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WATER RESOURCES OF SALT LAKE COUNTY, UTAH

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With a section on geologic setting

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WATER RESOURCES OF SALT LAKE COUNTY, UTAH

by

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ABSTRACT

Although the task of providing adequate water supplies in Salt Lake County has been a recurring problem for more than a century, large quantities of usable water are discharged to Great Salt Lake and are lost every year by evapotranspiration of ground water in low-lying areas. Among the factors responsible for this situation are (1) lack of storage capacity to regulate runoff from the Wasatch Range within the county, (2) legal attitudes prior to 1969 that tended to limit ground-water development, (3) lack of coordination of withdrawals from surface and subsurface sources, and (4) lack of knowledge about the hydrologic effects of withdrawals of ground water.

Some improvement of this situation has occurred in recent years, but serious problems remain. The first major unit of a surface-storage system in the county was authorized in 1968. A decision of the Supreme Court of the State of Utah in 1969 reversed prior judicial decisions regarding liability of the owner of a discharging well for damages caused by reduced yields of other wells with senior water rights. The coordination of withdrawals from surface and subsurface sources for optimum use of storage capacity in the ground-water reservoir has not been attempted (1970) and may be difficult because of the large numbers of independent water users and suppliers. This report presents quantitative descriptions of the hydrologic environment and the probable effects of selected programs for ground-water development.

The sources of water available to the Jordan Valley in Salt Lake County are (1) precipitation on the valley, (2) streams in the adjoining Wasatch Range and Oquirrh Mountains, (3) the Jordan River, (4) imports through canals and pipelines, and (5) ground water.

During the water years 1964-68, the mean annual surface inflow to Jordan Valley (the principal populated area of Salt Lake County) was 463,000 acre-feet; and the outflow, discharged to Great Salt Lake, was 324,000 acre-feet. Approximately half the inflow was suitable for municipal and most industrial uses (dissolved-solids content generally less than 500 milligrams per liter). The other half, which was not suitable for municipal use because of poor chemical and sanitary quality, was the principal supply for irrigation and those industrial uses without stringent quality requirements.

Most ground water is withdrawn from an aquifer composed of unconsolidated deposits of Quaternary age (principal aquifer), some is withdrawn from an overlying aquifer (shallow unconfined aquifer) also of Quaternary age, and some is withdrawn from underlying semiconsolidated deposits of Tertiary age.

The chemical quality of the ground water varies markedly. Water from the principal aquifer in most of Jordan Valley is suitable for municipal use, irrigation, and most industrial uses; but water from some areas (chiefly the northern part of the valley, near Great Salt Lake) is suitable only for uses without stringent quality requirements.

Ground water in the principal aquifer has the lowest dissolved-solids content (100-250 milligrams per liter) chiefly in the vicinity of Big Cottonwood and Little Cottonwood Creeks in

the eastern part of the valley. The dissolved-solids content increases from the Cottonwoods area northwestward toward the shoreline of Great Salt Lake, where it exceeds 2,000 milligrams per liter.

The chemical quality of water in the principal aquifer is being degraded locally in the southwestern part of the valley, where seepage losses from irrigation and mining infiltrate the ground-water reservoir. Degradation of water quality in the principal aquifer has not been observed in other parts of the valley. Water quality in the shallow unconfined aquifer is being degraded at many places, however, by seepage from irrigation and other sources. Water quality in the deposits of Tertiary age probably is not being degraded.

The total withdrawal of water for all uses except in waterfowl-management areas in Jordan Valley during 1964-68 was about 581,000 acre-feet per year, of which about 455,000 acre-feet was from surface sources and about 126,000 acre-feet was from wells and springs in Jordan Valley. Withdrawal of water for waterfowl-management areas during 1964-68 was about 226,000 acre-feet per year. Of this about 205,000 acre-feet was from surface sources and about 11,000 acre-feet was ground water in Salt Lake County and about 10,000 acre-feet was from surface sources in Davis County. The mean annual withdrawal from six of the principal Wasatch streams in Salt Lake County (94,000 acre-ft) was less than two-thirds of the runoff in those streams; and the withdrawal from Deer Creek Reservoir on Provo River, Wasatch County, for municipal use in Salt Lake County (14,500 acre-ft) was about a quarter of the amount available for that use. The withdrawal from the Jordan River (285,000 acre-ft) exceeded the mean annual discharge of the river at any point because of regulation of runoff in Utah Lake, Utah County, and the gains from tributaries, ground-water discharge, and return of water diverted. The withdrawal of ground water was about a third of the mean annual recharge (about 367,000 acre-ft, of which about 133,000 acre-ft was a result of man's activities).

Although withdrawals from the ground-water reservoir in Jordan Valley nearly tripled during 1932-68, the amount of ground water in storage increased in 28 percent of the valley; and the result was a net storage increase of about 8,000 acre-feet for the entire valley. The amount of ground water in storage in the valley in 1969 was estimated to be 60,000,000 acre-feet; however, only part of this can be withdrawn for use. At water levels of February 1969, about 13,000 acre-feet can be removed per foot of uniform decline in water levels over the entire valley. The amount that could be removed per foot of decline would increase to about 42,000 acre-feet if water levels were 166 feet below those in 1969.

Both the relatively small ratio of ground-water withdrawal to the total ground-water recharge and studies made with an electric analog model of the ground-water reservoir in Jordan Valley indicate that the mean annual withdrawal could be at least doubled in all areas except northwest of Magna. This increase of withdrawal would not cause excessive declines of water level or streamflow or deterioration of chemical quality. A tripled rate of ground-water withdrawal could be maintained for periods of 1 to about 5 years, with lesser rates during other periods to allow recovery of water levels.

Pumping ground water in a relatively undeveloped area in the northern part of Jordan Valley would result in substantial salvage of water now lost by evapotranspiration. Pumping 51,700 acre-feet per year, for example, would salvage about 29,000 acre-feet annually.

Management of the ground-water reservoir would enable use of substantial amount of natural storage capacity that could be used in conjunction with artificial recharge to supplement surface storage. This, however, would not eliminate the need for surface storage.

INTRODUCTION

Salt Lake County is the approximate center of the most thickly populated and highly developed region in Utah. In 1960[1] the county included about 43 percent of the State's population and much of its industry. It also was one of the leading counties in agricultural production. Salt Lake City, Utah's capitol and largest city, is the seat of county government and the nucleus of a metropolitan area that extends beyond the northern border of the county.

The growth pattern exemplified by the concentration of people and industry in this region at the west edge of the Wasatch Range (fig. 1) is expected to continue. The county's population was 383,000 in 1960, had increased to 462,000 by 1968 (Billings, 1969), and is expected to reach 794,000 by 1985 (see table 36). Despite the continuing urban growth, the area under irrigation is expected to decline only slightly.

The task of providing adequate water supplies for Salt Lake City and County within the framework of existing water law has been a continuing struggle for more than a century (Marsell, 1964, p. 141), and the provision for future growth is one of the most critical water problems in Utah. The low flows of streams suitable for municipal use were fully appropriated for such use or for irrigation soon after the original settlement of the county. The needs of the increasing population have been met by providing a small amount of surface storage, transferring water from irrigation to municipal use, exchanging water of poor quality for water of better quality, importing water from outside the county, and withdrawing substantial amounts of ground water. Despite these actions to keep pace with the demand, large quantities of potable water still flow unused to Great Salt Lake; and ground-water levels in parts of the county remain excessively high.

Eventually, Salt Lake County will need to make the maximum feasible use of its local water resources, and this will require comprehensive information about both streamflow and ground water and their interrelations. Recognizing this need, Federal, State, and local authorities (see page 229) entered into an agreement for the U.S. Geological Survey to investigate the water resources of the county. The investigation began in July 1963, and most of the field and laboratory work was completed by 1969.

This report describes the water-resource system and the potential results of different schemes of water-supply development. Its purpose is to provide information required for planning and for sound administrative and legal decisions regarding water resources. Because such decisions often require legal, economic, and engineering information in addition to the hydrologic information, there is no intention to advocate any particular plan of development without consideration of other factors.

WATER PROBLEMS

Most water problems are caused by interaction of man and his hydrologic environment; and hence, are due in part to natural phenomena and in part to man's activities or his rules of conduct. For example, urban encroachment on natural floodways often has been accompanied by flood damage; excessive pollution of some water sources has destroyed much of their original usefulness and caused water shortages; prevailing legal concepts in some states have permitted drastic overdevelopment of water resources and in others have prevented full use.

[1] All years given in this report are calendar years unless designated as water years. (See p. 37.)

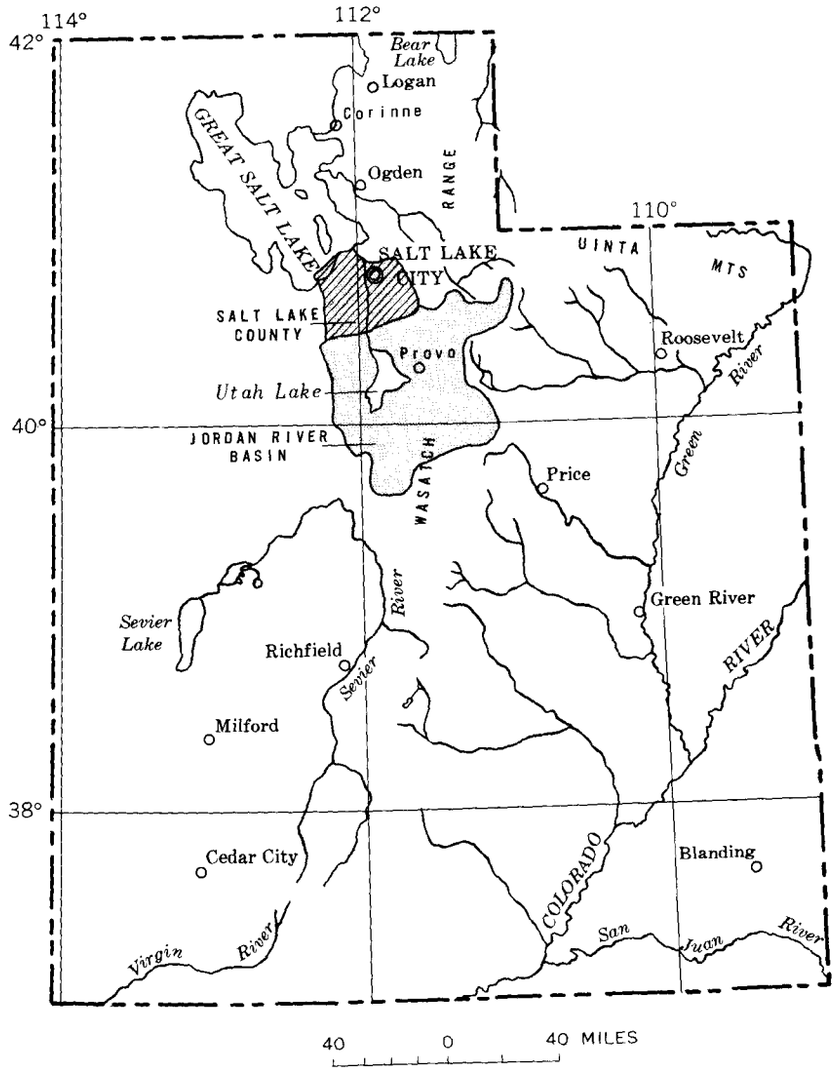


Figure 1.—Locations of Jordan River basin and Salt Lake County.

When considering water-supply problems, it is necessary to distinguish between the total yield of a basin and the usable supply, which is limited by the amount available at the time of need and its quality. It is seldom feasible to make the total yield usable, but prudent management of storage capacity to capture surplus streamflow for later use during drought periods can greatly increase the usable supply.

Lack of sufficient effective storage capacity appears to be the greatest deficiency of the present water-supply system for Salt Lake County. Although the large capacity of Utah Lake is available for regulation of the Jordan River, this regulation affects municipal supplies only indirectly, because of the poor quality for municipal use of Jordan River water. Deer Creek Reservoir, on the Provo River in Wasatch County (see fig. 2), provides useful seasonal storage and some carryover (year to year) storage. Rights to water stored in a previous year, however, are nullified when runoff in the Provo River is sufficient to fill the reservoir. The capacity of surface reservoirs available for regulation of runoff from within the county is only a small fraction of the amount needed for effective regulation. The proposed Little Dell project (authorized in 1968) will provide for regulation of runoff from parts of the area but will leave the largest flows unregulated. Because of the steep topography of the major drainage areas, the costs per unit of capacity in most potential surface reservoirs is relatively high.

The ground-water reservoir underlying the Jordan Valley has a capacity greatly exceeding that required for maximum feasible regulation of the county's water supply. Relatively little use for this purpose has been made of the ground-water reservoir, however, partly because of the nature of the water-supply systems and the water laws that have evolved, and partly because of a lack of information about the ground-water reservoir and its relation to streamflow.

In Utah, as in most other States, the development of both water-supply systems and water laws has been based largely on tradition and an acceptance of conditions 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 serious reduction of water level, artesian head, or discharge in wells with earlier water rights. An example of such a case (Currant Creek Irrigation Co. v. Andrews) was presented by Criddle (1960, p. 48-49).

Although this legal concept was reasonably consistent with ordinary uses of water when the amount of water used was only a small fraction of the amount readily available, it becomes increasingly inconsistent as the need for water approaches the total water yield. The effect of this policy was (1) to maintain a full ground-water reservoir with water levels and artesian heads near their natural state, unless all owners of wells in a particular reservoir reached an agreement to allow substantial lowering; (2) to prevent the most effective use of the reservoir storage capacity, because such use of any reservoir requires fluctuation of its contents throught a considerable range; and (3) to prevent salvage of much of the water now wasted by discharge to Great Salt Lake and by evapotranspiration from areas of shallow water table.

Because of this legal policy, some engineering plans for development of ground water in the county specified a certain quantity of ground-water withdrawal during normal or wet years and a much smaller quantity during drought years, because the water levels and heads are naturally lower then (Berger Associates, Inc., 1964, p. 97). Such use of ground water tends to intensify, instead of alleviate, the problems resulting from a lack of storage capacity in the entire water-supply system.

Simple removal of all legal restraints on withdrawal of ground water might solve part of the problem noted above, but also, might encourage overdevelopment of the ground-water

reservoir and produce a situation worse than the one just described. Unlimited withdrawals would tend to cause large and continuing declines of water level, severe reduction of streamflow, encroachment of salt water into some of the reservoir, and probably land subsidence in areas of large declines.

A recent unanimous decision of the Supreme Court of the State of Utah (1969) suggests that henceforth the legal policies concerning water resources will not follow either of the extremes described above. 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 that the greatest amount of available water is put to beneficial use."

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."

Optimum development of the total water resource can occur only under unified or coordinated management. 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 make a larger proportion of the total water yield usable. Although past withdrawals have followed this pattern in some degree, the county could greatly increase its use of the existing 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 be difficult 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 of successful management tend to increase.

In 1958, a survey of the county by the Utah State Engineer showed that 28 municipal-type systems supplied more than 85,000 service connections (Marsell, 1964, p. 148); and by 1969, 36 systems supplied more than 110,000 service connections (determined largely from records in the State Engineer's office). 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 report presents appraisals based on conditions that may be attainable in the future even though they may not be attainable at present.

In addition to being available when needed, a usable water supply must meet certain standards of quality for its intended use. Although water is a chemical compound of unvarying composition, it contains varying amounts of other substances in solution or suspension. Moderate concentrations of such substances as dissolved oxygen and certain dissolved solids improve the quality of water for some uses; but most water-quality problems are a result of excessive concentrations of dissolved solids, organic compounds, undesirable micro-organisms, sediment, or excessive temperature.

Salt Lake County's largest stream (the Jordan River) is unsuitable for municipal use without intensive treatment because of many contaminants. Nevertheless, the river south of Salt Lake City is the principal source of water in the county for irrigation and heavy industrial use. The river is contaminated from natural sources and activities of man upstream from the Jordan Narrows where it enters the county. Nearly all of this water is diverted within a few miles downstream from the Jordan Narrows, but the discharge increases again as the river flows northward. Municipal, industrial, and agricultural wastes entering the river within Jordan Valley render the quality of water in the lower part of the river unsuitable for any uses but those with the lowest quality requirements, such as cooling in industrial or power plants, irrigation of meadow, and maintenance of waterfowl-management areas.

Because of the limitations on the use of the county's largest water supply, preservation of the quality of other major supplies is especially important.

A complete understanding of the water-resources problems in Salt Lake County and the most effective planning for use and administration of these water resources require a detailed, quantitative examination of the hydrologic environment, which is presented in the following sections. The description of each major water source includes a discussion of quantities and a description of its chemical characteristics. The relations of these chemical characteristics to certain uses of the water are discussed in a section on water use and water loss. This section is followed by an appraisal based largely on electric analog studies of several possible courses of water-resources development. All appraisals are in general terms rather than in relation to specific projects; hence, they differ from an engineering design study. The information, however, should be useful for any activity involving the hydrology of the county.

HYDROLOGIC ENVIRONMENT

Water in the ground and in streams and lakes is the source of water supply (other than precipitation) and provides the best opportunities for control or management of water resources. Although some control of precipitation by cloud seeding has been attempted for several years, such programs are still in the experimental stage and no evaluation is included herein. If such programs become feasible, the chief result will be an increase of the mountain snowpack, and the need for management of both surface and underground supplies will not be lessened.

Because of the interchange of water between the ground-water reservoir and streams, any marked change in the regimen of one affects the other. As withdrawals of water in Salt Lake County are largely concentrated in Jordan Valley, however, the most significant changes of the hydrologic regimen resulting from increased water-supply development will be in the valley and in reaches of streams below surface reservoirs. Hence, except for estimates of ground-water discharge and recharge, the study of ground water is largely limited to the valley.

Physiographic setting

Salt Lake County coincides with the lower part of the Jordan River basin (fig. 2) except for a few square miles of the basin, north of Salt Lake City and east of the river, which are in Davis County. Although an area near Garfield and Magna in the northwestern part of Salt Lake County drains to Great Salt Lake through small streams and artificial channels, it is considered part of the Jordan River basin because it is part of the same structural valley and much of the water in these streams is diverted from the Jordan River.

The Jordan River enters the county at Jordan Narrows, a gap in the low Traverse Mountains that mark the southern boundary of the county and flows northward to Great Salt Lake through the broad Jordan Valley (also known as Salt Lake Valley). The valley floor has considerable relief, the altitude ranging from about 4,200 feet at Great Salt Lake to about 5,200 feet where it joins the bordering mountains. Beyond the western margin of the valley the Oquirrh Mountains rise to more than 9,000 feet, and beyond the eastern margin the Wasatch Range rises to more than 11,000 feet.

The total area of the county is about 780 square miles. Of this total, nearly 500 square miles are in the Jordan Valley; and the remainder is rugged, mountain terrain (pl. 1) suitable chiefly for forests, mines, recreation, and watershed.

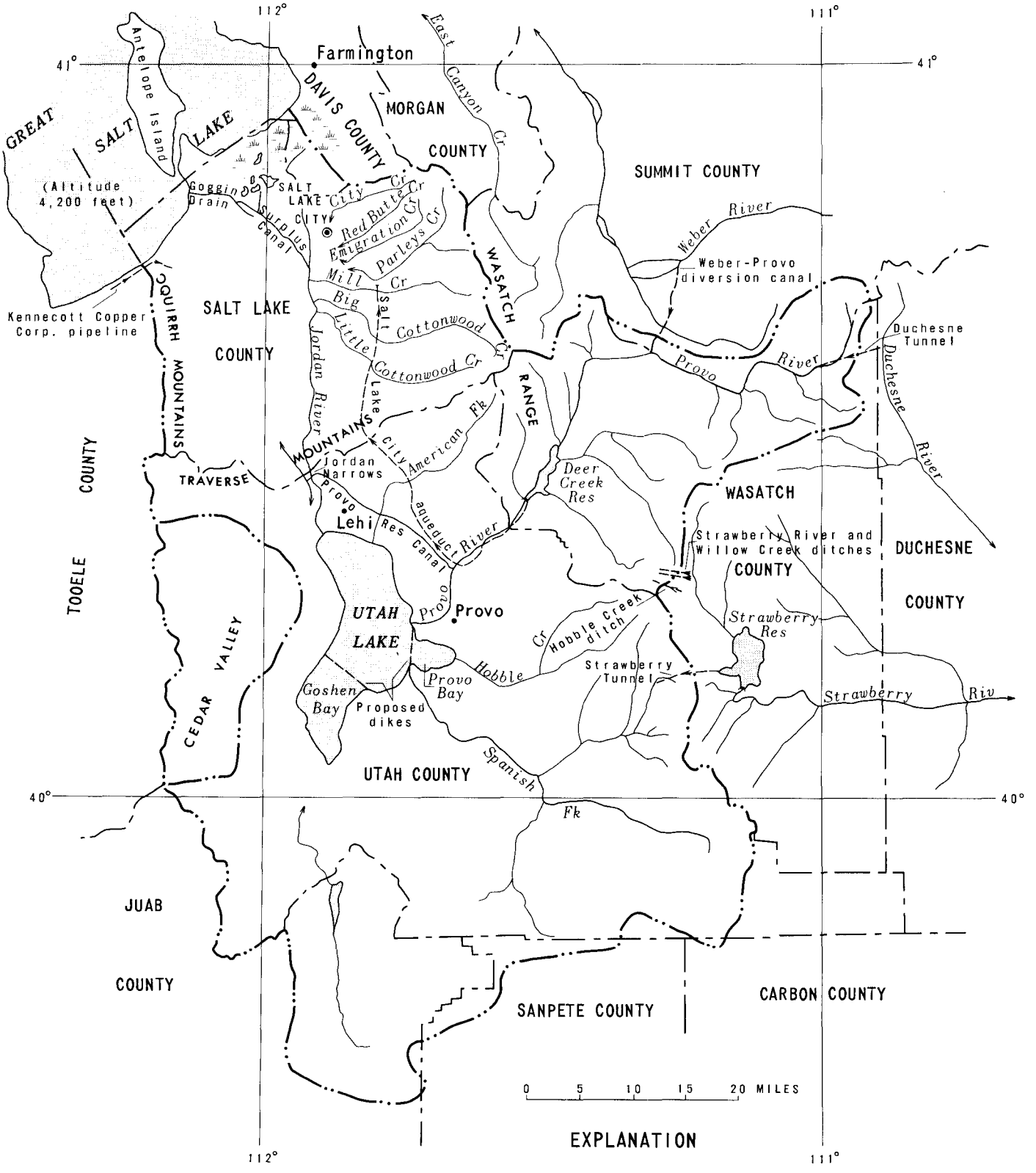
The climate ranges from semiarid in parts of the Jordan Valley to humid in the highest mountains. Conditions in the county generally are favorable for absorption of water into the soils and parts of the underlying ground-water reservoir. Ground-water discharge maintains substantial streamflow in some mountain canyons and in parts of the valley and streams lose water by seepage into the ground in other parts of the valley. Summer precipitation in the valley is generally light and undependable so that agriculture depends largely on irrigation.

The principal water sources within the county are the Jordan River, several creeks draining parts of the Wasatch Range, and the unconsolidated saturated valley fill, which locally is more than 2,000 feet thick. Water is now being imported from other basins and current plans include additional imports of up to 50,000 acre-feet per year.

The drainage area of the Jordan River at the narrows comprises about 3,000 square miles of mountain and valley terrain, including 255 square miles in a closed basin in Cedar Valley west of Utah Lake (fig. 2) which usually is included as a part of the river basin. The head of the river, 7.5 miles upstream from the narrows, is the natural outlet of Utah Lake, a shallow lake occupying about 150 square miles. The outflow is controlled by gates in the river channel or by pumping from the lake when the water level is too low to maintain the desired outflow.

The principal tributaries of Utah Lake are Spanish Fork, Hobble Creek, Provo River, and American Fork, all of which drain parts of the Wasatch Range. The Provo River also drains a part of the Uinta Mountains. The natural flow of some of these streams is supplemented by transmountain diversions from the Weber River in the Great Salt Lake basin and from the Duchesne and Strawberry Rivers in the Colorado River basin. Much of the flow in these tributaries is diverted and never reaches Utah Lake. Some water, from Deer Creek Reservoir on the Provo River and from the Provo River below the reservoir, is diverted to Salt Lake County without passing through the lake.

Salt Lake County's water supply from all major sources is distributed through the Jordan Valley in a complex system of closed conduits and open canals—some of them interconnected.



Base from U.S. Geological Survey State base map, 1959, scale 1:500,000

Figure 2.—Jordan River basin.

Geologic setting

by

Ted Arnow

The hydrology of Salt Lake County is profoundly affected by differences among the rocks that form and underlie the surface of the land. The rocks in the mountains that fringe the valley are consolidated, with little primary porosity; and they would not be expected to yield large quantities of water to wells. Some of these rocks do have considerable overall secondary porosity in the form of joints, fractures, and solution openings, however; and they act as important conduits for the underground transmission of water.

The rocks shown on plate 1 in the mountains are grouped in four hydrologic units based on their inferred relative ability to transmit water in the subsurface. The grouping was based on a consideration of rock types and an evaluation of the amount of runoff observed in streams that drain areas underlain by each type. Rocks in the lowest permeability unit would be expected to absorb water most slowly; and therefore, precipitation on rocks in this unit would result in maximum runoff. Precipitation on rocks in the highest permeability unit would result in minimum runoff. The rocks in each hydrologic unit are described below.

Rocks of highest permeability.

> Weber Quartzite of Pennsylvanian age - Quartzite and limy sandstone with some interbedded limestone and dolomites; greatly fractured in places; reported by Baker (1970, p. 18) to be the principal source of water in the mines of the Park City Mining District on the east side of the Wasatch Range.

Rocks of moderately high permeability.

> Rocks of Mississippian age - predominantly limestone in which bedding planes, joints, and other fractures are subject to enlargement by solution; these rocks are known to be cavernous in Neffs Canyon.

Rocks of moderately low permeability.

> Rocks of Pennsylvanian (excluding the Weber Quartzite), Permian, and Mesozoic age and sedimentary rocks of Tertiary age older than the Salt Lake Formation—shale, siltstone, sandstone, conglomerate, and limestone, whose original porosity for the most part was not great and has not been appreciably changed by secondary processes.

Rocks of lowest permeability.

> Precambrian, Cambrian, and Devonian rocks, and intrusive and volcanic rocks of Tertiary age—crystalline rocks, shale, tillite, limestone, and volcanic rocks having either low original porosity or porosity that has been decreased by secondary processes.

The rocks that constitute the valley fill in the Jordan Valley are mainly unconsolidated, but in places they are semiconsolidated or consolidated. Some of the unconsolidated rocks are very porous and permeable and yield large quantities of water to wells. The valley fill consitutes

the main ground-water reservoir in the valley. Differences in water-yielding capacity from place to place in the reservoir are affected by the type of rock, its history of deposition, and the saturated thickness.

The principal rock types in the valley fill are made up of clay, silt, sand, gravel, tuff, and lava. They were laid down as lake deposits (in beaches, spits, bars, deltas, or on the lake bottom); mud-rock flow deposits; alluvial fans; sand dunes; glacial deposits; flood-plain deposits; ash falls; or lava flows. The history and sequence of deposition was complex, as described by Marine and Price (1964, p. 23):

"The type of material that was deposited in any locality was determined to some degree by the nearness of the locality to a canyon mouth, the mountain front, or a valley stream channel. Thus, no stratigraphic sequence is applicable to the valley as a whole. Some of the areas that were inundated by Lake Bonneville received deposits from the lake, other areas were eroded by lake currents; some areas that received Lake Bonneville deposits were later subjected to extensive stream erosion which removed the lake deposits, other areas were covered by post-lake stream deposits."

Because of the complex history of depostion and erosion, the rocks that constitute the surface of the valley fill in the Jordan Valley are not necessarily the same as the rocks to be encountered at depth. Thus, it was not felt necessary to differentiate the surficial rocks on plate 1. Furthermore, it was not found feasible to correlate individual water-bearing zones throughout the valley fill, although it was possible to divide the fill into an upper more permeable zone and a lower less permeable zone. The more permeable zone consists essentially of unconsolidated rocks of Quaternary age, whereas the underlying less permeable zone consists to a great extent of semiconsolidated and consolidated rocks of Tertiary age. The Quaternary rocks in many places in the valley yield large quantities of good quality water to wells. At no place in the valley are the Tertiary rocks known to yield large quantities of water; but several public supply and irrigation wells obtain some water from these rocks. Arnow and others (1970) describe the method of differentiating the Quaternary from the Tertiary rocks; and this differentiation and the water-level map (pl. 1) were used as a basis for constructing the saturated thickness map shown in figure 64 of this report.

For more detailed descriptions of surface and subsurface geology, geologic structure, and geologic history of Salt Lake County, the reader is referred to the references listed later in this report.

Climate

The climate of Salt Lake County is characterized by a rather wide range of temperatures, but the extremes in the populated areas are less severe than those common to many regions in the western United States. The growing season in the valley generally lasts about 7 months, April to October, for some common types of vegetation.

Most features of the climate are strongly influenced by the altitude and topography. Air temperatures, for example, tend to decrease as altitude increases but are influenced to a smaller degree by several other factors.

In winter, masses of moist air that form over the Pacific Ocean move eastward across the continent and supply nearly all the precipitation in Utah. Each mountain range in the path of the moist air forces it upward, causing a decrease in temperature and an increase in precipitation; and as the air descends the eastern slopes, the temperature rises and precipitation decreases.

In summer, moist air may reach Salt Lake County from either the Pacific Ocean or the Gulf of Mexico, and the influence of mountain ranges is less significant than in winter because uneven heating of the land surface is an important cause of vertical air currents. Summer precipitation commonly occurs in many isolated thunderstorms, each covering only a few square miles.

The climatic factors that have the greatest influence on water resources and needs are precipitation, temperature, and evaporation, which are discussed in the following sections. The characteristics of each factor are best defined by the longest available records. However, as the periods of record for climatologic and other hydrologic data vary greatly, several periods have been selected for convenience in comparisons and water-budget studies. The U.S. Weather Bureau and the World Meteorological Organization have defined current normals of climatologic data as the means for 1931-60. Each decade new normals will be computed using the 30 years ending in 1970, 1980, etc.

The locations of climatologic stations, except for several stations with short-term or fragmentary precipitation records, are shown in figure 3. The letter symbols aid identification of stations mentioned in the text.

Precipitation

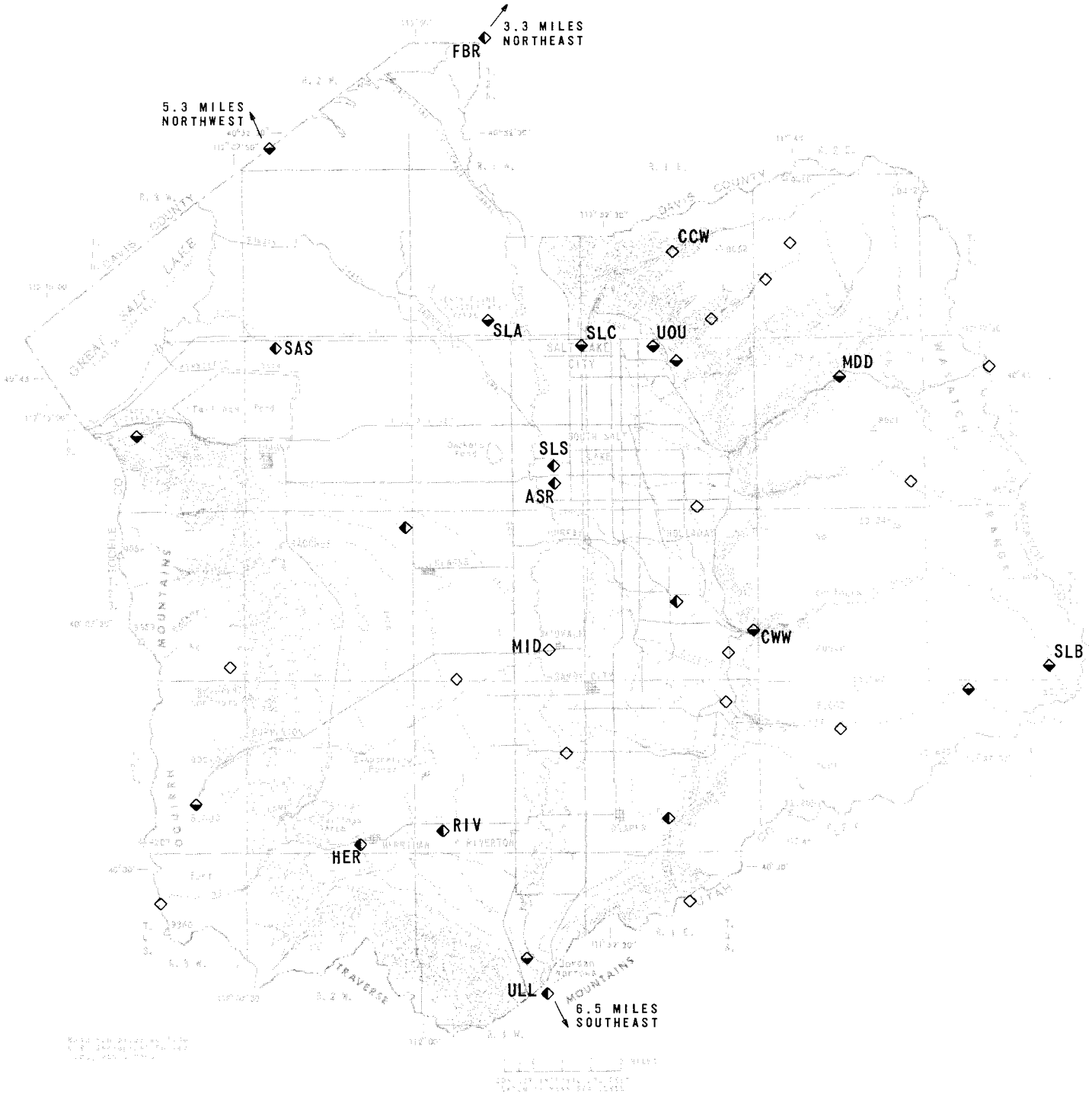
Areal variations

Although a general relation between topography and precipitation in Salt Lake County is obvious, the precise nature of the relation has been difficult to define until recent years, partly because altitude is only one of several factors involved and partly because there are few precipitation gages at high altitudes. In one of the numerous studies of this problem, Peck and Brown (1962) developed a method that has been widely used to produce isohyetal maps for the western part of the United States, including maps of normal October-April, May-September, and annual precipitation in Utah (U.S. Weather Bur., 1963a and b). The Weather Bureau also developed a large-scale (1:62,500) map of normal annual precipitation for part of the Wasatch Range. This unpublished map shows greater detail but is otherwise the same as the State map.

All stations with 5 or more years of record were used by the Weather Bureau in developing these maps. The normal for a station with less than 30 years of record was computed from the normal for a nearby full-term station and the ratio of the short-term means.

Figure 4, which shows the normal annual precipitation in Salt Lake County, was compiled using the large-scale map for the eastern part and the State map for the remainder. The 14-inch isohyet, which does not appear on the Weather Bureau maps, was added to provide more detail in the valley.

The mean annual precipitation in Jordan Valley during October 1963 to September 1968—required for water-budget studies in this investigation—is shown in figure 5. Short-term or fragmentary records for stations not shown in figure 3 and the effects of topography as exemplified by figure 4 were considered in drawing the isohyets. The areal pattern is similar to that of the normals (fig. 4), but the mean annual precipitation is about 2 inches higher.



EXPLANATION

◇ Precipitation

◆ Precipitation and air temperature

◐ Precipitation, air temperature, and pan evaporation

— · — · — Boundary of drainage basin

The letter symbols identify stations as follows:

ASR, American Smelting and Refining Co.
CCW, City Creek Water Plant
CWW, Cottonwood Weir
FBR, Farmington Bay Refuge
HER, Herriman
MDD, Mountain Dell Dam
MID, Midvale
RIV, Riverton (near)
SAS, Saltair Salt Plant
SLA, Salt Lake City International (formerly Municipal) Airport
SLB, Silver Lake Brighton
SLC, Salt Lake City (main post office)
SLS, Salt Lake City Suburban Sewage Plant
ULL, Utah Lake Lehi
UOU, University of Utah

Figure 3.—Locations of principal climatologic stations.

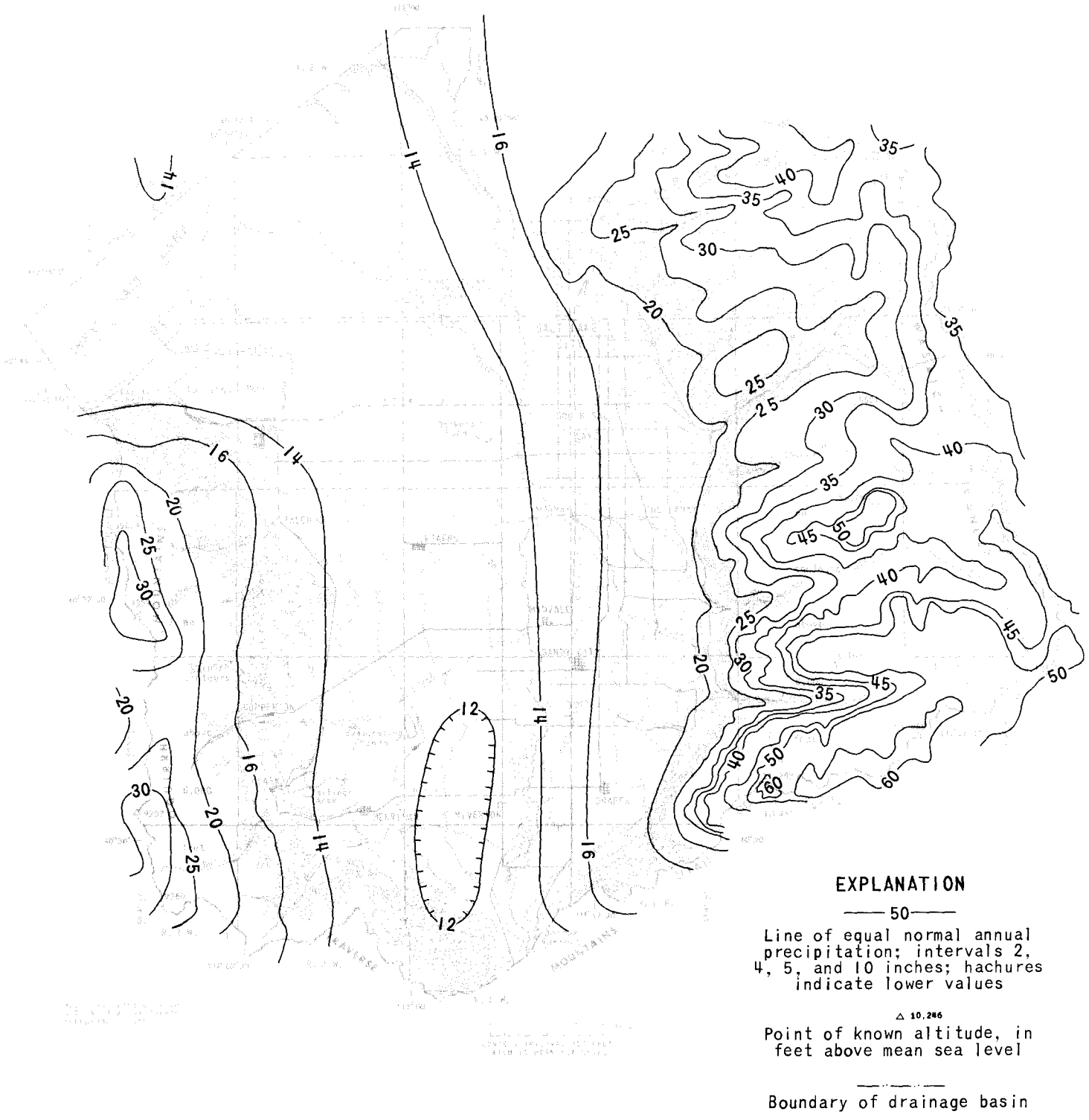


Figure 4.—Normal annual precipitation in Salt Lake County (1931-60). (Adapted from U.S. Weather Bureau, 1963a).

Annual precipitation near the Salt Lake City main post office for 1875-1967[1] has ranged from about 10.5 inches, 66 percent of the 93-year mean (15.9 in.), to about 23.5 inches (148 percent of mean). Although precipitation has often been above the mean for several consecutive years, and below the mean for similar periods, no significant trend is evident. In areas of higher precipitation the range, in inches, is greater but the corresponding percentages are similar.

The record for the Salt Lake City main post office, where the Weather Bureau operated a station from 1875 to 1953 (see table 1), is the longest record for Salt Lake County. Hence, it is the best record to indicate the relation of precipitation during shorter periods to a long-term mean. During this period the gage was at six different sites but all were within two city blocks of Main and 2nd South Streets. The annual precipitation at the latter site during 1954-67 has been estimated from the observed precipitation at the Salt Lake City International Airport, 3.5 miles west, and at the University of Utah, 2.2 miles east. Simultaneous observations at the three sites for 1949-53 indicate that the best estimate is one-third the sum of precipitation at the university plus twice the precipitation at the airport. A record for approximately the same site as the main post office—kept by H. E. and W. W. Phelps, published currently by a Salt Lake City newspaper (The Deseret News), and republished in the Weather Bureau's (no date) climatic summary—covers an earlier period, 1857-66. As the two periods are not consecutive, the earlier data are not included in the long-term mean; but they are of interest because the precipitation during 1866 (27.56 in.) was nearly 4 inches greater than during 1875 and more than 5 inches greater than during any year since 1875. The entire record is shown as a bar graph in figure 6.

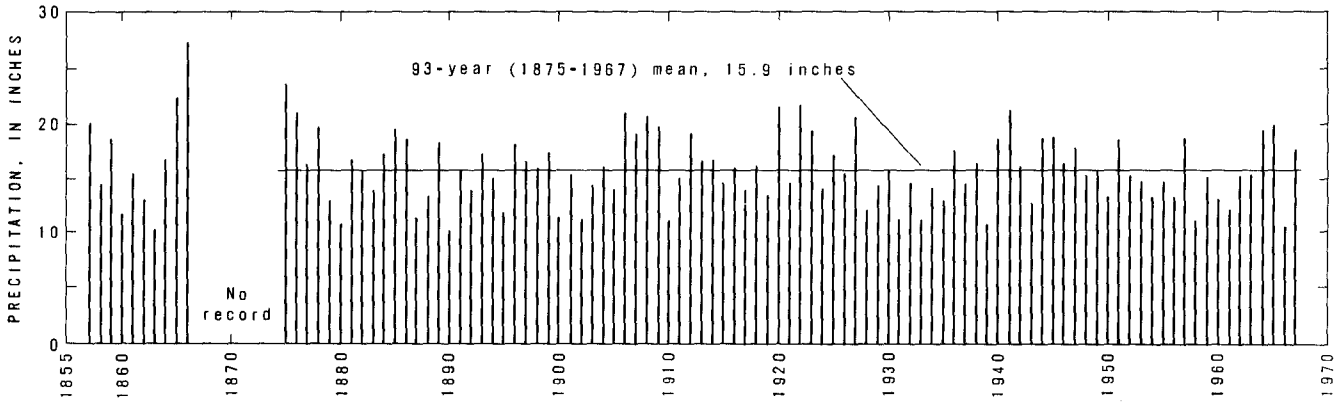


Figure 6.—Annual precipitation at Salt Lake City (near main post office), 1857 to 1967. Data prior to 1954 are from published reports of the U.S. Weather Bureau; those for 1954-67 are estimated from records of precipitation of the Salt Lake City International Airport and the University of Utah.

[1] Long-term means for this and other stations are for periods ending in 1967 because many of the analyses were completed before 1968 records were available.

Many long-term records consist of observations made at two or more sites that are close enough together to be considered a single station. Sometimes, however, even a seemingly minor change in location causes a significant difference in the observed amounts of precipitation, so that the combined record is not homogeneous. Such a condition generally can be detected by a simple test. Cumulative precipitation at one station is plotted against corresponding accumulations for another in the same region. If the plotted points scatter only slightly about a single straight line through the origin of the plot, there has been no change in the relation between the observed amounts and both records probably are homogeneous. On the other hand, if the plotted points define two or more lines with significantly different slopes, one or more changes have occurred and one or both records are nonhomogeneous.

The cumulative precipitation at Salt Lake City is compared with corresponding accumulations for five other stations in figure 7. Each relation is adequately defined by a single straight line; hence, all records probably are homogeneous for the periods since 1912 or the beginning of the shorter record (which is no later than 1920).

To obtain a similar check on the reliability of earlier records, the cumulative precipitation at Salt Lake City was compared with that at Corinne, Utah, 56 miles north. A single straight line (not shown herein) adequately defines the relation applicable from about 1880 to about 1928. Consequently, both records probably are homogeneous for that period. As the period of homogeneity of the Salt Lake City record determined by comparison with the Corinne record overlaps the period determined by comparisons in figure 7, the Salt Lake City record probably is homogeneous for the period 1880-1967. A significant change in the Salt Lake City-Corinne relation that occurred about 1928 must, then, be attributed to some change that has affected the Corinne record. There is no adequate check on the reliability of records prior to 1880.

Table 1 presents a summary of annual precipitation at six sites during four periods—two selected for comparisons with streamflow data, the base period for normals (1931-60), and the period of this investigation.

Four of the records summarized in table 1 did not begin until after 1914, and consequently, the means for 1914-67 were derived from the relations shown in figure 7. For example, the record for Mountain Dell Dam began in 1920, and the mean for 1920-67 is 22.30 inches; but the mean for 1914-67 was estimated to be 1.45 x 15.6 = 22.6 inches.

In most of the mountainous areas in the western part of the United States the longest precipitation records are for sites at relatively low altitudes, whereas most streamflow is produced by precipitation at relatively high altitudes. Hence, it is pertinent to consider the validity of low-altitude precipitation as an index of high-altitude precipitation or runoff.

Figure 8 shows the correlation of annual precipitation at Midvale, in Jordan Valley, with that at two other stations which are within 18 miles of Midvale. However, one of these (Salt Lake City) is at about the same altitude as Midvale and the other (Silver Lake Brighton) is about 4,400 feet higher. Although the comparison of cumulative precipitation (fig. 7) indicates that long-term means may be proportional even when large differences in altitude are involved, the comparison of annual precipitation (fig. 8) shows that correlative estimates of annual precipitation at a high altitude (or runoff from high mountains) based on annual precipitation at a low altitude may be subject to large errors.

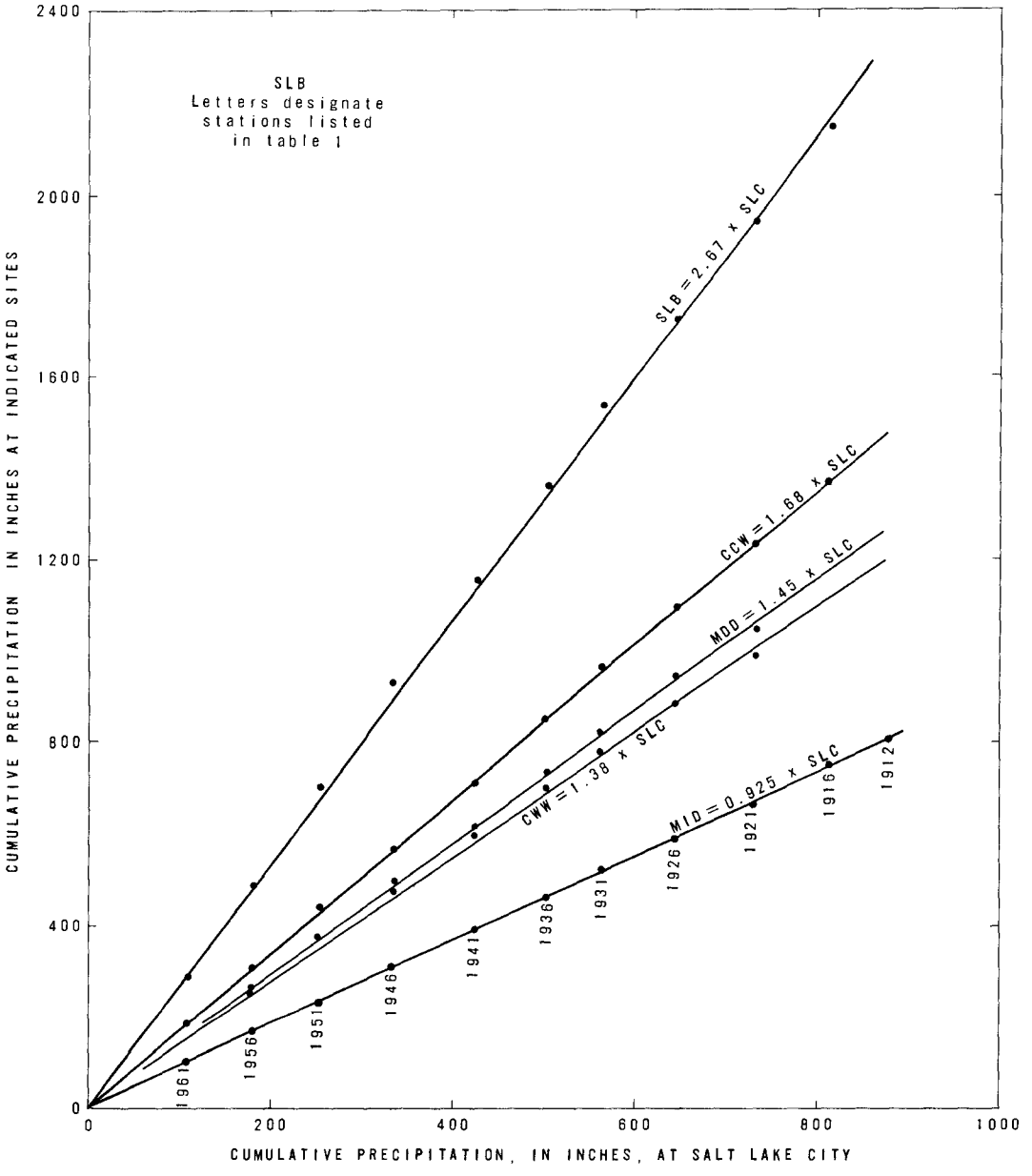


Figure 7.—Comparison of cumulative precipitation at selected sites. The cumulation is from December 31, 1967, backwards to January 1 of the year indicated. The equations show the relations of cumulative precipitation at each site to that at Salt Lake City.

Table 1.–Summary of annual precipitation, in inches, at long-term stations

[Figures in parentheses following maximum and minimum values are percentage of mean.]

Map symbol (fig. 3)	Station	Statistic	Calendar years 1914-67		Calendar years 1943-67		Calendar years 1931-60		Water years 1964-68
CCW	City Creek Water Plant[1]	Maximum	36.46	(139)	36.44	(139)	33.22	(129)	35.88
	(altitude, 5,340 ft)	Mean	26.2 [2]		26.24		25.70		30.08
		Minimum	18.53	(71)	19.97	(76)	18.53	(72)	19.32
CWW	Cottonwood Weir	Maximum	29.10	(135)	29.06	(132)	29.10	(138)	28.69
	(altitude, 4,950 ft)	Mean	21.5 [2]		22.02		21.04		24.25[3]
		Minimum	14.17	(66)	15.45	(70)	14.17	(67)	15.15
MID	Midvale	Maximum	24.49	(169)	19.39	(135)	22.02	(157)	20.43
	(altitude, 4,340 ft)	Mean	14.51		14.40		14.02		16.27
		Minimum	9.54	(66)	9.54	(66)	10.21	(73)	10.14
MDD	Mountain Dell Dam	Maximum	35.04	(155)	35.04	(154)	29.67	(135)	34.88
	(altitude, 5,420 ft)	Mean	22.6 [2]		22.81		21.91		26.72
		Minimum	14.52	(64)	17.08	(75)	14.84	(68)	18.38
SLC	Salt Lake City[4]	Maximum	21.69	(139)	19.9	(128)	21.24	(140)	.....
	(altitude, about 4,260 ft)	Mean	15.6		15.5		15.2		.....
		Minimum	10.5	(67)	10.5	(68)	10.68	(70)	.....
SLB	Silver Lake Brighton	Maximum	54.69	(131)	54.69	(128)	54.69	(132)	54.69
	(altitude, 8,700 ft)	Mean	41.7 [2]		42.92		41.45		43.15
		Minimum	27.31	(65)	29.62	(69)	27.31	(66)	34.37

[1] Published as Highline City Creek prior to 1956.

[2] Computed from relation in figure 7. Records began as follows: CCW and SLB, 1916; CWW, 1918; and MDD, 1920.

[3] Partly estimated.

[4] Data for 1954-67 estimated. See figure 6 for record prior to 1914.

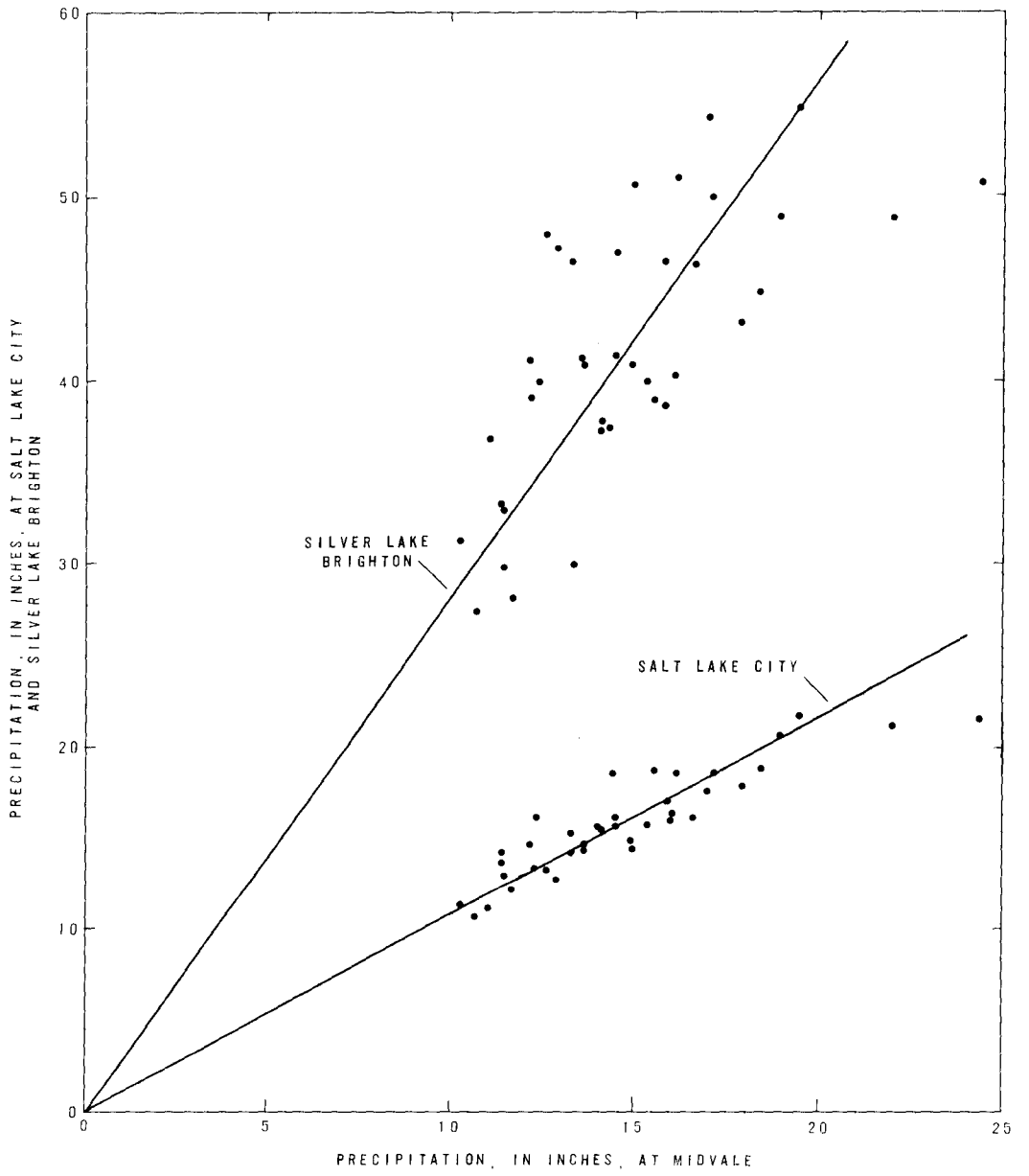


Figure 8.—Correlation of annual precipitation at Midvale with that at Salt Lake City and Silver Lake Brighton, 1916-53.

Seasonal variations are shown by the bar graph of means and extremes of monthly precipitation (fig. 9) for a valley station (Midvale) and a mountain station (Silver Lake Brighton). The effect of the higher altitude of Silver Lake Brighton is reflected in the larger means and ranges and also in greater seasonal variation.

As communities along the base of the Wasatch Range are vulnerable to flooding by unusually high runoff from the mountains, the amounts of rain that fall within a few hours are very significant even though they are much smaller than those experienced in many other parts of the nation. The U. S. Weather Bureau (written commun., 1968) has presented a summary of 6-hour and 24-hour precipitation in a series of maps of Utah. The Salt Lake County portions of four of these maps are reproduced in figure 10. At latitude 40° 30′, longitude 112° , for example, the upper left map indicates that the 6-hour rainfall with a 50-percent chance of being exceeded is about 0.7 inch. That is, this amount will be exceeded in half the years or will have an average recurrence interval of 2 years. For the same site, the upper right map indicates that the 6-hour rainfall with a 2-percent chance of being exceeded (average recurrence interval, 50 yrs) is about 1.75 inches.

Maps based on data for both winter and summer months indicate somewhat higher amounts of precipitation than those in figure 10. Since the greatest amounts in winter generally occur as snow, however, the amounts based on the May-October data are more significant as potential flash-flood producers.

A series of thunderstorms during a 28-hour period of September 5-6, 1965, may be fairly typical of the more intense summer storms in the county. Figure 11 shows isohyets for this period as developed by the Weather Bureau (written commun., 1965) from observations at about two dozen gages. The small areal extent of the most intense precipitation and the relative independence from the effects of topography are evident, as the isohyets are predominantly perpendicular to the mountain range instead of parallel as they would be for the usual winter storm.

Chemical Quality

Although precipitation is the purest natural water available it contains appreciable quantities of dissolved solids and gases by the time it reaches the earth. Sodium, chloride, boron, aluminum, silica, calcium, magnesium, some of the sulfate and nitrogenous compounds, and other elements are derived from airborne evaporites or floating continental dust. Solution of atmospheric gases provides bicarbonate and additional sulfate and nitrogenous compounds. The sulfate is usually most abundant near certain types of industry.

Two sets of data pertaining to the quality of precipitation in Salt Lake County are available. Samples of all precipitation at 2044 East 2920 South, Salt Lake City, collected between August 4, 1963, and September 27, 1964, were analyzed for chloride content, and the specific conductance was measured. Evaporation of the samples was minimized by funneling the rain (or snow melted shortly after each storm) into a covered container through a small opening. The weighted-mean concentration of chloride for the period was 3.96 mg/l (milligrams per liter). This set of data which is summarized in figure 12, shows fair correlation (coefficient, 0.7) between the chloride content and specific conductance, the latter usually being a good index of dissolved-solids content. (See discussion of chemical quality of water in the Wasatch streams.) Only slight correlation exists (coefficient, 0.30) between the chloride content and the amount of precipitation, the largest chloride content tending to occur in the smallest amounts of precipitation. This relationship probably results chiefly from the washing of dust from the atmosphere during the first few minutes of a storm. For example, the chloride content of precipitation amounting to only 0.05 inch, Sept. 1-8, 1964, was 20 mg/l, but 2.02 inches that fell during April 26 to May 3, 1964, contained only 1.6 mg/l. Although chloride content may be inversely related to the amount of precipitation, the total quantity of chloride is directly related to precipitation. Thus, in the example above the total chloride during the heavy April storm was nearly three times that of the light September storm.

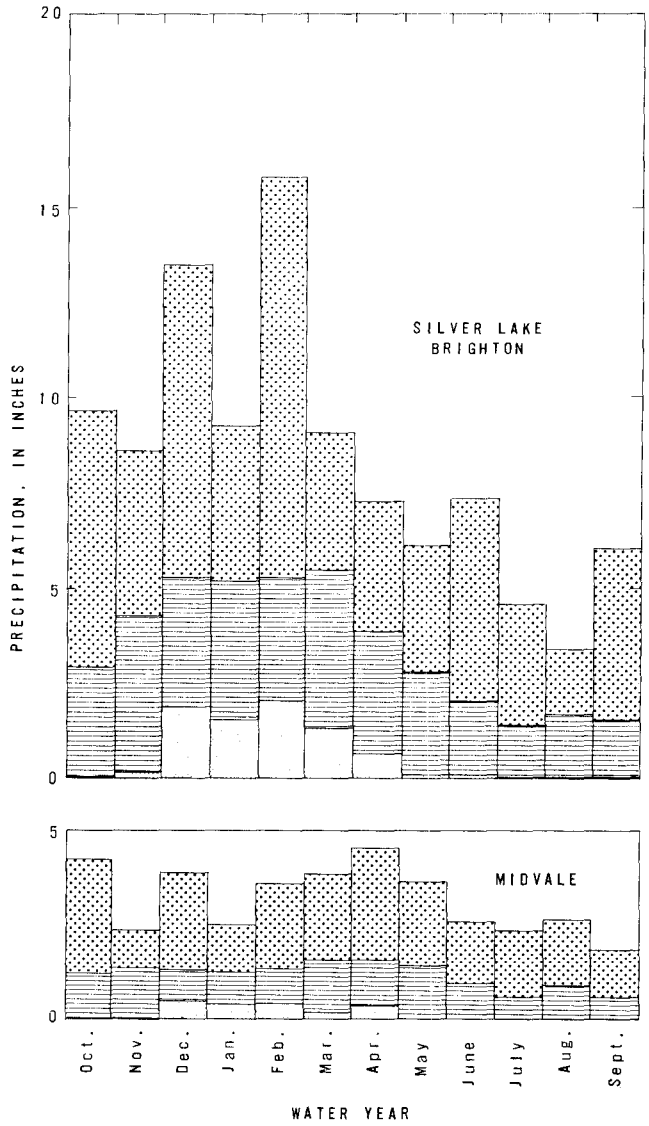


Figure 9.—Seasonal variations of precipitation at Midvale and Silver Lake Brighton, 1931-60. The bars show maximum, mean, and minimum values for each month. The minimum for some months is zero.

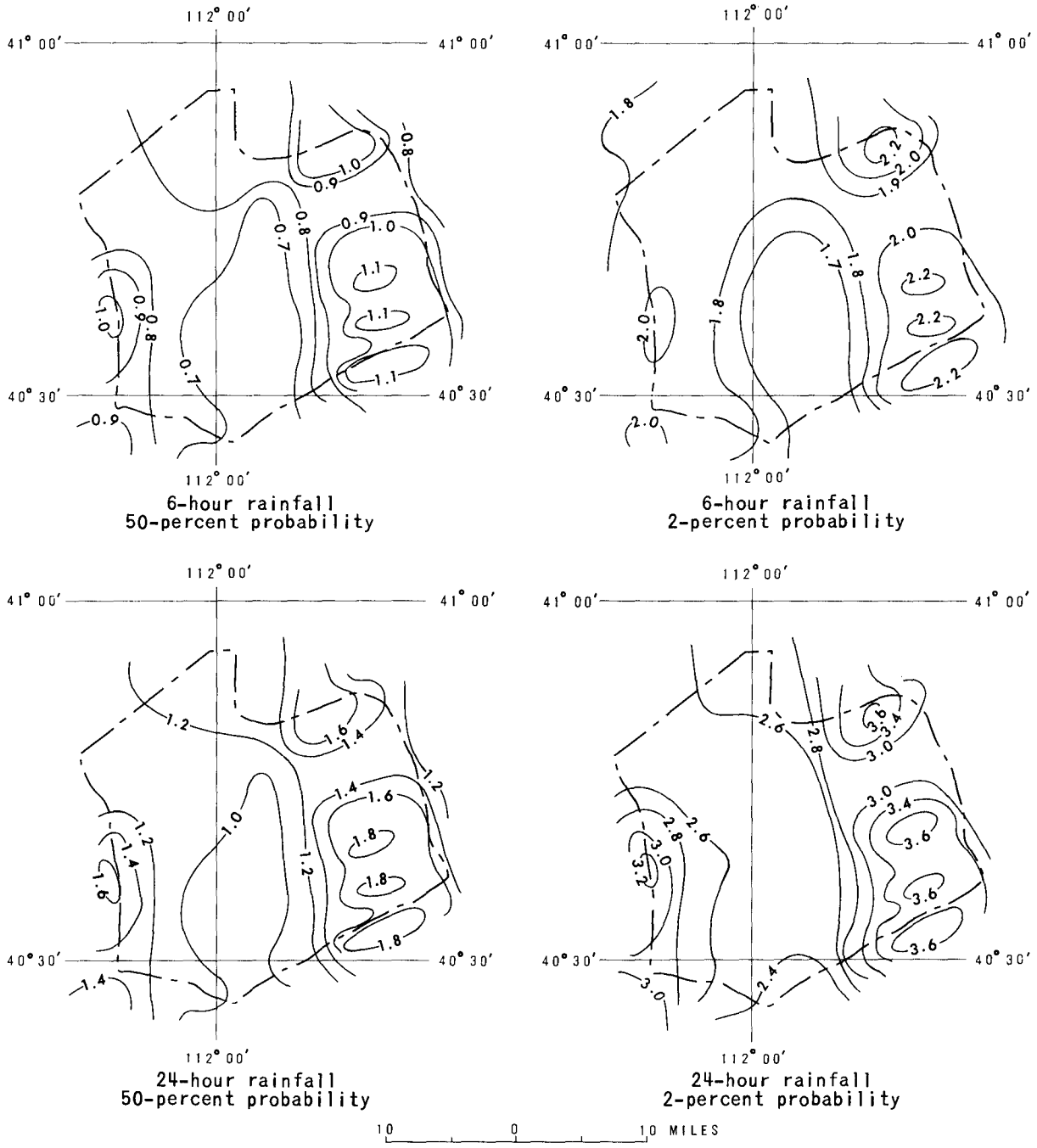


Figure 10.—Rainfall in Salt Lake County during 6-hour and 24-hour periods, May-October, with 2-percent and 50-percent probabilities of being exceeded. (After U.S. Weather Bur., written commun., 1968.)

