Summary Appraisals of the Nation's Ground-Water Resources—Great Basin Region

GEOLOGICAL SURVEY PROFESSIONAL PAPER 813-G

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By THOMAS E. EAKIN, DON PRICE, *and* J. R. HARRILL

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A regional appraisal and discussion of planning the future ground-water development in a region characterized by a semiarid climate and closed-basin drainage

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SYSTEM OF MEASUREMENT UNITS

To convert English unit	Multiply by conversion factor	To obtain metric unit
Acres	4.047×10^{-3}	Square kilometres (km²).
Acre-feet (acre-ft)	1.233×10^{-3}	Cubic hectometres (hm³).
Cubic feet (ft³)	2.832×10^{-2}	Cubic metres (m³).
Feet (ft)	3.048×10^{-1}	Metres (m).
Gallons (gal)	3.785	Litres (l).
Gallons (gal)	3.785×10^{-3}	Cubic metres (m³).
Inches (in)	25.4	Millimetres (mm).
Miles (mi)	1.609	Kilometres (km).
Square miles (mi²)	2.59	Square kilometres (km²).
Gallons per minute (gal/min)	6.309×10^{-2}	Litres per second (l/s).
Gallons per minute per foot [(gal/min)/ft].	.207	Litres per second per metre [(l/s)/m].

SUMMARY APPRAISALS OF THE NATION'S GROUND-WATER RESOURCES—GREAT BASIN REGION

By THOMAS E. EAKIN, DON PRICE, and J. R. HARRILL

ABSTRACT

Ground-water withdrawals by wells in the Great Basin Region were about 1.1 million acre-feet (1,360 cubic hectometres) in 1970. Most of these withdrawals were from 87 of the 234 hydrographic areas in the region. Withdrawals ranged from about 1,000 acre-feet (1.2 cubic hectometres) to more than 100,000 acre-feet (123 cubic hectometres). Jordan Valley, which includes Salt Lake City, had the largest withdrawal, about 115,000 acre-feet (142 cubic hectometres).

An appraisal of the regional ground-water resource indicates the region could sustain an annual net pumpage of about 2.6 million acre-feet (3,200 cubic hectometres). Larger withdrawals could be sustained if only part of the pumped water was used consumptively, if conflicts with existing surface-water rights are resolved, and if extensive treatment, artificial recharge, and reuse of water prove feasible. Ground water stored in the upper 100 feet (30 metres) of saturated deposits of the valley ground-water reservoirs is estimated to be on the order of 300 million acre-feet (370,000 cubic hectometres). Total ground-water storage probably exceeds several billion acre-feet; however, much of this could not be developed within economic feasibility expected over the next several decades.

Only a few areas of the Great Basin Region have been studied in detail sufficient to enable adequate design of an areawide ground-water development. These areas already have been developed. As of 1973 data for broadly outlining the ground-water resources of the region had been obtained. However, if large-scale planned development is to become a reality, a program for obtaining adequate hydrologic and related data would be a prerequisite. Ideally, the data should be obtained in time to be available for the successively more intensive levels of planning required to implement developments.

INTRODUCTION

Development of ground-water resources has traditionally been a piecemeal process. In a given area, ground-water supplies are typically developed by individuals, industries, and municipalities to meet specific needs. The magnitude and distribution of pumping is dependent largely on the needs and locations of individual users. If combined net withdrawals of ground water do not exceed the average long-term replenishment (recharge) to the ground-water system, problems caused by development may be minimal. In some parts of the United States, net ground-water withdrawals greatly exceed the recharge, and ground-water resources are being mined—extracted at rates in excess of rates of replenishment. More often, however, problems occur because of local overdevelopment, the concentration of pumping in too small an area. This results in excessive pumping lifts and may lead to reduced well yields and deterioration in water quality. Detrimental land subsidence has occurred in some areas because of local overdevelopment. In most cases, the ground-water system was not well understood in advance.

The purpose of this report is to: (1) Outline the overall ground-water resources of the Great Basin Region, (2) describe the regional ground-water use as of 1970, (3) evaluate the potential for ground-water development in the Great Basin Region, (4) identify some information necessary to plan ground-water development, and (5) discuss some options for ground-water development.

The ground-water resources of the Great Basin Region consist of two components: (1) A large volume of water stored in alluvial and consolidated-rock reservoirs, and (2) an annual replenishment which is much smaller than the total volume of water in storage. That part of the total resource that may be successfully developed is limited by various constraints. Specific constraints vary with each area but always include: (1) Physical constraints imposed by the natural system, (2) economic constraints based on the cost of water in relation to benefits derived from use, and (3) legal and administrative constraints imposed by local, State, and Federal Governments. If the ground-water system has been adequately defined in advance, a supply system can be planned, constructed, and operated to provide optimum use of water within limitations posed by the preceding constraints.

All numerical values in this report are given in English units. For those who prefer to use metric units, the conversion factors are given on preliminary page IV.

Chemical concentration and water temperature are given only in metric units. Chemical concentration is given in milligrams per litre. For concentrations less than 7,000 mg/l (milligrams per litre), the numerical values are about the same as those for concentrations given in parts per million.

THE LAND

The Basin and Range physiographic province (Fenneman and Johnson, 1946) is an area of about 200,000 square miles (518,000 km^2) of internal drainages; it has no surface outlet to the ocean. The Great Basin Region, as described in this report, is that part of this physio-

TABLE 1.—*Size and principal features of subregions in the Great Basin Region*

Subregion	Area (thousands of mi²)	Principal drainages[1]		Principal sinks	Number of hydrographic areas in subregion
		Major	Secondary		
Bear River	7.5	Bear River (8)	Logan River (1)	None—drains to Great Salt Lake subregion.	9
Great Salt Lake	29.0	None	Ogden River (2), Weber River (3), Provo River (2), Jordan River (2).	Great Salt Lake	37
Sevier Lake	16.2	Sevier River (4)	San Pitch River (2), Beaver River (2).	Sevier Lake	14
Humboldt	30.0	Humboldt River (16)	Little Humboldt River (2) Quinn River (5)[2] Kings River (1).	Humboldt Sink (with overflow to Carson Sink).	59
Central Lahontan	11.5	Truckee River (7), Carson River (5), Walker River (7).		Pyramid Lake, Carson Sink, Walker Lake.	33
Tonopah	49.7	None	None	None—Many small sinks in individual valleys.	82
Region (rounded)	144	....	....	....	234

[1]Number in parentheses is the number of hydrographic areas traversed or bounded by the river.
[2]Perennial flow in only one area.

graphic province whose drainage is into Nevada and Utah.[1] It includes parts of California, Idaho, and Wyoming and covers about 70 percent of the physiographic province (about 144,000 mi², or 373,000 km²). Boundaries and general features of the region are shown on plate 1*A*.

The Great Basin Region is characterized by generally parallel, north- to northeast-trending mountain ranges that are separated by broad alluviated desert basins. The mountain ranges commonly are 40 to 80 miles (64 to 128 km) long and are rather regularly spaced 15 to 25 miles (24 to 40 km) apart. Their crests are commonly 3,000 to 5,000 feet (915 to 1,525 m) above the adjacent valley floors. The higher ranges, which are in central and eastern Nevada and along the east and west margins of the region, have crests more than 10,000 feet (3,050 m) above sea level; elsewhere, the altitudes of the mountain areas generally are less than 9,000 feet (2,740 m).

Altitudes of the valley floors range from about 2,100 feet (640 m) in the Amargosa Desert to about 7,000 feet (2,130 m) in central Nevada. However, the altitudes of the floors of most valleys are between 4,000 and 6,000 feet (1,220 and 1,830 m). Typically, there is an intermediate slope from the valley floors to the bordering mountain ranges. The slope, sometimes called the alluvial apron, is formed either by coalescing alluvial fans or by sedimentary materials thinly mantling eroded bedrock surfaces. Gradients of these slopes generally range from a few tens of feet to several hundreds of feet per mile.

There are 234 valleys in the Great Basin Region. Many are topographically closed; however, others are interconnected and drain directly or by way of eight major river systems (Bear, Weber, Jordan, Sevier, Humboldt, Carson, Truckee, and Walker) into five major terminal lakes or sinks. These sinks are the Great Salt Lake and Sevier Lake in Utah, and Humboldt-Carson Sink, and Pyramid and Walker Lakes in Nevada (pl. 1*A*). Black Rock Desert in Humboldt subregion, a sixth major terminal sink, is associated with the Quinn River, a secondary river system. Great Salt Lake, Pyramid Lake, and Walker Lake are remnants of two large lakes that occupied much of the region about 10,000 to 20,000 years ago—Lake Bonneville that covered about 20,000 square miles (52,000 km²) in Utah and Lake Lahontan that covered about 8,000 square miles (20,700 km²) in Nevada.

The region is divided into six subregions (pl. 1*A*). Each subregion is further divided into hydrographic areas which provide the basic units used to present hydrologic information. Table 1 lists the subregions and some of their principal features. Plate 1*B* shows the 234 hydrographic areas in the Great Basin Region and lists area names. Some hydrographic areas listed are parts of larger hydrologic systems, such as areas tributary to the principal drainages. Other areas have smaller, self-contained hydrographic systems that would be virtually unaffected by development in adjacent valleys. This variability between areas and the boundary effects of mountain ranges which

[1]The boundary of the region described in this report differs from the boundary of the recently completed Great Basin Region Comprehensive Framework Study (Pacific Southwest Inter-Agency Committee, 1971a, b, c), which follows the California and Oregon State lines and includes some closed basins whose subsurface flow drains to the Lower Colorado River Region.

commonly separate valleys complicate regional evaluation of the ground-water resources. An adequate analysis must take the above factors into account. In this report, quantitative information will be presented graphically on an area-by-area basis and then summarized in tabular form by subregions. Selected information for each hydrographic area is listed in table 8.

The variability in hydrographic areas is one of the characteristics of the region. Adequate description of the detailed differences of some 234 areas is not possible in this report. Instead, areas are classified on the basis of selected characteristics, in seven general groups. Areas within each group have enough similarity that knowledge gained in the more intensively developed areas in each group may have significant transfer value in planning development of remaining areas.

The classification used in this report is an extension of the scheme used by Snyder (1962) to propose a hydrologic classification of valleys in the Great Basin. Valleys are classified primarily on two parameters—the topographic nature of area boundaries and the degree of ground-water drainage.

Topographically, areas are classified as either open or closed. A topographically open area is one where there is surface inflow, or surface outflow, or both. In contrast, no surface flow crosses the boundary of a topographically closed basin.

The degree of ground-water drainage is described in terms of the ground-water regimen of the area. The following three categories are used:

1. Undrained: There is no discernible subsurface leakage to adjacent areas. All ground-water discharge is by evapotranspiration from areas of shallow ground water, areas of spring-supported vegetation, or bare ground.
2. Partly drained: There is discernible subsurface outflow from the area; however, magnitude of the outflow is insufficient to completely drain the area. Consequently, significant ground-water evapotranspiration occurs in areas of shallow ground water. This is a transitional category and includes valleys which vary from those where ground-water discharge is primarily by evapotranspiration to those where ground-water discharge is primarily by subsurface outflow.
3. Drained: Virtually all ground-water discharge is by subsurface outflow. This outflow has lowered the water table so that there are no appreciable areas of shallow ground water and, consequently, no significant ground-water evapotranspiration.

The category for partly drained topographically open areas is divided into three subcategories based on relation between the surface-water and ground-water regimens in an area.

Table 2 shows the classification scheme used in this report. The classification of hydrographic areas in the Great Basin Region is shown on plate 1*B*.

THE CLIMATE

The climate of the Great Basin Region is highly variable, owing to large variations in altitude, the wide range in latitude, and the presence of numerous mountain ranges; generally, it is arid to semiarid. Average annual precipitation ranges from less than 5 inches to about 16 inches (127 to 406 mm) on the valley floors and from about 16 inches (406 mm) to more than 60 inches (1,524 mm) in the mountains (pl. 1C). Estimated annual precipitation over the entire region averages about 11 inches (279) mm), or about 88 million acre-feet (108,500 hm^3; table 3). Most of the precipitation occurs during the winter and provides the mountain snowpack which melts and runs off in the spring and summer as a major component of the region's total water supply.

Average annual temperature ranges from about minus 1°C (30°F) in some high northern valleys to about 16°C (60°F) in the extreme southern valleys. One of the more characteristic features is the wide range between daily maximum and minimum temperatures. The daily range exceeds 17°C (30°F) in most valleys and 28°C (50°F) in some valleys of western Nevada. Large variations in temperature also occur within short distances, owing to the wide variations in altitude. The average length of the growing season in the principal agricultural areas of the region ranges from about 100 to 175 days; it exceeds 200 days in the extreme south but is less than 30 days in some higher, northern mountain valleys.

Average annual humidity ranges from about 30 to 40 percent over most of the region and is about 20 percent in the extreme south. The low humidity, coupled with abundant sunshine and light to moderate winds produce very rapid evaporation. Average annual lake evaporation ranges from about 45 in. (1,143 mm) in the north to more than 90 in (2,286 mm) in the extreme south (Kohler and others, 1959).

POPULATION AND INDUSTRY

The Great Basin Region is sparsely populated. Population densities range from about 0.4 person per square mile in the Tonopah subregion to about 30 persons per square mile in the Great Salt Lake subregion. The greatest concentrations of population are in the Provo–Salt Lake City–Ogden area of Utah and the Reno-Carson City area of Nevada (fig. 1). In general, population is concentrated in the river segment or perennial stream valleys shown on plate 1*B*. Total population for the region in 1970 was about 1.2 million people; the distribution of the population by hydrologic subregion, together with projected increases to the year 2020, are listed in figure 1.

TABLE 2.—*Classification of areas in the Great Basin*

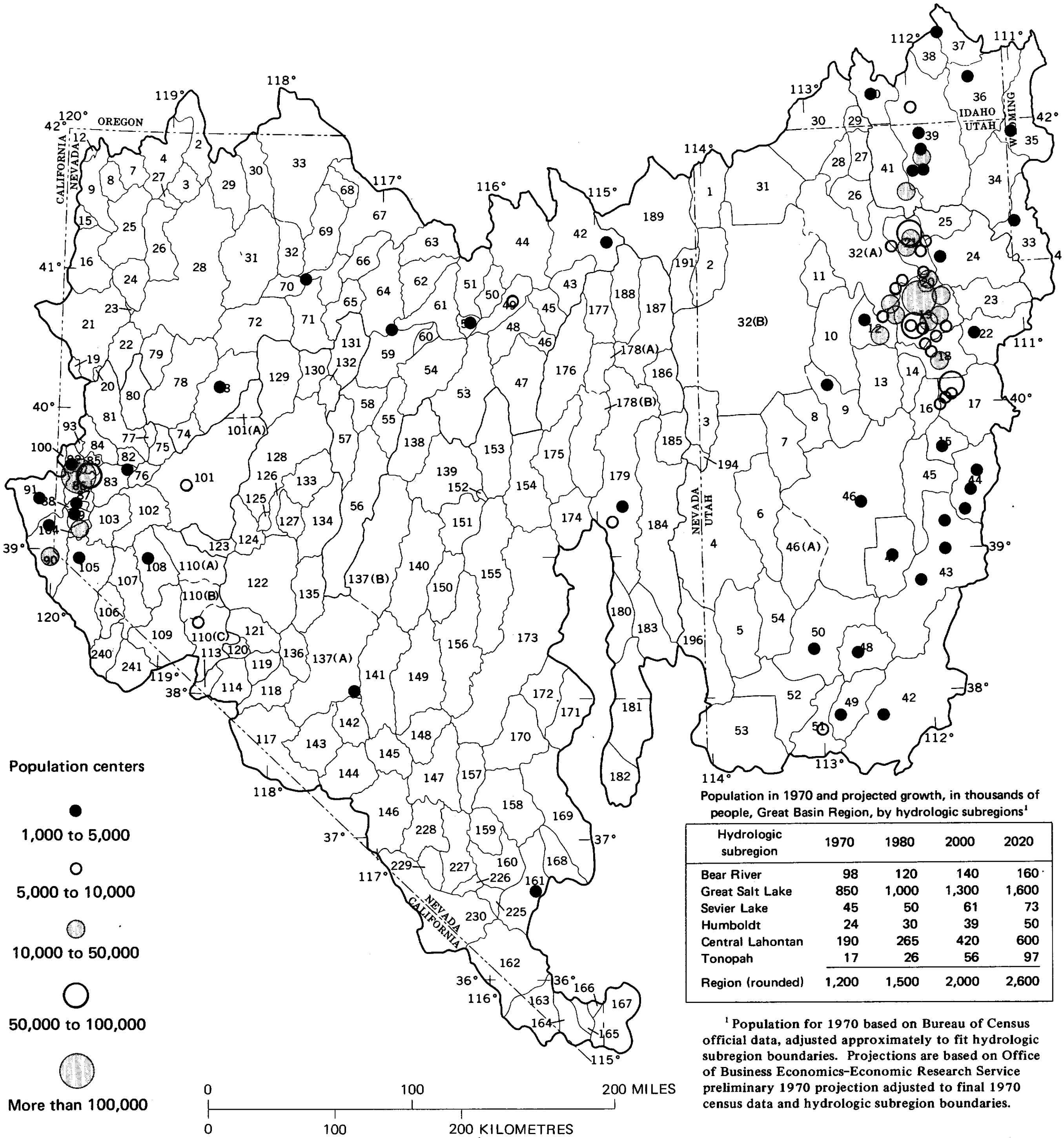
Ground-water regimen		Topographic nature of boundary: Closed	Topographic nature of boundary: Open
Ground-water regimen	Undrained	*Closed basins.*—Areas with no surface flow across boundary; all ground-water discharge ultimately by evapotranspiration. Typified by valleys with wet playas and phreatophyte stands in shallow ground-water areas. Ground-water gradient toward center, or low part, of valley.	*Sinks.*—Surface and (or) subsurface inflow across boundaries. All ground-water discharge ultimately by evapotranspiration. Most have terminal lakes or wet playas which are large in proportion to the size of the area. Valley may contain a large volume of saline ground water. (Undrained valley with only surface outflow not recognized at present in the Great Basin. Lake Tahoe and Bear Lake Valleys nearly fit this category.)
	Partly drained	*Topographically closed areas.*—No surface inflow or outflow, but discernible subsurface outflow. Valley has moist playa and stand of phreatophytes. Area of ground-water discharge may be small in comparison to undrained basins of similar size. Ground-water gradients may indicate subsurface outflow, if wells are strategically located.	*Tributary areas.*—(divided into three subcategories to allow for various relations between the ground-water and surface-water regimen): *Arid area.*—Surface outflow and (or) inflow, typically in ephemeral channels. Some subsurface outflow, but significant areas of ground-water evapotranspiration. Hydrologic regimen dominated by the ground-water flow system. *Perennial stream areas.*—Surface outflow and (or) inflow. Perennial streams prominent. Streams generally do not flow through area. Section or boundary of area may be traversed surface-water system dominates the hydrologic regimen of the area. Both are important. *River segment areas.*—Surface inflow and (or) outflow by way of perennial streams or rivers. Most subsurface inflow and (or) outflow typically underflow in stream-channel deposits. Areas of ground-water evapotranspiration generally along flood plain. Hydrologic regimen dominated by surface-water system. Most areas in this category are either headwater areas or river-reach segments of principal drainages.
	Drained	*Drained area (closed).*[1]—No surface flow across boundary; virtually all ground-water discharge is by subsurface outflow. No significant areas of ground-water evapotranspiration. Shallowest depth to water is more than 50 feet. Playas dry and may exhibit large desiccation cracks.	*Drained area (open).*[1]—Surface inflow and (or) outflow, virtually all ground-water discharge is by subsurface outflow. No significant areas of ground-water evapotranspiration. Shallowest depth to water is more than 50 feet. Playas (if present) dry and may exhibit large desiccation cracks.

