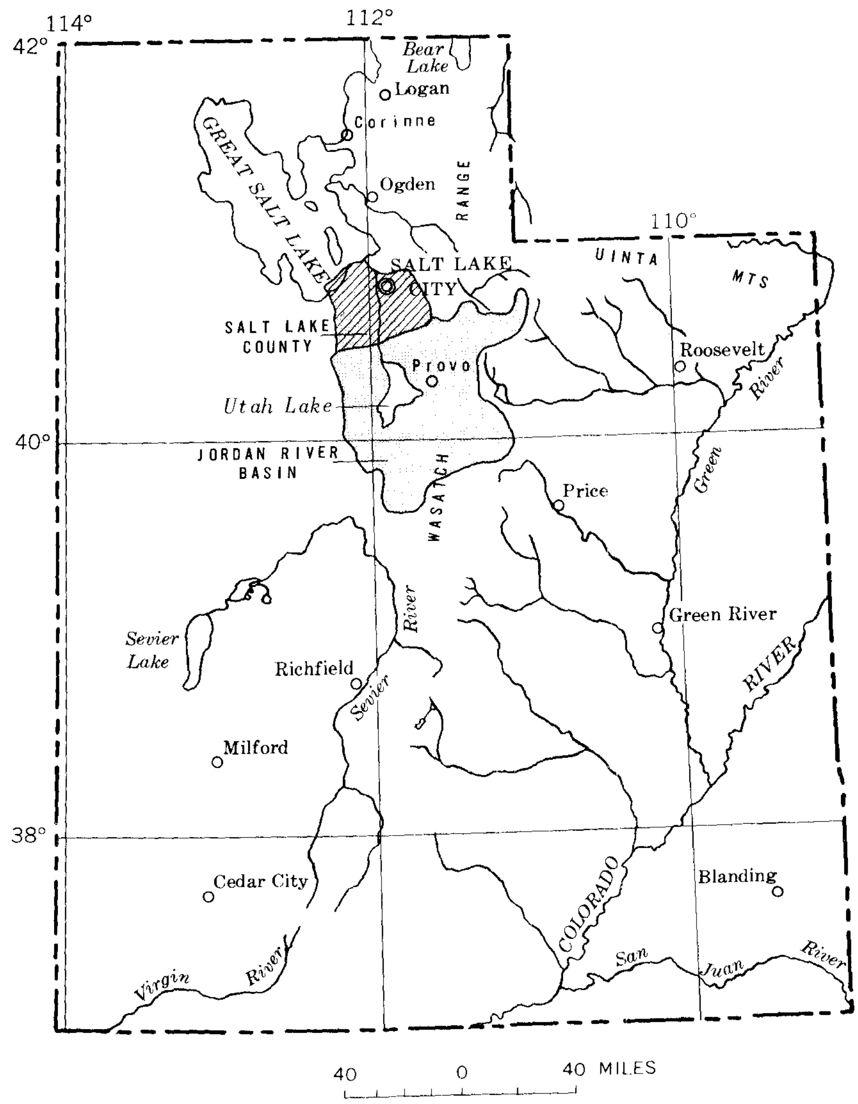

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STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

Technical Publication No. 34

SUMMARY OF WATER RESOURCES OF SALT LAKE COUNTY, UTAH

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Prepared by the U.S. Geological Survey
In cooperation with
The Utah Department of Natural Resources
Division of Water Rights

1971

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ABSTRACT

This report is a summary of a comprehensive report[1] on the present water resources of Salt Lake County, Utah, and the potential for additional development.

The average total annual withdrawals from surface and underground sources during 1964-68 were about 580,000 acre-feet for all uses that deplete the supply, except that used for maintenance of waterfowl-management areas. The withdrawals projected for the year 2020 are 1,200,000 acre-feet. The maximum annual firm supply that can be derived from the sources now available is about 700,000 acre-feet, of which about 200,000 acre-feet would be derived from subsurface sources. Achievement of this annual yield would require nearly complete regulation of streamflow that now is practically unregulated, larger drawdowns of ground-water levels than have been experienced, and overall management of surface and subsurface sources as parts of a single resource.

INTRODUCTION

The steady growth of population and industry in Salt Lake County has been accompanied by ever-increasing demands for water. Although the task of providing adequate supplies has been a recurring problem for more than a century, large quantities of usable water still are discharged to Great Salt Lake and additional quantities are lost by evapotranspiration[2] of ground water in low-lying areas. Eventually the county will need to make the maximum feasible use of its water resources to meet the increased water requirements.

To make the most effective decisions regarding future water supplies, the various governmental units and water districts operating within the county will need detailed information concerning present water resources and the changes that would result from more intensive use. Recognizing this need, Federal, State, and local organizations entered into an agreement for the U.S. Geological Survey to investigate and report on the county's water resources. The investigation began in 1963 and was completed in 1970.

This report summarizes the physical aspects of the present water situation, some of the related human aspects, and possibilities for more intensive use of the local water resources for those who wish to be informed but do not wish to pursue the many details required for a complete appraisal. A more comprehensive report on the investigation (including a list of references) has been prepared by the writers of this report[1].

[1] Hely, A.G., Mower, R.W., and Harr, C.A., 1971, Water resources of Salt Lake County, Utah: Utah Dept. Nat. Resources Tech. Pub. 31.

[2] See appendix for explanations of selected hydrologic terms and acknowledgments.

Decisions regarding the development of water supplies involve far more than physical aspects of the supplies. Legal, economic, social, aesthetic, ecological, and engineering considerations all play important roles that are mostly beyond the scope of this report. Consequently, no statement herein should be considered an unqualified recommendation for a particular course of action.

THE PHYSICAL SETTING AND CLIMATE

Salt Lake County covers 780 square miles in the lower part of the Jordan River basin (fig. 1). The Jordan River enters the county at Jordan Narrows, a gap in the Traverse Mountains which mark the southern boundary. The county boundary follows natural drainage divides from that point to Great Salt Lake except for a few miles north of Salt Lake City, where it follows the Jordan River.

The valley of the Jordan River from Jordan Narrows to Great Salt Lake, known as Jordan Valley or Salt Lake Valley, covers about 500 square miles of the county and is the most populous and industrialized area in Utah. It is also one of the most productive agricultural areas of the State. The altitude of the valley floor ranges from about 4,200 feet above mean sea level at Great Salt Lake to about 5,200 feet where it meets the bordering mountains.

East of the Jordan Valley the Wasatch Range rises abruptly to altitudes of more than 11,000 feet, and west of the valley the Oquirrh Mountains rise to more than 9,000 feet. The mountainous areas are sparsely populated, but they exert powerful influences on the climate and the water resources of the entire county.

Most of the precipitation occurs during the cold months in storms that originate in the north Pacific Ocean and move generally eastward across the continent. As the masses of moist air move up the western slopes of mountain ranges, the precipitation tends to increase; and as they move down the eastern slopes, the precipitation decreases sharply. The normal annual (average for 1931-60) precipitation in Salt Lake County ranges from about 12 inches in the south-central part of Jordan Valley to the more than 60 inches in the highest parts of the Wasatch Range (see fig. 2).

Most of the precipitation in the mountains occurs as snow, which accumulates throughout the winter and melts during the spring and summer. The snowmelt produces abundant flow in several streams draining the Wasatch Range but very little flow in streams draining the Oquirrh Mountains. Both mountain ranges, however, absorb large quantities of the snowmelt and much of the absorbed water migrates slowly toward Jordan Valley through openings (pore spaces, bedding planes, fractures, and solution channels) in the bedrock.

Precipitation on the valley is very erratic during the growing season. Although the moisture supply usually is sufficient for growing some hay and grain crops on dry farms, irrigation is required for the successful production of others, especially fruits and vegetables.

Deposits of loose gravel, sand, silt, and clay form the floor of Jordan Valley and locally attain depths of more than 2,000 feet. This unconsolidated valley fill is saturated with water to within a few hundred feet of the surface near the edges of the valley. In a few low-lying areas near the center of the valley and at the north end the fill is saturated up to the surface.

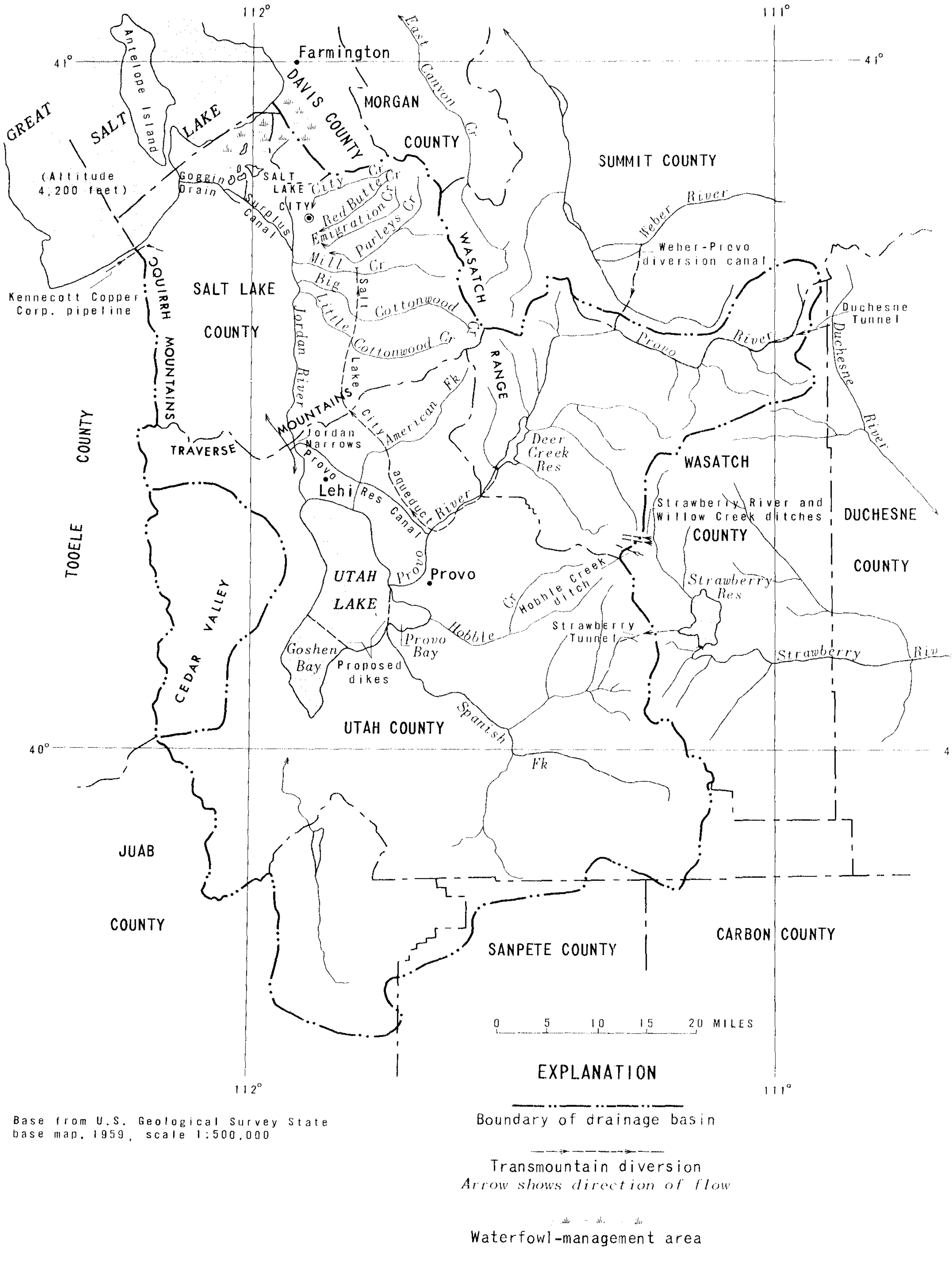

Figure 1.—Map of Jordan River basin.