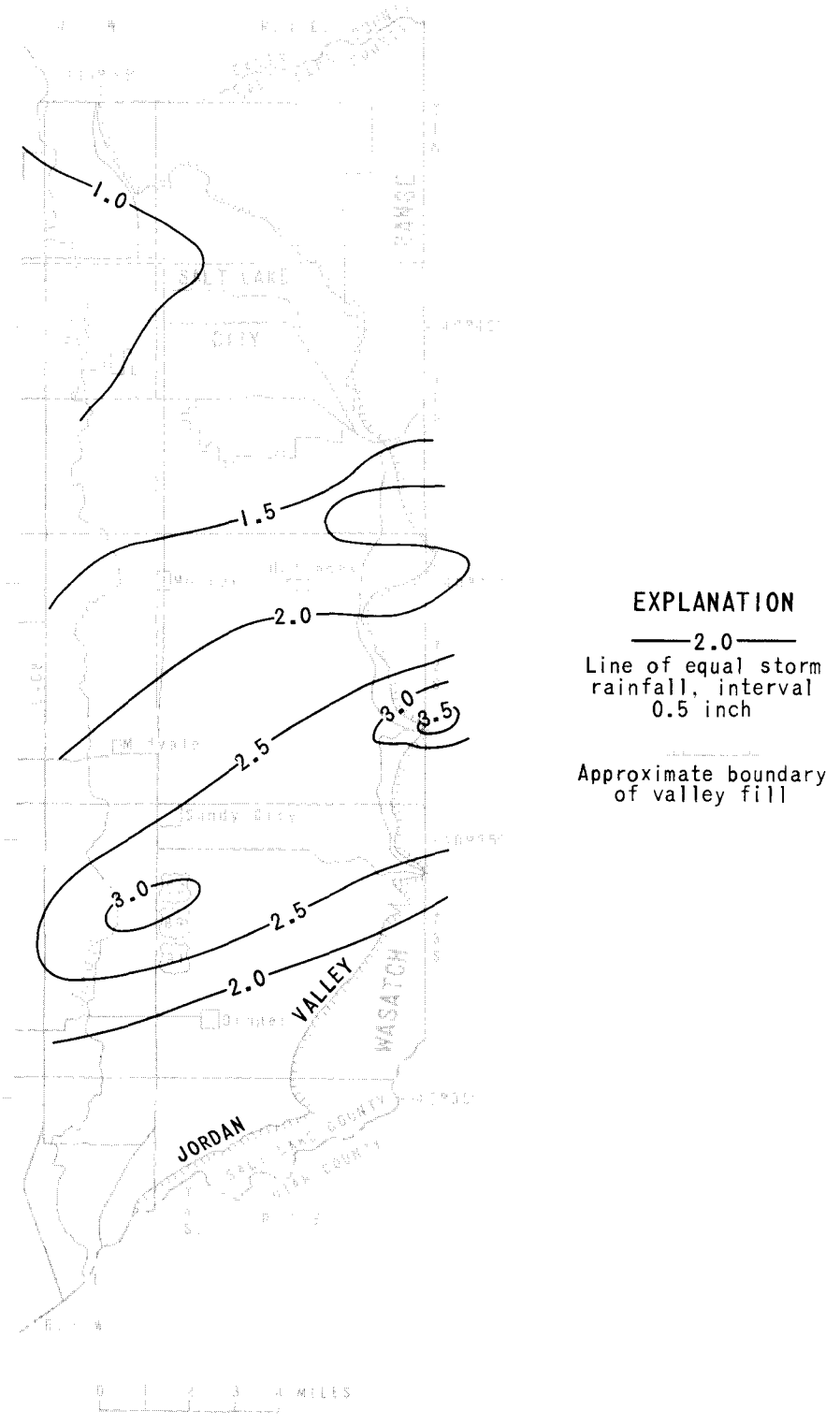


Figure 11.—Rainfall in eastern Jordan Valley during the 28-hour period, 2 p.m. September 5 to 6 p.m. September 6, 1965. (After U.S. Weather Bureau, written commun., 1965).

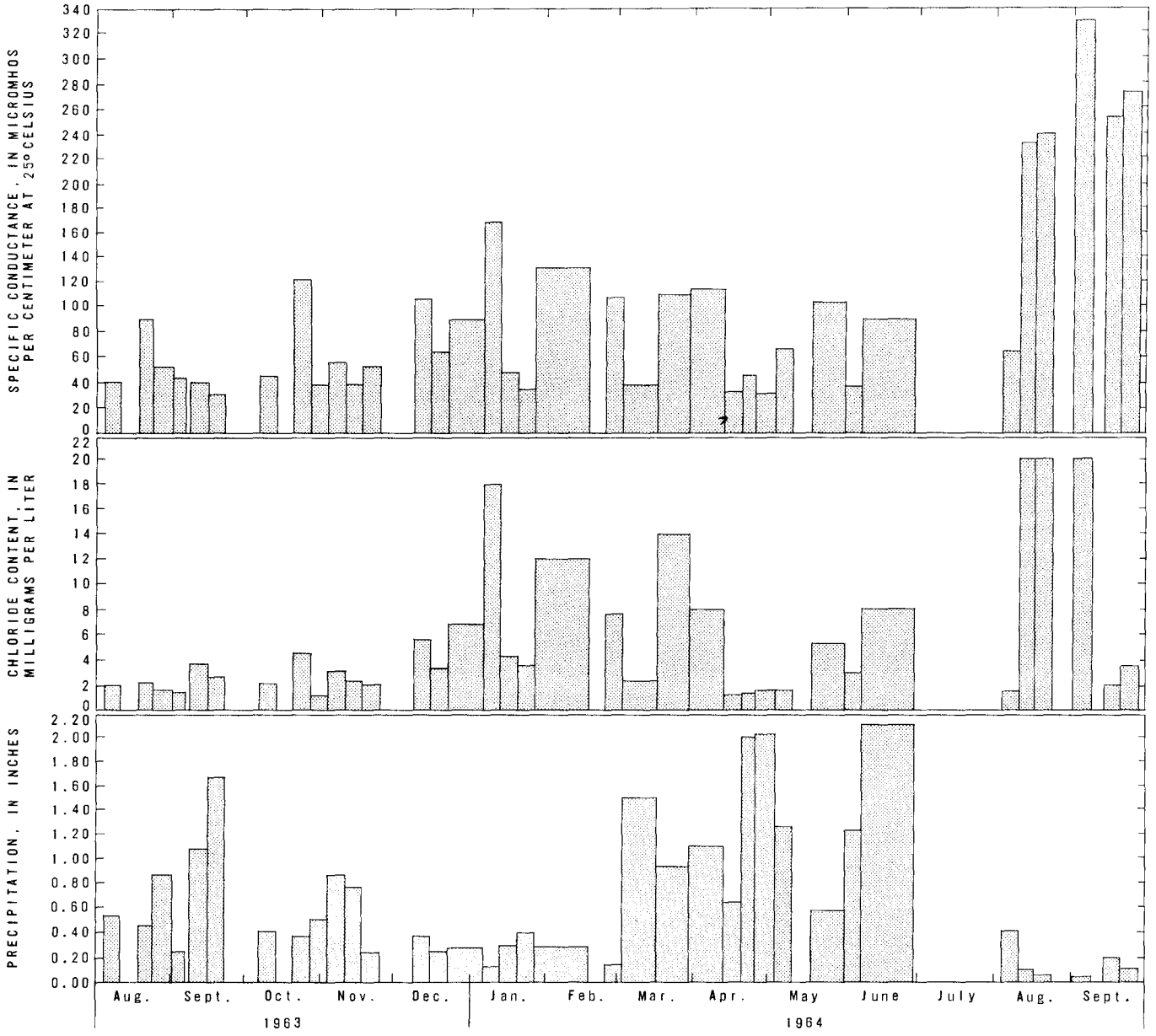


Figure 12.—Specific conductance, chloride content, and precipitation during August 1963 to September 1964 at 2044 East 2920 South, Salt Lake City.

The second set of data was obtained by A. J. Eardley (written commun., 1969) in a study of chloride fallout on the Great Salt Lake drainage area. Three of his sampling sites are in Salt Lake County—the Salt Lake City International Airport; 2618 Skyline Drive (about 1600 South, at base of Wasatch Range); and Alta, near the head of Little Cottonwood Canyon. These data are summarized in figure 13, which shows a striking variation of chloride content with location.

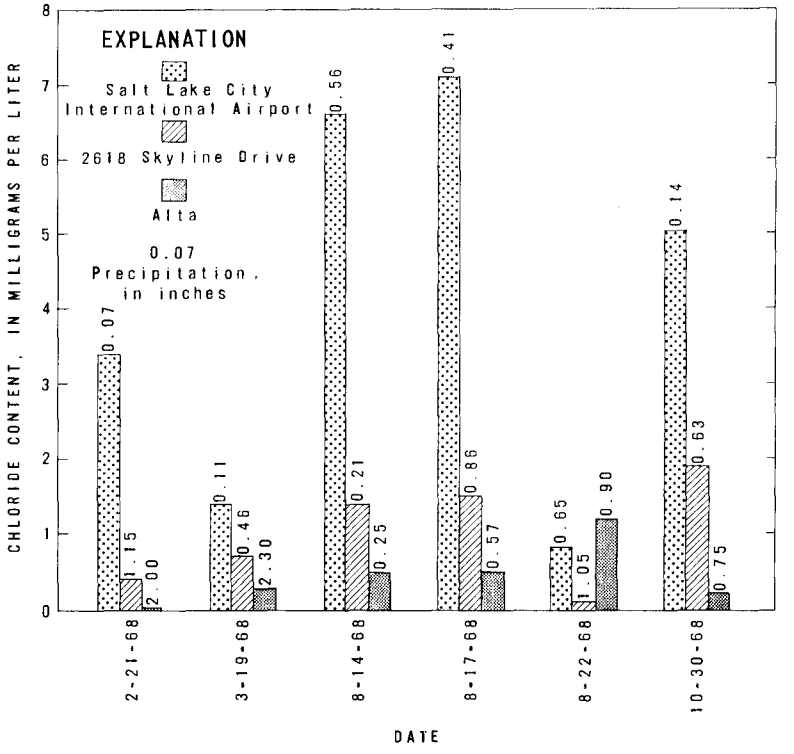


Figure 13.—Chloride content of precipitation at three sites in Salt Lake County.

The weighted-mean concentrations of chloride at the three sample sites are as follows:

	mg/l
Salt Lake City International Airport	3.82
Skyline Drive	2.02
Alta	.54

The airport site generally shows by far the greatest chloride content and Alta the least. This pattern undoubtedly is a reflection of the difference in exposure to atmospheric contamination at the three sites. The airport is directly exposed to dust from desert areas and to aerosols from Great Salt Lake. Alta, on the other hand, is above the largest concentrations of dust and aerosols. The exposure of the Skyline Drive site is intermediate between the other two. The single exception to the pattern described above (Aug. 22, 1968) probably resulted from the extreme variability of precipitation, wind, and dust that was associated with a summer thunderstorm.

The mean chemical composition of snow collected from mountains in Utah in 1959 is given by Feth and others (1964, p. J1, J14-J15) as:

Constituent	Concentration, in mg/l	Number of analyses
Calcium (Ca)	2.23	7
Magnesium (Mg)	.33	6
Sodium (Na)	.60	18
Potassium (K)	.47	6
Bicarbonate (HCO_3)	6.29	7
Sulfate (SO_4)	2.25	6
Chloride (Cl)	.97	18
Dissolved solids (calculated)	10.58	6

These writers state that the above data adequately represent the chemical characteristics of snow on the mountainous backbone of Utah at the time of sampling, but probably do not represent the yearly average chemical composition of snow in Utah. The data may roughly approximate the average chemical characteristics of snow on Salt Lake County, except that sulfate concentrations in snow in parts of the county are probably higher than indicated (Billings Brown, oral commun., 1970). The use of the data from Feth and others to estimate the total annual deposition of chemical constituents at any given site is not advisable because of the variability of storm patterns, amounts of precipitation, and atmospheric conditions preceding storms. The data, however, probably represent average conditions for mountainous parts of the county.

Chemical quality of precipitation data collected by the Geological Survey during this study, by Eardley, and by Feth and others indicate that precipitation in Salt Lake County has an initial load of dissolved constituents. Even in the highest mountains the initial dissolved-solids content may average about 10 mg/l, and at lower altitudes it may be substantially greater because of greater availability of airborne dust and aerosols. Nevertheless, the concentration of dissolved constituents in precipitation is much less than the concentration in either surface water (fig. 34) or ground water (pl. 4).

Temperature

Air temperature has powerful indirect effects on water resources, chiefly by its influence on the form of precipitation, storage in the snowpack, and the rate at which moisture returns to the atmosphere, as shown for example, in table 31.

The seasonal variations of temperature at the Salt Lake City International Airport are illustrated in figure 14. As the winter normals are close to freezing, precipitation occurs as either rain or snow, and snow may melt quickly or remain on the ground for several weeks.

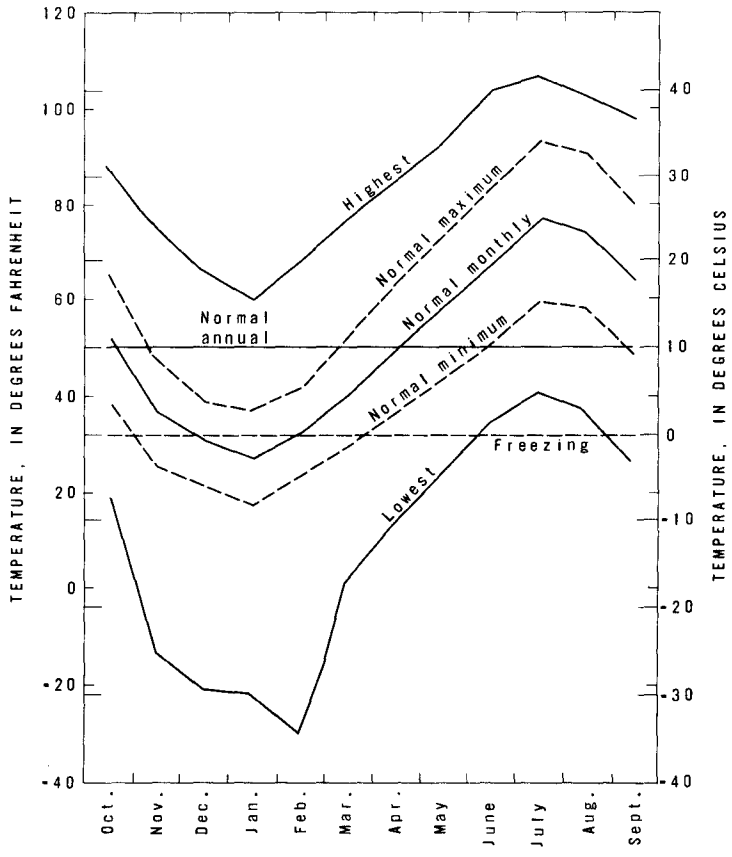


Figure 14.—Seasonal variations of temperature at Salt Lake City International Airport. Normals are for 1931-60, and the extremes are for 1929-67. Some of the extremes may not be strictly comparable because of differences in observation sites.

The areal variation of temperature in the county is influenced by several factors, such as cool-air drainage down mountainsides and canyons and aspect of land surface, but the dominant factor is altitude. The approximate relation between mean annual temperature and altitude at 14 stations in or near Salt Lake County is about 36°F (2°C) per thousand feet. Consequently, at high altitudes winter temperatures generally are well below freezing; and practically all precipitation occurs as snow. Even midsummer precipitation occasionally occurs as snow, and the snowpack remains on the ground all winter and well into spring or summer.

The loss of water vapor to the atmosphere from a land or water surface depends on the availability of moisture and characteristics of the surface as well as meteorological factors. Estimates of actual losses are considered in later sections of this report. The following discussion concerns the index of evaporation provided by measurements in class A evaporation pans maintained by the U.S. Weather Bureau or other agencies. As such pans are placed far enough above ground to allow free air circulation beneath them, the observed evaporation depends chiefly on meteorological factors. However, some meteorological factors, especially wind speed at a height of 2 feet above ground, are strongly influenced by surface features near the pan. Hence, in an area of complex culture and topography, pan evaporation varies markedly. For example, since the evaporation record at Saltair Salt Plant began in 1956, the maximum monthly evaporation recorded there was 17.35 inches; and during the same period the maximum at Utah Lake Lehi (about 31 mi southeast and about 300 ft higher) was only 11.32 inches.

Jordan Valley

Measurements of evaporation during 1964-68 are available for 10 sites in or near the Jordan Valley (fig. 3). However, two stations (ASR and HER) were discontinued during the period and replaced by two others (SLS and RIV) so that only eight stations operated simultaneously. Evaporation pans generally are not operated during the cold months because ice damages the pans.

Figure 15 illustrates the marked variation of both evaporation and wind speed that occur within this relatively small area and also indicates a significant correlation between evaporation and wind. Because of this variation there is no assurance that the mean of observations at eight stations (or a smaller number for some months) is a reliable estimate of the valley-wide mean of either evaporation or wind speed; but such means are the best available indexes. Indexes of evaporation based on the means for eight stations, however, would be limited to the warm months during 1964-68 and to altitudes near those of the stations involved (about 4,200-4,700 ft).

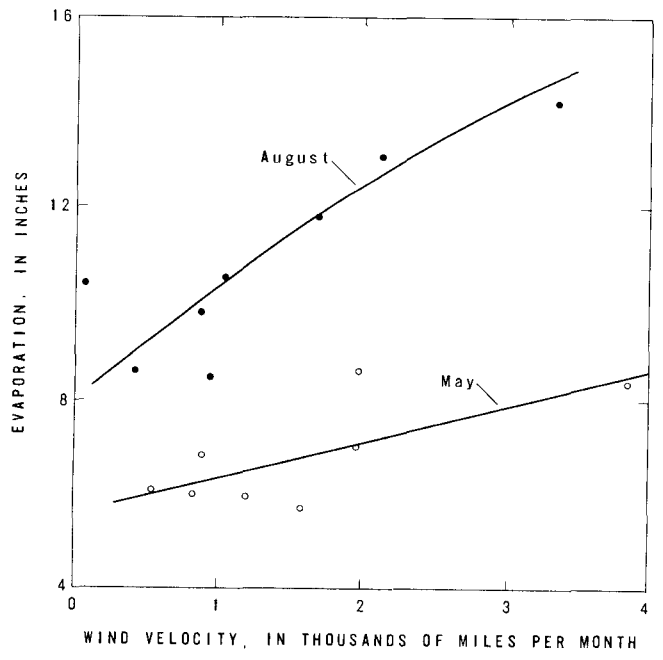


Figure 15.—Variations of observed monthly pan evaporation and mean wind speed in and near Jordan Valley during May and August 1967.

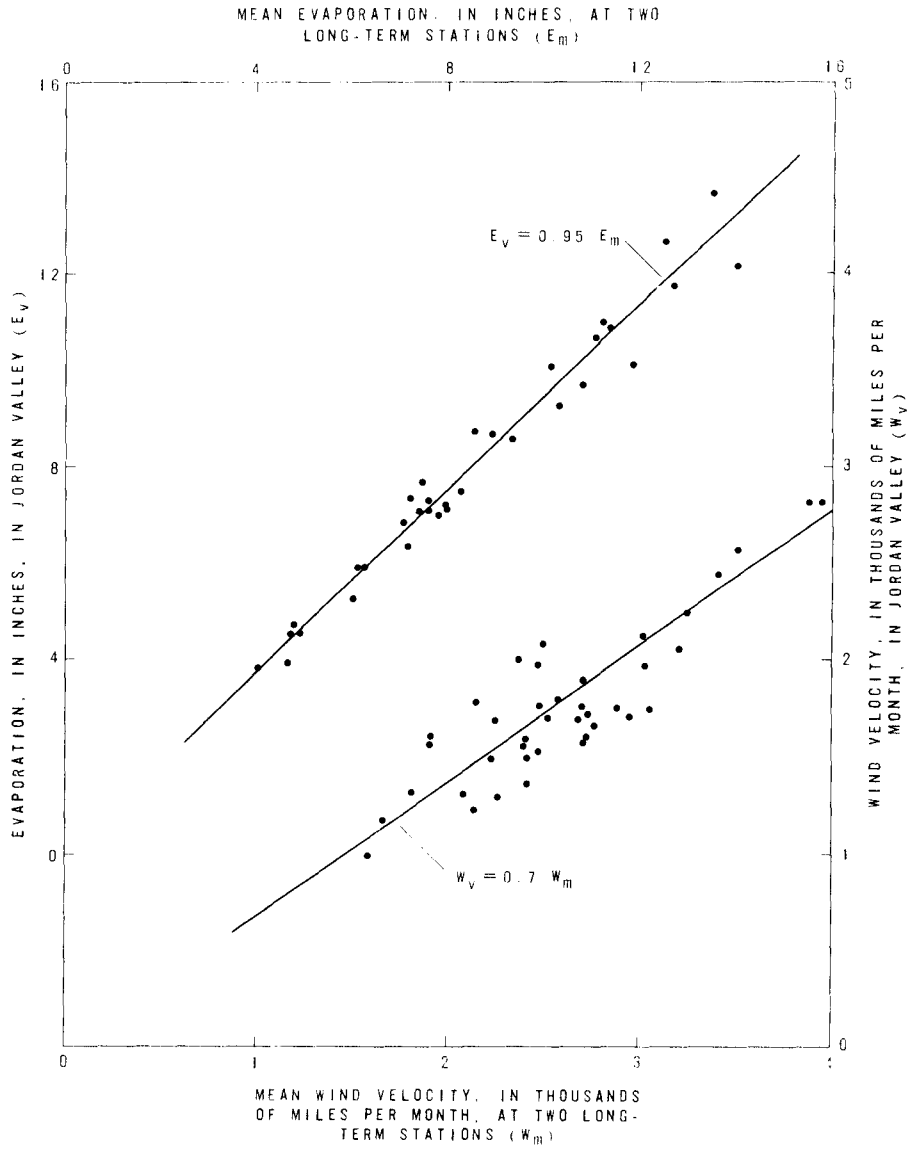


Figure 16.—Relations of mean monthly evaporation and wind speed at eight stations in Jordan Valley to corresponding means for two long-term stations, 1964-68 water years.

Similar indexes can be derived from the two longer records that have been published—Saltair Salt Plant since 1956 and Utah Lake Lehi since 1923. In figure 16 the means of observations of pan evaporation at eight stations in the Jordan Valley are compared with the corresponding means for the two long-term stations. As the correlation is good, the relation shown has been used to extend the evaporation indexes back to 1956. Evaporation in the Jordan Valley, as represented by the index described above, is summarized by the bars in figure 17.

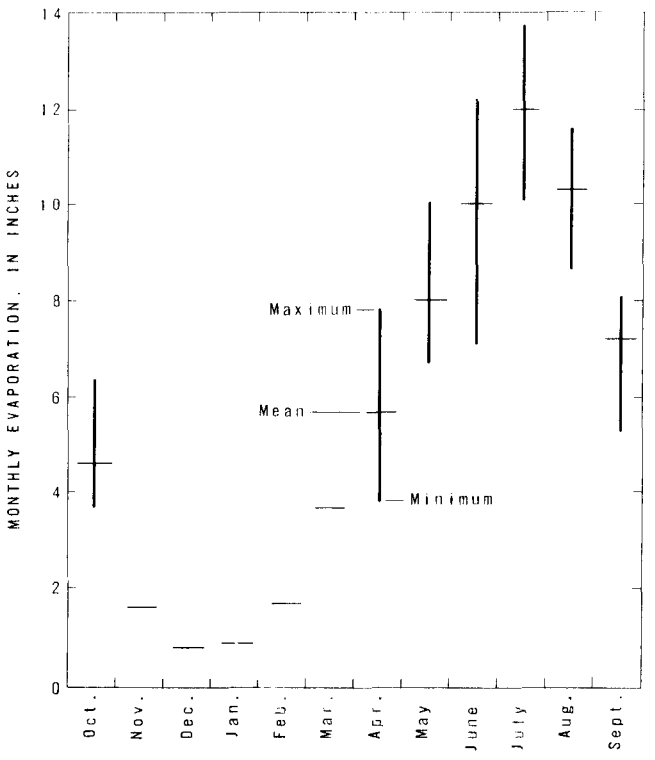


Figure 17.—Seasonal variations of pan evaporation in Jordan Valley, 1956-68. The horizontal lines indicate means of the index values described in the text; and the ends of the vertical bars indicate maximum and minimum values of the index for months when observations are available.

To obtain an estimate of mean annual evaporation, the means for cold months (when evaporation pans are inoperative) were calculated from other meteorological data using the method described by Christiansen (1968). These means for the cold months also are shown in figure 17.

Christiansen described a study of worldwide evaporation data, developed an empirical formula for pan evaporation (equation 1), and presented much of the data needed for its solution.

$$E = 0.473 R \; C_T \; C_W \; C_H \; C_S \; C_A \; C_M \qquad (1)$$

where, E = monthly pan evaporation, in inches,
R = solar radiation at the top of the atmosphere, in equivalent inches of evaporation
C = a dimensionless coefficient related to the factor designated by its subscript
T = mean temperature
W = mean wind speed
H = mean relative humidity
S = percent of possible sunshine
A = altitude[1], and
M = month.

The monthly coefficient, C_M, varies with both season and locality. Fortunately, northern Utah is one of the localities for which values were presented.

The calculations of mean monthly pan evaporation in Jordan Valley and indexes based on observations during warm months and calculations for cold ones are summarized in table 2.

The values of R corresponding to the mean latitude of the valley and values of each C for various values of the subscripts were obtained from tables in Christiansen's paper. T is the mean monthly temperature during 1956-68 at four weather stations (Utah Lake Lehi, Cottonwood Weir, Salt Lake City International Airport, and Farmington, the latter being about 2 miles northeast of station FBR, fig. 3). For 1964-68, W was assumed to be the mean of all observed monthly wind speeds; and for 1956-63, it was derived from the mean of observed speeds at the stations Saltair Salt Plant and Utah Lake Lehi using the relation defined by 1964-68 data in figure 16. H is the mean of relative humidity observations at about 11 a. m. and 5 p. m. Both humidity and sunshine data are for the Salt Lake City International Airport.

Considering that some of the values entered in table 2 are only rough approximations of the true valley-wide means, the agreement between calculated values and the indexes based on observed values for warm months is remarkably good. As the indexes exceed calculated values for warm months by about 5 percent, they were made to exceed calculated values for cold months by the same percentage. The indexes so determined are the best available estimates of the average pan evaporation in Jordan Valley. It should be kept in mind, however, that marked departures from the index values occur in many places.

Mountain ranges

Rates of evaporation in the mountains adjacent to the Jordan Valley are much less well known than those in the valley because there are no records of pan evaporation above 4,700 feet in Salt Lake County and few adequate data for use in equation 1 (above). However a network of 17 stations at altitudes ranging from about 4,300 feet to nearly 9,000 feet in and near the Wasatch Range, near Farmington, Davis County, was operated for short periods during 1962-66 (E.L. Peck, written commun., 1967). Records of June-September evaporation covers 2-4 years; and hence, are only roughly comparable to the longer term records and indexes for Jordan Valley. The total June-September evaporation at each station is plotted against altitude in figure 18.

Although solution of equation 1 for mountainous areas must be based on some poorly supported assumptions or approximations, the solution aids the estimation of annual evaporation and its seasonal distribution. An altitude of 8,700 feet was selected for this calculation because temperature records are available for Silver Lake Brighton, at that altitude. Most of the data used and the results, however, are intended to be representative of average conditions in all areas at 8,000-9,000 feet in Salt Lake County. The computations are summarized in table 3, and the assumptions are explained below.

[1] The nomenclature herein is the same as Christiansen's except that he used E and elevation for altitude.

Table 2.—Mean monthly pan evaporation in Jordan Valley, 1956-68

[Columns 2-11 contain data for the solution of equation 1. Values of R (at lat 40.6°) and C from tables by Christiansen (1968). C_A = 1.108 for altitude 4,600 ft]

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	
Month	R (inches)	T (° F)	C_T	W (miles per day)	C_W	H (percent)	C_H	S (percent)	C_S	C_M	E (inches) Calculated	E (inches) Index
October	11.28	53.6	0.746	53	0.97	38	1.010	76	0.972	0.97	4.1	4.6
November	7.86	39.6	.513	52	.96	57	.908	55	.849	.98	1.5	1.6[2]
December	6.49	31.2	.38 [1]	51	.96	72	.784	46	.805	.99	.77	.8[2]
January	7.35	29.4	.35 [1]	58	.99	69	.814	46	.805	1.00[1]	.87	.9[2]
February	9.14	35.1	.442	64	1.02	61	.880	55	.849	1.00[1]	1.6	1.7[2]
March	13.55	41.8	.549	70	1.04	46	.970	66	.908	.98	3.5	3.7[2]
April	16.48	49.7	.679	81	1.08	40	1.000	64	.897	.90	5.1	5.7
May	19.54	59.8	.853	68	1.03	35	1.025	71	.939	.85	7.3	8.0
June	19.89	69.2	1.024	59	1.00	28	1.060	79	.993	.84	9.4	10.0
July	19.99	77.8	1.182	60	1.00	21	1.099	85	1.039	.83	11.7	12.0
August	17.96	75.0	1.129	56	.98	25	1.076	83	1.023	.91	10.4	10.3
September	14.34	65.6	.957	54	.97	30	1.050	82	1.015	.92	6.8	7.2
Annual											63.0	66.5

[1] Extrapolated.

[2] Calculated value times 1.05.

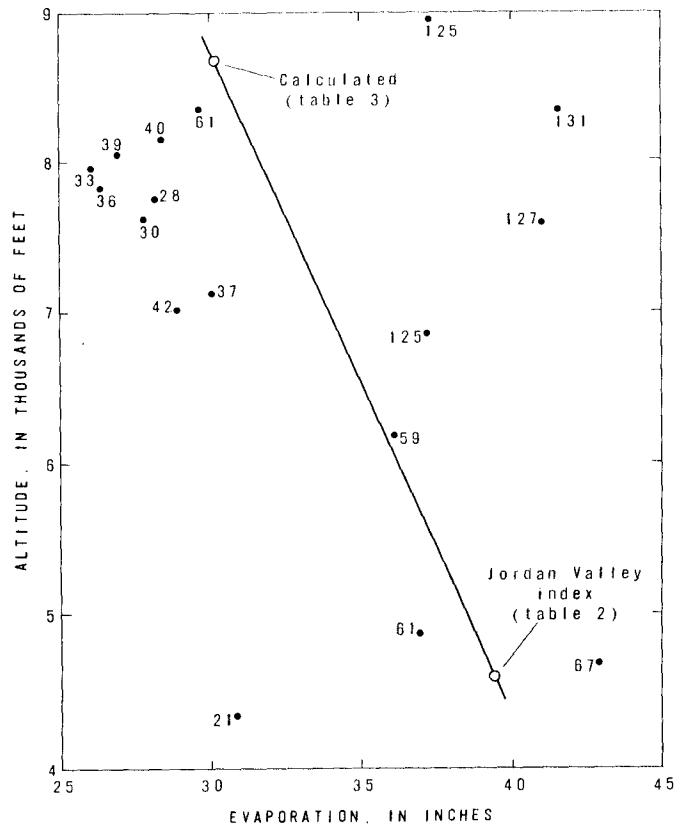


Figure 18.—June-September evaporation at 17 stations at various altitudes in the Wasatch Range near Farmington, Davis County, and at two sites in Salt Lake County. Numbers represent June-September wind speed (in miles per day) at individual stations near Farmington. (Data from E.L. Peck, written commun., 1967, table 3.) Open circles represent estimated mean evaporation at the indicated altitudes in Salt Lake County.

The monthly wind speeds were assumed to be 50 percent greater than the corresponding means for Jordan Valley, because the means for five stations above 8,000 feet (fig. 18) were about 160 percent of the means for three stations below 5,000 feet and nearly 140 percent of the means for Jordan Valley. The relative humidity was estimated from mean maximum and mean minimum temperatures at Silver Lake Brighton in accordance with a relation given by Christiansen (1968), $H = 113 - 2.5\ T_d$, where T_d is the difference between the mean maximum and mean minimum temperatures. The percent of possible sunshine was assumed to be the same as at the airport in the absence of any better information. Although cloud cover in the mountains often exceeds that in the valley, fog is usually limited to the valley; and the two effects compensate in some degree.

Table 3.—Calculated mean monthly pan evaporation at 8,000-9,000 feet in Salt Lake County

[Columns 2-12 contain data for the solution of equation 1 (p. 32). *R* and *S* are the same as in table 2. *T* is the 23-year mean for Silver Lake Brighton. *W* is estimated as 1.5 times *W* in table 2. *H* is estimated from the difference (T_d) between mean maximum and mean minimum temperatures at Silver Lake Brighton. C_A is 1.23 for altitude 8,700 ft. All values of *C* are from Christiansen, 1968.]

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Month	*R* (inches)	*T* (°F)	C_T	*W* (miles per day)	C_W	T_d (° F)	*H* (percent)	C_H	*S* (percent)	C_S	C_M	*E* (inches)
October	11.28	39.2	0.506	80	1.08	25.5	49	0.95	76	0.97	0.97	3.2
November	7.86	27.1	.30 [1]	78	1.07	25.3	50	.95	55	.85	.98	1.2
December	6.49	22.1	.21 [1]	76	1.07	24.2	52	.94	46	.80	.99 [1]	.6
January	7.35	18.5	.15 [1]	87	1.11	23.8	54	.93	46	.80	1.00 [1]	.5
February	9.14	19.9	.17 [1]	96	1.14	24.8	51	.94	55	.85	1.00 [1]	.8
March	13.55	24.1	.25 [1]	105	1.17	24.6	52	.94	66	.91	.98	1.9
April	16.48	32.7	.404	122	1.23	24.0	53	.93	64	.90	.90	3.6
May	19.54	41.3	.541	102	1.16	24.6	52	.94	71	.94	.85	5.3
June	19.89	49.6	.678	88	1.11	27.5	44	.98	79	.99	.84	7.1
July	19.99	57.7	.815	90	1.12	29.1	40	1.00	85	1.04	.83	9.1
August	17.96	56.4	.793	84	1.10	28.6	42	.99	83	1.02	.91	8.3
September	14.34	49.3	.673	81	1.08	29.8	38	1.01	82	1.02	.92	5.7
Annual												47.3

[1] *Extrapolated.*

The comparison of calculated June-September evaporation with observed values (E. L. Peck, written commun., 1967) in figure 18 is considered satisfactory, particularly if the more exposed sites (characterized by high wind speed) are regarded as the least typical of the average mountain terrain.

Disposal of precipitation

The initial disposal of precipitation on Salt Lake County is by (1) direct evaporation from moist surfaces, (2) seepage into the soil, and (3) overland runoff to streams or drains. Some of the water that enters the soil percolates downward until it reaches the ground-water reservoir, and some is consumed by evapotranspiration (evaporation plus transpiration) without reaching the reservoir. Water in the reservoir moves vertically or laterally toward areas of lower altitude, until it is intercepted by a stream, a lake, a marsh, a discharging well,or a phreatophyte (a plant whose roots commonly penetrate to the ground-water reservoir). Water in the streams continues to flow downstream until it evaporates, seeps into the ground, is diverted, or reaches Great Salt Lake.

Ultimately, all the water that reaches the county—by precipitation, inflow in the Jordan River, or importation—returns to the atmosphere by evapotranspiration either from areas within the county or from Great Salt Lake. However, water in the lowest parts of the ground-water reservoir moves so slowly that it may remain there for centuries or millenniums.

Although water that is evaporated or transpired without reaching either surface- or ground-water sources is commonly considered a loss, it largely determines the natural productivity of the land. Also, it partly determines the need for supplemental water for both irrigation and municipal use. A better indication of this need, however, is provided by comparison of precipitation and an evaporation index. Thus, figure 19 portrays monthly precipitation and the corresponding evaporation at a mountain site and at a valley site.

For this illustration, the pan-evaporation data in tables 2 and 3 have been multiplied by 0.71, which is the average coefficient[1] for converting pan evaporation to evaporation from fresh lakes in the county (Kohler and others, 1959, pl. 3). The results are assumed to be comparable with normal monthly precipitation.

At the mountain site, late fall and winter precipitation greatly exceeds evapotranspiration and the large surplus of moisture retained in the snowpack produces the spring runoff, deep seepage, and much of the soil moisture used by growth of vegetation. By late summer or fall a relatively small moisture deficit usually occurs. At the valley site, in contrast, the small winter surplus runs off or seeps into the ground quickly and a large deficit prevails during most of the growing season.

SURFACE WATER

During the 1964-68 water years, the mean discharge of streams, canals, and aqueducts entering Salt Lake County was 284,000 acre-feet per year. Runoff from mountainous areas within the county was about 179,000 acre-feet per year. Thus, excluding the effects of the ground-water reservoir in Jordan Valley and the small amount of runoff from the valley floor, the surface-water supply for the valley was about 463,000 acre-feet per year; but not all of this could be used because of variations of the discharge. A more complete summary of surface-water supply follows the discussions of the principal elements of that supply.

[1]Pan coefficients vary seasonally and also with the characteristics of the water body and the evaporation station.

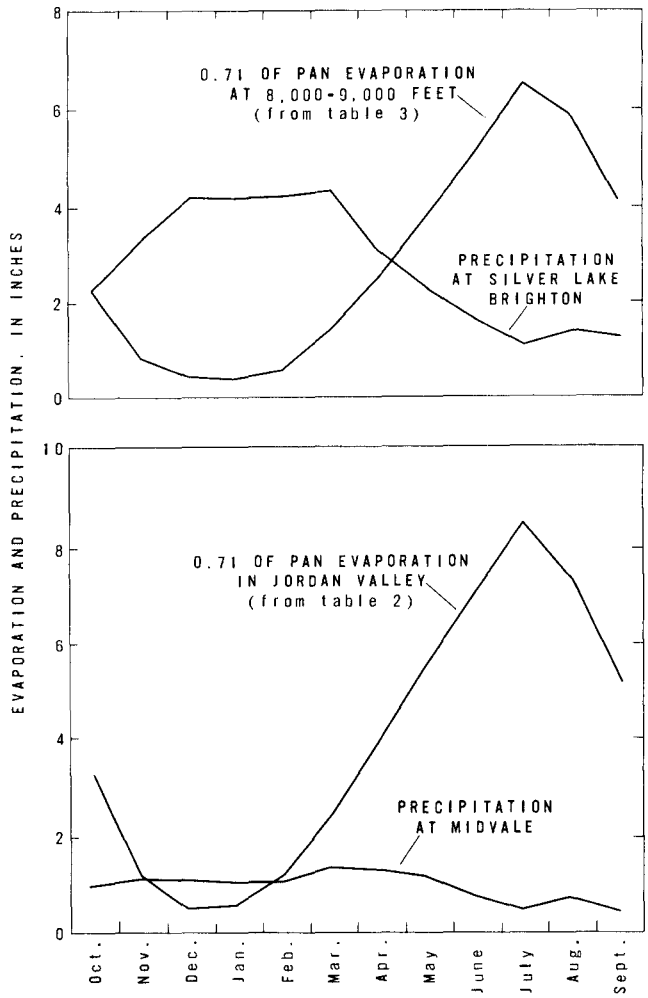


Figure 19.—Comparison of mean monthly precipitation and evaporation in Jordan Valley and at 8,000-9,000 feet.

The following sections describe the analyses of streamflow records and the resulting conclusions, some of which relate to ground water as well as surface water. Several different periods are involved in these studies because some records cover 5 or fewer years, some cover more than 60 years, and others are of intermediate length. The longest reliable records provide the best guides to future streamflow, but records for the same period are needed for the best comparisons of data. Hence, periods have been selected to meet these two criteria as nearly as possible. Some analyses were made before the 1968 records were available to avoid unnecessary delay in completing the report. In comparing streamflow data, a period of more than 10 years that ends in 1967 is practically equivalent to the period that is 1 year longer and ends in 1968.

The term "water year" applies to the 12-month period from October 1 to September 30 and is designated by the calendar year in which it ends.

The term "runoff," as used herein, refers to streamflow that is not affected by artificial storage or diversion. Often it is computed by combining the flow in two or more channels and adjusting for changes in storage. When runoff cannot be reliably computed, the more general terms "streamflow" and "discharge" are used.

The most strategic sites in the county for the measurement of surface water are at the Jordan Narrows, where the Jordan River enters the county, and at the canyon mouths, where the principal mountain streams enter the Jordan Valley. Consequently, the longest streamflow records are for these sites; but additional records have been obtained to aid the definition of changes in streamflow as it passes through the valley. Also, short records have been obtained at the sites of several potential storage dams and diversions. (See p. 233.)

Most of the sites in the county where records of both quantity and quality of surface water were obtained are shown in figure 20. Water samples for chemical or sediment analyses and measurements of discharge were obtained occasionally at numerous other sites as described in the text.

Wasatch streams

The earliest supply of good-quality surface water for Salt Lake County was from the major streams draining the Wasatch Range within the county. Runoff from about 80 percent of this area is defined by streamflow records, but runoff from the remaining 20 percent can only be estimated from occasional measurements and other considerations. As most of the ungaged area is at a relatively low altitude and is drained by small streams only a few miles long, its runoff characteristics differ markedly from those of the gaged area. Furthermore, the small, intermittent flows in most of the ungaged streams offer little opportunity for additional development of water supply. Hence, estimates of the ungaged runoff are discussed in a later section on "other sources."

Runoff at canyon mouths

Although continuous records of runoff in some of the Wasatch streams began in 1898, records for some others did not begin until much later. A period beginning October 1, 1906, (start of the 1907 water year) has been selected for this study because it includes a period of high runoff early in this century; and little estimation was required to derive complete and comparable records of annual runoff in six of the seven gaged streams. The six streams are Little Cottonwood, Big Cottonwood, Mill, Parleys, Emigration, and City Creeks. The record for the seventh one (Red Butte Creek) began in 1943 and is discussed separately.

Comparisons of cumulative runoff in the six streams (similar to those of cumulative precipitation in fig. 7) indicate that all records except the one for Little Cottonwood Creek are homogeneous. Figure 21 shows the comparison of the cumulative runoff recorded for Big Cottonwood and Little Cottonwood Creeks. As the comparison with other records indicates that the record for Big Cottonwood Creek is homogeneous, the significant break in the relation line at 1924 indicates that records for Little Cottonwood Creek prior to that date are not comparable to later records. The change in the relation was caused by changes in the measuring site and unmeasured diversions.

To obtain a homogeneous record back to the 1907 water year, runoff in Little Cottonwood Creek for 1907-11 was estimated on the basis of the relation established since 1924 ($L = 0.91\ B$, fig. 21), and the recorded discharge for 1912-23 was adjusted to conform to the

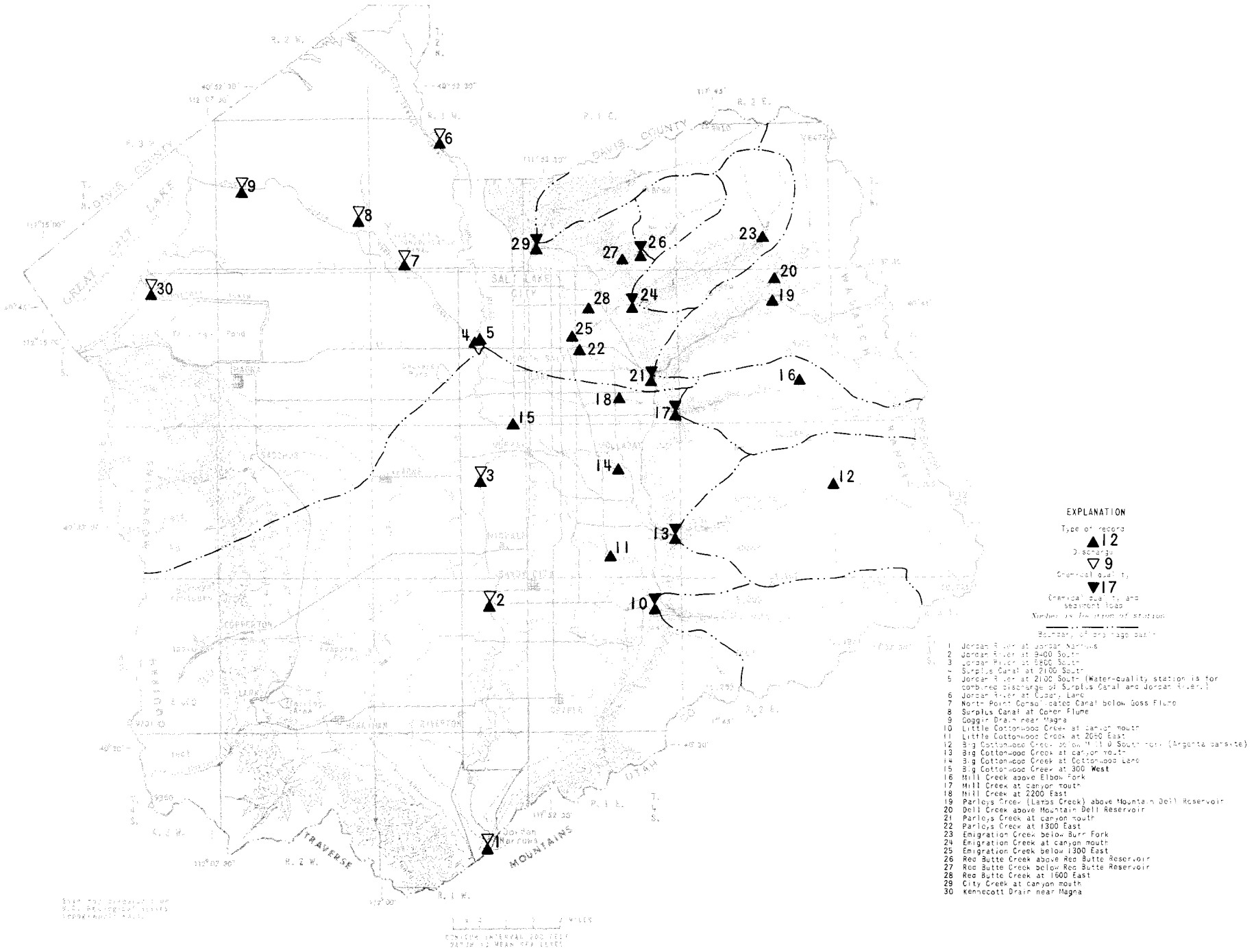


Figure 20.—Locations of stations for measurement of stream discharge and water quality. Measurements and water samples were obtained occasionally at numerous other sites.

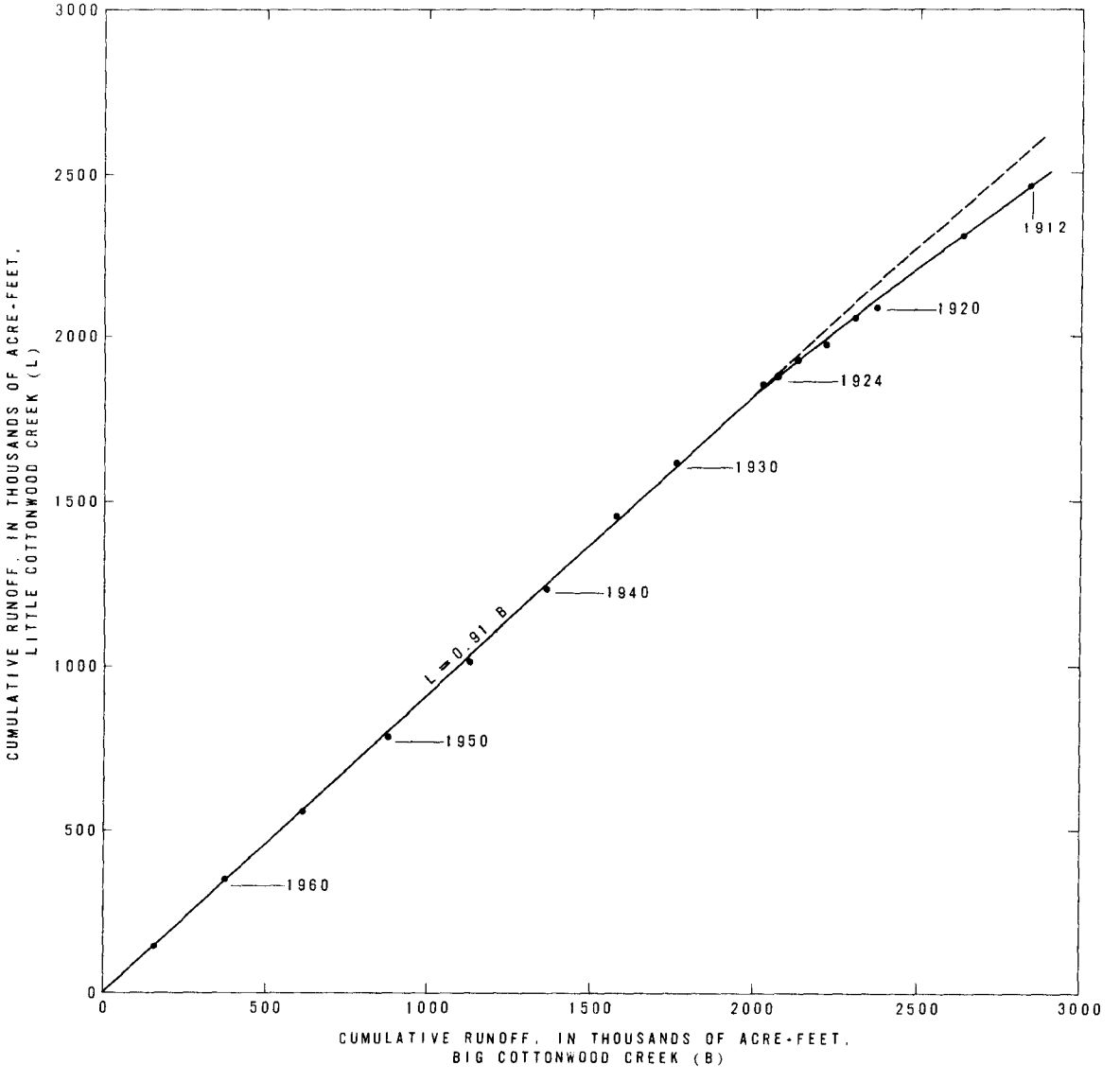


Figure 21.—Comparison of cumulative runoff in Big Cottonwood and Little Cottonwood Creeks, 1912-67 water years. The plotted points represent runoff cumulated from September 30, 1967, backward to the beginning of the water year shown. The dashed line is an extension of the relation defined since 1924.

same relation. The total adjustment required for the period is about 114,000 acre-feet, which is equivalent to 9,500 acre-feet per year or to an average of 19.4 percent of the recorded discharge. Annual values adjusted by adding 9,500 acre-feet to each recorded annual discharge and by adding 19.4 percent of the recorded annual discharge differ from each other by less than 6 percent, and mostly less than 3 percent. Hence the final adjusted annual runoff, obtained by averaging these two estimates, probably is nearly as accurate as the later records.

A summary of the magnitude and variability of annual runoff in these six streams is presented in table 4. The figures represent surface runoff at the mouths of the respective canyons, discharge in the stream channel and diversions being combined when necessary.

The records of annual combined runoff in the six streams and of runoff in Big Cottonwood Creek (the largest component) are shown graphically in figure 22.

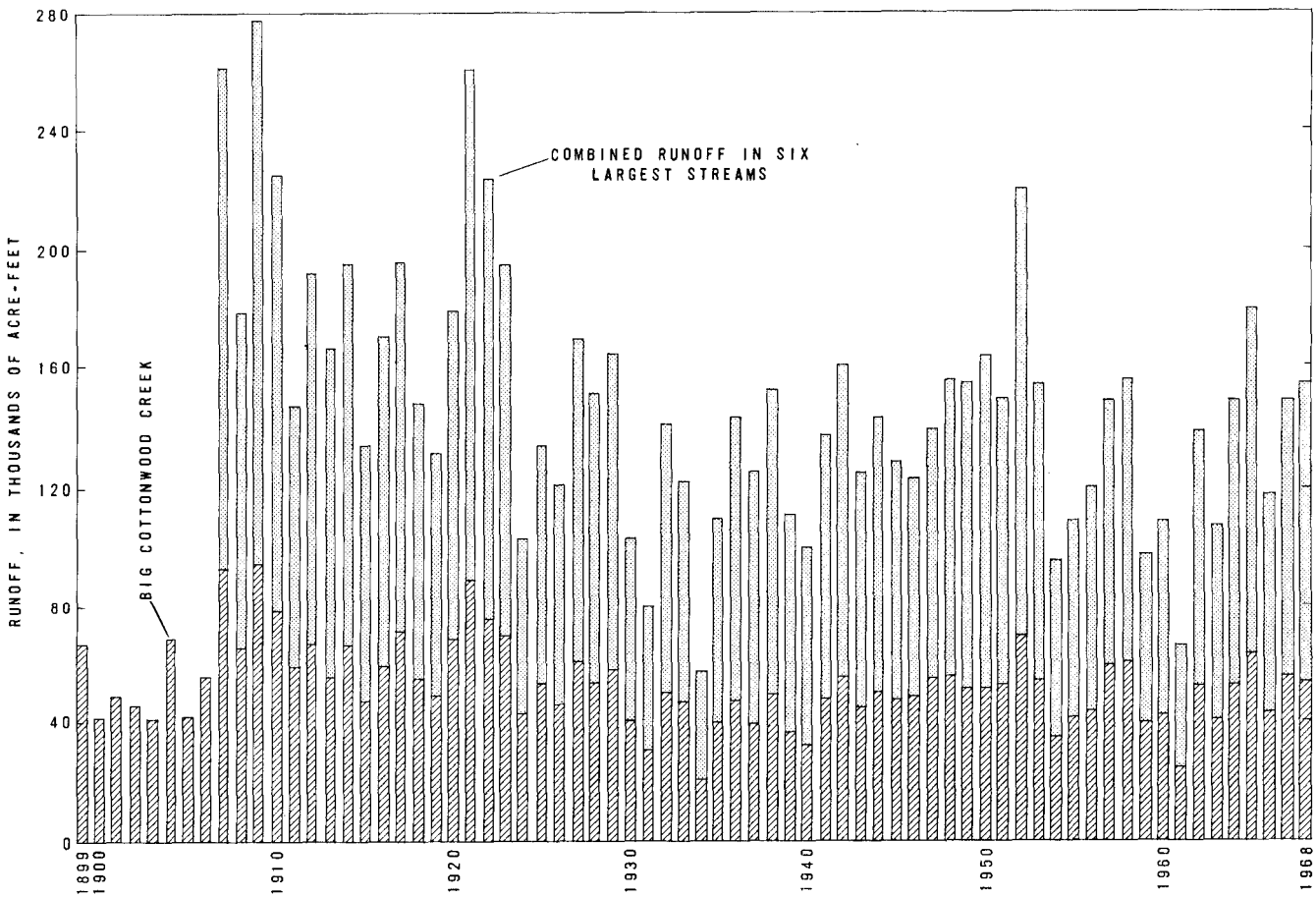


Figure 22.—Annual combined runoff in six Wasatch streams, 1907-68 water years and annual runoff in Big Cottonwood Creek, 1899-1968 water years.

Table 4.—Summary of annual runoff, in acre-feet, in six Wasatch streams at the canyon mouths

[Figures in parentheses following maximum and minimum values are percent of mean.]

Stream	Statistic	Water years							
		1907-67		1931-60		1943-67		1964-68	
Little Cottonwood Creek[1]	Maximum	86,400	(179)	62,560	(147)	62,560	(143)	54,930	(112)
	Mean	48,250		42,430		43,770		49,110	
	Minimum	20,630	(43)	20,630	(49)	26,090	(60)	37,540	(76)
Big Cottonwood Creek	Maximum	94,900	(179)	69,410	(150)	69,410	(141)	63,280	(118)
	Mean	53,050		46,250		49,100		53,490	
	Minimum	20,230	(38)	20,230	(44)	25,510	(50)	42,830	(80)
Mill Creek	Maximum	21,000	(194)	17,610	(183)	17,610	(180)	11,530	(117)
	Mean	10,840		9,630		9,770		9,880	
	Minimum	4,520	(42)	5,110	(53)	4,520	(46)	8,310	(84)
Parleys Creek	Maximum	43,600	(234)	38,560	(233)	38,560	(226)	26,000	(136)
	Mean	18,640		16,580		17,040		19,190	
	Minimum	4,250	(23)	4,440	(27)	4,250	(25)	14,960	(78)
Emigration Creek[2]	Maximum	15,110	(257)	13,170	(256)	13,170	(248)	9,030	(150)
	Mean	5,870		5,140		5,320		6,040	
	Minimum	1,330	(23)	1,740	(34)	1,330	(25)	4,240	(70)
City Creek	Maximim	20,800	(178)	18,560	(172)	18,560	(174)	14,210	(122)
	Mean	11,670		10,820		10,640		11,640	
	Minimum	4,920	(42)	4,920	(45)	5,120	(48)	9,530	(82)
Combined flow	Maximum	277,300	(187)	219,900	(168)	219,900	(162)	179,000	(120)
	Mean	148,300		130,800		135,600		149,400	
	Minimum	57,070	(38)	57,070	(44)	65,820	(49)	117,300	(79)

[1] *Records for 1907-11 estimated, and those for 1912-23 adjusted to correspond to those since 1923.*

[2] *Includes discharge of Emigration Tunnel Springs.*

Seasonal fluctuations are illustrated by the hydrograph of monthly combined runoff in figure 23, which shows the concentration of much of the runoff in a few months of spring and early summer. The period shown, however, is far from typical as it includes the severest sustained drought of record. In 1929, the annual runoff was slightly above the 1907-67 mean; and in all other years it was below, that for 1934 being only 38 percent of mean (table 4). The role of ground-water seepage in sustaining the fall and winter discharge, even during a succession of dry years, is evident. The range of monthly combined runoff is from little more than 2,000 acre-feet in September 1934 (fig. 23) to more than 75,000 acre-feet in June 1921 and probably more than 80,000 acre-feet in June 1909.

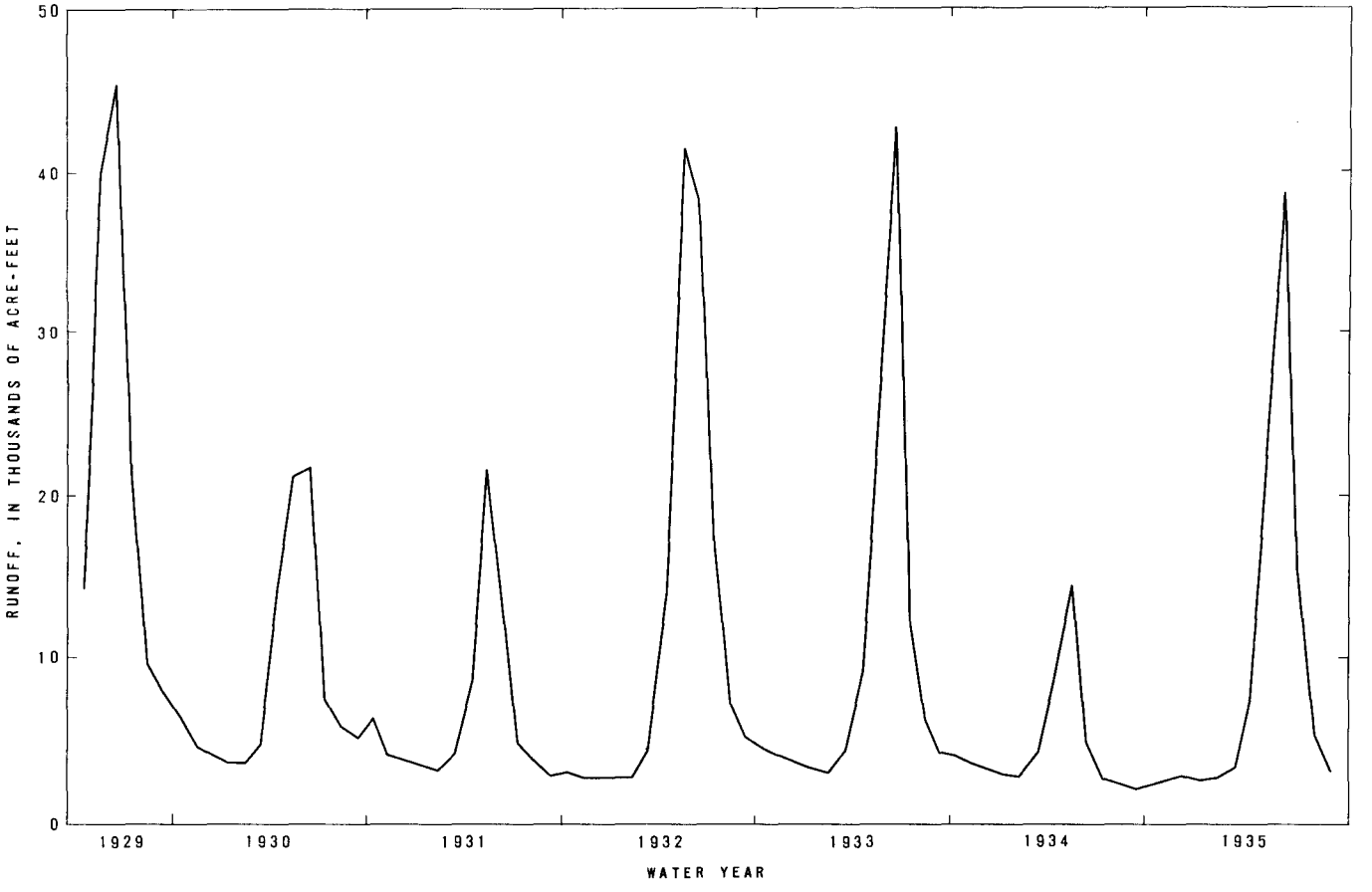


Figure 23.—Monthly combined runoff in six Wasatch streams, April 1929 to September 1935.

Means and extremes of runoff in each calendar month for each of the six streams are shown by the bar graphs in figure 24. For these bars the period beginning with 1924, rather than 1907, was selected to avoid use of estimated or adjusted monthly values for Little Cottonwood Creek, which would necessarily be less reliable than the corresponding annual runoff. Means for the longer period generally are somewhat higher than those shown by the bars, and runoff in many months prior to 1924 greatly exceeds the maximum since then. Figure 24 indicates the magnitude and variability of runoff in each stream and also shows the striking contrast in both magnitude and range between the period of snowmelt runoff and the remainder of the year.

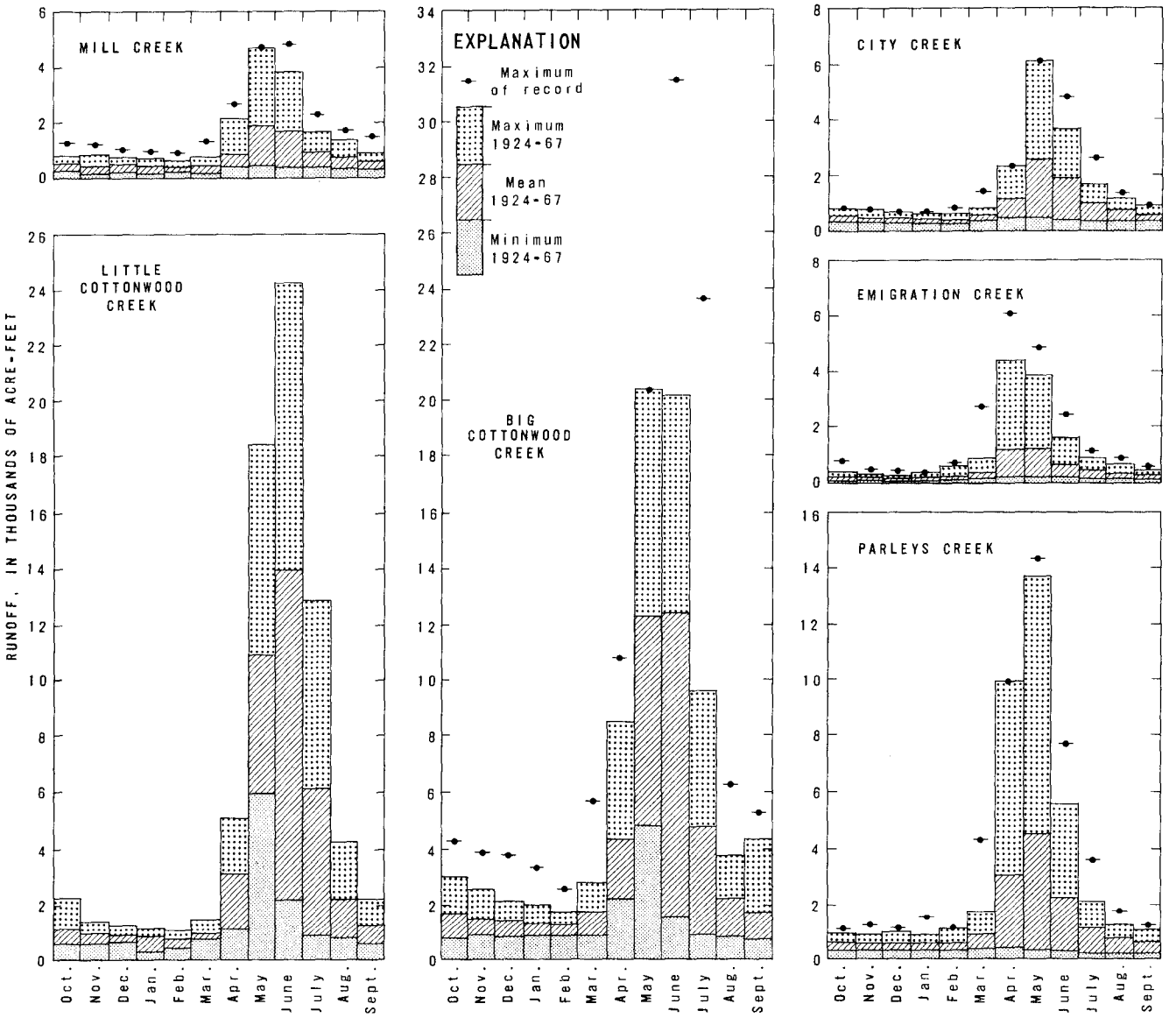


Figure 24.—Means and extremes of monthly runoff in each of six Wasatch streams, 1924-67 water years. The maximum monthly runoff of record (generally beginning about 1898) also is shown except that such maximums for Little Cottonwood Creek are omitted because they are not comparable with records since 1924.

Records of runoff from the Wasatch Range include a record for Red Butte Creek above Red Butte Reservoir, at Fort Douglas, that is not included in the preceding discussion of six of the principal streams. The record began in 1943, but correlative estimates for earlier years were made by Reid and others (1968). A summary of the records and estimates for three periods is shown in the following tabulation.

[Annual runoff of Red Butte Creek, in acre-feet]

Water years	1907-67	1931-60	1964-68
Maximum	6,150	5,100	3,630
Mean	2,700	2,420	2,420
Minimum	689	890	1,710

Potential effects of storage

Storage of runoff from the Wasatch Range may serve several purposes, some of which conflict in some degree. For example, use of a surface reservoir for flood control requires that it be drawn down sufficiently to provide space for flood runoff when it occurs; whereas use for water supply requires that it be kept as full as practicable to help meet unpredictable future deficiencies of streamflow. Both of these uses require substantial fluctuation of water level, but most recreational uses are served best when the water level is nearly constant. Such conflicts, however, do not prevent multiple use of reservoirs. Generally, the conflicts are resolved or mitigated by allocation of space for each use, sometimes on a seasonal basis.

The following discussion concerns the potential effects of storage on water supply and applies to a reservoir system which might consist solely of surface reservoirs or to a system which might also include parts of the ground-water reservoir in the Jordan Valley.

When two or more streams contribute to a common water supply or reservoir system, a storage analysis based on combined runoff may be more pertinent than separate analyses of individual records. As the combined runoff usually is somewhat less variable than its components, the storage requirements for combined runoff are less than, but similar to, the sums of storage requirements determined for individual streams. Both types of analyses are pertinent to the Wasatch streams. Some potential reservoirs would regulate a single stream, but the proposed Little Dell Reservoir would regulate part of the runoff from the drainage basins of Mill, Parleys, and Emigration Creeks. Also, adjacent streams are potential sources of water for artificial recharge of the ground-water reservoir in the Jordan Valley.

The amounts of storage required to sustain specific drafts generally are determined by comparing cumulative runoff with cumulative draft, either analytically or graphically. (The draft

considered here is the total outflow from the reservoir system, including losses by evaporation and seepage from surface reservoirs and any natural discharge from ground-water reservoirs.) The storage requirements equal the amounts by which cumulative draft during certain critical periods exceeds the corresponding runoff.

Graphs of the accumulations (mass diagrams) are useful for illustration and greatly facilitate the selection of critical periods. A simple mass diagram for a long period, however, involves an excessive range of runoff scale. This can be avoided by substituting for the simple accumulations the cumulative departure from any selected value. Then, the graph rises when rates exceed the selected value and declines when they are less.

Figure 25 shows cumulative departures of annual combined runoff in the six Wasatch streams listed in table 4. It indicates the relative abundance of runoff prior to 1930, sharply decreased runoff during the next two decades, and a brief recovery in the early 1950's followed by another decrease.