[1]For purposes of this report, topographically closed and open drained valleys are grouped together because most interarea surface flow is by way of ephemeral streams. Significant flow occurs infrequently.

TABLE 3.—*Estimated annual precipitation by subregion, Great Basin Region*

Subregion	Precipitation (millions of acre-ft)	Average precipitation (in.)
Bear River	7.7	19.2
Great Salt Lake	19.3	12.4
Sevier Lake	12.5	14.6
Humboldt	16.0	10.1
Central Lahontan	8.0	9.3
Tonopah	24.7	9.6
Region (rounded)	88	11

The economy of the Great Basin Region is based chiefly on mining (mostly metallic ores), farming, and livestock. Recently, light manufacturing and warehousing have also contributed to the economy of parts of the region. Most of the towns and cities grew from early farming, mining, and ore-processing communities, and from early railroad settlements. Since the early 1940's defense facilities, industries, tourism, and recreation have been major contributors to the economy of the region.



Population in 1970 and projected growth, in thousands of people, Great Basin Region, by hydrologic subregions[1]

Hydrologic subregion	1970	1980	2000	2020
Bear River	98	120	140	160
Great Salt Lake	850	1,000	1,300	1,600
Sevier Lake	45	50	61	73
Humboldt	24	30	39	50
Central Lahontan	190	265	420	600
Tonopah	17	26	56	97
Region (rounded)	1,200	1,500	2,000	2,600

[1] Population for 1970 based on Bureau of Census official data, adjusted approximately to fit hydrologic subregion boundaries. Projections are based on Office of Business Economics-Economic Research Service preliminary 1970 projection adjusted to final 1970 census data and hydrologic subregion boundaries.

FIGURE 1.—Distribution of population in the Great Basin Region, 1970.

HISTORY OF WATER-RESOURCE DEVELOPMENT

Most of the developed water supply in the Great Basin is used for irrigation, which began during the summer of 1847, when Mormon pioneers arrived in Jordan Valley, Utah. Water was diverted by structures consisting of simple rock and brush dams across small mountain streams from which ditches conveyed it to nearby fields. Subsequent immigrants to the region generally settled along mountain streams or close to springs, where water could be readily obtained.

As the demand for water increased, the water systems were improved. Small storage reservoirs were built, and supplies from larger streams were developed. With further demand, private developments were supplemented by construction of Federal projects after the passage of the Reclamation Act in 1902. These projects were constructed principally on the major stream systems and generally included large storage reservoirs to regulate flow to downstream areas of use.

The first substantial development of water supplies for nonirrigation purposes dates back to the early mining boom in Nevada, which began about 1849. Providing water for the mining industry presented a somewhat different problem than for irrigation. Generally, land suitable for irrigation was developed adjacent to, or relatively near, a source of supply, whereas mines commonly were distant from the nearest source of water. Mining towns and the requisite supporting supplies and services had to be near the mines. The situation commonly led to development of the nearest supply of water and transporting it to the mines and towns. On occasion, the water was transported many miles by tank wagons or pipelines. The development of some of these supplies involved complex and very imaginative engineering designs and were very costly (Shamberger, 1971, 1972).

Water supplies for public, municipal, and industrial use evolved partly by incorporation with large-scale irrigation systems, partly as an extension of the water supply for the mining industry, and partly from a need by the railroads and other industrial activities.

Initially, most ground-water supplies were obtained from dug wells by use of hand-drawn buckets. Windmills and small mechanical pumps came into use near the end of the 1800's. As pump designs improved, fuel and electrical power became cheaper and more plentiful, and more effective well-drilling and developing methods were used, large-yield wells capable of operating economically with high pumping lifts became a reality. These advances made ground water more attractive to develop for irrigation, public supply, and industrial needs, especially in areas where surface-water supplies were not readily available or where virtually all surface water was appropriated. Consequently, use of ground water has increased steadily, and as of 1970 more than 1 million acre-feet (1,233 hm^3) per year of ground water was withdrawn from wells in the Great Basin Region.

WATER SUPPLY

The water supply of the Great Basin Region is derived from precipitation, which falls within the region boundaries, and from some imported water. Much of the average precipitation of about 88 million acre-feet (108,500 hm^3) per year (table 3) is evaporated from the soil near the place where it falls. The remainder supplies streamflow and recharges ground water. The average annual replenishment to surface water and ground water makes up the renewable water supply of the region. It does not include stored ground water that is available for use on a one-time basis.

A rough estimate of the renewable water supply of the region is made as follows:

1. The contribution from the principal drainages is estimated by selecting a gaging station near the point of maximum annual flow on each major stream. Flow past the gage plus evapotranspiration from both streamflow and ground water above the gage compose the renewable supply generated above each station. Figure 2 shows locations of the gaging stations and upstream areas of streamflow depletion (evapotranspiration) above the stations.
2. The average flow of secondary and minor streams is estimated from available streamflow records and by indirect methods.
3. Natural ground-water discharge from areas not recharged by perennial streams was estimated. This required a subjective judgment as to which areas were supported by recharge from rivers and streams. Insufficient data or errors in judgment may result in some water included in streamflow estimates being counted again as natural ground-water discharge.
4. The sum of the first three items is a rough estimate of the renewable water supply of the Great Basin Region. Errors caused by counting some water twice probably are small in terms of the total.

Estimates of the above components are listed in table 4. The total of about 9.7 million acre-feet (11,960 hm^3) includes about 0.1 million acre-feet (123 hm^3) of water imported from the Colorado River basin. Undepleted water from the principal streams, from some secondary streams, and from some ground water flows to terminal lakes.

Of the several components of renewable water supply, ground water is the most widely distributed in the region. It is the only component stored in natural reservoirs and readily available during dry periods. Accordingly, ground water offers significant potential to meet part of the water needs of the region.

The degree to which the supply can be ultimately developed depends on what the user is willing and able to pay for water and to what degree the use will adversely affect the environment. Maximum utilization of the water supply in the region would require management of ground-water and surface-water resources in such a way that use of one would complement the other. Also maximum utilization would include use of return flows where possible.

GROUND-WATER RESOURCES

In the arid Great Basin Region, ground water is a vital constituent of the total water resource. The average ground-water recharge is only about 5 percent of the total precipitation and is only about half as large as the average annual runoff. However, both precipitation and stream-

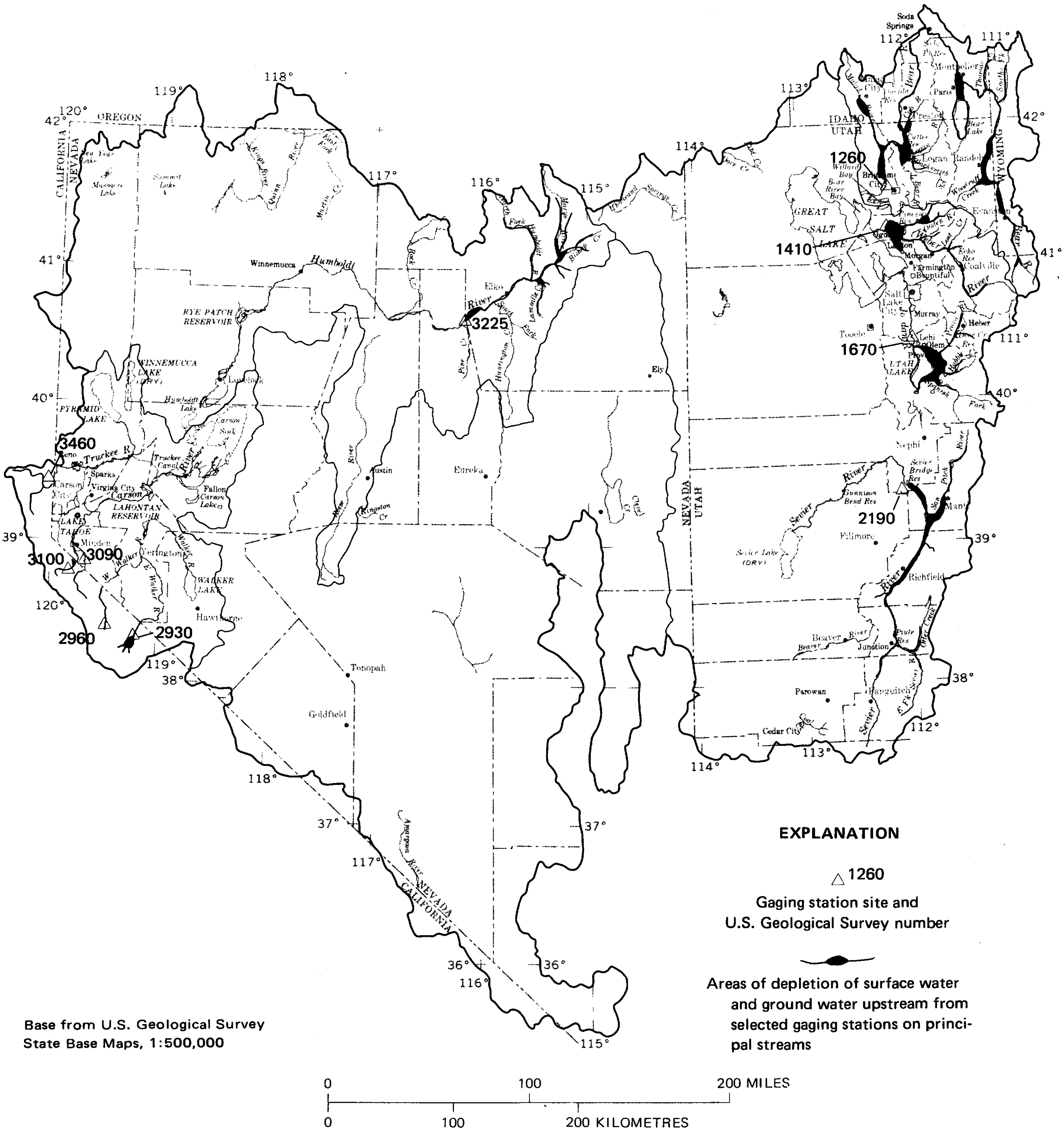


FIGURE 2.—Location of selected stream-gaging stations representing principal streamflow and areas of upstream depletion.

flow occur unevenly throughout the year, and the amounts vary from year to year. Most of the precipitation falls during the spring and winter months, and most of the streamflow occurs during the spring runoff. Consequently, storage and conveyance facilities must be provided to store water and distribute it during periods of heavy summer demand. During prolonged dry periods, water demand may exceed the storage capacities of surface reservoirs and water shortages may result.

In contrast, ground-water reservoirs typically have large volumes and store sufficient water to supply heavy demands during prolonged dry periods. Most valleys in the Great Basin Region have ground-water reservoirs, but comparatively few have abundant surface-water

TABLE 4.—*Summary of renewable water supply in the Great Basin Region*[1]

[Thousands of acre-feet per year]

Subregion	Principal streams: Gaged streamflow[2]	Principal streams: Upstream depletion[3]	Secondary and minor streams	Natural ground-water discharge[4]	Combined supply
Bear River	838	1,150	102	40	2,130
Great Salt Lake	517	1,009	388	630	2,544
Sevier Lake	139	539	234	328	1,240
Humboldt	254	300	300	480	1,334
Central Lahontan	1,120	[5]176	108	104	1,508
Tonopah	.....	.....	290	680	970
Region (rounded)	2,900	3,200	1,400	2,300	9,700

[1]Modified from Pacific Southwest Inter-Agency Committee (1971b, table 23).
[2]Annual average for 1931-60 reference period modified for the 1965 level of development. Other values are considered to represent long-term annual averages.
[3]Supplied from surface water and ground water undifferentiated.
[4]Generally excluding ground water supplied from principal streams.
[5]Included in this report due to adjustment in Regional boundary from that used in the Great Basin Region Comprehensive Framework Study.

supplies. In these arid areas, ground water is the only source of water that might be developed on a large scale.

CONSOLIDATED-ROCK RESERVOIRS

A large amount of ground water is stored in consolidated rocks that occur both in the mountains and beneath the valley alluvium. These ground-water reservoirs generally are not continuous and are extremely difficult to evaluate. Local barriers formed by faults or rock units of low permeability produce a complex pattern of perched ground-water bodies in the mountains. These perched ground-water bodies supply numerous springs and late-season flow of mountain streams.

Carbonate rocks and volcanic rocks compose the consolidated-rock reservoirs. (See pl. 1*D* for areas underlain by these rocks.) Carbonate rocks in most areas are highly permeable and transmit substantial quantities of water to large springs in eastern Nevada and western Utah. In southern Tonopah subregion, carbonate rocks transmit water in several multi-valley ground-water systems.

In some areas, volcanic rocks have fracture and interflow openings that store and transmit large quantities of ground water, which sustain the flow of many streams and of numerous springs near bedrock-alluvial contacts. Locally, volcanic rocks transmit water readily, such as the Quaternary basalt in Soda Creek and Gem Valleys in the Bear River subregion. Other areas with known volcanic-rock aquifers include Pavant Valley in the Sevier Lake subregion, Curlew Valley in the Great Salt Lake subregion, Winnemucca area in the Humboldt subregion, and Fallon area in the Central Lahontan subregion.

VALLEY GROUND-WATER RESERVOIRS

Valley ground-water reservoirs are composed of alluvial deposits which partly fill the structural depressions that form intermontane basins. These deposits generally contain sand and gravel aquifers which, in most places, provide the only supply of ground water available for large-scale development. Distribution of the principal valley ground-water reservoirs is shown on plate 1*D*.

Ground water occurs in the porous valley alluvium in a zone of continuous saturation. The water table is near the land surface in topographically low parts of most valleys. Depth to water increases toward the mountains and may be several hundred feet beneath the upper parts of some alluvial fans. The position of the water table is regulated by surface-water altitudes in valleys that contain lakes or large streams that flow through the valleys. Artesian conditions occur where layers of silt and clay are abundant enough to confine or partly confine water in underlying deposits. This condition is common in the lower parts of most valleys. The most extensive artesian conditions occur in the eastern part of the region. This results in part from the extensive silt and clay deposits that formed during high stages of Lake Bonneville.

Detailed information on thickness of valley ground-water reservoirs generally is not available. Maximum thickness probably varies greatly from area to area. Available information indicates maximum thicknesses of more than 1,000 feet (300 m) are common in the larger valleys, but the information available is insufficient to make any generalized statement about the smaller areas.

STORED GROUND WATER

A large volume of water is in transient storage in valley ground water reservoirs throughout the Great Basin Region (pl. 1*D*). The recoverable quantity stored to a selected depth below the water table may be estimated as the product of an area, a selected depth, and the specific yield of the deposits. The depth selected for this study is the uppermost 100 feet (30 m) of saturation. Volumes of water are estimated without regard to water quality.

For purposes of this report, average specific yield of the upper 100 feet (30 m) of saturated deposits was assumed to be 10 percent, except in areas of extensive fine-grained deposits, such as the Salt Lake Desert, Black Rock Desert, and Carson Sink. Specific yield is assumed to average 5 percent in parts of these areas. Specific yield along some river flood-plain areas, such as in parts of the Bear River basin, is assumed to average 15 percent. These averages probably give reasonably representative estimates for subregion areas. Specific yield locally ranges from less than 5 percent to more than 30 percent. Higher values are associated with the well-sorted sand and gravel in stream channels or with the beach deposits of ancient lakes. Lower values are associated with the silt and clay in lake and playa deposits. Thus, different values are used for specific areas where they are known as a result of detailed local studies.

In areas where artesian conditions are extensive, significant pumping may occur before heads in the artesian aquifers are drawn down sufficiently to induce any lowering of the water table. In time, however, if artesian heads are permanently lowered, deposits weil drain in response to pumping and a quantity of water equal to the specific yield will be recovered from storage.

Plate 1*G* shows the distribution of ground-water storage in the Great Basin Region. The tabulation on the figure summarizes estimates of recoverable ground-water storage in the upper 100 feet (30 m) of saturated deposits by subregions. Estimates for individual hydrographic areas are listed in table 8 at the end of the report. For planning and development purposes, these quantities can be expressed as an annual rate for a specified number of years. For example, the regional total is about 300 million acre-feet (370,000 hm^3). This quantity is equivalent to a withdrawal rate of 6 million acre-feet (7,400 hm^3) a year for a 50-year period, excluding that part of the annual supply made available by salvage of natural discharge.

The estimate of recoverable stored ground water is only a fraction of the total amount of stored ground water in the region. Saturated alluvium occurs to depths of several thousand feet beneath some valleys. Ground water also occurs in consolidated rocks in the mountains and beneath the valleys. Undoubtedly, the total stored ground water amounts to several billion acre-feet, but data are too few for a firm estimate to be made. As economic need arises, studies probably will be made to determine the amount of ground water stored to greater depths in the valley ground-water reservoirs and elsewhere.

GROUND-WATER FLOW SYSTEMS

Ground water percolates along the path of least resistance from areas of high head to areas of lower head. In arid basins water recharges the ground-water system in or near the mountains and moves downgradient to areas of spring flow and ground-water evapotranspiration in the low part of the valley. The various types of areas shown on plate 1*B* and variations within types precludes choice of any one ground-water flow system to describe a "typical valley" in the Great Basin Region. Instead, examples are presented for selected types of areas described in table 2.

Ground-water flow systems are evaluated on two levels. The first level considers the factors that control flow between basins and regional patterns of ground-water flow. The second level considers those factors that regulate subsurface flow within a single basin. This involves geologic and topographic factors and, where perennial streams are present, relations between the ground water and surface water.

Two conditions must be met before significant interbasin flow can occur. Consolidated rocks separating areas must be permeable enough to transmit appreciable amounts of water and a hydraulic gradient must exist between two areas. Hydraulic continuity and a gradient may extend across more than two valleys and result in a regional flow system where all or part of the ground-water recharge from several valleys drains to a common sink and ultimately is consumed by evapotranspiration. Figure 3 illustrates some ground-water flow systems present in the great Basin Region.

Factors that affect the flow system in any one valley are the relative locations of recharge and discharge areas and geologic factors that influence the capability of valley-fill deposits to transmit water. Recharge areas are typically in the mountains and on the upper parts of alluvial fans, whereas discharge areas commonly are in the low parts of the areas near the central parts of the valleys. The manner in which ground water moves between these areas in regulated by the geologic properties of the valley-fill deposits. One condition that strongly affects the flow regimen is the interlayering of deposits having different permeabilities. For example, sand and gravel aquifers of high permeability may be underlain and overlain by silt, clay, or mudflow deposits of low permeability. On a smaller scale, lake-bed deposits may contain thin layers of interbedded silt and clay. The result is that in most places it is much easier for water to move horizontally than vertically. Another factor that strongly affects the ground-water flow regimen is the variation of permeability within a valley. Generally, composition of the valley fill grades from highly permeable coarse-grained deposits along the margins of a valley to poorly permeable fine-grained deposits near the center of a valley. Exceptions to this generalized pattern may be mudflow deposits of low permeability near the mountains, highly permeable stream-channel deposits in the central part of a valley, or extensive lake-bed deposits of low permeability.