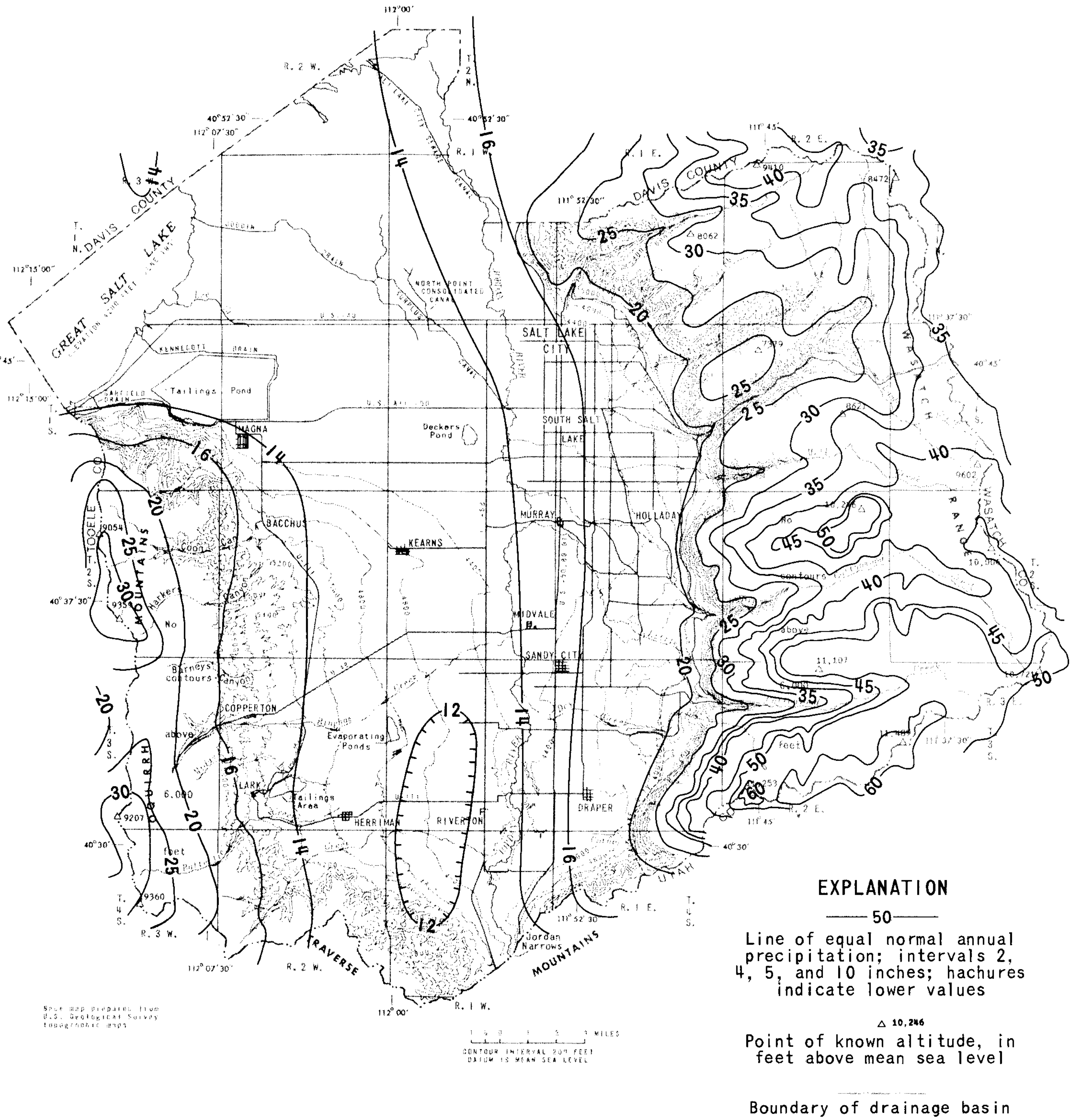

Figure 2.—Map showing normal annual precipitation in Salt Lake County.

SOURCES OF WATER SUPPLY

Nearly all the requirements for water in Salt Lake County (aside from the consumption of water by the native vegetation on mountain ranges) are for water used in Jordan Valley. Four distinct sources for the valley (in addition to the precipitation on the valley floor, which averaged 464,000 acre-feet per year during 1964-68) are designated for convenience, although they are not independent: (1) the Jordan River, (2) major creeks draining the Salt Lake County part of the Wasatch Range, (3) imports by pipeline and canal, and (4) the saturated valley fill (the ground-water reservoir). There are many interchanges of water between streams and the ground-water reservoir and also between some streams and pipelines or canals. Consequently, the quantities representing these sources should not be combined, except in special circumstances when no duplications are involved.

Jordan River

All major tributary streams in the Jordan River basin south of Jordan Narrows discharge into Utah Lake after their flows have been depleted by numerous diversions for irrigation, municipal, and industrial uses. The flow of three tributaries is augmented by transmountain diversions from the Duchesne and Strawberry Rivers in the Colorado River basin; and the flow of the largest tributary (Provo River) is augmented by a transmountain diversion from the Weber River also (see fig. 1).

The outflow from Utah Lake is regulated, in accordance with the demand for water from the Jordan River, by gates in the outlet channel (head of Jordan River), and by pumping from the lake when the natural outflow is less than the demand. However, water cannot be retained in the lake by artificial means above a "compromise level" agreed to in 1885 by water users in Salt Lake County and owners of property on the lakeshore in Utah County.

Evaporation consumes a substantial part of the water stored in any lake, but it consumes an unusually large proportion of the water in Utah Lake because the lake is shallow and the surface area is very large in relation to the volume. The evaporation exceeds the outflow in Jordan River during most years.

Between Utah Lake and Salt Lake City, the Jordan River gains substantial quantities of water by seepage from the saturated valley fill as well as by inflow from tributaries, and it loses water by numerous diversions. The largest diversions from the river are made in Jordan Narrows or a few miles to the north. Nearly all the water remaining in the river at 9400 South (about 9 miles north of the narrows, fig. 2) is diverted at that point, except when extra water is released from Utah Lake to prevent flooding of property on its shore. The inflow to the river north of 9400 South is sufficient to meet the current requirements for water from the lower part of the stream. The average flow at 2100 South (fig. 2) in Salt Lake City is only slightly less than the flow at Jordan Narrows.

The annual flows of Jordan River upstream from the diversions at Jordan Narrows fall within the relatively narrow range of 180,000-300,000 acre-feet during most years because of the regulated outflow from Utah Lake. However, during 1922 the annual flow was 640,000 acre-feet and during 1935 it was only 76,000 acre-feet. (Utah Lake was nearly dry at times during 1934 and 1935.) The average annual flow during 1943-67[1] was 253,200 acre-feet.

[1] The period ending in 1967, rather than 1968, was used for several averages because some of the analyses were completed before the 1968 records were available.

At 2100 South in Salt Lake City, the flow of Jordan River is divided between the river channel and the Surplus Canal (fig. 2), which was constructed chiefly to divert floods away from the city but also serves to distribute water to some users. Surplus water is routed through the canal and Goggin Drain to Great Salt Lake, but the combined capacity of the river and canal is not great enough for large floods such as the one that occurred in 1952. The average annual flow of the Jordan River upstream from the Surplus Canal was 227,900 acre-feet during 1943-67.

A large, marshy area at the mouth of Jordan River has been altered by dikes and weirs to convert it from a natural marsh with a highly variable water supply to a group of public and private waterfowl-management areas with a more stable supply. Water in the river channel flows or is diverted into these management areas, some of the water in the Surplus Canal is diverted to them, and small streams in Davis County contribute an undetermined amount. Precipitation and upward seepage of ground water also contribute to their water supply. Water that is not consumed is discharged to Great Salt Lake.

The Jordan River is by far the largest of the surface-water sources available in Jordan Valley; but its use is restricted to irrigation and industries that do not require water of good quality. Throughout its length the river is turbid, polluted by municipal and industrial wastes, and characterized by high concentrations of dissolved solids. Concentrations generally are about 1,000 mg/l (milligrams per liter) or higher—far above the generally recommended limit of 500 mg/l for municipal supplies. These concentrations are higher than is desirable but not excessive for irrigation. Pollution by municipal and industrial waste generally is greater in the lower part of the river than in the upper part (near Jordan Narrows), and water from the lower part is used chiefly for maintenance of waterfowl-management areas and irrigation.

The diversion of practically all flow of the Jordan River at or above 9400 South during most years indicates a fairly high degree of utilization of the river. However, the large loss by evaporation from Utah Lake, the occasional release of water from the lake when it is not needed, and the continuing discharge of usable water (mostly from inflow below 9400 South) to Great Salt Lake indicate less than maximum utilization within the Jordan River basin.

Salvage of some water now lost by evaporation or discharge to Great Salt Lake might be achieved by additional regulation of the upper Jordan River or tributaries to Utah Lake or by reduction of the evaporation from Utah Lake. More water could be salvaged by regulation of tributary streams in Salt Lake County and by management of the water in the valley fill to reduce unwanted inflow to the river. The last two methods of salvage are considered further in following discussions of Wasatch streams and water in the valley fill.

Wasatch streams

About 85 percent of the streamflow from the Wasatch Range within Salt Lake County is included in the flow of six streams—Little Cottonwood, Big Cottonwood, Mill, Parleys, Emigration, and City Creeks. The flow varies greatly from month to month and also from year to year. Melting snow during the spring or early summer produces a large part of the annual flow, and seepage from the ground produces a smaller but more uniform flow. The low flows are insufficient to meet current demands, especially in late summer and early fall, and the high flows exceed the demands. The most effective use of streamflow generally requires storage of surplus water in reservoirs for later use during periods of low flow. By 1970, however, only a few thousand acre-feet of storage capacity in surface reservoirs has been provided for regulation of the Wasatch streams.