To determine the storage requirements, straight lines with slopes corresponding to selected annual drafts were drawn from a high point on the runoff graph and the maximum ordinates between the two graphs were determined. As the graph is based on annual runoff, these ordinates represent requirements for carryover storage—the amount required to regulate fluctuations of annual runoff without regard for any additional storage required to regulate the cyclical fluctuations of seasonal runoff.

A continuous draft equal to 90 percent of the 1907-67 mean annual runoff is clearly impractical because the hypothetical reservoir with the required capacity of 223,000 acre-feet (fig. 25) would not have completely refilled at any time since 1929. Reducing the draft to 80 percent of the mean runoff reduces the carryover storage requirement to 101,000 acre-feet and permits refilling by 1942. This carryover period of 13 years (1930-42) is rather long for practical application. However, only a slight additional reduction of the draft would reduce the carryover period to about 5 years, 1934-38.

The storage requirements for 1934-38 are more severe than for any other 5-year period since 1898 (the beginning of record on some of the streams). Hence, a more detailed analysis for a period that includes these water years is presented in figure 26. As the graphs in this figure are based on monthly runoff for several years, the indicated storage requirements are the amounts needed to regulate seasonal as well as annual fluctuations of runoff. Use of daily, rather than monthly runoff probably would result in a very slight increase of the storage requirements.

The draft lines in figure 26 were drawn to show the maximum draft that could be sustained during the period, July 1933 to September 1938, with the hypothetical reservoir system full near each end of the period. The sum of the drafts for the six streams is 9,750 acre-feet per month or 117,000 acre-feet per year.

The storage requirements reached a maximum or near maximum in 1935 and again in 1936. The largest combined requirement for the six streams was 116,000 acre-feet in 1936. (The maximum for Emigration Creek was combined with the others although it occurred a month earlier.)

All drafts in figures 25 and 26 include any losses by seepage and evaporation from surface reservoirs, which must be deducted from the gross draft to obtain the useful draft. Annual lake evaporation at the reservoir sites is 3-4 feet; hence, the loss from a 500-acre reservoir would be 1,500-2,000 acre-feet per year. Two or three surface reservoirs of this size would provide the required capacity, or the ground-water reservoir might provide a part.

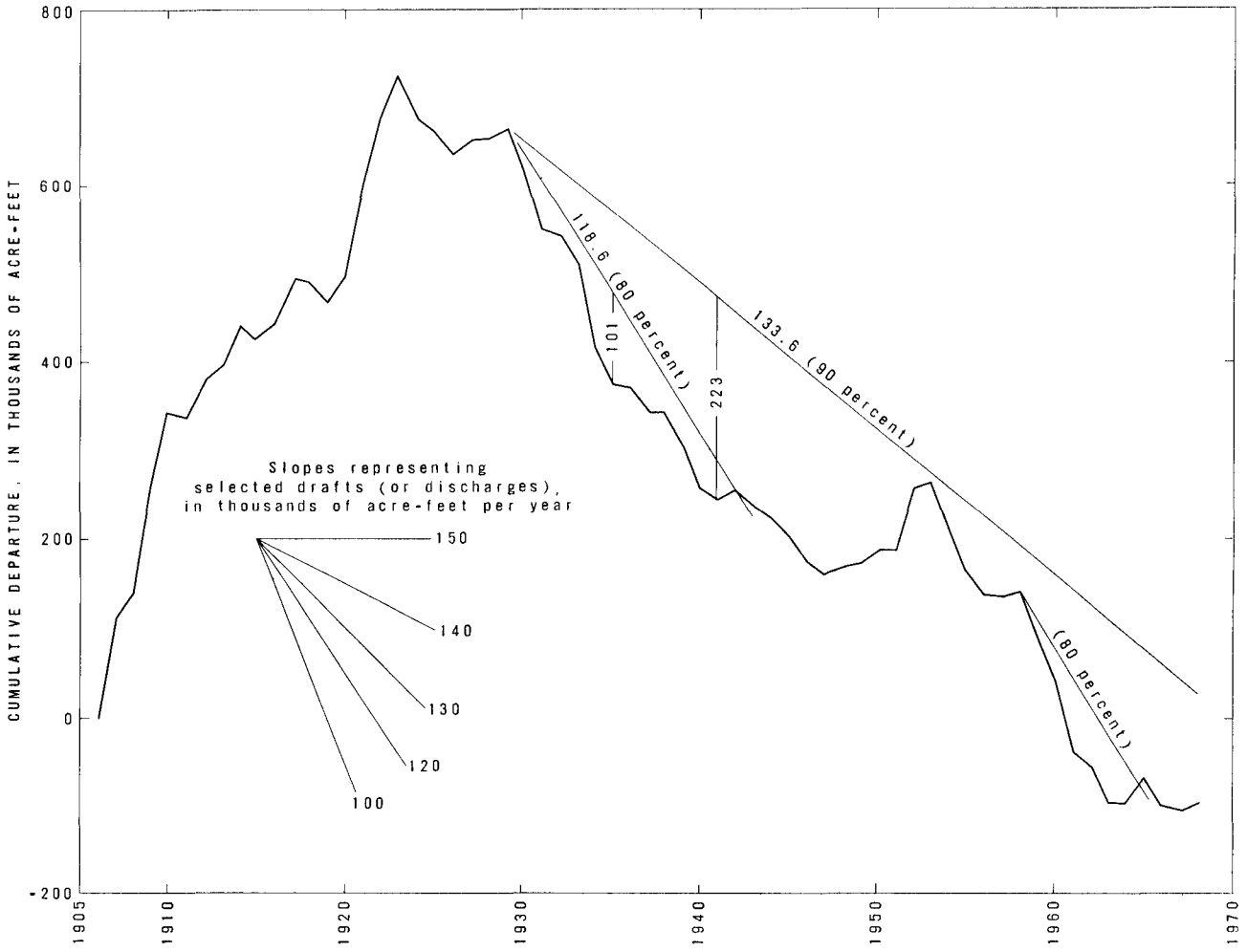


Figure 25.—Storage analysis of the annual combined runoff in six Wasatch streams (listed in table 4), 1907-68 water years. The irregular graph shows annual departures from 150,000 acre-feet cumulative since October 1, 1906; the straight lines represent constant drafts at the indicated annual rates, in thousands of acre-feet, and percent of mean annual runoff; and the vertical distances represent maximum carryover storage requirements.

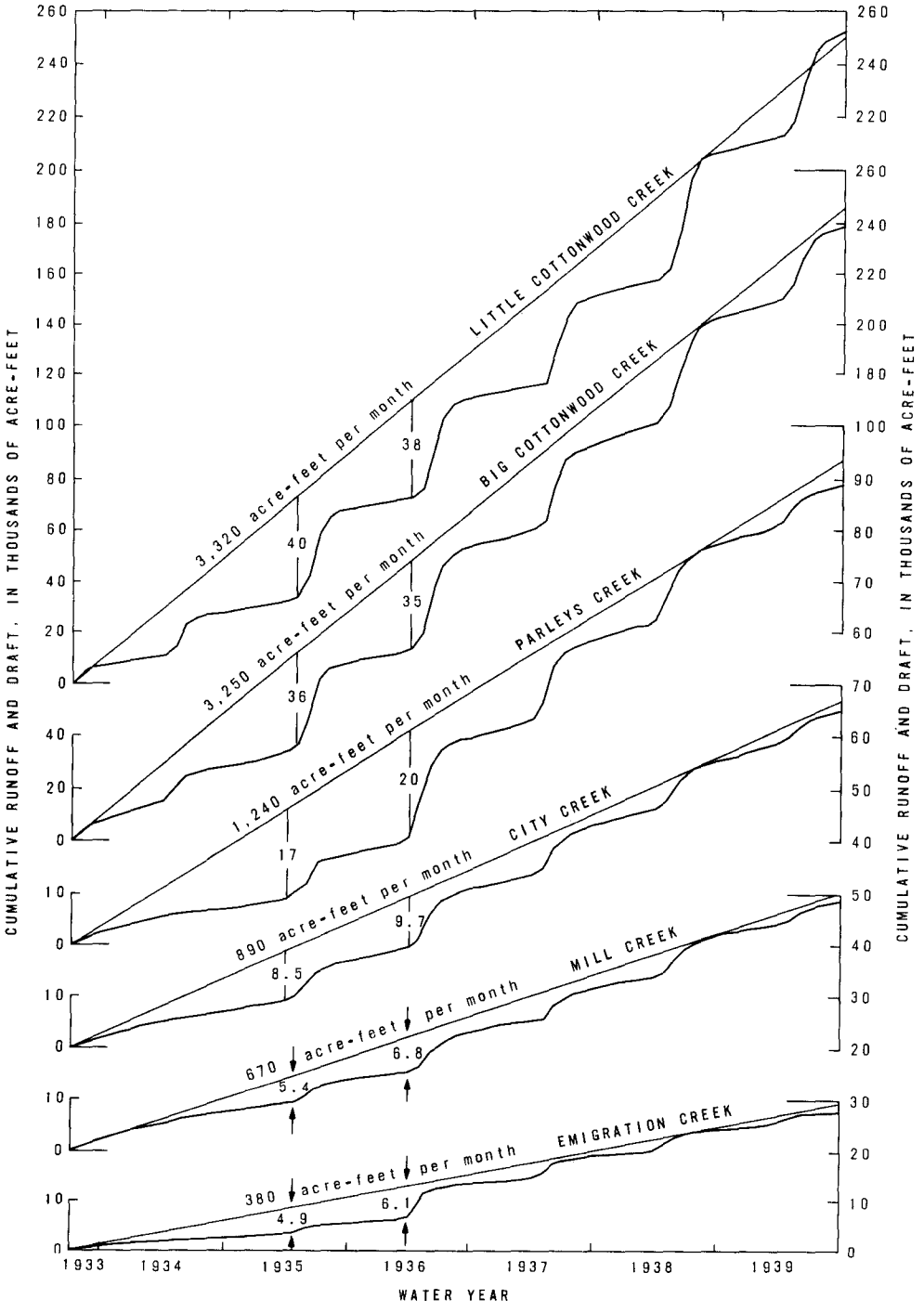


Figure 26.—Storage analysis of the monthly runoff in each of six Wasatch streams at the canyon mouth, July 1933 to September 1939. The irregular graphs show monthly runoff cumulative from July 1, 1933; the inclined lines show the maximum sustainable uniform draft with the carryover period limited to about 5 years. Vertical distances between runoff and draft represent storage requirements.

Actual drafts from reservoir systems generally vary seasonally rather than remaining constant as in figures 25 and 26. The seasonal pattern varies with weather conditions and with the use of the water. However, a rough idea of the effects of using a variable draft instead of a constant one can be gained from figure 27, which compares constant and variable drafts with the cumulative combined runoff in six streams. The annual draft was assumed to be 120,000 acre-feet, of which 27,000 acre-feet was for irrigation and the remainder was for municipal use. The monthly distribution for municipal use was based on monthly deliveries by the Salt Lake City Water Department during 1960-62 (from Berger Associates, Inc., 1964, p. 32); and the distribution for irrigation water was based on actual diversions from Big Cottonwood and Little Cottonwood Creeks during 1964-68.

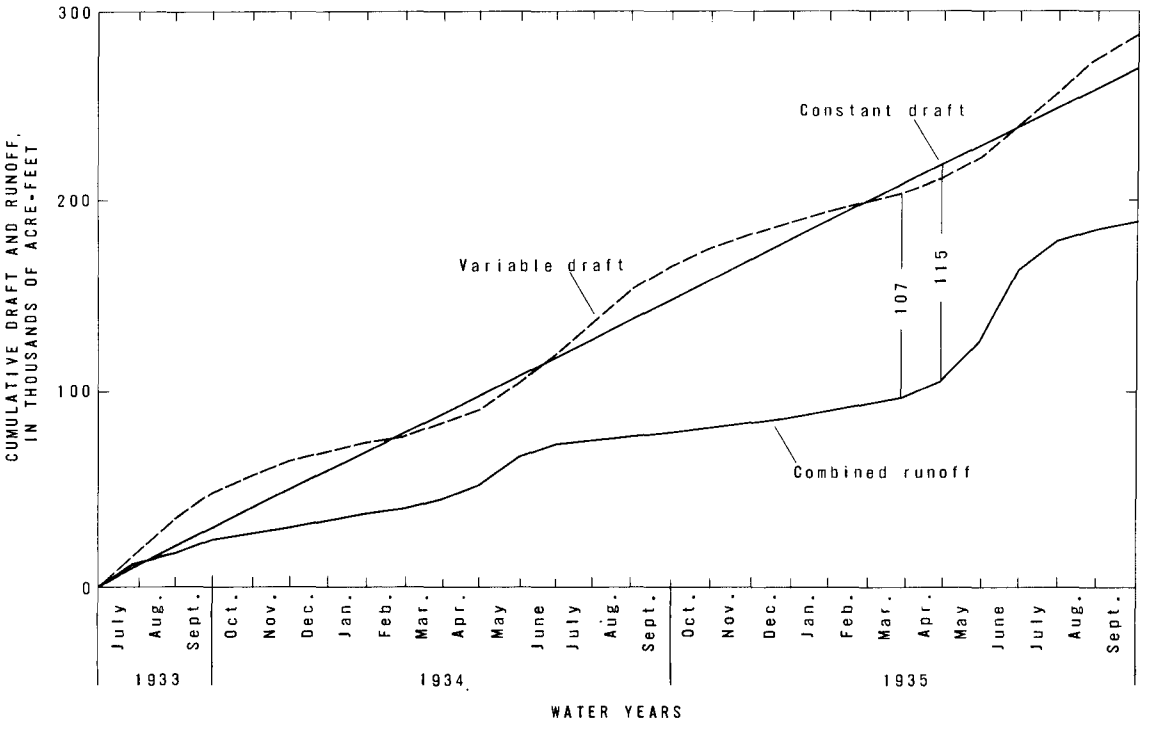


Figure 27.—Comparison of a seasonally variable draft with constant draft and monthly runoff, July 1933 to September 1935.

The comparison suggests that the variable draft tends to reduce the storage requirement in the spring and increase it at the end of the water year. The effects probably are significant for a reservoir design or operation study, but relatively minor for a water-resources appraisal. The combined draft determined by figure 26 may be 5-10 percent too large because the draft was assumed to be constant instead of variable.

As evaporation from a surface reservoir tends to reduce the usable draft (or conversely, to increase the storage requirement for a specific draft) and varying the draft seasonally tends to reduce the storage requirement, the combined effect is relatively small when the annual draft is in the range of 50-80 percent of mean annual runoff and may safely be ignored except in advanced stages of design or operation studies.

All values of draft and storage discussed above are considered as aids to a water-resources appraisal—not design criteria. It would not be possible to operate a reservoir system so that it

emptied just as the storage requirement reached a maximum and then refilled. However, in showing what could have been achieved under the severest conditions of record, they serve as useful guides. An indication of the probable rarity of such conditions would increase their usefulness.

Figure 28 is a cumulative probability plot of the annual combined runoff showing the probability of an annual runoff less than any particular value. The curve shown is empirical—not a theoretical distribution. The probability of an annual value less than the minimum of record is less than 2 percent. The probability of a sequence of annual flows that would produce the storage requirement derived from figure 26 cannot be reliably determined but almost certainly is less than 2 percent. Consequently, the annual draft and storage requirements derived from figure 26 are conservative estimates and should not be considered as limits to the practical draft during periods of abundant runoff. If an annual draft of 120,000-125,000 acre-feet were adopted as a normal operating value and 116,000 acre-feet of storage capacity were available for regulation of the runoff at the six canyon mouths, there would be few periods when the draft would have to be reduced.

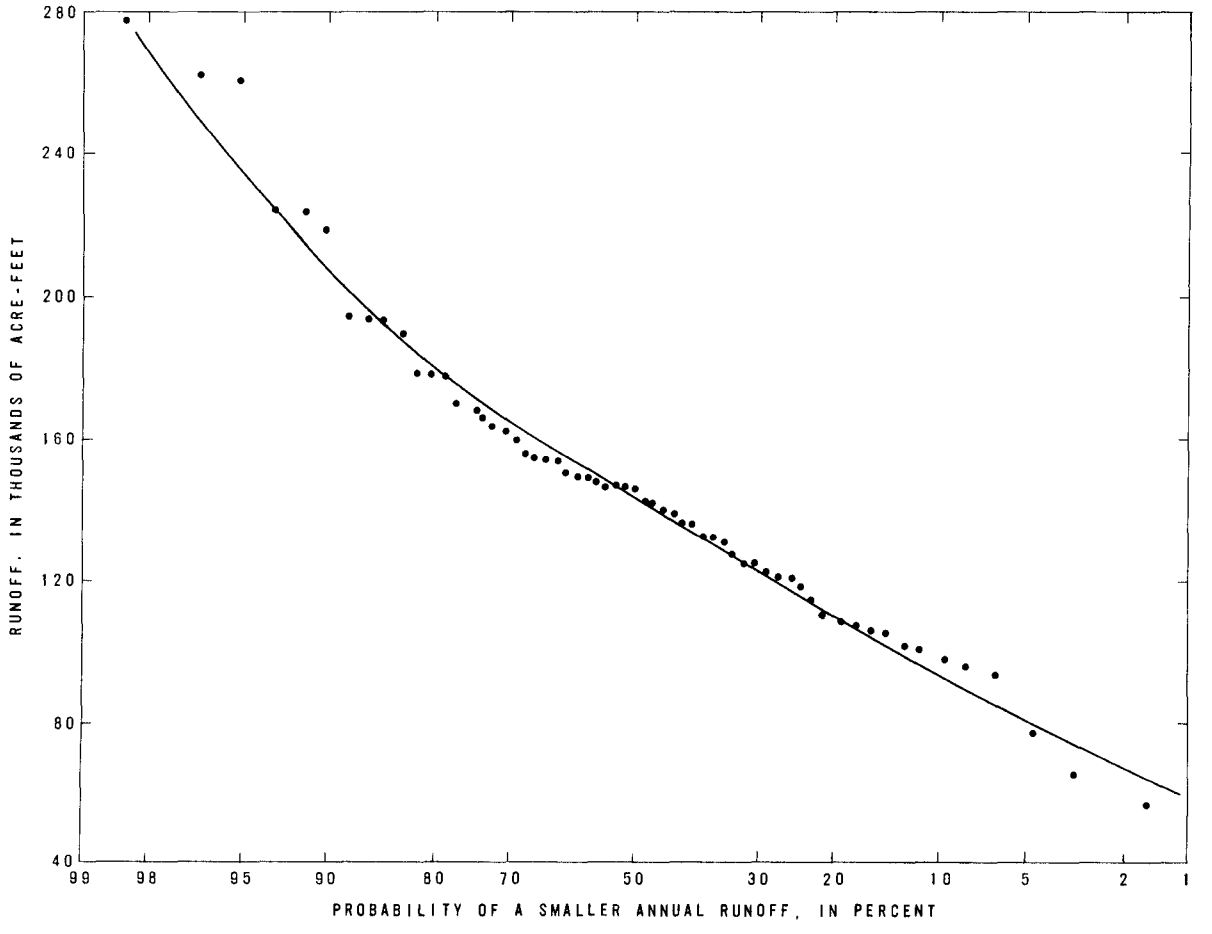


Figure 28.—Cumulative probability distribution of the annual combined runoff in six Wasatch streams, 1907-67 water years.

The runoff potentially subject to regulation in surface reservoirs is considerably less than that used in the preceding analyses, because some of the sites for reservoirs or diversions are far above the canyon mouths. Construction of Little Dell Dam and Reservoir just above the existing Mountain Dell Reservoir (pl. 1) was authorized by legislation in 1968. The combined capacity of the two reservoirs will be 50,000-55,000 acre-feet, which will regulate runoff from Parleys Creek basin above Mountain Dell Dam, flow diverted from Mill Creek above Elbow Fork, and flow diverted from Emigration Creek below Burr Fork.

Berger Associates, Inc. (1964, p. 19) describes other damsites on Little Cottonwood Creek near the canyon mouth, Big Cottonwood Creek near Mill D South Fork (Argenta), and City Creek near the canyon mouth.

A record for 1916-63 of runoff at the Argenta damsite on Big Cottonwood Creek is summarized and compared with that for the canyon mouth in figure 29 and in the following tabulation of means and extremes of annual runoff:

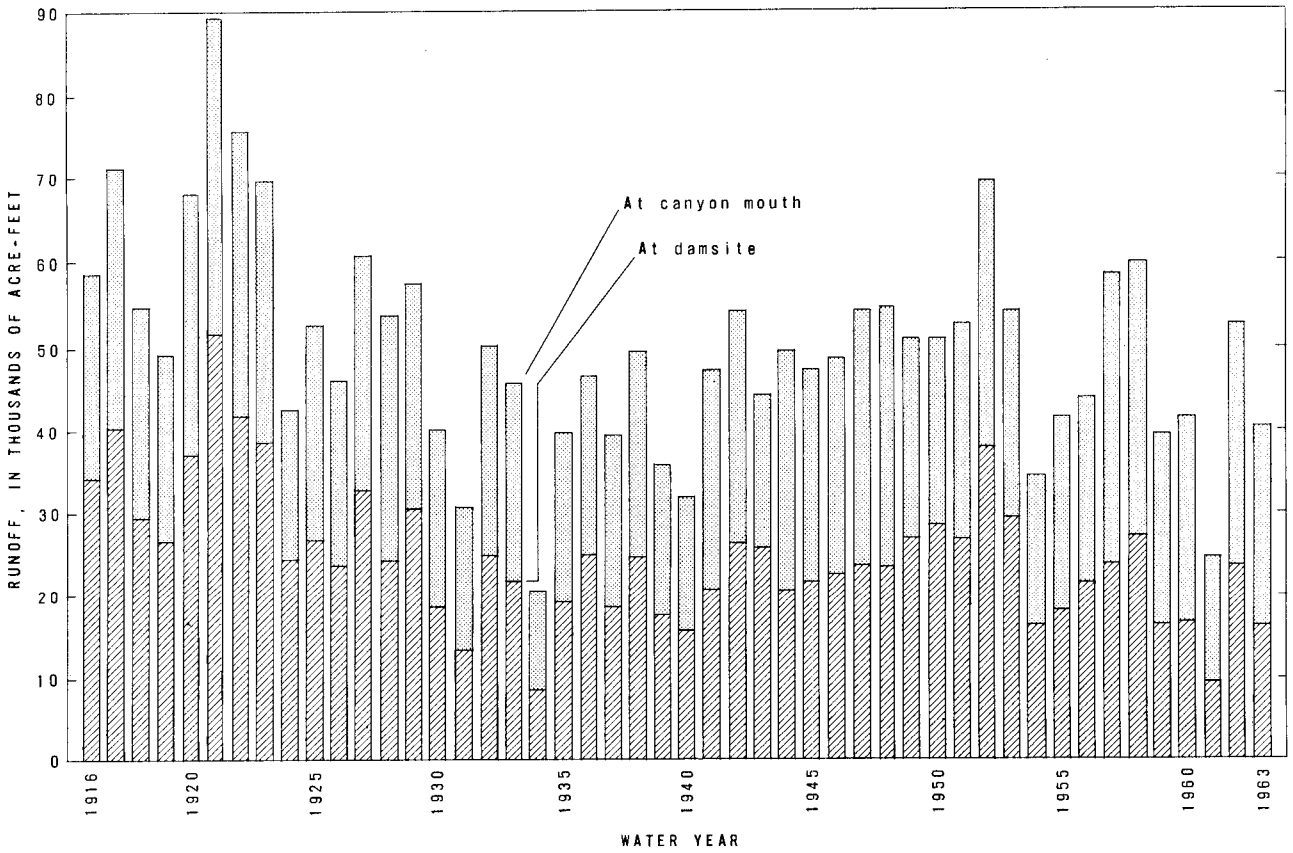


Figure 29.—Comparison of annual runoff in Big Cottonwood Creek at Argenta damsite and at canyon mouth, 1916-63 water years. Records furnished by Salt Lake City Water Department (except as noted on p. 233).

[Annual runoff, in acre-feet, and (percent of mean)]

	Damsite	Canyon mouth
Maximum	51,450 (207)	89,500 (180)
Mean	24,810	49,860
Minimum	8,380 (34)	20,230 (41)

The comparison of extreme values, expressed as a percentage of the mean, shows that the annual runoff at the damsite is somewhat more variable than that at the canyon mouth.

The mean annual runoff at the damsite is 49.8 percent of the corresponding runoff at the canyon mouth. Similar percentages for individual years, however, range from 38.2 to 58.0 and show only slight correlation with the runoff in acre-feet. For below-average runoff at the damsite, the mean percentage of the corresponding runoff at the canyon mouth is 46.9; and for above-average runoff, the mean percentage is 51.5.

Short-term records (often with little or no data for winter months) are available for other sites that are far above canyon mouths. The following tabulation, based on records for the 1964-68 water years, summarizes the runoff at dam or diversion sites in relation to the corresponding runoff at the canyon mouths. For this purpose, the runoff in two tributaries to Mountain Dell Reservoir on Parleys Creek have been combined.

[Runoff at upper sites (or site) in percentage of corresponding runoff at canyon mouth]

Site	Maximum annual percentage	1964-68 mean	Minimum annual percentage
Mill Creek above Elbow Fork	68.2	58.9	53.5
Parleys Creek above Mountain Dell Reservoir[1]	78.3	70.5	59.9
Emigration Creek below Burr Fork[2]	41.7	38.0	21.3
Emigration Creek below Burr Fork[3]	66.2	51.3	33.4

[1]Combined runoff in Parleys Creek (including runoff in Lambs Creek) and Dell Creek.

[2]Based on runoff at canyon mouth, including flow in Emigration Tunnel.

[3]Based on flow in creek channel, excluding flow in tunnel.

As the percentages described above vary markedly from year to year, the 5-year average percentages in the above tabulation provide a means of obtaining only rough estimates of the long-term mean runoff at the short-term stations. Using these ratios, it is estimated that about 73 percent of the runoff at the mouths of the six principal canyons would be subject to regulation by the proposed system of surface reservoirs (including reservoirs near the mouths of Little Cottonwood and City Creek Canyons). As the runoff at the upper stations is more variable than that at the lower ones, the storage requirements are a somewhat larger percentage of those determined herein for the canyon-mouth sites.

Gains and losses in Jordan Valley

As the Wasatch streams leave the canyons and cross the benchlands in the eastern part of the valley, they traverse valley fill in which the ground-water level is far below the streambeds. Here they lose water by seepage. In some areas between the benchlands and the lowlands, however, the streams gain water by seepage from bodies of perched ground water. Farther downstream, in the lowlands near the Jordan River, the two Cottonwood Creeks and Mill Creek are lower than the ground-water levels and they gain by seepage. The other streams have been diverted into underground drains through the low-lying parts of Salt Lake City.

The natural regimen has been modified by diversions at or above the canyon mouths for municipal use and by irrigation diversions from the three southernmost streams at numerous points in the valley. When the runoff in these streams is insufficient to meet all demands, it is supplemented by diversions from the Jordan River and by ground-water withdrawals.

The changes in regimen as the streams traverse the valley are illustrated by hydrographs of Big Cottonwood Creek at three sites (fig. 30). The record for the canyon mouth represents natural runoff at that point; the one for Cottonwood Lane (about 2350 East) shows the flow after depletion by most of the diversions and the channel losses; the one for 300 West (Second West Street) shows a substantial gain despite additional diversions below Cottonwood Lane. At times, this gain is caused in part by the addition of Jordan River water or ground water from wells.

Losses from stream channel.—To help determine the magnitude of ground-water recharge from stream channels, observations were made during 1964-68 at sites where losses generally cease and gains begin. These sites are shown in figure 20, and the names of the stations follow: Little Cottonwood Creek at 2050 East, Big Cottonwood Creek at Cottonwood Lane, Mill Creek at 2200 East, Parleys Creek at 1300 East, Emigration Creek below 1300 East, and Red Butte Creek at 1600 East. (Flow at the latter station is compared with flow of Red Butte Creek below Red Butte Reservoir.)

During 1964, two records were obtained for City Creek also; but the sites (about 950 North and 550 North) were less than a mile apart and any effects of gain or loss were obscured by effects of error in the observations. It was concluded that there was no significant gain or loss in the reach between the two sites.

Precise determinations of the losses between the canyon mouths and the indicated sites are impossible because of errors in all observations involved, the occasional storm or snowmelt runoff between stations, the return of unmeasured amounts of water diverted for irrigation, the use of Jordan River water and ground water to supplement the flow in the two Cottonwood Creeks, and the time lag involved when a particular volume of water moves from one station to another. Also, the gage on Parleys Creek at 1300 East was in backwater from debris on a trashrack much of the time. (Because only fragments of the record are usable, this record was not published.)

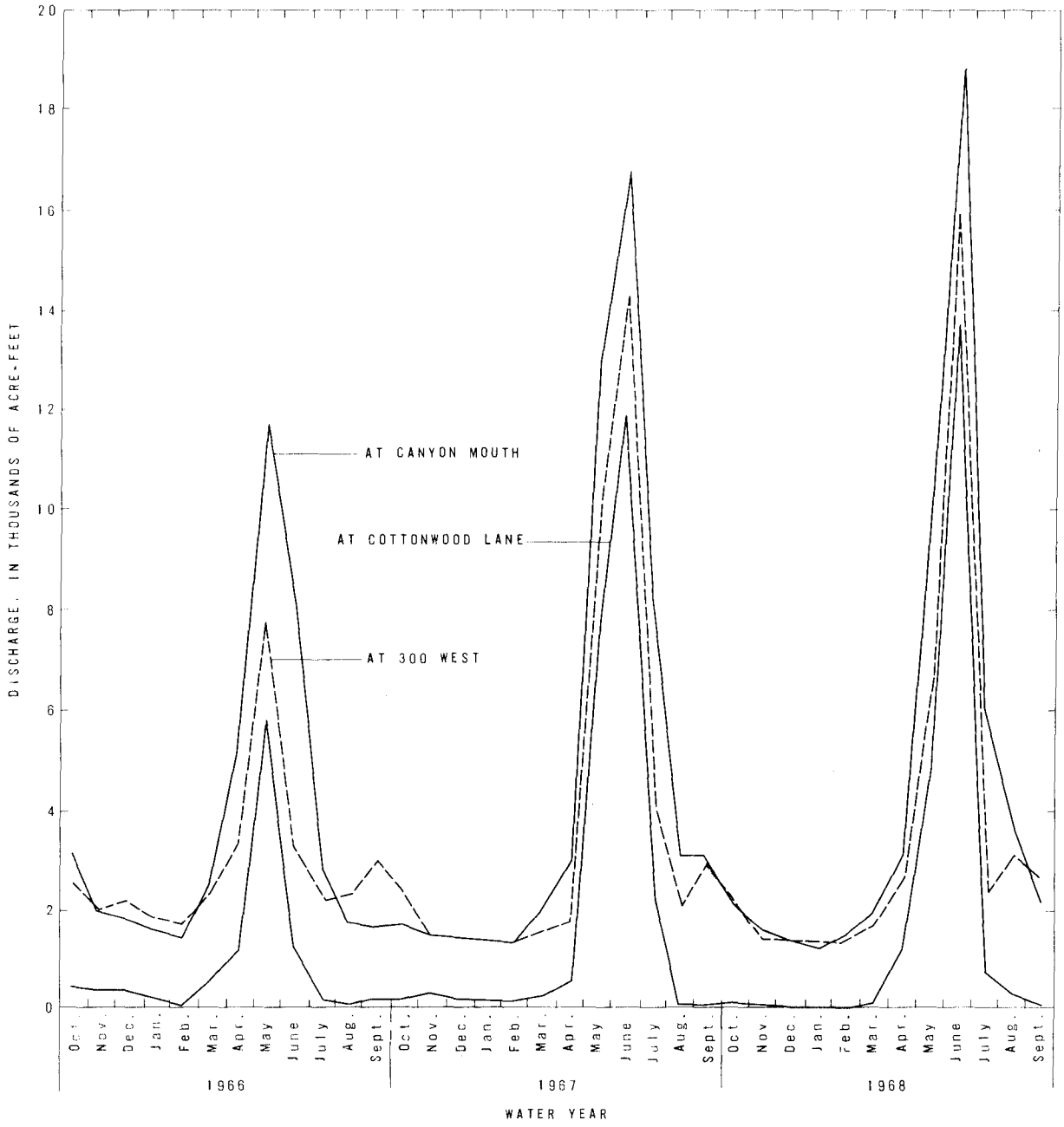


Figure 30.—Regimen of Big Cottonwood Creek in Jordan Valley, 1966-68 water years. The downstream order of sites is (1) canyon mouth, (2) Cottonwood Lane (2350 East, the approximate location of the change from loss to gain), and (3) 300 West, near the Jordan River.

Despite the many uncertainties, fairly reliable guides to the magnitude of the seepage loss were obtained by subtracting daily flows at the lower stations plus diversions between stations from the corresponding flows at the canyon mouths. When these daily differences were plotted on hydrographs, it was usually possible to identify periods when they represent actual seepage loss. Using such periods as a base, the losses for other periods were estimated.

The average losses during 1964-68, listed by months in table 5, probably are near the long-term averages because runoff during that 5-year period was close to the 1907-67 average.

Table 5.—Summary of mean monthly channel losses, in acre-feet, in six Wasatch streams in eastern Jordan Valley, 1964-68 water years

Stream	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
Little Cottonwood Creek	210	160	160	90	70	90	470	910	990	890	520	220	4,780
Big Cottonwood Creek	160	40	20	10	50	110	540	1,150	1,370	700	310	240	4,700
Mill Creek	130	140	120	130	130	130	120	130	170	140	130	110	1,580
Subtotal	500	340	300	230	250	330	1,130	2,190	2,530	1,730	960	570	11,060
Parleys Creek	110	110	90	90	80	220	110	300	350	400	120	130	2,110
Emigration Creek	50	40	40	40	50	60	140	200	110	120	100	70	1,020
Red Butte Creek	10	10	20	30	40	60	90	140	70	50	10	10	540
Total	670	500	450	390	420	670	1,470	2,830	3,060	2,300	1,190	780	14,730

The channel losses are influenced chiefly by the magnitude and duration of streamflow in the reaches where losses occur. Unfortunately, there is no fully satisfactory index of such magnitude and duration because of the complex system of diversions, return flows, and imports. A general relation between runoff at the canyon mouths and losses from stream channels is indicated by figure 31, in which the 5-year average losses for each calendar month, combined for the six streams, are plotted against corresponding runoff at the canyon mouths. In this figure the scatter of the points has been minimized by the use of averages. Similar plots of data for a single stream exhibit considerably more scatter, and plots of individual monthly values exhibit a great deal of scatter but indicate the same general shape of relation curve.

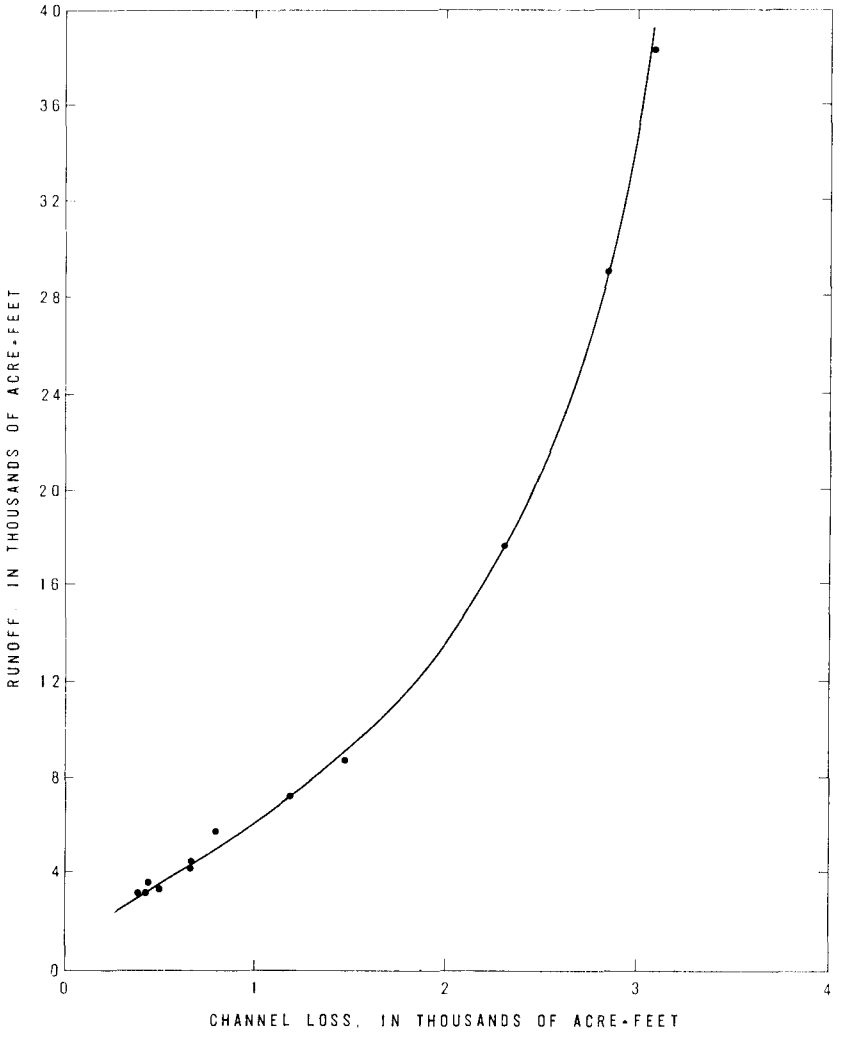


Figure 31.—Relation of channel loss in Wasatch streams in eastern Jordan Valley to runoff at canyon mouths. The values of loss and runoff are 5-year averages (1964-68 water years) of the monthly total values for six streams.

Part of the scatter in such plots is caused by the inadequacy of the runoff at the canyon mouth to serve as an index of magnitude and duration of flow in the reach where losses occur. Other factors, such as variations in permeability of the streambeds, changes in water temperature, and the changing areal extent of saturated sediments beneath stream channels, also may significantly influence the monthly losses.

The mean annual loss from the six streams during 1964-68 was 11.4 percent of the corresponding runoff. The percentage loss, however, varies with runoff; the range derived from figure 31 being about 8-16 percent. For periods of low or moderate runoff the average percentage is about 15.

Gains in stream channels.—Records for only one stream (Big Cottonwood Creek) are available to indicate the gain from ground water as the Wasatch streams traverse the lowlands in Jordan Valley. Daily gross gains were computed by subtracting the discharge at Cottonwood Lane from the sum of diversions below that point plus the discharge at 300 West. These computed gains are affected by the same factors that affect the computed losses in the reach upstream. Examination of either a daily hydrograph or monthly hydrograph (fig. 32) of the gains reveals that greatly increased gains are associated with the irrigation season. Hence, the increases probably are caused chiefly by unmeasured return flows of water diverted for irrigation. The gain from ground-water seepage was estimated, as shown in figure 32, by examination of both daily and monthly hydrographs of gross gain.

The gains shown in figure 32 are included in gains of the Jordan River described in a later section.

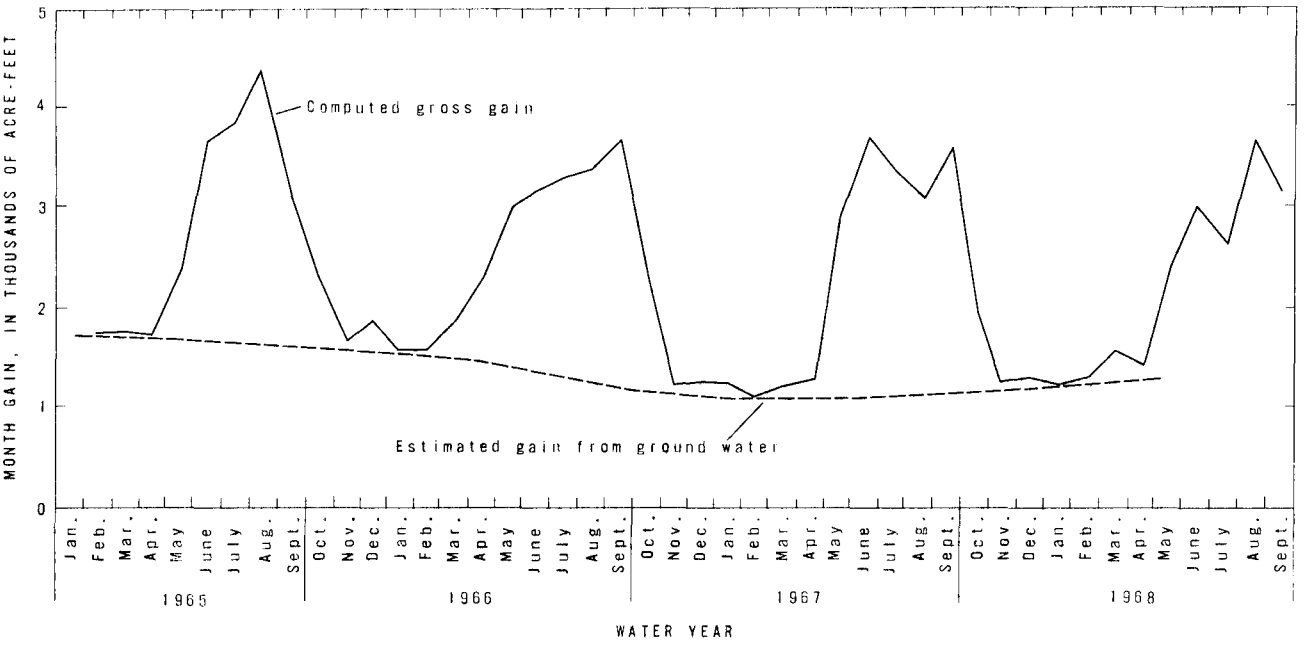


Figure 32.—Monthly gains in Big Cottonwood Creek between Cottonwood Lane and 300 West, 1965-68 water years.

Chemical quality

The chemical quality of water in the Wasatch streams is indicated by the dissolved-solids content and by the concentrations of significant dissolved constituents. A fairly close empirical relation between dissolved solids and specific conductance, which can be measured periodically or continuously, can be used to estimate dissolved-solids content when specific conductance was measured but no analysis for dissolved solids was made. Such empirical relations have been developed for each of six principal Wasatch streams at or near the canyon mouths and for Red Butte Creek above Red Butte Reservoir, and the relation for Little Cottonwood Creek is shown in figure 33.

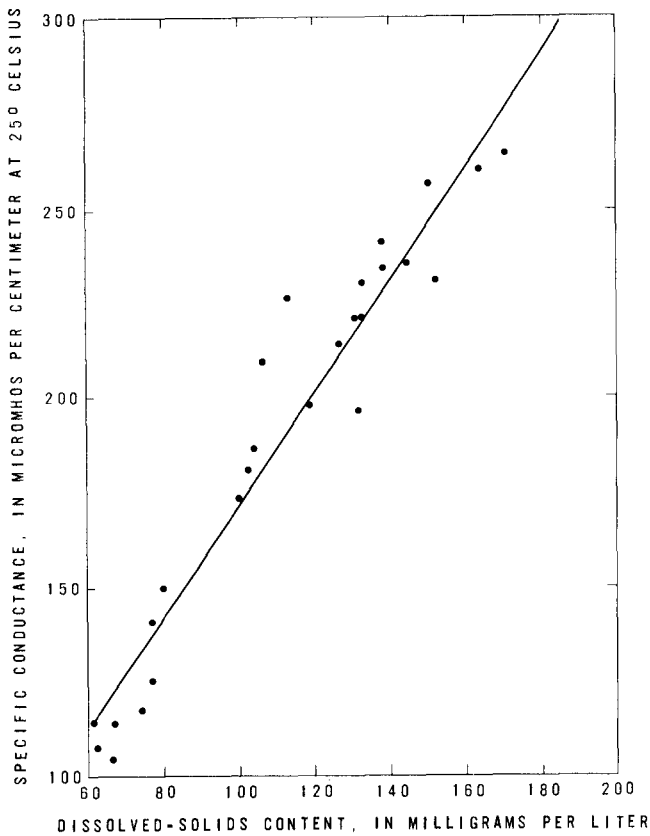


Figure 33.—Relation of specific conductance to dissolved-solids content for Little Cottonwood Creek, 1964-66 water years.

For each stream at or near the canyon mouth the chemical quality is based on measurements of specific conductance and analyses of samples from the stream channel, although the streamflow at all stations except Red Butte Creek above Red Butte Reservoir usually is divided among two or more channels. For Little Cottonwood, Big Cottonwood, Mill, and Red Butte Creeks the water-quality data apply to the runoff (discharge in the channel plus diversions) because the quality of most of the water diverted is the same as that of the water sampled. For Parleys, City, and Emigration Creeks the data apply only to water in the stream channel because the quality of the water diverted several miles above the canyon mouths and the discharge of Emigration Tunnel Springs probably differ significantly from that of the water sampled.

The approximate maximum, average, and minimum dissolved-solids contents for each stream shown in figure 34, are lowest for Little Cottonwood and highest for Emigration Creek. The differences are due to differences in the drainage basins between rock types and mineral content and the activities of man. Most of the Little Cottonwood Creek drainage basin, for example, is underlain by relatively impermeable, solution-resistant crystalline rocks, and the drainage basin is relatively unmodified by the activities of man. The Emigration Creek drainage basin, by contrast, is underlain mostly by shale, siltstone, and limestone of Mesozoic age, which

are less resistant to weathering and erosion, and much of the canyon floor has undergone extensive urbanization. The extremes of concentration shown in figure 34 are based on data gathered during the 1964-66 water years, but the ranges defined probably are very close to the actual ranges for the 1964-68 water years.

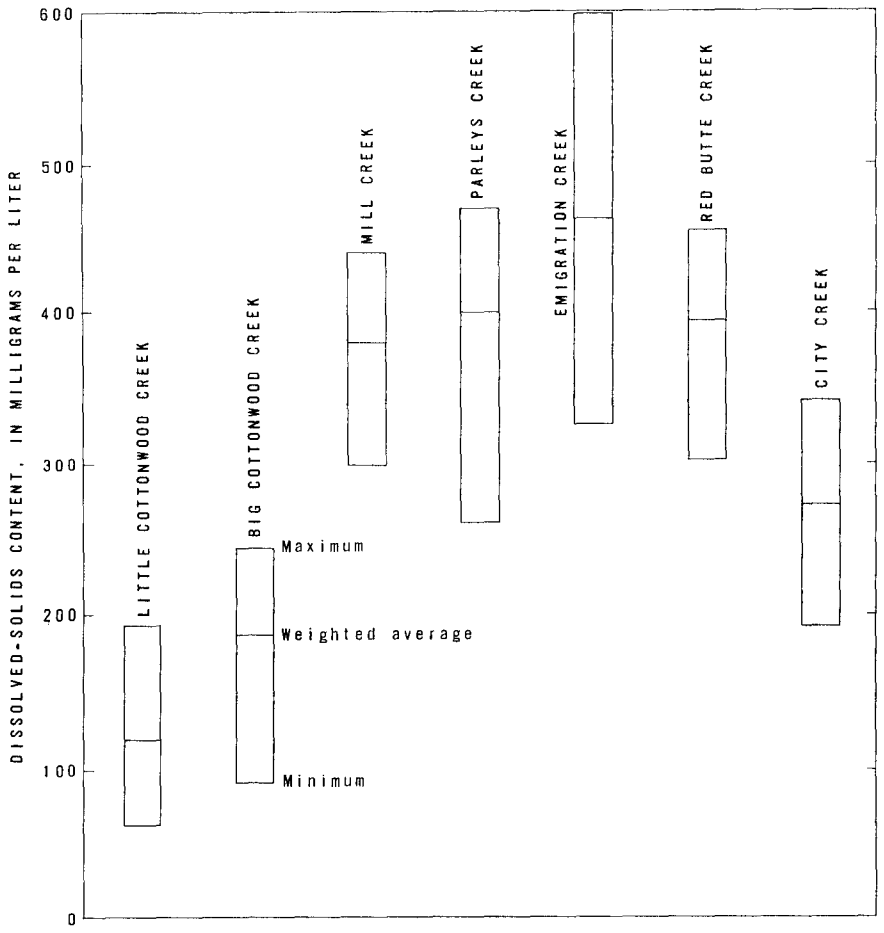


Figure 34.—Discharge-weighted averages, 1964-68 water years, and observed ranges of the dissolved-solids content of seven Wasatch streams, 1964-66 water years.

Average concentrations can be weighted on the basis of time or discharge. A time-weighted average is an arithmetical average of concentrations determined at regular intervals during a specific period. A discharge-weighted average is equivalent to the concentration that would be determined if the total discharge during a specific period were collected in a single container and thoroughly mixed. Discharge-weighted averages for unregulated streams generally are less than time-weighted averages because the dissolved-solids content tends to be greatest when the discharge is lowest and composed chiefly of ground-water inflow that has been in

contact with soils and rocks for a relatively long time. Conversely, the dissolved-solids content is lowest when the discharge is greatest because the rainfall and snowmelt runoff has been in contact with soils and rocks only briefly and hence has dissolved less material. The averages in figure 34 are discharge weighted, and the method of computation is described below.

The relation of specific conductance to daily stream discharge for Little Cottonwood Creek at the canyon mouth is shown graphically in figure 35. Daily discharge, rather than discharge at the time of sampling, was used because the discharge past the gaging station usually is divided among several channels and instantaneous discharges in some channels are not available. The equation for estimating specific conductance (as a measure of dissolved-solids content) from daily discharge is derived by simple linear regression analysis.

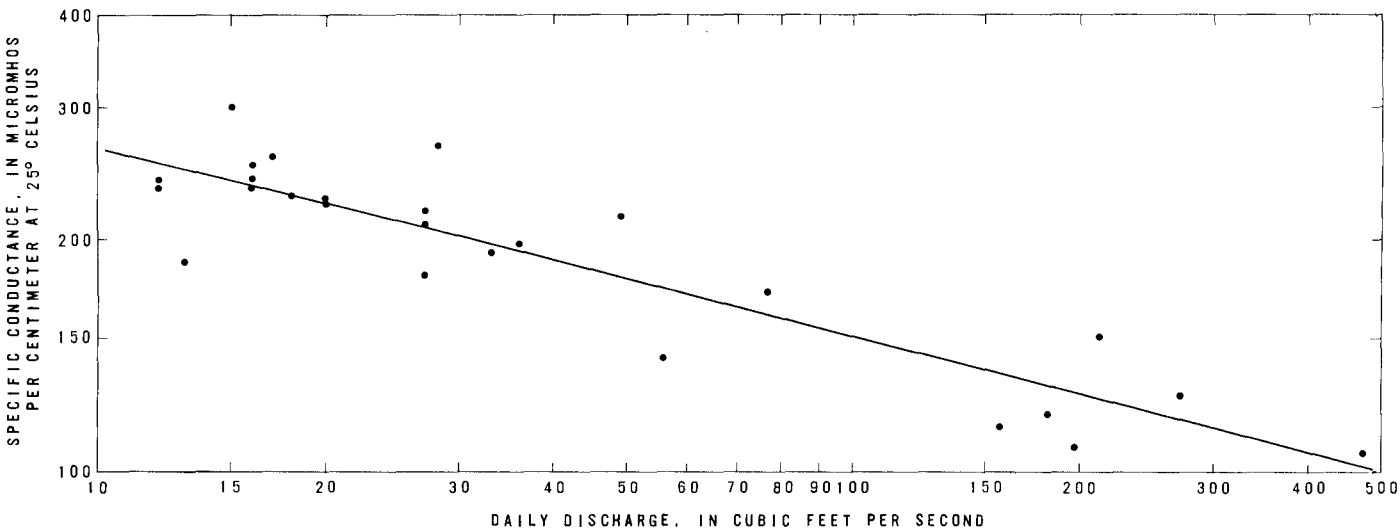


Figure 35.—Relation of specific conductance to stream discharge for Little Cottonwood Creek, 1964-66 water years. The discharge includes water diverted above the canyon mouth.

This equation and others similarly derived are listed in table 6. The coefficients of correlation indicate the proportion of the variation of specific conductance that is associated with variation of daily discharge—a value of 1.0 representing perfect correlation. Although these relations are based on measurements of specific conductance during the 1964-66 water years, they have been used to estimate water quality during the 1964-68 water years because there is no reason to expect a change in the relations during the longer period.

The discharge-weighted averages of dissolved-solids content were computed by using 1964-68 flow-duration data for each stream and the appropriate equation from table 6 to determine the corresponding specific conductance, which in turn was converted to dissolved-solids content by use of the appropriate relation curve (fig. 33, for example). Results of

the computations for Little Cottonwood Creek are presented in table 7. The corresponding averages for each of the seven Wasatch streams are shown in table 8, which also shows averages of other analytical values.

Table 6.—Relations of specific conductance to stream discharge for seven Wasatch streams

[Stream-gaging stations are at or near canyon mouths except for Red Butte Creek, where the station is above Red Butte Reservoir.]

K = specific conductance, in micromhos per centimeter at 25 °C.
Q = daily discharge, in cubic feet per second.

Little Cottonwood Creek	$\text{Log } K = 2.677 - 0.250 \log Q$	0.89
Big Cottonwood Creek	$\text{Log } K = 2.969 - 0.300 \log Q$	.89
Mill Creek	$\text{Log } K = 2.893 - 0.128 \log Q$	.81
Parleys Creek	$\text{Log } K = 2.882 - 0.098 \log Q$	.83
Emigration Creek	$\text{Log } K = 2.922 - 0.121 \log Q$	.78
Red Butte Creek	$\text{Log } K = 2.827 - 0.088 \log Q$	.73
City Creek	$\text{Log } K = 2.709 - 0.080 \log Q$	.76

The values for the dissolved constituents shown in table 8 were derived from relations between individual constituents and the dissolved solids, except that values of sodium plus potassium were calculated by differences. Figure 36 shows the relations for Little Cottonwood Creek (including a relation for sodium plus potassium). Similar relations for each stream were developed from the analytical data collected during 1964-66, and the relations are considered applicable to the 1964-68 water years. By using discharge-weighted averages for the dissolved-solids values in applying these relations, the derived values of dissolved constituents are approximately equal to the discharge-weighted values that would be computed by the method described for dissolved solids. The sodium plus potassium values that were given in table 8 differ only slightly from values derived from the relations shown in figure 36. For example, the two values for Little Cottonwood Creek are 6.6 and 6.2 mg/l, respectively.

Figure 37 illustrates the discharge-weighted average chemical composition of water in the seven Wasatch streams. The water is of the calcium bicarbonate type with calcium comprising about 54-64 percent of the cations and bicarbonate comprising about 58-68 percent of the anions, except for the water from City Creek where bicarbonate constitutes 81 percent. Magnesium is the next most abundant cation comprising about 28-33 percent. Sulfate comprises 22-38 percent of the anions, except for the water from City Creek where it constitutes only 7 percent. The high percentage of bicarbonate and low percentage of sulfate in City Creek water is attributed to the fact that much of the drainage basin is underlain by limestone.

Table 7.—Computation of discharge-weighted average dissolved-solids content for Little Cottonwood Creek at canyon mouth, 1964-68 water years

Time limits (percent)	Time interval (percent)	Mean of interval (percent)	Discharge (cfs)	Increment of discharge (cfs)	Specific conductance (micromhos/ cm at 25° C)	Dissolved solids (mg/l)	Increment of dissolved solids (mg/l)
0.00 - 0.02	0.02	0.01	424	0.08	105	55	0.01
.02 - .10	.08	.06	421	.34	105	55	.04
.10 - .20	.10	.15	419	.42	105	55	.06
.20 - 1.0	.80	.60	417	3.34	105	55	.44
1.0 - 3.0	2.0	2.0	400	8.0	107	56	1.1
3.0 - 5.0	2.0	4.0	353	7.1	110	58	1.2
5.0 - 9.0	4.0	7.0	289	11.6	116	62	2.5
9 - 15	6	12	185	11.1	129	71	4.3
15 - 25	10	20	92	9.2	154	88	8.8
25 - 35	10	30	46	4.6	182	107	10.7
35 - 39	4	37	30	1.2	203	121	4.8
39 - 45	6	42	25	1.5	214	128	7.7
45 - 55	10	50	21	2.1	223	134	13.4
55 - 65	10	60	18	1.8	232	140	14.0
65 - 75	10	70	17	1.7	235	142	14.2
75 - 85	10	80	16	1.6	238	144	14.4
85 - 95	10	90	15	1.5	242	147	14.7
95 - 99	4	97	13	.5	250	152	6.1
99 - 99.8	.8	99.4	12	.1	256	156	1.2
99.8 - 100.0	.2	99.9	6.5	.01	299	185	.4
Totals	100.0			67.8[1]			120[2]

[1]This total equals the mean discharge.

[2]This total is the discharge-weighted average dissolved-solids content.

Table 8.—Chemical quality of water from seven Wasatch streams, 1964-68 water years

[All chemical data are discharge-weighted averages computed from relations described in the text. Sampling points are at canyon mouths, except for Red Butte Creek where the sampling point is above Red Butte Reservoir.]

Discharge: Combined flow (creek channel and diversion) for Little Cottonwood, Big Cottonwood, and Mill Creeks; and residual flow (excluding diversions to Salt Lake City water supply) for Parleys, Emigration, and City Creeks.

Sodium and potassium: Calculated and reported as sodium.

Dissolved solids: Determined as residue on evaporation at 180° C.

		Creek						
		Little Cottonwood	Big Cottonwood	Mill	Parleys	Emigration	Red Butte	City
Mean discharge, in cubic feet per second		67.8	73.8	13.6	13.5	6.14	3.34	6.01
Silica (SiO_2)	mg/l	6.4	6.7	8.3	12	15	11	11
Calcium (Ca)	mg/l	27	40	82	79	90	76	66
Magnesium (Mg)	mg/l	5.8	13	26	24	27	28	18
Sodium (Na)	mg/l	6.6	6.9	7.2	26	30	22	12
Bicarbonate (HCO_3)	mg/l	77	142	231	263	287	286	263
Sulfate (SO_4)	mg/l	30	36	120	80	107	94	17
Chloride (Cl)	mg/l	7.5	10	9.1	38	38	14	23
Nitrate (NO_3)	mg/l	.8	.4	.3	1.2	.9	.4	.1
Dissolved Solids	mg/l	120	187	380	401	464	393	272
Tons per acre-foot		.16	.25	.52	.54	.63	.53	.37
Tons per day		21.5	36.6	14.0	14.5	7.67	3.51	4.41
Hardness as $CaCO_3$								
Calcium, magnesium	mg/l	91	153	312	296	334	305	239
Noncarbonate	mg/l	28	37	122	80	100	70	23
Sodium adsorption ratio		.3	.2	.2	.6	.7	.5	.3
Specific conductance, in micromhos per centimeter at 25° C		202	319	576	647	727	621	481
pH		7.4	7.8	7.8	7.7	7.8	8.0	7.6

Dissolved-solids-duration curves for the Wasatch streams for the 1964-68 water years are shown in figure 38. These curves are based on flow-duration data for the same period. A comparison of data in Big Cottonwood Creek for two periods, 1964-68 and 1931-59, indicates that flow durations for the short period differ only slightly from those for the longer period. Hence, if future changes in land use do not substantially alter the chemical regimen, the curves shown in figure 38 should provide reasonably good indications of future dissolved-solids durations.

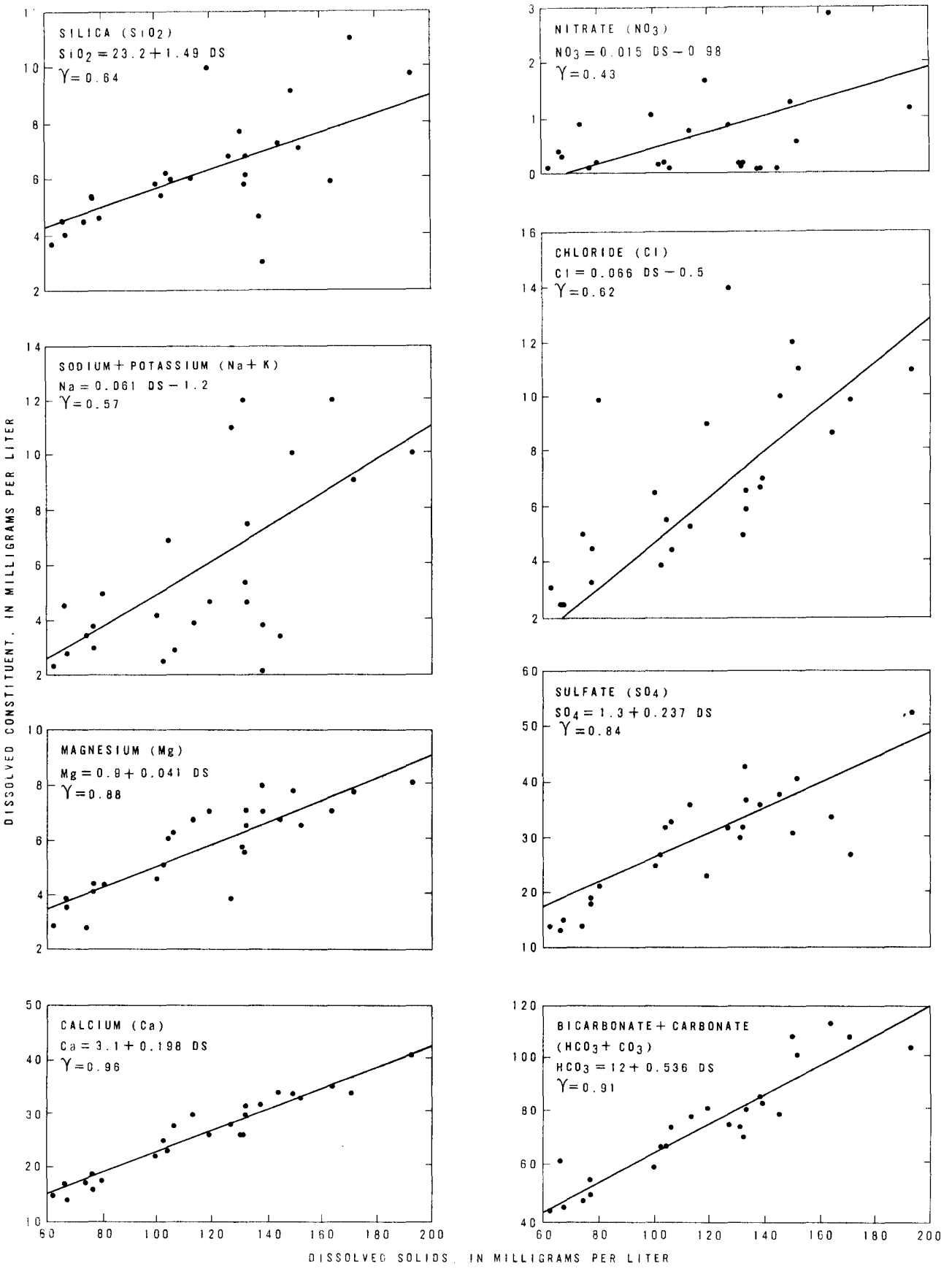


Figure 36.—Relations of dissolved constituents to dissolved solids for Little Cottonwood Creek at canyon mouth, 1964-66 water years. Equations for the regression line are given for each constituent; *DS* = dissolved-solids content, *r* = coefficient of correlation.

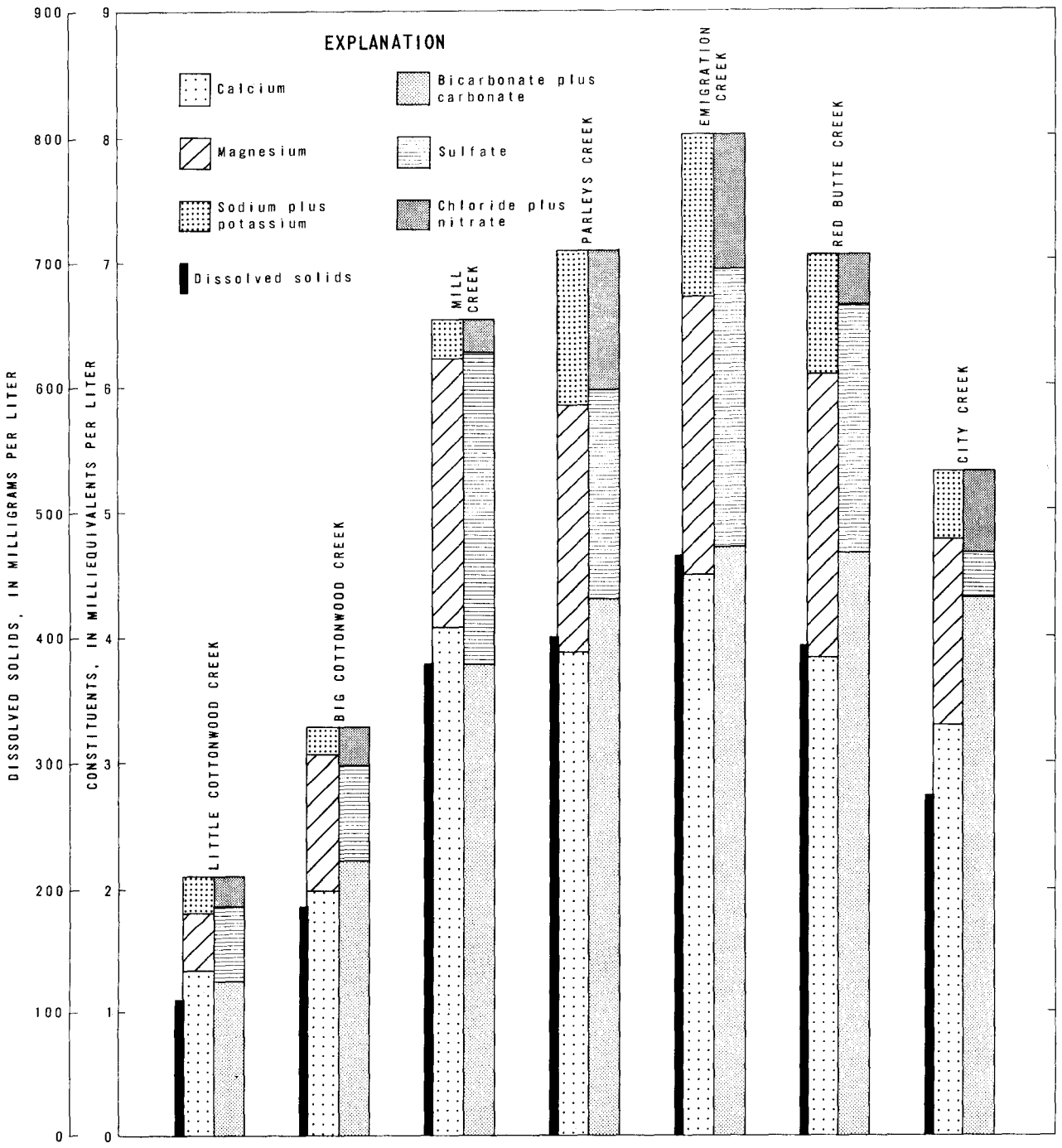


Figure 37.—Discharge-weighted average chemical composition of water from seven Wasatch streams at or near the canyon mouths, 1964-68 water years.