The ground-water system is also affected by perennial streams. A stream may lose or gain water by seepage or have no loss or gain, depending on the relative water-surface altitude in the stream, the altitude of the water table, and the permeability of the bed and banks. Altitudes of both the water table and the water surface of the stream vary with time, so during the course of a year all three conditions may occur in parts of some stream channels. The segments of the principal streams upstream from the gage where depletion was estimated in

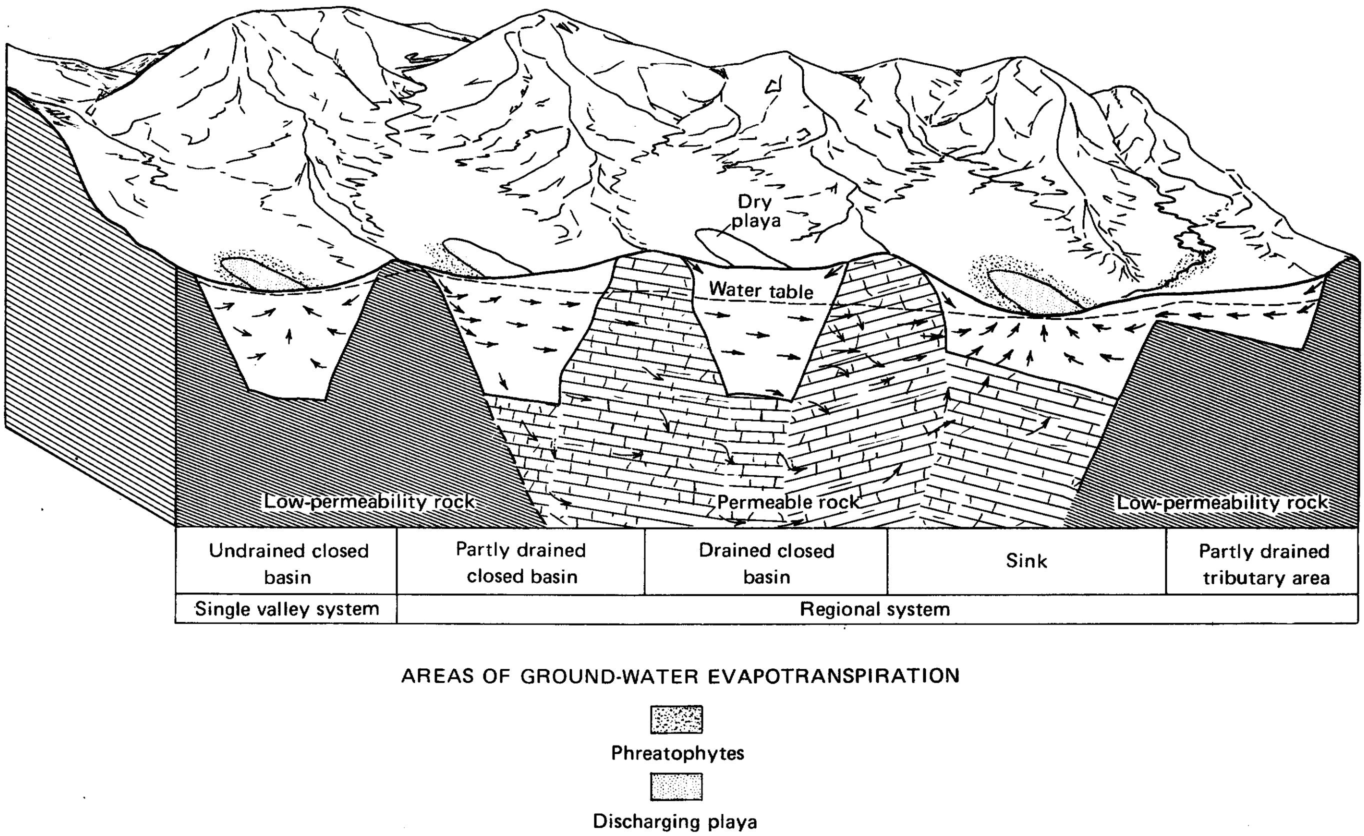


FIGURE 3.—Common ground-water flow systems.

figure 2 are generally gaining reaches. The lower reaches of these streams are generally losing streams; however, some segments may gain due to natural inflow or irrigation return flows.

Figure 4 shows diagrammatically some of the common relationships between ground water and surface water in the Great Basin.

The principal lakes receive inflow from ground water as well as precipitation and surface flow. The water levels of these lakes in turn control ground-water levels in adjacent saturated deposits. Lakes that discharge into rivers, such as Utah Lake and Bear Lake, maintain fairly uniform ground-water levels in adjacent areas. Variations in water supply caused by climatic or other factors commonly result in variations in outflow from the lake while the lake stage and adjacent ground-water levels remain fairly constant. Lakes that have no outlets, such as Great Salt Lake, Pyramid Lake, and Walker Lake, discharge water entirely by evaporation. Water levels in those lakes fluctuate in response to variations of evaporation and inflow. Sustained periods of water-level decline in those lakes result in consequent depletions of adjacent ground-water storage by either evaporation or drainage into the declining lake. For example, water levels in Walker Lake declined 105 feet (32 m) between 1908 and 1965, resulting in a depletion of ground-water storage in the adjacent valley deposits of about 150,000 acre-feet (185 hm^3) (Everett and Rush, 1967, p. 24).

INFLOW TO THE GROUND-WATER SYSTEM

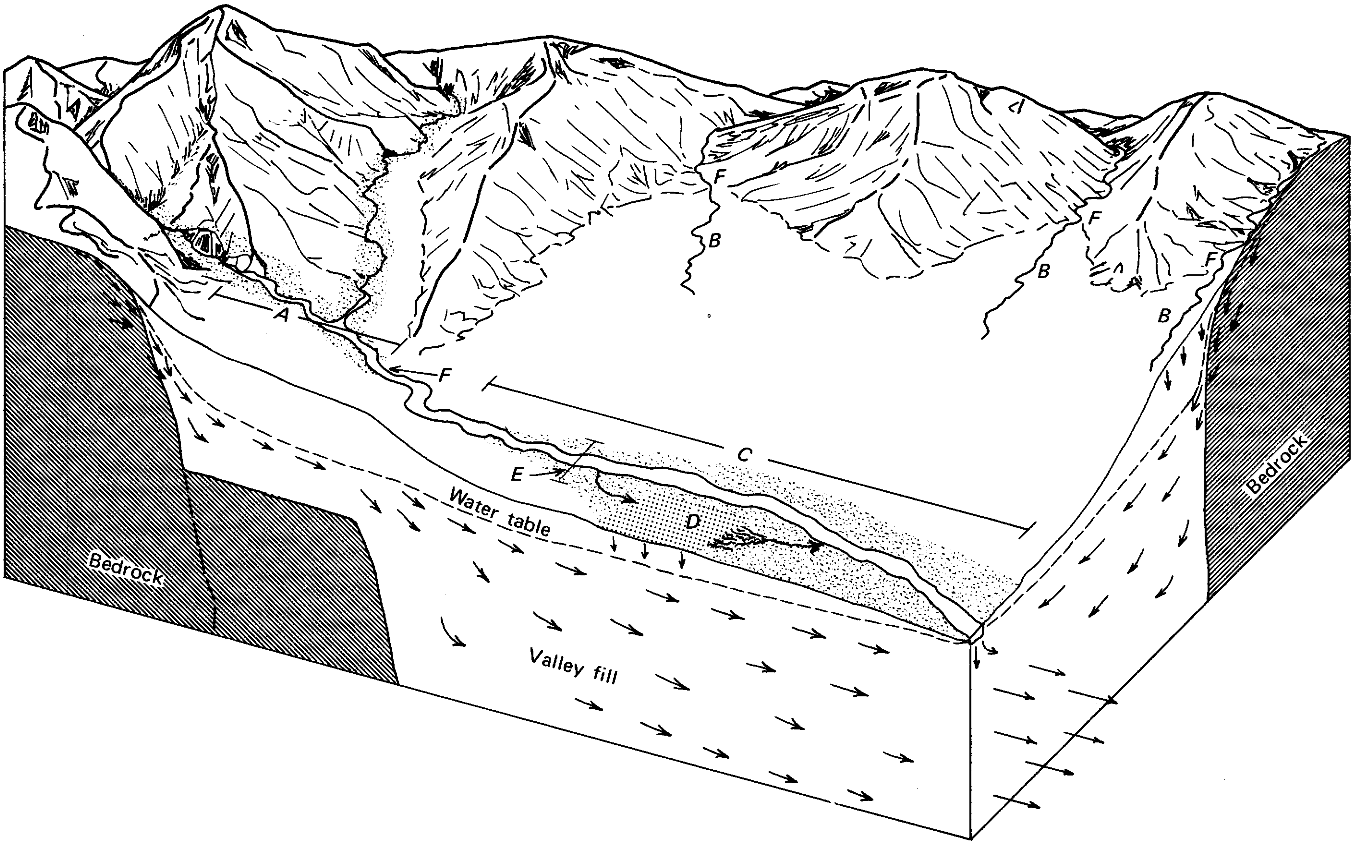
Precipitation ultimately is the source of virtually all ground-water recharge in the Great Basin. Most natural recharge is generated from precipitation that falls in the mountains; however, recharge may occur either in the mountains or in the valleys, where streams lose water by infiltration into permeable valley-fill deposits.

Available recharge estimates for individual valleys are listed in table 8. Estimates are not available for all areas in the Great Basin Region. However, available information suggests that ground-water recharge generally is between about 3 and 7 percent of the total precipitation on an individual drainage basin. Using these percentages, average annual recharge to the entire region is estimated to be within the range of about 3 to 6 million acre-feet (3,700 to 7,400 hm^3) per year.

OUTFLOW FROM GROUND-WATER SYSTEM

Outflow from ground-water systems, or discharge, occurs in four principal ways: (1) By evapotranspiration in areas of phreatophytes, (2) by direct evaporation from bare soil where the capillary fringe is near the land surface, (3) by discharge from springs or directly to streams, and (4) by subsurface outflow to adjacent areas.

The principal areas of natural ground-water discharge in the Great Basin Region are shown on plate 1*E*. Table 5 summarizes estimates of natural ground-water dis-



A, Gaining reach, net gain from ground-water inflow although in localized areas stream may recharge wet meadows along flood plain. Hydraulic continuity is maintained between stream and ground-water reservoir. Pumping can affect streamflow by inducing stream recharge or by diverting ground-water inflow which would have contributed to streamflow.

B, Minor tributary streams, may be perennial in the mountains but become losing ephemeral streams on the alluvial fans. Pumping will not affect the flow of these streams because hydraulic continuity is not maintained between streams and the principal ground-water reservoir. These streams are the only ones present in arid basins.

C, Losing reach, net loss in flow due to surface water diversions and seepage to ground water. Local sections may lose or gain depending on hydraulic gradient between stream and ground-water reservoir. Gradient may reverse during certain times of the year. Hydraulic continuity is maintained between stream and ground-water reservoir. Pumping can affect streamflow by inducing recharge or by diverting irrigation return flows.

D, Irrigated area, some return flow from irrigation water recharges ground water.

E, Flood plain, hydrologic regimen of this area dominated by the river. Water table fluctuates in response to changes in river stage and diversions. Area commonly covered by phreatophytes (shown by random dot pattern).

F, Approximate point of maximum stream flow.

FIGURE 4.—Common relationships between ground water and surface water in the Great Basin Region. Not to scale.

charge for valleys exclusive of the areas of upstream depletion (fig. 2). It includes published estimates for many valleys, and provisional estimates for areas where no previous estimates were available. Estimates for specific areas are listed in table 8. It was not possible to make estimates of ground-water discharge separate from surface-water discharge for that part of the principal stream systems identified as upstream depletion areas. Thus, total ground-water discharge is the 2.3 million acre-feet (2,840 hm^3) per year of ground-water discharge estimated in table 5 plus that part of the 3.2 million acre-feet (3,950 hm^3) per year of upstream depletion (table 4) that is supplied from ground water.

GROUND-WATER FLOW BETWEEN REGIONS

The quantity of interregion flow is small in relation to the total water supply; however, it may be a significant part of the hydrologic budget in some valleys along the regional border. Table 6 summarizes estimates of the principal occurrence of interregion ground-water flow.

TABLE 5.—*Estimated natural ground-water discharge exclusive of areas of upstream depletion*[1]

[Values significant to two figures]

Subregion	Number of valleys	Approximate area of natural ground-water discharge (thousands of acres)	Quantity of natural ground-water discharge (thousands of acre-ft/yr)
Bear River	1	70	40
Great Salt Lake	17	2,400	[2]630
Sevier Lake	11	920	330
Humboldt	32	1,700	480
Central Lahontan	19	320	[2]100
Tonopah	74	2,400	680
Region (rounded)	154	7,800	2,300

[1]Areas of upstream depletion are shown in figure 2. As used here, such areas refer to flood plains of principal streams and their upstream tributaries, other upstream irrigated areas supplied from that stream system, and any water exported from that area. In those areas, a combined estimate of evapotranspiration from both surface-water and ground-water sources was made, because ground-water and surface-water components could not be separated. The combined estimate was about 3.2 million acre-feet per year (pl. 1G).

[2]Excludes that supplied from streamflow, such as 170,000 acre-feet supplied by principal and secondary streams in Jordan Valley, Great Salt Lake subregion, and 101,000 acre-feet from principal streams in Central Lahontan subregion.

TABLE 6.—*Summary of estimates of ground-water flow between regions*

[Acre-feet per year]

Region	Inflow to the Great Basin (+)	Outflow from the Great Basin (-)	Net inter-region flow
Columbia–North Pacific	(1)	(1)	(1)
California	14,000	[2]24,000	-10,000
Lower Colorado	0	18,000	-18,000
Upper Colorado	10,000	7,000	+3,000
	24,000	49,000	-25,000

[1]Inflow to Soda Springs Valley, Bear River subregion, and outflow from Gem Valley to the Columbia-North Pacific Region may be on the order of several tens of thousands of acre-feet a year; a net gain to the Great Basin Region is believed to occur.

[2]Includes underflow from Nevada part of Amargosa Desert, which may be on the order of 3,000 acre-feet per year (Walker and Eakin, 1963), and from Nevada part of Pahrump Valley, about 12,000 acre-feet per year (Malmberg, 1967).

CHEMICAL QUALITY OF GROUND WATER

The chemical quality of ground water in the Great Basin Region ranges from fresh (less than 1,000 mg/l, milligrams per litre, dissolved solids) to brine (more than 35,000 mg/l dissolved solids). Waters between these extremes are classed as saline, as follows: slightly saline (1,000 to 3,000 mg/l dissolved solids), moderately saline (3,000 to 10,000 mg/l dissolved solids), and very saline (10,000 to 35,000 mg/l dissolved solids). Generally, in sheds and alluvial aprons at the margins of most valleys, the ground water is fresh. Saline water occurs locally near some thermal springs and in areas where the aquifer includes rocks containing large amounts of soluble salts, such as in parts of the middle Sevier River area. The general distribution of the dissolved-solids concentration of ground water is shown on plate 1*F*. Other areas can be delineated in greater detail as more data become available.

In sink areas, such as the Great Salt Lake, Sevier Lake, and Carson Sink, the dissolved-solids concentrations may exceed that of ocean water. The ground water beneath the playas of smaller closed valleys may be brackish but ordinarily does not reach the concentrations found in the major terminal sinks. Common assumption is that the poor quality water extends to substantial depths below the playas. However, this is not necessarily so. For example, water from a well 1,200 feet (366 m) deep on the northern margin of the playa in Railroad Valley, Tonopah subregion, has a dissolved-solids concentration of less than 350 mg/l. This quality apparently reflects the deep circulation in the valley fill. In valleys with subsurface discharge into a regional ground-water system, the water throughout the valley-fill reservoir generally is fresh.

Individual constituents may present a quality problem even though the dissolved-solids concentration may be low. In much of the Tonopah subregion, the fluoride concentration in ground water exceeds Public Health Service recommended standards for drinking water (U.S. Public Health Service, 1962). The distribution of high-fluoride ground water may be associated with volcanic tuff that is extensive in that subregion.

GEOTHERMAL ENERGY

Geothermal areas are those in which above-normal temperatures occur below land surface and in which there is a reasonable possibility of finding reservoir rocks that will yield steam or heated water to wells. The fluid involved is either fresh or saline ground water. The high-temperature water generally is localized and occupies only a part of the ground-water reservoir in which it occurs. Because the thermal fluid is ground water, the States consider development of geothermal resources to be subject to State ground-water laws.

Many, but not all, geothermal areas are indicated by hot springs. In some areas, the thermal water does not reach the land surface but instead circulates below ground in various kinds of conduit and aquifer systems. Some of the more favorable areas for potential development in the Western United States have been designated as known geothermal resources areas (KGRA's) under the Geothermal Steam Act of 1970 (Godwin and others, 1971, and the Federal Register). Of the 33 areas listed (Godwin and others, 1971, p. 2), 13 are in the Nevada part and 2 in the Utah part of the Great Basin Region (fig. 5).

Federal lands in KGRA's can be leased for geothermal prospecting only by competitive bidding. Interest in several geothermal areas, such as Steamboat Hot Springs (near Reno), Bradys Hot Springs, Beowawe Hot Springs, and Monte Neva areas in the western Great Basin Region has included test drilling within the past 10–15 years. Geothermal steam-generated electricity has not been produced in commercial quantity to date in the region. However, at various times, some of the springs have been used for limited space-heating, swimming pools, agriculture, and industrial processing.

Before substantial commercial development of the

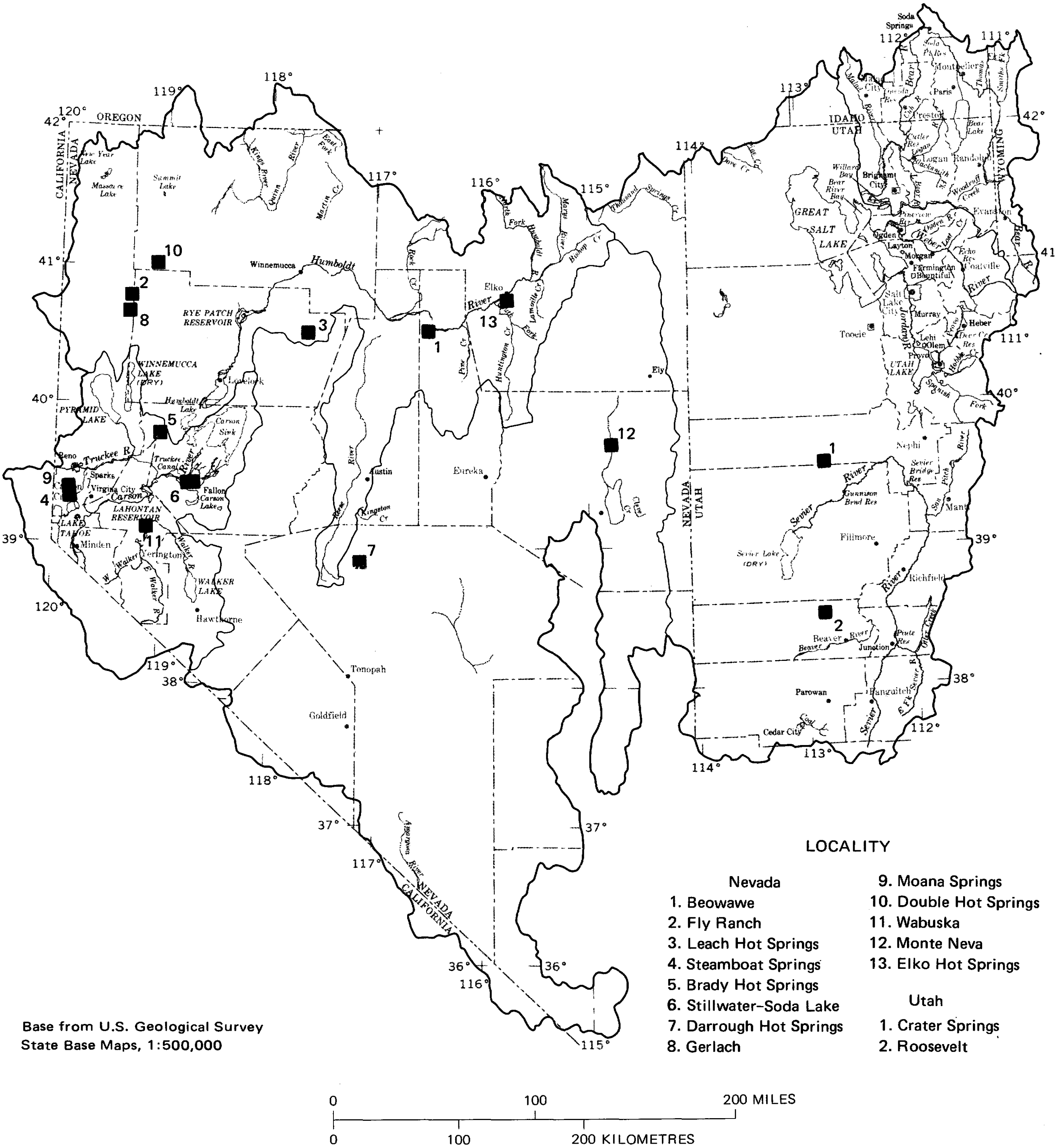


FIGURE 5.—Locations of known geothermal areas in the Great Basin Region.

energy of the geothermal areas is undertaken, a better evaluation of the reservoirs, their capacity to produce energy, either as steam or hot water, and improvement in the technology of using the geothermal resources are probably needed.