The average annual flow in the six streams at the canyon mouths (east edge of Jordan Valley) during 1943-67 was 135,600 acre-feet. For individual years within this period the flows ranged from 65,820 to 219,900 acre-feet. Both higher and lower flows were recorded before 1943. About two-thirds of the total flow in the six streams is in Little Cottonwood and Big Cottonwood Creeks.

The chemical quality of the water in the upper reaches of all Wasatch streams is good. The concentrations of dissolved solids generally are less than 500 mg/l, and the concentrations in water from the two Cottonwood Creeks generally are less than 200 mg/l. The most undesirable feature is the hardness. Softening generally is desirable for uses such as laundering.

All but the smallest streams in the Salt Lake County part of the Wasatch Range are used for municipal, domestic, or irrigation supplies, and some are used for all three. The average annual withdrawal from the six streams previously named during the moderately wet period 1964-68 was 93,700 acre-feet (table 1) or 69 percent of the corresponding streamflow (including diversions) at the canyon mouths (135,600 acre-ft). If all this streamflow had been regulated, the average annual withdrawal could have been about 120,000 acre-feet, except during periods of extreme drought (such as 1934-36) when it would be slightly less.

The present (1971) storage capacity in surface reservoirs is less than 5,000 acre-feet, which provides only short-term regulation of flow in a few streams. The proposed Little Dell Reservoir, authorized in 1968, will provide about 50,000 acre-feet of capacity for long-term regulation of streamflow from parts of Mill, Parleys, and Emigration Creek basins. However, this will leave more than 80 percent of the streamflow from the Wasatch Range unregulated. Other reservoirs have been proposed to regulate the flow of Little Cottonwood, Big Cottonwood, and City Creeks.

Imports

As used in this report, an import means a water supply derived from sources outside the natural drainage basin of the Jordan River or a supply that reaches Salt Lake County by unnatural route. The county imports water from Deer Creek Reservoir, on the Provo River in Wasatch County (fig. 1), from the Provo River downstream from the reservoir, and from springs in Tooele Valley west of the Oquirrh Mountains.

Some of the water from Deer Creek Reservoir that was available for municipal use in Salt Lake County but not delivered for such use was delivered instead through canals for irrigation in the county.

Rights to water stored in Deer Creek Reservoir are subject to prior rights. If inflow during a particular year is more than sufficient to fill the reservoir, carryover-storage priveleges may be nullified. Consequently, the reservoir does little to fulfill Salt Lake County's need for storage to provide long-term regulation of its water supply.

A diversion from Provo River downstream from the reservoir also bypasses the natural route into Salt Lake County and is used for irrigation. The annual diversion ranged from 4,600 to 34,400 acre-feet and averaged 22,100 acre-feet during 1957-67. There are no records for years prior to 1957.

The flow of three groups of springs near the base of the Oquirrh Mountains in Tooele Valley is imported by pipeline for industrial use in the Garfield-Magna area in Salt Lake County. The average annual flow is about 10,700 acre-feet.

The sources of present and potential imports to Salt Lake County are subject to the effects of severe drought (such as that of the early 1930's) at the same time as are the streams within Salt Lake County. Consequently, a source that is less affected by drought is especially desirable. The huge reserve of water stored in the valley fill is such a source.

Most of the water stored in Deer Creek Reservoir is supplied by the transmountain diversions from the Colorado and Weber River basins, because the natural flow of the Provo River was largely appropriated for use before construction of the reservoir.

The quality of the water in both the river and the reservoir is similar to that of water in the Wasatch streams in Salt Lake County. The quality of the water imported for municipal use is preserved by transporting it in a pipeline (Salt Lake City aqueduct) instead of allowing it to follow its natural course through Provo River, Utah Lake, and Jordan River.

The Metropolitan Water District of Salt Lake City is allotted 61,700 acre-feet of water from Deer Creek Reservoir for municipal use each year, except for drought years when less water is available. For example, only 18,600 acre-feet was allotted for such use from the current annual yield during the drought year of 1961. Delivery of water from the reservoir began in 1951; but if the reservoir had been in operation as early as 1943, the average annual allotment for 1943-67 would have been 59,000 acre-feet. The average annual delivery to the county through the Salt Lake City aqueduct during 1964-68 was 14,500 acre-feet, including 1,000 acre-feet that leaked from the aqueduct or was spilled to Little Cottonwood Creek.

The actual delivery of water from Deer Creek Reservoir through the aqueduct was less than 24 percent of the 61,700 acre-feet per year available to the Metropolitan Water District during 1964-68. This import probably will increase as the need arises until it equals the total allotment.

Water in the valley fill

Ground water occurs in subsurface materials throughout Salt Lake County; but only the water in the valley fill is a major source for wells.

In mountainous areas some of the ground water escapes to the atmosphere by evapotranspiration (where ground water is near the land surface); some seeps into stream channels and flows to Jordan Valley; and the rest moves downward and laterally through openings in the bedrock into the valley fill. Thus, like surface water, most of the ground water eventually reaches the valley.

In Jordan Valley, the unconsolidated fill consists of various deposits, ranging from coarse sand and gravel to fine silt and clay, resting on a bed of semiconsolidated deposits or solid rock. All the unconsolidated valley fill that is saturated is included in the ground-water reservoir of Jordan Valley. Although the underlying rocks also contain water, they generally yield only minor amounts to wells and are not considered part of the reservoir.

Water moves readily through the deposits of sand and gravel but moves extremely slowly through the deposits of silt and clay, even though the silt and clay may contain as much water as the sand and gravel. In much of the valley fill, permeable beds of sand and gravel alternate with much less permeable beds of fine materials, and the arrangement of the beds affects the behavior of water in the fill.

In northern and central parts of Jordan Valley, a segment of the valley fill 40 to 100 feet thick and 50 to 150 feet beneath the land surface contains many beds of low permeability that act collectively as a single bed and retard the vertical movement of water. Hence, the segment tends to confine water in the aquifer beneath it and is designated the confining bed. Because this bed divides the more permeable fill into segments, each of which is characterized by a different pattern of water movement, several distinct aquifers within the reservoir are recognized. The relation of the confining bed to the individual aquifers is illustrated by the highly generalized diagram (fig. 3) of a block of valley fill and the adjacent mountain range.

The approximate areal extent of the aquifers (described below) is shown in figure 4. The confining bed occurs in the areas designated as confined and shallow unconfined aquifers and also in the area designated as perched aquifer. The actual boundary between the confined and the deep, unconfined aquifer is not precisely known, and it changes with changing rates of recharge and discharge.

Near the mountains at the edges of Jordan Valley (except at the north end of the Oquirrh Mountains) there is no effective confining bed, and the top of the saturated zone (generally known as the water table) is a few hundred feet below the land surface. Hence, this segment of the saturated valley fill is a deep unconfined aquifer (see right well in fig. 3). Water enters the aquifer by percolation from the land surface and from openings in the adjoining bedrock beneath the mountains. It leaves by downward and lateral movement to areas of lower altitude near the center and northern end of the valley and by pumping from wells.

Near the center of the valley, all the valley fill beneath the confining bed is saturated. Although this segment of the fill consists of many beds with differences in permeability, the beds act collectively as a single aquifer. Water moves into this aquifer from higher altitudes in the adjoining unconfined aquifer described above; and the escape of water is retarded by the confining bed. Consequently, the water is under pressure, and this segment is a deep confined or artesian aquifer. In a well that taps this aquifer, the water rises above the base of the confining bed (see middle well in fig. 3), and in places water may rise above the land surface so that wells flow without pumping (see left well in fig. 3). The level to which the water rises is the potentiometric surface. Note that the potentiometric surface of the confined aquifer and the water table of the adjoining unconfined aquifer together form a continuous surface. Water leaves the confined aquifer by upward leakage through the confining bed or by withdrawal from wells. The leakage is very slow because of the low permeability of the confining bed, but nevertheless it is substantial because of the large area.

Because nearly all the water in the confined aquifer comes from the adjoining unconfined aquifer, these two aquifers together may be regarded as a single unit, which is designated the principal aquifer of Jordan Valley.

The valley fill above the confining bed is saturated to various depths—in places to the land surface. Water enters this shallow unconfined aquifer by percolation from the land surface and by upward leakage from the confined aquifer. It escapes naturally by seepage to springs, streams,