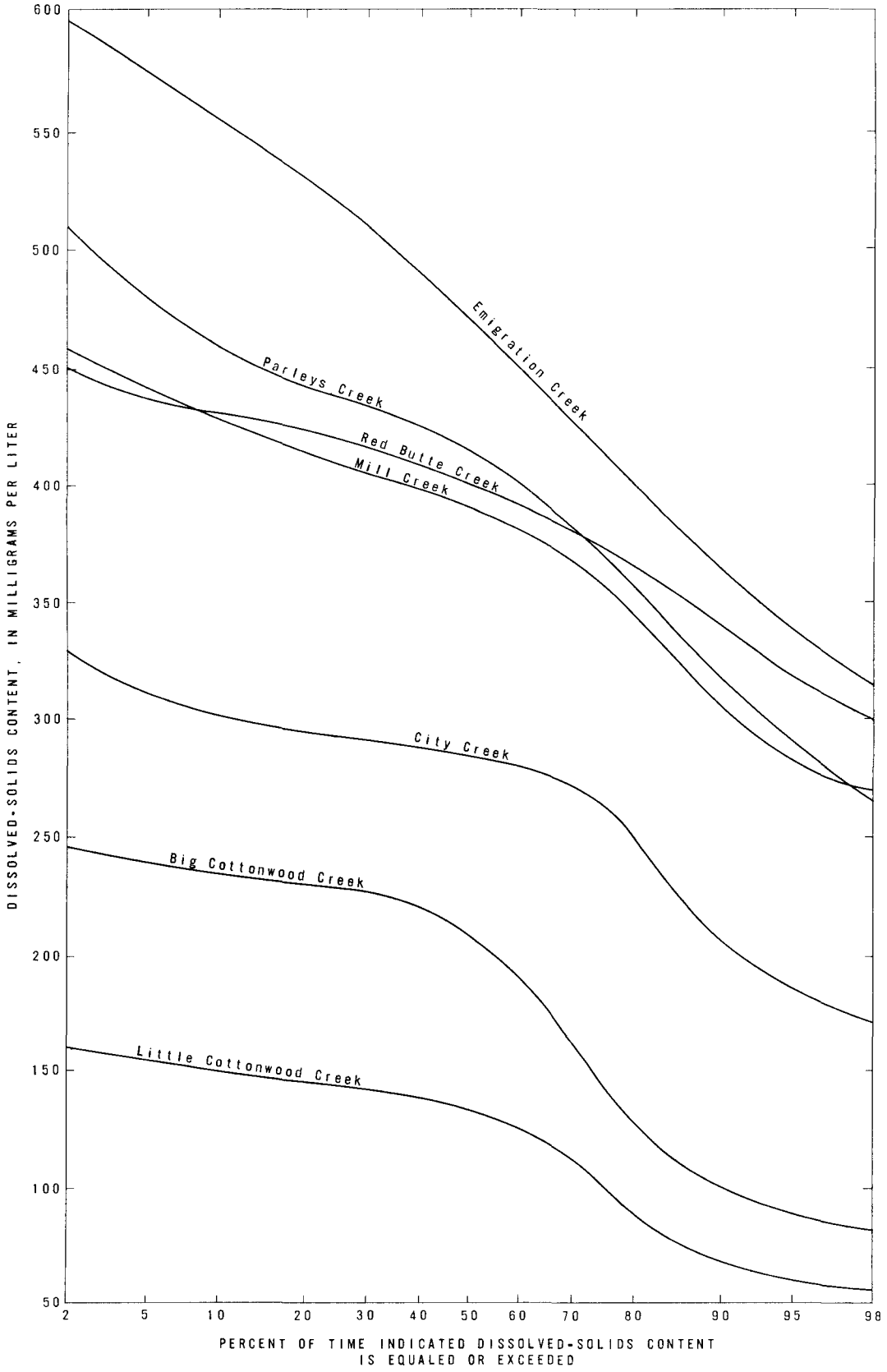


Figure 38.—Dissolved-solids duration curves for seven Wasatch streams, 1964-68 water years. The data for Little Cottonwood, Big Cottonwood, Mill, and Red Butte Creeks apply to runoff (discharge in stream channel plus diversions) for each stream at or near its canyon mouth; the data for other creeks apply to the discharge in the channel at the canyon mouth.

Changes in chemical quality with location

In addition to the variations in chemical quality of a stream at a particular site, the quality differs at different locations along the stream. The nature of these differences depends on whether the inflow in a particular reach contains more or less dissolved solids than the receiving stream. In general, the chemical quality of a stream degrades from its headwaters to its mouth as a consequence of longer contact with soluble materials, use and reuse of the water, and inflow of pollutants.

The average chemical quality of four Wasatch streams several miles above the canyon mouths, at the canyon mouths, and in the valley are given in table 9 and illustrated in figure 39. For sites other than the canyon mouths, the data listed in table 9 are simple averages computed from occasional samples collected during the study period.

Table 9.—Average chemical quality of four Wasatch streams at various sites, 1964-68 water years

[All chemical data, except for that at canyon mouths, based on analyses of occasional samples; data for canyon mouths are from table 8.]

Sodium and potassium: Calculated and reported as sodium.
Dissolved solids: Residue on evaporation at 180° C.

	Little Cottonwood Creek			Big Cottonwood Creek			Mill Creek				Emigration Creek	
	Alta	Canyon mouth	300 West	Brighton	Canyon mouth	300 west	Above Elbow Fork	Canyon mouth	100 East	900 West	Below Burr Fork	Canyon mouth
Number of samples	4	----	7	4	----	4	6	----	4	4	5	----
Silica (SiO_2) (mg/l)	4.8	6.4	14	8.6	6.7	8.4	8.3	8.3	10	12	10	15
Calcium (Ca) (mg/l)	42	27	80	14	40	64	57	82	83	106	82	90
Magnesium (Mg) (mg/l)	14	5.8	37	5.4	13	24	17	26	36	42	17	27
Sodium (Na) (mg/l)	3.2	6.6	78	6.5	6.9	40	13	7.2	76	82	18	30
Bicarbonate (HCO_3) (mg/l)	120	77	225	53	142	207	213	231	245	282	278	287
Sulfate (SO_4) (mg/l)	62	30	156	16	36	91	42	120	170	222	48	107
Chloride (Cl) (mg/l)	4.4	7.5	103	7.6	10	56	15	9.1	98	100	26	38
Nitrate (NO_3) (mg/l)	.2	.8	5.8	.5	.4	2.8	.2	.3	5.5	16	.1	.9
Dissolved solids (mg/l)	188	120	603	80	187	415	255	380	632	741	338	464
Hardness as $CaCO_3$ (mg/l)												
Calcium, magnesium	163	91	352	58	153	259	212	312	356	438	275	334
Noncarbonate	64	28	143	14	37	89	38	122	155	206	47	100
Specific conductance, in micromhos per centimeter at 25° C	304	202	965	133	319	661	429	576	931	1,090	566	727

Table 9 and figure 39 indicate a general increase in dissolved solids with distance from the headwaters as additional ground water enters the streams. The reach of Little Cottonwood Creek from Alta to the canyon mouth, however, is an exception. The relatively high dissolved-solids content of the water at Alta is attributed to mine drainage from limestone and shale which contain minerals that are readily dissolved. Below Alta, this water is diluted by inflow with relatively low dissolved-solids content as the stream passes over crystalline rocks that are relatively insoluble. The dissolved-solids content increases in the valley portion of the stream because of inflow of surface drainage from the urban area (which is sometimes affected by the use of salt to help clear streets of snow and ice); irrigation return flow; and water imported from Utah Lake. However, the contribution of dissolved solids from any particular source cannot be identified because of the complex pattern of diversions and return flows.

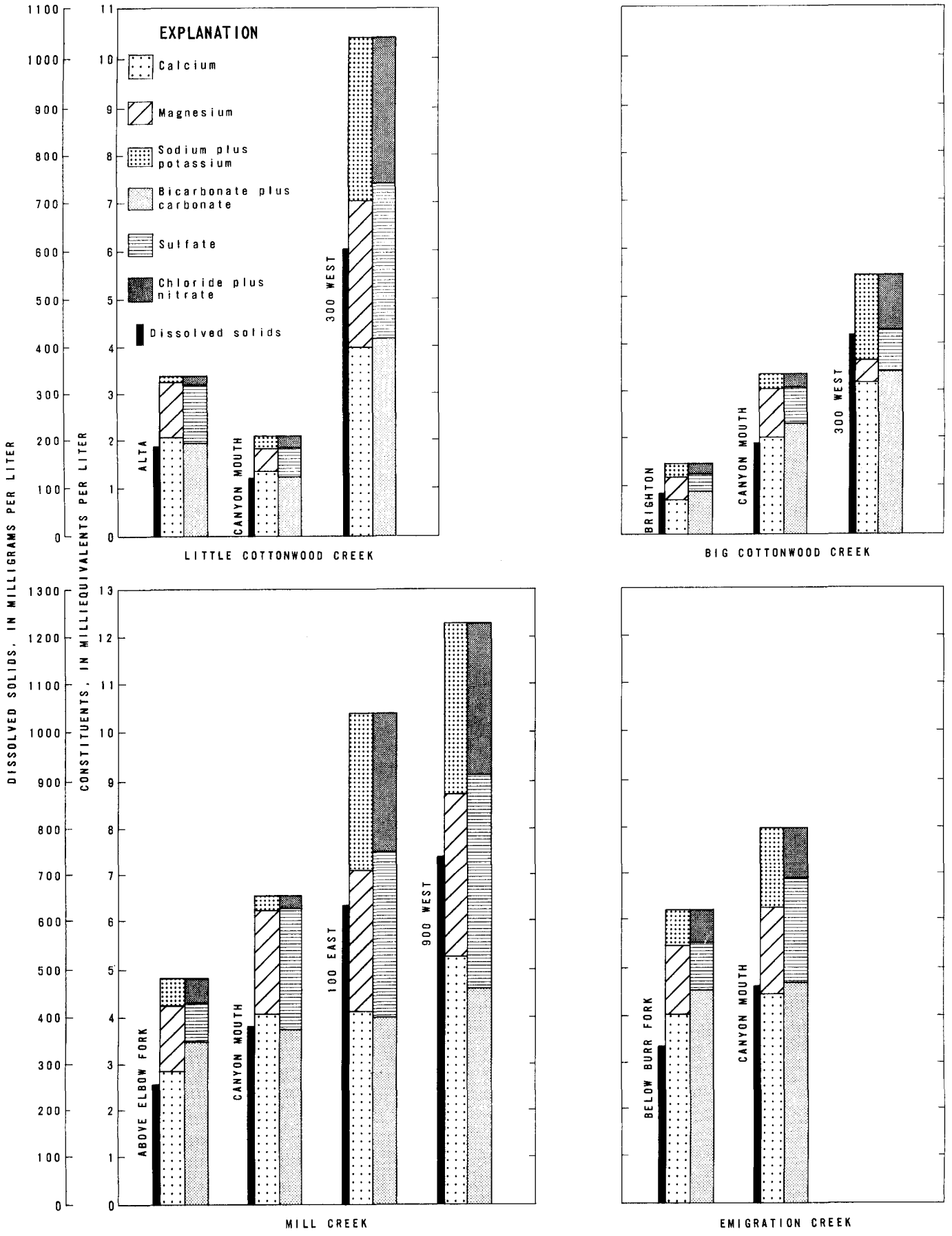


Figure 39.—Downstream changes in the chemical composition of water in four Wasatch streams.

Fluvial sediment includes all solid particles carried by streams, either in suspension or by sliding and rolling along the streambeds. No quantitative information about the movement of materials along streambeds (bedload) in Salt Lake County is available. The bedload, however, is believed to be a minor part of the total load of streams within Jordan Valley, and it has little effect on water withdrawn for use. The suspended load, on the other hand, tends to remain in suspension whether or not the water is withdrawn until it is removed by treatment or natural settling.

A sediment rating was developed for each of the seven Wasatch streams by plotting daily sediment load for the 1966-68 water years against stream discharge, and the resulting rating was used with the flow-duration data for the 1964-68 water years, to obtain sediment discharge or load. The computed loads are shown in table 10, and the sediment rating for Little Cottonwood Creek is shown in figure 40.

Table 10.—Average discharge of suspended sediment in seven Wasatch streams at or near canyon mouths, 1964-68 water years

[The data for Little Cottonwood, Big Cottonwood, Mill, and Red Butte Creeks apply to runoff (discharge in the stream channel plus diversions); the data for other creeks apply to the discharge in the channel at the canyon mouth]

Stream	Mean discharge, in cubic feet per second	Suspended sediment	
		Tons per day	Tons per year
Little Cottonwood Creek	67.8	4.91	1,790
Big Cottonwood Creek	73.8	8.90	3,250
Mill Creek	13.6	3.06	1,120
Parleys Creek	13.5	4.46	1,630
Emigration Creek	6.14	23.2	8,470
Red Butte Creek[1]	3.34	.47	172
City Creek	6.01	.47	172

[1] Above Red Butte Reservoir.

The sediment loads computed from data collected during the 1964-68 water years probably are representative of near-normal conditions, except that none of the samples obtained represented the higher concentrations during flash floods that usually follow intense rainfall. Hence, annual loads (especially for years when intense rainstorms occur) may be much higher than those shown in table 10.

Sediment data obtained at the mouths of the canyons in the Wasatch Range are not representative of the sediment characteristics of the streams between the canyon mouths and their junction with the Jordan River. For example, the highest suspended-sediment concentration measured during the 1966-68 water years in Little Cottonwood Creek at the canyon mouth was 41 mg/l; and most concentrations were less than 10 mg/l. In contrast, during May-July 1965 when runoff was similar to that of 1967, suspended-sediment concentrations as high as 416 mg/l

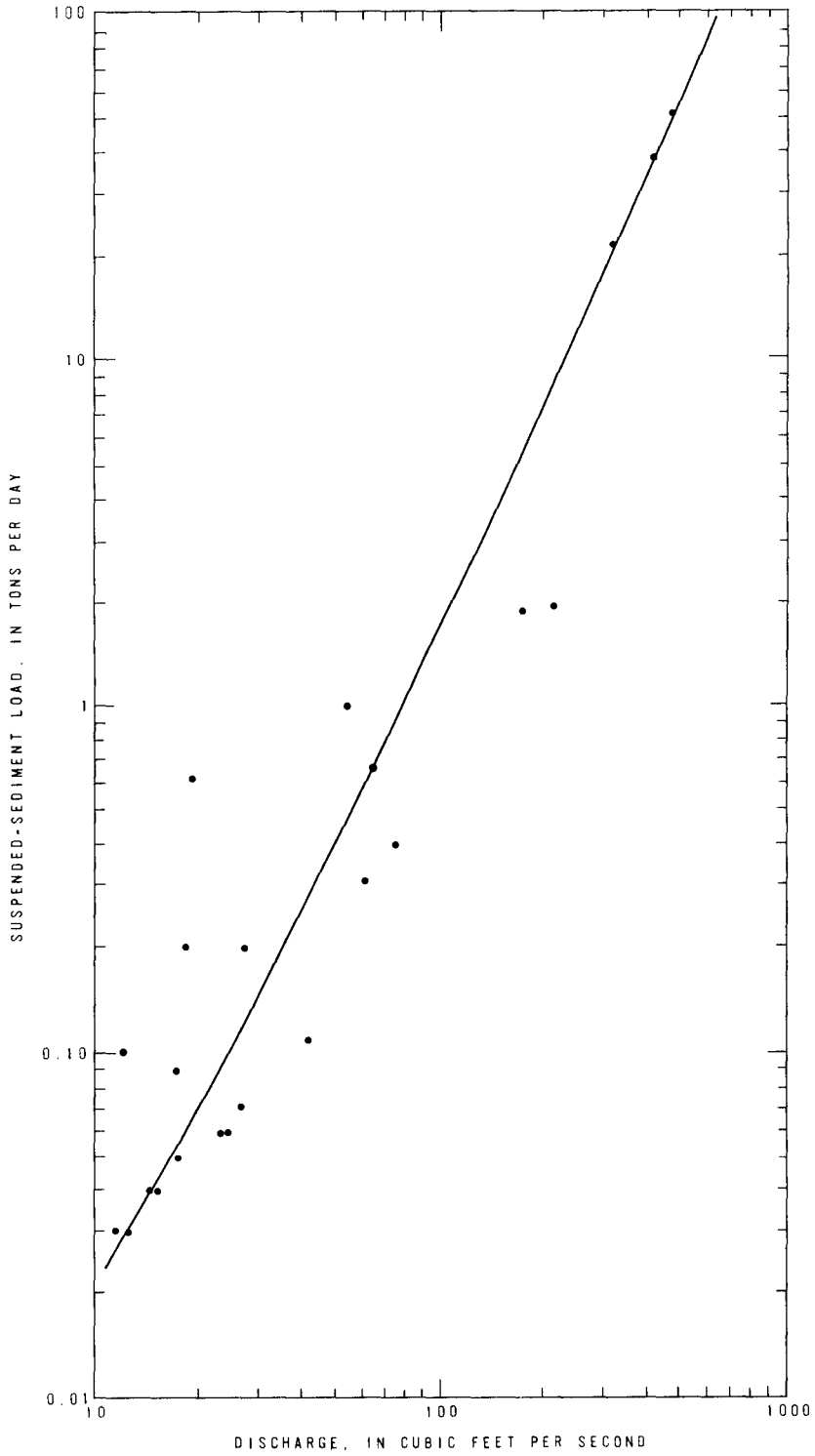


Figure 40.—Relation of suspended-sediment load to stream discharge for Little Cottonwood Creek, 1966-68 water years.

and sediment discharges as high as 674 tons per day were observed in Little Cottonwood Creek at 6600 South and 1100 East (about midway between the canyon mouth and the Jordan River). The lowest sediment concentration observed was greater than the highest concentrations observed at the canyon mouth during the 1966-68 water years.

Data on suspended-sediment discharge are not necessarily representative of the total sediment discharge of a stream because they generally do not include the bedload. Of two sets of data obtained on Little Cottonwood Creek at 6600 South on May 6, 1965, one set represents suspended-sediment discharge at a typical stream section and the other is fairly representative of total sediment discharge of the stream because the stream and its sediment load pass through a concrete flume, which causes high velocities and suspension of practically all sediment. The suspended-sediment concentration at the typical section was 110 mg/l, of which 43 percent was sand. The total sediment concentration at the concrete flume, about 300 feet downstream, was 300 mg/l, of which 78 percent was sand. Thus, the actual concentration of silt and clay remained fairly constant but the concentration of sand increased by more than 300 percent. Only about 35 percent of the total sediment discharge at the flume was included in the amount measured at the typical section by standard methods for measurement of suspended-sediment discharge.

In May 1970, two sets of sediment data were obtained at several sites on Little Cottonwood Creek between the canyon mouth and the Jordan River; neither set represents large snowmelt or thunderstorm runoff. The first set of data shows that at the canyon mouth the total sediment concentration, which was measured at a concrete flume, was 39 mg/l; at the gaging station at 2050 East (a natural section) it was 16 mg/l; at a natural section at 6600 South it was 41 mg/l; at a flume about 300 feet downstream it was 63 mg/l. At 360 West, a natural section about 4 miles downstream from 6600 South, the suspended-sediment concentration was 82 mg/l. Thus, the total sediment concentration at the canyon mouth was only about half the suspended-sediment concentration near the junction with the Jordan River. Comparative data, obtained a week later, show that at the natural section at 6600 South the suspended-sediment concentration was 53 mg/l, and at the concrete flume immediately downstream from 6600 South the total-sediment concentration was 129 mg/l.

Although Little Cottonwood Creek may be somewhat different from some of the other streams draining the Wasatch Range, the available data suggest that the sediment characteristics of the streams change significantly between the canyon mouths and the Jordan River, and the total sediment discharges of some reaches of the streams are significantly greater than the measured suspended-sediment discharges of the streams.

Deer Creek Reservoir and the Provo River

The flow of the Provo River, which drains about 680 square miles in the Wasatch Range and Uinta Mountains southeast of Salt Lake County, has been augmented by transmountain diversions from the Strawberry River since 1915, from the Weber River since 1932, and from the Duchesne River since 1952 (see fig. 2). Much of the flow is diverted for use in Salt Lake, Utah and Wasatch Counties, and the remainder contributes to Utah Lake.

The flow is regulated by several small reservoirs in the headwaters and by Deer Creek Reservoir, which is formed by a dam on the Provo River just above Deer Creek. Since most of the runoff from the Provo River basin had been appropriated prior to construction of the dam, the reservoir's water supply in most years is chiefly from the Weber and Duchesne River diversions.

Water is delivered to Salt Lake County by diversion from the reservoir[1] through the Salt Lake City aqueduct (fig. 2 and pl. 1), owned by the Metropolitan Water District of Salt Lake

[1]The point of diversion is below the powerplant at the toe of the dam.

City, and by diversion from the river below the reservoir through the Provo Reservoir Canal. The canal conveys water across the Jordan River in Jordan Narrows and supplies the north branch, serving Salt Lake County, and the south branch, serving Utah County. Some of the water is delivered to similar north and south branches of the Utah Lake Distributing Co. Canal, which receives part of its supply by pumping from the Jordan River.

The usable[1] capacity of Deer Creek Reservoir is 149,700 acre-feet at the top of the radial spillway gates. The usable contents sometimes exceed this amount by a few thousand acre-feet because of a surcharge (water above the top of the gates) that can be maintained only during periods of high inflow. Storage began in 1940, and the reservoir filled to capacity for the first time in 1946. The upper part of figure 41 shows the annual ranges of reservoir contents.

Actual and potential deliveries to Salt Lake County

Deer Creek Reservoir was designed to provide 100,000 acre-feet of water (about two-thirds of its capacity) in most years. The difference between this annual yield and the capacity provides for evaporation losses and some carryover storage. The yield is considerably reduced in very dry years, especially when two or more dry years occur in succession.

The total yield is allocated to numerous water users, the largest allocation being 61,700 acre-feet (when the full supply is available) to the Metropolitan Water District of Salt Lake City. To help determine the amounts that will be available from the reservoir and its associated diversions, the U. S. Bureau of Reclamation made an operation study using the streamflow data for 1921-63. The annual quantities available to all users and to the Metropolitan Water District were reported by Berger Associates, Inc. (1964, table 18) and are shown graphically in the central part of figure 41. The results of this study are readily extended to the entire period 1907-68 because runoff preceding 1921 and following 1963 was near or above normal and full allocations would be assured. The long-term (1907-67) average allocation to the Metropolitan Water District thus determined is 60,000 acre-feet, the normal (1931-60) is 56,800 acre-feet, and the minimum of record (1961) is 18,600 acre-feet.

Water allocated to the district is primarily for municipal supply, which is delivered through the Salt Lake City aqueduct. Some of the district's water, however, has been delivered through the Utah Lake Distributing Co. Canal (north branch)[2] for irrigation in Salt Lake County, in accordance with an exchange agreement. Actual annual deliveries to the county through the aqueduct are shown in the central part of figure 41 (the average for the 1964-68 water years was 14,500 acre-feet, including an estimated 1,000 acre-feet that leaked from the aqueduct or was spilled to Little Cottonwood Creek) and deliveries of water from the Provo River and the reservoir through the canal are shown in the bottom part (1964-68 average, 5,650 acre-ft). Total deliveries from the district's share have been much less than the allocations except in 1961, when deliveries exceeded the allocation because water was carried over the preceding year. Such carryover of unused water can be very useful at times, and the required storage space usually would be available at the most critical times; but it is not an entirely satisfactory answer to Salt Lake County's need for carryover storage, because the district's rights to previously stored water are subject to other rights and often are lost.

[1] Usable capacity and contents are 2,870 acre-feet less than the total capacity and contents published in the Geological Survey's annual reports on surface-water records.

[2] Most of the water for this canal is pumped from the Jordan River above the gaging station at Jordan Narrows.

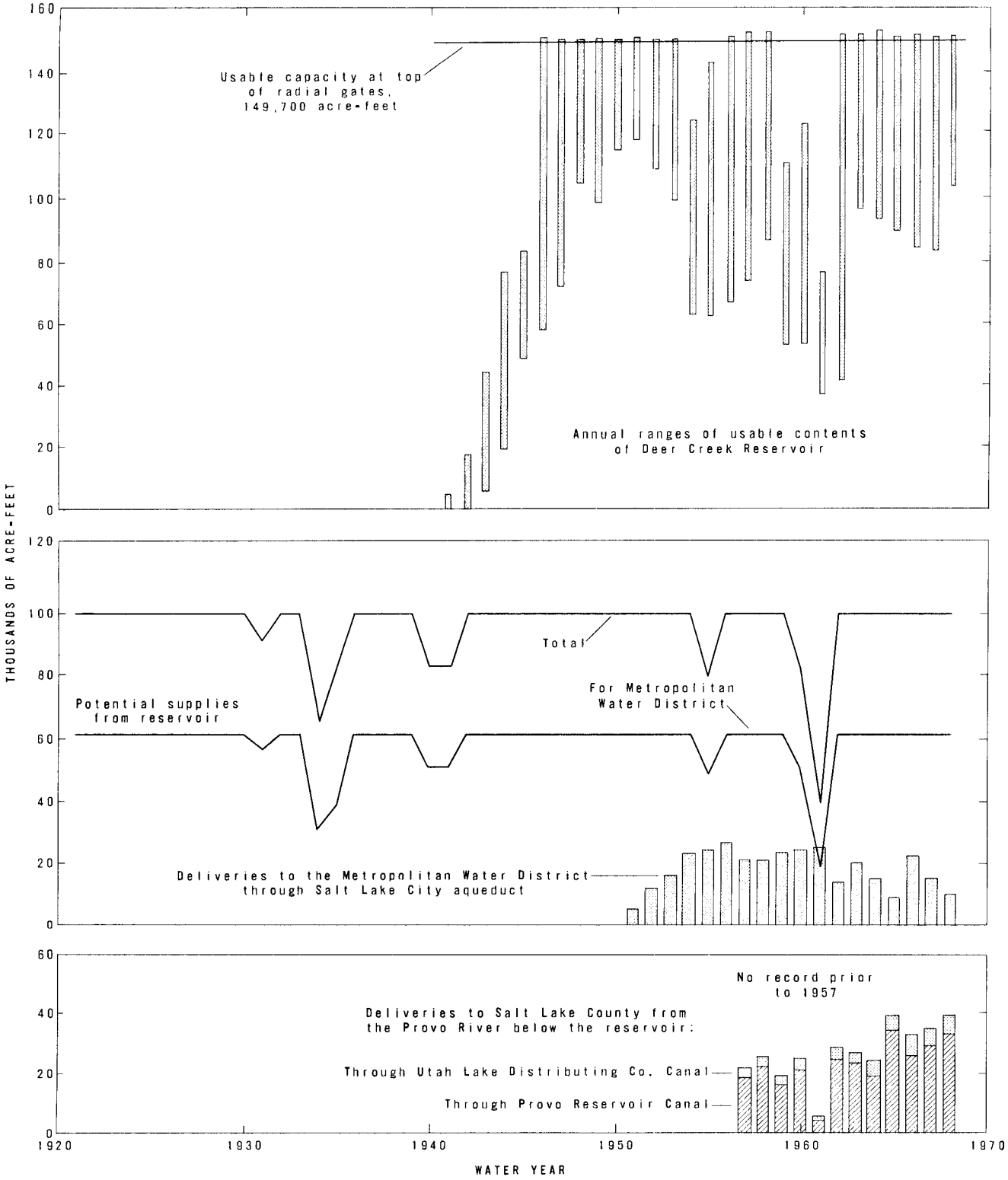


Figure 41.—Annual ranges of usable contents of Deer Creek Reservoir, the potential water supply, and the actual deliveries. The delivery through Salt Lake City aqueduct in 1961 exceeded the corresponding potential supply because of water carried over from 1960. Deliveries shown for the Utah Lake Distributing Co. Canal are from the Provo River; additional water was pumped from the Jordan River.

The deliveries through the north branch of the Provo Reservoir Canal depend on water rights that preceded the construction of Deer Creek Reservoir as well as rights (9,600 acre-ft per yr) to water stored therein but not included in the Metropolitan Water District's share. Annual deliveries since 1957 are shown in the bottom part of figure 41. There are no records for earlier years. The annual deliveries ranged from 4,600 acre-feet in the 1961 water year to 34,400 acre-feet in 1965. The average for 1957-67 is 22,100 acre-feet. Omitting the unusually low value for 1961, the average for the remaining 10 years is 23,800 acre-feet, which may be more representative of normal conditions. The average for 1964-68 is 28,000 acre-feet of which 9,600 acre-feet was Deer Creek Reservoir water.

Chemical quality

The chemical quality of water delivered through the Salt Lake City aqueduct and Provo Reservoir Canal to Salt Lake County is indicated by the discharge-weighted average chemical analysis for the 1964-68 water years given below.

[All chemical data are discharge-weighted averages computed from relations described in text]

Sodium and potassium: Calculated and reported as sodium.
Dissovled solids: Residue on evaporation at 180° C.
Basic data: Furnished by Metropolitan Water District of Salt Lake City.

Mean discharge, in cubic feet per second		419
Silica (SiO_2)	mg/l	8.4
Calcium (Ca)	mg/l	50
Magnesium (Mg)	mg/l	12
Sodium (Na)	mg/l	10
Bicarbonate (HCO_3)	mg/l	151
Sulfate (SO_4)	mg/l	53
Chloride (Cl)	mg/l	12
Nitrate (NO_3)	mg/l	.6
Dissolved solids	mg/l	231
Tons per acre-foot		.31
Tons per day		258
Hardness as $CaCO_3$		
Calcium, magnesium	mg/l	174
Noncarbonate	mg/l	50
Sodium adsorption ratio		.3
Specific conductance, in micromhos per centimeter at 25° C		368
pH		7.8

The water is of the calcium bicarbonate type, with calcium and bicarbonate comprising about 63 percent of the cations and anions, respectively. Magnesium and sulfate are the next most abundant constituents, comprising about 28 percent of the cations and anions. The dissolved-solids content ranged from 155 to 340 mg/l as shown in figure 42.

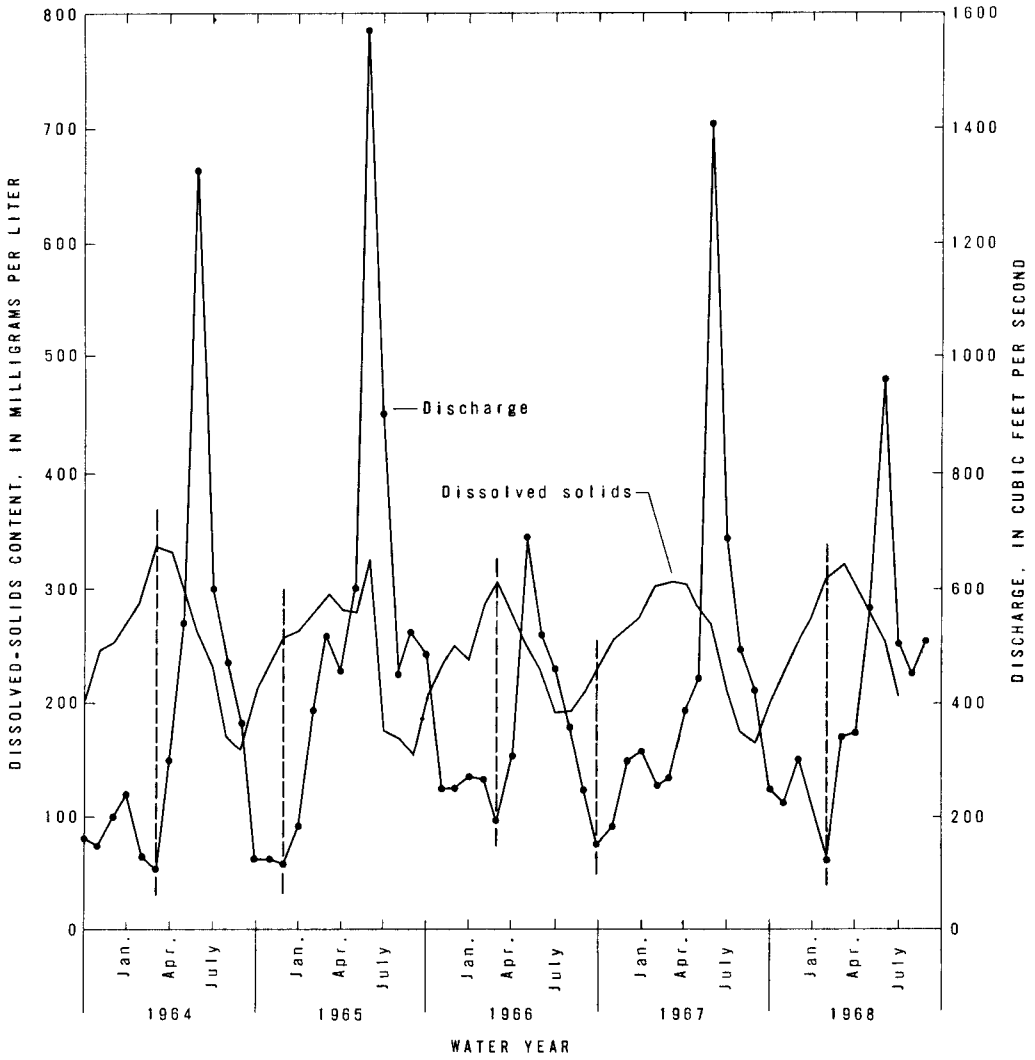


Figure 42.—Monthly discharge and dissolved-solids content of the Provo River below Deer Creek Reservoir, 1964-68 water years. The dashed lines through the annual minimums of discharge aid comparison of such minimums with the peaks of dissolved-solids content.

The pattern of variation of dissolved solids in the Provo River differs from that in the Wasatch streams in Salt Lake County because of storage and mixing in Deer Creek Reservoir. In the unregulated streams, the dissolved solids tend to follow a simple inverse relation with streamflow, so that maximum dissolved-solids contents accompany minimum flows and minimum dissolved-solids contents accompany maximum flows. The storage and mixing of water in Deer Creek Reservoir alters this basic pattern by reducing the range of dissolved solids, increasing the average dissolved solids because of evaporation loss, and destroying the simple time relation between peaks and lows of discharge and dissolved solids. Figure 42 shows that peak dissolved solids in the Provo River may occur at about the same time as the minimum discharge or several months later when the discharge is much higher.

Utah Lake and the Jordan River

Regimen of Utah Lake

Utah Lake, the source of the Jordan River, occupies the lowest part of Utah Valley, a highly developed agricultural, urban, and industrial area. Owners of land bordering the lake have long been interested in limiting damage from high lake levels, and users of water from the lake or river have been interested in storing as much water as possible. As a result of this conflict of interests, a compromise level (4,489.34 feet above mean sea level at the head of the Jordan River) was established by a "Compromise Agreement" in 1885. The lake rises above this level at times, but no water may be held in the lake above compromise level by artificial means.

Because of the large area and shallow depth of Utah Lake, the evaporation loss per unit of storage capacity is unusually high. Consequently, proposals to reduce this loss by diking off parts of the lake have been considered for many years. Current (1969) plans of the U. S. Bureau of Reclamation include a proposal that would reduce the loss somewhat and convert part of the loss to beneficial use. Dikes would separate Goshen and Provo Bays from the lake; the inflow that now enters Provo Bay would be rerouted into the lake; and the loss of storage capacity would be compensated by the creation of new capacity at other sites. Provo Bay would be drained and converted to agricultural use, and Goshen Bay would be converted to a waterfowl refuge.

The relations of surface area and contents of Utah Lake to water levels, both with and without the proposed dikes, are shown in figure 43. Construction of the dikes would reduce the area at compromise level by 33,000 acres (about 35 percent) and the contents by 256,000 acre-feet (about 29 percent).

The contents of Utah Lake continually change in response to changes in the inflow (streamflow, ground-water seepage, and precipitation) and outflow (flow of the Jordan River, other withdrawals, and evaporation). Like natural streamflow, the contents fluctuate seasonally as well as annually. The seasonal fluctuations are illustrated for two periods by the hydrographs in figure 44. The first period (1933-36 water years) includes the severest drought of record, when the lake was nearly dry at times. The second one (1951-54 water years) was a period of moderately high levels and includes a year (1952) of outstanding floods.

The upper part of figure 45 shows the range of contents for each water year during the period 1884 to 1968. Although the outflow from the lake is largely regulated in accord with the demand for water, an abundance or shortage of water in storage is clearly reflected in the annual outflow, which is approximated by the discharge of Jordan River water into Salt Lake County (shown in the lower part of fig. 45). A small part of the flow at Jordan Narrows is from ground-water seepage between the lake and the narrows; and this compensates in some degree for additional water pumped from the lake for irrigation in Utah County.

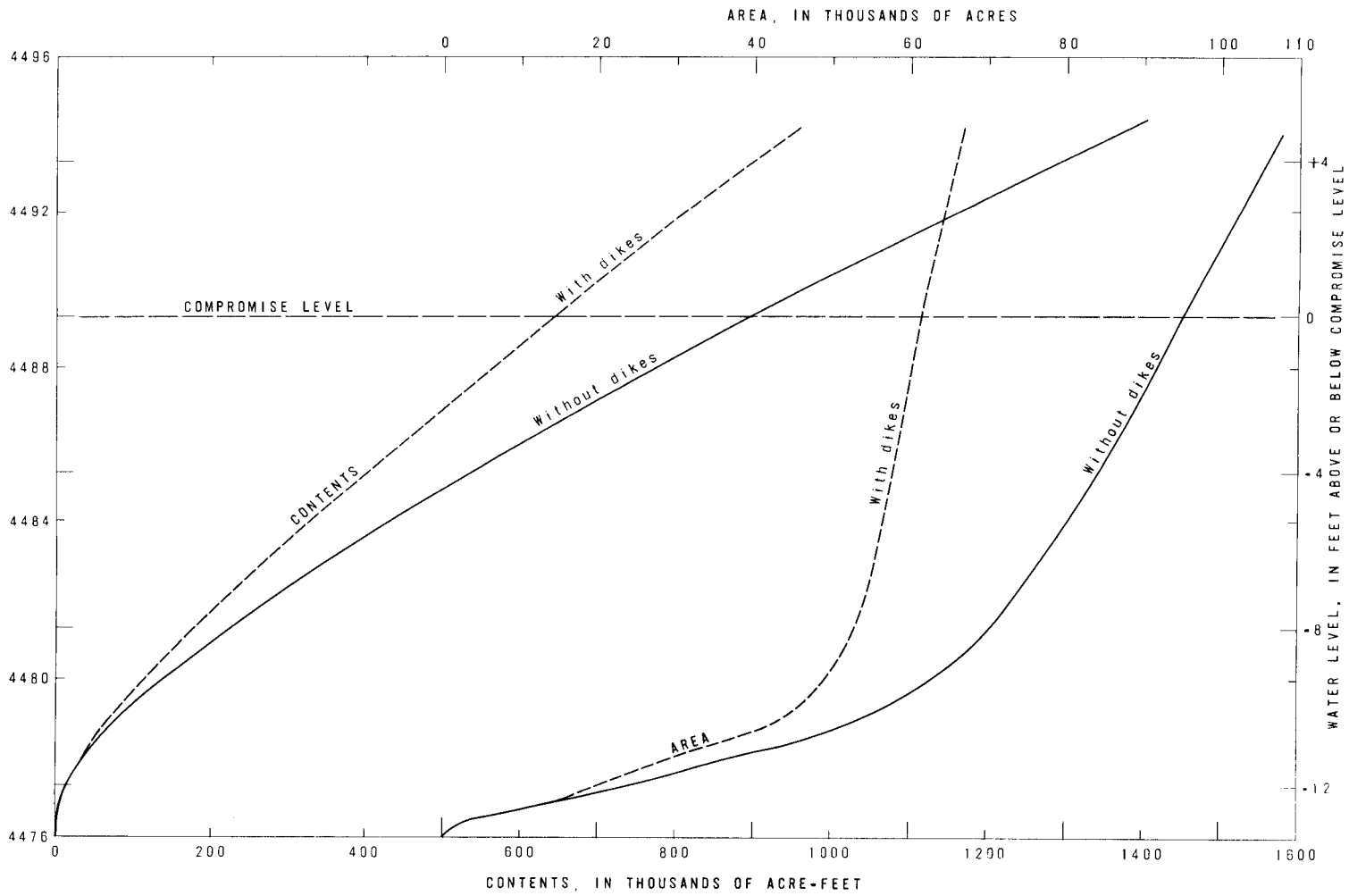


Figure 43.—Relations of surface area and contents of Utah Lake to water levels. From tables dated October 28, 1963, furnished by U.S. Bureau of Reclamation.

The Utah Lake and Jordan River Water Commissioner has computed evaporation from the lake using observed pan evaporation at Utah Lake Lehi and a coefficient of 0.80, which was established by a hydrologic study of the lake made by the U.S. Bureau of Reclamation many years ago. This coefficient is considerably higher than the 0.71 indicated by the U.S. Weather Bureau (Kohler and others, 1959, pl. 3) map showing average coefficients for converting pan evaporation to lake evaporation. The previous discussion of evaporation, however, showed that observed evaporation varies markedly, depending on the immediate surroundings of the pan. The observations at Lehi are considerably below the average for Jordan Valley, and hence, may be less than the values that represent average conditions for Utah Lake. If so, the correct coefficient for this particular pan-to-lake combination may be closer to 0.80 than to 0.71.

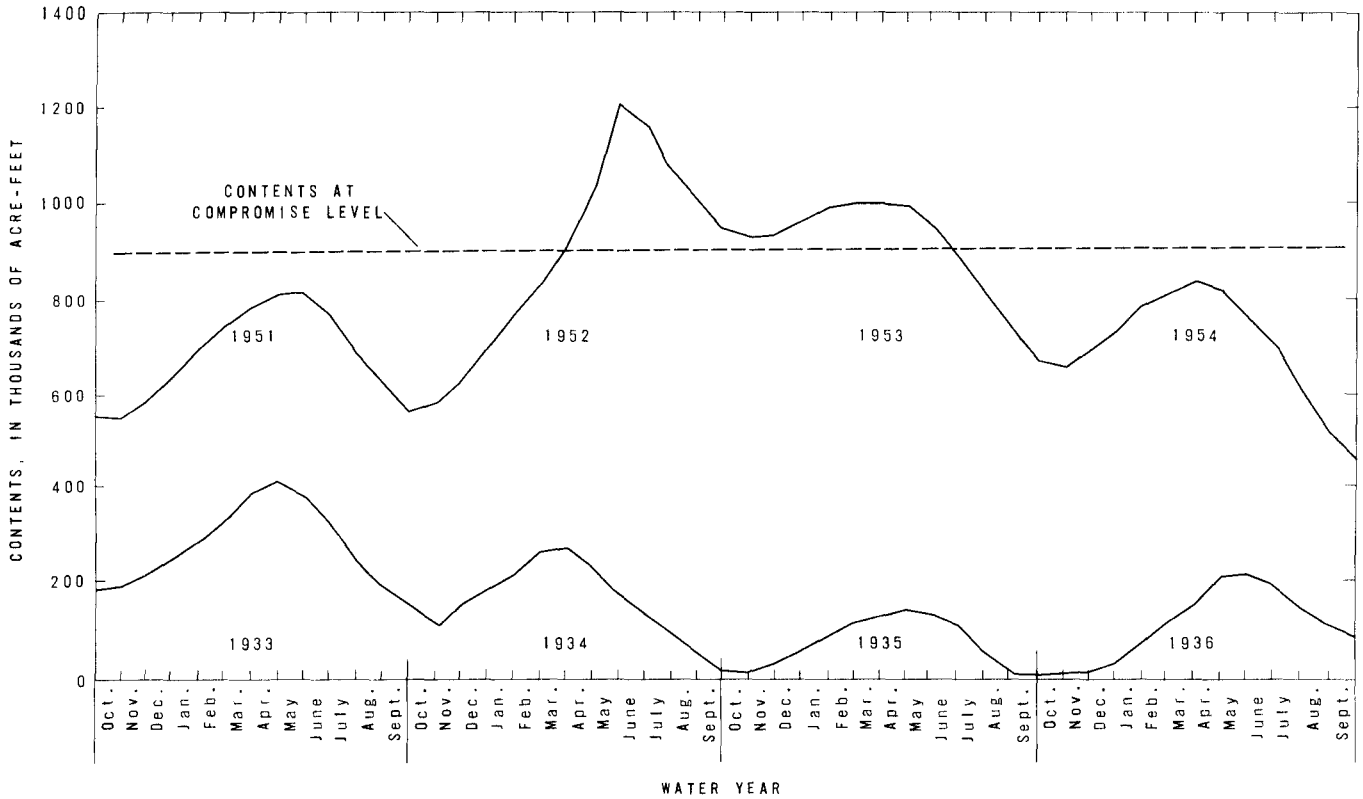


Figure 44.—Seasonal fluctuations of Utah Lake during a period of extremely low levels (1933-36 water years) and a period of moderately high levels (1951-54 water years). Graphs show contents at beginning of each month.

The commissioner has computed the average annual rate of evaporation as 3.9 feet or 47 inches using the coefficient of 0.80, and this is the same as the lake evaporation determined for Jordan Valley (0.71 x 66.5 in. = 47 in., table 2). Consequently, the commissioner's records are accepted for this report.

Regimen of the Jordan River

The flow of the Jordan River at its source is regulated to meet the requirements for irrigation and industrial use, except that extra water may be released from Utah Lake when it is above compromise level or when runoff from a heavy snowpack threatens to raise it above that level. Practically all the water released for use is diverted in or near Jordan Narrows. Some of it returns to the river, some reaches Great Salt Lake through other channels, and some is consumed by evapotranspiration (including consumptive use by industry). Most water needs in the lower reaches of the river are met by the gains from ground water, return flows, and tributaries.

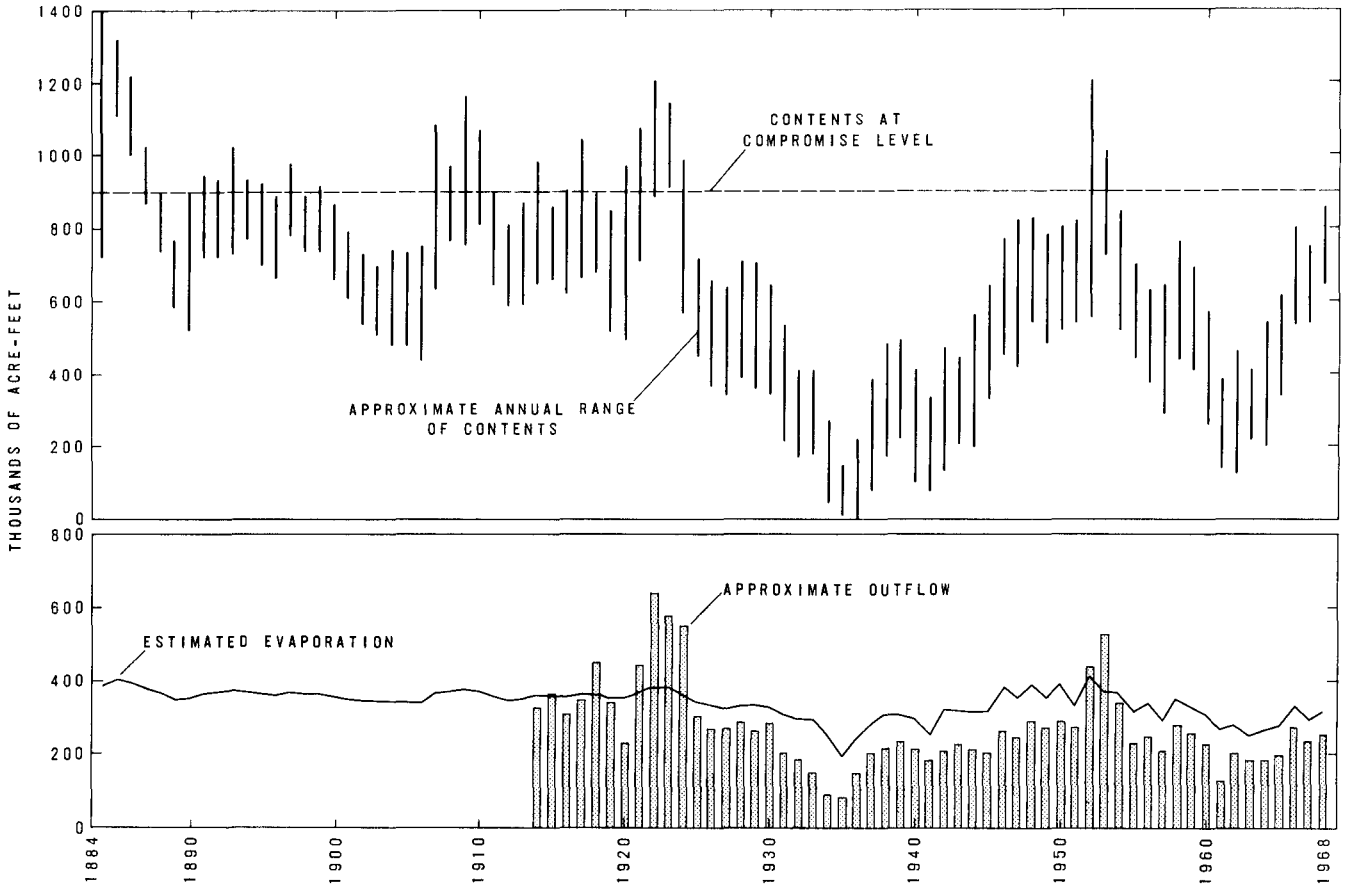


Figure 45.—Annual range of contents of Utah Lake, evaporation, and approximate outflow. Contents are from first-of-month gage readings prior to 1961 water year and from daily hydrographs thereafter. Evaporation prior to 1936 water year was estimated using an average annual rate (3.9 ft); values for 1936-68 water years are from reports of the Utah Lake and Jordan River Water Commissioner. The outflow shown is the discharge of Jordan River at Jordan Narrows, including water that bypasses the gaging stations; and it approximates the surface outflow from the lake.

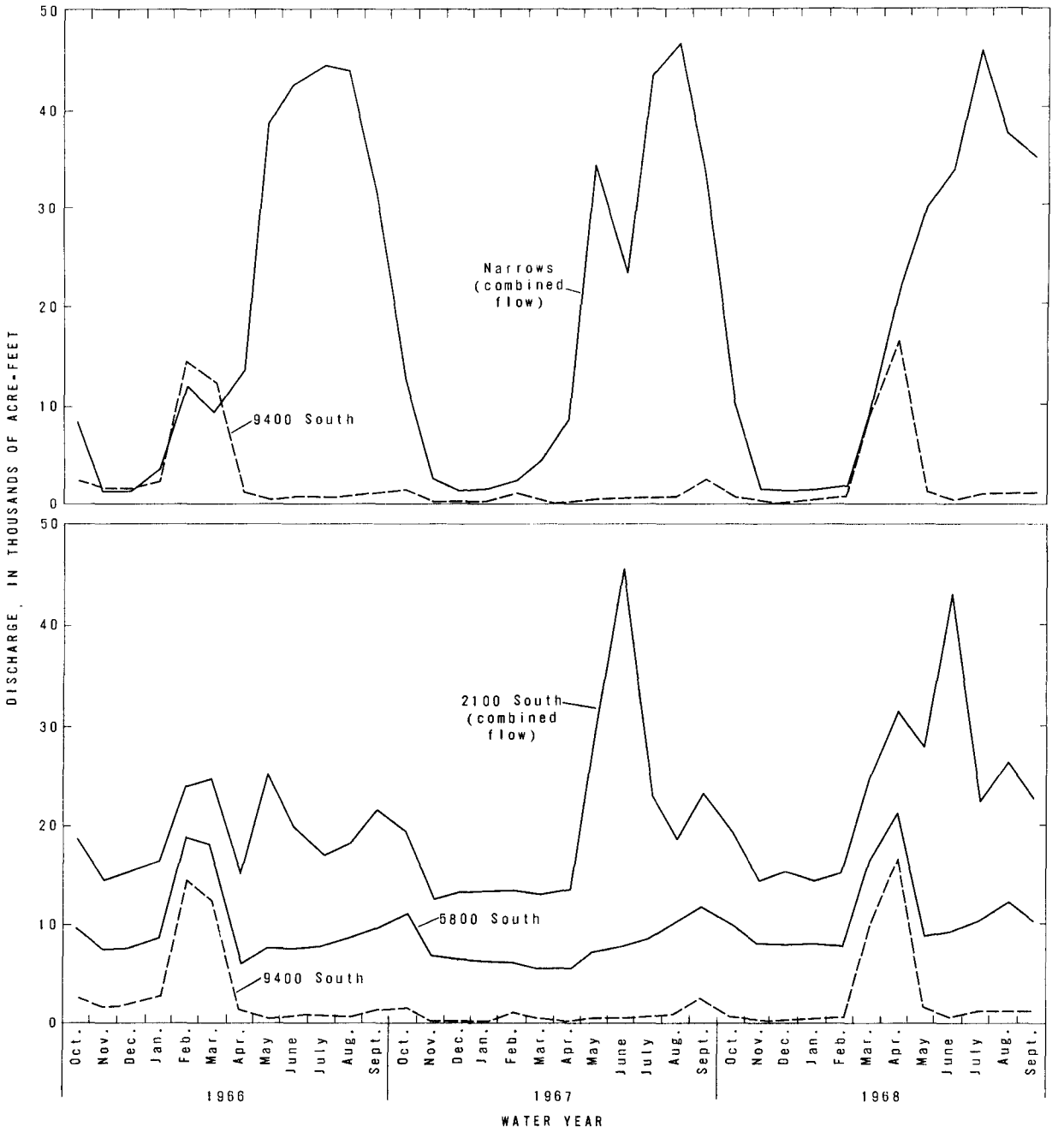


Figure 46.—Monthly discharge of Jordan River at narrows, at 9400 South, at 5800 South, and at 2100 South, 1966-68 water years.

Continuous records of two major diversions in the narrows and of the river below them have been maintained since July 1913. The combined discharge of these three streams (record published as Jordan River at narrows, near Lehi) includes most of the Utah Lake-Jordan River water that enters Salt Lake County. The total amount includes in addition the water pumped from the river above the gaging stations into the north branch of the Utah Lake Distributing Co. Canal. This total discharge, which is represented by the bars in the lower part of figure 45, has ranged from 76,000 acre-feet in the 1935 water year to 640,000 acre-feet in 1922 and averaged 271,000 acre-feet during 1914-68. During the 1964-68 water year, the total discharge averaged 226,200 acre-feet per year, of which 206,300 acre-feet passed the gaging stations and 19,900 acre-feet was pumped into the Utah Lake Distributing Co. Canal. The average discharge of this canal, including water from both the Jordan and the Provo Rivers, was 25,600 acre-feet per year.

At 2100 South, in Salt Lake City, the river flow is divided between the river channel and the Surplus Canal, which was built to divert flood flows away from the city but also serves to distribute water for irrigation and waterfowl ponds. Records of discharge in the canal and the river below the canal have been maintained since 1943. The combined discharge represents flow of the river above the canal.

Two gaging stations between the narrows and 2100 South were operated from July 1965 to September 1968 to help define the changes in discharge as the river traverses the valley. These changes are illustrated by the hydrographs in figure 46.

The upper part of the figure shows the seasonal pattern of releases from Utah Lake, modified by extra releases prior to the irrigation season in 1966 and 1968, and the drop to almost negligible flows at 9400 South except for the periods of extra release. As a major diversion (to the North Jordan Canal) is made just above the station at 9400 South, the effects of any inflow to the river in the reach are obscured in these hydrographs.

The lower part of the figure, in contrast, clearly shows a pronounced gain in each reach below 9400 South. There are no major tributaries or diversions between 9400 South and 5800 South; there are three major tributaries (Big Cottonwood, Little Cottonwood, and Mill Creeks) and one diversion (Brighton Canal) between 5800 South and 2100 South.

Gains and losses in Jordan Valley above 2100 South

A substantial part of the gain in streamflow as the Jordan River traverses its valley is discharge from the ground-water reservoir that underlies the valley. Hence, a determination of the gains in streamflow aids the determination of ground-water discharge.

For this purpose, gross monthly gains between gaging stations were computed by subtracting the measured inflow to a reach from the measured outflow. The computations apply to specific reaches of the central part of the river valley rather than the river alone, and gains include those in the lower reaches of the tributary streams. They apply to the entire reach from Jordan Narrows to 2100 South, except that this long reach was divided into three subreaches for the water years 1966-68. The inflowing and outflowing streams in each reach are as follows:

River reach	Inflow	Outflow
Narrows to 9400 South	Jordan River at narrows (includes two canals)	Jordan River at 9400 South Major diversions[1]
9400 South to 5800 South	Jordan River at 9400 South Effluent from two sewage plants	Jordan River at 5800 South
5800 South to 2100 South	Jordan River at 5800 South Effluent from six sewage plants Little Cottonwood Creek Big Cottonwood Creek Mill Creek	Jordan River above Surplus Canal Brighton Canal
Narrows to 2100 South	Jordan River at narrows Effluent from eight sewage plants Three creeks shown above	Jordan River above Surplus Canal Major diversions above 9400 South Brighton Canal

[1] Includes the following: East Jordan Canal, Utah and Salt Lake Canal, South Jordan Canal, Jordan and Salt Lake City Canal, Mousley Canal, Galena Canal, Beckstead Ditch, North Jordan Canal, and Gardner Mill Race. A few small diversions to industrial plants were excluded because virtually all the water returns to the river.

As approximations are involved in the determination of discharge of some of these streams, computed gains for a particular month may not be reliable; but the errors are at least partly compensating. The approximate discharge from sewage plants during 1966-68 was determined from information furnished by plant operators (total effluent about 2,300 acre-feet per month); and the sewage discharge during November 1957 was determined by Ward and others (1957) to be about 1,250 acre-feet per month. A trend line through these two values was used for estimating sewage discharge during other years. Records of the diversion through Brighton Canal were not available, so estimates were based on occasional discharge measurements and comparison with other diversions. The inflow from creeks during 1964-68 was computed as flow at the sites where channel losses cease, and gains begin, less diversions below those sites. For winter months in earlier years, equivalent flows were estimated from available records near the canyon mouths and relationships established by the 1964-68 data.

The monthly gross gains during the 1965-68 water years are shown in figure 47. These gains include local storm and snowmelt runoff and return flows from irrigation. They are influenced by the net error in all records involved and by the effect of the time lag involved as water moves from station to station. The marked increase of the gains during the irrigation season is caused chiefly by return flow, which is mostly in surface channels but may include some shallow ground water that reaches the river rather quickly after irrigation of a field.

Estimates of the gain from ground water (excluding that which returns quickly, as described above), based on the gross gains least likely to be affected by local runoff or return flow, also are shown in figure 47. The average annual gains during the 1966-68 water years are summarized in table 11.

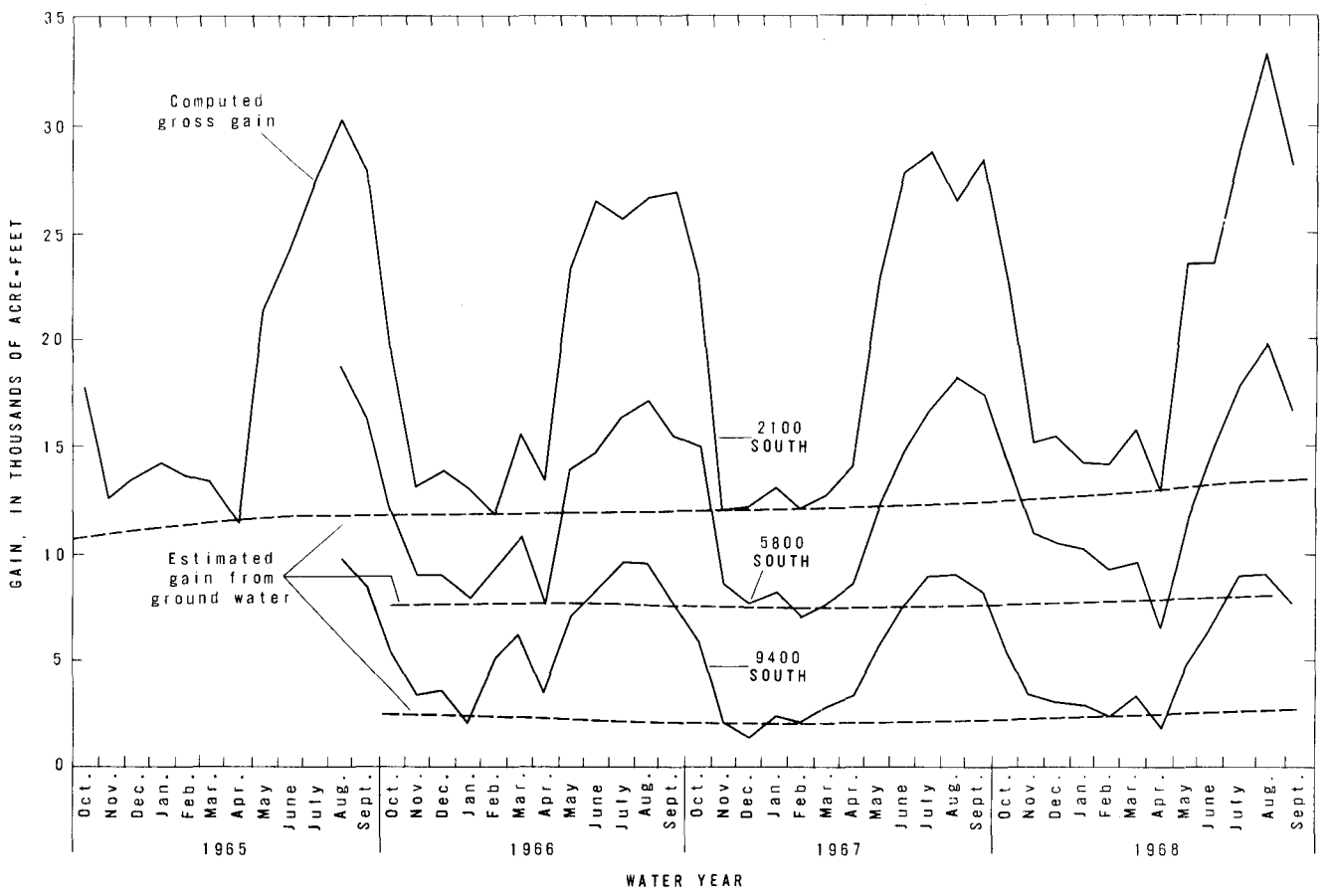


Figure 47.—Monthly gains of the Jordan River from the narrows to 9400 South, 5800 South, and 2100 South, 1965-68 water years.

Table 11.—Average annual gains of the Jordan River, in acre-feet, 1966-68 water years

River reach	Computed gross gain	Estimated gain from ground water
Narrows to 9400 South	63,300	27,000
9400 South to 5800 South	82,600	64,000
5800 South to 2100 South	90,500	56,000
Narrows to 2100 South	236,400	147,000

Because the gain from ground water is generally determined by a few of the lowest of the gross monthly gains during each year, the latter were computed only for the months from November to March prior to 1964 and only the two lowest of these monthly gains in each year were plotted in figure 48. The annual fluctuations of gain from ground water are not well defined, but the average gains for several years probably are fairly reliable.

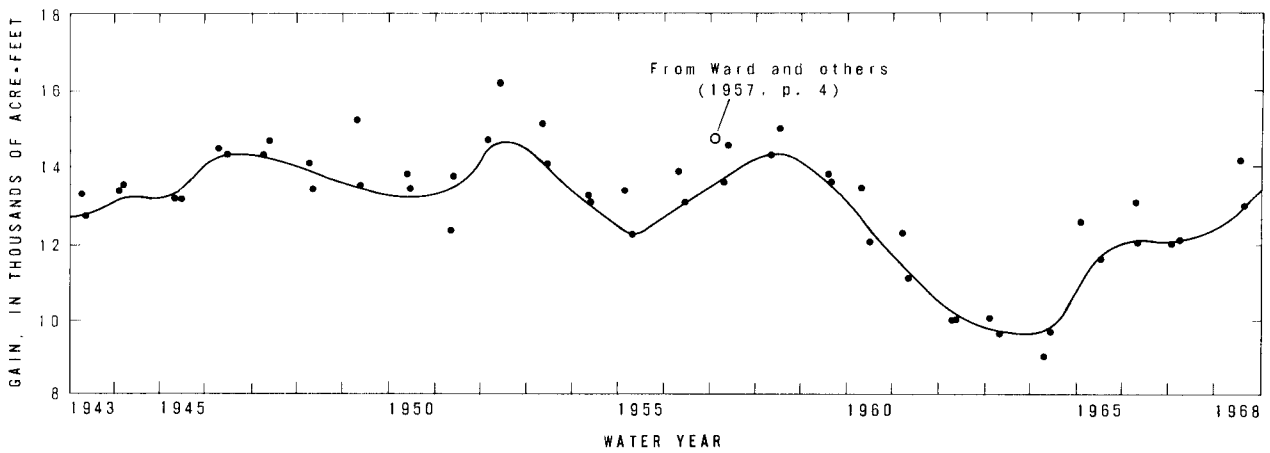


Figure 48.—Estimated monthly gains from ground water to the Jordan River between Jordan Narrows and 2100 South, 1943-68 water years. The points represent the two lowest computed monthly gross gains in each year.

Taylor and Leggette (1949, p. 42) reported a field determination of the gain during November 1932. The gain in the river channel and three creek channels (corresponding to the gains described above if all flow reported at the mouths of the three creeks was ground-water seepage) was 14,100 acre-feet. Ward and others (1957, p.4) reported a similar determination during November 1957 of 14,700 acre-feet (fig. 48). These November gains, however, may be appreciably greater than the lowest monthly gains in those water years, because the computations for figures 47 and 48 indicate that the gross monthly gain seldom reaches its minimum value as early as November.

The gain from ground water generally is between 10,000 and 14,000 acre-feet per month and the 1943-68 average is about 12,800 acre-feet per month or 153,000 acre-feet per year.

The depletion by diversion and use of the water from streams entering Jordan Valley greatly exceeds the gains described above. Figure 49 shows a comparison of the flow of the Jordan River above Surplus Canal, at 2100 South, with the sum of all measured inflows to the valley above that station. This segment of the valley (fig. 20) includes most of the irrigated area and much of the urban and suburban area.

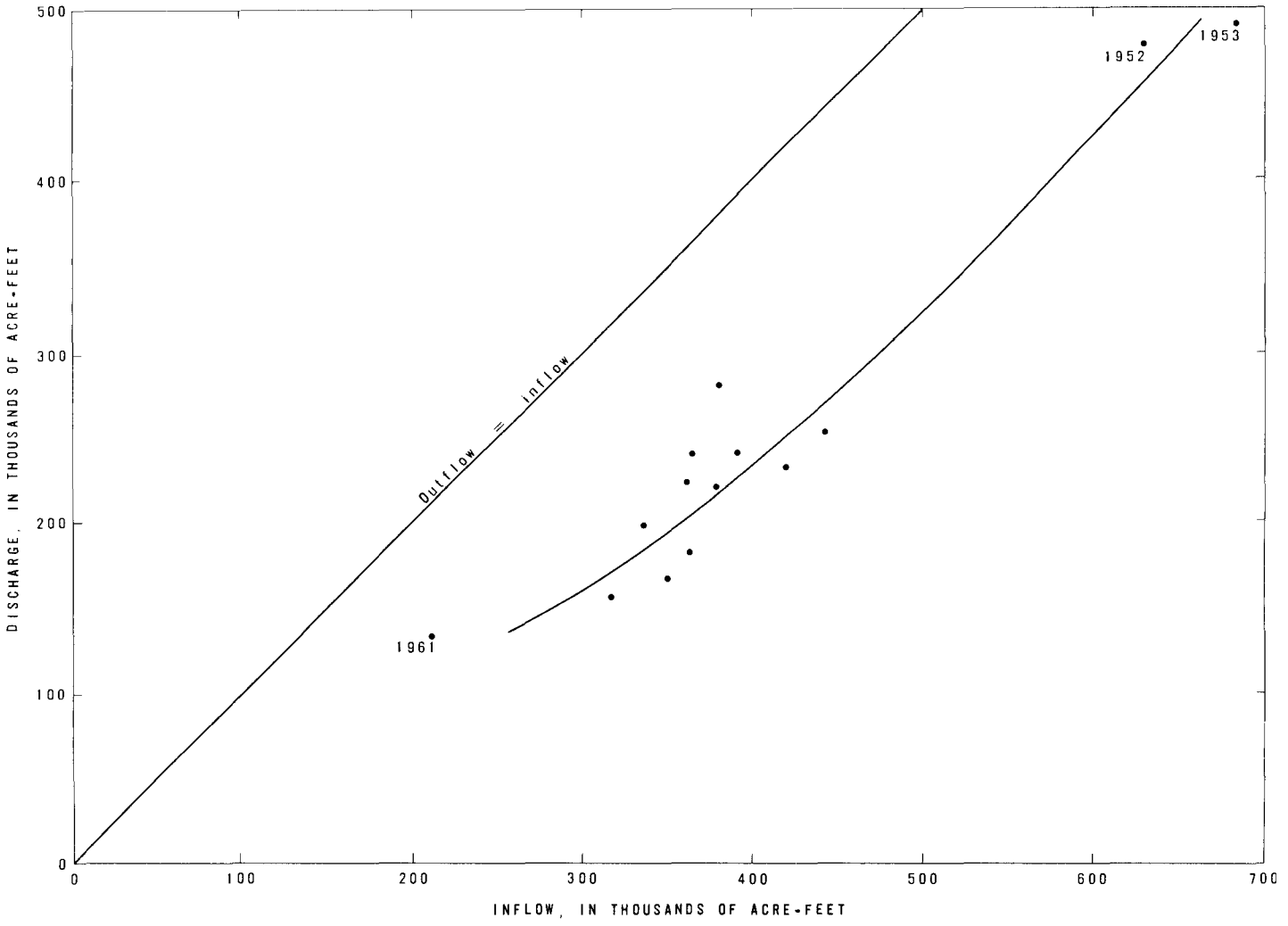


Figure 49.—Comparison of annual discharge of Jordan River above Surplus Canal, at 2100 South, with inflow to the valley above that station, 1952, 1953, 1957-68 water years. Vertical departures from the line of equality represent depletions of streamflow.