YIELD OF THE GROUND-WATER SYSTEM

Knowledge of how much water an area can produce without creating undesirable effects is necessary to plan the orderly development of ground-water supplies. However, determination of this quantity is difficult because of the requirement to define undesirable effects in advance and then determine the degree to which they may be tolerated in the future. Thus, yield of a ground-water system is determined in part by hydrologic factors that control cause-and-effect relationships and in part by nonhydrologic constraints based on the degree to which specified effects are to be tolerated.

Some of the more significant hydrologic factors are (1) the configuration of the ground-water reservoir, (2) the ability of deposits to yield water to wells, (3) the ability of deposits to store water, (4) the distribution of water quality, and (5) the location and quantity of ground-water recharge and discharge. In most alluvial basins these factors vary considerably from place to place. Consequently, the location of pumping has a great effect in determining the results of development in any given case.

The nonhydrologic constraints vary from area to area. Examples of two constraints present in some areas of the Great Basin Region are as follows:

1. Regulation of pumping to protect existing surface-water rights. Heavy pumping near streams which are in hydraulic continuity with the ground-water reservoir will eventually induce additional recharge from streamflow at the expense of water already appropriated for use. If one of the primary objectives in managing the area's water resources is to protect preexisting surface-water rights, and if no satisfactory arrangement for retribution can be worked out between users, then ground-water development near streams may necessarily be curtailed.
2. Regulating development when net pumpage reaches the approximate level of natural inflow to and outflow from the ground-water system. In some arid basins the chance of inducing additional recharge by pumping and the probability of obtaining imported water as a supplemental supply in the future are nil. Limiting net pumping to a rate about equal to the natural ground-water inflow and outflow is a possible alternative in regulating development so that sustained mining will not occur. Even so, if pumping is not strategically distributed with regard to the flow system, large quantities of water will eventually be removed from storage. However, pumping could be relocated within the area without reducing the level of development, and problems that may occur will be postponed for many years and will be of lesser magnitude than if sustained mining were allowed.

Application of the above constraints limits development below the level possible if water were allowed to be depleted from storage on a planned basis or if the surface water and ground water were managed conjunctively as a source of supply. The amount of ground-water storage available for consumption on a one-time basis greatly exceeds the annual rate of replenishment. The degree to which storage should be depleted and the rate at which depletion should be allowed are questions which arise in every area where large-scale ground-water development occurs. Possibilities range between two extremes. One is realization of maximum economic returns over a given period of time. This would require a large-scale planned depletion of storage. The other extreme is conservation of a near maximum amount of storage for future generations. This would restrict development to limited pumping near areas of natural discharge. One development alternative would be a compromise which allowed significant economic returns and still conserved adequate storage for possible future use. Such a development would also have to be feasible within constraints posed by State water laws. The above statements give some idea of the difficulties involved in estimating meaningful values of ground-water yield.

Pumped ground water must be derived from one of three possible sources—depletion of storage, additional recharge induced by pumping, or capture of existing natural discharge.

The distribution of ground-water storage shown on plate 1*G* gives an approximate indication of the magnitude of water in storage potentially available to be consumed on a one-time basis. The amount that can actually be used will be determined by economic and legal factors. It could be more or less than the quantities tabulated on plate 1*G*.

The various types of hydrographic areas in the Great Basin Region preclude the use of one concept of yield to approximate the annual rate of net pumpage that could be sustained for an indefinite period of time. This rate is much less than the volume of storage indicated on plate 1*G*, but it ultimately is the limiting factor to sustained ground-water development. The preceding statement assumes that no additional water is imported at some time in the future and that average climatic conditions over the next several centuries will be about the same as those indicated by available records.

In arid areas, such as the closed basins listed in table 2, no appreciable recharge can be induced by pumping. Consequently, after a period of storage depletion, ground-water development will be limited to the amount of natural discharge that can be captured by wells. This rate has been referred to as the perennial yield. The perennial yield of a ground-water reservoir is defined as the maximum amount of water of usable chemical quality that can be withdrawn each year for an indefinite period of time. It generally cannot exceed the natural discharge from the reservoir and in a practical sense is limited to that part of the natural discharge that economically can be captured for use.

In wetter areas, such as the perennial stream areas and river reach areas listed in table 2, ground water and surface water are interconnected. The one cannot be developed without some effect on the other. The yield of these areas has been considered in terms of a system yield (Worts and Malmberg, 1966, p. 39). The yield of a discrete hydrologic system is the maximum amount of surface and ground water of usable chemical quality that can be obtained and consumed each year from sources within the system for an indefinite period of time. The system yield cannot be more than the natural inflow to or the outflow from the system. Under practical conditions of development, system yield is limited to the maximum amount of surface water, ground water, and water-vapor outflow that can be captured economically each year for beneficial use. In this report, where a river system has been divided into several hydrographic areas, system yield has been apportioned among the various areas based on the distribution of flow as of 1970.

Estimates of perennial yield or system yield for individual areas have been grouped into five categories. Plate 1*H* shows the distribution of these categories in the Great Basin Region. A summary of yield estimates is also shown on plate 1*H*. Provisional estimates were used for 48 areas so the tabulation must be considered only as approximations to provide a relative concept of magnitude. The total yield of about 8.7 million acre-feet (10,700 hm^3) per year is smaller than the combined renewable supply of about 9.7 million acre-feet (11,960 hm^3) per year (table 4). It would not be feasible to capture the entire water supply for beneficial use. Total perennial yield of all arid areas is about 1.8 million acre-feet (2,220 hm^3) per year. This includes about 0.2 million acre-feet (250 hm^3) per year of water that may require treatment to be suitable for most uses. The amount of pumping desirable from system-yield areas depends largely upon the point at which pumping causes adverse effects on existing surface-water rights. The optimum rate is not known. However, if wells are strategically situated and seasonal pumping is properly regulated, probably 0.8 million acre-feet (990 hm^3) per year could be pumped without significant adverse effects. Thus, the ground-water system in the Great Basin Region can sustain a net pumpage of at least 2.6 million acre-feet (3,200 hm^3) per year. Higher sustained withdrawals are possible if conflicts with existing surface-water rights are resolved and if extensive treatment and reuse are feasible. More detailed information on the yield of specific areas is presented in the references listed in table 8.

GROUND-WATER DEVELOPMENT IN 1970

Ground-water development ordinarily refers to the use of wells to obtain water. Wells have been used extensively to produce water for domestic, stock, municipal, industrial, and irrigation purposes. Flowing wells have been obtained in many areas, such as Malad and Cache Valleys in the Bear River subregion, parts of the East Shore area, Utah Valley, and Jordan Valley in the Great Salt Lake subregion, Pavant, Parowan, and Sevier Desert in the Sevier Lake subregion, and elsewhere in the eastern subregions.

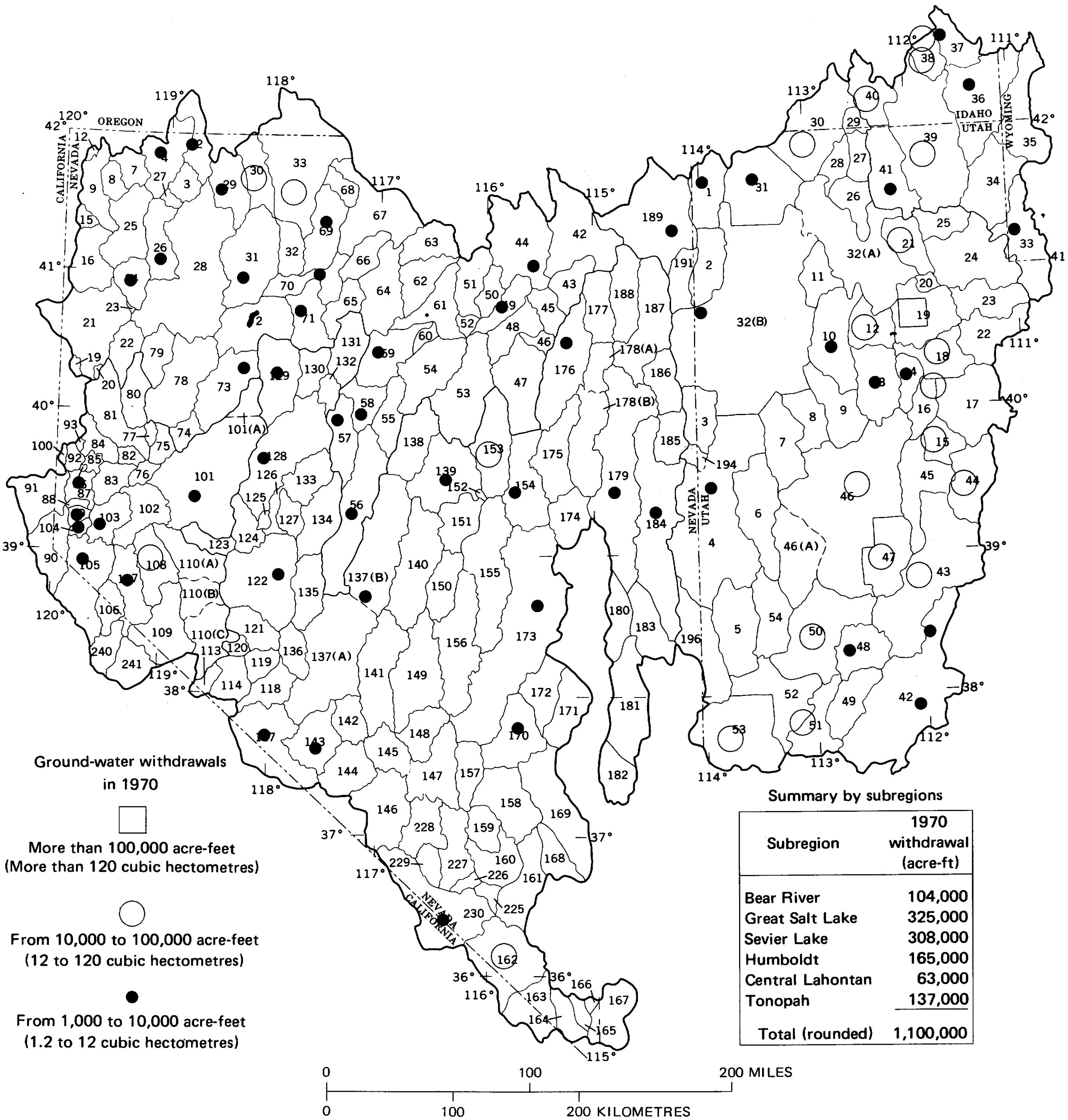
TABLE 7.—*Yield characteristics of large-capacity wells in the Great Basin Region*

Subregion	Well yields: Number of areas	Number of wells	Range in yield (gal/min)	Average yield (gal/min, rounded)
Bear River	5	169	80-4,650	1,060
Great Salt Lake	19	611	10-8,600	930
Sevier Lake	11	677	20-3,500	840
Humboldt	17	213	90-4,000	1,700
Central Lahontan	9	108	12-4,400	1,500
Tonopah	16	210	76-3,300	1,200
Region	......	1,988	10-8,600	1,050
	Specific capacity: Number of areas	**Number of wells**	**Range in specific capacity [(gal/min)/ft]**	**Average specific capacity [(gal/min)/ft]**
Bear River	5	130	1-1,500	116
Great Salt Lake	19	430	0.2-1,370	48
Sevier Lake	12	182	0.2-2,900	70
Humboldt	15	160	3-200	28
Central Lahontan	8	100	0.1-160	33
Tonopah	8	112	2-260	32
Region	......	1,114	0.1-2,900	43

Flowing wells occur in a few areas in the western subregions, such as Smith, Mason, and Carson Valleys, and Truckee Meadows in Central Lahontan subregion, parts of the flood plain of the Humboldt River in Humboldt subregion, and the lower parts of Diamond, Railroad, and Spring Valleys in Tonopah subregion.

Large-capacity pumped wells have accounted for most of the annual withdrawals of ground water. Individual yields of these wells are as much as 8,600 gal/min (540 l/s), and the specific capacities may be as much as 3,000 (gal/min)/ft [620(l/s)/m] of drawdown. The average pumping rate, however, is about 1,000 gal/min (63 l/s), according to an analysis of nearly 2,000 large-capacity wells in the region. Table 7 shows the yield characteristics of large-capacity wells by subregion.

In 1970 water was withdrawn by wells in about 230 areas. Withdrawals in more than 60 of these areas ranged from 1,000 to 10,000 acre-feet (1.2 to 12 hm^3). In 23 areas withdrawals exceeded 10,000 acre-feet (12 hm^3). The greatest single area of ground-water withdrawal was Jordan Valley, with 115,000 acre-feet (142 hm^3). Total withdrawal in the region in 1970 is estimated to be about 1.1 million acre-feet (1,360 hm^3). A summary of withdrawals and the distribution of the principal areas of withdrawal are shown in figure 6.



Subregion	1970 withdrawal (acre-ft)
Bear River	104,000
Great Salt Lake	325,000
Sevier Lake	308,000
Humboldt	165,000
Central Lahontan	63,000
Tonopah	137,000
Total (rounded)	1,100,000

FIGURE 6.—Distribution of ground-water pumpage in 1970.

LEGAL FACTORS AND LARGE-SCALE GROUND-WATER DEVELOPMENT

Water rights are granted by the several States in the Great Basin Region under the appropriation doctrine (Pacific Southwest Inter-Agency Committee, 1971a, p. 194–200). Initially, the doctrine applied only to surface water, but later it was extended to include ground water.

Large-scale surface-water development has been successfully accomplished within the framework of the appropriation doctrine. Planned large-scale ground-water development also should be possible. The development from either source, however, will require solutions to various legal problems.

Some conflicts have arisen in water-resources law that may have a bearing on any particular ground-water development; for example, the question of the relationship between the States' water laws and the Federal "reserved water doctrine." The States' water laws imply that all water in the State is subject to appropriation. The Federal "reserved water doctrine" is based on the principle that when land is reserved by the Federal Government, the water necessary to use the land for the intended purpose is also reserved.

The Federal Government controls more than three-quarters of the land of the Great Basin Region. Possibly 80 percent of the usable runoff of the region is generated on the mountainous parts of the Federal land, and a similar percentage of the ground-water recharge may be derived from those lands. It is evident, then, that any planned large-scale ground-water development for a particular area could be affected substantially if a legal decision involving both the State water laws and the Federal "reserved water doctrine" were required.

Areas may be limited in some degree to further ground-water development under existing State water laws. The limitations ordinarily apply to areas where the magnitude of existing development is significant, although they also apply to areas preserved for specific uses in the future. Areas having some limitation on additional development are shown in figure 7. Any proposal for substantial additional water-resources development in those areas needs to carefully consider the legal limitations on the development.

POTENTIAL FOR DEVELOPMENT

Ground water in the Great Basin Region was withdrawn primarily through large-capacity wells at an annual rate of about 1.1 million acre-feet (1,360 hm^3) per year in 1970. Plate 1*H* shows that the region probably can sustain an annual net pumpage of at least 2.6 million acre-feet (3,200 hm^3). Thus, an additional 1.5 million acre-feet (1,850 hm^3) per year of ground water is potentially available. Some of this water is now used for low-value purposes, such as subirrigated saline pastures. Development of the full additional 1.5 million acre-feet (1,850 hm^3) per year of ground water potentially available would require intensive management and water treatment in some areas, detailed evaluation of surface-water–ground-water relations and resolution of legal conflicts in other areas, and encouragement of small-scale developments in areas with low yields.

The amount of ground water that may be developed from one-time storage reserve is highly dependent upon the constraints imposed. The annual amount could be large, perhaps several million acre-feet, if legally allowed with no concern as to how long it might be economically possible to withdraw the ground water in the particular areas of development.

If an amortization period is utilized, for an interval of say 50 years, a substantial annual supply could be provided. Thus, 1.0 million acre-feet (1,233 hm^3) of ground water might be withdrawn annually for 50 years from a one-time storage reserve by planned development in 20 areas, supplying an average of 50,000 acre-feet (62 hm^3) per year each. Obviously, the finite time limit may present serious problems to a permanent community if an alternative supply were not available when needed. Even if the ground water systems continue to be legally restricted to the sustained-yield concept, considerable storage is used. Ground-water storage will always be reduced until the well-field withdrawals consist only of intercepted natural recharge or of captured natural discharge.

An evaluation of the relative potential for moderate to large-scale development of ground-water resources was made using an arbitrary scheme based on yield and ground-water storage of individual hydrographic areas. The following factors were considered:

1. Ultimately, yield is the limiting factor in determining the long-term viability of a large-scale ground-water development. Consequently, yield was given more weight than storage. Where a system yield was involved, no consideration was given to the relative proportions of surface water and ground water.
2. Stored ground water represents water available for use on a time-limited basis. A large volume of water per foot of dewatering also indicates a large area of valley fill. This allows for more options in the location and spacing of any ground-water development.

In conjunctive-use areas, ample ground-water storage would be valuable during droughts or short-term emergencies. In arid valleys storage might be depleted on a planned basis and then pumping decreased to a rate compatable with the yield. Because of these options, the availability of stored ground water was also incorporated into the rating scheme. If water quality was not suitable for most uses or if depth to water was prohibitive, storage was not considered.

The actual procedures were as follows: The distribution of yield and storage shown on plate 1*G* and 1*H* provided the basic information. The categories shown on each map were assigned index numbers from 1 to 5. If there was no restriction on quality or depth to water, the index of potential for each area was computed as the sum of the yield-index number and half the storage-index number. If there was a restriction due to water quality or depth to water, the index of potential was assumed equal to the yield-index number. The distribution of areas of poor water quality is shown on plate 1*F*. Valleys where excessive depth to water would hinder large-scale development are the drained areas on plate 1*B*. Each area was rated, and the ratings were grouped into four categories.

Plate 1*I* shows the distribution of relative potential for development in the Great Basin Region. Numerical magnitudes were not assigned to the categories because requirements of any proposed development need to be

FIGURE 7.—Critical ground-water areas (as of 1973).

evaluated in terms of the more detailed information in the references for each area listed in table 8.

The above rating scheme was based only on the availability of water; however, many other factors affect the suitability of an area for the objectives of a specific development. Some restrictions on development are shown in figure on plate 1*I*. Many areas which have the highest potential for development correspond with the existing centers of population (fig. 1) and the distribution of pumpage (fig. 6). The several valleys which have a high development potential with regard to water and are still relatively undeveloped generally either have a short growing season, which would hinder agricultural development, or are remote.

INFORMATION TO PLAN GROUND-WATER DEVELOPMENT

Planning for additional water development and improved operation of present developments has been increasing at all levels of government. Few planners are completely familiar with all elements that make up a plan. Water supply is a significant element in nearly all planning of areal development. In general, many planners may only want to know that the necessary water supply can be provided in the quantity and quality desired at an acceptable cost. Others specialize in finding the most effective way to provide the water required. These specialists must have detailed technical information about the resource.