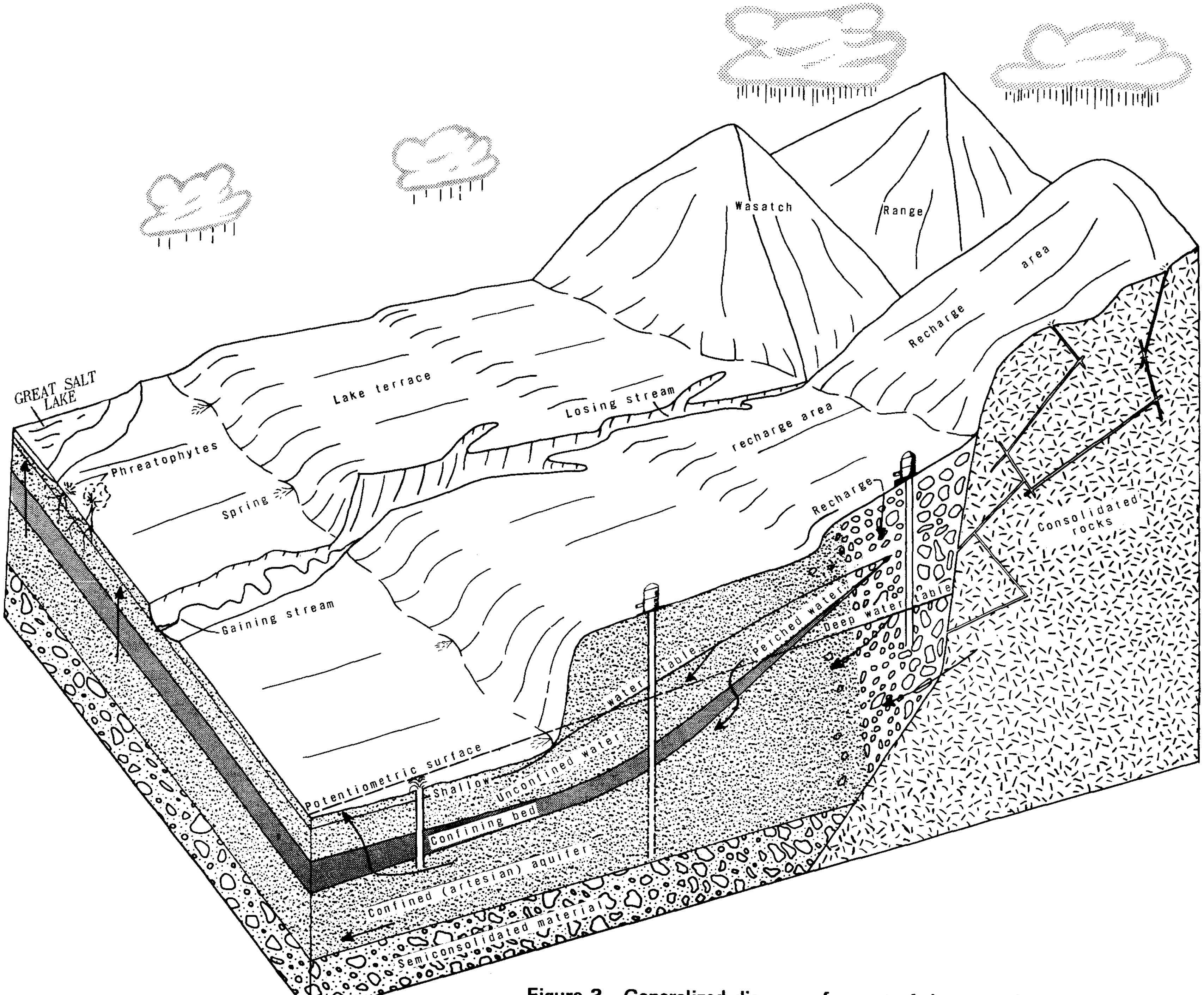

Figure 3.—Generalized diagram of a part of the ground-water reservoir in Jordan Valley.

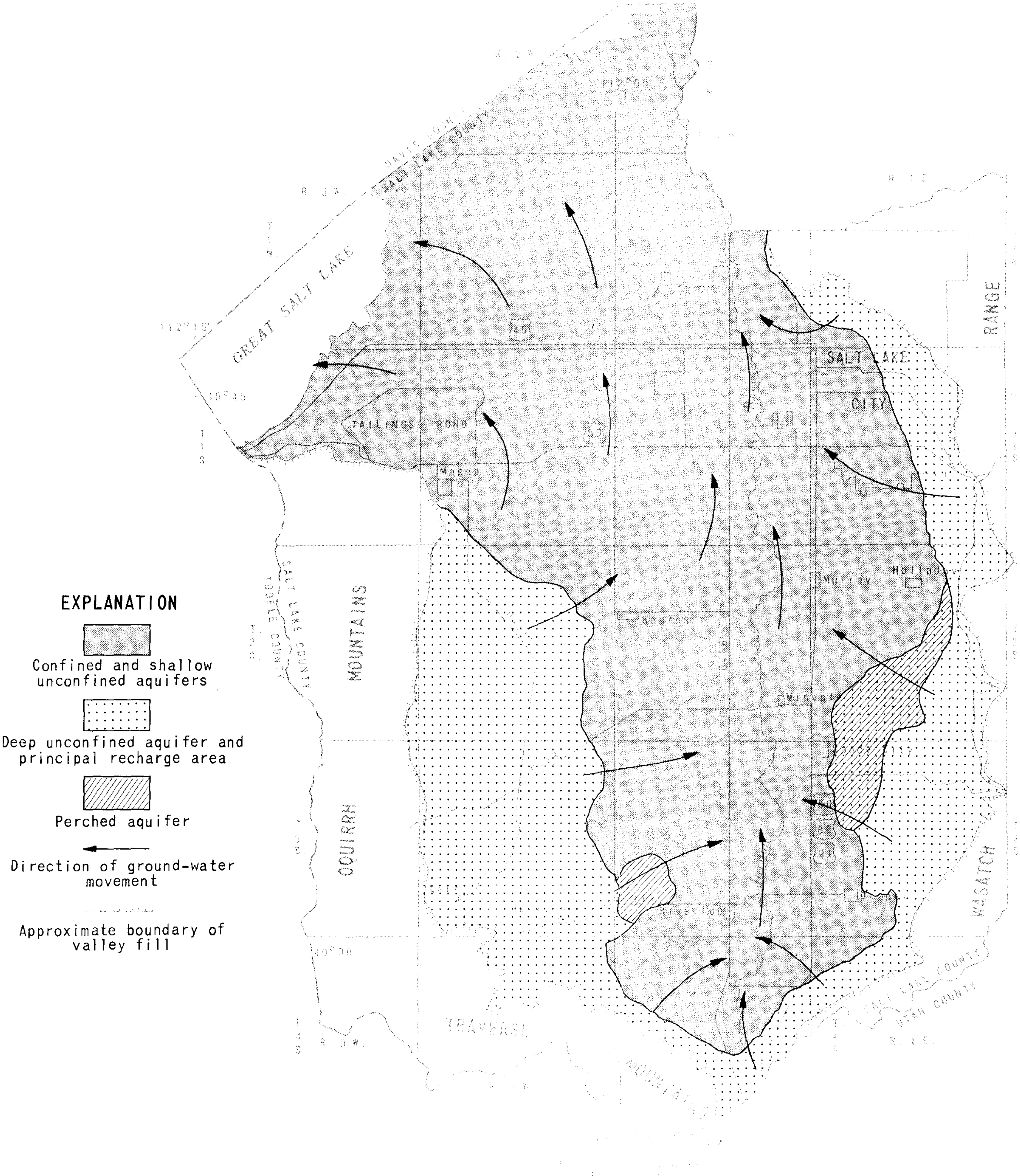

Figure 4.—Map showing approximate extent of various aquifers in Jordan Valley.

and lakes. Seepage from this shallow aquifer supplies much of the flow of the Jordan River below 9400 South (fig. 2). Also, large quantities of water are lost from the aquifer by evapotranspiration where the water table is within about 15 feet of the land surface. Loss by transpiration occurs even where the water table is beyond reach of most plant roots because capillary forces hold water against the pull of gravity to various heights above the water table in a capillary fringe. When plant roots absorb water from the fringe, capillary forces lift additional water from the saturated zone to replace it. Although some water is pumped from shallow wells, the aquifer is little used for water supply because larger yields of better water generally can be obtained from wells that tap the confined aquifer.

In some areas where the bottom of the confining bed lies above the deep water table (fig. 3), water is perched on top of the bed. Thus, an unsaturated zone exists between the deep water table and the body of perched water above it. Although water moves slowly down through the beds of fine-grained materials supporting the body of perched water, most perched bodies never drain completely. The extent of these small bodies of perched water is not fully known. They are at most a few tens of feet thick, and the largest ones usually are extensions of the shallow unconfined aquifer.

Water enters the perched aquifers by seepage from the land surface. It leaves by pumping from a few stock wells, by seepage to the underlying principal aquifer, by seepage to streams, by evapotranspiration, or by lateral movement into the shallow unconfined aquifer.

When the amount of water entering the ground-water reservoir (recharge) exceeds the amount leaving (discharge), the excess water adds to the amount in storage and water levels generally rise. When the recharge is less than the discharge, storage and water levels decline. Rises in one area and declines in another may occur at the same time, especially when the recharge and discharge processes are affected by man's activities (such as irrigation and pumping from wells). Long-term records indicate local changes in water level of more than 30 feet, but a valley-wide change of less than 2 feet since 1932 and probably since the settlement of the valley.

The amount of water in storage in the valley fill increased only slightly during 1964-68—about 3,000 acre-feet per year. Consequently, the average recharge and discharge were nearly equal. Independent estimates of these two quantities are in very close agreement, 369,000 and 367,000 acre-feet per year, respectively.

The estimates of average annual recharge to the ground-water reservoir from various sources are summarized as follows:

	(Acre-ft per year)
Subsurface inflow to Jordan Valley	139,000
Seepage from precipitation on valley floor	62,000
Seepage from stream channels and canals	68,000
Seepage from Kennecott Copper Corp. tailings pond and from irrigated fields, lawns, and gardens	100,000
Total	369,000

Nearly all the subsurface inflow (135,000 out of 139,000 acre-ft) is seepage from openings in the bedrock beneath the mountains directly into the valley fill. Another large segment of recharge (133,000 acre-ft) is the net result of several activities of man—chiefly irrigation and urbanization.

The average annual discharge of ground water from the reservoir is summarized as follows:

		(Acre-ft per year)
Seepage to streams (including springs in Jordan Valley) and to Great Salt Lake		200,000
Evapotranspiration		60,000
Withdrawals from wells		107,000
	Total	367,000

The total amount of ground water diverted for use in 126,000 acre-feet annually, and it includes 19,000 acre-feet of spring flow in addition to the withdrawal from wells.

The total quantity of water stored in the valley fill is estimated to be about 60 million acre-feet—a quantity that equals the cumulative flow of Jordan River at Jordan Narrows for more than 200 years. Generally, however, it is feasible to withdraw only a small fraction of the total quantity in storage. Determination of practical limits of such withdrawal was a major objective of the 1963-70 investigation and is discussed later in this report.

The quality of ground water varies widely and depends on the sources of recharge and the nature of the materials through which it has percolated. Water in the shallow aquifer in Jordan Valley generally contains more dissolved solids and is more subject to contamination by wastes than water in the principal aquifer.

The map of Jordan Valley in figure 5 shows how the concentrations of dissolved solids in water from the principal aquifer vary with location. Water of good quality for municipal use (concentrations less than 500 mg/l) occurs in a large area extending from the east-central part of the valley westward beyond the Jordan River and northward along the river. Water that is less desirable but usable for municipal supply (concentrations 500-1,000 mg/l) occurs in an irregular, enveloping area. Water of the poorest quality occurs in areas adjacent to Great Salt Lake and in small areas where the water is contaminated by mine drainage or saline springs. Large quantities of such poor-quality water are used in the Garfield area for industrial purposes that do not have stringent standards for water quality.

Summary description of water in Jordan Valley

The magnitude of each of the major sources of water supply described above is indicated by the length of a bar in figure 6. As previously indicated, these sources are not independent and the indicated quantities cannot be added. Some of the flow at Jordan Narrows continues past 2100 South (fig. 2), but most of the flow at 2100 South enters the river downstream from the narrows. Some of the water represented by the ground-water bar is included in the flow of Jordan River at 2100 South. The bar for imports is based on the amount available for import (rather than actual import) from Deer Creek Reservoir plus the actual imports from Provo River and Tooele Valley. The bar for ground water indicates the magnitude of the mean annual recharge in Jordan Valley.