Complete records of the inflow to this segment are available only since 1957, and no unusually high annual inflows occurred during this period. To extend the range of inflows covered, the missing component of the inflow (Deer Creek Reservoir-Provo River water through canals in Jordan Narrows) was estimated for 2 years (1952, 1953) when the inflow was considerably higher than during 1957-68. If the central cluster of points in figure 49 represents near-normal conditions, the normal annual depletion in this segment of the valley is about 155,000 acre-feet.

One of the principal causes of this depletion is the evapotranspiration from irrigated fields and lawns. Another major cause is the discharge of waste water from Salt Lake City and the Garfield-Magna area to Great Salt Lake through other channels—Salt Lake City Sewage Canal, Lee Creek, Garfield and Kennecott Drains. During 1964-68 these channels discharged 114,300 acre-feet per year (table 19), of which an unknown amount was supplied by the inflow above 2100 South.

During extremely dry years, such as 1961, the depletion is below normal partly because water supplies are insufficient to meet the usual irrigation demands, and partly because discharge from the large ground-water reservoir underlying the valley maintains the outflow at a rate much closer to normal than the inflow is. If the dry conditions persist for several years, the outflow decreases and the depletion increases.

Distribution of discharge below 2100 South

The records of annual and monthly discharge of the Jordan River and the Surplus Canal at 2100 South for the water years 1943-68 are summarized in figure 50. Discharges for October and November 1942 were estimated to complete the record of the 1943 water year for this summary. The discharge was about evenly divided between the river and the canal much of the time, but the canal carries most of the flood water and its discharge is much more variable than that of the river below the canal.

Several additional stations were operated during 1964-68 to help define the distribution and any gains or losses. A summary of mean annual discharge at all stations at and below 2100 South is presented in table 12. Drains in the Garfield-Magna area which discharge some of the water diverted from the Jordan River above 9400 South, are not included in this table.

Table 12.—Summary of mean annual discharge at and below 2100 South

Gaging station	Discharge, in acre-feet	
Water years 1943-68		
Jordan River above Surplus Canal		229,900
Surplus Canal at 2100 South	129,700	
Jordan River below Surplus Canal		100,200
Water years 1964-68		
Jordan River above Surplus Canal		237,000
Surplus Canal at 2100 South	148,700	
Jordan River below Surplus Canal		88,970
North Point Consolidated Canal	17,300	
Surplus Canal at Cohen Flume	92,300	
Goggin Drain	43,700	
Subtotal (preceding three items)	153,300	
Jordan River below Cudahy Lane		111,200

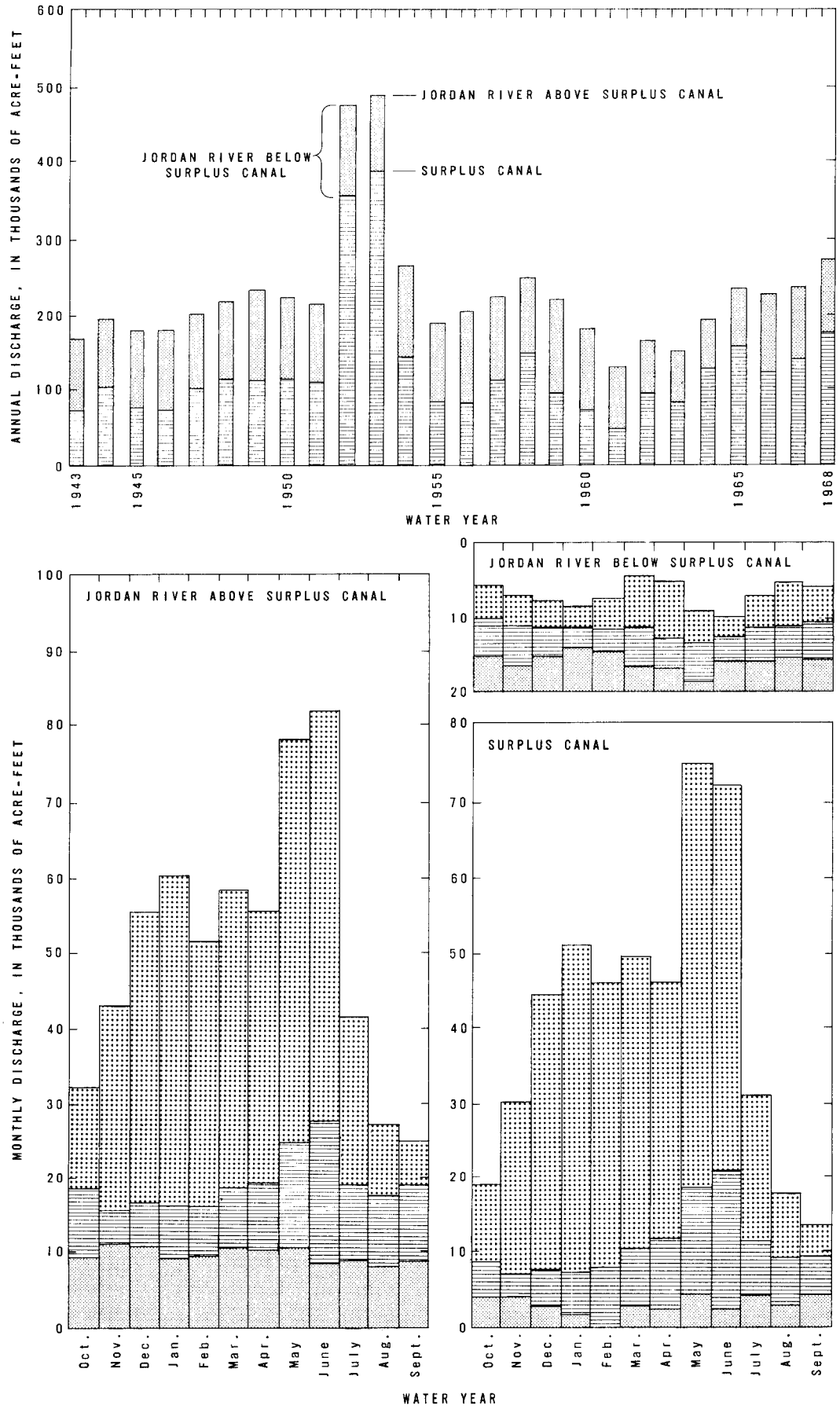


Figure 50.—Mean annual discharge and maximum, mean, and minimum monthly discharge of Jordan River and Surplus Canal at 2100 South, Salt Lake City, 1943-68 water years.

The 1964-68 means for stations at 2100 South differ only moderately from the long-term means. Hence, the means for stations below 2100 South may be fairly representative of normal conditions.

The discharge at the lowest stations on Parleys, Emigration, Red Butte, and City Creeks accounts for about 77 percent of the 22,200 acre-foot gain in the Jordan River between 2100 South and Cudahy Lane (table 12, right column). The remainder is from runoff and other drainage. The effect of numerous small diversions from the river between the Surplus Canal and Cudahy Lane is not descernible in the streamflow records. There is no evidence of appreciable gain from or loss to ground water below 2100 South—a conclusion that is in agreement with those of Taylor and Leggette (1949, p. 42) and Ward and others (1957, p. 4), who found no evidence of gain in the river channel below 3300 South. However, this may be due to a balance of gains and diversion or losses.

Some of the water in the Surplus Canal is diverted through North Point Consolidated Canal for irrigation and use in waterfowl-management areas, some is conveyed directly to such areas, and the rest is spilled to Goggin Drain and discharged to Great Salt Lake. The record for North Point Consolidated Canal generally shows the diversion from the Surplus Canal; that for Surplus Canal at Cohen Flume shows the deliveries through that canal to waterfowl-management areas; and that for Goggin Drain shows the spill from the Surplus Canal plus some natural drainage from the northern end of Jordan Valley. The sum of the mean annual discharges in these distributaries exceeds the discharge at 2100 South by only 4,600 acre-feet, which probably is from local surface runoff and ground-water inflow to Goggin Drain.

Most of the water in the Jordan River below Cudahy Lane, all the water in the Surplus Canal at Cohen Flume, and part of the diversion to North Point Consolidated Canal discharges into waterfowl-management areas. Much of this water is consumed by evapotranspiration in these areas and the remainder discharges to Great Salt Lake.

Some of the discharge that passes the Cudahy Lane station discharges to the Salt Lake City Sewage Canal and thence to Great Salt Lake.

Chemical quality

The chemical quality of the water in Jordan River at Jordan Narrows reflects the chemical quality of water in Utah Lake, which is influenced mostly by the relative rates of inflow, outflow, and evaporation. Hence, the dissolved-solids content of the lake tends to be highest when the lake is low and tends to decrease as the lake rises.

Analyses of samples collected at the lake outlet afford an approximate measure of the lake quality. Although the quality at the outlet sometimes differs considerably from the average quality for the entire lake (C. E. Viers, written commun., 1969), the average quality at the outlet for a period of a few months probably is close to the average quality for the entire lake. Such averages have been used to define the approximate relations of dissolved-solids content to level and volume of the lake in figure 51.

Nearly all the water released from Utah Lake is diverted above 9400 South (except for periods of extra releases when the lake is high); thus, the river practically becomes a new stream below that point, and its quality from 9400 to 5800 South is controlled chiefly by ground-water inflow and irrigation-return flow. Below 5800 South, the quality is controlled by the same factors plus tributary inflow. Ground-water inflow is negligible below 2100 South. (See p. 136.) Despite this difference in sources, the chemical quality of the water at Jordan Narrows and Cudahy Lane is remarkably similar.

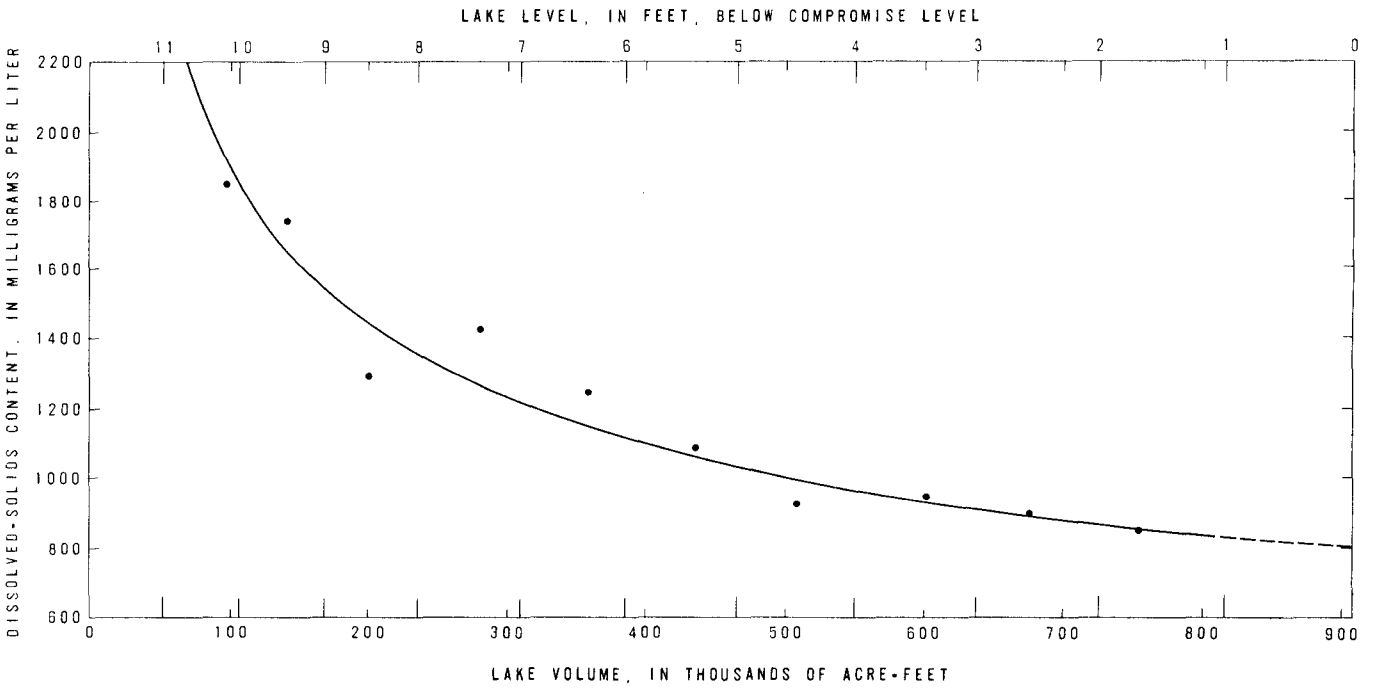


Figure 51.—Approximate relation of dissolved-solids content to level and volume of Utah Lake, June 1959 to November 1966. The points represent averages for specific ranges of lake level during the period, based on analysis of samples taken at the lake outlet. Data furnished by U.S. Bureau of Reclamation.

The chemical quality of Jordan River water (including that in Goggin Drain, the principal channel for discharge of surplus water to Great Salt Lake) is indicated by the discharge-weighted averages in table 13 and the graphs in figure 52.

The discharge-weighted averages for the Jordan River above 9400 South, at 9000 South, at 5800 South, and below Cudahy Lane were computed by linear regressions, relating the daily discharge to the daily mean specific conductance obtained from a recorder. The relation of daily discharge to the specific conductance of occasional samples was used for sites at the Jordan Narrows and 2100 South, and for the Surplus Canal, and Goggin Drain. The relations between specific conductance and dissolved solids and between dissolved solids and individual constituents were computed as described for Wasatch streams.

Table 13.—Chemical quality of water from several sites on the Jordan River system, 1964-68 water years

[All chemical data are discharge-weighted averages computed from relations described in the text.]

Sodium and potassium: Calculated and reported as sodium.
Dissolved solids: Calculated from determined constituents.
Data: Sites above 9400 South, at 9000 South, and at 5800 South are for the 1966-68 water years.

		Jordan River						Surplus Canal at Cohen Flume	Goggin Drain near Magna
		Jordan Narrows	Above 9400 South	9000 South	5800 South	2100 South	Cudahy Lane		
Mean discharge, in cubic feet per second		285 [1]	79.9 [2]	46.7 [3]	156	328 [4]	154	127	44.9
Silica (SiO_2)	mg/l	18	27	22	20	17	17	17	13
Calcium (Ca)	mg/l	85	176	122	145	127	111	122	117
Magnesium (Mg)	mg/l	71	85	71	73	65	60	66	76
Sodium (Na)	mg/l	203	261	268	241	186	178	195	402
Bicarbonate (HCO_3)	mg/l	270	319	260	281	264	259	277	279
Sulfate (SO_4)	mg/l	351	518	361	440	368	323	359	423
Chloride (Cl)	mg/l	254	392	323	324	271	251	279	572
Nitrate (NO_3)	mg/l	1.3	4.5	6.2	5.1	10	11	7.3	3.6
Dissolved solids	mg/l	1,120	1,620	1,330	1,370	1,180	1,080	1,180	1,740
Tons per acre-foot		1.52	2.20	1.81	1.86	1.60	1.47	1.60	2.37
Tons per day		859	349	168	576	1,040	449	403	211
Hardness as $CaCO_3$									
Calcium, magnesium	mg/l	505	789	597	663	585	524	576	605
Noncarbonate	mg/l	283	528	384	432	368	312	349	376
Sodium adsorption ratio		3.9	4.0	4.8	4.0	3.3	3.4	3.5	7.1
Specific conductance, in micromhos per centimeter at 25° C		1,740	2,480	1,950	2,150	1,850	1,710	1,850	3,260
pH		7.7	7.8	8.0	7.7	7.3	7.7	7.5	7.6

[1] *Combined discharge of Jordan River, Utah and Salt Lake Canal, and East Jordan Canal.*

[2] *Combined discharge of Jordan River and North Jordan Canal.*

[3] *Calculated by adding prorated gain between 9400 South and 5800 South to river discharge below diversion dam at 9400 South.*

[4] *Combined discharge of the Jordan River and the Surplus Canal.*

The quality degrades between the Jordan Narrows and the head of the North Jordan Canal, above the diversion dam at 9400 South, chiefly because of return flow and drainage from irrigated fields. At 9000 South, below the diversion dam, where the river is practically a new stream, the chemical quality reflects the quality of ground-water inflow. From 9000 South to 5800 South the quality degrades slightly; and between 5800 South and Cudahy Lane, it improves as the river gains from ground-water seepage and tributary inflow. Table 13 shows that the quality of the water in the Surplus Canal at Cohen Flume was nearly the same as that at 2100 South; hence, the Cohen Flume site was omitted from figure 52. Although much of the flow in Goggin Drain is from the Jordan River, return flow from irrigation and ground-water seepage of poor quality are sufficient to cause considerable degradation of the quality of water in the drain.

Seasonal variations of the chemical quality of water in the Jordan River are analogous to those of the Provo River previously described. However, the variations with time are related to activities of man—particularly irrigation and storage—more closely than to natural conditions. The variability of the quality is indicated by the graphs of means and extremes of dissolved-solids content in figure 53.

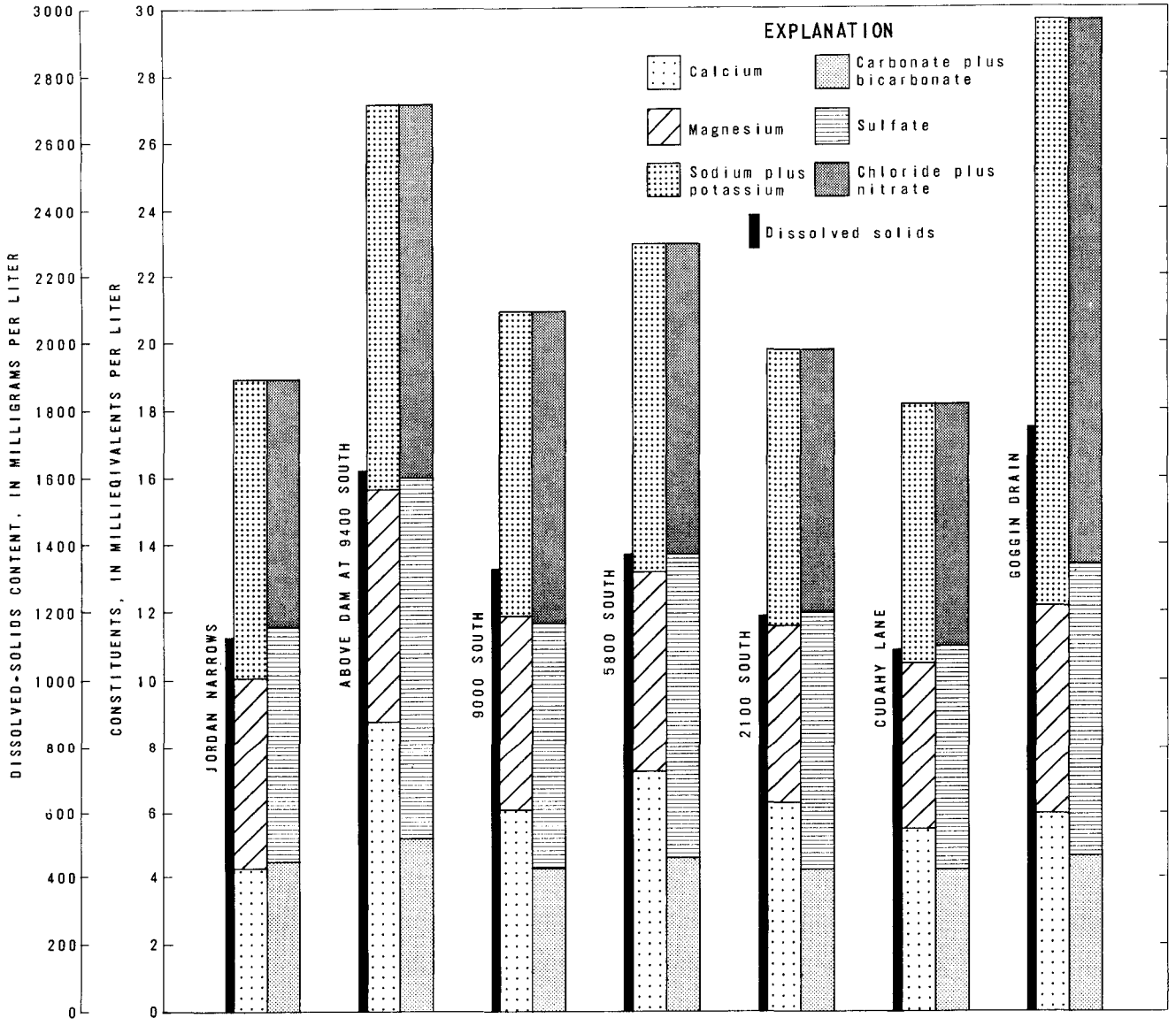


Figure 52.—Discharge-weighted average chemical composition of water at several sites on the Jordan River system, 1964-68 water years. Data for Jordan River above dam at 9400 South and at 9000 South are for the 1966-68 water years. (Goggin Drain is a major channel for disposal of surplus water from the Jordan River.)

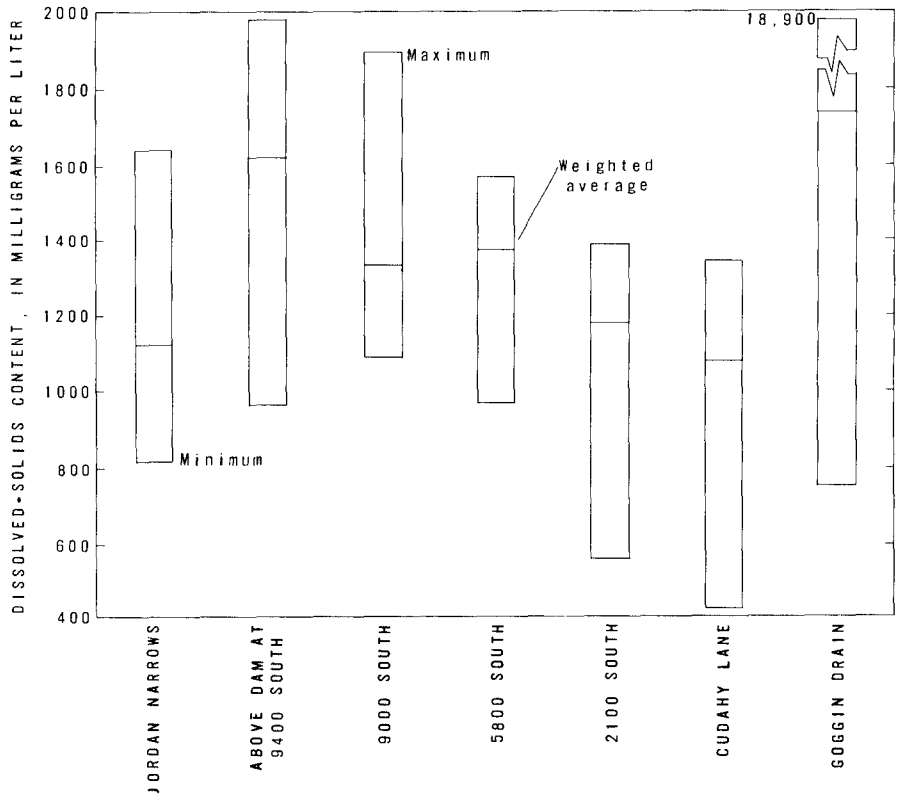


Figure 53.—Discharge-weighted average and range of dissolved-solids content of water at several sites on the Jordan River system, 1964-68 water years. Data for the Jordan River above the dam at 9400 South and at 9000 South are for the 1966-68 water years.

The changes in water quality below the diversion dam at 9400 South reflect the quality of the inflow to the river below that point. The dissolved-solids content of the inflow within each reach can be computed from equation 2 below.

$$C_i = \frac{C_1Q_1 - C_2Q_2}{Q_i} \qquad (2)$$

where C_i = dissolved-solids content, in milligrams per liter, of the inflow,

Q_i = inflow within the reach, in cubic feet per second,

C_1, C_2 = dissolved-solids content, in milligrams per liter, at the downstream and upstream ends of the reach, and

Q_1, Q_2 = the corresponding discharges, in cubic feet per second

Solving equation 2 for three reaches below 9000 South produces the following results:

Reach	Dissolved solids (mg/l)
9000 South to 5800 South	1,390
5800 South to 2100 South	966
2100 South to Cudahy Lane	646

Because of large diversions between Jordan Narrows and 9400 South, the available data are insufficient to compute the dissolved-solids content of the inflow within the reach by equation 2. However, table 14 shows the chemical data for water near the mouths of several tributaries to the Jordan River; and the dissolved-solids content for the first three (which are above 9400 South) ranges from 1,780 to 2,720 mg/l. Also, water from a shallow test well near 11800 South 1300 West (well (C-3-2)27aaa-1, 12 feet deep) had a dissolved-solids content of 2,330 mg/l, which is an indication of the dissolved-solids content of irrigation return flow to this reach of the river.

Fluvial sediment

Data on the sediment discharge of the Jordan River are indicative only of the sediment problems in the main channel and are not representative of erosion and sedimentation in the entire drainage area of the Jordan River. Most of the sediment that reaches the Jordan River is derived from a relatively small part of the drainage basin, chiefly Jordan Valley and Utah Valley.

Even small and shallow reservoirs that are insignificant for storage of water retain nearly all the sand and a large part of the silt and clay from upstream areas. For example, during the 1965-69 water years, an estimated 200 tons of sediment was deposited in three beaver ponds immediately above the gaging station in Red Butte Canyon. These ponds did not exist until 1964. Thus, in a short reach of Red Butte Creek, about 40 tons of sediment has been deposited annually. Reservoirs such as Mountain Dell and Lower Bells Canyon probably trap a significant part of the sediment that might enter the Jordan River from the Wasatch Range within Salt Lake County. Sediment from the Oquirrh Mountains is insignificant because the runoff does not reach the Jordan River during most years. Most of the sediment that originates in the upper three-fourths of the Jordan River drainage area probably is trapped in Deer Creek Reservoir, Utah Lake, and other lakes and reservoirs. Thus, only a small part of the Jordan River drainage area contributes a significant amount of sediment to the river.

Table 14.—Estimated average chemical quality of water near mouths of tributaries to the Jordan River below Jordan Narrows, 1964-68 water years

[All chemical data are estimated from analyses of occasional samples.]

Sodium and potassium: Calculated and reported as sodium.

Dissolved solids: Values greater than 1,000 mg/l are calculated from determined constituents; those less than 1,000 mg/l are residue on evaporation at 180°C.

Data: Part of data furnished by the Utah State Division of Health, Bureau of Environmental Health.

	East side										West side		
	Corner Creek, 13400 South	Willow Creek, 11400 South	Dry Creek, 10000 South	Sandy City Sewer, 8800 South	Midvale Sewer, 7000 South	Little Cottonwood Creek, 300 West	Big Cottonwood Creek, 300 West	Sanitary District Sewer 3100 South	Mill Creek, 900 West	Parleys, Emigration, and Red Butte Creeks, 1350 South	Bingham Creek, 7950 South	Kearns Sewer, 4900 South	Granger-Hunter Sewer, 3100 South
Number of samples	3	2	3	5	5	7	4	5	4	3	3	5	5
Discharge, in cfs	-----	-----	-----	1.5	3.9	-----	55.2	18.6	-----	-----	-----	1.5	1.2
Silica (SiO_2) (mg/l)	44	36	26	18	17	14	8.4	15	12	12	21	13	26
Calcium (Ca) (mg/l)	182	199	120	66	74	80	64	96	106	70	171	46	94
Magnesium (Mg) (mg/l)	107	154	90	39	29	37	24	47	42	22	76	15	51
Sodium (Na) (mg/l)	468	474	335	142	120	78	40	154	82	33	232	108	326
Bicarbonate (HCO_3) (mg/l)	481	486	256	343	230	225	207	238	282	214	374	205	342
Sulfate (SO_4) (mg/l)	588	818	516	127	158	156	91	231	222	75	435	87	342
Chloride (Cl) (mg/l)	628	635	452	149	135	103	56	195	100	57	338	99	348
Nitrate (NO_3) (mg/l)	26	18	16	14	27	5.8	2.8	71	16	3.8	9.2	15	33
Dissolved solids (mg/l)	2,340	2,720	1,780	783	693	603	415	1,000	741	415	1,560	520	1,390
Tons per acre-foot	3.18	3.70	2.42	1.06	.94	.82	.56	1.36	1.01	.56	2.12	.71	1.89
Tons per day	-----	-----	-----	3.15	7.27	-----	61.3	50.2	-----	-----	-----	2.11	4.50
Hardness as $CaCO_3$ (mg/l)													
Calcium, magnesium	895	1,130	670	325	304	352	259	433	438	265	740	177	445
Noncarbonate	500	732	460	44	116	143	89	237	206	90	433	8	164
Sodium adsorption ratio	6.8	6.1	5.6	3.4	3.0	1.8	1.1	3.2	1.7	.9	3.7	3.5	6.7
Specific conductance, in micromhos per centimeter at 25°C	3,450	3,800	2,440	1,150	1,140	965	661	1,520	1,090	682	2,290	902	2,190

The principal sediment problem relative to the Jordan River is the effect of sediment on the capacity of the river channel to carry water through a developed flood-plain area. High sediment concentrations and large sediment loads are not major problems. Long periods of sediment deposition when the discharge is highly regulated and sluggish causes serious problems during the relatively infrequent short periods of exceptionally high runoff.

During 1967-68, suspended-sediment data were obtained periodically at three sites on the Jordan River. The observed instantaneous suspended-sediment concentration was regarded as representative of the concentration for the entire day on which the sample was obtained. A daily suspended-sediment load was computed using the instantaneous concentration and the daily mean discharge for that day. Plots of the daily suspended-sediment load versus daily discharge for the Jordan River at the narrows, 2100 South, and Cudahy Lane, shown in figure 54, show no consistent variation of daily suspended-sediment load with discharge and no seasonal pattern. For most streams, such plots define sediment ratings that can be used with flow-duration data to compute mean annual sediment loads. (See p. 69.) The extremely poor definition of sediment rating for the Jordan River may be due to several factors, such as the effects of wind in stirring up sediment from the bottom of Utah Lake, the effects of return flows from irrigated tracts, and the short period of record.

Any estimate of the mean annual sediment load of the Jordan River from available data must be subject to large error. Sediment ratings were computed from a few measurements by the method of least squares and used with curves of daily flow duration for estimating the mean annual sediment load at three points on the Jordan River during the 1964-68 water years. The results are tabulated below:

[Discharge at Jordan Narrows is the combined flow of the Jordan River, Utah and Salt Lake Canal, and East Jordan Canal; that at 2100 South is the combined flow of the Jordan River and Surplus Canal. Data on sediment concentration furnished by Utah State Division of Health, Bureau of Environmental Health.]

Location on Jordan River	Mean discharge	Number of samples	Suspended sediment: Mean annual concentration (mg/l)	Suspended sediment: Tons per year
Jordan Narrows	285	20	366	103,000
2100 South	328	20	460	149,000
Cudahy Lane	154	12	842	128,000

Except for periods of high flow, most of the suspended-sediment load entering the county at Jordan Narrows is diverted into irrigation canals above 9400 South. Consequently most of the suspended-sediment load of the Jordan River at 2100 South and at Cudahy Lane is derived from erosion of the river channel below 9400 South, from suspended-sediment loads of tributary inflow, and from organic matter which enters the river in municipal and industrial wastes. The tributary inflow in part is return flow of water originally diverted from the Jordan River and in part is runoff from urbanized areas, which contains large amounts of sediment from street and gutter washing.

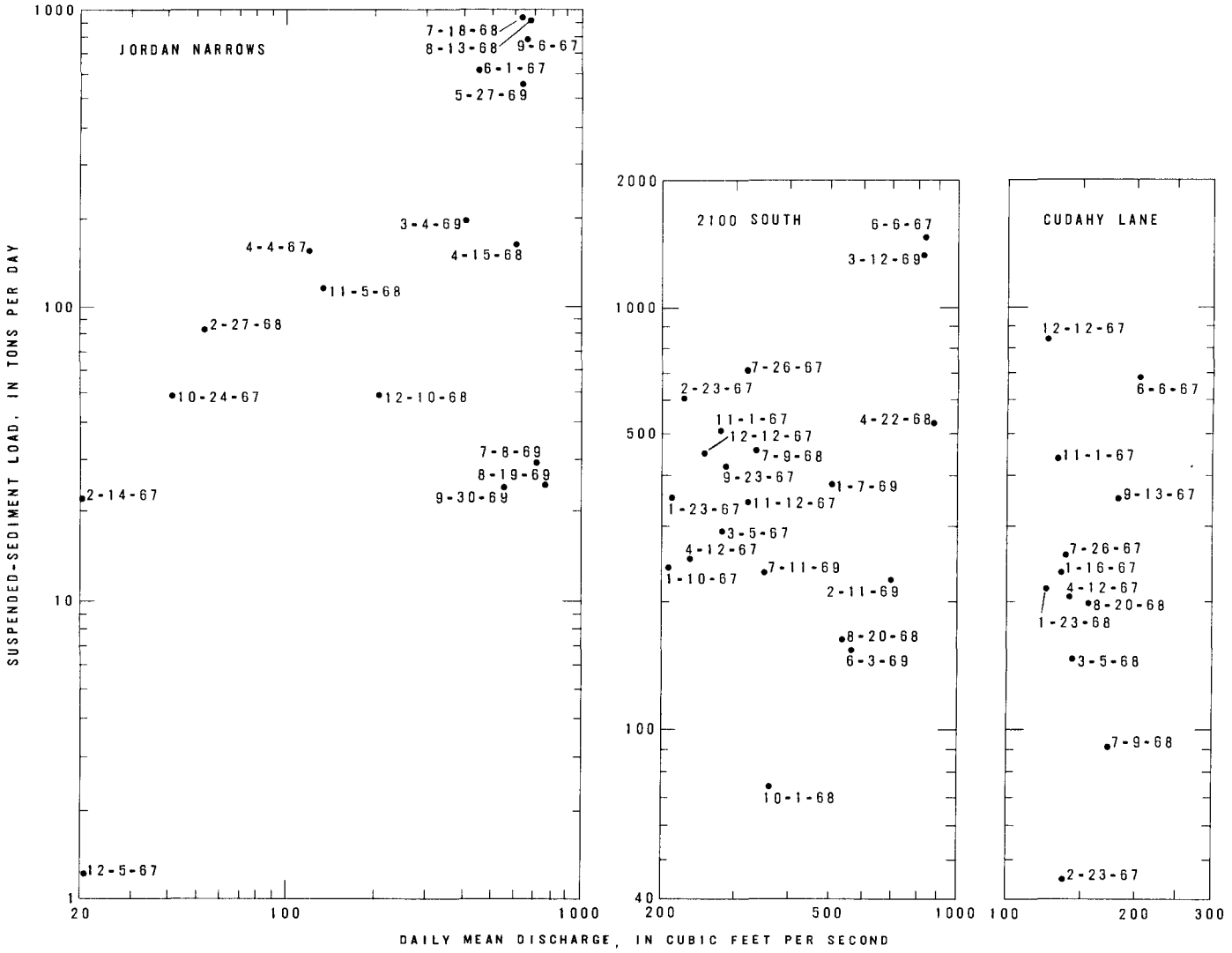


Figure 54.—Scatter diagrams of daily suspended-sediment load versus discharge of Jordan River at Jordan Narrows, at 2100 South, and at Cudahy Lane. (Sediment data from Utah State Division of Health.)

The suspended-sediment load of the Jordan River probably represents a much higher percentage of the total sediment load (probably more than 90 percent) than the percentage represented by corresponding loads of tributary streams. Thus, for practical purposes, the estimates listed above may be considered total loads.

Other Sources

Wasatch Range.—In addition to the area drained by the seven gaged streams, the Salt Lake County part of the Wasatch Range includes about 48 square miles drained by several small streams for which there are no continuous records. Occasional measurements of the discharge of eight of these small streams were made during 1964-68, chiefly during periods of spring runoff. These measurements and the hydrographs for streams with continuous records provided a basis for estimating hydrographs for ungaged streams. Independent estimates for a few of the largest streams were obtained by using a method described by Moore (1968) and based on a relation between mean annual discharge and certain features of the stream channel. The U.S. Bureau of Reclamation also made independent estimates based on the available records of streamflow and topography (W.E. Cook and R.L. Jensen, written commun., 1969).

Considering all these estimates, the runoff from the ungaged area is estimated to be about 20,000 acre-feet per year.

Oquirrh Mountains.—Because of the small runoff from the Oquirrh Mountains, no continuous records of discharge of any of the eight principal streams have been maintained. The mean annual discharge from the entire area within the county is estimated to be about 7,000 acre-feet, on the basis of occasional measurements during 1964-68. This total flow includes some discharge from mine tunnels that tap underground sources.

Kennecott Copper Corp. pipeline.—The discharge of three groups of springs (Dunnes Pond, Mill Pond, and Sixmile Creek) in Tooele County generally is delivered to the Garfield-Magna area by pipeline. Records of the spring discharge, based on occasional discharge measurements and gage readings, are available for the period May 1965 to September 1968. Only part of the available supply was delivered from July 1967 to May 1968 because of a labor strike and plant shutdown. The normal annual delivery is estimated to be 10,700 acre-feet, the sum of means for each calendar month computed from records that were not affected by the shutdown. Using this normal for the period prior to May 1965, the mean annual delivery to Salt Lake County during the 1964-68 water years is computed as 9,500 acre-feet.

Drains in the Garfield-Magna area.—Garfield Drain enters Great Salt Lake west of Garfield, Kennecott Drain enters north of Garfield, and Lee Creek enters northwest of the Saltair salt plant. These streams receive some natural runoff and some drainage from irrigation, but much of their discharge is from industrial operations. Most of the water is derived from Jordan River diversions, the pipeline from Tooele County, and ground-water withdrawals.

The average annual discharge of Kennecott Drain during the 1964-68 water years (from continuous records) was 67,460 acre-feet. On the basis of occasional measurments, the average annual discharge of Garfield Drain is estimated as 2,200 acre-feet, and that of Lee Creek is estimated as 9,400 acre-feet. Thus the average annual discharge of the three drains was about 79,000 acre-feet.

Salt Lake City Sewage Canal.—Sewage from Salt Lake City prior to 1966 and effluent from the treatment plant thereafter were discharged to Great Salt Lake through the Salt Lake City Sewage Canal, which roughly parallels the Jordan River. The mean annual discharge in this canal at the treatment plant was about 35,000 acre-feet. This does not include water spilled from the Jordan River below the Cudahy Lane station into the lower reaches of the canal. The amount is based on complete records of the flow for the 1964 water year and January 1966 to September 1968 and records of a part of the flow during most of the remainder of the 1964-68 water years.

Wasatch Range.—Determinations of the specific conductance of water from ungaged streams at the canyon mouths south of Mill Creek were used with equations relating the specific conductance to dissolved-solids content for Big Cottonwood and Little Cottonwood Creeks to estimate the average dissolved-solids contents given below. Because of the similarity in the geology of the drainage areas the chemical composition of the water is probably similar to that of Big Cottonwood and Little Cottonwood Creeks.

	Number of samples	Specific conductance (micromhos/cm at 25° C)		Dissolved solids (mg/l)
		Range	Average	
Corner Creek near Draper	8	150-329	191	110
Draper Irrigation Co. Ditch	6	74-137	98	47
Bells Canyon Irrigation Co. Ditch	4	43-75	58	22
Little Willow Creek at Wasatch Boulevard	5	70-117	91	44
Heughs Creek above Wasatch Boulevard	6	85-117	100	50

Oquirrh Mountains.—The average chemical quality of water from the Oquirrh Mountains, estimated from occasional samples of mine drainage and streams during periods of flow, is given in table 15. Water from areas not associated with mining activities (Rose Creek, Dry Fork, and Coon Creek) is of the calcium bicarbonate type with a dissolved-solids content in the range of 200 to 500 mg/l. Water from areas associated with mining activities (Butterfield Creek, Keystone Gulch, and Bingham Creek) is of the calcium sulfate type with a dissolved-solids content in excess of 900 mg/l.

Mining is a dominant influence on the chemical quality of water in some parts of the Oquirrh Mountains. Leaching of the products of oxidation of lead, zinc, and copper sulfides in the Bingham area yields waters containing large quantities of sulfate, iron, and other ions. Acid produced in the oxidation and leaching process is neutralized by the carbonate rocks of the Oquirrh Formation. In Bingham Creek near Copperton, however, the water flowing from the Kennecott Copper Corp.'s leaching operations is acid. In addition to the constituents listed in table 15, this water contains as much as 300 mg/l of copper, 250 mg/l of zinc, and 4,000 mg/l of iron. The chemical quality of mine drainage and its effect is discussed in the section on chemical quality of ground water.

Drains in the Garfield-Magna area.—The chemical quality of water from Kennecott and Garfield Drains and Lee Creek is given in table 16. The average annual discharge of dissolved solids to the Great Salt Lake from the three sources during the 1964-68 water years was 1,458,000 tons. This is equivalent to about 78 percent of the total discharge to Great Salt Lake from major surface-water sources in Salt Lake County.

Table 15.—Estimated average chemical quality of surface water from the Oquirrh Mountains, 1964-68 water years

[All chemical data are estimates based on analyses of occasional samples.]

Sodium and potassium: Calculated and reported as sodium.
Dissolved-solids: Values greater than 1,000 mg/l are calculated from determined constituents; those less than 1,000 mg/l are residue on evaporation at 180° C.

		Rose Creek near Herriman	Butterfield Creek near Herriman	Keystone Gulch at Lark	Bingham Creek near Copperton	Dry Fork near Copperton	Coon Creek near Bacchus
Number of samples		2	9	7	7	3	2
Silica (SiO_2)	mg/l	39	7.1	17	42	9.3	10
Calcium (Ca)	mg/l	70	164	204	90	48	74
Magnesium (Mg)	mg/l	20	35	90	2,830	21	16
Sodium (Na)	mg/l	39	113	58	152	19	13
Bicarbonate (HCO_3)	mg/l	219	183	19	(1)	209	273
Sulfate (SO_4)	mg/l	70	581	867	31,800	35	27
Chloride (Cl)	mg/l	62	31	61	837	28	17
Nitrate (NO_3)	mg/l	1.9	1.1	1.4	3.8	.8	2.4
Dissolved solids	mg/l	426	985	1,310	44,400	280	293
Tons per acre-foot		.58	1.34	1.78	60.4	.38	.40
Hardness as $CaCO_3$							
Calcium, magnesium	mg/l	257	554	880	12,000	206	251
Noncarbonate	mg/l	78	403	864	12,000	35	27
Sodium adsorption ratio		1.1	2.1	.9	.6	.6	.4
Specific conductance, in micromhos per centimeter at 25° C		660	1,280	1,560	19,600	479	512

[1] Acidity as H_2SO_4, 50 mg/l.

Floods

Flood damage is one of the best known examples of interaction between man and his hydrologic environment. No damage, notable to man, occurs until man utilizes land that is naturally flooded at times, obstructs a floodway, or alters the local runoff regime by such means as the construction of buildings and pavements, thereby increasing the storm runoff and sometimes creating floods where none occurred before.

Floods that result from such activities of man have no relation to floods in the major stream channels, and they can be controlled by use of adequate drainage facilities. The first phase of a master storm-drainage plan for Salt Lake County has been described by Caldwell, Richards, and Sorenson, Inc. (1964).

The intense rains that cause such floods sometimes cause devastating floods from the mountain canyons also. Woolley (1946) has described qualitatively a large number of so-called

Table 16.—Chemical quality of water from drains in the Garfield-Magna area, 1964-68 water years

[Chemical data for Kennecott Drain are discharge-weighted averages; for other streams they are estimated averages from analysis of occasional samples.]

Sodium and potassium: Calculated and reported as sodium.
Dissolved solids: Calculated from determined constituents.

		Lee Creek	Kennecott Drain	Garfield Drain
Number of samples		4	-	5
Mean discharge, in cubic feet per second		13[1]	85.1	3[2]
Silica (SiO_2)	mg/l	14	37	45
Calcium (Ca)	mg/l	158	254	374
Magnesium (Mg)	mg/l	3,230	110	92
Sodium (Na)	mg/l	14,400	936	1,540
Bicarbonate (HCO_3)	mg/l	304	162	[3]
Sulfate (SO_4)	mg/l	7,260	740	2,350
Chloride (Cl)	mg/l	26,400	1,570	2,520
Nitrate (NO_3)	mg/l	23	6.5	9.4
Dissolved solids	mg/l	81,400	3,730	6,550
Tons per acre-foot		111	5.07	8.91
Tons per day		2,860	857	53.1
Hardness as $CaCO_3$				
Calcium, magnesium	mg/l	13,700	1,090	2,660
Noncarbonate	mg/l	13,400	954	2,660
Sodium adsorption ratio		53	12	13
Specific conductance, in micromhos per centimeter at 25° C		91,800	6,080	15,400
pH		7.6	7.0	1.3

[1]Estimated from 18 discharge measurements.

[2]Estimated from 13 discharge measurements.

[3]Acidity as H_2SO_4, 1,320 mg/l.

cloudburst floods prior to 1939. An example of the runoff that can be generated by intense rain on a small mountain watershed is afforded by the flood of August 19, 1945, on Perrys Hollow above the City Cemetery between Red Butte and City Creeks. Butler, Reid, and Berwick (1966, table 4) report an estimated peak of 1,800 cfs (cubic feet per second) from an area of 0.59 square mile (more than 3,000 cfs per sq mi).

Floods in the principal stream channels may be caused by rapid snowmelt (as in the record-breaking flood of 1952), by intense rainfall, or by a combination of the two. Although the most damaging flood to date (that of 1952) was caused by snowmelt, a much larger flood would

result from a heavy rain during a similar period of rapid melting.The probability of such a coincidence may be rather low, but the possibility should be recognized.

The 1952 floods are described in detail by the U.S. Geological Survey (1957). Whitaker (1969) has described maximum known discharges for Utah streams, and Butler, Reid, and Berwick (1966) have presented a method of determining flood frequencies. Flood problems and the areas subject to flooding by the Jordan River and the Wasatch streams have been described by the U.S. Army, Corps of Engineers (1969).

Most of the data for streams in Salt Lake County are not suitable for use in the usual types of flood analysis. The Jordan River is regulated at its source, and the maximum flows may be influenced as much (or more) by activities of man as by natural events. Many of the records for the Jordan River and the Wasatch streams show combined flows in two or more channels, hence only maximum daily flows (rather than flood peaks) are available. In some streams the peaks may by only slightly higher than daily flows; peaks caused by snowmelt may be as much as 20 percent higher; and peaks caused by rainfall generally are much higher than the corresponding daily flow.

Figure 55 summarizes flood experience during the periods of record for the Jordan River and the Surplus Canal. The central part of a cumulative frequency graph, such as those in figure 55, is a good indicator of the average recurrence interval for floods of a specific magnitude provided the graph represents a sufficiently long period and no change in the regimen of the stream is involved. The reliability of the indicated recurrence interval decreases sharply as the maximum interval is approached for reasons best explained by an example.

The highest point plotted in figure 55 represents the 1952 flood on the Jordan River above the Surplus Canal. As this flood was the highest in the 26-year period of record, its recurrence interval was computed as 27 years—(number of years of record plus one) divided by the order number, which is one for the highest flood. If the period of record had been only 10 years, instead of 26 years, the recurrence interval would have been computed as 11 years. On the other hand, the 1952 flood may have been the highest flood in a period much longer than the 26-year period of record. The recurrence interval for the same flood at the Jordan Narrows was computed as 56 years. The difference between the recurrence intervals at the two sites may be due partly to difference in the period of record and partly to the inflow between gaging sites.

The flood experience for six Wasatch streams is similarly summarized in figure 56. The lower part of a graph for Little Cottonwood Creek would be so close to that for Big Cottonwood Creek that it was omitted to avoid congestion. The divergence of these two graphs at the upper end is caused chiefly by the difference in periods used. Although the daily discharge shown generally exceeds the corresponding discharge in the stream channels, it represents potential discharge in the channels if diversions are inoperative during floods. The graphs in figure 56 are more reliable indicators of recurrence intervals than those in figure 55 because of the longer periods of record and because the daily discharges represented were not appreciably altered by activities of man.

Summary and discussion of surface water

The long-term mean annual discharge of Salt Lake County's principal surface-water sources is listed in table 17. The values shown for the six Wasatch streams are total runoff. With complete regulation of the streamflow at the canyon mouths, the maximum sustainable constant draft from the six streams during 1907-68 would have been 117,000 acre-feet per year (fig. 26) less the amount lost by evaporation from surface reservoirs. The values for Deer Creek Reservoir

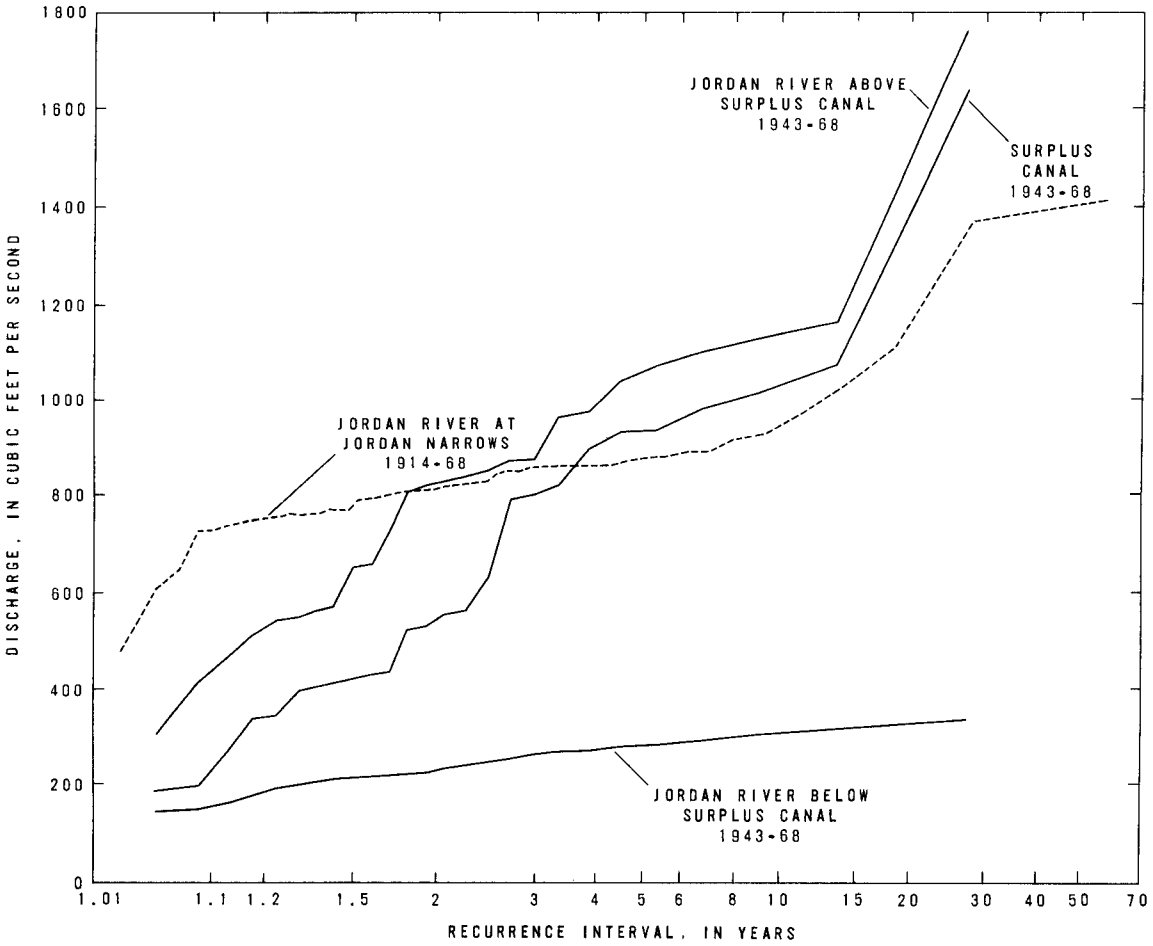


Figure 55.—Cumulative frequency graphs of annual maximum daily discharge of the Jordan River and the Surplus Canal. Periods of record shown in water years.

show the amounts that would have been available if the reservoir and associated diversions had been in operation. The values shown for Provo Reservoir Canal and the Jordan River are actual flows except as noted for the canal. Some increases in the available storage capacity would be required for complete utilization of the Jordan River supply. The values for the Jordan River above Surplus Canal indicate the supply available in the lower part of the river system.

Tables 18 and 19 are summaries of the surface inflow and outflow for Jordan Valley during the water years 1964-68. The flow that reached Great Salt Lake from some of the streams was derived by subtracting the estimated depletion in waterfowl-management areas from the inflow to those areas. The estimate of this depletion is described in the section on water use and water loss. (See p. 188.)

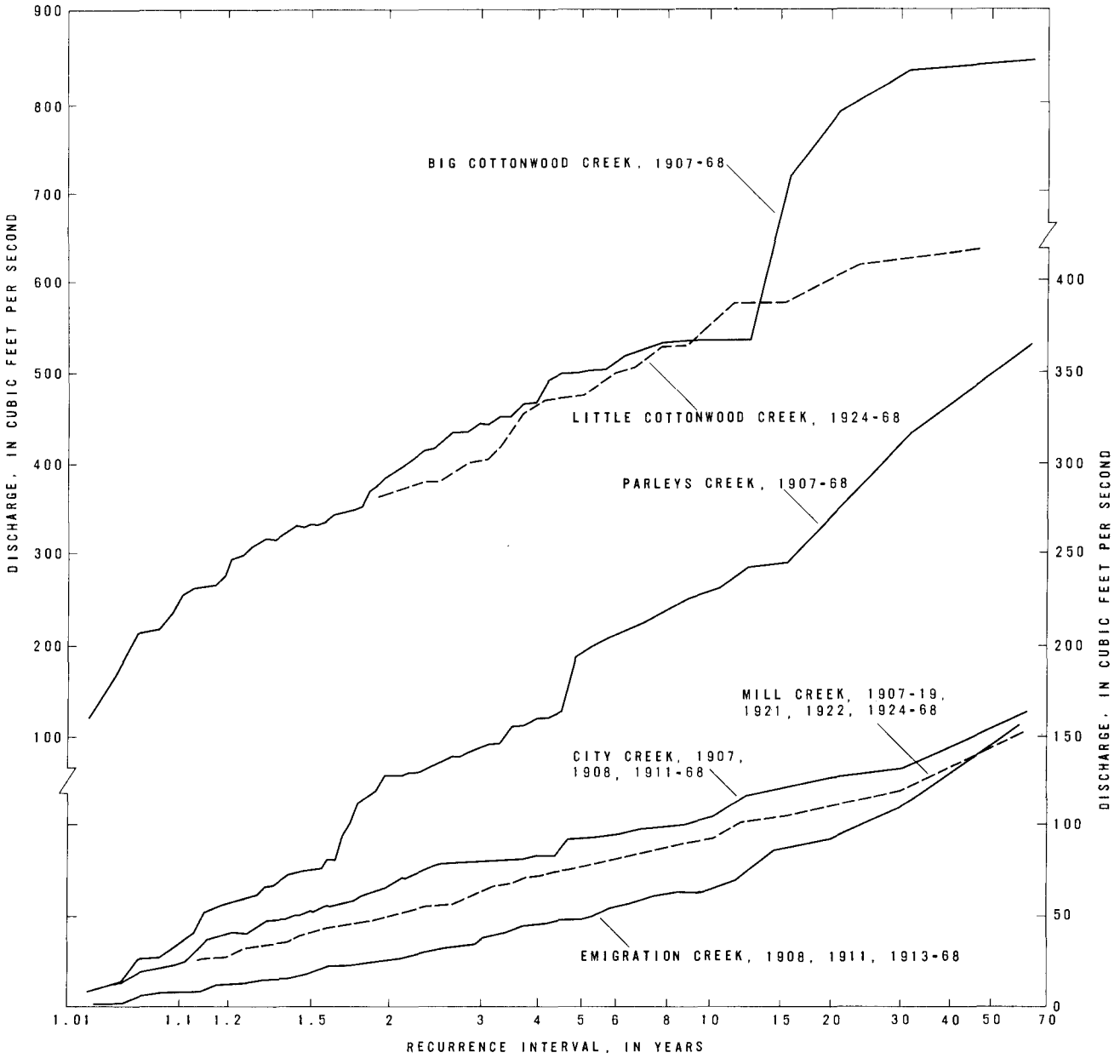


Figure 56.—Cumulative frequency graphs of annual maximum daily discharge of six Wasatch streams at canyon mouths. The discharge for all creeks except Emigration include diversions above the canyon mouths. Periods of record shown in water years.

Table 17.—Summary of major surface-water sources

[Mean annual flow, in acre-feet]

Source	Water years			
	1907-67	1914-67	1943-67	1957-67
Six creeks in Wasatch Range[1]	148,300	140,800	135,600	128,300
Deer Creek Reservoir allocation[2]	60,000	59,800	59,000	56,800
Provo Reservoir Canal[3]	-	(22,100)	(22,100)	22,100
Jordan River at Jordan Narrows[4]	-	270,900	253,200	212,300
Total	-	493,600	469,900	419,500
Jordan River above Surplus Canal	-	-	227,900	204,200

[1] Little Cottonwood, Big Cottonwood, Mill, Parleys, Emigration (including Emigration Tunnel Springs), and City Creeks.

[2] Amounts that would have been available to the Metropolitan Water District of Salt Lake City, including water delivered through the Utah Lake Distributing Co. Canal. Actual deliveries began in 1951.

[3] Approximate amount delivered to Salt Lake County. No record prior to 1957, but the average for 1914-67 was assumed to be the same as for 1957-67 for computation of the total supply.

[4] Includes amounts pumped from the Jordan River to the Utah Lake Distributing Co. Canal.

Table 18.—Summary of surface inflow to Jordan Valley, 1964-68 water years

Source	Mean annual inflow, in acre-feet
Jordan River at Narrows	206,300[1]
Utah Lake Distributing Co. Canal	25,600[2]
Provo Reservoir Canal	28,000[3]
Salt Lake City aqueduct	14,500[4]
Little Cottonwood Creek	49,110
Big Cottonwood Creek	53,490
Mill Creek	9,880
Parleys Creek	19,190
Emigration Creek and Tunnel	6,040
Red Butte Creek (above reservoir)	2,420
City Creek	11,640
Other runoff from Wasatch Range	20,000[5]
Runoff from Oquirrh Mountains	7,000[5]
Kennecott Copper Corp. pipeline	9,500[5]
Total	463,000

[1] Excluding water pumped to Utah Lake Distributing Co. Canal.

[2] Includes 5,650 acre-feet from Deer Creek Reservoir.

[3] Includes 9,600 acre-feet from Deer Creek Reservoir.

[4] Includes about 1,000 acre-feet of leakage and spill to Little Cottonwood Creek.

[5] Estimated.

Table 19.—Summary of surface outflow from Jordan Valley, 1964-68 water years

Source	Mean annual outflow, in acre-feet
Discharge to waterfowl-management areas	
Jordan River[1]	111,200
Surplus Canal	92,300
North Point Consolidated Canal[2]	1,700
Subtotal (rounded)	205,000
Depletion in waterfowl-management areas[3]	39,000
Discharge to Great Salt Lake	
Net flow from waterfowl-management areas	166,000
Salt Lake City Sewage Canal	35,000
Goggin Drain	43,700
Lee Creek[4]	9,400
Kennecott Drain	67,500
Garfield Drain[4]	2,200
Total (rounded)	324,000

[1]No adjustment made for unknown quantity spilled to Salt Lake City Sewage Canal but not included in the record for the canal.

[2]The total discharge in the canal was 17,300 acre-feet, of which probably less than 10 percent reached waterfowl-management areas.

[3]The depletion of streamflow occurs in Farmington Bay Bird Refuge and private clubs. (See p. 188.)

[4]Estimated.

The disposal of precipitation on the county was previously discussed in a qualitative manner. Quantitative information on some aspects of the disposal is presented in table 20. The precipitation shown is the average for the designated area obtained from the map of normal annual precipitation (fig. 4). The previously described runoff values were converted to depth, in inches, for this comparison. The difference, often termed "natural water loss," is disposed of by evapotranspiration and, in some areas, by subsurface outflow. As the losses from Big Cottonwood Creek and Mill Creek basins, for example, are much greater than those from adjacent areas, with similar amounts of precipitation, large amounts of water apparently are leaving these basins without reaching the stream channels. Additional analyses of these losses are presented in a later section on water use and water loss. (See p. 174-177.)

Water represented by the first three items in table 17 is of good quality, the dissolved-solids content generally being less than 500 mg/l. As the creeks cross Jordan Valley and approach the Jordan River, the quality degrades appreciably, but not excessively. Water from the Jordan River has much higher concentrations of dissolved solids, the average generally being

Table 20.—Normal precipitation and runoff for selected mountain areas

[Runoff in creeks measured at or near canyon mouths]

Drainage basin or area	Drainage area, in square miles	Precipitation, in inches	Runoff, in inches	Water loss, in inches
Little Cottonwood Creek	27.4	48	29	19
Big Cottonwood Creek	50.0	44	17	27
Mill Creek	21.7	37	8.3	29
Parleys Creek	50.7	31	6.1	25
Emigration Creek	18	28	5.3	23
Red Butte Creek	7.25	29	6.3	23
City Creek	17.7[1]	31	11	20
Oquirrh Mountains[2]	61.0	21	2[3]	19

[1]Area at Salt Lake City's station about 0.6 mile below Wasatch Drive, revised in 1969.

[2]Data for area within Salt Lake County.

[3]Estimated.

within the range of 1,000 to 2,000 mg/l. The quality of water in drains in the Garfield-Magna area varies greatly but is generally poor. The estimated average dissolved-solids content of water in Lee Creek was more than 80,000 mg/l.

GROUND WATER

Ground water occurs in subsurface materials throughout Salt Lake County. Some of the ground water in the mountainous areas discharges by evapotranspiration, some discharges to streams in the canyons, and the remainder moves through the bedrock directly into the unconsolidated fill in Jordan Valley. Like surface runoff from the mountains, most of the ground water eventually reaches the valley.

The quantity and rate of movement of water in various subsurface materials depend in part on the nature of materials. In unconsolidated deposits, the size, sorting, and arrangement of the particles are governing factors. Sand and gravel, for example, may contain large quantities of water and transmit it readily. Clay also may contain large quantities of water, but it transmits water slowly. In consolidated rock, the joints, fractures, faults, and solution channels are the principle water-bearing channels. Some of these may be large enough to transmit water as freely as a surface stream. Most of them are small, however, and water moves through them as slowly as it does through unconsolidated deposits.

Almost all materials at or near the earth's surface contain and transmit some water, but the porosity and permeability vary greatly. A deposit that readily yields water to wells is called an aquifer. Other deposits have such low permeability that their ability to retard flow or confine water in a contiguous aquifer is of greater hydrologic significance than their ability to transmit water.

A relatively impermeable bed usually forms a floor under each aquifer, and another impermeable bed may form an upper boundary to parts of an aquifer. The storage characteristics of such confined aquifers differ greatly from those of unconfined aquifers.

The top of the saturated zone is called the water table and is defined by the level at which water in the rocks is at atmospheric pressure. This level is marked by the water level in an open well. Capillary forces hold water in **saturated** voids above the water table against the pull of gravity. Hence, a capillary fringe extends to varying heights above the water table, the heights varying inversely (within limits) with sizes of the voids. This fringe is significant chiefly because ground water is consumed by evapotranspiration when the fringe is close to the land surface. Replenishment or recharge of an unconfined aquifer generally is by downward percolation of water from the land surface or by upward leakage from an underlying confined aquifer. Discharge occurs naturally by evapotranspiration, seepage into streams or spring areas, and movement into adjoining aquifers.

In a confined aquifer, natural recharge may occur by downward or lateral movement from adjoining aquifers or by upward movement from underlying confined aquifers. The water in a confined aquifer is under artesian pressure, and when a well taps the confined aquifer, the water rises above the bottom of the confining bed and sometimes above the land surface. The levels at which water would stand in an open well or pipe is called the potentiometric level, and the imaginary surface formed by connecting such levels is called the potentiometric surface. Natural discharge from a confined aquifer generally is by slow upward leakage through the confining bed, into an overlying confined aquifer or into an unconfined aquifer.

Occurrence in Jordan Valley

Ground water in Jordan Valley occurs (1) in a confined (artesian) aquifer, (2) in a deep unconfined aquifer between the artesian aquifer and the mountains, (3) in a shallow unconfined aquifer overlying the artesian aquifer, and (4) locally, in unconfined perched aquifers (fig. 57). All the unconsolidated water-bearing materials in the valley are connected hydraulically to some degree; thus together they compose the ground-water reservoir in Jordan Valley. The aquifers described under (1) and (2) above compose the principal aquifer. Although water in each part of the ground-water reservoir has its own important role in the hydrologic regimen of the valley, the ultimate source of most of the ground water withdrawn from wells is the principal aquifer.

Confined Aquifer

The confined aquifer in Jordan Valley consists of Quarternary deposits of clay, silt, sand, and gravel, all hydraulically interconnected, with individual beds ranging in thickness from less than one foot to several tens of feet. The confined aquifer attains a maximum thickness of more than 1,000 feet in the northern part of the valley.

Underlying the confined aquifer are relatively impermeable consolidated and semiconsolidated Tertiary and pre-Tertiary deposits (Arnow and others, 1970). Where some of the more permeable Tertiary deposits contain at least moderate proportions of sand and gravel, they may yield small quantities of water to wells. Three areas where the Tertiary is known to yield some water are delineated approximately in figure 64 as (1) the area in the vicinity of Kearns encompassed by the zero-thickness contour of saturated unconsolidated fill and the edge of the valley fill, (2) the area near Murray encompassed by the 200-foot contour, and (3) the area between Herriman and Riverton encompassed by the 200-foot contour. These water-yielding parts of the Tertiary are included with the principal aquifer, unless stated otherwise, in the discussions that follow.