Where surface-water resources are to provide the supply, much information on water quantities, structural design, and concepts for managing large-scale water development is available. In contrast, few areas in this country have had the full benefit of advance planning and implementation of large-scale ground-water development. In some places, lack of experience may have resulted in not utilizing ground water to the best advantage.

The supply developed from the ground-water system may be the only water available; it may be the supply for a period of years until another supply can be developed and imported to the area of use; or, it may be used jointly with surface-water supplies. As a part of a joint-use development, the ground-water supply may provide a significant part of the normal supply or be used for special purposes, such as meeting peak-demand requirements, supplementing supplies during seasonal low-flow periods, and to supply demands through drought years.

Opportunities exist to make more effective use of ground water based on a sound knowledge of the total water system. A specific plan may call for full utilization of a ground-water system as a single major project, or it may call for development of ground water as a coordinated series of smaller projects designed to provide increased supply as the demand increases. The plan may be implemented under public or private auspices as deemed preferable. There needs to be a rough balance between the ability to predict future water demands, the detail of planning initiated, and the type of hydrologic information collected. Information needs vary, depending on the character of an area and its stage of development. Examples of data needs for several types of valleys are presented in the following paragraphs.

Sufficient information is needed for an undeveloped arid valley, where development is not anticipated in the near future, to provide provisional estimates of the area's ground-water resource. When grouped with estimates from adjacent areas, this information is useful in forming long-range plans and policies for the orderly development of water resources throughout large areas, such as a county, State, or river basin. At the local level there is a need to be able to judge whether an area has sufficient potential to be considered as a possible site for developments as demands for water arise. To the extent possible, conditions in the natural system should be documented to provide a basis for comparison in the future. Generally, these data needs can be satisfied by a reconnaissance-level study which roughly delineates boundaries of the principal aquifers or ground-water reservoirs; indicates areas of ground-water recharge and discharge; determines if there is inflow from or outflow to adjacent areas; estimates the approximate magnitude of ground-water recharge, discharge, and storage; and documents the depth to water in wells, chemical quality of ground water; magnitude of spring discharge, and types and distribution of phreatophytes under near natural conditions. These brief studies provide a great deal of information relative to their cost; however, when significant development occurs, additional information is needed.

When significant development is anticipated in an area, such as the arid valley discussed in the preceding paragraph, the data needs are more specific. Reconnaissance-level information generally provides estimates of the total resources of an area with little regard as to how they are distributed within the area. However, the manner in which the ground-water system will respond to a specific development is strongly influenced by its location with respect to various hydrologic features of the system. Consequently, information needs to be developed regarding the distribution of water-bearing deposits (primarily sand and gravel), extensive deposits of clay, transmissivity, specific yield or storage coefficient, areas of confined and unconfined water, recharge, discharge, chemical quality of ground water, subsurface inflow or outflow, if any, and the location of barriers to ground-water movement.

These data can be used to evaluate results expected to occur under various distributions and rates of pumping. Information developed would be useful in planning the orderly development of an area and in optimizing use of the ground-water resource.

Information needs for a river-segment area where significant development is anticipated include all items mentioned for an arid valley plus specific data on the relation between surface and ground water. Some additional items needed are surface-water inflow and outflow, flow durations, seepage gains or losses during low flow, location of areas where irrigation diversions cause significant secondary recharge, delineation of flood plains, transmissivity and specific yield of flood-plain deposits, and subsurface extent of the flood-plain deposits. Specific studies may be required to evaluate the degree to which various distributions of pumping will affect streamflow.

In all studies, establishment of a network of observation wells at the earliest possible opportunity provides information on water-level changes with time that is essential to evaluating cause-and-effect relations and refining reconnaissance-level estimates.

Figure 8 shows the level of available ground-water information in the Great Basin Region as of 1973. Most of the area has been covered by reconnaissance studies; how-

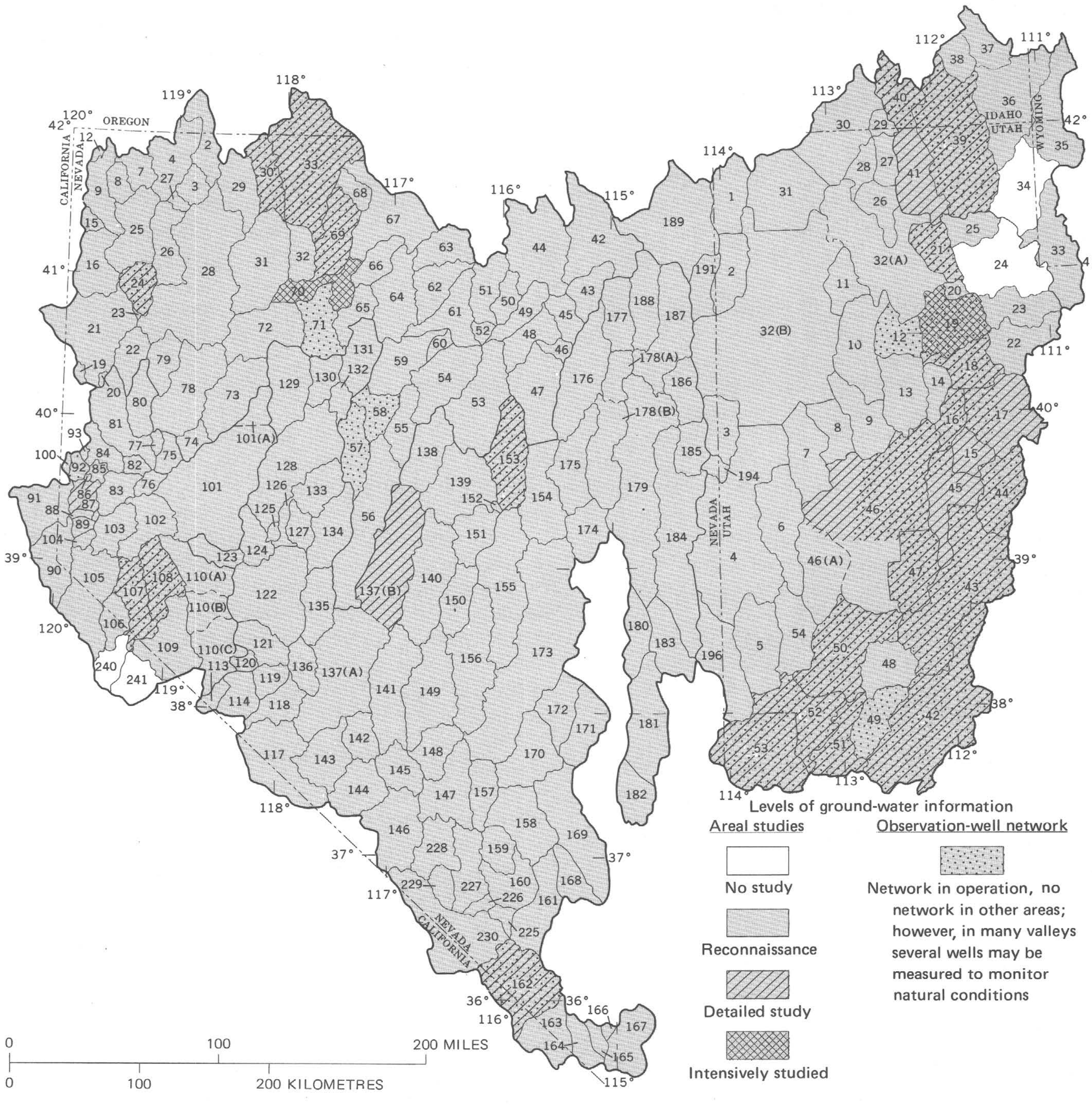


FIGURE 8.—Levels of ground-water information in the Great Basin Region, 1973.

ever, some earlier studies are mainly descriptive and contain few quantitative estimates.

The information available as of 1973 is sufficient to crudely identify the distribution, magnitude, and quality of ground-water resources throughout the region. Thus, the first phase of progressive ground-water data acquisition is nearing completion. The next phase of study needs to emphasize acquisition of time-series data to provide a base for defining changes in storage, discharge, and recharge to the ground-water system. This will allow for detailed studies to refine quantitative aspects of the ground-water system in areas where there is significant development. Where full development or overdevelopment of the water resource is foreseen, intensive studies may be needed to determine how the resource can be managed most efficiently to meet demands.

OPTIONS FOR GROUND-WATER DEVELOPMENT

The preceding sections of this report have made a broad appraisal of ground-water resources of the Great Basin Region, shown relative potentials for development of hydrographic areas, and briefly discussed the information necessary for planned developments. This section will illustrate some options available for the utilization of ground water in the region. A factor which might significantly limit the options available in a given area is the set of constraints imposed by existing development. If development has proceeded without much regard to the hydrologic regimen of an area, optimum utilization of water might not be obtained without some modification of the development.

The degree to which surface and ground water are each developed depends on conditions in individual areas. The wetter areas on the region are the river reach, prominent stream, and some sink areas shown on plate 1*B*. In these valleys, joint development of both surface and ground water may be the best way the system can be managed and optimum use of water obtained. Most closed basins, partly drained valleys other than river-reach and prominent stream areas, and some sinks have scant surface-water supplies and ground water is the only source suitable for large-scale development. The following sections illustrate some of the options available.

DEVELOPMENT OF A SUPPLEMENTAL GROUND-WATER SUPPLY

TO MEET SEASONAL DEMANDS

In areas where surface water is the principal source of supply for irrigation and other uses, the peak demand comes during periods of low flow and a seasonal water deficiency results. The usual procedure has been to construct dams which provide storage on local streams and alleviate these short-term deficiencies. In some areas, such facilities are not feasible, in other areas the supply is already completely adjudicated and highly regulated. An alternative to further regulation is to develop ground water to augment the surface supply during high-demand periods.

The Sevier Desert area, Utah, is used as an example. There is an average demand of about 160,000 acre-feet (197 hm^3) per year, primarily for agricultural purposes. System yield is about 186,000 acre-feet (229 hm^3) per year so adequate water is available to meet the annual demand. However, the August to September supply from surface-water sources is only on the order of 20,000 acre-feet (25 hm^3), but demand during this period is on the order of about 80,000 acre-feet (99 hm^3). Thus, during average and below average years a 2-month seasonal deficiency of at least 60,000 acre-feet (74 hm^3) occurs. Ground water could provide adequate water to cover this deficiency and assure a firm supply of 160,000 acre-feet (197 hm^3) per year. Any local overdraft caused by seasonal pumping could be made up by recharge during the nonpumping months or during subsequent wetter years. A properly designed well field would reduce the potential for local overdraft. Much of the ground-water withdrawal would be drawn primarily from nonbeneficial natural discharge.

Upstream areas of the Humboldt River basin, Nevada, are other places where ground water could supplement seasonal irrigation demands. Streamflow is unregulated; consequently, substantial areas of pasture or native hay receive irrigation water only in the spring and early summer. If wells were drilled to produce late-summer irrigation water, some parts of this area might sustain higher value crops, such as alfalfa. Wells could be located so that pumping would have minimal effects on downstream surface-water rights. Evaluation of the location and of the amount of seasonal pumping possible would require detailed study but might result in a significant increase in crop value.

TO OFFSET DEFICIENCIES DURING DROUGHTS OF 1 OR MORE YEARS

During droughts of 1 year to several years, the surface-water supply for an area may be inadequate, even where the supply is well regulated by storage and imports. In a densely populated area, such intermediate-term surface-water deficiencies may become critical. Larger storage facilities and imports are the usual means of minimizing such shortages until the cost of providing carryover storage for periods of several years becomes prohibitive. Planned development of supplemental ground water could be an alternative approach to the problem. The general prerequisite for this type of development is that sufficient stored ground water be available to supply the temporary depletion and that the stored water be of suitable quality for the intended use. Also, well yields would have to be adequate for the anticipated pumping, and wells would have to be distributed so pumping would have minimal effects on surface-water supplies.

Jordan Valley, Utah, is an example of an area where such a system might be beneficial. System yield plus water imported from outside the area exceeds 600,000 acre-feet (740 hm^3) per year. During 1964–68 the annual withdrawal of water for all uses averaged about 580,000 acre-feet (715 hm^3) per year. Of this amount, about 78 percent was from surface-water sources, and the remainder was from ground water.

The annual supply required to supplement surface water during a dry period of one to several years might be as much as 410,000 acre-feet (506 hm^3)—the difference between the minimum annual recorded surface flow of 170,000 acre-feet (210 hm^3) and the average annual demand of 580,000 acre-feet (715 hm^3). However, the net withdrawals might be somewhat less than this amount.

For example, if about 160,000 acre-feet (197 hm^3) of ground water were used for irrigation, roughly 25 percent, or 40,000 acre-feet (49 hm^3), would be returned to the ground-water system by deep percolation. The net ground-water withdrawal thus would be 370,000 acre-feet (456 hm^3) during years of minimum surface-water supplies. Some of the water withdrawn for industry, public supply, and other uses also probably would return to the ground-water body. Nevertheless, the net withdrawals still would be substantial and periodically would put a severe stress on the ground-water system. Ideally, the required well field or fields would be distributed and designed to minimize potential problems of local overdraft, depletion of flow in the lower reaches of streams and wetland areas, and local deterioration of water quality.

About 2 million acre-feet (2,470 hm^3) of water is stored in the upper 100 feet (30 m) of saturated valley fill, so ample stored water is available to supply a deficit of 370,000 acre-feet (456 hm^3) per year for several years. Withdrawals of this magnitude would last only during the dry periods and recovery probably could be expected during the intervening wet cycles. Recovery could be augmented by artificial recharge if necessary by utilizing excessive wet-period streamflow.

A system of this type also would be available to provide an emergency public supply during a disaster that might destroy or cause extensive damage to the surface-water-supply system.

DEVELOPMENT BY PUMPING GROUND WATER ONLY

WITHDRAWAL PLANNED TO MAINTAIN SOME NATURAL DISCHARGE

In many areas in the Great Basin Region, some natural ground-water discharge is beneficial. It may be desirable to maintain this discharge when the area is developed, particularly where extensive areas of wildlife habitat are sustained primarily by ground-water discharge. Ruby Valley, Nev., is an example of this type of area. The valley is a topographically closed basin about 60 miles (97 km) long and 8 to 12 miles (13 to 19 km) wide. It receives some subsurface inflow from adjacent Huntington Valley. Perennial yield is estimated to be about 58,000 acre-feet (72 hm^3) per year, and each foot of dewatering throughout the valley-fill reservoir would provide about 33,000 acre-feet (41 hm^3) of stored ground water. Because of these large quantities of water, the valley is classed among those with the highest potential for development (p. *11*). However, a large marsh in the south half of the valley has been designated as the Ruby Lake National Wildlife Refuge. Almost half the ground-water resource is consumed by evapotranspiration in and near the Refuge. Any large-scale ground-water development would have to be strategically situated in the northern part of the valley, where pumping would have minimal effect on the marsh area. Consumptive use of the pumped water may eventually have to be limited to an amount equal to evapotranspiration in the northern part of the valley that could be captured by pumping. Eakin and others (1951, p. 90) estimated that about 20,000 acre-feet (25 hm^3) per year could be captured by pumping in the north end of the valley. If this water was used primarily for irrigation, perhaps one-third of the pumpage would not be consumed and would recirculate to the ground-water reservoir. Under these conditions, an annual pumpage of nearly 30,000 acre-feet (37 hm^3) could be sustained in the northern part of the valley, and the Wildlife Refuge at the south end could be maintained at near-natural conditions. Detailed cause and effect studies would be required after some significant development, but before the valley approached full development. Analytical models of the ground-water reservoir would be useful in predicting long-term effects of pumping, including salt buildup from recycling, and in refining the initial estimate of allowable pumpage.

DEVELOPMENT DESIGNED TO CAPTURE ALL NATURAL DISCHARGE

Where ground water is the principal source of supply and availability of water is the limiting factor to development, it is desirable to plan developments so that all natural discharge will be captured. Ideally, this would involve situating wells strategically in and near areas of ground-water discharge so that the natural discharge could be captured with only minimal water-level declines and storage depletion. In reality, most ground-water discharge areas are associated with concentrations of poor-quality water and saline soils. Consequently, pumping generally should be located as strategically as possible within the constraints posed by water and soil conditions. Consumption of pumped ground water may eventually have to be limited to the amount of discharge that economically can be captured (the perennial yield). Temporary higher withdrawals are possible hydrologically but may result in legal problems. Regulation of pumpage is at the discretion of the appropriate State Engineer.

Hualapai Flat, Nev., is an area where this option has been employed. The area is a small topographically closed basin on the northwest flank of the Black Rock Desert. Perennial yield is about 6,700 acre-feet (8.3 hm^3) per year, and each foot of dewatering of the valley-fill reservoir will provide about 3,500 acre-feet (4.3 hm^3) of stored water. Intensive agricultural development began in about 1960 and by 1967 the gross annual pumpage was about 11,000 acre-feet (13.6 hm^3) per year. However, only about two-thirds of the gross pumpage was consumed (7,400 acre-ft or 9.1 hm^3 per year) the remainder was recirculated to the ground-water reservoir (Harrill, 1969, p. 41). Allowing for some errors in estimates, the consumption of pumped water was about equal to the perennial yield. At this same time, a decision was made by the Nevada State Engineer to restrict development, and no permits to pump ground water for additional irrigated acreages have been issued for several years. Pumping was situated primarily with respect to land availability and good soil and is concentrated at one end of the valley. Ultimately, some pumping may have to be relocated in order to capture all available natural discharge. Also, problems in salt balance may develop in the pumping areas. However, regulation of pumpage early in the course of the area's development has probably minimized future problems and insured a moderate-sized, viable agricultural development for many years.

UTILIZATION OF GROUND-WATER STORAGE

Stored ground water is a valuable component of the region's water resource. There are about 300 million acre-feet (370,000 hm³) of recoverable water stored in the upper 100 feet (30 m) of saturated valley deposits. This water may be withdrawn as part of a planned depletion, it may be utilized principally during periods of drought or peak demand, or it may be held in reserve for possible future use.

USE AS A TRANSITIONAL RESERVE

This method of utilizing stored ground water is based on the concept that prior to any development a ground-water reservoir is in a state of dynamic equilibrium, where average recharge to the system equals average discharge, and there is no long-term change in storage. Any pumping will create an imbalance where water is pumped from storage until water levels decline sufficiently to cause natural discharge to decrease or recharge to increase and return the system to a new equilibrium where recharge equals natural discharge (if any) plus pumpage. In most desert valleys, there are no appreciable areas where recharge can be increased by pumping. If wells are strategically located in and near areas of natural discharge, the water that must be removed from storage before a new equilibrium can be obtained will be minimal. The minimal quantity of water that must be pumped from storage before an arid ground-water basin can attain a new equilibrium when developed at a rate equal to the perennial yield has been called the transitional storage reserve (Worts, 1967, p. 50). This quantity is a property of the ground-water basin and may be useful in long-term planning.

Diamond Valley, Nev., is an area where some planned storage depletion may be an option for the future. The valley is about 50 miles (80 km) long and averages about 12 miles (19 km) wide. All natural discharge is in the north half of the valley. Perennial yield is about 30,000 acre-feet (37 hm³) per year, and each foot of dewatering of the valley-fill reservoir will produce about 28,000 acre-feet (35 hm³) of stored water. Transitional storage reserve is about 1,400,000 acre-feet (1,730 hm³). The area has been developed for agricultural use. Permits to pump ground water were issued for large tracts of land at the south end of the valley. In 1969 about 23,000 acre-feet (28 hm³) of water was pumped from this part of the valley. Future increases are anticipated because of increased demand for hay and grain and because of the recent availability of electric power in the area. Most of the pumping is at least 10 miles (16 km) south of the area of natural discharge and a local overdraft is probable before all natural discharge is captured by pumping from the present area of development.