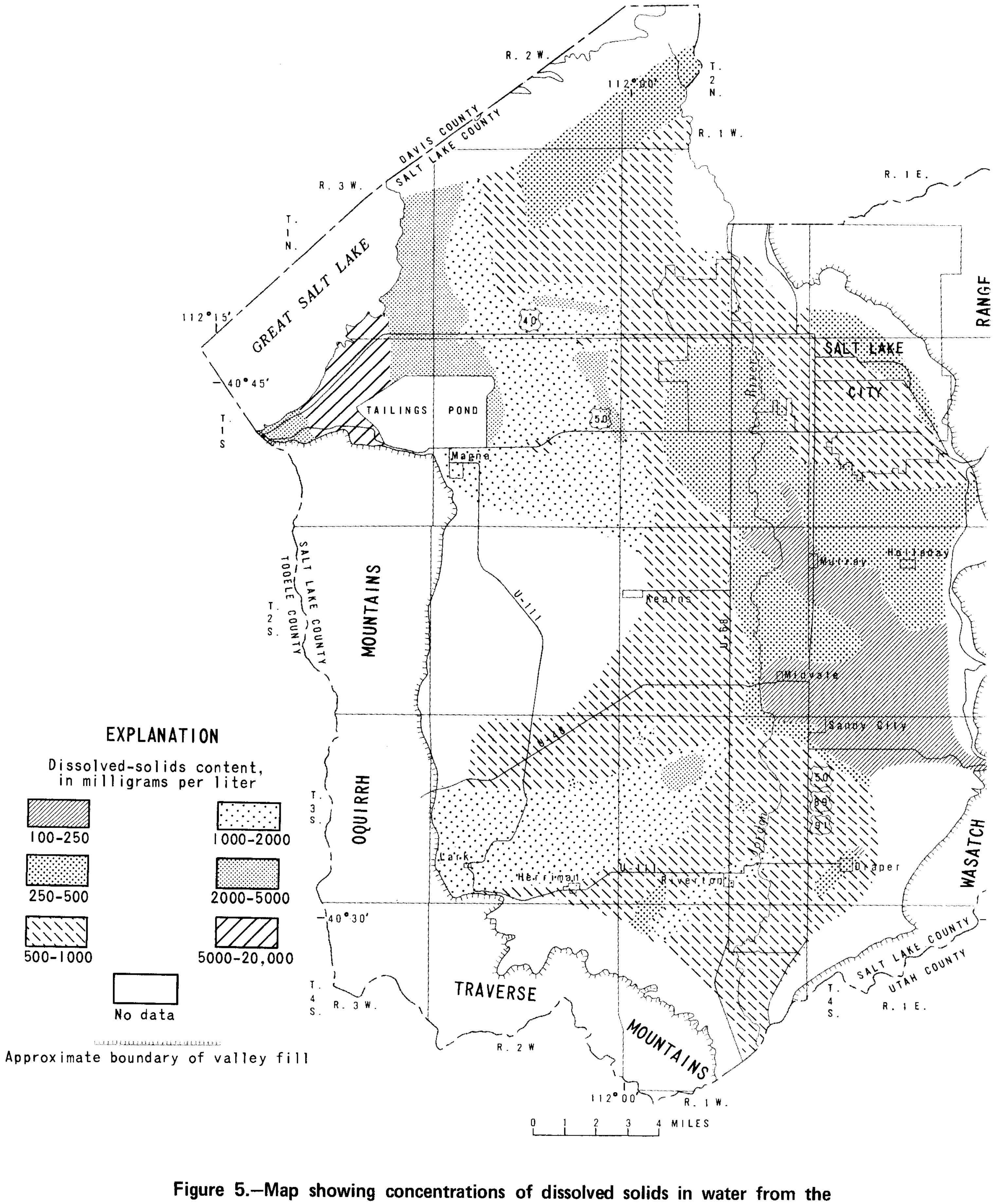

Figure 5.—Map showing concentrations of dissolved solids in water from the principal aquifer.

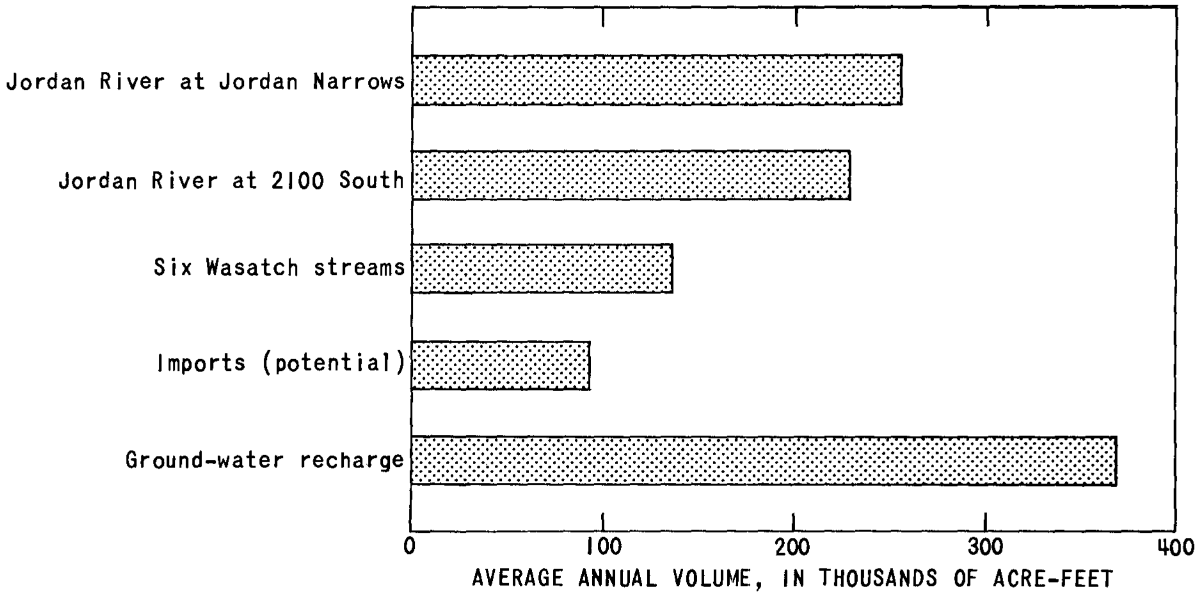

Figure 6.—Comparison of the major sources of water supply for Jordan Valley. (The potential imports shown are for existing diversion and storage facilities and do not include planned imports using facilities not completed by 1970.)

The average annual quantity of water that reached Jordan Valley during 1964-68 was estimated to be 1,066,000 acre-feet—463,000 acre-feet in surface channels and conduits, 139,000 acre-feet by ground-water seepage, and 464,000 acre-feet by precipitation on the valley floor. An insignificant part of this total (3,000 acre-ft) contributed to an increase of storage in the ground-water reservoir, leaving 1,063,000 acre-feet to be accounted for by consumption (chiefly evaporation and transpiration) within the valley and outflow to Great Salt Lake. The outflow totaled 328,000 acre-feet—324,000 acre-feet in the Jordan River and several drains and 4,000 acre-feet by ground-water seepage. Therefore, the total consumption of water in the valley was 735,000 acre-feet per year. This figure includes both natural and man-caused consumption of water.

These figures are shown in tabular form below:

	(Acre-ft per year)
Surface inflow	463,000
Subsurface inflow	139,000
Precipitation on valley floor	464,000
Total inflow	1,066,000
Increase in ground-water storage	3,000
Total consumption plus outflow	1,063,000
Surface outflow	324,000
Subsurface outflow (to Great Salt Lake)	4,000
Consumption (chiefly by evapotranspiration)	735,000

PROSPECTS AND PROBLEMS OF FUTURE DEVELOPMENT

The above description of the ground-water reservoir, as of 1964-68, suggests that a considerable increase in the use of ground water would be physically feasible. The total withdrawal for use from wells and springs (126,000 acre-ft per year) was about a third of the total ground-water recharge and was slightly less than the recharge resulting from man's activities. The average water level in Jordan Valley was nearly the same in 1968 as it had been before the valley was settled. A large part of the 60,000 acre-feet per year lost by evapotranspiration from the water table where it is near the land surface was wasted. Also, part of the winter discharge of Jordan River (some of which is supplied by upward leakage from the principal aquifer) was wasted. However, increasing the pumpage of ground water could cause declines of water level that may have adverse as well as beneficial physical effects. Also, the legal situation, as it relates to ground water, and the various organizations and individuals involved in the development or supplying of water must be considered in any plans for additional development.

In Utah, as in most other States, the development of both water-supply systems and water laws has been based largely on tradition and conditions that existed during early stages of development when surface water and ground water usually were treated as though they were quite independent. Until 1969, Utah courts generally held that the owner of a discharging well was liable for damages resulting from reduction of water level, artesian head, or discharge in wells with earlier water rights.

A unanimous decision of the Supreme Court of the State of Utah in 1969[1] suggests a reversal of this concept. In the case involved, a lower court had ruled in favor of the plaintiffs (owners of small wells) because withdrawals from a new well for municipal supply had diminished the flow in the small wells. In reversing this decision, the Supreme Court stated:

"there has come to be recognized what may be referred to as the 'rule of reasonableness' in the allocation of rights in the use of underground water. This involves an analysis of the total situation: the quantity of water available, the average annual recharge in the basin, the existing rights and their priorities. All users are required where necessary to employ reasonable and efficient means in taking their own waters in relation to others to the end that wastage of water is avoided and the greatest amount of available water is put to beneficial use."

[1]Supreme Court of the State of Utah, 1969, Louis Wayman et al, plaintiffs, *v.* Murray City Corp. and Wayne D. Criddle, State Engineer, defendants: An opinion of the Court, 5 p.

In a specific reference to the maintenance of natural artesian pressure, the court also stated: "We perceive nothing in our statutory law * * * which compels a conclusion that owners of rights to use underground water have any absolute right to pressure."

The most effective development of the total water resource can occur only under unified or coordinated management of both surface and subsurface supplies. Then, the largest ground-water withdrawals can be made when surface supplies are deficient and the smallest withdrawals made when surface supplies are abundant. Ground-water storage thus operates in the same manner as surface storage to enable use of a large proportion of the total water resource. Although past withdrawals have followed this pattern in some degree, the county could greatly increase its use of the huge ground-water storage capacity.

Such management does not necessarily require that every domestic well be operated in accordance with a master plan, because the aggregate withdrawal from such wells is relatively small. Control of withdrawals from large wells for municipal, industrial, and irrigation supplies generally would be sufficient. However, such management does result in substantial declines of water levels at times in some areas. It also provides for subsequent recovery of water levels by natural or artificial recharge and prevents most of the undesirable effects of overdevelopment.

The management needed to achieve this goal may not be possible when the water-supply function is divided among many independent water-supply systems, some of which supply only surface water and some only ground water. As the number of systems decreases and interconnection of the various systems increases, however, the prospects for successful management tend to increase.