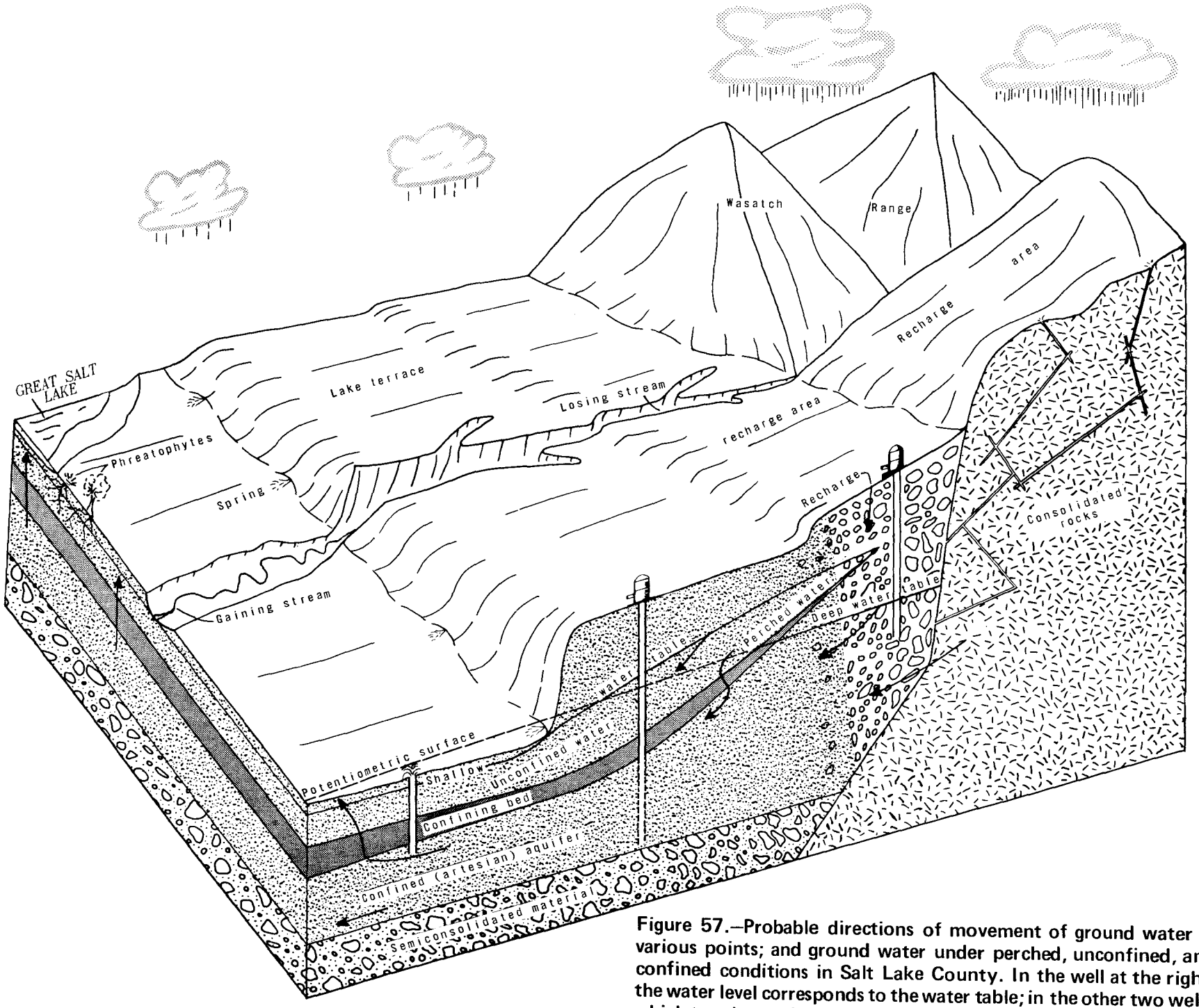


Figure 57.—Probable directions of movement of ground water at various points; and ground water under perched, unconfined, and confined conditions in Salt Lake County. In the well at the right, the water level corresponds to the water table; in the other two wells, which tap the confined aquifer, the water rises above the confining layer to the potentiometric surface.

Within the confined aquifer relatively thin beds and lenses of fine-grained material, up to about 20 feet thick but usually not more than a few feet thick, tend to confine water in each of the many individual beds of sand and gravel. The fine-grained material is slightly to moderately permeable and is discontinuous, therefore, there is appreciable movement of water between the various permeable beds of sand and gravel.

Overlying the confined aquifer are relatively impermeable Quaternary deposits of clay, silt, and fine sand, which act collectively as a single bed that ranges from about 40 to 100 feet in thickness. The top of the confining bed generally lies between 50 and 150 feet below the land surface, and in most of Jordan Valley the bed is coextensive with the outlines of the confined and perched aquifers shown in figure 58.

The hydraulic connection between the different water-bearing beds in the confined aquifer has been demonstrated many times during aquifer tests when pumping one well has quickly caused water-level declines in other wells finished in different beds. During short-term aquifer tests (usually less than 48 hours of continuous pumping), the magnitude of the observed effects in observation wells varied inversely with the vertical distance between the beds tapped by the pumped and the observation wells. A measurable effect was observed during such tests, however, even when observation wells were finished near the top of the confined aquifer and the pumped well was finished near the bottom of the aquifer. Over a long period of steady pumping (one or more years) recharge and discharge within the area of influence of the pumped well approaches a new equilibrium. The effect of pumping then becomes approximately equal throughout the vertical section of the confined aquifer, indicating that all the unconsolidated material beneath the confining beds acts as a single aquifer.

In low-lying parts of Jordan Valley, including most of the northern part and an area along the Jordan River, the potentiometric surface for the confined aquifer is above the land surface, causing wells to flow (pl. 1). In February 1969 this area included 181 square miles. Earlier investigations showed an area of 173 square miles in 1904 (Richardson, 1906, pl. 7) and also in 1931-33 (Taylor and Leggette, 1949, pl. 2). These earlier investigations did not consider the full area covered in 1969, however, and if this is taken into account, the area of flowing wells decreased in size by about 3 square miles between 1933 and 1969. This indicates a very slight decline in the potentiometric surface, probably due chiefly to increasing withdrawals of ground water from wells.

The confined aquifer generally yields water readily to wells. The most productive wells are around the edge of the aquifer (fig. 58), near the mountains, where it contains thick coarse-grained deposits. Most of the least productive wells are in the northern and central parts of the valley, where the aquifer consists largely of fine-grained deposits.

Unconfined Aquifers

Deep aquifers near the mountains.—The deep body of water that is in the confined aquifer actually extends to the edges of Jordan Valley. However, the bed that confines the aquifer in the central part of the valley is either absent or above the potentiometric surface in a band of varying width adjacent to the mountains (figs. 57 and 58). In this band, the ground water is unconfined (under water-table conditions). Much of the water that reaches the confined aquifer first passes through this deep unconfined zone at each side of the valley. Thus, the principal aquifer in Jordan Valley includes both the confined and unconfined portions of the deep aquifer. The line between these portions can be located only approximately because it shifts as the water table or potentiometric surface fluctuates in response to changing rates of recharge and discharge.

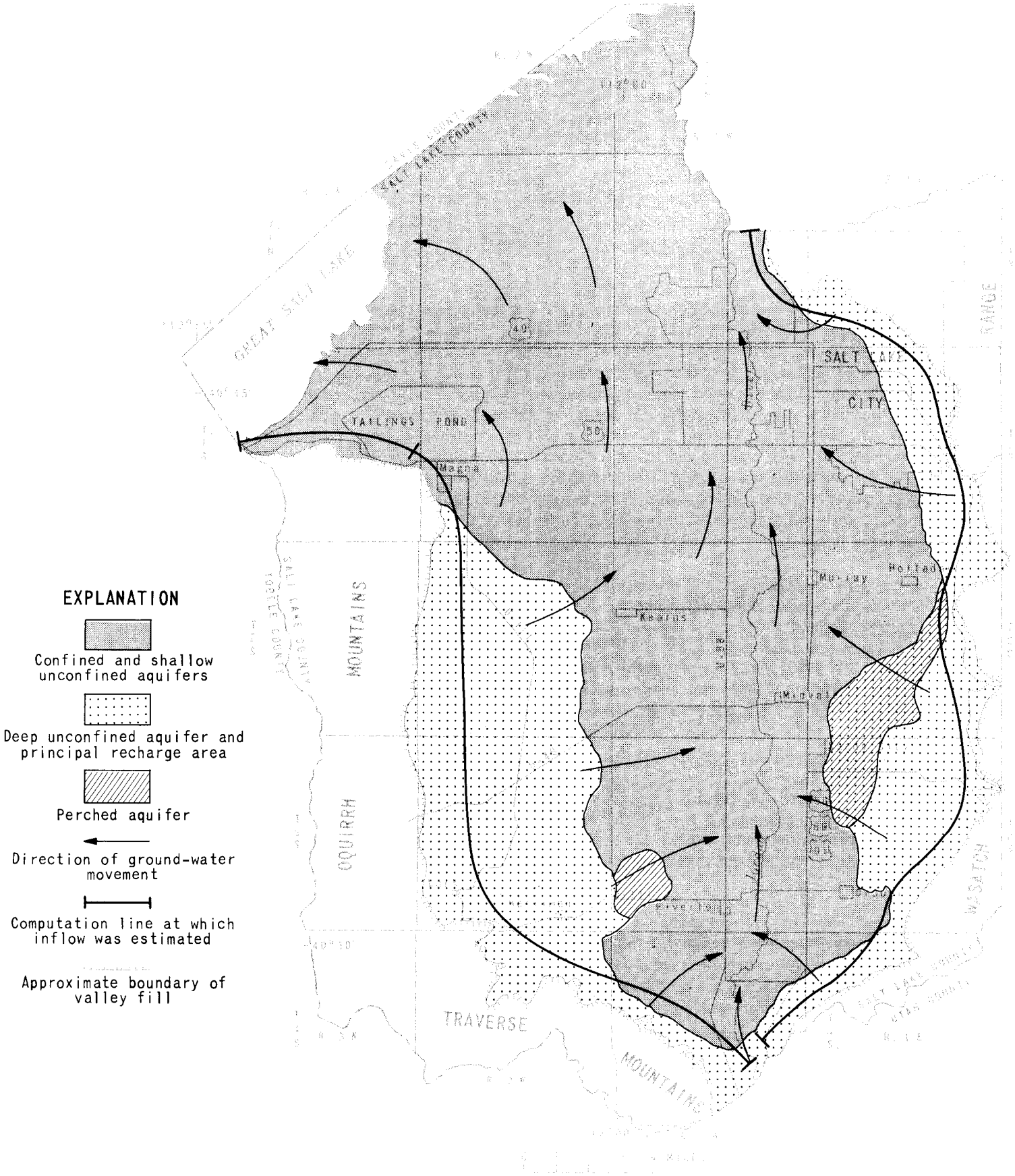


Figure 58.—Approximate areas in which ground water occurs in confined, shallow unconfined, deep unconfined, and perched aquifers in Jordan Valley.

In Jordan Valley, the unconfined parts of the ground-water reservoir near the mountains generally have yielded little water to wells. In some places, the water-bearing materials are so thin that they cannot yield large quantities to wells; in other places, the depth to water is too great—more than 500 feet—for economical pumping. A few public-supply and industrial wells with moderate to high yields have been constructed in the unconfined part of the reservoir near the mountains, but a larger number of wells with yields too low to be considered successful have been drilled. Most of the low-yield wells are in areas between stream channels; whereas most of the productive wells are along or near stream channels, where the deposits are better sorted and more recharge is available.

Shallow aquifer.—The shallow unconfined aquifer overlies the bed of low permeability that confines water in the artesian aquifer. The shallow aquifer is composed principally of clay, silt, and fine sand; and in some parts of the valley, this aquifer has a permeability only slightly greater than that of the underlying bed. Thus, the exact thickness of the shallow aquifer is difficult to determine, but the maximum thickness probably is about 50 feet. This aquifer extends over approximately the same area as the confined aquifer; and where the potentiometric surface of the confined aquifer is above the top of the confining bed, water moves upward from the confined aquifer through the confining bed into the shallow unconfined aquifer. Another major source of recharge is water diverted from the Jordan River for irrigation. Because of the poor chemical quality of contained water and the low yield to wells, the shallow aquifer is seldom used for water supply.

Perched water.—The perched water, as referred to in this report, is in areas where the bottom of the confining bed lies above the deep water table (fig. 57). 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 fine-grained bed supporting the body of perched water, most perched bodies never drain completely. They form or enlarge during periods when the rate of infiltration from the surface exceeds the rate at which water moves downward through the fine-grained bed, and they shrink during periods of little or no recharge.

The principal areas of perched water are east of Midvale and between Herriman and Riverton (fig. 58), but smaller bodies of perched water are scattered around the county. For example, during May-July 1969 water flowed from a spring near the southeastern corner of Salt Lake City, about 300 feet above the deep water table; west and southwest of Kearns, where the deep water table is 100-300 feet below the land surface, several shallow dug wells near ephemeral streams are reported by residents to have yielded small supplies of water; other similar springs and wells have been reported by residents along the east side of Jordan Valley. The extent of these small bodies of perched water is not fully known and no attempt has been made to show them in figure 58. The perched aquifers are at most a few tens of feet thick, and the largest ones usually are extensions of the shallow unconfined aquifer.

The perched aquifers supply water to only a few stock wells. Water from the perched aquifers infiltrates to the underlying principal aquifer or helps maintain the base flow of streams, some is discharged by evapotranspiration, and the remainder recharges the shallow unconfined aquifer.

Hydraulic Properties

The ability of a deposit to transmit water depends on the physical and hydraulic properties of the materials that constitute the deposit. Knowledge of these properties enables prediction of hydraulic behavior of the deposit under specified pumping stresses. Detailed

lithologic descriptions of materials recovered in drilling wells and the observed thickness of a deposit enable the estimation of its hydraulic properties, but more accurate quantitative estimates are obtained from comprehensive laboratory or field tests. The terms hydraulic conductivity, transmissivity, storage coefficient, and specific yield are used to denote the principal hydraulic properties of aquifers.

Hydraulic conductivity (K) and transmissivity (T)[1] are measures on an aquifer's (or confining bed's) ability to transmit water. In this report, K is expressed in terms of the volume of water that would be transmitted in 1 day through a section 1-unit square and perpendicular to the direction of flow under a unit hydraulic gradient (e.g., 1 ft change in ground-water level per ft of distance along a flow line). Thus, if the volume-rate of flow is 1 cubic foot per day through a cross section of 1 square foot, K is 1 cubic foot per square foot per day, or 1 ft day^{-1}. T applies to a section 1 foot wide extending from top to bottom of the aquifer and is equal to K times the aquifer thickness. With the above K and a thickness of 100 feet, $T = 100$ ft^2 day^{-1}.

The flow of a fluid through porous materials is influenced by the kinematic viscosity of the fluid as well as the properties of the materials. However, the range of viscosities encountered in ground water in Jordan Valley is so small that the effects of viscosity can be disregarded.

The storage coefficient (S) is a dimensionless indicator of storage characteristics of a deposit; and when used with the areal extent of the deposit and the change in water level, it enables calculation of a change in storage. The storage coefficient is defined as the amount of water released from or taken into storage per unit surface area of the aquifer per unit of change in water level or head.

For confined aquifers, the storage coefficient is very small because if reflects only changes in volume due to compression or expansion of the water and of the saturated materials in response to changes in pressure. For unconfined aquifers, the coefficient reflects in addition to these changes in volume the much larger volume of water that drains from saturated materials by gravity or is taken into storage in response to a change in water level.

Specific yield (Sy) is defined as the ratio (sometimes expressed as a percentage) of the volume of water that a saturated deposit will yield by gravity to the volume of the deposit dewatered. The specific yield is generally several thousand times larger than the small quantity released by compaction of the deposit and expansion of the water. For practical purposes, the specific yield (Sy) can be considered equal to the storage coefficient (S) for unconfined aquifers.

Not all the water in the interstices of an unconfined aquifer is drained by gravity; some is retained by capillary and hygroscopic forces. The ratio of the volume of water released to the volume of retained capillary and hygroscopic water is related to the shape, size, sorting, and structure of the aquifer materials. In general, the finer and better sorted the particles are, the smaller is the ratio. For example, in saturated clay the volume of water may be 50 percent of the total volume of the saturated deposit, but the volume of water released may be less than 0.1 percent of the total volume. At the other extreme, in gravel the volume of water may be less than 20 percent of the total volume whereas the volume of water released is more than 15 percent of the total volume. In most parts of the unconfined ground-water reservoir in Jordan Valley the specific yield ranges from about 0.1 to 0.3 (10 to 30 percent) of the total volume.

[1] Hydraulic conductivity and transmissivity replace terms formerly used by the U.S. Geological Survey, coefficient of permeability and transmissibility respectively.

The most dependable values of the hydraulic properties of the principal aquifer in Jordan Valley were determined by analyzing 25 drawdown and recovery tests in wells for which pumping effects were observed in 73 observation wells. In addition, transmissivity was estimated at about 75 other sites from the specific capacities[1] of industrial, irrigation, and public supply wells. The storage coefficient at eight sites was estimated from the relation of barometric efficiencies[2] in artesian wells to the storage coefficient of confined aquifers.

Data from the aquifer tests were analyzed by means of the nonequilibrium formula (Theis, 1935), the generalized graphical method (Cooper and Jacob, 1946), and the modified leaky aquifer formula (Hantush, 1960). Transmissivity and hydraulic conductivity at some wells were estimated by using the specific capacity in a method described by Theis, Brown, and Meyer (1963). A method described by Jacob (1940) was used to determine the storage coefficient at several wells equipped with recording gages by using water-level fluctuations caused by barometric changes. The hydraulic properties determined by aquifer tests and estimated by using specific capacity and barometric efficiency were used to prepare maps of transmissivity (fig. 59) and storage coefficient (fig. 60) of the principal aquifer in Jordan Valley.

During an aquifer test, a well was pumped at a measured constant rate for periods ranging from 5 to 48 hours; and periodic water-level measurements were made in 1-5 observations wells at distances from the pumped well ranging from 35 to about 10,000 feet. As the area influenced by pumping for such short periods was relatively small, the results apply only to small areas around the pumped wells. For this reason and because of differences in hydraulic conductivity and thickness of the aquifer, the transmissivity and storage coefficients in figures 59 and 60 should be applied with caution at distances of more than half a mile from the data points.

The transmissivity (T) of the principal aquifer ranges from less than 1,000 to more than 50,000 $ft^2\ day^{-1}$. The largest values of T were observed in the eastern part of the valley, about 1-3 miles from the foot of the Wasatch Range, and in some areas between Riverton and Herriman, where the aquifer consists mostly of thick deposits of fairly-well sorted coarse sand and gravel. The smallest values of T are generally in areas where the aquifer is thin and hydraulic conductivity (K) is relatively low; for example, near and west of Kearns, where some water may be obtained from the underlying Tertiary deposits, and southeast of Draper. Although K, in general, diminishes with increasing distance from the mountains, T increases toward the northern end of the valley because of greater aquifer thickness. Lines of equal T in figure 59 were extrapolated between wells used in aquifer tests by comparing gamma-ray and lithologic logs of tested wells with logs of untested wells and by taking into account differences in the saturated thickness of the aquifer.

The observed storage coefficient (S) of the principal aquifer ranges from slightly more than 0.15 in some parts of the unconfined section around the periphery of the valley to slightly less than 0.0001 in the confined section of the aquifer near the central part of the valley (fig. 60). The computed values of S were increased from zero in some unconfined parts of the aquifer to one order of magnitude in the part encompassed by the 0.0001 contour. The adjustments were indicated by electric analog model studies discussed in a later section of the report, and they are necessary to compensate for the slow drainage of some of the aquifer materials. In defining the

[1]The specific capacity of a well, as used in this report, is the yield of the well in gallons per minute per foot of drawdown after pumping for 24 hours.

[2]Barometric efficiency indicates the degree, in percent, in which fluctuations of barometric pressure are reflected by fluctuations in water level in wells.

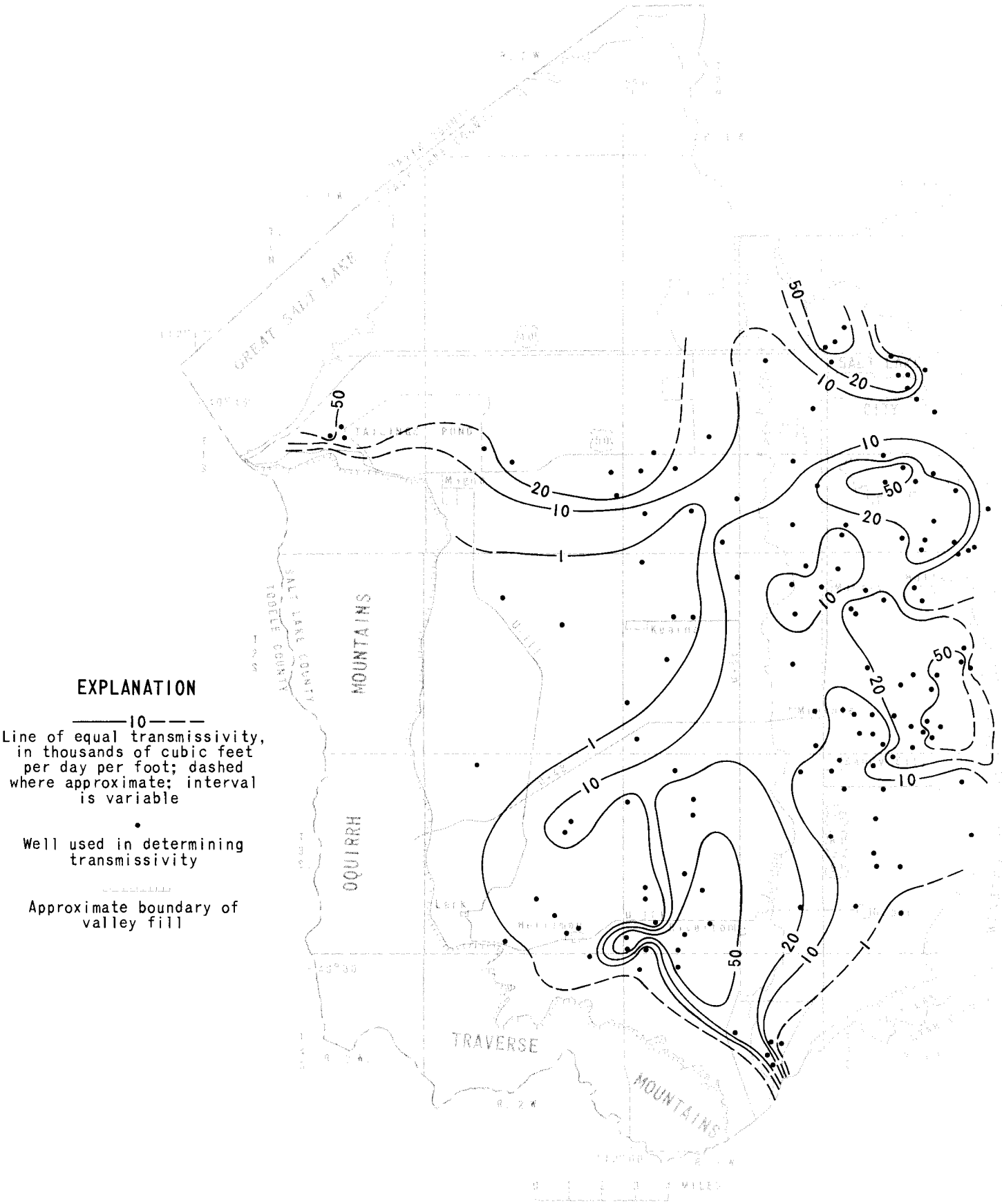


Figure 59.—Transmissivity of the principal aquifer in Jordan Valley.

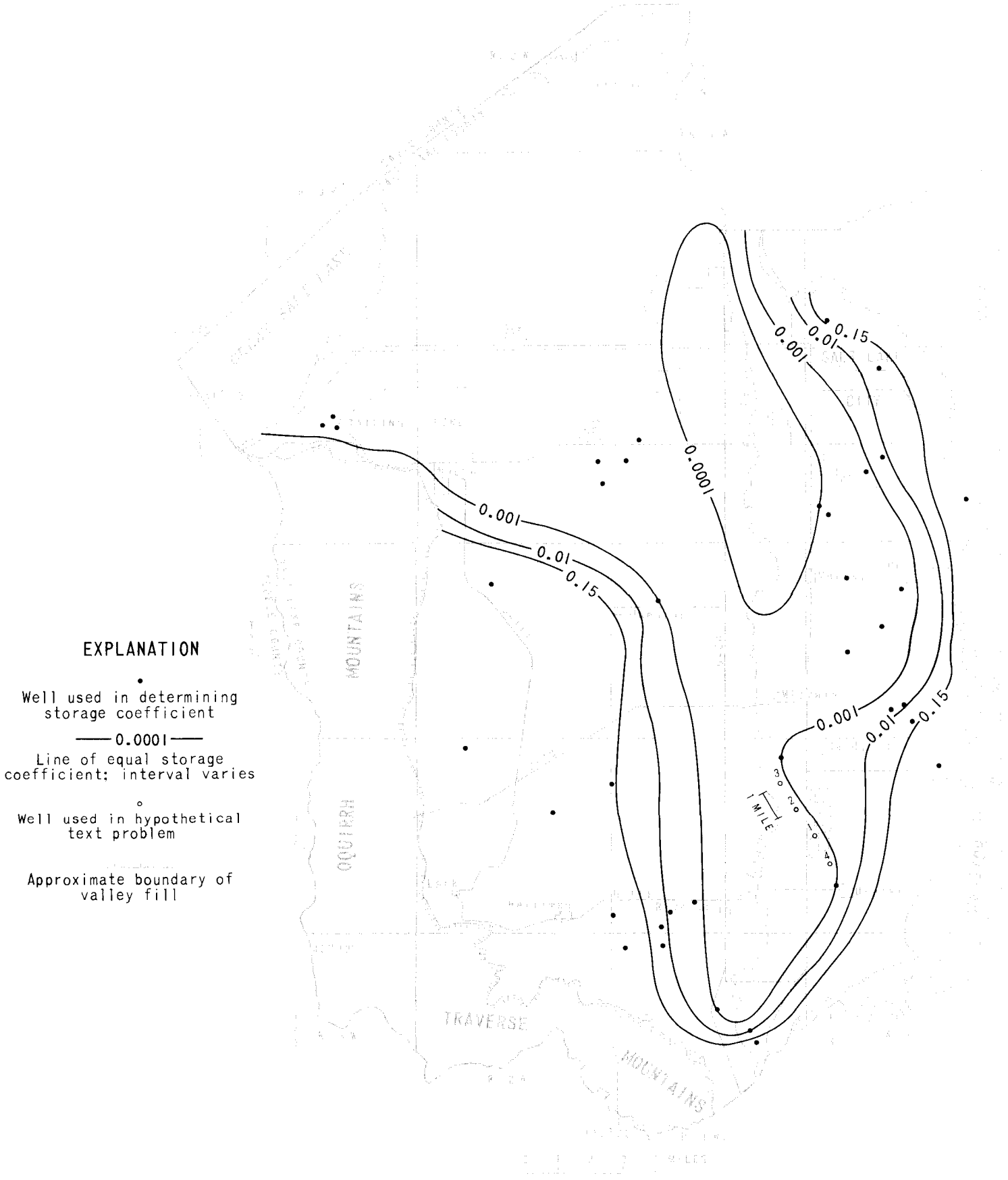


Figure 60.—Approximate storage coefficient of the principal aquifer in Jordan Valley.

lines of equal S in figure 60, other information was used to supplement the data from aquifer tests. Jacob (1940, p. 574-586) explained the relation between S and fluctuation of water level in wells caused by changes in barometric pressure, assuming certain ideal aquifer conditions. Although these ideal conditions were not fully satisfied, the departures from such ideals at points where S was determined in Jordan Valley were not sufficient to cause appreciable error in performance of the analog.

For uncemented materials in most of the confined aquifer in Jordan Valley

$$S = (\gamma_o \ \theta \ b \ \beta) \ \left(\frac{1}{BE}\right) \tag{3}$$

where,

γ_o = the specific weight of the ground water at the existing temperature,
θ = the porosity of the aquifer material,
b = the thickness of the aquifer in feet,
β = the bulk modulus of compression of water (reciprocal of the bulk modulus of elasticity),
and, BE = the barometric efficiency.

For the confined aquifer in Jordan Valley the values of these parameters are as follows:

γ_o = 0.0361 lb in. $^{-3}$,
θ = 0.30 where more than 50 percent of the aquifer materials are gravel, and 0.35 where more than 50 percent are sand, or finer,
b = 150-625 feet (individual values from well logs or fig. 64),
β = 3.3 x 10^{-6} in.^{3} lb^{-1} (approximate average for the aquifer),
BE = 15-75 percent (individual values determined by comparing fluctuations of water level at several sites with corresponding fluctuations of barometric pressure).

The values of S estimated by this barometric efficiency method compare well with values determined by aquifer tests at nearby sites.

Properties of the shallow unconfined aquifer

The transmissivity and storage coefficients of the shallow unconfined aquifer were estimated on the basis of lithology rather than aquifer tests because few wells were available for testing. In general, T ranges from about 1,300 to 4,000 ft^2 day^{-1} (fig. 61). The largest values of T are near Murray, where the saturated thickness exceeds 25 feet and the deposits contain coarse sand and some gravel. The smallest values are around the periphery of the aquifer, where the saturated thickness is very thin, or in small areas (not indicated in fig. 61) where the materials are medium sand and clay. The estimated values of T in figure 61 are generalized and should be used with caution if applied locally.

A relatively large proportion of the material in the shallow unconfined aquifer is sand, silt, and clay according to drillers' logs (Marine and Price, 1963; Iorns, Mower, and Horr, 1966; and Hely, Mower, and Horr, 1967-69); S, therefore, was estimated to range from 0.10 to 0.20. Because all values of S were estimated and are within a narrow range, 0.15 is assumed to be a reasonable average value for the shallow unconfined aquifer.

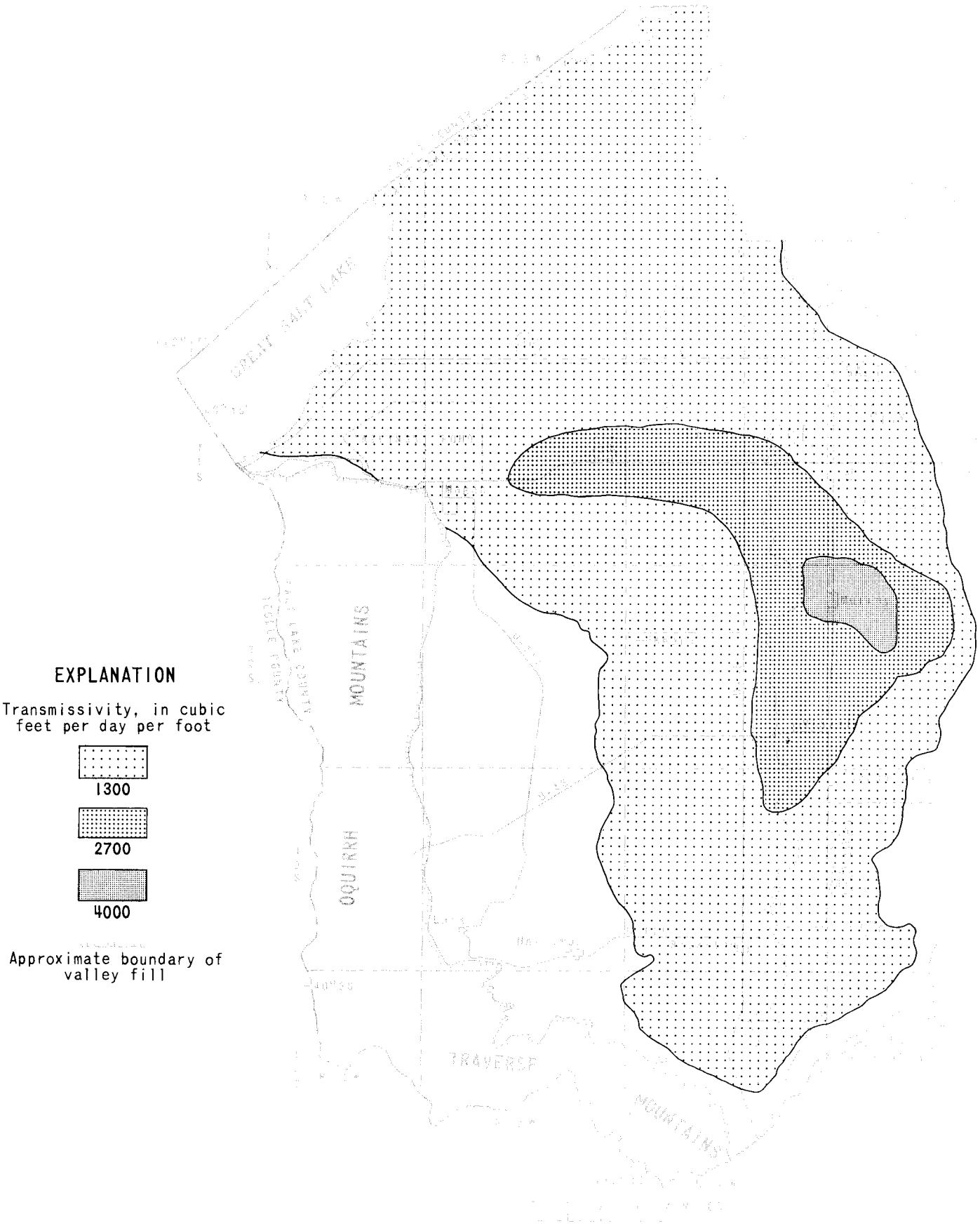


Figure 61.—Estimated transmissivity of the shallow unconfined aquifer in Jordan Valley.

Vertical hydraulic conductivity of the confining bed between the principal aquifer and the shallow unconfined aquifer was determined using a form of Darcy's equation:

$$K' = \frac{Q}{I'A} \tag{4}$$

where

K' = hydraulic conductivity of the confining bed,

Q = discharge through a known area, A, of the confining bed, and,

I' = hydraulic gradient through the confining bed.

The data required for solution of equation 4 are available for two areas—one near Great Salt Lake and the other between Holladay and Murray. For the area near the lake, T. 1 N., R. 2 W., Q = 16,000 acre-feet per year (table 33 and estimated ground-water discharge to Lee Creek and Goggin Drain) or 1,910,000 ft^3 day^{-1}; A = 36 square miles or 1,000,000,000 ft^2; and I'= 0.12 (average difference in levels of the potentiometric surfaces for wells finished at the bottom and at the top of the confining layer, 10 ft, divided by the average thickness of the layer at 19 wells, 83 ft). Hence,

$$K' = \frac{1{,}910{,}000 \text{ ft}^3\text{day}^{-1}}{(0.12)\ (1{,}000{,}000{,}000 \text{ ft}^2)} = 0.016 \text{ ft day}^{-1}$$

For the area between Holladay and Murray, Q = about 30,000 acre-feet per year or 3,580,000 ft^3 day^{-1} (determined by estimates of evapotranspiration from ground water in the area—T. 2 S., R. 1 E., table 33—withdrawals from wells, and the estimated ground-water discharge to Little Cottonwood and Big Cottonwood Creeks); A = about 21 square miles or 585,000,000 ft^2; and I' = 0.125 (average difference in levels of the potentiometric surfaces for wells finished at the bottom and at the top of the confining layer, 13 ft, divided by the average thickness of the layer at 100 wells, 104 ft). Hence,

$$K' = \frac{3{,}580{,}000 \text{ ft}^3 \text{ day}^{-1}}{(0.125)\ (585{,}000{,}000 \text{ ft}^2)} = 0.049 \text{ ft day}^{-1}$$

These two computed values define the probable range of average values of K' for areas of 10 or more square miles, but in some smaller areas the value may be far beyond this range. The weighted-average value of K' for the two areas is about 0.025; and this value probably is near the average for the entire valley.

Recharge

Sources of recharge to the ground-water reservoir in Jordan Valley include (1) seepage from bedrock in the adjacent mountains, (2) underflow in channel fill in mountain canyons, (3) underflow from Utah Valley through the Jordan Narrows, (4) seepage from creek channels, (5) seepage from major canals, (6) seepage from irrigated fields, (7) seepage from lawns and gardens in urban and suburban areas, (8) seepage from a tailings pond, and (9) seepage from precipitation on the valley floor. In addition, an unknown but relatively small amount of water rises from deep-seated strata along faults, principally in the northern part of the valley from about 8th North Street in Salt Lake City to the Davis County line and in the southern part of the valley from about 1 mile north of the Utah County line to about 106th South Street near Crescent. Also, an undetermined but probably small amount of underflow enters Jordan Valley from Davis County where the Jordan River marks the boundary between Davis and Salt Lake Counties (fig. 2).

The recharge from the various sources is summarized in table 21. The quantities in table 21 (and also those in table 22) were derived from data compiled by both calendar years and water years. This procedure is considered valid because the differences between the calendar-year data and the corresponding water-year data are generally insignificant and because of the many estimates and generalizations involved in the derivations. The recharge from source 8 and part of the recharge from sources 6 and 7 was determined by electric analog model studies discussed in a later section of the report. The amounts of the other sources were estimated by other methods as described in the following sections.

Table 21.—Summary of ground-water recharge to Jordan Valley, 1964-68

Source	Mean annual quantity, in acre-feet
Seepage from bedrock	135,000
Underflow in channel fill	1,500
Underflow at Jordan Narrows	2,500
Seepage from creek channels	20,000
Seepage from major canals	48,000
Seepage from irrigated fields	81,000
Seepage from lawns and gardens	17,000
Seepage from tailings pond	2,400
Seepage from precipitation on valley floor	60,000
Total (rounded)	367,000

Seepage from bedrock

All the precipitation that falls on the Wasatch Range and the Oquirrh and Traverse Mountains eventually leaves the mountains by evapotranspiration, runoff in surface streams, or subsurface outflow. Subsurface outflow may enter the valley fill in Jordan Valley as seepage directly from bedrock or as underflow in the channel fill at the canyon mouths.

The amount of recharge to the valley fill directly from bedrock can be estimated by two methods: (1) from the disposal of precipitation, when all the other variables are known, and (2) from a variation of the Darcy equation when the aquifer characteristics are known. Estimates for the disposal of precipitation are described in the section on water use and water loss (see p. 174-177). Although estimates of recharge by this method are based on normal (1931-60) precipitation and runoff data, they probably apply equally well to the 1964-68 period of this study because changes in the bedrock recharge probably occur slowly and averages of precipitation and runoff for 1960-68 are near normal. The well-sustained base flow of Wasatch streams, even after a period of 2 extremely dry years, is evidence of the stability of subsurface outflow.

Estimates of seepage from bedrock were made by using the Darcy equation in the following form:

$$Q = T\,I\,L \qquad (5)$$

where,

Q = discharge, in $ft^3\ day^{-1}$,
T = transmissivity, in $ft^2\ day^{-1}$,
I = hydraulic gradient (dimensionless),

and

L = length of contact between bedrock and valley fill, in feet.

Equation 5 was used to compute the amount of water moving in the valley fill away from the mountains. The line of computation is shown in figure 58.

This line, in places, is more than 1 mile from the bedrock-saturated valley fill contact, because most of the wells from which usable data for entry in equation 5 could be obtained are that distant from the contact. Although relatively few data are available for solution of equation 5, the computed results are a useful indication of the actual magnitude of the recharge laterally from the bedrock.

Near the Wasatch Range the average value of the factors in equation 5 are: T = 7,000 $ft^2\ day^{-1}$, I = 0.014, and L = 130,000 feet. Hence, Q = (7,000 $ft^2\ day^{-1}$) (0.014) (130,000 ft) = 12,700,000 $ft^3\ day^{-1}$, or 106,000 acre-feet per year.

Near the east side of the Oquirrh Mountains, south of Magna, and the north side of the western half of the Traverse Mountains, the average value of the factors in equation 5 are: T = 500 $ft^2\ day^{-1}$, I = 0.04, and L = 135,000 feet. Hence, Q = (500 $ft^2\ day^{-1}$) (0.04) (135,000 ft) = 2,700,000 $ft^3\ day^{-1}$, or 23,000 acre-feet per year.

Near the north end of the Oquirrh Mountains, west of Magna, the average values of the factors in equation 5 are: T = 27,000 $ft^2\ day^{-1}$, I = 0.002[1], and L = 30,000 ft. Hence,

Q = (27,000 $ft^2\ day^{-1}$) (0.002) (30,000 ft) = 1,620,000 $ft^3\ day^{-1}$, or 14,000 acre-feet per year.

[1] I was determined from measurements made in 1931 before large wells in the area were pumped.

The actual seepage from bedrock consists of the amounts computed above minus the amount of recharge from other sources in the area between the edge of valley fill and the line of computation used in equation 5 (fig. 58). Nearly all such recharge is in this intervening area by infiltration of precipitation. This is estimated to be 2.3 inches or about 120 acre-feet per year per square mile. (See p. 129.) Thus, on 20 square miles along the eastern side of the valley the recharge from precipitation was 2,400 acre-feet; and on 25 square miles along the western side of the valley the recharge was 3,000 acre-feet.

Summarizing estimates of seepage from bedrock at the east side of Jordan Valley: the method based on equation 5 indicates an average annual recharge of 104,000 acre-feet (106,000 acre-ft - 2,400 acre-ft). The method based on disposal of precipitation (see p. 175-177) indicates about 110,000 acre-feet per year of subsurface outflow. This includes 1,500 acre-feet of underflow in the channel fill at canyon mouths (see p. 122), thus leaving a net subsurface outflow from bedrock of about 108,000 acre-feet. Results by the two methods are in good agreement, and the mean is about 106,000 acre-feet per year.

For the west side of the valley, the method based on equation 5 indicates an average annual recharge of about 34,000 acre-feet (23,000 acre-ft + 14,000 acre-ft - 3,000 acre-ft). The method based on disposal of precipitation indicates about 20,000 acre-feet. The discrepancy in these figures probably is due largely to lack of adequate data for use in each method; but some of the difference may be caused by a difference in the locations of the ground-water and surface-water drainage divides. If the ground-water divide is west of the surface-water divide, that is, outside the surface drainage basin, more ground water moves toward Jordan Valley in the Oquirrh Mountains than is indicated by the precipitation-disposal method. Gilluly (1932, p. 91) described the Oquirrh Mountains as a block, faulted and uplifted on its west edge and tilted to the east. Such a condition would favor the eastward drainage of ground water from some unknown distance west of the topographic divide. No basis for a quantitative estimate of the amount of such drainage is available; but because of this condition, the estimate of seepage from bedrock based on equation 5 is given twice as much weight as the estimate based on the disposal of precipitation in arriving at a final value. Thus the final estimate of subsurface outflow from the Oquirrh Mountains to Jordan Valley is 29,000 acre-feet per year

$$\left(\frac{2 \times 34{,}000 + 20{,}000}{3} \right)$$

For the entire ground-water reservoir in Jordan Valley the seepage from bedrock is 106,000 acre-feet plus 29,000 acre-feet or 135,000 acre-feet per year.

Underflow in channel fill in mountain canyons

Water enters Jordan Valley as underflow through channel fill in canyons of the Wasatch Range and Oquirrh Mountains. The fill in the canyons consists principally of stream-laid deposits of silt, sand, and gravel; however, in some canyons it may also contain glacial deposits, mudflows, or lake deposits. Water in the fill is unconfined and is moving toward the ground-water reservoir in Jordan Valley.

The depth of channel fill near the mouth of each of seven major canyons in the Wasatch Range was determined by a seismic-refraction method (Mattick, 1968). Using these data Mower (1969a) calculated the underflow in each canyon by means of Darcy's law. Results of these computations are summarized below.

Canyon	Hydraulic conductivity (ft day^{-1})	Hydraulic gradient (ft ft^{-1})	Saturated cross section (ft^2)	Underflow (acre-ft yr^{-1})
Little Cottonwood	40	0.028	350,000	3,300[1]
Big Cottonwood	40	.043	400	6
Mill	17	.063	7,500	67
Parleys	17	.034	1,475	7
Emigration	17	.026	2,700	10
Red Butte	17	.052	385	3
City	17	.039	725	4
Total (rounded)				3,400[1]

[1]About 2,000 acre-feet of this underflow is discharged by wells or springs through Beaver Pond Springs pipeline and is included in the calculated runoff of Little Cottonwood Creek.

Underflow in the other canyons of the Wasatch Range and Oquirrh Mountains has not been measured. On the basis of few available data, principally records of streamflow and small saturated sections, the total underflow from other canyons is probably in the order of 100 acre-feet per year. Hence, the total underflow in all canyons is about 3,500 acre-feet per year and the net amount recharging the ground-water reservoir in Jordan Valley is about 1,500 acre-feet per year.

Underflow from Utah Valley through the Jordan Narrows

Ground water enters the southern part of Jordan Valley as underflow from Utah Valley through a gap in the Traverse Mountains called the Jordan Narrows (fig. 2). The Jordan Narrows was formed by a series of faults (Pitcher, 1957) and downcutting by the Jordan River; but more recently, the gap has been partly filled with river and lake deposits of clay, silt, sand, and gravel. The depth and nature of the deposits were determined by examination of well logs and several geophysical (seismic-refraction, gravity, and electrical resistivity) surveys (Mower, 1970).

The unconsolidated deposits lie on semiconsolidated sedimentary rocks of the Salt Lake Formation of Tertiary age in the western part of the narrows and possibly on an alternating sequence of limestones and quartzite of the Oquirrh Formation of Pennsylvanian age in the eastern part. Although the consolidated and semiconsolidated rocks are relatively impermeable, some of the unconsolidated deposits are extremely permeable and where saturated readily transmit ground water.

By means of Darcy's law, Mower (1970) estimated the annual underflow through the Jordan Narrows to be between 2,000 and 3,000 acre-feet with a probable average of 2,500 acre-feet.

Seepage from creek channels

The losses by seepage from six of the principal streams that cross the highlands at the east edge of Jordan Valley were described in the discussion of Wasatch streams and are listed in table 5. Nearly all this seepage loss reaches the ground-water reservoir and, hence, is a significant element of recharge.

The total loss from the six streams—14,700 acre-feet per year—also provides a basis for estimating similar losses from ungaged streams. Flow in the ungaged streams is more nearly comparable to the low and medium flows in gaged streams than to the high flows, and the computed loss for low flows is about 15 percent of the corresponding runoff. Using this percentage, the loss from ungaged streams from the Wasatch Range and the eastern half of the Traverse Mountains is estimated to be about 3,000 acre-feet (15 percent of 20,000 acre-ft, table 18). Hence, the total recharge by seepage from streams in the eastern part of Jordan Valley is about 17,700 acre-feet per year.

Similarly, the recharge by seepage from streams in the highlands of the western part of Jordan Valley is estimated as 15 percent of 7,000 acre-feet (table 18) or about 1,000 acre-feet per year. The lengths of channels in which losses can occur are greater on the west side of the valley than on the east side, but the effects of greater length probably are nullified by lower permeability of the channel fill and lower flows. Thus the estimate of seepage from creek channels for the entire valley is nearly 20,000 acre-feet per year.

Seepage from major canals

Unlined canals and ditches in Jordan Valley lose water where they traverse unsaturated valley fill. In recent years, urbanization has reduced the number of canals and ditches east of the Jordan River, and some sections of others on both sides of the valley have been lined or replaced with pipelines to reduce seepage.

Proof that canal losses infiltrate the ground-water reservoir is shown in figure 62. Well (C-4-1) 23dbd-1 is about 30 feet from the right bank of the East Jordan Canal, which traverses valley fill where the ground-water level is about 30 feet below the canal bed. A recording gage on the well shows that water levels in the well begin to rise or decline within hours after water is turned into or out of the canal. This water-level record, however, is influenced by seepage from other sources, and hence, cannot be used to determine the amount of seepage from the canal.

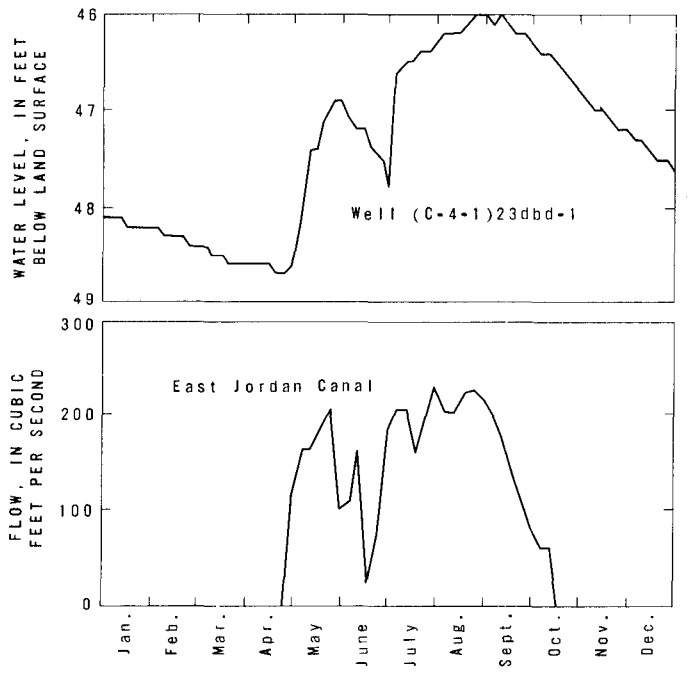


Figure 62.—Water level in well (C-4-1)23dbd-1 and flow in East Jordan Canal, 1967.

Seepage from canals and ditches occurs chiefly under the combined influence of the forces of gravity and the soil moisture-tension gradient. For a short time after water is first turned into a dry canal the force of gravity is exceeded by the soil moisture-tension gradient; however, as the canal lining and underlying soil approach saturation the moisture-tension gradient becomes small. The canal may lose a large amount of water at first under the forces of gravity and moisture-tension gradients, but the loss due to the latter action soon diminishes and the effect of gravity predominates. The moisture-tension gradient may act in any direction and it may cause the soil water to rise upward to the root zone of plants along the canal or to the land surface. Water then is lost through the transpiration of plants or through evaporation from the soil. However, such losses are generally small in comparison with seepage due to gravity.

The effect of gravity depends in part on the relative water levels in the canal and in the ground beneath and adjacent to the canal. When the ground-water level is above the water level in the canal, as it sometimes is in parts of Jordan Valley, water seeps from the ground into the canal. When the ground-water level is moderately lower than the water level in the canal and is hydraulically connected with the canal, the seepage from the canal is proportional to the difference in levels. When the ground-water level is far below the canal, the seepage is no longer proportional to the difference in levels because the resistance to flow through the soil limits the seepage rate.

Many factors influence seepage rates through influence on the forces inducing seepage or on resistance to flow. Among these are (1) the physical nature of the canal bed and underlying soil, (2) the wetted perimeter of the canal, (3) temperature of the water and soil, (4) dissolved-solids content of the water and soil, (5) amount of entrapped air in the soil, (6) barometric pressure, (7) concentration and particle size of sediment in the canal water, (8) certain biological factors, and (9) length of time water is in the canal. It is difficult to segregate the effects of individual factors because they all act simultaneously and some tend to counteract each other. A detailed investigation of the canal losses in the valley was not feasible because of the many variables involved and the complexity of their relations. The number of canals and ditches is large, and the pattern of flow changes frequently. A large number of recording gages, sampling stations, and permeameters would be required to make a detailed inventory of canal loss.

Discharge measurements in August 1967 on the Provo Reservoir Canal between the siphon at Camp Williams and the southern edge of sec. 8, T. 3 S., R. 1 W., a distance of 11 canal miles, showed that the canal lost about 1 cfs per mile. The discharge of the canal was measured with a current meter and diversions were measured with weirs or a current meter. Measurements were made at a time when changes of diversion in the test reach were at a minimum. Little water-loving vegetation grows in this reach of the canal, therefore, essentially all the water lost reached the ground-water reservoir.

Losses from other major canals in the valley probably occur at roughly the same rate as the measured losses from the Provo Reservoir Canal. Losses from smaller canals and ditches which distribute water to farms are much smaller because of the shorter duration and lower rates of flow in them and their short length. These losses were not estimated separately but were included with estimates of losses from irrigated fields.

The average annual volume of losses from major canals during the water years 1964-68 that reached the ground-water reservoir and the information on which the estimates are based are summarized in the following tabulation.

[The canals listed inlcude all major canals and branches or extensions but not small canals or laterals of the distribution systems. Distances include unlined portions where canals are above the water table. Durations are for days when the discharge exceeded 25 percent of the maximum. Losses from all major canals, where they are several feet above the water table, were based on the average channel loss of 1 cfs per mile determined during periods of appreciable flow for the Provo Reservoir Canal.]

Canal	Distance, in miles	Mean annual duration of flow, in days	Estimated mean annual recharge, in acre-feet
Provo Reservoir	15	140[1]	4,200
Utah Lake Distributing Co.	18	160	5,700
East Jordan	18	160	5,800
Utah and Salt Lake	27	195	7,500
South Jordan	18	160	5,700
Jordan and Salt Lake City	23	125	5,700
Draper	14	130	3,600
North Jordan	11	160[1]	3,500
Lower, Upper, and Big Ditches (combined)[2]	13	160[1]	1,300
Brighton	15	160[1]	4,800
Total (rounded)	172	-	48,000

[1]Partly estimated.

[2]Diversions from Big Cottonwood Creek.

In some reaches of the canals there undoubtedly are large departures from the measured seepage rate of 1 cfs per mile, chiefly because of differences in soils traversed. Consequently, the losses computed for individual canals are considered approximate; they were computed only as a means of estimating the total recharge from canal seepage.

Seepage from irrigated fields

The seepage from irrigated fields depends largely on the amount of water applied. The records of diversions from streams and pumpage from wells for 1964-68 indicate a mean annual withdrawal of 317,000 acre-feet for irrigation in Jordan Valley (table 30). The records, however, exclude an unknown, but probably small, amount of pumpage from the lower Jordan River. Subtracting the 48,000 acre-feet of seepage from major canals (table 21) leaves about 270,000 acre-feet that was available for delivery to irrigated tracts. An unknown part of this amount, however, returned to the Jordan River without being delivered to an irrigated tract. The net effect of pumpage from the lower Jordan River and the unused return flow was assumed to be negligible in deriving the following estimate of seepage from irrigated fields.

Seepage losses occurred in the canals and ditches of the distribution system that are not discussed in the preceding section. These losses are included with the seepage from the irrigated fields, which necessarily results from the application of sufficient water to insure adequate restoration of soil moisture in all parts of the fields. Also, some water probably ran off the fields when excess water was applied. Thus, part of the water delivered to irrigated tracts is consumed by evapotranspiration or incorporation in vegetal matter, and most of the remainder infiltrates to the ground-water reservoir.

Seepage from fields and associated ditches is influenced by the same factors that influence seepage from canals and also by the irrigation practices employed. No detailed studies of the disposal of water delivered to irrigated tracts in Salt Lake County have been made. However, the U.S. Bureau of Reclamation (1967, 1968, and 1969) made such studies for several farms in Utah County and found losses of 20 percent in 1966, 36 percent in 1967, and 49 percent in 1968, or an average for the 3 years of 35 percent. The percentage of irrigation losses was found to be lowest in years when irrigation water was in short supply and highest in years when supplies were abundant. The measured losses include a small amount of runoff at the ends of fields, thus the average loss going to recharge is about 30 percent of the farm deliveries. Soils on the test farms range from clay to sandy loam and are similar in type to soils in Jordan Valley.

Because of the similarity of soil types, comparable growing seasons and irrigation practices in Utah Valley and Jordan Valley, irrigation losses in Jordan Valley probably are similar to losses in Utah Valley and are estimated to average 30 percent of the farm delivery. This figure is substantiated by Willardson and Bishop (1967) in an analysis of surface irrigation application efficiency in which they concluded "that a 60 percent water-application efficiency (40 percent loss) is probably attainable under most conditions." Although they suggest that the average irrigation efficiency in an irrigated area is less than 60 percent, curves developed by them show that for field conditions generally existing in Jordan Valley the average irrigation efficiency probably is between 60 and 80 percent (loss between 40 and 20 percent). Recharge from irrigation losses in Jordan Valley, therefore, is estimated to be about 30 percent of the average annual farm delivery of 270,000 acre-feet, or 81,000 acre-feet per year.

Seepage from lawns and gardens

Irrigation practices for lawns and gardens generally differ markedly from those for commercial crops. Lawns and gardens usually receive less water per unit area at each irrigation but they are irrigated more frequently. For lack of better information, deep seepage from lawns and gardens is estimated to be the same as from the irrigated fields (30 percent of the water applied) as described in the preceding section.

To estimate the total quantity applied, the use of municipal water for all purposes except lawn and garden watering was assumed to be represented by the average winter deliveries. In the area served by the Salt Lake City Water Department, the average monthly delivery in winter is about 4.8 percent of the total annual delivery. Hence, 57.6 percent (12 x 4.8 percent) of the total delivery was used for nonirrigation purposes, and the remainder (42.4 percent) was used for lawns and gardens. Assuming that 40 percent of all water for municipal, domestic, and stock uses (141,000 acre-ft, table 30) was applied to lawns and gardens during 1964-68, the average annual application was about 56,000 acre-feet. The corresponding loss by deep seepage was about 30 percent of this, or about 17,000 acre-feet.

Although urbanization has been encroaching onto irrigated lands for many years, there probably has been little change in the amount of recharge in these areas because seepage from lawn and garden watering has replaced seepage from irrigated lands. Urbanization during recent

years has resulted in an increase of recharge, however, in some new residential areas. Part of the increase may have been caused by watering lawns and gardens and part by absorption of the concentrated runoff from roofs and streets. These areas are on the highly permeable soils of the foothills and alluvial fans around the northeastern and eastern sides of the valley, and they were not formerly irrigated.

Seepage from tailings pond

The Kennecott Copper Corp. tailings pond, the surface of which is 80-100 feet above the surrounding land surface, is a source of ground-water recharge because it contains many thousands of acre-feet of water used to carry the tailings from the mills to the tailings pond plus water used for frequent sprinkling to control dust. Operation of an analog model, described in the section on analog model of the ground-water reservoir (see p. 156-158) indicated an apparent recharge from the pond of 4,700 acre-feet per year. The weight of the tailings themselves tends to compact the materials in the underlying aquifers, however, and the effect of such compaction cannot be distinguished in the model from the effect of actual recharge. For this estimate of recharge, approximately half the apparent amount or 2,400 acre-feet per year was assumed to be actual recharge.

Seepage from precipitation on the valley floor

Recharge from precipitation on the valley floor undoubtedly varies markedly from year to year and from place to place. However, the mean annual amount for 1964-68 can be estimated from an accounting of precipitation, local surface runoff, evapotranspiration, and other information included in this report. The accounting is shown below and the items are explained in the text that follows.

[Mean annual quantities, in acre-feet, 1964-68]

Precipitation on the valley floor (derived from fig. 5)	464,000
Local surface runoff	10,000
Balance available for evapotranspiration and ground-water recharge	454,000
Total evapotranspiration (table 32)	735,000
Evapotranspiration of irrigation water	176,000
Evapotranspiration of municipal and domestic water	39,000
Evaporation of industrial water	27,000
Evapotranspiration of ground water (table 33)	60,000
Evapotranspiration of surface water in waterfowl-management areas	39,000
Evapotranspiration of precipitation (total minus sum of components listed above)	394,000
Ground-water recharge from precipitation on the valley floor (454,000 - 394,000)	60,000

An extremely small part of the precipitation on the valley floor ran off, leaving most of it available for evapotranspiration and ground-water recharge.

The amount of surface runoff from part of the valley can be approximated by a comparison of streamflow data as follows. The discharge of Jordan River below Surplus Canal, at 2100 South, was about 89,000 acre-feet (table 12) and this was augmented by about 16,000 acre-feet from Parleys, Emigration, Red Butte, and City Creeks (runoff at canyon mouths minus diversions and channel losses—tables 18, 30, and 5, respectively). The discharge at Cudahy Lane, north of Salt Lake City, exceeded this augmented discharge by about 6,000 acre-feet, which is an approximation of the runoff between 2100 South and Cudahy Lane, chiefly from impervious areas in Salt Lake City and environs.

The runoff from other areas in the valley probably did not exceed 4,000 acre-feet. The impervious areas outside of Salt Lake City are much less extensive than those in the city and are interspersed among pervious areas. Furthermore, during most of the period 1964-68, much of the runoff from the impervious areas was not conducted in drains to stream channels but was absorbed in pervious areas. A striking example of this was afforded by an intense storm and flash flood in May 1965. Heavy local runoff in the vicinity of 4500 South, at the east edge of the valley, flooded lawns and basements and eroded streets. Discharge records of Big Cottonwood Creek, however, showed that none of this runoff reached the creek. Storm drains constructed about 1968 have changed this situation somewhat, so that future runoff from suburban areas probably will be greater.

The local surface runoff from the entire valley thus is estimated to be about 10,000 acre-feet.

The total quantity of water consumed by evapotranspiration in Jordan Valley is estimated in the section on water use and water loss. The total quantity included water from several sources, and the amounts consumed were approximated as follows.

The discussion of seepage from irrigated fields indicates that 30 percent of the delivered water recharged the ground-water reservoir. Assuming that 5 percent ran off in surface channels, the remaining 65 percent of 270,000 acre-feet, or 176,000 acre-feet, was consumed.

The discussion of seepage from lawns and gardens provides similar indications of the disposal of municipal and domestic water. Assuming no runoff, the consumption was about 70 percent of the water applied to lawns and gardens (56,000 acre-ft), or 39,000 acre-feet.

The consumption of industrial water varies from negligible quantities to very large percentages of the withdrawals when recycling is employed. Table 30 indicates a total withdrawal of 122,000 acre-feet for industrial use, of which about 15,000 acre-feet was returned to the Jordan River without appreciable depletion. The largest amounts of industrial water are used near Magna and Garfield and the discharge is through drains to Great Salt Lake. The total discharge of Lee Creek and Kennecott and Garfield Drains during the 1964-68 water years was about 80,000 acre-feet, of which 70,000-75,000 acre-feet probably was industrial drainage. Thus 75-80 percent of the total water withdrawn for industrial use was discharged and the balance consumed. Thus estimated consumption is 22 percent of 122,000 acre-feet or about 27,000 acre-feet.

The evapotranspiration of ground water is discussed in the section on water use and water loss. (See p. 179-187.)

The evapotranspiration of surface water in waterfowl-management areas is 49,000 acre-feet. (See p. 188.) Of this, about 10,000 acre-feet is assumed to be supplied by small streams in Davis County.

The evapotranspiration of precipitation is computed from the total and the other components of the total. The ground-water recharge is the difference between the balance available for evapotranspiration and recharge and the evapotranspiration. This quantity (60,000 acre-ft) represents an average depth on the 320,000 acre-budget area of 2.3 inches.

Movement of ground water

Ground water moves in the general direction of the slope of the water table or potentiometric surface. Irregularities in the amount and direction of slope are caused by unequal additions or withdrawals of water and by differences in thickness or hydraulic conductivity of aquifers. In shallow unconfined aquifers, the water table generally is a subdued replica of the land surface, and the direction of ground-water movement is approximately the same as the direction of the slope of the land surface. In confined aquifers, however, the potentiometric surface bears less resemblance to the land surface and is above it in places, thus the direction of ground-water movement may not be in the direction of the slope of the land surface. The general direction of ground-water movement in the principal aquifer in Jordan Valley is shown in figure 58; more detailed information on the direction of flow in February 1969 is available by analysis of plate 1.

Ground water moves from deeper to shallower aquifers and from deeper to shallower zones within each aquifer throughout most of the valley. The recharge areas for the deeper aquifers are at higher altitudes than those for the shallower aquifers; thus, the resulting pressure on the water in the deep aquifer causes upward leakage through the confining beds into shallower aquifers and zones. As the water moves, head is lost due to friction between the water and aquifer materials. The hydraulic gradient may be reversed locally by heavy pumping, causing the head in the principal aquifer to decline below the head in a shallower aquifer. At such times, water may move from shallower to deeper aquifers.

In the principal aquifer in Jordan Valley, the hydraulic head increases 1 foot with each increase of 50-150 feet in depth. In the overlying confining bed, the head increases 1 foot with each increase of 8 feet in depth. In the principal aquifer the smaller head-depth ratios occur where the aquifer contains the largest proportion of coarse materials and few lenses of fine-grained materials, and the larger head-depth ratios occur where the aquifer contains the smallest proportion of coarse materials.

Water-level measurements used in the definition of the contours on plate 1 were made in observation wells finished at various depths in the principal aquifer, although most of the wells are finished in the lower part. It was necessary, therefore, to adjust a few water-level measurements to compensate for differences in well depth, particularly in the area of flowing wells and where the gradient of the potentiometric surface was relatively small. Where necessary, water-level measurements were adjusted to reflect the approximate maximum head for the locality of the observation well.

The changes in the potentiometric surface between 1932 and 1969 as shown in figure 63 did not affect the overall pattern of ground-water movement in the valley. Declines have occurred in a few small areas of large withdrawals, generally east of Murray and Sandy City; and rises have occurred in areas where recharge has increased because of seepage from canals and irrigated lands, particularly in the area between Riverton and Herriman.

The rate of movement of ground water in Jordan Valley is extremely slow in comparison with the flow of surface streams. The velocity of ground water (v) is related to the hydraulic conductivity (K) and porosity (θ) of the aquifer materials and the hydraulic gradient (I) in accordance with a form of Darcy's law,

$$v = \frac{KI}{\theta} \qquad (6)$$

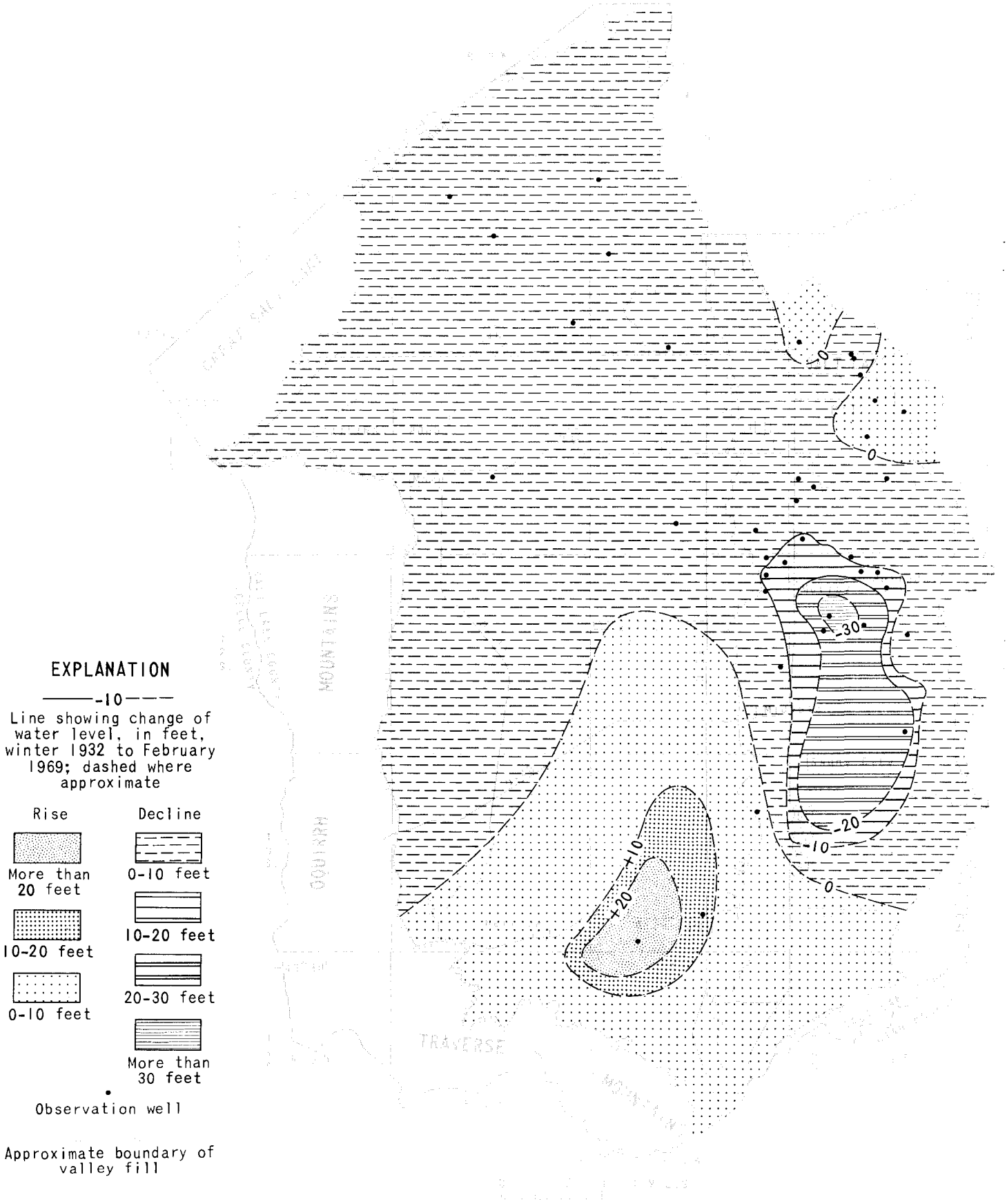


Figure 63.—Change in water level for the principal aquifer from winter 1932 to February 1969.