One alternative in regulating storage depletion in the south end of the valley would be to allow a depletion equal to the transitional storage reserve to occur and then redistribute pumping with more regard to the natural system. If net pumpage (consumption) were held to 30,000 acre-feet (37 hm³) per year, the time required to deplete the storage can be approximated by the following formula (Worts, 1967, p. 52):

$$\text{Net annual pumping rate} = \frac{\text{Transitional storage reserve}}{\text{Time, in years}} + \frac{\text{Perennial yield}}{2}.$$

For the Diamond Valley area, time equals about 93 years. Thus, water could be depleted from the south end of the valley at a rate of 30,000 acre-feet (37 hm³) per year for almost 100 years before the transitional storage reserve would be depleted. At that time it might be desirable to redistribute pumping as the average decline of non-pumping water levels in the south half of the valley would be about 100 feet (30 m); greater declines would be expected near centers of pumping. When a new equilibrium is finally attained, the total depletion of storage would only be slightly more than if the original pumping had been in or near the discharge areas. If desired, this same volume of storage could be depleted by pumping at a higher rate for a shorter period of time. After significant depletion has occurred, analytical models could be used to refine the initial estimates of time and to evaluate the optimum distribution of pumpage.

USE TO SUPPLY A TIME-LIMITED DEVELOPMENT

Ground water may be withdrawn at a rate greater than the perennial yield of the ground-water system for a limited period of time. This results in depletion of storage; however, it is not uncommon for an amount equal to several hundred times the perennial yield of the ground-water system to be stored at economically recoverable depths. Thus, in many areas, appreciable amounts of water might be removed from storage before seriously adverse economic effects occur. Ultimately, however, withdrawals would have to be limited to the approximate perennial yield of the ground-water system under the State laws or policies. Time-limited developments could be either (1) semipermanent developments, which could be economically terminated or reduced at the end of a given period of time, or (2) permanent developments, which must obtain additional water at the end of a given period of time.

The Beryl-Enterprise area, Utah, is used to illustrate this option. This valley in southwestern Utah has a warm climate and has been intensively developed for agriculture. Perennial yield is about 6,000 acre-feet (7.4 hm^3) per year and pumpage in 1972 was about 77,000 acre-feet (95 hm^3) per year. The valley contains about 5 million acre-feet (6,165 hm^3) of recoverable stored water in the upper 200 feet (61 m) of the ground-water reservoir.

At the present time there is a large overdraft in the basin; eventually, all economically recoverable storage will be depleted. At that time either the pumping draft will have to be reduced to approximately the perennial yield or water will have to be imported. For purposes of illustration, assume the economically recoverable storage is about 5 million acre-feet (6,165 hm^3) and that 50 years was determined to be the optimum amortization period in which to deplete this storage. The formula (Worts. 1967, p. 52) by which the average annual quantity of depletion can be estimated is:

$$\text{Net annual pumping rate } (Q) = \frac{\text{Depletable storage}}{\text{years}} + \frac{\text{Perennial yield}}{2}.$$

which for the area is

$$Q = 100{,}000 \;+\; 3{,}000,$$

or about 100,000 acre-feet (123 hm^3) a year (rounded).

If the development was principally for agricultural purposes, the local return flow to the ground-water system probably would be about 25 percent of the pumpage. Because the computation of water available from reuse is a geometric progression, a gross pumpage of about 130,000 acre-feet (160 hm^3) per year could be maintained throughout the 50-year amortization period. Degradation in water quality due to reuse would be partly offset by mixing with water withdrawn from storage for the first time.

This average annual rate could be maintained for the selected period if the distribution of the well field or well fields were such as to permit full depletion of the storage area used to define the quantity of depletable storage. Development of this magnitude will result in important changes in the preexisting conditions. The following changes are the most likely ones to occur:

1. Extensive changes in water quality over a period of time. This may be considered as a constraint on the development. However, treatment ranging from minimal to desalination could be incorporated in the development plan to maintain the quality of the supply.
2. Natural areas of ground-water discharge may be dried up. Thus, parts or all of natural wetlands and phreatophyte vegetation may be desiccated. This would adversely affect some wildlife habitat. Antecedent knowledge of this potential problem may permit devising a development plan whose effects would be within acceptable limits.
3. Substantial pumping from the ground-water reservoir may result in land subsidence that locally may have adverse effects. Land subsidence due to withdrawal of ground water is generally more severe in close proximity to well fields. The most serious problems would occur where the well fields are located in metropolitan areas—that is, in populous areas with their associated concentrations of buildings, water and sewer lines, and other structures potentially subject to damage by subsidence. However, a planned ground-water development would locate wells where subsidence would have minimal adverse effects.

FOR USE AS A FUNCTIONAL RESERVOIR

Throughout the Great Basin Region, most of the water supply is generated during the winter and spring; however, the highest demand occurs during the late summer. Consequently, dams have been built on most of the principal rivers so that regulating reservoirs can distribute the water more in accord with demand. Most of the principal rivers are highly regulated, and for many of them, construction of additional surface-water storage facilities may not be practical. Also, many areas do not contain adequate sites for the construction of surface-water storage facilities. In these areas, utilization of the valley ground-water reservoir as a managed storage reservoir may be a desirable alternative. The examples already given for the Sevier Desert and Jordan Valley illustrate two ways in which ground-water reservoirs may be used as functional storage reservoirs.

SECONDARY OPTIONS

The preceding sections have illustrated ways that ground-water resources may be utilized in selected areas with characteristics typical of many valleys in the Great Basin Region. The discussion has dealt principally with the primary option selected in each area. There are additional options which may be utilized to increase efficiency of water use and overcome problems posed by specific conditions in individual areas. Examples of four of these are reuse of water, treatment of water, redistribution of water, and augmenting ground-water storage. These are the options most commonly considered; however, there are others that may be more important in specific areas.

REUSE OF WATER

In arid areas with limited water supplies, reuse of water is one means of extending the available supply. Each use generally results in some degradation of quality, and treatment may be required. In a simple form, planned reuse may consist of no more than a series of uses where lower quality water is acceptable for each successive use. The most common example of this type is use for municipal purposes, secondary treatment, and then use of the effluent for irrigation. More sophisticated schemes may require elaborate tertiary treatment which would enable reuse for high-quality purposes. Unplanned reuse generally occurs in irrigated areas where some unconsumed irrigation water becomes secondary recharge. The maximum reuse possible varies with the quantity consumed in use. If it is assumed that water will be used and reused until it is consumed, the rate at which a given inflow of new water can be used may be estimated as the rate of new water input divided by the consumption (expressed as a decimal fraction). The following examples, from areas already discussed, illustrate how reuse may be applied to planned ground-water developments.

Example A.—Full use of perennial yield:

Area—Hualapai Flat;

Perennial yield—7,000 acre-feet (8.6 hm^3) per year;

Use—Irrigation, about $^2/_3$ (0.67) of pumpage consumed in use;

$$\text{Maximum sustained pumping rate} = \frac{\text{Perennial yield}}{\text{Consumption}}$$

$$= \frac{7{,}000}{0.67} = 10{,}000 \text{ acre-feet } (12 \text{ hm}^3) \text{ per year (rounded).}$$

Example B.—Storage depletion:

Area—Beryl-Enterprise area;

Rate of depletion—100,000 acre-feet (123 hm^3) per year;

Use—Irrigation, about ¾ (0.75) of pumpage consumed in use;

$$\text{Pumping rate} = \frac{\text{Rate of depletion}}{\text{Consumption}} = \frac{100{,}000}{0.75}$$

$$= 130{,}000 \text{ acre-feet } (160 \text{ hm}^3) \text{ per year (rounded).}$$

TREATMENT OF WATER

Treatment is another option that may be used to extend usefulness of the available water. Water treatment in conjunction with reuse has already been mentioned. If significant development occurs in some sink areas where water quality is marginal for most uses, then some treatment may be required. Facilities available range from large plants used for public-supply systems to small units suitable for use by individuals. The type and degree of treatment required, if any, vary with each area. Generally, specialized technical assistance is available to assist in planning a development that would use a specific type of water treatment.

REDISTRIBUTION OF WATER

Commonly, developments are located on the basis of accessibility, land ownership, soil conditions, or climate. Where ground-water development is poorly situated with respect to the occurrence of water, and local overdraft is anticipated, relocation of pumping and transportation of water to the existing area of development may be more desirable than attempting to relocate the development.

Occasionally, it may even be necessary to import water from outside the area. If this type of development is anticipated, cause and effect relationships at the proposed pumping sites, along transmission lines, and at development where the water is to be used need to be evaluated.

AUGMENTING GROUND-WATER STORAGE

In most valley ground-water reservoirs in the Great Basin Region, the level of stored ground water responds to the variations of natural recharge and discharge. A succession of years of significantly higher than average recharge will raise the level of storage until the increased natural recharge is balanced by an increased natural discharge. Conversely, the level of storage will lower following years of reduced recharge until the natural discharge and recharge are in balance. However, in most ground-water reservoirs, natural variations in stored water are minor.

In the Great Basin Region, part of the annual pumpage is supplied from ground-water storage. Some of the depletion is temporary and is necessary for the natural system to adjust to well-field development. Part, however, is a local or basin overdraft and is a continuing depletion. Examples of areas of overdraft are in the Beryl-Enterprise district in Sevier Lake subregion, Quinn River Valley in Humboldt subregion, and Pahrump Valley in Tonopah subregion.

Areas of overdraft might benefit from artificial recharge. However, in each of the named areas, no local supply is available, nor is there a convenient nearby source for possible importation. Several conditions are required for artificial recharge to be successful: (1) Underground space must be available for storing the additional water; (2) the physical and chemical characteristics of the rock units in and above the ground-water reservoir must be suitable to accept water either from surface spreading grounds or through wells; (3) additional water must be available; (4) the water to be used must be chemically suitable; and (5) the cost should be within the range of "willingness and ability to pay."

Artificial recharge might be advantageous where ground-water development significantly depletes stored ground water. Properly incorporated into planning a large-scale ground-water development, it could permit significant augmentation of the natural yield of the system.

In drained valleys, the depth to water is as much as several hundred feet below land surface. In these areas, natural ground-water discharge is by underflow and not by evapotranspiration. Obviously, a large volume of underground space is available between the water table and land surface. However, artificial recharge would raise the level in these reservoirs and increase discharge by increasing underflow. Consequently, it may not be feasible to augment storage in these areas even though the increased discharge would be augmenting recharge to a downgradient valley. The time lag involved in these flow systems may be many years. Much more needs to be known of the details of regional ground-water systems before decisions can be reached as to whether plans for their augmentation are practical and economically sound.

Underground space might be used for purposes other than for artificial recharge. For example, in southern Tonopah subregion the deep water levels in the valleys have been a significant factor in using the area for underground nuclear-detonation experiments. In other areas, brine or other waste disposal might be proposed by underground emplacement. However, any proposed use of underground space ideally should require specific investigations be made to determine the suitability of the area for the specific use contemplated. Few, if any, areas in the region have been evaluated for such purposes to date.

CLOSING STATEMENT

Ground water has been developed in the past in response to individual needs. Supplies from individual wells or groups of wells have been planned to a degree, but fuller development of the ground-water basins may not have been considered. Many ground-water basins or areas are now being managed through administration of ground-water laws, or resulting legal actions, particularly in the Nevada and Utah parts of the Great Basin Region. However, full development of some areas may not be possible without drastic adjustments in the distribution of existing withdrawals in these areas.

The present trend of formulating State water plans is leading to more emphasis on achieving near optimal use of the limited water resources of the States in the region. The ground-water potential for additional development is receiving substantial attention in this planning. If an effective planning effort is to be made, more information is needed on the ground-water resources, the potential for additional development, the conditions to be met for successful development, and the planning, implementation, operation, and maintenance of ground-water supply systems.

The development of additional ground water could be of significant benefit to the Great Basin Region. Some idea of the approximate value of water may be obtained by the following illustrations:

1. At the current level of water use, irrigation accounts for about 80 percent of the withdrawals. A common yearly rate of water application for irrigation is about 4 acre-feet per acre. If it is assumed that ground-water withdrawals for irrigation were planned for an additional 1 million acre-feet (1,233 hm^3) annually, then about 250,000 acres (1,010 km^2 could be irrigated. Or,
2. Current levels of municipal and industrial use in the region range from about 200 to 400 gallons (760 to 1,510 litres) per day per capita. If it is assumed that an average use of 300 gallons (1,140 litres) per day per capita will be adequate, then additional ground-water withdrawals of 1 million acre-feet (1,233 hm^3) could support a population of more than 2 million people.

Development of ground water could be of substantial benefit in helping to meet future demands for water in the Great Basin Region, and sound planning for its most effective development is dependent upon the availability and adequacy of the information on this valuable resource at the time of planning.

REFERENCES

Eakin, T. E., and others, 1951, Contributions to the hydrology of eastern Nevada: Nevada State Engineer Water Resources Bull. 12, p. 79–91.

Everett, D. E., and Rush, F. E., 1967, A brief appraisal of the water resources of the Walker Lake area, Mineral, Lyon, and Churchill Counties, Nevada: Nevada Dept. Conserv. and Nat. Resources Water Resources–Reconn. Ser. Rept. 40, 44 p.

Fenneman, N. M., and Johnson, D. W., 1946, Physical division of the United States: U.S. Geol. Survey Map.

Godwin, L. H., and others, 1971, Classification of Federal lands valuable for geothermal steam and associated geothermal resources: U.S. Geol. Survey Circ. 647, 18 p.

Harrill, J. R., 1969, Hydrologic response to irrigation pumping in Hualapai Flat, Washoe, Pershing, and Humboldt Counties, Nevada, 1960–67: Nevada Dept. Conserv. and Nat. Resources Water Resources Bull. 37, 75 p.

Kohler, M. A., Nordenson, T. J., and Baker, D. R., 1959, Evaporation maps for the United States: U.S. Dept. Commerce, Weather Bur. Tech. Paper 37, 13 p.

Malmberg, G. T., 1967, Hydrology of the valley-fill and carbonate-rock reservoirs, Pahrump Valley, Nevada-California: U.S. Geol. Survey Water-Supply Paper 1832, 47 p.

Pacific Southwest Inter-Agency Committee, 1971a, Great Basin Region Comprehensive Framework Study, Appendix III, Legal and Institutional Environments: Salt Lake City, Water Resources Council, 227 p.

——1971b, Great Basin Region Comprehensive Framework Study, Appendix V, Water Resources: Salt Lake City, Water Resources Council, 109 p.

——1971c, Great Basin Region Comprehensive Framework Study, Appendix XV, Water Quality, Pollution Control and Health Factors: Salt Lake City, Water Resources Council, 164 p.

Shamberger, H. A., 1971, The story of Rawhide, Mineral County, Nevada: Nevada Dept. Conserv. and Nat. Resources, Historic mining camps of Nevada, Rept. 2, 50 p.

——1972, The story of the water supply for the Comstock: U.S. Geol. Survey Prof. Paper 779, 53 p.

Snyder, C. T., 1962, A hydrologic classification of valleys in the Great Basin, Western United States: Internat. Assoc. Sci. Hydrology Bull., v. 7, no. 3, p. 53–59.

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

Walker, G. E., and Eakin, T. E., 1963, Geology and ground water of Amargosa Desert, Nevada-California: Nevada Dept. Conserv. and Nat. Resources Ground-Water Resources–Reconn. Ser. Rept. 14, 58 p.

Worts, G. F., Jr., 1967, The available water supply, *in* Rush, F. E., and Glancy, P. A., Water-resources appraisal of the Warm Springs-Lemmon Valley area, Washoe County, Nevada: Nevada Dept. Conserv. and Nat. Resources, Water Resources–Reconn. Ser. Rept. 43, p. 48–53.

Worts, G. F., Jr., and Malmberg, G. T., 1966, Hydrologic appraisal of Eagle Valley, Ormsby County, Nevada: Nevada Dept. Conserv. and Nat. Resources, Water Resources–Reconn. Ser. Rept. 39, 55 p.

TABLE 8 AND TABLE 8 REFERENCES

A regional quantitative appraisal of the ground-water resources in the Great Basin Region is given in an earlier section of this report entitled "Yield of the Ground-Water System." Table 8 presents quantitative estimates of various parameters of the ground-water system in the hydrographic areas of the region. The general locations of these hydrographic areas are shown on plate 1*B*.

TABLE 8.—*Summary of selected ground-water resources data in the Great Basin Region*[1]

[L, large amount; Sm, small amount; S, some; M, minor amount; leaders (...) indicate no data]

Hydrographic area number and name[2]	Approximate area (mi²)	Approximate altitude of valley floor	Average growing season (days)	Average annual precipitation (acre-ft)	Ground-water recharge from precipitation (acre-ft/yr)[3]	Ground-water inflow (acre-ft/yr)	Ground-water outflow (acre-ft/yr)	Ground-water evapotranspiration (acre-ft/yr)	Ground water in storage (acre-ft/ft)[4]	Report reference (See table references)
WESTERN GREAT BASIN										
Humboldt subregion										
2 Continental Lake valley	214	4,200	......	100,000	4,000	......	0	10,500	3,800	R22.
3 Gridley Lake valley	195	4,500	......	98,000	[3]4,500	......	0	3,000	2,300	R22.
4 Virgin Valley	494	4,800	42	230,000	7,000	......	0	6,000	420	R22.
7 Swan Lake valley	226	5,700	42	130,000	[3]6,700	0	0	0	M	R15.
8 Massacre Lake valley	176	5,700	42	97,000	3,500	0	2,000	2,500	1,400	R15.
9 Long Valley	433	5,600	42	240,000	[3]10,000	5,000	0	11,000	10,000	R15.
12 Mosquito Valley	32	5,700	42	16,000	700	0	0	1,600	470	R15.
15 Boulder Valley	88	5,700	42	52,000	[3]2,700	0	2,000	< 2,700	600	R15.
16 Duck Lake valley	533	4,700	75	270,000	9,000	0	0	7,000	5,600	R17.
19 Dry Valley	39	4,200	......	14,000	200	0	180	20	1,000	R44.
20 Sano Valley	12	4,000	160	3,100	< 10	0	0	30	200	R44.
21 Smoke Creek Desert	980	3,900	160	440,000	13,000	380	0	19,000	20,000	R44.
22 San Emidio Desert	305	4,000	160	100,000	2,100	0	< 300	3,000	8,400	R44.
23 Granite basin	9	5,000	......	6,000	[3]400	0	M	0	50	R20.
24 Hualapai Flat	315	4,100	150	170,000	7,000	0	400	6,300	3,500	R11, B37.
25 High Rock Lake valley	665	5,000	......	435,000	13,000	0	9,000	750	610	R20.
26 Mud Meadow	495	4,000	......	220,000	8,000	9,000	1,500	11,000	8,500	R20.
27 Summit Lake valley	60	5,900	......	43,000	[3]4,200	0	S	M	630	R20, R22.
28 Black Rock Desert	2,179	4,000	179	840,000	20,000	4,700	M	35,000	56,000	R20.
29 Pine Forest Valley	528	4,000	77	260,000	10,000	250	2,700	11,000	18,000	R4.
30 Kings River valley	413	4,200	88	260,000	[3]15,000	300	100	16,000	20,000	B31.
31 Desert Valley	1,052	4,200	......	370,000	5,000		150	10,000	40,000	R7.
32 Silver State Valley	313	4,200	......	140,000	1,400	4,500	100	5,800	16,000	B34.
33 Quinn River valley	1,224	4,300	112	880,000	[3]62,000	M	4,700	51,000	42,000	B34.
42 Marys River area	1,073	5,600	......	700,000	[3]54,000	......			[5]8,000	B32.
43 Starr Valley area	332	6,000	......	230,000	[3]26,000	......	M	83,000	[5]11,000	B32.
44 North Fork area	1,110	5,400	......	750,000	[3]58,000	M			[5]5,000	B32.
45 Lamoille Valley	257	5,400	140	180,000	[3]36,000	0	......	......	[5]8,000	B32.
46 South Fork area	99	5,600	100	98,000	[3]4,000	0	600	3,000	2,400	R35, B32.
47 Huntington Valley	787	5,500	90	550,000	[3]14,000	0	10,400	14,000	32,000	R35, B32.
48 Dixie Creek–Tenmile Creek area	392	5,400	100	240,000	[3]13,000	1,000	9,000	4,000	16,000	R35, B32.
49 Elko segment	314	5,100	103	170,000	[3]7,400	......	......	13,000	[5]6,000	B32.
50 Susie Creek area	223	5,000	......	130,000	[3]8,000	......	M	6,100	[5]300	B32.
51 Maggie Creek area	396	5,300	......	240,000	[3]16,000	......			[5]1,000	B32.
52 Marys Creek area	61	5,200	......	34,000	1,500	......	......	......	[5]300	B32.
53 Pine Valley	1,002	5,400	105	660,000	[3]50,000	0	9,300	15,000	20,000	R2, B32.
54 Crescent Valley	752	5,000	110	430,000	[3]13,000	> 300	M	12,000	15,000	B15, B32.
55 Carico Lake valley	376	5,100	120	160,000	[3]4,300	0	300	3,800	8,000	R37, B32.
56 Upper Reese River valley	1,138	5,800	117	700,000	[3]37,000	0	500	37,000	12,000	R31, B32.
57 Antelope Valley	452	5,000	120	260,000	[3]11,000	......	6,000	500	5,000	R19, B32.
58 Middle Reese River valley	319	4,900	120	170,000	7,000	6,500	9,000	3,000	5.000	R19, B32.
59 Lower Reese River valley	588	4,700	120	280,000	14,000	17,000	3,000	22,000	[5]17,000	B32.
60 Whirlwind Valley	94	4,800	......	45,000	1,700	......			[5]800	B32.
61 Boulder Flat	544	4,700	......	240,000	17,000	M	2,000	30,000	[5]13,000	B32.
62 Rock Creek valley	444	4,900		240,000	9,000	......	......	2,800	[5]100	B32.
63 Willow Creek valley	405	5,100		250,000	[3]15,000	......	......		[5]100	B32.