In 1969, 36 municipal-type systems supplied more than 110,000 service connections in Jordan Valley. Also, many individual users of domestic, irrigation, and industrial water have no public supply. Thus, considerable consolidation of the water-supply function may be needed for unified management. The combined effects of increasing urbanization and need for better use of water resources may eventually make such management mandatory. Consequently, this investigation concerned appraisals for conditions that may be attainable in the future even though they may not be attainable at present.

Predictions of the changes that would result from selected programs of ground-water development in Jordan Valley were greatly aided by an electric-analog model of the ground-water reservoir. Electrical components of the model are analogous to physical features of the reservoir; voltage is analogous to water level or pressure; and electric current is analogous to the flow of water. The model was designed and constructed by using the available field data on the physical properties of the valley fill at various sites. As the construction progressed, tests of the model were made to compare reactions of the model to corresponding reactions of the reservoir. During early stages of construction the model reactions differed somewhat from the reservoir reactions, indicating a need to change certain features of the model to provide better correspondence with the reservoir. When the appropriate modifications were completed the reactions of model and reservoir were in good agreement, and the model was then used to predict what would happen in the ground-water reservoir if pumpage were increased by various amounts.

Twenty-two alternative programs of ground-water development were tested with the model, and the resulting changes in water level were determined. In one group of programs, it was assumed that pumping would continue after 1968 at the pumping centers (individual wells or groups of closely spaced wells) in use during 1959-68 at rates proportional to those for 1959-68. In a second group, part of the pumpage was shifted to other parts of Jordan Valley, especially the relatively undeveloped area west of Salt Lake City; and in a third group, the natural recharge was assumed to be augmented by artificial recharge. The results of these tests are in the files of the U.S. Geological Survey, Salt Lake City. Results of seven of them are described in the comprehensive report (Utah Dept. Nat. Resources Tech. Pub. 31).

The tests support the conclusion that a considerable increase in the use of ground water is physically feasible. The average annual withdrawal of ground water from pumped and flowing wells in existing centers could be increased to at least 150,000 acre-feet with no serious adverse effects. If pumping from large wells near Garfield increased in proportion to the average, water from Great Salt Lake would infiltrate the wells. This probably would not seriously affect the usability of the water in its present application of ore processing. If desired, the contamination by lake water could be avoided by limiting the increase of withdrawal from those wells.

If the annual withdrawals increased to more than 200,000 acre-feet after 1968, the aquifer underlying eastern Salt Lake City would be dewatered before the year 2020 and poor-quality water from the Jordan River and from areas west of the river would contaminate wells east of the river. Thus, the practical limit of continuous withdrawals from existing pumping centers is between 150,000 and 200,000 acre-feet annually.

Additional water could be recovered by shifting part of the withdrawal to other parts of Jordan Valley. For example, withdrawing 51,700 acre-feet annually from a potential industial area west of Salt Lake City would salvage about 29,000 acre-feet annually from evapotranspiration, and would provide water suitable for many industrial uses but not for municipal use.

The use of artificial recharge would increase the average annual yield of the ground-water reservoir and also would increase the amount of storage capacity that could be used for regulation of the total water supply without excessive water-level declines.

WATER USE

Water is used in Salt Lake County for such diverse purposes as recreation, generation of hydroelectric power, municipal and domestic supply, stockwatering, manufacturing, cooling in industrial plants and stream powerplants, ore processing, irrigation, and maintenance of waterfowl-management areas. Some recreational uses and the generation of hydroelectric power have virtually no effect on the amount of water available for other uses or on its quality. Most other uses, however, involve withdrawals of water from streams, lakes, or aquifers, consumption of some of the water, and return of the rest. Many uses cause degradation of water quality, either by an addition of pollutants or by an increase in the concentration of dissolved solids, and some cause undesirable local increases of water temperature. Consumption of water is chiefly by evapotranspiration, which removes nearly pure water and leaves most of the dissolved solids in the smaller remaining volume.

A summary of the principal water withdrawals for uses that deplete the supply (except maintenance of waterfowl-management areas) is presented in table 1. Withdrawals of ground water include water from both flowing and pumped wells and from springs in Jordan Valley.

(The flow of springs in mountain canyons is included as part of the streamflow.) In table 1, domestic use refers largely to rural domestic use but also includes domestic use in urban areas with no public-water supply.

Table 1.—Summary of water withdrawals, 1964-68

Types of use	Source	Average annual withdrawal, in acre-feet
Municipal	Wasatch streams	53,900
	Imports	13,500
	Ground water	44,000
	Subtotal (rounded)	111,000
Domestic and stock	Ground water	30,000
Industrial	Jordan River	66,100
	Imports	9,500
	Ground water	46,700
	Subtotal (rounded)	122,000
Irrigation	Jordan River	219,000
	Wasatch streams	39,800
	Imports	53,600
	Ground water	5,000
	Subtotal (rounded)	317,000
All uses	Jordan River	285,100
	Wasatch streams	93,700
	Imports	76,600
	Ground water	125,700
	Total (rounded)	580,000

The use of water in the waterfowl-management areas was not included in table 1 because the supply is derived from several sources (Jordan River, small streams in Davis County, precipitation on the management areas, and ground water) and the use is partly natural and partly artificial. Although the water is used just before its final discharge to Great Salt Lake and its quality is poor, such use could affect the supply for other uses if it should be necessary to release water from a lake or reservoir to satisfy established water rights in the management areas. The average annual consumption of Jordan River water in these areas was estimated to be about 39,000 acre-feet. However, the total requirement for river water is higher because enough water must flow through the marshes to prevent excessive salinity, which would make them unusable for waterfowl management. The 1964-68 mean annual discharge of Jordan River water to the management areas (including water from the Surplus Canal) was 205,000 acre-feet.

The requirements for water in Jordan Valley will increase as the population increases. Practically all the increase, however, will be for municipal and industrial supplies. The requirements for irrigation are not expected to change much, and the requirements for domestic use probably will decrease somewhat as municipal systems expand. Requirements for municipal use are closely related to population, and consequently the reliability of the estimated requirements depends largely on the reliability of the population projections. Estimates of the requirements for industry generally are less reliable because of the great differences in the requirements of different industries and also because of differences between plants within a particular industry. Some plants use water only once and then discharge it; others recycle the water many times before discharging it, thus reducing the amount withdrawn from the source.

Although such estimates or projections are subject to large errors, they are a necessary basis of plans to meet future water requirements. Some commonly used projections of population and water requirements for municipal and industrial use are listed in table 2. The projections were made during 1966 by the Bureau of Economic and Business Research, University of Utah.

Table 2.—Projections of population and annual water requirements for Salt Lake County

Year	Population	Water withdrawal, in acre-feet	
		Municipal only	Municipal and industrial
1975	604,000	144,960	314,080
1985	794,000	190,520	428,760
2000	1,043,000	250,320	597,067
2020	1,406,000	337,440	848,350

The total water requirements, in terms of withdrawal, include the following items (from table 1) in addition to the amounts listed in table 2: (1) water for irrigation (317,000 acre-ft during 1964-68 and expected to remain about the same) and (2) water for domestic and stock use (about 30,000 acre-ft during 1964-68 and may decrease somewhat as municipal systems expand). Thus the projected total requirement (excluding that for waterfowl management) for the year 2020 is about 1,200,000 acre-feet per year—more than double the 1964-68 withdrawals. The requirement for waterfowl-management areas generally has been met by waste water from other applications and by surplus water. If such surpluses should be largely eliminated by increased future regulation of streamflow, provision for water requirements in the management areas would be needed.

DISCUSSION AND CONCLUSIONS

The hydrologic objectives of managing the ground-water reservoir in Jordan Valley, in general, would be (1) to salvage water that is now wasted through natural discharge (evapotranspiration, underflow to Great Salt Lake, and seepage to streams when the water cannot be used) and (2) to use the storage capacity of the ground-water reservoir to supplement or replace surface storage. The first objective requires a lowering of ground-water levels in areas of natural discharge; the second requires marked fluctuations of water levels and coordination of withdrawals with the availability of surface-water supplies.

It would be possible to lower the ground-water levels sufficiently to eliminate practically all waste through natural discharge. However, the drastic lowering required would be accompanied by undesirable effects, such as induced recharge from Great Salt Lake, unless special measures were taken to control them. For example, an area where a large drawdown of water levels is permissible could be isolated from Great Salt Lake by injecting fresh water into a line of recharge wells to create a ridge in the potentiometric surface between the lake and discharging wells. The ridge should be as near the lake as is convenient to place it and high enough to maintain a gradient toward the lake. Most of the injected water would be recovered from the discharging wells because the water-level gradient would be steeper toward them than toward the lake.

Water levels can be controlled for use of the ground-water storage capacity within the limits imposed by natural recharge and discharge; or more of the storage capacity can be used by permitting greater drawdown during drought periods and augmenting the recharge with surplus surface water during periods of abundant runoff. The source for such artificial recharge might be the Wasatch streams in Salt Lake County, Deer Creek Reservoir, or any imported supply of good quality.

Surplus water from the unregulated Wasatch streams would be available only for a few weeks in each year of near-normal or above-normal runoff. Hence, the usefulness of the ground-water reservoir in regulating the supply from the Wasatch streams would be limited unless the streamflow were partly regulated in surface reservoirs and were thus made available for longer periods.

The water supply from Deer Creek Reservoir could readily be used for artificial recharge, and such use would eliminate the greatest fault in the present system. As previously explained, carryover-storage priveleges may be nullified if runoff is more than sufficient to fill the reservoir. Such stored water could be transferred from the reservoir to an artificial recharge system during winter and spring months, when the full capacity of the aqueduct is not needed for delivery of municipal supplies.

Artificial recharge may be accomplished by injecting water into wells or by spreading it through ditches or basins in pervious materials. Satisfactory design of an extensive system requires additional research at the specific sites involved, including research into legal and economic aspects, local effects of additional recharge on water levels, the physical and chemical compatibility of the aquifer deposits and recharge water, and rates at which the aquifer can absorb recharge. Additional recharge under present conditions would tend to aggravate the problem of high water levels in low-lying parts of the county.

The need for artificial recharge and fresh-water barriers probably is several years away. The potential regulating capacity of the ground-water reservoir, however, should be considered in the appraisal of overall storage requirements for Salt Lake County. If appropriately managed, the ground-water reservoir could supply part of the capacity needed for long-term regulation of the total water supply but could not supply all needs.

The perennial supply of water obtainable from present sources is roughly 700,000 acre-feet, derived as follows:

Jordan River (assuming future withdrawals will be approximately equal to those during 1964-68	285,000
Wasatch streams (assuming adequate regulation of six streams)	120,000
Imports (assuming 59,000 acre-ft from Deer Creek reservoir and 1964-68 rates for others)	92,000
Ground water (assuming near-maximum development from springs and wells without serious adverse physical effects)	200,000
Total (rounded)	700,000

Roughly half this amount is water suitable for municipal use and the other half is suitable for irrigation or industrial uses without stringent requirements for water quality.

