahranagat and Sheep ranges form the est side of Pahranagat and Coyote Spring alleys, respectively. Recharge from precipita- on in these mountains, although limited, prob- bly maintains a hydraulic divide along the ountain alignment. Data on water levels in he Paleozoic carbonate rocks in these moun- ins are not available. However, the altitude of he water level in a well (point 32, Figure 4) in he valley fill is about 4025 feet, or about 220 et higher than Crystal Springs, about 3½ iles to the east in Pahranagat Valley. This ltitude suggests that the gradient of ground- ater in the underlying carbonate rocks may lso be generally from the Pahranagat Range oward the White River Wash to the east. Some- what similarly, the semiperched groundwater upplying Coyote Springs in Coyote Spring Valley is considered to be derived from recharge n the Sheep Range to the west and moves through the older valley fill toward the White River Wash. As the recharge area is necessarily at a higher altitude than the spring area, it may be assumed to be at an altitude high enough to provide a hydraulic barrier in the carbonate rocks in the Sheep Range.

The Delamar Range and Meadow Valley Mountains form the east sides of Delamar and Kane Springs valleys. Some groundwater is perched in the Tertiary volcanic rocks and supplies several small springs in the Kane Spring Valley side of the Delamar Range. Near the townsite of Delamar (Figure 4), some water initially was developed at several small seepages from limestone and granite [*Carpenter*, 1915, p. 67] and was insufficient for the requirements. That these springs were derived from perched groundwater is suggested strongly by the fact that, according to Carpenter, the mine at Delamar was totally dry to a depth of 1400 feet. The altitude of the bottom of the mine is not known but apparently was of the order of 5300 feet. West of Delamar, in the lower part of Delamar Valley, the apparent water-level altitude may be below 3700 feet, based on reports that a well (point 30, Figure 4) was dry at a depth of 900 feet. East of Delamar, water levels in the floor of Meadow Valley Wash are at an altitude of about 3800 feet. The meager recharge in the Delamar Range and the presence of relatively impermeable Paleozoic clastic and Tertiary volcanic rocks are probably sufficient to maintain a hydraulic divide between Meadow Valley Wash and Delamar Valley, even though the divide may be much below the level of Delamar mine in that area.

More generally, on the basis of substantial recharge potential, it may be inferred that the Butte Mountains and Egan, Schell Creek, Bristol, and Highland ranges, which form the eastern boundaries of Long, Jakes, White River, Cave, and Dry Lake valleys, respectively, are probably aligned with the east side hydraulic boundaries of those valleys. Similarly, the Maverick Springs, Ruby, and the White Pine mountains and Grant and Quinn Canyon ranges are probably aligned with the west side hydraulic boundaries of Long, Jakes, White River, and Garden valleys.

Some sections of these east- and west-side groups of mountains, such as the Antelope Mountains and Horse Range, are relatively low,