64 Clovers area	702	4,500	120	300,000	[3]9,000	......			[5]24,000	B32.
65 Pumpernickel Valley	299	4,500	......	130,000	3,400	......	1,000	72,000	[5]6,000	B32.
66 Kelly Creek area	301	4,400	......	130,000	4,000	......			[5]8,000	B32.
67 Little Humboldt Valley	975	4,600	110	500,000	[3]21,000	0	300	4,000	8,000	B32, B39.
68 Hardscrabble area	167	5,200	110	120,000	[3]9,000	0	M	M	< 100	B32, B39.
69 Paradise Valley	600	4,500	120	900,000	10,000	300	3,500	40,000	36,000	B32, B39.
70 Winnemucca segment	435	4,400	141	170,000	4,400	9,000	3,000	16,000	15,000	B19, B20, B22, B24, B27, B32.
71 Grass Valley	520	4,400	130	250,000	12,000	......	4,000	13,000	15,000	R29, B32.
72 Imlay area	771	4,200	128	300,000	7,000	3,000	1,000	7,400	8,000	R5, B32.
73 Lovelock Valley	635	4,000	128	260,000	3,200	1,000	S	3,100	20,000	R32, B32.
74 White Plains	164	3,900	......	51,000	M	S	S	......	4,200	R59.
78 Granite Springs valley	967	4,000	150–170	350,000	3,500	1,000	0	4,400	26,000	R55.
79 Kumiva Valley	333	4,500	150–160	120,000	1,000		1,000	0	10,000	R55.
Central Lahontan subregion										
75 Bradys Hot Springs area	178	4,200	150–170	59,000	160	1,200	0	3,000	3,500	R55.
76 Fernley area	120	4,200	......	43,000	600	0	5,800	......	4,200	B17, R57.
77 Fireball Valley	58	4,700	150–170	21,000	200	......	200	0	1,300	R55.
80 Winnemucca Lake valley	371	3,800	137	130,000	8,000	400	0	> 5,000	9,600	B15, R57.
81 Pyramid Lake valley	672	3,800	137	270,000	6,600	350	350	......	[6]19,000	R57.
82 Dodge Flat	92	4,200	......	43,000	1,400	2,800	150	......	2,600	R57.
83 Tracy segment	285	4,300	......	110,000	6,000	2,100	700	......	1,000	R57.
84 Warm Springs valley	247	4,300	140	130,000	6,000	0	≤ 200	1,500	4,200	R43, R57.
85 Spanish Springs valley	76	4,500	140	30,000	600	0	100	900	1,700	R43, R57
86 Sun Valley	10	4,700	140	4,000	50	0	25	2	200	R43, R57.
87 Truckee Meadows	203	4,500	155	160,000	[3]27,000	1,100	M	......	4,500	W1779, R57.
88 Pleasant Valley	39	4,500	......	46,000	[3]10,000	50	300	......	300	R57.
89 Washoe Valley	82	5,100	120	87,000	[3]15,000	0	50	8,500	2,700	R41, R57.
90 Lake Tahoe basin	139	6,200	......	180,000	[3]45,000	0	0	M	[6]300	W1972.
91 Truckee Canyon segment	84	4,900	......	110,000	[3]27,000	400	700	......	400	R57.
92 Lemmon Valley	93	5,000	130	48,000	2,100	......	......	1,200	2,300	R43.
93 Antelope Valley	18	5,200	130	9,000	300	0	S	0	470	R43.
100 Cold Spring valley	30	5,100	130	18,000	[3] 900	0	M	130	450	R43.
101 Carson Desert	2,182	3,900	127	720,000	2,000	M?	M?	......	85,000	R59.
A. Packard Wash		......	......	......	......	......	......	......	......	R59.
102 Churchill Valley	480	4,200	......	170,000	1,300	M?	M?	......	7,400	R59.
103 Dayton Valley	369	4,400	......	180,000	7,900	M?	M?	......	4,400	R59.
104 Eagle Valley	69	4,700	119	58,000	[3] 8,700	0	M	4,000	2,000	R39, R59.
105 Carson Valley	419	4,800	114	270,000	[3]25,000	3,000	M	......	7,100	P417–F, R59.
106 Antelope Valley	115	5,000	......	69,000	[3] 5,000	S	200	5,700	2,000	R53.
107 Smith Valley	479	4,700	120	270,000	[3]21,000	200	500	......	9,800	W1228.
108 Mason Valley	516	4,500	118	160,000	2,000	500	1,500	57,000	29,000	B38.
109 East Walker area	586	6,800	......	250,000	12,000	S	150	6,500	8,000	R53.
110 Walker Lake valley	1,350	4,300	136	......	......	......	......		......	R40.
A. Schurz subarea	502	4,200	136	160,000	500	1,400	S	17,000	15,000	R40.
B. Lake subarea	307	4,000	......	......	600	S	0	800	[6]1,000	R40.
C. Whiskey Flat Hawthorne subarea	541	4,800	......	210,000	5,400	300	S	4,600	9,000	R40.
240 Upper West Walker River		......	......	......	......	......	......	......	[5]100	
241 Bridgeport Valley		......	......	......	......	......	......	......	[5]2,000	
113 Huntoon Valley	97	5,800	100–150	43,000	800	0	300	300	1,200	R52.
114 Teels Marsh valley	323	5,000	170–200	120,000	1,300	< 300	0	1,400	2,600	R52.
117 Fish Lake valley	706	4,800	96+	270,000	7,300	S	> 200	22,000	16,000	B11.
118 Columbus Salt Marsh valley	370	4,600	186	100,000	700	> 200	0	4,000	5,300	R52.

See footnotes at end of table, p. G35.

TABLE 8.—*Summary of selected ground-water resources data in the Great Basin Region*—Continued

Hydrographic area number and name[2]	Approximate area (mi²)	Approximate altitude of valley floor	Average growing season (days)	Average annual precipitation (acre-ft)	Ground-water recharge from precipitation (acre-ft/yr)[3]	Ground-water inflow (acre-ft/yr)	Ground-water outflow (acre-ft/yr)	Ground-water evapotranspiration (acre-ft/yr)	Ground water in storage (acre-ft/ft)[4]	Report reference (See table 8 references)
WESTERN GREAT BASIN—Continued										
Central Lahontan subregion—Continued										
119 Rhodes Salt Marsh valley	199	4,600	170–200	59,000	500	400	0	1,000	3,400	R52.
120 Garfield Flat	92	5,700	100–150	34,000	300	0	300	0	1,500	R52.
121 Soda Springs valley	376	4,600	170–200	110,000	700	500	900	330	7,100	R52.
122 Gabbs Valley	1,277	4,300	100–120	520,000	5,000	0	0	> 3,700	16,000	R9.
123 Rawhide Flats	227	4,000	......	75,000	150	350	0	800	600	R40.
124 Fairview Valley	285	4,200	......	100,000	500	0	500	0	7,800	R23.
125 Stingaree Valley	43	4,400	......	16,000	110	M	M	}	{ 1,300	R23.
126 Cowkick Valley	110	4,700	......	44,000	800	M	M	} 400	{ 1,700	R23.
127 Eastgate Valley area	216	4,800	......	100,000	[3]4,000	0	M	}	{ 1,900	R23.
128 Dixie Valley	1,303	3,600	220	460,000	6,000	1,800	0	16,500	35,000	R23.
129 Buena Vista Valley	742	4,100	110	310,000	10,000	0	0	12,500	24,000	B13.
130 Pleasant Valley	285	4,400	......	110,000	3,000	0	800	2,200	6,200	R23.
131 Buffalo Valley	504	4,700	120	240,000	12,000	0	8,000	4,000	17,000	R32.
132 Jersey Valley	142	4,200	......	56,000	800	0	500	0	1,600	R23.
133 Edwards Creek valley	416	5,200	120	190,000	8,000	0	0	7,300	7,000	R26.
134 Smith Creek valley	582	6,100	......	280,000	12,000	0	0	6,600	15,000	R28.
135 Ione Valley	460	6,000	......	230,000	8,000	0	2,000	1,300	13,000	R28.
136 Monte Cristo Valley	284	5,400	100–150	94,000	500	0	0	400	7,200	R52.
137 Big Smoky Valley	2,926	......	......	......	......	......	......	......	......	B41.
A. Tonopah Flat	1,603	4,800	150	580,000	12,000	2,000	8,000	6,000	70,000	B41.
B. Northern part	1,323	5,500	130	740,000	[3]65,000	0	0	64,000	50,000	B41.
138 Grass Valley	595	5,700	120	290,000	13,000	0	0	12,000	16,000	R37.
139 Kobeh Valley	868	6,200	100	560,000	11,000	6,000	M	15,000	27,000	R30.
140 Monitor Valley	1,038	6,500	100	510,000	21,300	2,000	8,000	11,200	20,000	R30.
141 Ralston Valley	971	5,600	144	360,000	5,000	3,000	5,500	2,500	27,000	R12, R45.
142 Alkali Spring valley (Esmeralda)	313	5,000	140	100,000	100	5,500	5,000	400	13,000	R45.
143 Clayton Valley	555	4,400	150	180,000	1,500	13,000	0	24,000	13,000	R45.
144 Lida Valley	535	5,000	140	170,000	500	200	700	0	15,000	R45.
145 Stonewall Flat	381	4,800	140	110,000	100	S?	0	200	8,200	R45.
146 Sarcobatus Flat	812	4,100	150	190,000	1,200	1,300	3,000	500	24,000	R10, R54.
147 Gold Flat	684	5,200	......	250,000	3,800	0	0	3,800	16,000	R54.
148 Cactus Flat	403	5,400	......	130,000	600	0	0	600	14,000	R54.
149 Stone Cabin Valley	985	5,700	144	350,000	5,000	0	2,000	3,000	22,000	R12, R45.
150 Little Fish Lake valley	434	6,600	75–100	230,000	11,000	0	10,000	200	8,000	R38.
151 Antelope Valley (Eureka and Nye)	444	6,200	100	190,000	4,100	0	4,200	S	12,000	R30.
152 Stevens basin	17	7,200	100	8,500	200	0	0	200	500	R30.
153 Diamond Valley	752	5,900	100	400,000	[3]21,000	9,000	30,000	0	28,000	R6, B35.
154 Newark Valley	801	5,900	80–100	410,000	17,500	1,000	18,500	0	15,000	R1.
155 Little Smoky Valley	1,158	6,100	75–150	450,000	5,600	S	1,900	1,200	25,000	R38.
156 Hot Creek valley	1,036	5,300	150	390,000	7,000	> 200	4,600	S	23,000	R38.
157 Kawich Valley	350	5,500	......	150,000	3,500	1,000	0	4,500	9,600	B12, R54.
158 Emigrant Valley	104	4,600	......	284,000	3,200	0	0	3,200	16,000	R54.
159 Yucca Flat	305	4,000	......	100,000	700	0	0	700	5,200	R54.
160 Frenchman Flat	463	3,200	......	150,000	100	33,000	0	33,000	7,900	R54.
161 Indian Springs valley	655	3,200	......	270,000	10,000	22,000	32,000	M	18,000	R54.

162 Pahrump Valley	789	2,800	......	420,000	22,000	0	13,000	10,000	23,000	W1832.
163 Mesquite Valley	236	2,600	200–250	90,000	1,400	700	M	2,200	7,000	R46.
164 Ivanpah Valley	235	2,700	......	81,000	700	800	1,500	0	7,400	R46.
165 Jean Lake valley	96	2,800	......	32,000	100	1,500	> 100	0	3,200	R46.
166 Hidden Valley	34	3,100	......	11,000	M	M	M	0	800	R46.
167 Eldorado Valley	530	1,800	275	190,000	1,100	M	1,100	0	14,000	R36.
168 Three Lakes valley	298	3,600	......	110,000	2,000	6,000	8,000	0	8,300	R54.
169 Tikapoo valley	998	3,400	......	380,000	6,000	2,600	8,600	0	21,500	R54.
170 Penoyer Valley	700	5,000	......	270,000	4,300	0	0	6,400	22,000	B12.
171 Coal Valley	460	5,000	150	170,000	2,000	8,000	10,000	M	15,000	R18, B33.
172 Garden Valley	493	5,500	150	230,000	10,000	0	8,000	2,000	15,000	R18, B33.
173 Railroad Valley	2,752	4,900	......	1,240,000	52,000	S	1,000	50,000	81,000	B12.
174 Jakes Valley	422	6,400	......	240,000	17,000	8,000	25,000	0	9,800	B33.
175 Long Valley	651	6,100	100	250,000	10,000	0	8,000	2,200	16,000	R3, B33.
176 Ruby Valley	1,004	6,000	107	720,000	[3]68,000	10,800	0	53,000	33,000	B12.
177 Clover Valley	464	5,700	100	260,000	[3]21,000	0?	M	19,000	15,000	B12.
178 Butte Valley	1,010	......	100–130	......	......	......	......	......	......	R49.
A. Northern part	271	6,100	......	140,000	3,900	0	800	6,900	9,800	R49.
B. Southern part	739	6,300	......	420,000	[3]15,000	0	?	11,000	22,000	R49.
179 Steptoe Valley	1,942	5,900	119	1,200,000	[3]85,000	0	S	70,000	50,000	R42.
180 Cave Valley	362	6,100	......	220,000	[3]14,000	0	14,000	200	10,000	R13, B33.
181 Dry Lake valley	882	4,800	150	340,000	5,000	0	5,000	M	28,000	R16, B33.
182 Delamar Valley	383	4,600	150	140,000	1,000	5,000	6,000	M	12,000	R16, B33.
183 Lake Valley	557	6,000	100	290,000	13,000	0	3,000	8,500	18,000	R24.
184 Spring Valley	1,661	5,700	100	960,000	[3]75,000	2,000	4,000	70,000	42,000	R33.
185 Tippett Valley	345	5,700	110	160,000	6,900	0	7,000	0	11,000	R56.
186 Antelope Valley	395	5,600	110	170,000	4,700	3,300	7,900	100	9,900	B12, R56.
187 Goshute Valley	954	5,600	100	440,000	11,000	S	2,300	10,000	22,000	B12.
188 Independence Valley	562	5,600	100	250,000	9,300		0	9,500	18,000	B12.
225 Mercury Valley	110	3,200	......	38,000	250	16,000	17,000	0	M	R14, R54
226 Rock Valley	82	3,300	......	26,000	30	17,000	17,000	0	1,500	R14, R54.
227 Forty Mile Canyon	519	3,500	......	188,000	2,300	13,000	15,300	0	7,400	R14, R54
228 Oasis Valley	460	3,800	184	150,000	1,000	2,500	1,500	2,000	4,000	R10, R54.
229 Crater Flat	182	3,200	......	61,000	220	1,500	1,700	0	3,500	R14, R54.
230 Amargosa Desert	896	2,600	180–200	240,000	600	44,000	19,000	24,000	35,000	R14, R54.
EASTERN GREAT BASIN										
Great Salt Lake subregion										
189 Thousand Springs valley	1,446	5,600	100-110	587,000	12,300	> 18,000	>20,500	>5,700	38,000	R47.
191 Pilot Creek valley	326	4,600	110	130,000	2,400	1,000	300	4,600	11,000	R56.
194 Pleasant Valley	75	6,200	......	54,000	4,800	0	3,000	M	420	R34.
196 Hamlin Valley	413	5,800	......	260,000	10,000	4,000	10,000	400	12,000	R34.
1 Grouse Creek valley	430	4,800	132	276,000	14,000	......	2,000	11,000	1,600	T29, T42.
2 Pilot Valley	470	4,200	130	184,000	3,400	......	......	7,400	5,000	T41, T42.
3 Deep Creek valley	440	5,500	95	290,000	17,000	......	......	15,000	3,200	T24.
4 Snake Valley	2,700	4,900	152	1,420,000	44,000	30,000	10,000	69,000	107,000	T14.
5 Pine Valley		......	......	......	......	......	......	......	[5]12,000	W1475–N.
6 White Valley		......	......	......	......	......	......	......	[5]14,000	W277, W1475–N.
7 Fish Springs Flat	400	4,400	......	......	......	......	......	......	[5]12,000	W277, W1475–N.
8 Dugway Valley		......	......	......	......	......	......	......	[5]13,000	W1475–N.
9 Government Creek valley		......	......	......	......	......	......	......	[5]7,000	W1475–N.
10 Skull Valley	880	4,700	140	490,000	30,000–50,000	......	800–1,600	23,000–37,000	23,000	T18.
11 Sink Valley	150	4,400	205	54,000	1,000	......	1,000	0	3,700	T26, T42.
12 Tooele Valley	400	4,500	209	[7]200,000	100,000	Sm	......	40,000	[5]14,000	T12.

See footnotes at end of table, p. G35.