The figure of potential supply from local sources and present imports is much less than the projected requirement for water withdrawal in the year 2020 (1,200,000 acre-ft plus the requirement for river water in the waterfowl-management areas). Consequently, if the requirement reaches the projected level, intensive reuse of the available supply or an additional supply will be needed.

The withdrawal requirement might be reduced considerably by greater use of recycling than was assumed in making the projections. Recycling of water used for cooling, for example, involves circulation of the water through a cooling tower or pond after each of several passes through the plant. Such recycling tends to increase with increasing cost of water or scarcity of supply.

The withdrawals during 1964-68 (about 580,000 acre-ft plus river water for waterfowl-management areas) reflect some reuse of water, because the drainage from irrigated areas returned to a stream where it could be withdrawn again. However, most of the water withdrawn for municipal and industrial use in Salt Lake City and the Garfield-Magna area was discharged to Great Salt Lake. Some of this water was treated before discharge and probably was usable for irrigation of meadows or grain crops, for waterfowl-management areas, or for industry.

In addition to the sources of water supply discussed in this report, potential sources include new imports from outside the Jordan River basin, increased precipitation induced by cloud-seeding techniques, and desalted water from sources that are otherwise unfit for use. Cloud-seeding and desalting techniques are in the research and development stage and may become increasingly significant in the development of water resources within the next few decades.

APPENDIX

Acknowledgments

This investigation was a cooperative project between the State of Utah and the U.S. Geological Survey. The following State and local organizations contributed to the investigation through the Utah Department of Natural Resources: Utah Division of Water Rights (formerly State Engineer), Utah Division of Water Resources (formerly Water and Power Board), Utah Division of Fish and Game (formerly Fish and Game Commission), Central Utah Water Conservancy District, Salt Lake County, Salt Lake County Water Conservancy District, Metropolitan Water District of Salt Lake City, Salt Lake City Chamber of Commerce, City of Murray, Granger-Hunter Improvement District, Taylorsville-Bennion Improvement District, Holladay Water Co., Magna Water and Sewer District, Kennecott Copper Corp., and Utah Power and Light Co. The U.S. Bureau of Reclamation also made a contribution to the investigation.

Many agencies cooperated by furnishing hydrologic data or information. The details of such cooperation generally are given in basic-data reports, but the following deserve special recognition: U.S. Weather Bureau, U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, Salt Lake City Water Department, Salt Lake County Water Conservancy District, Metropolitan Water District of Salt Lake City, Provo River Water Users Association, Utah Lake and Jordan River Water District, Kennecott Copper Corp., and Utah Power and Light Co.

Explanation of selected hydrologic terms

Acre-foot: The volume represented by a uniform depth of 1 foot on an area of 1 acre. It equals 43,560 cubic feet or 325,900 gallons. This in enough water to supply domestic needs of a family of four for nearly 1½ years—based on a national average rate of 155 gallons per day for each individual. However, 1 acre-foot is less than the annual requirement for irrigation of 1 acre of cropland in a semiarid climate such as that of Jordan Valley.

Aquifer: A deposit or rock formation that yields water to wells. Where water is trapped or confined beneath a relatively impermeable bed and is under pressure greater than atmospheric, the aquifer is a confined or artesian aquifer. Where there is no confining bed above the aquifer, it is an unconfined or water-table aquifer. Where an aquifer is underlain by a relatively impermeable bed that in turn is underlain by a zone of aeration, the aquifer is perched.

Aquifer, principal: The principal aquifer of Jordan Valley consists of two parts: the deep unconfined aquifer at the edges of the valley and the deep confined aquifer in the center.

Chemical quality (of water): The chemical quality of water is determined by the presence of chemical substances and is expressed as concentrations of total dissolved solids (minerals), of the principal constituents (such as sodium and chloride), and of minor constituents that may be especially harmful. In this report, however, the only concentrations considered are those of total dissolved solids. They are expressed in milligrams of dissolved solids per liter of solution (mg/l). Concentrations below 7,000 mg/l are practically the same as those in parts per million (ppm), the unit used in many other reports on water quality, especially prior to 1968. Public health authorities generally recommend water with concentrations of less than 500 mg/l for drinking; but many drinking-water supplies have higher concentrations. Water with concentrations of several thousand milligrams per liter has been used successfully for irrigation, but concentrations of less than 1,000 mg/l are preferable.

Confining bed: A bed of relatively impermeable, fine-grained material (usually silt or clay) that confines water in an adjacent aquifer.

Consolidated deposits: Solid rock formed by the cementing of loose particles.

Consumption (of water): Conversions of liquid water on or in the earth to vapor in the atmosphere, or incorporation of water into living matter or a manufactured product.

Desalting: Removal of dissolved solids (mostly salts) and other impurities from water by processes such as distillation.

Discharge: The flow of water in a surface channel or from an aquifer or ground-water reservoir.

Dissolved solids: See chemical quality

Evaporation: Conversion of liquid water at the land or water surface to vapor in the atmosphere.

Evapotranspiration: Water loss by evaporation and transpiration.

Flowing well: A well in which the water rises above the land surface without pumping and flows unless the well is sealed to prevent it.

Ground water reservoir (in Jordan Valley): The saturated part of the unconsolidated valley fill. This includes several distinct aquifers and numerous beds of fine-grained materials.

Import: As used in this report, water derived from a drainage basin outside the Jordan River basin, or water that reaches Salt Lake County by an unnatural route.

Overdevelopment (of ground water): Withdrawals of ground water at rates and for durations that would produce serious adverse effects. Continued withdrawal at rates that exceed recharge (replenishment) of a reservoir results in eventual exhaustion of the supply.

Potentiometric surface: The surface to which water would rise in wells penetrating a confined aquifer. It is analogous to the water table in an unconfined aquifer.

Recharge: Replenishment of an aquifer. The quantity of water entering the aquifer.

Recharge, artificial: A diversion of water into wells, basins, or ditches so that it will enter an aquifer and augment the natural recharge.

Recharge, induced: Replenishment of an aquifer from a source that does not ordinarily contribute to it or increasing the flow from the source to the aquifer, caused by lowering the water level in the aquifer below that in the source or below the natural level.

Recycle: Use of water several times within an industrial plant or water system before discharge.

Regulation: Control of water supply by storage of surplus and release or withdrawal of water as needed.

Reuse: Withdrawal of water that has previously been withdrawn and returned to a stream or aquifer.

Saline: Salty. Generally refers to water that is too salty for a specific use. Sometimes applied to water with dissolved-solids concentration of more than 1,000 mg/l.

Salinity: Saltiness. Concentration of dissolved solids.

Saturated zone: That part of the valley fill where all voids are filled with water. This usually is overlain by an unsaturated zone or zone of aeration where some voids contain air.

Transmountain diversion: A diversion from one drainage basin across a drainage divide (usually mountainous) to another drainage basin.

Transpiration: Transfer of water from the soil or a ground-water reservoir through growing plants to the atmosphere.

Unconsolidated deposits: Deposits of uncemented or loose particles.

Valley fill: Sediment derived from mountains or upland areas by erosion and deposited in a valley. In Jordan Valley it includes some rocks of volcanic origin.

Water requirement: The amount of water needed for a specific purpose. It may be expressed in terms of the total amount withdrawn or the amount consumed.

Water table: The surface at which water stands in open wells in an unconfined aquifer.

Withdrawal (of water): Removal of water from a lake, stream, or aquifer by diversion, pumping, or flowing wells.

Year: Two different years are commonly used in compiling hydrologic data: the calendar year (ending December 31) for climatologic and ground-water data and the water year (ending September 30) for streamflow data. The effect of using these different years in comparing averages for 5 or more years usually is insignificant and has been ignored for simplicity in this report.

PUBLICATIONS OF THE UTAH DEPARTMENT OF NATURAL RESOURCES, DIVISION OF WATER RIGHTS

(*)—Out of Print

TECHNICAL PUBLICATIONS

No. 1. Underground leakage from artesian wells in the Flowell area, near Fillmore, Utah, by Penn Livingston and G. B. Maxey, U. S. Geological Survey, 1944.

No. 2. The Ogden Valley artesian reservoir, Weber County, Utah, by H. E. Thomas, U. S. Geological Survey, 1945.

*No. 3. Ground water in Pavant Valley, Millard County, Utah, by P. E. Dennis, G. B. Maxey, and H. E. Thomas, U. S. Geological Survey, 1946.

*No. 4. Ground water in Tooele Valley, Tooele County, Utah, by H. E. Thomas, U. S. Geological Survey, in Utah State Eng. 25th Bienn. Rept., p. 91-238, pls. 1-6, 1946.

*No. 5. Ground water in the East Shore area, Utah: Part I, Bountiful District, Davis County, Utah, by H. E. Thomas and W. B. Nelson, U. S. Geological Survey, in Utah State Eng. 26th Bienn. Rept., p. 53-206, pls. 1-2, 1948.

*No. 6. Ground water in the Escalante Valley, Beaver, Iron, and Washington Counties, Utah, by P. F. Fix, W. B. Nelson, B. E. Lofgren, and R. G. Butler, U. S. Geological Survey, in Utah State Eng. 27th Bienn. Rept., p. 107-210, pls. 1-10, 1950.

No. 7. Status of development of selected ground-water basins in Utah, by H. E. Thomas, W. B. Nelson, B. E. Lofgren, and R. G. Butler, U. S. Geological Survey, 1952.

*No. 8. Consumptive use of water and irrigation requirements of crops in Utah, by C. O. Roskelly and Wayne D. Criddle, 1952.

No. 8. (Revised) Consumptive use and water requirements for Utah, by W. D. Criddle, K. Harris, and L. S. Willardson, 1962.

No. 9. Progress report on selected ground water basins in Utah, by H. A. Waite, W. B. Nelson, and others, U. S. Geological Survey, 1954.

*No. 10. A compilation of chemical quality data for ground and surface waters in Utah, by J. G. Connor, C. G. Mitchell, and others, U. S. Geological Survey, 1958.

*No. 11. Ground water in northern Utah Valley, Utah: A progress report for the period 1948-63, by R. M. Cordova and Seymour Subitzky, U. S. Geological Survey, 1965.

No. 12. Reevaluation of the ground-water resources of Tooele Valley, Utah, by Joseph S. Gates, U. S. Geological Survey, 1965.

*No. 13. Ground-water resources of selected basins in southwestern Utah, by G. W. Sandberg, U. S. Geological Survey, 1966.

*No. 14. Water-resources appraisal of the Snake Valley area, Utah and Nevada, by J. W. Hood and F. E. Rush, U. S. Geological Survey, 1966.