An example is afforded by substituting in equation 6 the data applicable to a line from the center of the irrigated area west of Riverton to the center of Riverton, a distance of about 2 miles. K is 120 ft day^{-1} (obtained from field data on transmissivity, 42,000 ft^2 day^{-1}, and thickness of the aquifer, 350 ft), I is 0.0066 (from change in potentiometric surface, 70 ft, and distance between points, 10,560 ft), and θ is 0.30. Hence,

$$v = \frac{(120 \text{ ft day}^{-1})\ (0.0066)}{0.30} = 2.6 \text{ ft day}^{-1}$$

This velocity of 2.6 feet per day or about 900 feet per year may be typical of velocities in Jordan Valley, but large variations are to be expected because of variations in hydraulic gradient and hydraulic conductivity. The above example represents average conditions during February 1969 when no large withdrawals were being made from wells.

Areal variations of the hydraulic gradient are indicated by the map of the potentiometric surface (pl. 1). The range of average values (not including local irregularities and effects of ground-water withdrawal) is from about 0.00019 (1 ft per mi) in the northern part of the valley to about 0.057 (300 ft per mi) near the mountains in the southwestern part of the valley.

The hydraulic conductivity of the principal aquifer is highest in the alluvial fans and deltas near the Wasatch Range and lowest in the lake deposits in the northern and central parts of the valley. Thus, both hydraulic gradient and hydraulic conductivity tend to produce highest velocities near the mountains.

However, the effect of velocity on the amounts of water moving through different parts of the aquifer is modified by the effect of aquifer thickness. The aquifer is thinnest near the mountains where velocities are highest and is thickest where velocities are low. Hence, there is less areal variation of the amount of water moving through the principal aquifer than the variations of controlling factors considered singly might suggest.

Ground-water storage

The amount of ground water in storage in the unconsolidated deposits in Jordan Valley was estimated from the volume of saturated deposits and their water content. To determine the volume of saturated deposits, a map of the potentiometric surface (pl. 1) and a map of the thickness of unconsolidated valley fill (Arnow and others, 1970) were used to derive a map of the thickness of saturated valley fill (fig. 64). The volume of saturated unconsolidated deposits in Jordan Valley is 150,000,000 acre-feet, exclusive of the underlying Tertiary deposits. For these computations, the Tertiary deposits were considered as devoid of water. Actually the amount of water in them probably is a very small percentage of the amount in the unconsolidated deposits, and the amount that could be pumped from wells in the Tertiary deposits is an even smaller percentage.

The water content of the saturated materials was estimated by examining well logs and assigning an estimated water content to various lithologic types, as follows:

Lithlogic material as described by drillers	Estimated water content (percent)
Clay; clay and silt	50
Clay and sand; sand and clay; sandy clay	40
Sand	30
Gravel	25
Sand and gravel	20
Hardpan; conglomerate; all others cemented materials	10

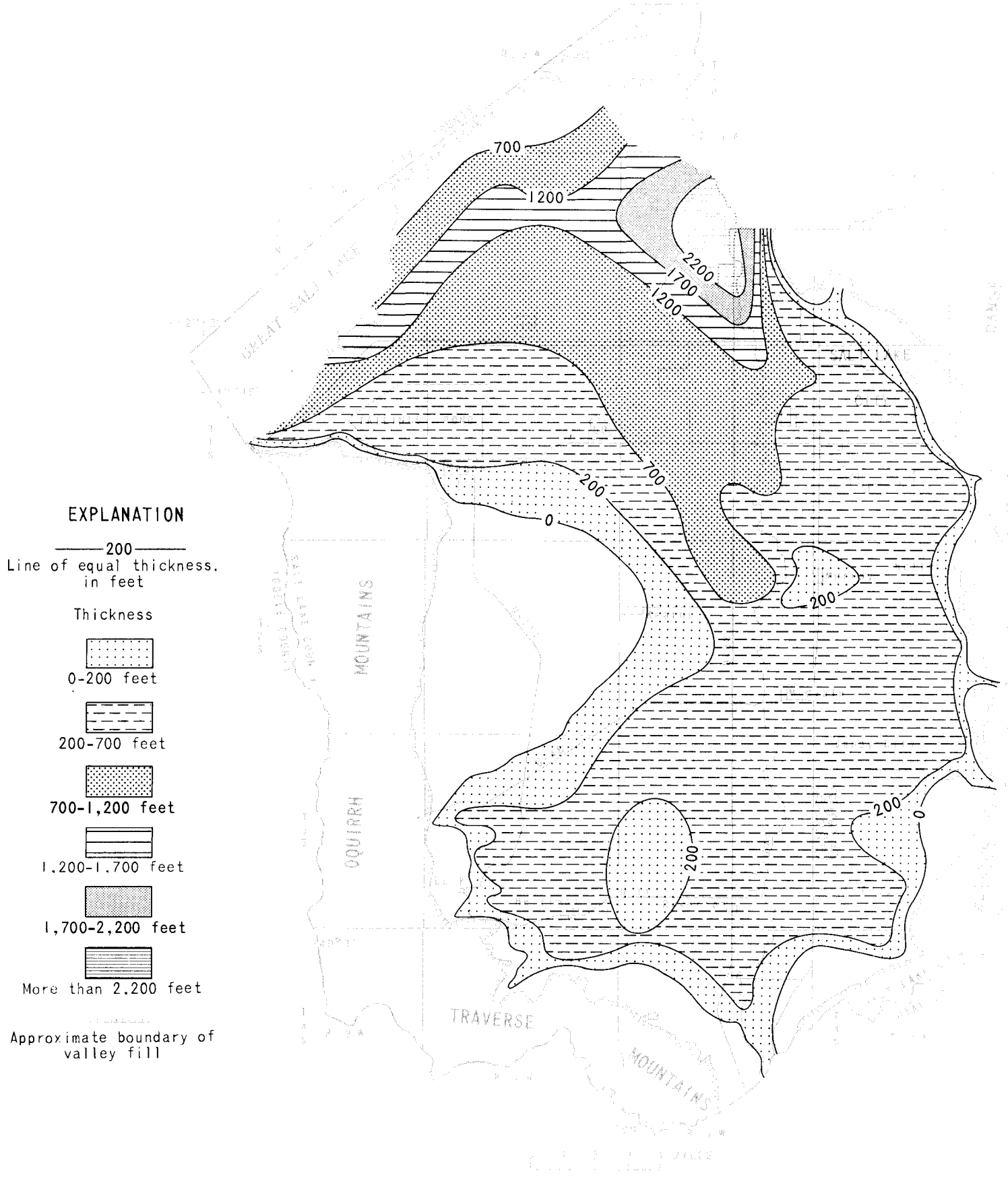


Figure 64.—Estimated thickness of saturated deposits of Quaternary age in Jordan Valley.

One lithologic log was examined for each section of land where logs were available, and usually the log of the deepest well in the section was used. On the basis of drillers' logs and the above tabulation it is estimated that the saturated materials in the valley contain about 40 percent water by volume. The amount of ground water in storage, therefore, is 0.40 times 150,000,000 acre-feet of saturated material, or 60,000,00 acre-feet.

The amount of ground water in storage is much greater than the amount that is readily available for withdrawal by means commonly in use. One measure of the amount of water so available is the quantity of water that can be removed from storage in a ground-water reservoir by lowering water levels a specified distance. This quantity is determined by the volume and the storage coefficient of the reservoir.

An average change in water level (potentiometric surface) in the principal aquifer of 1 foot over an area of 1 square mile will result in a change in ground-water storage ranging from an average of about 100 acre-feet in unconfined parts of the principal aquifer to an average of about 0.1 acre-foot in confined parts, assuming average storage coefficients as shown in figure 60. An average change in water level of 1 foot over the entire valley represents a change in storage of 13,000 acre-feet.

This relation is valid when water levels are approximately those of February 1969 (pl. 1), but it will change as water levels change. When water levels rise higher than they were in February 1969, a larger proportion of the aquifer will be confined and the increase in storage needed to cause a rise of 1 foot will be smaller. Conversely, when water levels are lower than they were in February 1969, the decrease in storage needed to cause a decline of 1 foot will be larger. Therefore, when estimating the amount of change in storage in areas where the aquifer may be either confined or unconfined depending upon the water level, due consideration must be given to the difference between the water levels being studied and those of February 1969. Figure 65 may be used for this purpose.

The upper curve in figure 65 shows that in February 1969, 34 percent of the area of the principal aquifer in Jordan Valley was unconfined and 66 percent was confined. If water levels decline uniformly over the valley, an increasingly larger part of the aquifer will become unconfined until the water levels reach a depth of 166 feet below their 1969 counterparts, at which point the entire reservoir would be unconfined. The lower curve shows the amount of change in storage per foot of change in water level at various levels below those of February 1969. The storage change per foot increases as water levels decline, from about 13,000 acre-feet per foot at 1969 levels to about 42,000 acre-feet per foot when water levels are 166 feet below their 1969 counterparts.

As water levels decline, the areal extent of the principal aquifer decreases; and when water levels are 166 feet below their 1969 counterparts, the areal extent is 12 percent less than it was in 1969. The lower curve in figure 65 has been adjusted to correct for the diminished area.

The quantity of water in storage increased in 84 percent of the principal aquifer from February 1964 to February 1969 and decreased in the remainder (fig. 73), with a net increase of 15,000 acre-feet in 5 years or 3,000 acre-feet per year. Even during 1932-68, when withdrawals from wells nearly tripled, storage increased in 28 percent of the valley (fig. 63), with a net increase of about 8,000 acre-feet for the entire valley.

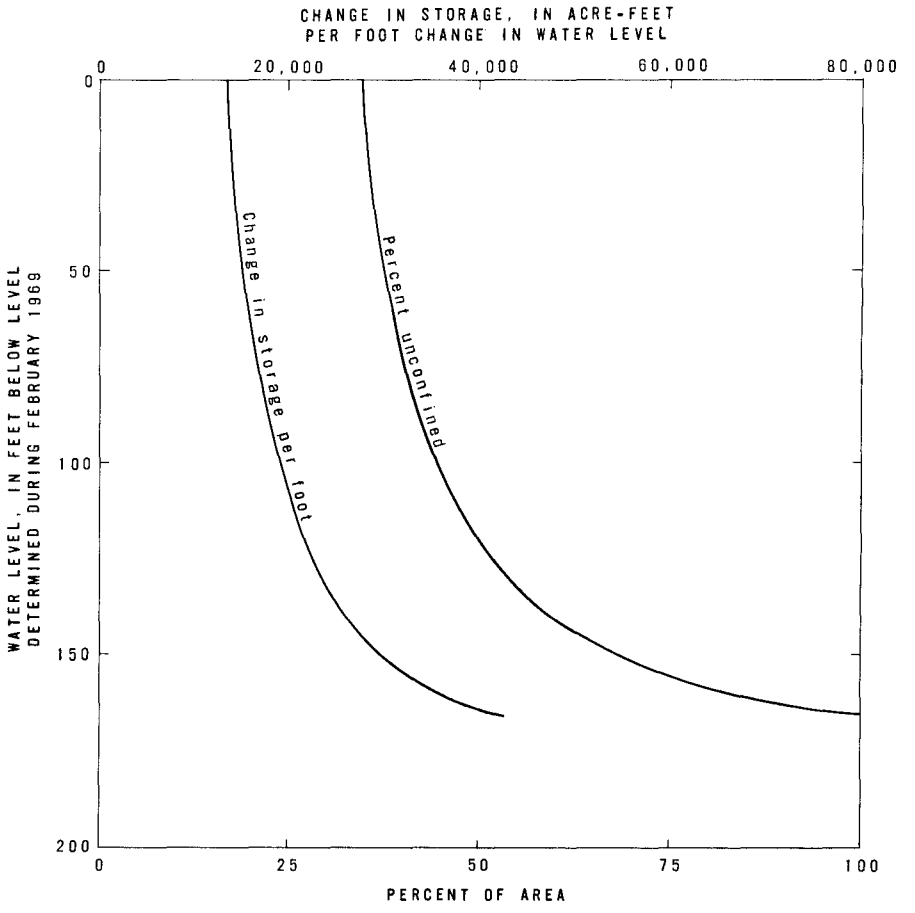


Figure 65.—Percent of area of principal aquifer containing unconfined water and the relation between water level and storage change per foot of change in water level.

Ground-water discharge

Ground water in Jordan Valley is discharged naturally by (1) seeps and springs into drainageways, by (2) evapotranspiration in the lower-lying parts of the valley, and by (3) underflow from the valley to Great Salt Lake. Ground water is discharged artificially by (1) pumped wells throughout most of the valley, (2) flowing wells in the northern third of the valley and in the Jordan River flood plain, and (3) seepage into open drainage ditches and tile drains in some of the low-lying farming and urban areas.

Before artificial discharge began, the long-term average annual discharge equaled the average annual recharge. The water discharged artificially may be derived from (1) an increase of recharge to the ground-water reservoir, (2) a decrease of the natural discharge, (3) a decrease of

the amount of ground water in storage, or (4) various combinations of these. The ground-water discharge by various modes is summarized in table 22, and details of each principal mode of ground water discharge are discussed below.

Table 22.—Summary of ground-water discharge, 1964-68

Mode of discharge	Mean annual quantity, in acre-feet
Evapotranspiration (table 33)	60,000
Seeps, spring, and drains	
Inflow to Jordan River	170,000
Inflow to drains near Garfield and Magna	5,000
Spring flow diverted for use[1]	19,000
Other[2]	2,000
Subsurface outflow to Great Salt Lake	4,000
Wells	107,000
Total	367,000

[1]Excluding flow of springs at or above canyon mouths, which is included as part of the calculated runoff from mountain basins.

[2]Mostly discharge from thermal springs that evaporates at or near the point of discharge.

Evapotranspiration

The average annual loss of ground water by evapotranspiration is about 60,000 acre-feet. (See p. 179-187.) Most of this loss is from the shallow unconfined aquifer, but much of the evapotranspiration from the shallow aquifer is replaced by water moving upward from the confined aquifer.

The potential evapotranspiration generally exceeds the total recharge to the shallow aquifer (from upward movement and all other sources), and the water table remains below the land surface, although the potentiometric surface of the confined aquifer is above the land surface in most of the area where ground water is lost by evapotranspiration. However, in some areas where surface irregularities (such as stream channels) exist, the water level intersects the surface and ground water is discharged as described in the following section.

Seeps, springs, and drains

The water discharged through seeps, springs, and drains is from the unconfined aquifers; but where the shallow unconfined aquifer is underlain by the confined aquifer, the latter is the ultimate source of much of the discharge. Most of the water so discharged reaches the Jordan River and is a major component of the gain in streamflow. Some of it discharges into drains in the Garfield-Magna area, and some (chiefly spring flow) is diverted for use.

In the part of Jordan Valley extending from the Jordan Narrows to 2100 South and including the Jordan River and the lower reaches of the principal tributaries, the measured outflow during the water years 1966-68 exceeded the measured inflow by 236,000 acre-feet per year (table 11). This gross gain includes an unknown amount of local runoff, surface return flow from diversions, and subsurface return flow from irrigation that reaches the river within a short time after application. The relatively stable portion (unaffected by seasonal changes) of the gross gain—147,000 acre-feet (table 11)—probably is chiefly from the confined aquifer. About one-fourth of the remaining 89,000 acre-feet, or 22,000 acre-feet, is estimated to be ground-water seepage from the shallow unconfined aquifer which is not supplied by the confined aquifer.

The streamflow records indicate no appreciable gain from ground water below (north of) 2100 South, but the potentiometric contours on plate 1 indicate a ground-water gradient toward the river from the west and east, and suggest some ground-water discharge to the river. If the gain below 2100 South is assumed to be 1,000 acre-feet, the mean annual ground-water discharge to the river is about 170,000 acre-feet. This discharge to the river includes the water from sump pumps and drains in urban and agricultural areas that are operated to prevent excessively high ground-water levels in the shallow aquifer.

Ground-water discharge to drains in the Garfield-Magna area was estimated to be about 5,000 acre-feet per year on the basis of measurements or records of low flows during water years 1964-68, when flow from industrial and other sources was known to be small.

The discharge of several large springs in the valley, whose chief source is the principal aquifer, is diverted for industrial purposes and public supply. Adamson Spring, (C-1-2)19bcc-S1, about half a mile northwest of Magna is reported to discharge 6,000 gpm (gallons per minute) (9,700 acre-ft per yr) (Royal Anderson, oral commun., 1963). Brinton, (D-2-1)9aad-S1, Casto, (D-2-1)2cdc-S1, Dry Creek, (D-2-1)11baa-S1, Spring Creek, (D-2-1)2cdb-S1, and McGhee Springs, (D-2-1)25bbd-S1 in the east-central part of the valley discharge an estimated 9,000 acre-feet per year, all of which is diverted into pipelines at or near their openings. The flow of Beaver Pond Springs, (D-3-1)12bcc-S1 (nearly 2,000 acre-ft per yr before the first public-supply wells were installed in 1941 less than 1 mi to the east of them) is included as part of the runoff from Little Cottonwood Creek basin and is not included with the discharge from springs. Thus, the total discharge of springs (excluding Beaver Pond Spring) that is diverted for use is about 19,000 acre-feet per year.

Several thermal springs—Becks, (B-1-1)14dcb-S1, Crystal, (C-4-1)11ad-S1, and Wasatch Springs, (B-1-1)25dbb-S1—were described by Taylor and Leggette (1949, p. 35-41) and they estimated that the total discharge was about 2,000 acre-feet per year. This water is essentially unused.

Subsurface outflow to Great Salt Lake

Ground water in Jordan Valley moves toward Great Salt Lake. As most of the discharge to the lake is by upward leakage resulting from artesian pressure, the amount varies with the area inundated by the lake and the lake stage. For this report, the discharge to the lake is considered to be that which would occur if the lake were at 4,205 feet above sea level, the approximate lower limit of perennial vegetation. The altitude of the shoreline selected makes no difference in the total estimate of ground-water discharge because water is assumed to discharge to the lake on one side of the line and by evapotranspiration on the other side.

Part of the subsurface outflow to Great Salt Lake was calculated by Mower (1968, p. D71-D74). The total quantity crossing the line of calculation (*A-A′* on pl. 1) has changed little, if any, since 1931 because the hydraulic gradient has changed very little since that time and is 8,000 acre-feet per year. About 1,000 acre-feet of this is intercepted by wells discharging near Garfield, west of the line of calculation, leaving a net flow of 7,000 acre-feet toward the lake. About 3,500 acre-feet of this is consumed by evapotranspiration between the line of calculation

and the lake, and about 200 acre-feet is discharged by flowing wells. Thus, the net discharge across line *A-A'* to the lake is about 3,300 acre-feet per year.

Additional subsurface outflow to the lake crosses a narrow strip of the valley north of the Oquirrh Mountains (*B-B'* on pl. 1). The amount of underflow across line *B-B'* could not be measured directly, but water-level data and Darcy's law provide a basis for estimating the amount. The water-level data for 1931 indicate that the discharge across line *B-B'* may have been as much as 7,000 acre-feet per year. The hydraulic gradient toward the lake at the west end of line *B-B'* has been virtually unaffected by pumping since 1931, but the gradient across the east half of the line has been reduced to approximately zero. Assuming that the discharge across the line in 1931 was uniformly distributed along the line, and that reductions of discharge since then are proportional to the decreases of gradient just described, the mean annual discharge across line *B-B'* during 1964-68 was about 1,750 acre-feet (one-fourth of 7,000 acre-ft). About 1,000 acre-feet of this amount was consumed by evapotranspiration between the line and the lakeshore, leaving about 750 acre-feet of underflow to the lake.

By combining the discharge of 3,300 acre-feet across line *A-A'* with the 750 acre-feet across line *B-B'*, the total underflow to Great Salt Lake is calculated as about 4,000 acre-feet.

Wells

The first wells in Jordan Valley probably were dug where ground water was within a few feet of the land surface, and they provided a more reliable sanitary supply than any nearby stream. No records concerning most of these early wells have been found, and few of the 73 dug wells of record (table 24) existed prior to 1870. The oldest dug well for which a record could be found was completed in 1854, and it was used until about 1955, when it was abandoned to make way for a housing development. The oldest flowing well in use, well (C-1-1)26cdb-2, was jetted or driven in 1860.

Many dug wells were abandoned as city or community water systems were developed and artesian wells in outlying areas were drilled. More recently many drilled and jetted wells in the confined aquifers were abandoned for the same reasons. In areas not served by public water-supply systems, however, many domestic wells are still being constructed in the principal aquifer.

Richardson (1906, p. 36, 59-75) estimated that in the fall of 1904 there were about 5,000 flowing wells in Jordan and Utah Valleys, of which less than half were in Jordan Valley. According to the claims for the use of ground water in Jordan Valley filed with the Utah Department of Natural Resources, Division of Water Rights (formerly State Engineer's Office), 799 of all the wells recorded in 1935 had been constructed prior to 1900, and 5,544 were completed during 1900-34. During the period 1935-69, 5,480 more wells were completed, resulting in an aggregate total of 11,823 (table 23).

Table 23 shows the cumulative total of wells in Jordan Valley based on records filed in the office of the Utah Division of Water Rights. The totals before 1935 do not include an unknown number of wells that were abandoned and filled when public water-supply systems were installed or extended to many parts of Jordan Valley or for other reasons, thus obviating the necessity of well owners establishing and maintaining water rights in the ground-water reservoir. The totals for all years do include, however, wells that were abandoned after water-right applications had been filed. Incomplete records of plugged wells show that at least 400 wells were plugged by the end of 1958—most of them since 1935—and that at least 465 wells were plugged during 1959-69. Wells that were constructed to replace the 865 known plugged wells are included in the totals. Probably the number of unknown abandonments is as large as the number of known abandoned wells, but it was impracticable to make a complete inventory of the wells in Jordan Valley. In the course of the investigation no wells were discovered for which there is no record in the State files, therefore, the State records are believed to include essentially all active wells.

Table 23.—Number of wells in Jordan Valley, by years

[Based on records in office of Utah Division of Water Rights.]

Year	Constructed during year	Cumulative total	Year	Constructed during year	Cumulative total	Year	Constructed during year	Cumulative total
Before 1900	799	799	1923	96	4,004	1947	297	8,748
1900	286	1,085	1924	105	4,109	1948	284	9,032
1901	54	1,139	1925	148	4,257	1949	251	9,283
1902	42	1,181	1926	144	4,401	1950	369	9,652
1903	39	1,220	1927	120	4,521	1951	177	9,829
1904	47	1,267	1928	105	4,626	1952	233	10,062
1905	123	1,390	1929	163	4,789	1953	218	10,280
1906	168	1,558	1930	179	4,968	1954	200	10,480
1907	100	1,658	1931	141	5,109	1955	158	10,638
1908	92	1,750	1932	125	5,234	1956	130	10,768
1909	49	1,799	1933	109	5,343	1957	136	10,904
1910	350	2,149	1934	202	6,343[1]	1958	133	11,037
1911	108	2,257	1935	140	6,483	1959	111	11,148
1912	115	2,372	1936	97	6,580	1960	109	11,257
1913	88	2,460	1937	69	6,649	1961	129	11,386
1914	103	2,563	1938	62	6,711	1962	88	11,474
1915	214	2,777	1939	146	6,857	1963	43	11,517
1916	177	2,954	1940	334	7,191	1964	71	11,588
1917	100	3,054	1941	260	7,451	1965	41	11,629
1918	122	3,176	1942	159	7,610	1966	49	11,678
1919	97	3,273	1943	163	7,773	1967	29	11,707
1920	403	3,676	1944	144	7,917	1968	29	11,736
1921	107	3,783	1945	209	8,126	1969	35	11,823[2]
1922	125	3,908	1946	325	8,451			

[1] Includes 798 wells constructed mostly during 1900-34 for which the year of construction is unknown.

[2] Includes 52 wells constructed during 1935-69 for which the year of construction is unknown.

As shown in table 24, most wells constructed as of 1969 were less than 300 feet deep and less than 6 inches in diameter. Probably most of the wells for which the depths and diameters are unknown also fall in these categories. Most of the wells supply water for domestic use, stock, or irrigation. Only 40 of those listed as irrigation wells are used for irrigation of commercial crops, 10 are used for irrigation of cemeteries and parks, and the others are used for irrigation of lawns and home gardens.

Several estimates of the volume of water discharged by wells at various times have been made. A thorough search during 1964-68 revealed the existence of many records that were not used in previous estimates. Hence, it was possible to refine estimates for years since 1930.

The first indication of the probable discharge by wells is a list of 263 wells with an average discharge of 19 gpm in 1904 (Richardson, 1906, p. 59-69). Probably about 630 wells, or half those in existence in 1904 were flowing wells and allowed to flow about

Table 24.—Classification of wells in Jordan Valley as of 1969

[Based on records in office of Utah Division of Water Rights.]

	Number of wells
Use:	
Domestic (D)	934
Stock (S)	1,354
Irrigation (I)	692
Combined (D), (S), and (I)	5,831
Industrial	285
Institutional	42
Public supply	355
Unused, unknown, and plugged	2,330
Total reported	11,823
Depth (ft):	
Less than 100	2,321
100-200	2,973
201-300	2,586
301-400	998
401-500	312
501-1,000	284
More than 1,000	18
Depth unknown	2,331
Total reported	11,823
Diameter (in.):	
Jetted, driven, or drilled:	
2 or less	6,298
2¼ - 3	2,874
3¼ - 4	836
4¼ - 6	422
More than 6	730
Diameter unknown	590
Dug	73
Total reported	11,823

210 days (the approximate length of the growing season) each year. Assuming that the average discharge per well from the 630 wells was 19 gpm for 210 days, the corresponding annual flow was about 12,000 acre-feet. Some of the wells, however, undoubtedly flowed all year, so that the total annual discharge probably was about 15,000 acre-feet. The contribution of nonflowing wells to this total probably was negligible (no more than a few hundred acre-ft) because most of them were equipped with hand pumps and were used for domestic supply.

Taylor and Leggette (1949, p.45) estimated that the total annual withdrawal of ground water (probably during 1934) was 36,000 acre-feet. They state that this figure probably is low because it was based on an incomplete survey of wells. The number of wells assumed in their estimate was 5,500; but later filings of claims with the State Engineer indicate that the actual number was 6,343 (table 23). If their estimate of discharge is increased in proportion to the increased number of wells, the estimated withdrawal was about 42,000 acre-feet.

The amount of ground water withdrawn through wells was next estimated by the Utah State Engineer in cooperation with the Works Progress Administration (Utah State Engineer, 1940, p. 33-41) to be 29,500 acre-feet in 1939. This does not include about 10,000 acre-feet of ground water withdrawn for industrial purposes. The total of 39,500 acre-feet is in fair agreement with that for 1934.

Ground-water withdrawals were estimated by Marine and Price (1964, p.49) to be 90,000 acre-feet in 1957. Of this total, about 35,000 acre-feet was from small diameter wells and 55,000 acre-feet from large diameter wells.

Examination of all the available records on well discharge has enabled more precise estimates of the total discharge during each year since 1930 and also of the discharge for each of four types of water use. These estimates are summarized in figure 66.

The total annual withdrawals increased from 38,000 acre-feet in 1931 to 118,000 acre-feet in 1966. Withdrawals in three of the categories showed similar trends, but withdrawals for domestic and stock use declined slightly. Most of the water from flowing wells is used for domestic and stock purposes; and for this reason, all withdrawals from flowing wells are classified in this report as being for domestic and stock use. Although the number of wells for such use was at a maximum in 1969, any resulting trend toward increasing use was offset by the effects of better control of flowing wells, declining potentiometric head in flowing wells, and extension of public supply systems into some areas.

Mean annual ground-water withdrawals from wells during 1964-68 was about 107,000 acre-feet (69,000 acre-ft from pumped wells and 38,000 acre-ft from flowing wells), subdivided as follows: 30,000 acre-feet for domestic and stock use, 35,000 acre-feet for public supply and institutions, 37,000 acre-feet for industry and air conditioning, and 5,000 acre-feet for irrigation. The increase in the amount of ground-water withdrawals since 1930 has approximately paralleled the population growth of Salt Lake County, and the year-to-year fluctuation in withdrawals are influenced by changes in annual precipitation (fig. 67).

Ground-water regimen

The ground-water regimen in Jordan Valley for 1964-68 is summarized in the budget tabulated below.

Table 25.—Ground-water budget for Jordan Valley, 1964-68

	Mean annual quantity, in acre-feet
Recharge (table 21)	367,000
Increase in storage (p. 133)	3,000
Recharge less increase in storage	364,000
Discharge (table 22)	367,000
Difference	3,000

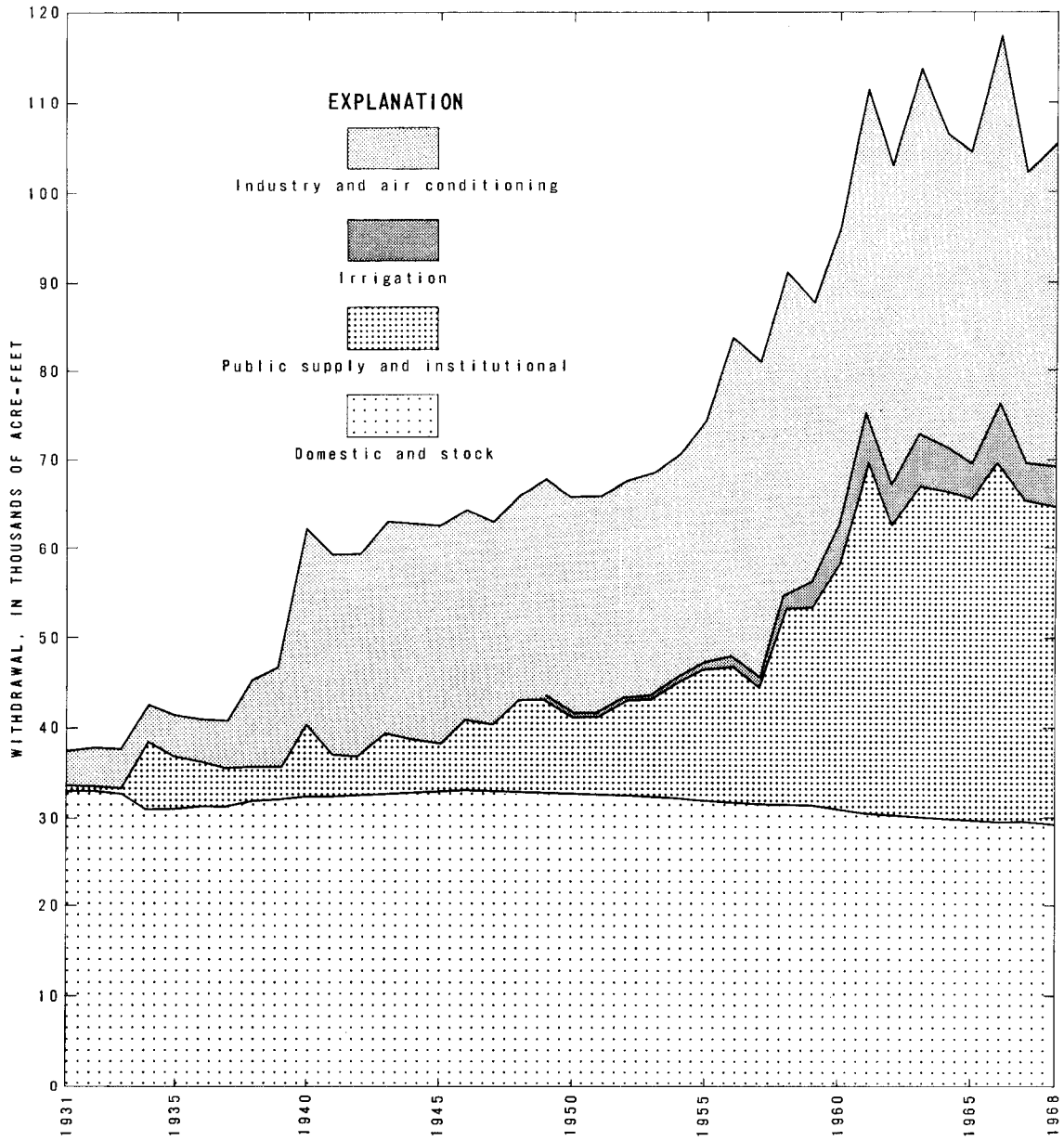


Figure 66.—Annual withdrawal of ground water for four types of use, 1931-68.

The difference in the last line of this tabulation indicates error in the figures tabulated, because in the actual ground-water reservoir, the recharge less the increase in storage must equal the discharge. The indicated error, however, is remarkably small (less than 1 percent of the discharge), considering the approximations and generalizations involved in some of the derivations of recharge and discharge. Although the small magnitude of the indicated error may be partly fortuitous, the actual error in the estimated values probably is less than 10 percent.

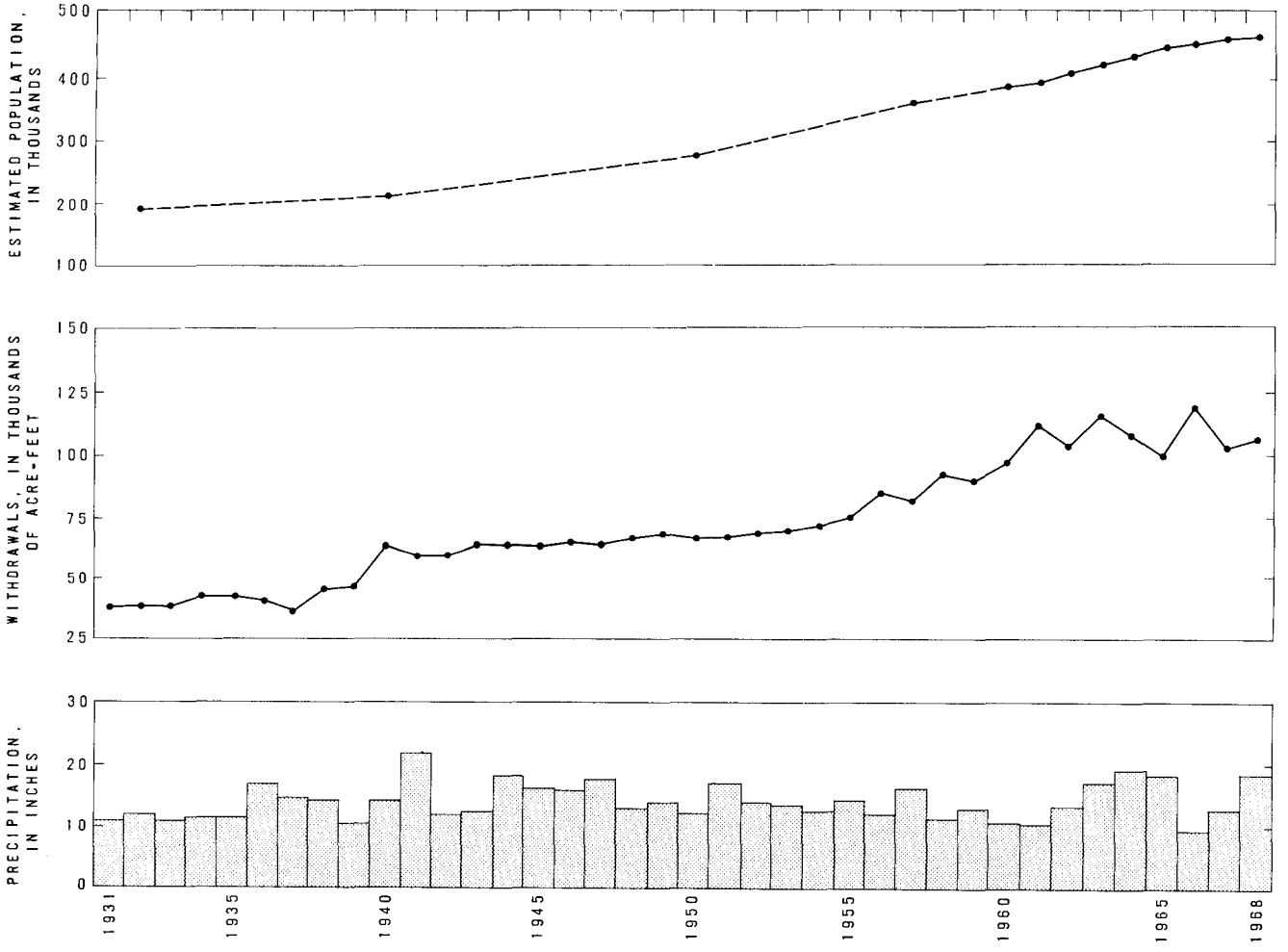


Figure 67.—Estimated population of Salt Lake County, annual withdrawals from wells, and annual precipitation at Midvale, 1931-68.

The ground-water regimen at a particular time reflects conditions that prevailed during an indefinite antecedent period. For example, the recharge from bedrock probably reflects average weather conditions for many years; but the recharge from precipitation on the valley floor probably reflects conditions for only a year or two. The precipitation on the valley floor during 1964-68 was about 2 inches above normal, suggesting that at least one component of the recharge was above normal. On the other hand, figure 48 indicates that a major component of the ground-water discharge (that to the Jordan River) during 1964-68 was less than the average for 1943-68 and was still recovering from the effects of dry years between 1953 and 1962. The writers conclude, therefore, that the values shown for 1964-68 in the budget tabulated above are near the means for the longer period, 1943-68.

A considerable part of the recharge itemized in table 21 is a result of man's activities, but another part is virtually unaffected by such activities. The probable effects of man's use of the water resources are summarized as follows. Seepage and underflow to Jordan Valley (first three items, table 21) have been virtually unaffected. Seepage from creek channels has been reduced because of diversions from streams that cross recharge areas. The seepage loss from natural streamflow probably was closer to 30,000 acre-feet per year than the 20,000 acre-feet per year

shown. Seepage from canals, irrigated fields, and the tailings pond results entirely from man's activities and totaled about 131,000 acre-feet per year during 1964-68. Seepage from lawns, gardens, and precipitation on the valley floor together reflect effects of urbanization, which has produced a net increase of about 12,000 acre-feet per year (table 26). The total increase of ground-water recharge from all these effects is 133,000 acre-feet per year. Hence, the corresponding natural recharge would be about 234,000 acre-feet per year (1964-68 recharge, 367,000 acre-ft, less increase, 133,000 acre-ft).

The proportion of the total recharge to the ground-water reservoir that enters the principal aquifer is pertinent because the shallow unconfined aquifer has been little used for water supply. By considering the locations where recharge in each of the categories indicated in table 21 occurs, it was estimated that 70 percent of the total recharge was to the principal aquifer. Under natural conditions, this percentage would increase to about 90. (These percentages do not include the intercharge of water between aquifers.)

Water-level fluctuations

The available records of water levels in Jordan Valley include charts from continuous recorders on selected wells and periodic measurements in many other observation wells. The interval between periodic measurements ranges from 2 weeks to 1 year. The annual measurements were made in February, when water levels in most of the heavily pumped wells were at or near their seasonal high.

Seasonal fluctuations

The normal seasonal fluctuations of the various components of recharge and discharge to the ground-water reservoir produce corresponding fluctuations of water levels. The water-level fluctuations produced, however, vary with distance from the principal areas of changing recharge and discharge. Consequently, seasonal high water levels may occur during any month of the year, depending on location. This is illustrated by figure 68, in which every month is represented by an annual high water level in at least one of the selected wells.

Typical seasonal fluctuations in two areas in which the dominant components of recharge and discharge differ markedly are illustrated in figure 69. The dominant influence on the water level in well (C-4-1)14abd-1 is recharge by seepage from canals and irrigated fields. Hence the level rises during the spring and summer and then recedes during the fall and winter. Large withdrawals from the ground-water reservoir near well (D-2-1)34acb-1 are made for public supply. Hence the water level in the well declines during the spring and summer months, when withdrawals are greatest, and then recovers during fall and winter.

The effect of distance from an important recharge area on both the magnitude and timing of seasonal water-level fluctuations is illustrated by figure 70. The fluctuations are large near the recharge area, sharply reduced at a distance of 4 miles, and nearly eliminated at a distance of 10 miles. Near the recharge area the annual high level is shortly after the time of maximum streamflow (a major source of recharge), and in the distant wells it is several months later.

The different rates and locations of recharge and discharge and the effect of distance from areas of recharge and discharge results in simultaneous rises and declines of water levels in the various parts of the valley. Thus any areal representation of seasonal change in water levels reflects many different situations. Figure 71 illustrates this between February and September 1968, the approximate times of maximum and minimum levels in wells used for public supply.

The rise of water levels in the southern part of Jordan Valley shown in figure 71 was caused chiefly by a relatively high rate of recharge by seepage from canals and fields supplies with surface water during the growing season. The declines of water levels in the eastern part of the

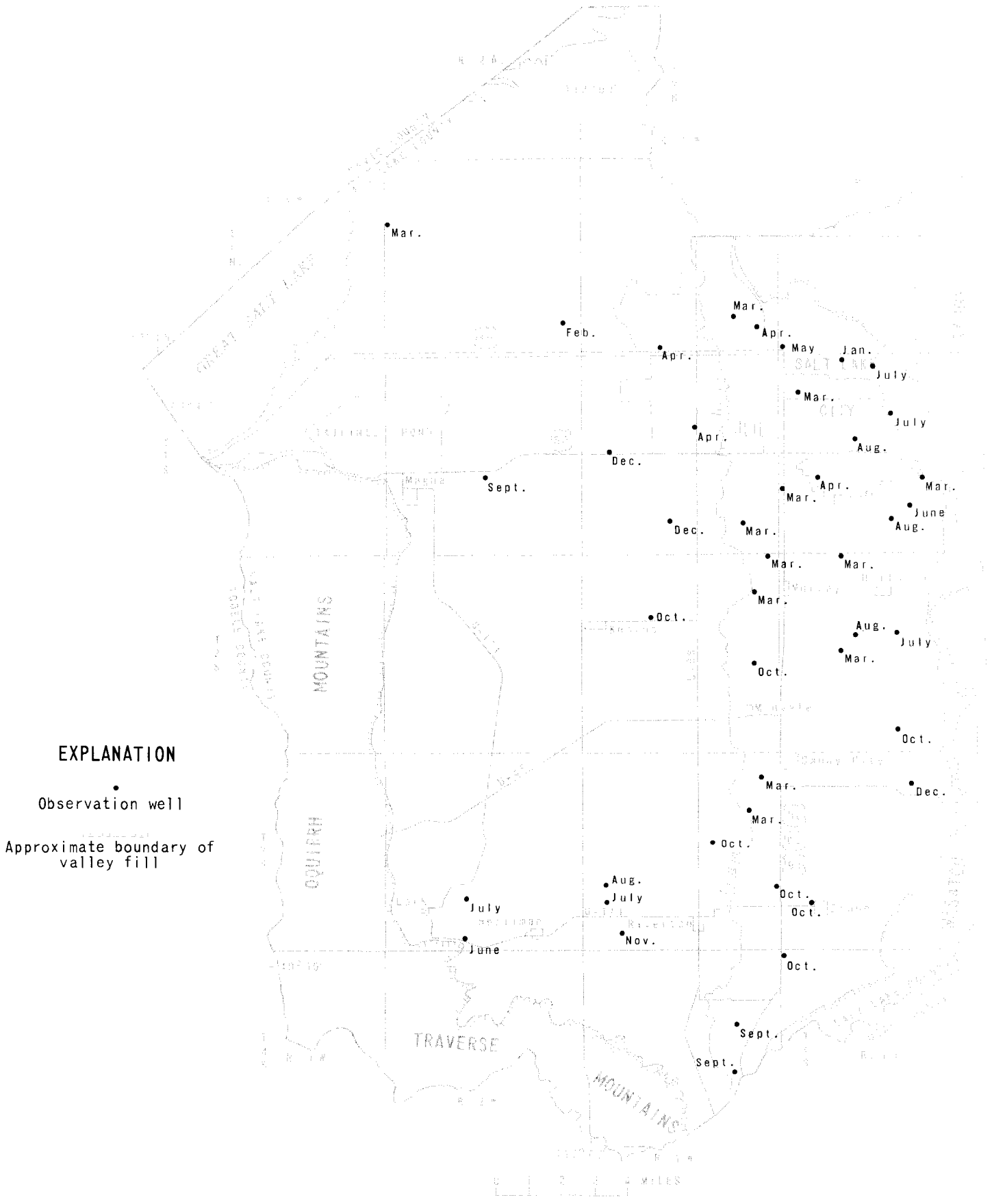


Figure 68.—Month when ground-water levels in selected wells usually are highest.

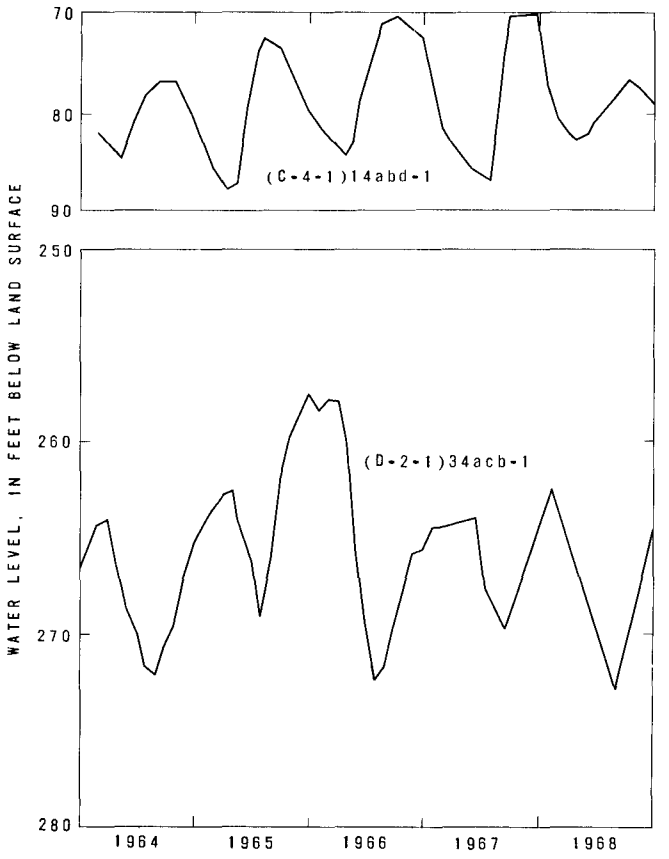


Figure 69.—Contrasting seasonal fluctuations of water levels. Well (C-4-1)14abd-1 is affected primarily by recharge through seepage from canals and irrigated fields and well (D-2-1)34acb-1 by large withdrawals for public supply.

valley reflect the effects of pumping for public supply during the summer. Areas outside of centers of concentrated pumpage were not appreciably affected and show a small rise of water levels, which may be partly due to recharge from lawn watering. The average change of water levels for the entire valley was a decline of 0.3 foot. This indicates that total discharge was only slightly greater than total recharge during this period of relatively large ground-water withdrawals from wells.

Long-term fluctuations

The areal pattern of water-level changes from year to year (using February as the reference month) differs markedly from the pattern of seasonal change (fig. 71) and is illustrated by figure 72. The year-to-year changes are smaller than the seasonal changes, but they also indicate that the changes are affected by a variety of factors. Figure 72 indicates a rise of water levels in 83 percent of Jordan Valley and a decline in the remainder, the average change being a rise of 0.8 foot. Most of the rises were in areas where pumpage from wells was less and canal deliveries were greater in 1968 than in 1967.

The areal pattern of water-level changes from February 1964 to February 1969 (fig. 73) is quite similar to the pattern of 1968-69. Figure 73 indicates a rise of water levels in 84 percent of Jordan Valley during 1964-69 and a decline in the remainder, the average change being a rise

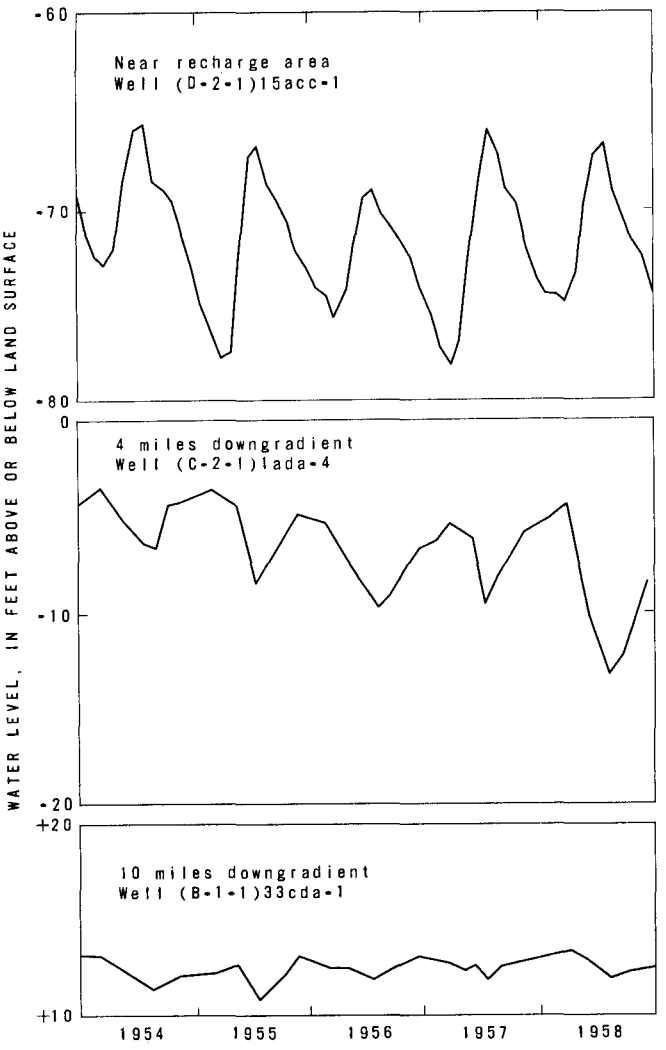


Figure 70.—Effect of distance from a source of recharge on magnitude and timing of seasonal high water levels.

of 1.1 feet. Most of the rises were in areas where pumpage from wells differed only slightly from that during the previous 5 years; consequently, the rises indicate an increase in recharge.

During 1932-69 water levels rose in the southern part and along the north-central edge of Jordan Valley. Figure 63 indicates a rise in 28 percent of the valley and a decline in the remainder, the average change being a decline of 1.8 feet. Most of the rises were in areas where return flow from irrigation recharged the principal aquifer, and the declines were generally in areas of relatively large withdrawals from wells and little or no increase in recharge from irrigation.

Long-term fluctuations of water levels in eight wells at widely dispersed locations in Jordan Valley are shown by hydrographs in figure 74. The patterns of fluctuation vary considerably because of local influences, but other influences had widespread effects. The drought in the early 1930's caused a general decline, which was followed by gradual recovery until about

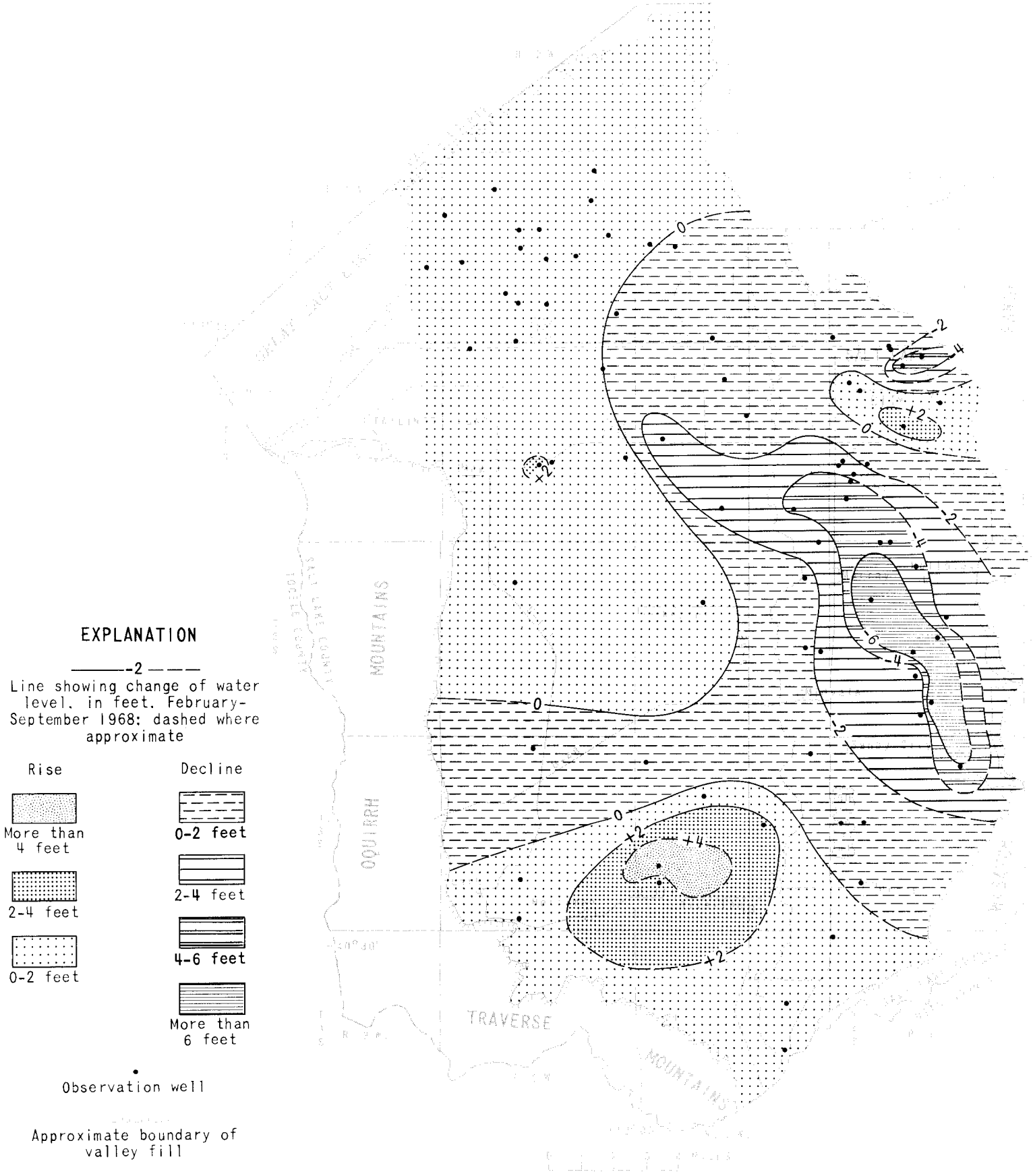


Figure 71.—Change of ground-water levels from February to September 1968.

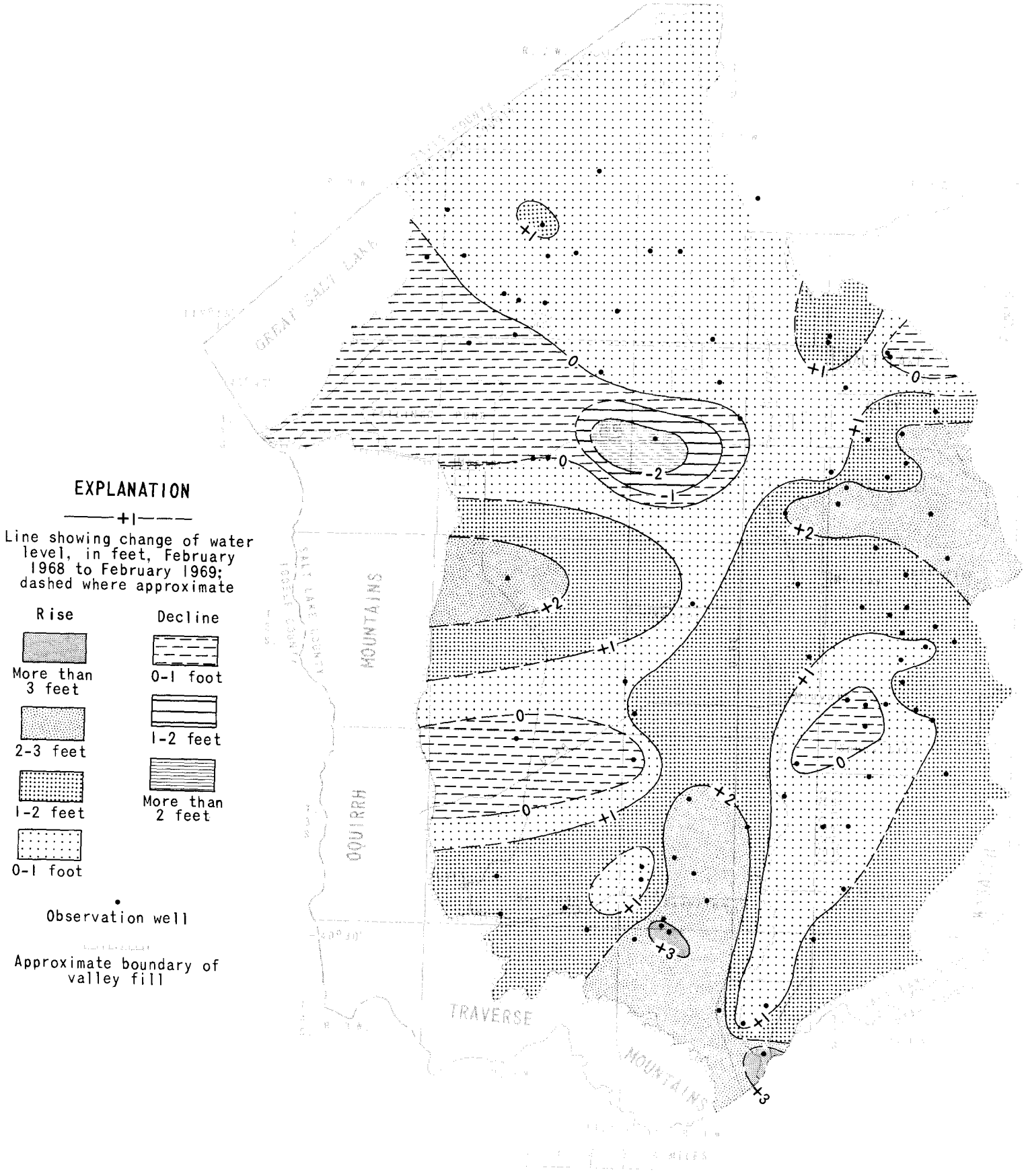


Figure 72.—Change of ground-water levels from February 1968 to February 1969.

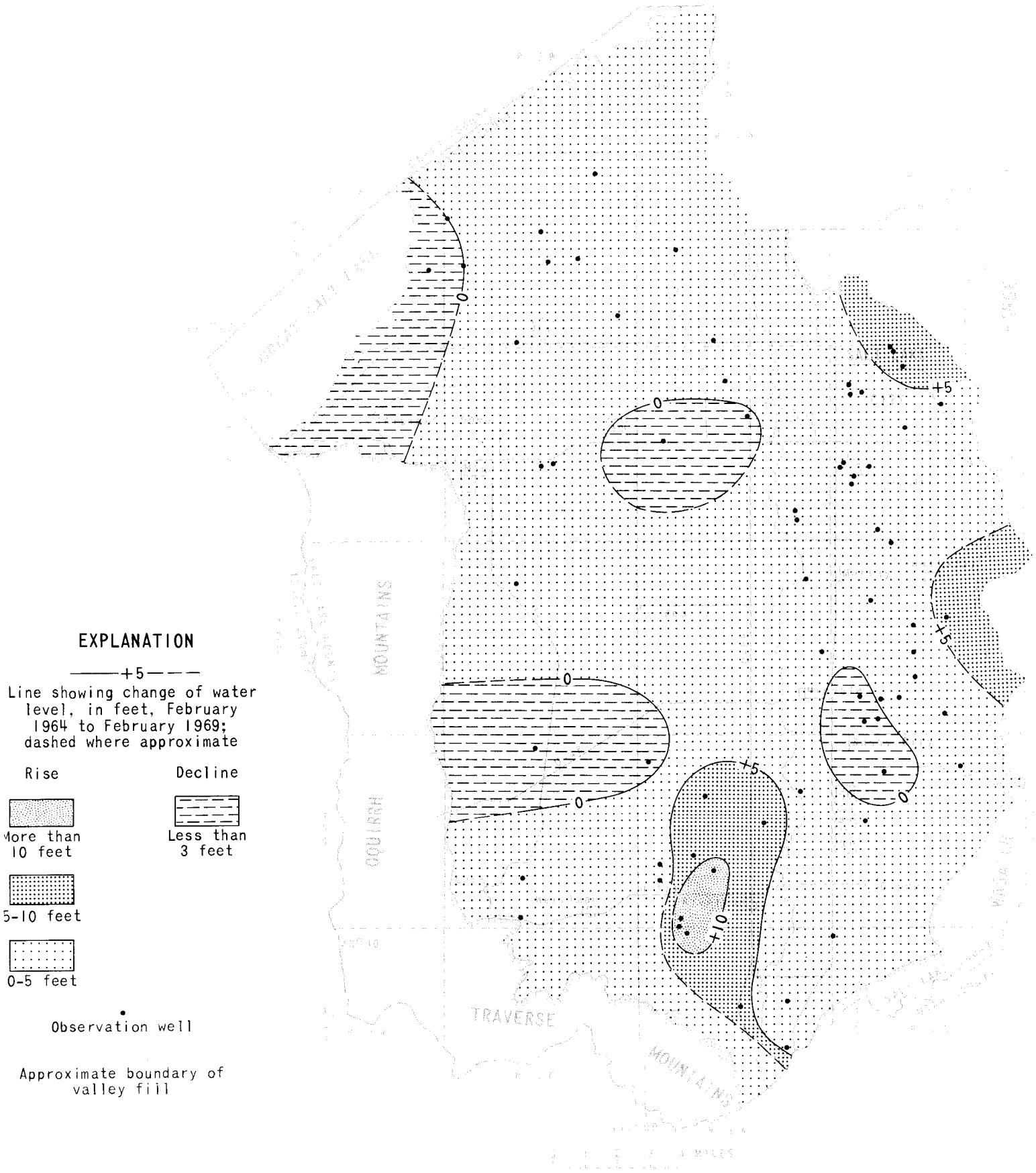


Figure 73.—Change of ground-water levels from February 1964 to February 1969.

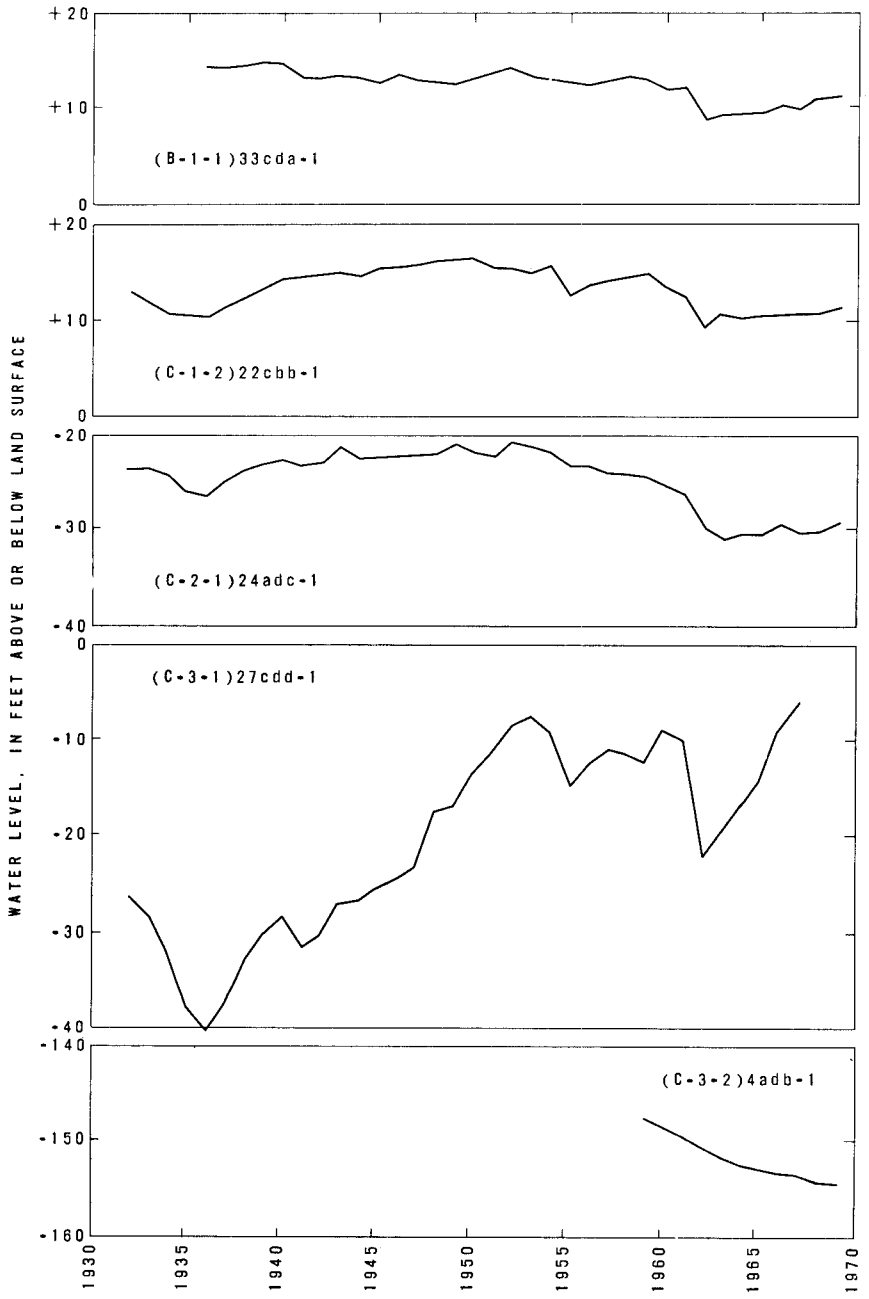


Figure 74.—Long-term fluctuations of water levels in eight wells in Jordan Valley.