TABLE 8.—*Summary of selected ground-water resources data in the Great Basin Region*—Continued

Hydrographic area number and name[2]	Approximate area (mi²)	Approximate altitude of valley floor	Average growing season (days)	Average annual precipitation (acre-ft)	Ground-water recharge from precipitation (acre-ft/yr)[3]	Ground-water inflow (acre-ft/yr)	Ground-water out flow (acre-ft/yr)	Ground-water evapotran-spiration (acre-ft/yr)	Ground water in storage (acre-ft/ft)[4]	Report reference (See table 8 references)
EASTERN GREAT BASIN—Continued										
Great Salt Lake subregion—Continued										
13 Rush Valley	730	5,200	195	550,000	34,000	......	5,000	27,000	16,000	T23.
14 Cedar Valley	300	5,000	120	[9]151,000	24,000	......	10,000	......	[5]8,000	T16.
15 Northern Juab Valley	120	5,000	148	......	......	Sm	Sm	18,000+	[5]5,000	T17.
16 Goshen Valley	400 (16–17)	4,800	......	......	[8]30,000	Sm	4,000(?)	27,000	[9]15,000	T28. (16–17)
17 Southern Utah Lake valley		4,800	......	......	[8]120,000	......	4,000	55,000	[6] [9]7,500	
18 Northern Utah Lake valley	225	4,800	......	......	[8]150,000+	......	2,500 +	13,000+	[5] [6]8,000	T11.
19 Jordan Valley	500	4,700	......	......	[8]361,800	2,500	4,000	60,000	13,000	T31.
20 Bountiful district	450 (20–21)	4,600 (20–21)	......	......	......	......	......	......	3,000	T5, T35, P518. (20–21)
21 Weber Delta district			......	......	[8]70,000	......	......	......	26,000	
22 Heber Valley	330	5,700	......	......	[8]86,000	30,000	17,000	11,000	2,800	T27.
23 Rhodes Valley		......	......	......	[8]22,000	......	....	10,000	3,100	T27.
24 Morgan Valley		......	......	......	......	......	......	......	[5]1,000±	
25 Ogden Valley		4,900	......	......	[8]23,000+	......	2,100	1,600	[5]1,000	W796–D.
26 Promontory Mountains area	360	4,300	170	240,000	12,000	15,000	9,000	14,000	7,600	T38, T42.
27 Blue Creek valley	220	4,800	122	184,000	14,000	......	5,500	200	2,000	T37, T42.
28 Hansel Valley and northern Rozel Flat	240	4,600	122	160,000	8,000	......	1,000	7,600	650	T33, T42.
29 Pocatello Valley		5,100	......	......	......	......	......	......	[5]2,000	W333.
30 Curlew Valley	1,200	4,500	122	868,000	75,600	......	Sm	[10]34,000	[10]10,000	T25, T42.
31 Park Valley area	1,050	4,900	149	520,000	24,000	......	8,000	16,000	5,000	T30, T42.
32 Great Salt Lake Desert		......	......	......	......	......	......	......	......	W1475–N, T42.
A. Lake subarea		......	......	......	......	......	......	......	(6)	
B. Western Desert		......	......	......	......	......	......	......	[5]80,000	
Bear River subregion										
33 Evanston area		....	....	....	....	......	......	......	[5]6,000	
34 Randolf area		....	....	....	....	......	......	......	[5]9,000	
35 Smith's Fork area		6,800	....	....	....	......	......	......	[5]9,000	W1539–U.
36 Bear Lake Valley		....	....	....	....	......	......	......	[5] [6]9,000	01969.
37 Soda Springs–China Hat area		6,000	....	....	....	......	......	......	[5]4,000	01969.
38 Gem Valley–Portneur area		5,500	....	....	....	......	......	......	[5]7,000	01969.
39 Cache Valley	1,840	4,700	150	......	[7]280,000	......	Sm	......	25,000	T36.
40 Malad Valley, Idaho	485	4,600	......	......	50,000(?)	......	3,400	28,500	3,000	W1412, 01969
41 Lower Malad Valley–Bear River Bay area		....	....	....	....	3,400	......	......	[5]19,000	

Sevier Lake subregion

42 Upper Sevier River basin	2,400	6,000–7,000	60–100	......	......	......	1,000–2,000	43,500	5,000	W1836.
43 Central Sevier River basin	2,800	5,100–6,000	120	......	......	1,000–2,000	Sm	100,000	6,200	W1787.
44 Sanpete Valley	850	5,500	128	......	......	L	2,200	113,000	18,000	W1896.
45 Yuba Dam–Leamington Canyon area	900	5,000	100–135	......	......	......	2,200	......	[5]10,000	W1848.
46 Sevier Desert	3,000	4,700	149	......	[5]169,800	16,200	< 5,000	135,000–175,000	70,000	W1854.
A. Dry Lake subarea	......	......	......	......	......	......	......	......	[5]12,000	
47 Pavant Valley	800	4,700	155	......	66,000	SM	14,000	24,000	[11]31,800	W1794.
48 Beaver Valley	200	5,800	......	......	......	......	100	......	[5]4,000	T13, W217.
49 Parowan Valley	150	5,800	150	......	......	......	3,000	......	[5]8,000	T13, W993.
50 Milford Valley		......	......	......	......	......	......	......	[5]29,000	T13, W659–A.
51 Cedar City Valley	300	5,500	150	......	[9]30,000	3,000	2,100	......	[5]15,000	T13, W993.
52 Lund district		......	......	......	......	......	......	......	[5]20,000	T13.
53 Beryl-Enterprise district	400	5,200	......	......	[9]5,000	......	Sm	5,000	[5]25,000	T13, W659–A.
54 Wah Wah Valley		......	......	......	......	......	......	......	[5]8,000	W277.

[1]Tabular material for Nevada from Office of the Nevada State Engineer, 1971, Water For Nevada, Nevada's Water Resources Water Planning Report 3.
[2]In Nevada, valleys are grouped by hydrographic regions as used by the Nevada State Engineer. These regions are shown in Nevada Planning Report 3, which also shows the hydrographic area numbers used in this report. Areas in Nevada outside the Great Basin Region also have assigned numbers; this is why some numbers are missing in this table. A separate numbering system is used in areas in Utah, Idaho, and Wyoming.
[3]Most estimates of recharge are based on an empirical relationship between precipitation and ground-water recharge. Estimates preceded by a footnote indicate areas where some potential recharge may be rejected and actual recharge may be less than estimated.
[4]Determined for upper 100 feet of saturated valley fill unless noted otherwise.
[5]Estimated by the authors for use in this report.
[6]Does not include storage beneath lake areas.
[7]Includes precipitation in recharge areas only.
[8]Includes recharge from surface water originating outside the drainage basin.
[9]Estimated from determinations of storage in upper 400 feet of valley fill.
[10]Utah part of valley only.
[11]Estimated from determinations of storage in upper 500 feet of saturated valley-fill materials.

TABLE 8 REFERENCES

PUBLICATIONS OF THE U.S. GEOLOGICAL SURVEY

PROFESSIONAL PAPERS

P417–F..............A water budget for Carson Valley, Nevada: A. M. Piper, 1969.

P518..................Lake Bonneville—Geology and hydrology of the Weber Delta district, including Ogden, Utah: J. H. Feth and others, 1966.

WATER-SUPPLY PAPERS

W217.................Water resources of Beaver Valley, Utah: W. T. Lee, 1908.

W277.................Ground water in Juab, Millard, and Iron Counties, Utah: O. E. Meinzer, 1911.

W333.................Ground water in Box Elder and Tooele Counties, Utah: Everett Carpenter, 1913.

W659–A............A method of estimating ground-water supplies based on discharge by plants and evaporation from soil—Results of investigations in Escalante Valley, Utah: W. N. White, 1932.

W796–D............Geology and ground-water resources of Ogden Valley, Utah: R. M. Leggette and G. H. Taylor, 1937.

W993.................Geology and ground-water resources of Cedar City and Parowan valleys, Iron County, Utah: H. E. Thomas and G. H. Taylor, 1946.

W1228...............Geology and water resources of Smith Valley, Lyon and Douglas Counties, Nevada: O. J. Loeltz and T. E. Eakin, 1953.

W1412...............Water consumption by water-loving plants in the Malad Valley, Oneida County, Idaho: R. W. Mower and R. L. Nace, 1957.

W1475–N..........Hydrology and stock-watering development on the public domain of western Utah: C. T. Snyder, 1963.

W1539–U..........Availability of ground water in the Bear River valley, Wyoming: C. J. Robinove and D. W. Berry, *with a section on chemical quality of the water*, by J. G. Connor, 1963.

W1779...............Evaluation of hydrogeology and hydrochemistry of Truckee Meadows area, Washoe County, Nevada: Philip Cohen and O. J. Loeltz, 1964.

W1787...............Ground-water conditions and storage in the central Sevier Valley, Utah: R. A. Young and C. H. Carpenter, 1965.

W1794...............Ground-water resources of Pavant Valley, Utah: R. W. Mower, 1965.

W1832...............Hydrology of the valley fill and carbonate-rock reservoirs, Pahrump Valley, Nevada–California: G. T. Malmberg, 1967.

W1836...............Ground-water conditions and geologic reconnaissance in the upper Sevier River basin, Utah: C. H. Carpenter, G. B. Robinson, Jr., and L. B. Bjorklund, 1967.

W1848...............Ground-water resources of the Sevier River basin between Yuba Dam and Leamington Canyon, Utah: L. J. Bjorklund and G. B. Robinson, Jr., 1968.

W1854............... Ground-water hydrology of the Sevier Desert, Utah: R. W. Mower and R. D. Feltis, 1968.

W1896...............Ground-water hydrology of the San Pitch River drainage basin, Sanpete County, Utah: G. B. Robinson, Jr., 1971.

W1972...............The Lake Tahoe Basin, California-Nevada: J. R. Crippen and B. R. Pavelka, 1970.

OPEN-FILE REPORTS

O1969................Availability of ground water for large-scale use in the Malad Valley-Bear River areas of southeastern Idaho—An initial assessment: W. L. Burnham, A. H. Harder, and N. P. Dion, 1969.

PUBLICATIONS OF THE NEVADA DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES

WATER RESOURCES—RECONNAISSANCE SERIES

R1......................Newark Valley: T. E. Eakin, 1960.
R2......................Pine Valley: T. E. Eakin, 1961.
R3......................Long Valley [White Pine County]: T. E. Eakin, 1961.
R4......................Pine Forest Valley: W. C. Sinclair, 1962.
R5......................Imlay area: T. E. Eakin, 1962.
R6......................Diamond Valley: T. E. Eakin, 1962.
R7......................Desert Valley: W. C. Sinclair, 1962.
R9......................Gabbs Valley: T. E. Eakin, 1962.
R10....................Sarcobatus Flat and Oasis Valley: G. T. Malmberg and T. E. Eakin, 1962.
R11....................Hualapai Flat: W. C. Sinclair, 1962.
R12....................Ralston and Stonecabin Valleys: T. E. Eakin, 1962.
R13....................Cave Valley: T. E. Eakin, 1962.
R14....................Amargosa Desert: G. E. Walker and T. E. Eakin, 1963.
R15....................Long Valley—Massacre Lake region: W. C. Sinclair, 1963.
R16....................Dry Lake and Delamar Valleys: T. E. Eakin, 1963.
R17....................Duck Lake Valley: W. C. Sinclair, 1963.
R18....................Garden and Coal Valleys: T. E. Eakin, 1963.
R19....................Antelope and Middle Reese River Valleys: E. G. Crosthwaite, 1963.
R20....................Black Rock Desert area: W. C. Sinclair, 1963.
R22....................Pueblo Valley—Continental Lake region: W. C. Sinclair, 1963.
R23....................Dixie—Fairview Valley area: Philip Cohen and D. E. Everett, 1963.
R24....................Lake Valley: F. E. Rush and T. E. Eakin, 1963.
R26....................Edwards Creek Valley: D. E. Everett, 1964.
R28....................Smith Creek and Ione Valleys: D. E. Everett and F. E. Rush, 1964.
R29....................Grass Valley [Pershing County]: Philip Cohen, 1964.
R30....................Monitor, Antelope, and Kobeh Valleys: F. E. Rush and D. E. Everett, 1965.

The following reports are water-resources appraisals of the specified areas.

R31....................Upper Reese Valley: T. E. Eakin, D. O. Moore, and D. E. Everett, 1965.
R32....................Lovelock Valley: D. E. Everett and F. E. Rush, 1965.
R33....................Spring Valley: F. E. Rush and S. A. T. Kazmi, 1965.
R34....................Snake Valley area: J. W. Hood and F. E. Rush, 1965.
R35....................Huntington Valley area: F. E. Rush and D. E. Everett, 1965.
R36....................Eldorado-Piute Valley area: F. E. Rush and C. J. Huxel, Jr., 1966.
R37....................Grass and Carico Lake Valleys: D. E. Everett and F. E. Rush, 1966.
R38....................Little Fish Lake, Hot Creek, and Little Smoky Valleys: F. E. Rush and D. E. Everett, 1966.
R39....................Eagle Valley: G. F. Worts, Jr. and G. T. Malmberg, 1966.
R40....................Walker Lake area: D. E. Everett and F. E. Rush, 1967.
R41....................Washoe Valley: F. E. Rush, 1967.
R42....................Steptoe Valley: T. E. Eakin and J. L. Hughes, 1967.
R43....................Warm Springs-Lemmon Valley area: F. E. Rush and P. A. Glancy, 1967.
R44....................Smoke Creek and San Emidio Deserts: P. A. Glancy, 1967.
R45....................Clayton Valley-Stonewall Flat area: F. E. Rush, 1968.
R46....................Mesquite-Ivanpah Valley area: P. A. Glancy, 1968.
R47....................Thousand Springs Valley: F. E. Rush, 1968.
R49....................Butte Valley, P. A. Glancy: 1968.
R52....................Columbus Salt Marsh-Soda Spring Valley area: A. S. Van Denburgh and P. A. Glancy, 1970.
R53....................Antelope Valley and East Walker River area: P. A. Glancy, 1971.
R54....................The Nevada test site area: F. E. Rush, 1971.
R55....................Granite Springs Valley area: J. R. Harrill, 1971.
R56....................Pilot Creek area: J. R. Harrill, 1971.
R57....................Truckee River basin: A. S. Van Denburgh, R. D. Lamke, and J. L. Hughes, 1973.
R59....................Carson River basin: P. A. Glancy and T. L. Katzer, 1976 (in press).

WATER-RESOURCES BULLETINS

B11....................Preliminary report on ground water in the Fish Lake Valley, Nevada and California: T. E. Eakin, 1950.
B12....................Contributions to the hydrology of eastern Nevada: T. E. Eakin, G. B. Maxey, T. W. Robinson, J. C. Fredericks, and O. J. Loeltz, 1951.
B13....................Geology and ground-water resources of Buena Vista Valley, Pershing County, Nevada: O. J. Loeltz and D. A. Phoenix, 1955.
B15....................Ground-water potentialities in the Crescent Valley, Eureka and Lander Counties, Nevada: C. P. Zones, 1961.
B17....................Ground-water conditions in the Fernley-Wadsworth area, Churchill, Lyon, Storey, and Washoe Counties, Nevada: W. C. Sinclair and O. J. Loeltz, 1963.
B19....................Preliminary results of hydrogeochemical studies in the Humboldt River Valley near Winnemucca, Nevada: Philip Cohen, 1962.
B20....................A summary of specific-yield and particle-size relation of Quaternary alluvium, Humboldt River valley, Nevada: Philip Cohen, 1963.
B22....................Preliminary results of hydrogeologic investigations in the valley of the Humboldt River near Winnemucca, Nevada: Philip Cohen, 1964.
B24....................An evaluation of the water resources of the Humboldt River valley near Winnemucca, Nevada: Philip Cohen, 1963.
B27....................Water in the Humboldt River valley near Winnemucca, Nevada: Philip Cohen, 1964.
B31....................The effects of pumping on the hydrology of Kings River valley, Humboldt County, Nevada, 1957-64: G. T. Malmberg and G. F. Worts, Jr., 1966.
B32....................Hydrologic reconnaissance of the Humboldt River basin, Nevada: T. E. Eakin and R. D. Lamke, 1966.
B33....................A regional interbasin ground-water system in the White River area, southeastern Nevada: T. E. Eakin, 1966.
B34....................Effects of irrigation development on the water supply of Quinn River Valley area, Nevada and Oregon, 1950-64: C. J. Huxel, Jr. 1966.
B35....................Hydrologic response to irrigation pumping in Diamond Valley, Eureka and Elko Counties, Nevada, 1950-65: J. R. Harrill, 1968.
B37....................Hydrologic response to irrigation pumping in Hualapai Flat, Washoe, Pershing, and Churchill Counties, Nevada, 1960-67: J. R. Harrill, 1969.

B38 .... Water resources and development in Mason Valley, Lyon County, Nevada, 1948-65: C. J. Huxel, 1969.

B39 .... Effects of pumping ground water in Paradise Valley on the hydrologic regimen of the Little Humboldt River basin, Humboldt and Elko Counties, Nevada: J. R. Harrill, 1970.

B41 .... Water-resources of Big Smokey Valley, Lander, Nye, and Esmeralda Counties, Nevada: F. E. Rush and C. V. Schroer, 1970.

PUBLICATIONS OF THE UTAH DEPARTMENT OF NATURAL RESOURCES (DIVISION OF WATER RIGHTS)

TECHNICAL PUBLICATIONS

T5 .... Ground water in the East Shore area, Utah, Part 1, Bountiful district, Davis County: H. E. Thomas and W. B. Nelson, 1948. (In Utah State Engineer 26th Bienn. Rept., p. 53-206).

T11 .... Ground water in northern Utah Valley, Utah—A progress report for the period 1948-63: R. M. Cordova and Seymour Subitzky, 1965.

T12 .... Reevaluation of the ground-water resources of Tooele Valley, Utah: J. S. Gates, 1965.

T13 .... Ground-water resources of selected basins in southwestern Utah: G. W. Sandberg, 1966.

T14 .... Water-resources appriasal of the Snake Valley area, Utah and Nevada: J. W. Hood and F. E. Rush, 1965.

T16 .... Ground-water conditions in Cedar Valley, Utah County, Utah: R. D. Feltis, 1967.

T17 .... Ground-water resources of northern Juab Valley, Utah: L. J. Bjorklund, 1967.

T18 .... Hydrologic reconnaissance of Skull Valley, Tooele County, Utah: J. W. Hood and K. M. Waddell, 1968.

T23 .... Hydrologic reconnaissance of Rush Valley, Tooele County, Utah: J. W. Hood, Don Price, and K. M. Waddell, 1969.

T24 .... Hydrologic reconnaissance of Deep Creek valley, Tooele and Juab Counties, Utah, and Elko and White Pine Counties, Nevada: J. W. Hood and K. M. Waddell, 1969.

T25 .... Hydrologic reconnaissance of Curlew Valley, Utah and Idaho: E. L. Bolke and Don Price, 1969.

T26 .... Hydrologic reconnaissance of Sink Valley, Tooele and Box Elder Counties, Utah: Don Price and E. L. Bolke, 1970.

T27 .... Water resources of the Heber-Kamas Park City area, north-central Utah: C. H. Baker, Jr., 1970.

T28 .... Ground-water conditions in southern Utah Valley and Goshen Valley, Utah: R. M. Cordova, 1970.

T29 .... Hydrologic reconnaissance of Grouse Creek valley, Box Elder County, Utah: J. W. Hood and Don Price, 1970.

T30 .... Hydrologic reconnaissance of the Park Valley area, Box Elder County, Utah: J. W. Hood, 1971.

T31 .... Water resources of Salt Lake County, Utah: A. G. Hely, R. W. Mower, and C. A. Harr, 1971.

T33 .... Hydrologic reconnaissance of Hansel Valley and northern Rozel Flat, Box Elder County, Utah: J. W. Hood, 1971.

T35 .... Ground-water conditions in the East Shore area, Box Elder, Davis, and Weber Counties, Utah: E. L. Bolke and K. M. Waddell, 1972.

T36 .... Ground-water resources of Cache Valley, Utah and Idaho: L. J. Bjorklund and L. J. McGreevy, 1971.

T37 .... Hydrologic reconnaissance of the Blue Creek Valley area, Box Elder County, Utah: E. L. Bolke and Don Price, 1972.

T38 .... Hydrologic reconnaissance of the Promontory Mountains area, Box Elder County, Utah: J. W. Hood, 1976 (in press).

T41 .... Hydrologic reconnaissance of Pilot Valley, Utah and Nevada: J. C. Stephens and J. W. Hood, 1973.

T42 .... Hydrologic reconnaissance of the northern Great Salt Lake Desert and summary hydrologic reconnaissance of northwestern Utah: Jerry C. Stephens, 1974.

☆ U.S. Government Printing Office: 1977-777-034/3