*No. 15. Water from bedrock in the Colorado Plateau of Utah, by R. D. Feltis, U. S. Geological Survey, 1966.

No. 16. Ground-water conditions in Cedar Valley, Utah County, Utah, by R. D. Feltis, U. S. Geological Survey, 1967.

*No. 17. Ground-water resources of northern Juab Valley, Utah, by L.J. Bjorklund, U.S. Geological Survey, 1968.

No. 18. Hydrologic reconnaissance of Skull Valley, Tooele County, Utah, by J. W. Hood and K. M. Waddell, U. S. Geological Survey, 1968.

No. 19. An appraisal of the quality of surface water in the Sevier Lake basin, Utah, by D. C. Hahl and J. C. Mundorff, U. S. Geological Survey, 1968.

No. 20. Extensions of streamflow records in Utah, by J. K. Reid, L. E. Carroon, and G. E. Pyper, U. S. Geological Survey, 1969.

No. 21. Summary of maximum discharges in Utah streams, by G. L. Whitaker, U. S. Geological Survey, 1969.

No. 22. Reconnaissance of the ground-water resources of the upper Fremont River valley, Wayne County, Utah, by L. J. Bjorklund, U. S. Geological Survey, 1969.

No. 23. Hydrologic reconnaissance of Rush Valley, Tooele County, Utah, by J. W. Hood, Don Price, and K. M. Waddell, U. S. Geological Survey, 1969.

No. 24. Hydrologic reconnaissance of Deep Creek valley, Tooele and Juab Counties, Utah, and Elko and White Pine Counties, Nevada, by J. W. Hood and K. M. Waddell, U. S. Geological Survey, 1969.

No. 25. Hydrologic reconnaissance of Curlew Valley, Utah and Idaho, by E. L. Bolke and Don Price, U. S. Geological Survey, 1969.

No. 26. Hydrologic reconnaissance of the Sink Valley area, Tooele and Box Elder Counties, Utah, by Don Price and E. L. Bolke, U. S. Geological Survey, 1969.

No. 27. Water resources of the Heber-Kamas-Park City area, north-central Utah, by C. H. Baker, Jr., U. S. Geological Survey, 1970.

No. 28. Ground-water conditions in southern Utah Valley and Goshen Valley, Utah, by R.M. Cordova, U.S. Geological Survey, 1970.

No. 29. Hydrologic reconnaissance of Grouse Creek valley, Box Elder County, Utah, by J.W. Hood and Don Price, U.S. Geological Survey, 1970.

No. 30. Hydrologic reconnaissance of the Park Valley area, Box Elder County, Utah, by J.W. Hood, U.S. Geological Survey, 1970.

No. 31. Water resources of Salt Lake County, Utah, by Allen G. Hely, R.W. Mower, and C. Albert Harr, U.S. Geological Survey, 1971.

No. 32. Geology and water resources of the Spanish Valley area, Grand and San Juan Counties, Utah, by C.T. Sumsion, U.S. Geological Survey, 1971.

No. 33. Hydrologic reconnaissance of Hansel Valley and northern Rozel Flat, Box Elder County, Utah, by J.W. Hood, U.S. Geological Survey, 1971.

WATER CIRCULARS

No. 1. Ground water in the Jordan Valley, Salt Lake County, Utah, by Ted Arnow, U. S. Geological Survey, 1965.

No. 2. Ground water in Tooele Valley, Utah, by J. S. Gates and O. A. Keller, U. S. Geological Survey, 1970.

BASIC-DATA REPORTS

*No. 1. Records and water-level measurements of selected wells and chemical analyses of ground water, East Shore area, Davis, Weber, and Box Elder Counties, Utah, by R. E. Smith, U. S. Geological Survey, 1961.

*No. 2. Records of selected wells and springs, selected drillers' logs of wells, and chemical analyses of ground and surface waters, northern Utah Valley, Utah County, Utah, by Seymour Subitzky, U. S. Geological Survey, 1962.

*No. 3. Ground water data, central Sevier Valley, parts of Sanpete, Sevier, and Piute Counties, Utah, by C. H. Carpenter and R. A. Young, U. S. Geological Survey, 1963.

*No. 4. Selected hydrologic data, Jordan Valley, Salt Lake County, Utah, by I. W. Marine and Don Price, U. S. Geological Survey, 1963.

*No. 5. Selected hydrologic data, Pavant Valley, Millard County, Utah, by R. W. Mower, U. S. Geological Survey, 1963.

*No. 6. Ground-water data, parts of Washington, Iron, Beaver, and Millard Counties, Utah, by G. W. Sandberg, U. S. Geological Survey, 1963.

No. 7. Selected hydrologic data, Tooele Valley, Tooele County, Utah, by J. S. Gates, U. S. Geological Survey, 1963.

No. 8. Selected hydrologic data, upper Sevier River basin, Utah, by C. H. Carpenter, G. B. Robinson, Jr., and L. J. Bjorklund, U. S. Geological Survey, 1964.

No. 9. Ground-water data, Sevier Desert, Utah, by R. W. Mower and R. D. Feltis, U. S. Geological Survey, 1964.

*No. 10. Quality of surface water in the Sevier Lake basin, Utah, by D. C. Hahl and R. E. Cabell, U. S. Geological Survey, 1965.

*No. 11. Hydrologic and climatologic data, collected through 1964, Salt Lake County, Utah by W. V. Iorns, R. W. Mower, and C. A. Horr, U. S. Geological Survey, 1966.

No. 12. Hydrologic and climatologic data, 1965, Salt Lake County, Utah, by W. V. Iorns, R. W. Mower, and C. A. Horr, U. S. Geological Survey, 1966.

No. 13. Hydrologic and climatologic data, 1966, Salt Lake County, Utah, by A. G. Hely, R. W. Mower, and C. A. Horr, U. S. Geological Survey, 1967.

No. 14. Selected hydrologic data, San Pitch River drainage basin, Utah, by G. B. Robinson, Jr., U. S. Geological Survey, 1968.

No. 15. Hydrologic and climatologic data, 1967, Salt Lake County, Utah, by A. G. Hely, R. W. Mower, and C. A. Horr, U. S. Geological Survey, 1968.

No. 16. Selected hydrologic data, southern Utah and Goshen Valleys, Utah, by R. M. Cordova, U. S. Geological Survey, 1969.

No. 17. Hydrologic and climatologic data, 1968, Salt Lake County, Utah, by A. G. Hely, R. W. Mower, and C. A. Horr, U. S. Geological Survey, 1969.

No. 18. Quality of surface water in the Bear River basin, Utah, Wyoming, and Idaho, by K. M. Waddell, U. S. Geological Survey, 1970.

No. 19. Daily water-temperature records for Utah streams, 1944-68, by G. L. Whitaker, U. S. Geological Survey, 1970.

No. 20. Water quality data for the Flaming Gorge area, Utah and Wyoming, R.J. Madison, U.S. Geological Survey, 1970.

No. 21. Selected hydrologic data, Cache Valley, Utah and Idaho, L.J. McGreevy and L.J. Bjorklund, U.S. Geological Survey, 1970.

INFORMATION BULLETINS

*No. 1. Plan of work for the Sevier River Basin (Sec. 6, P. L. 566), U. S. Department of Agriculture, 1960.

*No. 2. Water production from oil wells in Utah, by Jerry Tuttle, Utah State Engineer's Office, 1960.

*No. 3. Ground-water areas and well logs, central Sevier Valley, Utah, by R. A. Young, U. S. Geological Survey, 1960.

*No. 4. Ground-water investigations in Utah in 1960 and reports published by the U. S. Geological Survey or the Utah State Engineer prior to 1960, by H. D. Goode, U. S. Geological Survey, 1960.

*No. 5. Developing ground water in the central Sevier Valley, Utah, by R. A. Young and C. H. Carpenter, U. S. Geological Survey, 1961.

*No. 6. Work outline and report outline for Sevier River basin survey, (Sec. 6, P.L. 566), U. S. Department of Agriculture, 1961.

No. 7. Relation of the deep and shallow artesian aquifers near Lynndyl, Utah, by R. W. Mower, U. S. Geological Survey, 1961.

*No. 8. Projected 1975 municipal water-use requirements, Davis County, Utah, by Utah State Engineer's Office, 1962.

No. 9. Projected 1975 municipal water-use requirements, Weber County, Utah, by Utah State Engineer's Office, 1962.

*No. 10. Effects on the shallow artesian aquifer of withdrawing water from the deep artesian aquifer near Sugarville, Millard County, Utah, by R. W. Mower, U. S. Geological Survey, 1963.

No. 11. Amendments to plan of work and work outline for the Sevier River basin (Sec. 6, P.L. 566), U. S. Department of Agriculture, 1964.

*No. 12. Test drilling in the upper Sevier River drainage basin, Garfield and Piute Counties, Utah, by R. D. Feltis and G. B. Robinson, Jr., U. S. Geological Survey, 1963.

*No. 13. Water requirements of lower Jordan River, Utah, by Karl Harris, Irrigation Engineer, Agricultural Research Service, Phoenix, Arizona, prepared under informal cooperation approved by Mr. William W. Donnan, Chief, Southwest Branch (Riverside, California) Soil and Water Conservation Research Division, Agricultural Research Service, U.S.D.A., and by Wayne D. Criddle, State Engineer, State of Utah, Salt Lake City, Utah, 1964.

*No. 14. Consumptive use of water by native vegetation and irrigated crops in the Virgin River area of Utah, by Wayne D. Criddle, Jay M. Bagley, R. Keith Higginson, and David W. Hendricks, through cooperation of Utah Agricultural Experiment Station, Agricultural Research Service, Soil and Water Conservation Branch, Western Soil and Water Management Section, Utah Water and Power Board, and Utah State Engineer, Salt Lake City, Utah, 1964.

*No. 15. Ground-water conditions and related water-administration problems in Cedar City Valley, Iron County, Utah, February, 1966, by Jack A. Barnett and Francis T. Mayo, Utah State Engineer's Office.

*No. 16. Summary of water well drilling activities in Utah, 1960 through 1965, compiled by Utah State Engineer's Office, 1966.

No. 17. Bibliography of U. S. Geological Survey Water Resources Reports for Utah, compiled by Olive A. Keller, U. S. Geological Survey, 1966.

No. 18. The effect of pumping large-discharge wells on the ground-water reservoir in southern Utah Valley, Utah County, Utah, by R. M. Cordova and R. W. Mower, U. S. Geological Survey 1967.

No. 19. Ground-water hydrology of southern Cache Valley, Utah, by L. P. Beer, 1967.

No. 20. Fluvial sediment in Utah, 1905-65, A data compilation by J. C. Mundorff, U. S. Geological Survey, 1968.