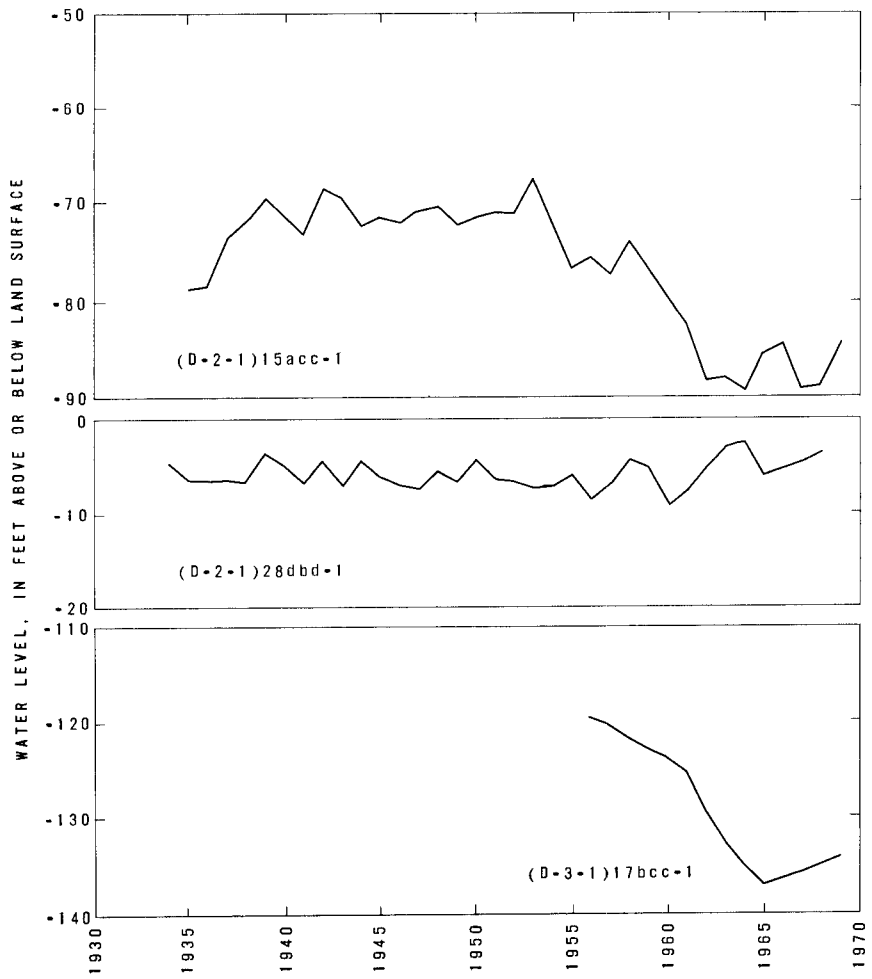


Figure 74.—Continued

1940. The marked rise in well (C-3-1)27cdd-1 during 1942-53 was caused chiefly by increasing recharge from irrigation with surface water. The decline in several wells beginning about 1953 was caused by increasing withdrawals for municipal use and irrigation. This decline generally was checked or reversed after 1962 because of above-normal precipitation and lessened demand for ground water.

Performance of wells

The performance of a well is determined by characteristics of both well and aquifer and is measured by the specific capacity, which in this report is defined as the yield of the well in gallons per minute per foot of drawdown after pumping for 24 hours. Water can be withdrawn

from a properly constructed and maintained well nearly as fast as the aquifer will yield it; but the rate of withdrawal may be severely limited by improper construction or lack of maintenance of the well.

Well characteristics that affect the specific capacity include: the depth of penetration of the well into the aquifer; the diameter of the well; the extent, type, and location of the perforations or screen; the extent of corrosion, incrustation, and plugging by aquifer materials of the perforations or screen; and the results of the well-development process. Proper well development removes some of the fine-grained material around the perforated casing or screen and forms a more permeable pack of coarse-grained material. Thus, the effects of well development is similar to that of increasing the diameter.

For optimum well performance in an aquifer containing fine materials, the width of the perforations or screen openings must be selected to allow a definite proportion of fine materials to pass into the well. An analysis of the grain sizes of the aquifer materials greatly facilitates such selection (Edward E. Johnson, Inc., 1966, p. 179-184). In the absence of a complete grain-size analysis, an opening width of five times the diameter of the median size may be used where the aquifer materials include a large range of sizes. Narrower widths are required where the aquifer materials are more uniform.

Water can be withdrawn from a well as fast as the aquifer can yield it if the efficiency of the well is 100 percent. The efficiency of a well is the ratio of the theoretical drawdown to the actual drawdown multiplied by 100. The theoretical drawdown may be determined using the nonequilibrium formula of Theis (1935). In a well that is 100 percent efficient, the water in the well and the water immediately outside the casing remain at the same levels regardless of drawdown. In a well that is less efficient, however, the water level in the well is below the outside level when the well is pumped.

Efficiencies were computed for 27 wells, all 16 inches in diameter, in Jordan Valley. Of these, seven have efficiencies of less than 25 percent, six have efficiencies of 26-50 percent, five have efficiencies of 51-75 percent, and nine have efficiencies of more than 75 percent. It is probable that renovation of many of the low-efficiency wells would greatly increase the yield and efficiency.

The specific capacities of wells used for public supply, irrigation, and industry in Jordan Valley range from 1 to 1,510 gpm per foot of drawdown. The newer wells in any particular part of the valley generally have higher rates of discharge and higher specific capacities than the older wells of the same diameter. This is probably due to a combination of more modern well construction, better development of the newer wells, encrustation of casing perforations of the older wells, and partial filling of the casings in the older wells. The specific capacity of 73 wells, ranging from 10 to 24 inches in diameter, tapping the unconsolidated deposits of the principal aquifer ranged from 10 to 1,510 gpm per foot of drawdown and averaged 60 gpm per foot of drawdown. The specific capacity of 18 wells,ranging from 12-20 inches in diameter, tapping the underlying semiconsolidated deposits of Tertiary age ranged from 1 to 7.8 gpm per foot of drawdown and averaged 4.2 gpm per foot of drawdown. About half the wells tapping Tertiary deposits, chiefly those with the largest specific capacity, also obtain some water from the principal aquifer. The wide difference between the specific capacity of wells tapping each type of deposit is probably the result of differences in transmissivity rather than differences in well efficiency, because the wells in both deposits were similarly constructed and developed.

Interference between wells

When a well tapping a confined aquifer flows or is pumped, the pressure head in the aquifer around the well and the corresponding potentiometric surface are lowered. The area of lowered potentiometric surface is called the cone of depression or cone of influence of the well. The amount of lowering increases with time but decreases with increasing distance from the discharging well. The cone of depression around a discharging well sometimes overlaps the cones of other discharging wells, a situation which results in additional water-level decline at each well. This is called interference between wells. The additional decline results in less discharge from flowing wells and greater pumping lifts and power costs at pumped wells.

The nonequilibrium formula (Theis, 1935) may be used to determine the amount of interference that a well exerts upon another well under actual or assumed conditions of transmissivity (T), storage coefficient (S), discharge, distance, and time. Theoretical graphs were constructed from numerous solutions of the Theis equation to provide a basis for estimating interference between wells and water-level declines due to pumping from the principal aquifer in Jordan Valley (fig. 75). The graphs were prepared by computing water-level declines for 11 commonly occurring combinations of T and S for distances of 0.1-10 miles from a hypothetical well pumping 1,000 gpm for periods of 1, 10, and 180 days. Values for T and S were assumed to be the same values as shown by the contours in figures 59 and 60; however, the maximum value used for S was 0.01. The accuracy of estimated drawdowns determined by using the graphs diminishes with distance and time; therefore, drawdown at distances greater than half a mile or discharge times longer than 10 days should be used only for approximation.

As an illustrative hypothetical interference problem in Jordan Valley, let it be assumed that three wells will be pumped simultaneously for 180 days a year. (See summary below for data for the hypothetical problem and figure 60 for locations of the hypothetical wells in the southeastern part of the valley.) Well 1 will be pumped continuously at 1,000 gpm, well 2 will be pumped 16 hours a day at 1,000 gpm, and well 3 will be pumped continuously at 100 gpm. The three pumped wells lie in a straight line with well 4 at 1-mile intervals. It is desired to estimate the water-level decline at well 4 at the end of the principal pumping season (180 days). For purposes of illustration, it will be assumed that T is 10,000 ft^2 day^{-1} and S is 0.001; and it is further assumed that intermittent pumping during a given period may be spread over the entire period at a proportionately lower rate. The average pumping rate during a principal pumping season for well 2, therefore, is 16/24 of 1,000 gpm or 667 gpm.

Pumped well	Average pumping rate during 180-day season (gpm)	Distance from pumped well to well 4 (mi)	Water-level decline at end of 180-day season (ft)
Well 1	1,000	1	7.7
Well 2	667	2	3.7
Well 3	100	3	.4
		Total decline in well 4, in feet	11.8

The effect on the water level at well 4, caused by pumping at wells 1, 2, and 3, is analyzed separately; the total decline (interference) is the sum of the effects of all three wells on well 4. The effect of well 1, at the end of a pumping season, is determined thus: on figure 75 locate the intersection of the curve designated 180 days and the vertical line at a distance of 1 mile, then move horizontally to the left edge and read 7.7 feet. Effects of wells 2 and 3 are determined in like manner except that the effect of well 2 is 667/1,000 of that read from the graph because its effective pumping rate is 667 gpm and effect of well 3 is 100/1,000 of that read from the graph.

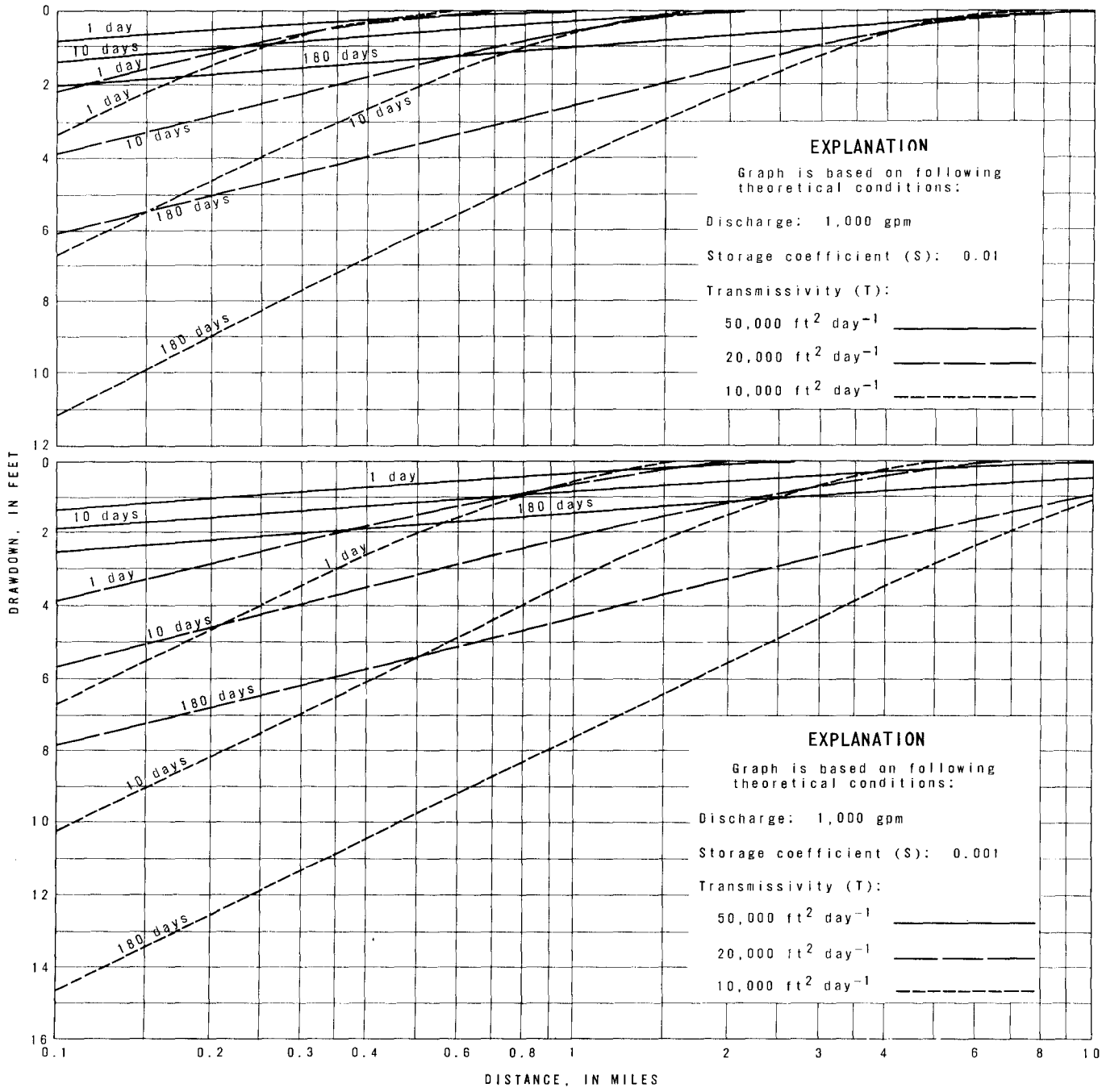


Figure 75.—Theoretical time- and distance-drawdown graphs for the principal ground-water aquifer in Jordan Valley.

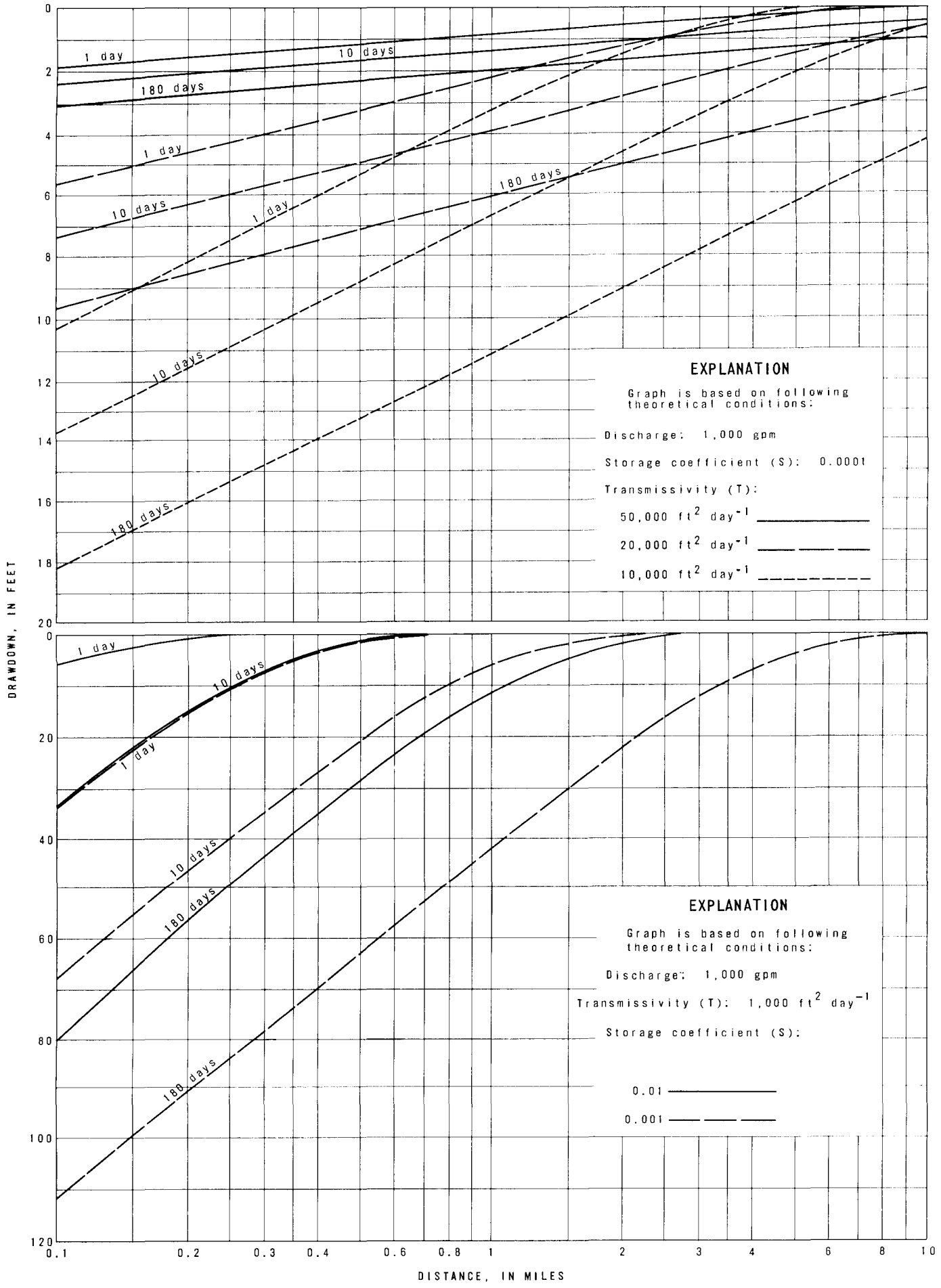


Figure 75.—Continued

Actual drawdown effects as measured in the field would not be as large as theoretical effects due to pumping alone if the cone of depression intercepts water that would otherwise discharge naturally. The theoretical effect will be reduced in a proportion related to the quantity of intercepted water and distance to the discharge area. In Jordan Valley, most such intercepted water is water that would otherwise discharge to streams or be consumed by phreatophytes. As the cones of depression of the discharging wells reaches ever farther into areas of phreatophytes, the cones will intercept an increasing amount of water now being consumed by the phreatophytes. This, in turn, lessens evapotranspiration by the phreatophytes and the rate of water-level decline.

Aquifer compaction and land subsidence

Hydrologic literature contains many references to land subsidence that has occurred because of compaction of aquifer materials after they were unwatered or artesian pressures were drastically lowered (Green, 1964; Lofgren and Klausing, 1969). Wherever subsidence has been studied, a correlation between the amount of subsidence and the decline of water levels has been found. The aquifer materials in Jordan Valley, occurring in strata with different particle sizes and containing considerable quantities of silt and clay, are similar to those in areas where subsidence has been observed. Hence, some subsidence probably would accompany any future large decline of water levels in Jordan Valley.

The subsidence usually occurs so gradually and so uniformly over extensive areas that little structural damage results. The most striking evidence of subsidence often is a deep well casing that protrudes farther above the land surface than it did before subsidence began. The severest damage may be the resulting change in grade of canals and sewer lines in or crossing the affected area.

The amount of subsidence depends on the physical nature of the aquifer materials, the thickness of the affected strata, the net change in the forces exerted by gravity and hydrostatic pressure, and the duration of the changed condition. As water is withdrawn from an aquifer the hydrostatic pressure is lowered. This pressure helps to support overlying strata, and its reduction transfers a larger part of the effective weight of such strata to the aquifer skeleton. This, in turn, causes a closer packing of unconsolidated particles in the aquifer. As fine-grained materials yield water slowly, the compaction process may continue slowly for several years.

Compaction may be elastic and reversible, or inelastic and permanent. In general, compaction of sand and gravel is small and is chiefly elastic and temporary; but compaction of silt and clay is greater and is chiefly inelastic and permanent. For this reason, large fluctuations of water level near the east and west sides of Jordan Valley probably would induce only slight subsidence, but similar fluctuations in the central part would induce greater subsidence.

Experimental data for application of the Terzaghi theory of consolidation (Terzaghi, 1943, p. 266-267) to subsidence problems in Jordan Valley are not available. A review of the literature, however, suggests that permanent land subsidence probably has begun in parts of the valley where declines have been greatest. Subsidence effects have not yet been recognized and may be too small to be easily measured.

Analog model of the ground-water reservoir

A principal objective of the investigation in Jordan Valley was to determine the probable changes in water level that would result from specific changes in recharge and discharge. Such determinations require a complete and accurate description of reservoir characteristics based

chiefly on geologic and hydrologic data gathered in the field. Observational data, however, are seldom completely sufficient for the required description, and assumptions must be made for parts of the reservoir or certain relations not defined by observational data. Then when the descriptive information is complete, the reservoir response can be determined by a time-consuming series of complex computations.

The determination of both the descriptive information and the reservoir response can be greatly facilitated by use of an electric analog model of the ground-water reservoir as described by Robinove (1962). As a reservoir response over a period of many years can be simulated on the model in an extremely short time, tests can be made for many assumed conditions.

A model of the ground-water reservoir in Jordan Valley was constructed at a scale of 1:24,000 (1 in. = 2,000 ft). It consists of two layers, one simulating the principal aquifer and the other simulating the shallow unconfined aquifer. Each layer is a network of nodes or electrical junctions of resistors and capacitors placed at the corners of 1-inch squares. Thus, each node represents aquifer characteristics in a 2,000-foot square. The capacitors simulate storage capacity in the aquifer; and resistors simulate resistance to flow of water, which is inversely proportional to the transmissivity. The two layers are connected through resistors that simulate the effects of the confining layer between the two aquifers.

A condition of no change in current or voltage at any node in the model corresponds to equilibrium in the reservoir (recharge equals discharge, and water level is constant). A change in electrical stimulus applied to one or more nodes of the model simulates a change in recharge or discharge at that point (destroying the equilibrium), and the model response at any other node can be measured by connecting that node to an oscilloscope. The voltage change over any desired period, simulating water-level or pressure change in the aquifer, registers as a graph on the oscilloscope. By measuring such changes at many nodes, information is obtained for construction of a water-level change map. If the condition tested is one for which actual water levels are known, and if the map derived from the model matches the one derived from field observations, the assumptions used in building the model are verified.

Construction of the Jordan Valley model was begun during an early stage of the investigation, starting with relatively simple generalized concepts of the ground-water reservoir. Several test runs were made during construction to help determine the places where additional information was needed and to check the validity of assumptions used. Where differences between the response of the model and the response of the reservoir were noted, the data and assumptions used were re-examined, data were supplemented with additional field data or reinterpreted, and assumptions were modified as necessary until good agreement was attained. In this way, the model contributed appreciably to the final concepts of the ground-water reservoir as described in preceding discussions.

The ground-water reservoir was assumed to be in equilibrium in 1931, changes in recharge and discharge that have occurred since 1931 were incorporated, and the model was verified by a test run for the period 1932-68. Most of the input to the model was made directly from available field data, but the interpretations involved with several types of data are explained below.

The amounts by which mean annual withdrawals from wells during four selected periods exceeded the withdrawal of 38,000 acre-feet during 1931 are as follows:

Calendar years	Mean annual excess, in acre-feet
1932-41	7,700
1942-51	25,200
1952-58	38,700
1959-68	67,700

The amount of evapotranspiration from ground water in areas of a shallow water table depends in part on the depth to water. Data for depth to water used in the model were based chiefly on field observations made during the summer of 1968 (fig. 80). The data were assumed to be applicable for 1931 also, because test runs of the model indicated that water-level changes were less than 1 foot in most of the area of evapotranspiration of ground water between 1931 and 1968.

The amount of ground water discharged to streams depends in part on ground-water levels. Test runs of the model, based on streamflow and ground-water data for southern Jordan Valley, provided approximate confirmation of an estimate of one million gallons per day per mile of stream per unit change of head.

The increased recharge during 1932-68 from irrigation near Herriman and Riverton, from the tailings pond near Magna, and in a suburban area near the Wasatch Range were determined from the model by a trial and error procedure. The mean annual increases were as shown in table 26.

Table 26.—Average annual recharge during 1932-68, in acre-feet of increase over that of 1931, determined by model studies

Source and area	Average annual quantity, in acre-feet
Irrigation near Herriman and Riverton	11,800
Industrial water at tailings pond	4,700 [1]
Effect of urbanization in eastern Salt Lake City	12,200

[1] Apparent recharge, of which about half (2,400 acre-ft) was assumed to be actual recharge and the remainder was due to the effects of the tailings load on the aquifers.

The completed model is a reasonably good (but not precise) representation of the ground-water reservoir when water-level fluctuations are limited to the relatively small historic (1931-68) range. It is impossible to verify assumptions used for water levels beyond that range. Hence, as assumed conditions and resulting water levels depart from the historic ones, the difference between simulated and real water levels may increase. Nevertheless, the model provides the best available predictive means of appraising the effects of assumed conditions, and it can be refined when additional information becomes available. Appraisals of various assumed conditions, based on the model, are described in a later section of this report. (See p. 201-217.)

Chemical quality

The chemical quality of ground water generally changes so slowly that representative data from analyses made during a specific period may be considered applicable for a much longer period. Most of the chemical analyses used in the report were obtained during 1964-68, although a few analyses were made as early as 1932 and several were made between 1955 and 1964. Hence no dates are specified for tables and illustrations in this report; they are considered applicable to an indefinite period prior to and including the 1964-68 study period. (See p. 233 for specific sources of data.)

Principal aquifer.—The dissolved-solids content of water in the principal aquifer in Jordan Valley varies systematically both areally and vertically. The dissolved-solids content at any given location and depth is the result of interaction among the several factors discussed in the section on relation of chemical quality to hydrology and geology; for example, water in the aquifer beneath the Jordan River generally is a mixture of waters from the recharge areas to the east and west.

The general areal distribution of dissolved solids in water in the principal aquifer, without distinction of depth of sampling, is shown on plate 2. The water with the lowest dissolved-solids content (100-250 mg/l) is chiefly in an irregular area extending downgradient from the Wasatch Range in the vicinity of Little Cottonwood and Big Cottonwood Creeks toward Midvale and Murray. The dissolved-solids content of the water increases from the Cottonwoods area northwestward toward the shoreline of Great Salt Lake where the dissolved-solids content exceeds 2,000 mg/l. The increase of dissolved solids toward the northwest indicates that the ground water, in following the flow pattern shown in figure 58, has progressively greater opportunity for solution of minerals as it moves through the aquifer. The same general pattern of increase of dissolved solids as the ground water moves from recharge to discharge areas shown in figure 58 is reflected in other areas on plate 2. This general pattern is modified locally because of differences in the types of consolidated rocks in the mountains from which recharge occurs; because of discharge from highly mineralized thermal springs; and because of mine drainage or seepage from tailings ponds, which contain highly mineralized water.

The dissolved-solids content also varies with depth in the principal aquifer. Generally, the dissolved solids in water at any given location decreases from the top of the principal aquifer toward the middle and then increases with depth. Thus, the chemical quality varies systematically, but the correlation of dissolved solids and depth is slight (correlation coefficient, 0.11). Examples of the variation with depth in the principal aquifer are shown in two sections on plate 3. (See pl. 2 for locations of the sections.) Section A-A′ follows the general direction of a flow line from a recharge area (point A′) to a discharge area (point A). It shows that the recharge water near point A′ contains less than 200 mg/l of dissolved solids, and that as the distance and therefore the time of travel increases, the dissolved-solids content increases. Because travel through the middle part of the principal aquifer is the most direct route and the rate possibly is the most rapid, the dissolved solids in that middle part is the lowest. Water in the lower part of the aquifer moves through a longer path and therefore acquires a greater dissolved-solids content; it also receives some water from the underlying deposits of Tertiary age. Water leaks from the principal aquifer upward to the shallow aquifer, beginning at about well (D-2-1)9cdb-1. The upward movement is slower and across beds of fine-grained deposits; the water thus acquires more dissolved solids.

Section B-B′ follows the general route of the Jordan River; it not only shows the relations described for section A-A′, but also shows the effects of mixing of waters from the east and west sides of the Jordan Valley. Thus, the recharge near Jordan Narrows (point B′) contains 600-1,100 mg/l of dissolved solids; as a large amount of fresh water moves from Little Cottonwood Canyon to the line of section near well (C-2-1)35ddd-3, the dissolved-solids content diminishes; and then as the water moves downgradient, the dissolved-solids content again increases.

Shallow unconfined aquifer. —Water in the shallow unconfined aquifer in Jordan Valley generally contains more dissolved solids than does water in the principal aquifer; for example, see well (C-2-1)14caa-1 in section B-B′ on plate 3. This may be due to a combination of reasons—solution of minerals as water from the principal aquifer moves upward through the confining bed into the shallow unconfined aquifer; evapotranspiration in areas where the water

table is close to the land surface; seepage from irrigation water; contamination from common salt that is used to remove snow and ice from roads and streets; and solution of minerals left in the upper part of the valley fill near the north end of the valley by the gradual desiccation of ancient Lake Bonneville.

Water from the shallow aquifer locally has a dissolved-solids content nearly the same as that of water from the principal aquifer. In parts of T. 1 S., R. 2 W., this similarity may be a fortuitous result of dilution of the water in the shallow aquifer by seepage of irrigation water of relatively low dissolved-solids content. In sec. 6, T. 4 S., R. 1 E., the similarity in dissolved-solids content probably results from local recharge to the shallow unconfined aquifer from the Traverse Mountains and from seepage of irrigation water.

The dissolved-solids content of water from wells obtaining water from the shallow aquifer at depths less than 100 feet, from open trenches, and from seeps is given in table 27.

Table 27.—Dissolved-solids content of water from the shallow unconfined aquifer in Jordan Valley

Well, trench, or spring number	Sampling depth (feet)	Dissolved solids (mg/l)	Well, trench, or spring number	Sampling depth (feet)	Dissolved solids (mg/l)
(B-1-1)23bdd-1	30	12,000	(C-3-1)6cac-1	90	928
23bdd-2	30	8,960	18abc-S1	---	24,300
(C-1-1)32bbb [1]	13	1,700	27aaa-1	12	2,330
(C-1-2)21dad-10	60	1,410	(C-4-1)10bdd-1	50	1,320
22bdd-4	35	967	(C-2-1)6dbb-12	85	270
22dcc-3	99	1,340	8ccd-8	86	458
28aaa-3	60	1,610	9dbd [1]	8	658
32aab-1	52	1,330	14bcc-1	17	809
35ada-2	64	1,140	17bcc-7	99	515
(C-2-1)12ada-1	82	342	20add [1]	14	1,330
14caa-1	63	1,430	(D-3-1)7ccd-1	62	2,050
34acb [1]	12	1,510	12adc-1	71	140
34dda-2	65	1,400	30dcb-1	10	2,030
(C-3-1)2cab-1	10	1,680	(D-4-1)6bdd-1	28	659

[1] Open trench.

Deposits of Tertiary age.—Water in deposits of Tertiary age varies considerably in dissolved-solids content (table 28) depending upon local conditions of recharge, degree of interconnection with the principal aquifer, or depth below the top of the Tertiary deposits. The dissolved-solids content generally is similar to that obtained from nearby wells in the principal aquifer. Locally, however, the dissolved-solids content may be half as great or twice as great as that of water in the principal aquifer. The average specific capacity of wells tapping deposits of Tertiary age is about 4 gpm per foot of drawdown (see p. 151-152), thus well tapping Tertiary deposits generally yield only small amounts of water.

Table 28.—Dissolved-solids content of water from deposits of Tertiary age in Jordan Valley

Well number	Sampling depth[1] (feet)	Dissolved solids (mg/l)	Well number	Sampling depth (feet)	Dissolved solids (mg/l)
(C-1-1)13bba-1	815	238	(C-3-1)32cdc-1	530-633	460
13dab-1	844-864	242	(C-4-1)14dcd-1	265-716	655
25acb-3	700-963	339	15bdc-1	198-425	1,210[2]
36dab-5	535	298	15bdc-2	180-522	713[2]
(C-1-2)21acc-5	368-412	2,820	(D-1-1)19dbc-1	574-840	608
21adb-1	380-416	2,070	20bab-1	468-475	681
25aad-1	300-968	1,620[2]	30acc-7	487-890	454
(C-2-1)1dbb-3	615-738	392	30ccd-10	644	334[3]
7ccc-1	258-895	578	30cda-10	611-850	359
12abc-3	356	293[3]	31dcd-21	365-375	319
12bba-6	473-499	318	33caa-1	385	763
12bbb-4	450-700	334	(D-2-1)4bcc-1	632-645	642
12daa-2	399	212	6dbb-10	518-852	315
(C-2-2)8baa-2	173	488	7dcd-7	485	369
8baa-3	295	546	7dda-1	460	127
9bca-1	526	501	8aaa-1	390	279
9bdb-1	515	647	17bbb-2	637-726	419

[1]Where only one figure is given, well is open ended at that depth.

[2]Part of the water may be from deposits of Quaternary age.

[3]Odor of hydrogen sulfide reported.

Chemical composition

Most of the dissolved solids in ground water in Jordan Valley are composed of six ions or groups of ions (calcium, magnesium, sodium plus potassium, bicarbonate, sulfate, and chloride) (see p. 61). Other ions sometimes are present in sufficient concentrations to have significant effects on the quality.

The concentrations of the six major ions in water in the principal aquifer, the shallow unconfined aquifer, and in deposits of Tertiary age are indicated by the diagrams on plate 4. Some of the reasons for the marked variations illustrated for the chemical composition of the water in the principal aquifer are discussed in the following section on chemical quality in relation to geology and hydrology.

Among the minor constituents that may have significant effects on water quality are nitrate, fluoride, and boron. The nitrate content of water from 401 wells and springs ranges from 0.0 to 20 mg/l and averages 4.1 mg/l; in sec. 5, T. 2 S., R. 2 W., near Bacchus, as the result of accidental dumping of ammonium nitrate, several springs discharge water containing as much as 900 mg/l of nitrate. The fluoride content of water from 68 wells in the valley ranged from 0.0 to 6.0 mg/l and averaged 0.5 mg/l; the maximum was in water from well (D-3-1)2ccc-1. The boron content of water from 20 wells ranged from 0.00 to 2.0 mg/l, but the data are too few to give a meaningful average.

The chemical quality of ground water in the principal aquifer depends chiefly on the chemical quality of the recharge, the chemical composition and physical properties of the sediments through which it passes, and the duration (up to some variable and unknown limit) of contact with such deposits. Water in the principal aquifer in the east-central part of the valley has a relatively low dissolved-solids content because water from the major sources of recharge has a low dissolved-solids content, and the water moves relatively rapidly through the coarse sediments near the mountain front. The major sources of recharge to this area are Big Cottonwood and Little Cottonwood Creeks and the bedrock in the Wasatch Range. The bedrock in this area consists primarily of crystalline and other relatively insoluble rocks. The chemical quality of recharge from the streams probably is similar to that of the quality of streamflow during periods of high flow, when most of the recharge from the streams occurs. The quality of recharge from bedrock probably is similar to that of the quality of streamflow during periods of low flow, as the latter is derived almost entirely from ground-water discharge to the streams in the mountain canyons. The dissolved-solids content of recharge from the Cottonwood Creeks and the five other major Wasatch streams and the bedrock is indicated by the tabulation given below:

Stream or area of recharge	Dissolved solids (milligrams per liter)	
	Average high flow	Average low flow
Little Cottonwood Creek	99	137
Big Cottonwood Creek	153	227
Mill Creek	345	458
Parleys Creek	312	414
Emigration Creek	378	520
Red Butte Creek	305	440
City Creek	209	245

The estimated dissolved-solids contents shown above are estimated on the basis of maximum and minimum monthly discharge of the seven streams and the equations given in table 6. The chemical composition of the recharge from bedrock probably is similar to that of the seven streams as shown in table 8.

The water in the principal aquifer north and south of the Cottonwoods area is of poorer quality than it is in the Cottonwoods area. The reason for the poorer quality to the north is apparent from the tabulation above. This indicates that water from the streams and bedrock, the main source of recharge to that area, contains more dissolved solids than do the sources of recharge in the Cottonwoods area. The reasons for the poorer quality to the south are that there is comparatively little recharge of water with a low dissolved-solids content from surface streams, and the small amount of recharge from the bedrock moves through relatively fine-grained sediments in the valley fill.

The chemical quality of ground water in the principal aquifer in the southwestern part of the valley generally is poorer than that in the eastern part. The principal reasons for this

are: lesser amounts of recharge from the bedrock in the Oquirrh Mountains, poorer quality of recharge water from the streams discharging from the Oquirrh Mountains, recharge resulting from irrigation with water of poor quality from the Jordan River, and contamination from mining operations.

The dissolved-solids content and chemical composition of recharge from the Oquirrh streams and major canals in the southwestern part of the valley are given in tables 13 and 15 and in the unnumbered table on page 74. The dissolved-solids content of the water, tabulated below, from all the sources except one greatly exceeds that of the Wasatch streams.

	Dissolved solids (milligrams per liter)
Utah Lake Distributing Co. and Utah and Salt Lake Canals[1]	1,120
Provo Reservoir Canal[2]	231
Rose Creek	426
Butterfield Creek	985
Keystone Gulch[3]	1,310
Bingham Creek	44,400

[1]These canals divert water from the Jordan River in the Jordan Narrows.

[2]Diverts water from the Provo River in Utah County.

[3]Mascotte Tunnel is the source of this water.

The chemical quality of recharge from bedrock of the Oquirrh Mountains probably is similar to that of water from wells near Herriman, Lark, Copperton, and in Barneys Canyon. The dissolved-solids content of water from these wells is given below:

	Dissolved solids (milligrams per liter)
(C-3-2)4adb-1	1,120
5aac-1	636
5acb-1	719
17cac-1	1,070
20bdd-1	1,460
32baa-1	408
34daa-1	553
(C-4-2)6acc-1	870

The general pattern of water quality in the southwestern part of the valley is modified locally because of differences in the source and quality of recharge. For example, the comparatively low dissolved-solids content of water in parts of secs. 5 and 6, T. 4 S., R. 1 W., and secs. 31 and 32, T. 3 S., R. 1 W. (pl. 2) is attributed to greater recharge from an area of bedrock that is more permeable than the bedrock in adjoining areas (pl. 1) and to recharge with water of low dissolved-solids content from the Provo Reservoir Canal.

In the area between Copperton and Lark, extending eastward toward the Jordan River near South Jordan, much of the ground water has been contaminated with drainage associated with mining activities and the use of mine drainage water for irrigation. Oxidation of sulfide minerals in the ore bodies near Bingham yields sulfates, sulfuric acid (which is neutralized by limestone in the Oquirrh Formation), metallic oxides, and other compounds, which are dissolved in percolating water that discharges into stream courses or recharges the ground-water reservoir. These reactions were occurring before mining began, thus there probably always was some contamination of ground and surface water near areas of sulfide minerals. Mining activity, however, particularly open-pit mining, probably increases the rate of oxidation by mechanically increasing the surface area exposed to the atmosphere. In addition, some contamination is caused by seepage of waste-dump leachates. Past disposal of liquid wastes in evaporating ponds in sec. 18, T. 3 S., R. 1 W., has resulted in contamination of ground water in an area of several square miles west of South Jordan. Although these ponds have been abandoned, the effects are continuing.

Data indicating contamination downgradient from the Bingham Canyon copper mining area are listed below:

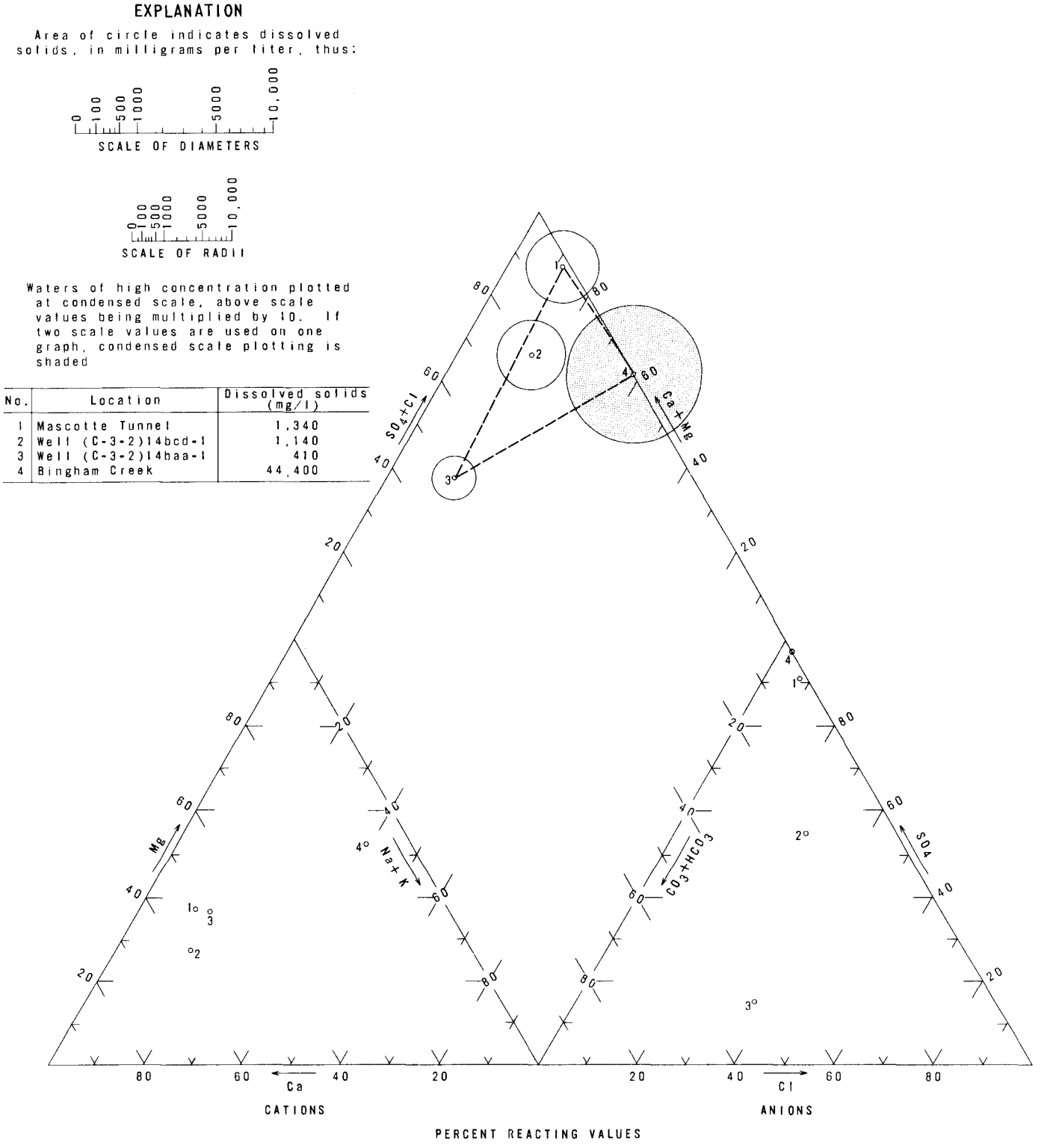
[Chemical analyses, in milligrams per liter]

	Mascotte Tunnel	Bingham Creek	Well (C-3-2)14baa-1	Well (C-3-2)14bcd-1
Silica (SiO_2)	17	42	20	23
Calcium (Ca)	204	90	66	214
Magnesium (Mg)	90	2,830	30	62
Sodium (Na)	58	152	22	67
Bicarbonate (HCO_3)	19	(1)	199	202
Sulfate (SO_4)	867	31,800	49	499
Chloride (Cl)	61	837	85	175
Nitrate (NO_3)	1.4	3.8	2.6	5.5
Dissolved solids	1,310	44,400	410	1,140
Specific conductance (micromhos/cm at 25° C)	1,560	19,600	689	1,600
pH	6.8	2.8	7.6	8.2

[1] Acidity as H_2SO_4, 50 mg/l.

Mascotte Tunnel drains active mine workings, and the dissolved-solids content of the water is approximately the same as that of water from wells (C-3-2)17cac-1 and (C-3-2)20bdd-1 (see p. 163) near the Oquirrh Mountains just below the mine. Hence, the chemical quality of the tunnel water probably is fairly representative of the present quality of recharge water from bedrock in the immediate vicinity.

The water in Bingham Creek is contaminated by seepage from the acid leaching of spoil dumps near the mouth of Bingham Canyon. Some of this seepage may also enter the ground-water reservoir downgradient from the dumps.



No.	Location	Dissolved solids (mg/l)
1	Mascotte Tunnel	1,340
2	Well (C-3-2)14bcd-1	1,140
3	Well (C-3-2)14baa-1	410
4	Bingham Creek	44,400

Figure 76.—Trilinear diagram of chemical constituents of water from Mascotte Tunnel, Bingham Creek, and wells (C-3-2)14baa-1 and (C-3-2)14bcd-1.

Well (C-3-2)14baa-1 was drilled in 1968 and at the time of sampling had been pumped only for testing. Well (C-3-2)14bcd-1 (about half a mile southwest) was drilled in 1962 and has been pumped almost continuously since July 1965. The casings of both wells are perforated in the same zone and the nonpumping water levels are similar. The general similarity between the chemical analyses of water from well (C-3-2)14bcd-1 and the water from Mascotte Tunnel suggests that ground water at the well has been contaminated by the mining operations. The quality of water from the newer well indicates no contamination.

The analyses given in the above table are plotted on the trilinear diagram in figure 76. Although the analysis for Bingham Creek cannot be adequately shown on such a diagram because of the acidity of the water, it is plotted by combining the acidity with sodium. The analysis of water from well (C-3-2)14bcd-1 plots in a triangular area enclosed by the points for Mascotte Tunnel, Bingham Creek, and well (C-3-2)14baa-1 in the upper field of the diagram; thus graphically indicating that the water from well (C-3-2)14bcd-1 could be a mixture of the other three waters.

Between Copperton and Garfield the principal aquifer contains little water and its chemical quality is generally unknown. In this part of the valley, the water is probably of the same chemical quality as that in the upper part of the deposits of Tertiary age. Analyses of water from wells (C-2-1)7ccc-1, (C-2-2)8baa-2, (C-2-2)8baa-3, (C-2-2)9bca-1, and (C-2-2)9bdb-1, which are in deposits of Tertiary age, indicate that the dissolved-solids content ranges from 488 to 647 mg/l. The dissolved-solids content of water from wells (C-3-2)4adb-1, (C-3-2)5aac-1, and (C-3-2)5acb-1, which are in the principal aquifer, ranges from 636 to 719 mg/l.

The recharge to the area west of Garfield, at the north end of the Oquirrh Mountains, is practically all from bedrock in the mountains. Heavy pumping of wells in secs. 15 and 17, T. 1 S., R. 3 W., has caused the potentiometric surface to become nearly flat near the Great Salt Lake (pl. 1). Comparison of chemical data of water from the well field and the lake, however, suggests that there has been no induced recharge from the lake up to 1969.

The dissolved-solids content of water from the Garfield well field ranged from 3,000 to 13,000 mg/l and that from Great Salt Lake from 197,000 to 261,000 mg/l. The mean chemical composition of these waters is given below:

	Garfield well field[1] (milligrams per liter)	Great Salt Lake[2] (milligrams per liter)
Calcium (Ca)	341	236
Magnesium (Mg)	143	7,360
Sodium plus potassium (Na+K)	2,740	74,102
Bicarbonate (HCO_3)	293	393
Sulfate (SO_4)	341	16,900
Chloride (Cl)	4,770	122,000
Dissolved solids	8,520	220,000

[1]Mean of 12 analyses of water from seven wells in secs. 15 and 17, T. 1 S., R. 3 W.

[2]Mean of 22 analyses of water from south end of Great Salt Lake (Hahl and Handy, 1969, p. 31-33).

The ratios of sodium to total cations and of chloride to total anions for water from the well field and Great Salt Lake are very similar, as shown below:

	Sodium / Total cations	Chloride / Total anions	Calcium / Magnesium	Calcium / Sodium	Magnesium / Sodium
Garfield well field	0.81	0.92	1.45	0.14	0.10
Great Salt Lake	.84	.90	.019	.004	.19

However, the marked differences in the calcium-magnesium ratio (76 times as great for the Garfield well field water as that for the lake), the calcium-sodium ratio (35 times as great), and the magnesium-sodium ratio (twice as great) indicates that water in the well field has not been contaminated with water from Great Salt Lake.

Jordan Valley receives small amounts of recharge as underflow from Davis County, as underflow from Utah County through the Jordan Narrows, and from water moving upward along faults. The underflow from Davis County north of the Salt Lake salient contains less than 500 mg/l of dissolved solids, thus accounting for water of similar quality in the extreme northeastern part of Jordan Valley (pl. 2). The dissolved-solids content of underflow through the Jordan Narrows probably ranges from 500 to 1,000 mg/l, which is similar to the dissolved-solids content of the water in the principal aquifer that is derived from recharge from bedrock in the adjoining area. The water moving upward along the Warm Springs fault north of Salt Lake City, as estimated from analyses of Becks Hot Springs, (B-1-1)14dcb-S1, and Wasatch Warm Springs, (B-1-1)25dbb-S1, contains about 10,000 mg/l of dissolved solids. The water issuing from Crystal Hot Springs, (C-4-1)11cab-S1, however, contains only 1,390 mg/l of dissolved solids.

The change in chemical quality of ground water in the principal aquifer as it moves through Jordan Valley from an area of recharge toward an area of discharge is illustrated graphically in figure 77. The direction of movement of the ground water is shown by the "Approximate flow line" on plate 2.

The chemical quality of the water at well (D-2-1)22cac-2, at the southeast end of the flow line near the mouth of Big Cottonwood Canyon, reflects the large amount of recharge water of good chemical quality to that area. Proceeding northwestward, the water at wells (D-2-1)22cac-2 and (C-1-1)35ddb-4 shows an increase in the dissolved-solids content and the concentration of all major ions in solution except for sodium, which decreases between wells (D-2-1)22cac-2 and (D-2-1)7cbd-4. The increases are due to the length of time that the water has been in contact with the aquifer materials; the slight decrease in sodium concentration suggests possible cation exchange. Between the wells (C-1-1)35ddb-4 and (C-1-1)26ccd-1 the sulfate, magnesium, and sodium concentrations decrease slightly, but the concentrations of all other constituents and the dissolved solids continue to increase as the water moves through the aquifer.

Proceeding northwestward, the principal change between the water from wells (C-1-1)26ccd-1 and (C-1-1)9aab-1 is the exchange of sodium for calcium and magnesium and the increase in chloride concentration, summarized from figure 77 in the table below:

	Concentrations, in milliequivalents per liter		
	(C-1-1)26ccd-1	(C-1-1)9aab-1	Difference
Calcium and magnesium	4.85	2.93	-1.92
Sodium	.91	3.52	+2.61
Chloride	.42	1.13	+.71
Surplus sodium			.69

Exchange of equivalent amounts of sodium for calcium and magnesium leaves a surplus of 0.69 milliequivalents of sodium, which is nearly equal to the 0.71 milliequivalent increase in the chloride concentration. Between wells (C-1-1)9aab-1, (C-1-1)5aad-4, and (B-1-1)19bab-1 the increase in dissolved-solids content is due principally to the large increase in the sodium and chloride content as the water moves slowly through thick deposits of fine sediments that contain large quantities of salts. Sulfate decreased between the latter two wells, due to reduction to sulfide. Hydrogen sulfide, and in places methane gas, is characteristic of ground water in most of the northern part of the valley.

Temperature

The temperature of ground water varies considerably areally and with depth, but it is not subject to pronounced fluctuation as is air temperature. At depths of only a few feet beneath the land surface, the insulation from temperature fluctuations at the surface is sufficient to maintain a nearly constant water temperature, which generally is a degree or two above the mean annual air temperature. At greater depths, the water temperature tends to increase with depth because of the geothermal gradient.

This general pattern of ground-water temperature is modified locally where recharge to an aquifer is by unusually cold or hot water. For example, large quantities of recharge by melting snow tend to lower the temperature; and upward movement of hot water from great depth or from near a local heat source (such as a large body of relatively recent volcanic rocks) tends to raise it.

Table 29 shows the water temperatures measured at various depths from temperature logs of selected wells in Jordan Valley and the change in temperature per 100 feet between the depths at which measurements were made. The average of the temperature gradients is 1.2°C per 100 feet. In general, the temperature gradient is much below the average in wells near areas of recharge. Those gradients that are much above the average are in wells near bodies of relatively recent volcanic rocks or areas of discharge near the Great Salt Lake.

The temperature of water in the principal aquifer ranges from about 7°C (45°F) at the mouth of Little Cottonwood Canyon to about 56°C (133°F) at Becks Hot Springs. The lower temperature is about 5.6°C (10°F) below the 1951-60 mean annual air temperature at the Cottonwood Weir climatologic station (near the mouth of Big Cottonwood Canyon) and reflects the effects of recharge by melting snow. The higher temperature is the result of upward movement of hot water along the Warm Springs fault.

The areal distribution of the water temperature in the principal aquifer is shown in figure 78. The indicated boundaries between temperature zones are only approximate because they are

Table 29.—Average change in the water temperature, in degrees Celsius, per 100 feet in selected wells, in Jordan Valley

Aquifer: A, principal aquifer; B, deposits of Tertiary age; C, principal aquifer and deposits of Tertiary age.
Temperature: Determined by thermistor survey in well.

Well number	Aquifer	Temperature (° C)	Depth (feet)	Temperature (° C)	Depth (feet)	Change in temperature per 100 feet (° C)
(A-1-1)31ccc-2	A	13.8	160	14.0	370	0.1
(B-1-3)34bcb-1	A	26.3	672	28.1	744	2.5
(C-1-1)19caa-1	C	25.5	452	32.8	1,038	1.2
20bdd-1	C	24.8	611	26.0	908	.4
24bbd-2	C	17.2	484	19.2	740	.8
25aab-4	C	13.9	100	20.5	930	.8
25bdb-1	C	17.1	550	18.2	986	.3
30dca-1	C	14.7	144	17.0	385	1.0
(C-1-2)24aaa-2	A	23.3	192	24.7	454	.5
24dba-1	C	23.8	307	30.9	840	1.3
25aad-1	C	15.1	300	26.1	778	2.3
(C-1-3)15bca-2	C	15.3	60	27.5	520	2.7
	B	27.5	520	27.7	869	.1
15cbb-2	C	16.3	35	30.5	430	3.6
	B	30.5	430	30.5	570	.0
15dbb-1	C	14.7	20	18.9	435	1.0
(C-2-1)3cdd-4	A	14.3	30	20.2	637	1.0
9ccc-1	B	16.6	187	23.8	781	1.2
12aab-1	C	14.0	150	19.2	608	1.1
(C-2-1)24bcd-1	C	12.7	80	25.3	986	1.4
25ddb-2	C	15.0	90	24.2	785	1.3
(C-2-2)9bdb-1	B	13.5	100	14.2	448	.2
(C-3-1)1cab-2	C	16.2	50	29.3	766	1.8
5dbb-1	C	13.9	185	17.6	440	1.5
(C-3-2)4adb-1	C	14.9	160	18.2	880	.5
(C-4-2)1bbb-1	C	13.0	82	17.0	531	.9
9bad-1	B	14.3	135	22.1	590	1.7
(D-1-1)16caa-1	A	11.2	60	13.3	466	.5
(D-2-1)6dbb-10	C	11.5	20	18.0	650	1.0
8daa-5	C	10.5	18	14.5	434	1.0
(D-3-1)2ccc-1	C	12.9	550	14.8	996	.4
4bbb-1	A	11.7	324	11.7	800	.0
	B	11.7	800	13.0	886	1.5
18cba-1	A	15.5	80	20.5	308	2.2
20baa-1	C	15.7	197	19.9	542	1.2
21ada-1	C	11.1	400	11.5	626	.2
29cbc-1	C	18.0	58	30.6	269	6.0

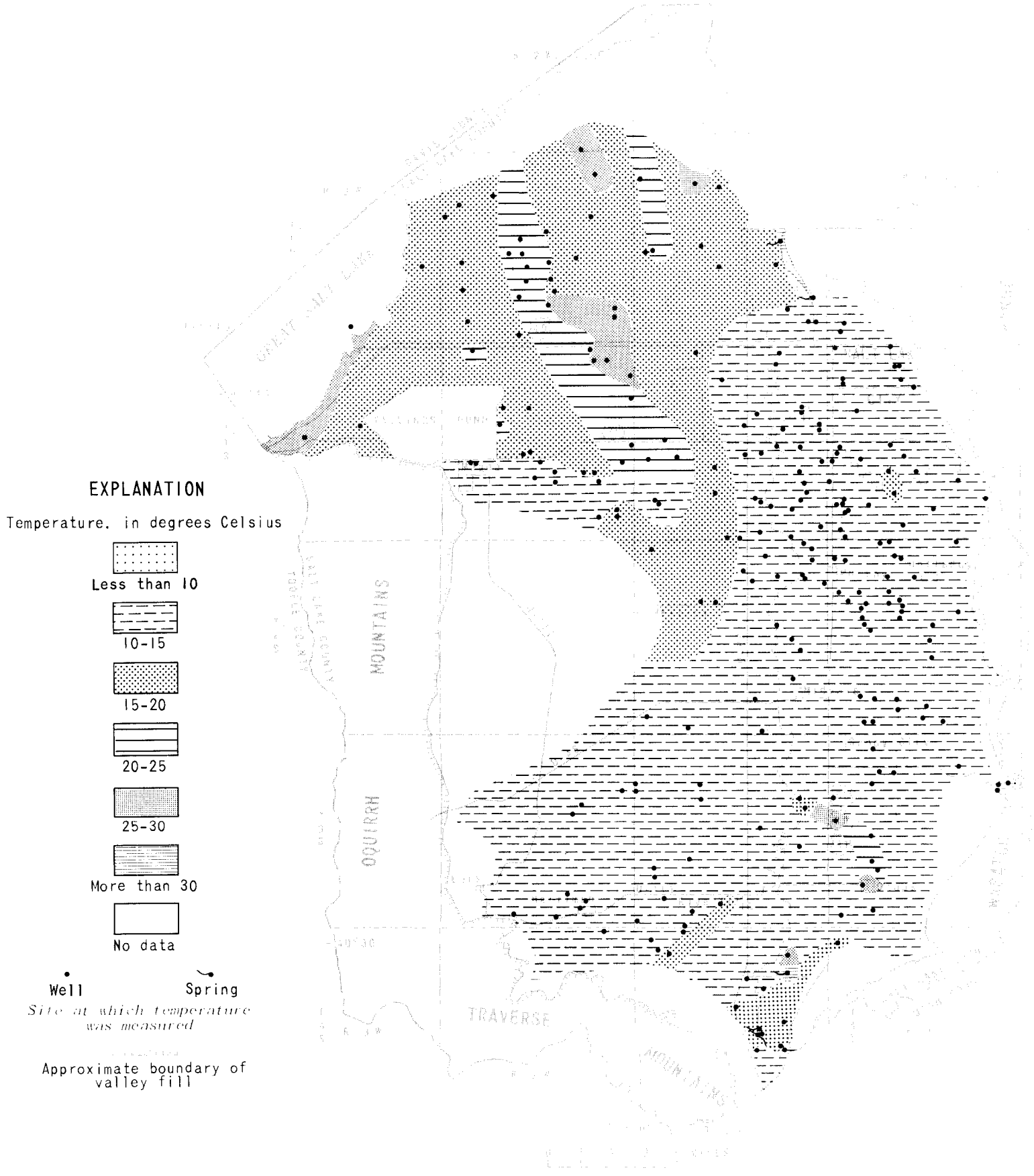


Figure 78.—Areal distribution of water temperature in the principal aquifer in Jordan Valley.

based on available temperature data, which generally represent only a portion of the aquifer. Thus, the map represents measured temperatures at existing wells rather than averages for the entire aquifer.

Figure 78 indicates that in general water temperatures are lower near areas of recharge from the mountains and higher near the area of discharge in the northern part of the valley. Departures from the general pattern exist locally near Becks and Crystal Hot Springs, (B-1-1)14dcb-S1 and (C-4-1)11ad-S1; in the southeast part of the valley near Draper where wells have encountered an extensive body of volcanic rocks; and in the north-central part of the valley. The source of heat in the latter area may be exothermic reactions in organic clays in the valley fill (Marine and Price, 1964, p. 59).

WATER USE AND WATER LOSS

Although the available water supply often limits the amount of water use, there is no simple relation between the two quantities because of the many kinds of use. Some uses, such as the generation of hydroelectric power, may involve neither depletion of the supply nor impairment of its quality. Most other uses, however, involve withdrawal of water from surface or underground sources, consumption of a part, and return of the remainder (usually with some impairment of the quality). Also, the storage of water in surface reservoirs to make it available for use involves a loss by evaporation.

Records of water use in Salt Lake County generally are limited to records of withdrawal. The amounts of water returned to streams and aquifers and the amounts consumed can be determined or approximated only by indirect means.

Summary of withdrawals

The mean annual withdrawal of surface water for use in Salt Lake County during October 1963 to September 1968 was 455,000 acre-feet, and the withdrawal of ground water during January 1964 to December 1968 was 126,000 acre-feet. All withdrawals are listed by type of use in table 30. The classification of uses is only approximate. Some of the water shown under municipal use, for example, may have been used in small industrial plants. Domestic use may be similar to municipal use, but as used herein, it applies where there is no public supply. Water from springs within Jordan Valley is included with ground water; and water from springs at or above canyon mouths is included with surface water. The summary in table 30 does not include temporary withdrawals in pipelines for hydroelectric-power generation.

The combined withdrawal from seven Wasatch streams during 1964-68 for all uses (except power generation) was 93,700 acre-feet per year—about 62 percent of the corresponding runoff at the canyon mouths and about 70 percent of the normal runoff (table 4). Most of the remaining runoff was wasted to Great Salt Lake.

The withdrawals from Deer Creek Reservoir through the Salt Lake City aqueduct were less than 22 percent of the amount available to the Metropolitan Water District of Salt Lake City (61,700 acre-ft), but some of the district's share was delivered through the Utah Lake Distributing Co. Canal for irrigation.

The total of the withdrawals from the Jordan River exceeded the discharge of the river at any one point because of the gains in streamflow within the Jordan Valley and reuse of water previously diverted and returned to the river.

Table 30.—Summary of water withdrawals in Salt Lake County, 1964-68

[Data from annual basic-data releases (Iorns and others, 1966a and 1966b; Hely and others, 1967-69), except that withdrawals from ground water are based on more complete data. Surface-water data are for water years and ground-water data are for calendar years]

Source	Mean annual withdrawal, in acre-feet
Municipal use	
Little Cottonwood Creek	10,700
Big Cottonwood Creek	22,300
Mill Creek	1,590
Parleys Creek	9,740
Emigration Creek	1,600
Red Butte Creek	640
City Creek	7,320
Salt Lake City aqueduct	13,500
Total surface water	67,400
Ground water (from wells and springs)	44,000
Total for municipal use (rounded)	111,000
Domestic and stock use	
Ground water	30,000
Industrial use	
Jordan River [1]	66,100
Kennecott Copper Corp. pipeline	9,500
Total surface water	75,600
Ground water (from wells and springs)	46,700
Total for industrial use (rounded)	122,000
Irrigation use	
Little Cottonwood Creek [2]	24,900
Big Cottonwood Creek [2]	12,600
Mill Creek	2,270
Jordan River	219,000
Utah Lake Distributing Co. Canal	25,600
Provo Reservoir Canal	28,000
Total surface water	312,000
Ground water	5,000
Total for irrigation use (rounded)	317,000
All uses	
Surface water	455,000
Ground water	126,000
Total for all uses (rounded)	580,000 [3]

[1] Includes 15,300 acre-feet diverted to industrial and powerplants but returned to the Jordan River with little depletion and not included in records of diversion in basic-data releases.

[2] Some water diverted from the Jordan River was spilled into the creek, where it was diverted again for irrigation. To avoid duplication, the amount shown here excludes the Jordan River water.

[3] This total does not include approximately 205,000 acre-feet of surface water from Jordan River system (table 19), 11,000 acre-feet of ground water (table 33), and 10,000 acre-feet of surface water from Davis County (p. 188), all used in the waterfowl-management areas.

Total withdrawal of ground water was about a third of the mean annual recharge (367,000 acre-ft) or half the natural recharge. (See p. 140-143.)

Evapotranspiration

For all practical purposes consumptive use in the Jordan Valley is by evapotranspiration. A large part of all the water that reaches Salt Lake County would be consumed by evapotranspiration (evaporation from water and moist surfaces plus transpiration by vegetation) even if no water were withdrawn for use. A part of the water withdrawn is consumed by evapotranspiration; and if the maximum possible use were made of the water supply, nearly all of it would be consumed.

In most areas the supply of moisture at the surface is limited or absent at times; consequently, the evapotranspiration generally is less than the corresponding evaporation from water surfaces. However, in a few areas where certain types of vegetation grow in shallow water or wet soil, the evapotranspiration exceeds the evaporation from water surfaces.

Evapotranspiration from most areas follows a seasonal pattern similar to that of evaporation from water surfaces (fig. 19) but modified by the availability of soil moisture. In addition to the seasonal variations, there are large areal variations because of differences in the vegetative cover, nature of the land surface, availability of soil moisture, and climatic factors.

Estimates of evapotranspiration often are based on some type of water budget, which may apply to a small experimental plot or to a large drainage basin. In many regions of the United States the best estimates are based on water losses as shown in table 20. Where subsurface outlfow is known to be very small relative to the runoff, the evapotranspiration is nearly equal to the water loss. However, the data in table 20 and a brief study of water losses[1] from most other gaged basins in the mountains of northern Utah indicate that substantial subsurface outflow from mountain drainage basins is common, because the water loss is larger and more variable than the evapotranspiration normally expected. Hence, other methods have been used to estimate evapotranspiration from the mountainous parts of Salt Lake County.

Mountainous areas

Estimates of evapotranspiration from mountainous areas enable the separation of water losses, listed in table 20, into their components of evapotranspiration and subsurface outflow. Most of the outflow moves through the mountain bedrock directly into aquifers beneath Jordan Valley and from the channel deposits in the mountain canyons into the fill in Jordan Valley as described in the discussion of ground-water recharge. Hence, estimates of evapotranspiration provide additional information or confirmation of other estimates concerning the ground-water recharge.

The most definitive information on evapotranspiration from the mountains of northern Utah has been derived from numerous experimental plots in several locations by the U.S. Forest Service in its studies of forest management and effects of vegetation on water yields (Croft and Monninger, 1953; Johnson, Tew, and Doty, 1969). In general, the method of determining evapotranspiration consisted of measuring the depletion of soil moisture during the growing season after the soil had drained to field-moisture capacity, adding the amount of rainfall during this period, and adding estimated evapotranspiration for the period (including the winter months) preceding the attainment of field capacity.

[1] Determination of a reliable value of the water loss requires precipitation and runoff data for the same period, preferable the 1931-60 water years. However, approximate values, determined by precipitation during 1931-60 and runoff during a shorter period, are useful for the selection of stations where the water loss is likely to be smallest, and hence, a fair approximation of evapotranspiration.

W.E. Cook and R.L. Jensen (written commun., 1969) of the U.S. Bureau of Reclamation used these Forest Service data to estimate basinwide evapotranspiration in each of the gaged basins and also in the ungaged basins of the Wasatch Range in Salt Lake County. In making these estimates, Cook and Jensen considered the effects of type of vegetation, bare ground, altitude, precipitation, and geology (generalized). The results of this study are summarized in table 31, and an estimate for the Oquirrh Mountains is added.

Table 31.—Estimated normal annual evapotranspiration and subsurface outflow from selected mountain areas in Salt Lake County

[Water losses are from table 20. Drainage area measured near canyon mouth or edge of Jordan Valley. Evapotranspiration from the Wasatch Range was estimated by W.E. Cook and R.L. Jensen (written commun., 1969). Subsurface outflow is water loss less evapotranspiration.]

Drainage basin	Drainage area (acres)	Water loss (inches)	Evapotranspiration (inches)	Inches	Acre-feet
Little Cottonwood Creek	17,500	19	14.9	4.1	6,000
Big Cottonwood Creek	32,000	27	18.8	8.2	22,000
Mill Creek	13,900	29	17.7	11.3	13,000
Parleys Creek	32,400	25	16.3	8.7	23,000
Emigration Creek	11,500	23	15.2	7.8	7,500
Red Butte Creek	4,640	23	15.7	7.3	2,800
City Creek	11,300	20	17.0	3.0	2,800
Ungaged adjacent areas	31,000	23[1]	15	8	21,000
Wasatch Range (rounded)	154,000	----	----	----	98,000[2]
Oquirrh Mountains (rounded)	39,000	19	13[3]	6	20,000

[1]Precipitation was about 31 inches, and the estimated runoff was about 8 inches.

[2]From additional considerations described on p. 176, the writers estimated the subsurface outflow from the Wasatch Range by this method to be 110,000 acre-feet (this includes 1,500 acre-feet of underflow in the channel fill at the canyon mouths).

[3]This value assumed to be somewhat less than any of those shown for the Wasatch Range because of lower precipitation and sparse vegetation.

Numerous errors that may be involved in the estimates just described could cause the results to be either high or low; but certain assumptions, described below, tend to produce estimates of evapotranspiration that are too high and estimates of subsurface outflow that are too low.

The assumption that no downward movement of moisture occurs after field-moisture capacity is attained once was believed to be valid but has since been proven erroneous (Willardson and Pope, 1963). The effect of continuing deep seepage probably would be appreciable for irrigated plots where moisture is frequently restored to field capacity but would be small (as assumed by the investigators) for unirrigated areas where summer rains seldom penetrate more than a few inches.

The assumption that all summer rainfall was lost by evapotranspiration probably is valid for the experimental plots, but obviously is not for some larger areas where summer rains often produce temporary increases of streamflow from surface runoff and from the discharge of ground water.

Perhaps the greatest uncertainty involved in transferring the experimental data to larger areas concerns the representativeness of the soil depths in the experimental plots. The soil depth in all plots was about 5-8 feet or more, so that approximately full root development could occur in each plot. Even casual observation suggests that vegetation of the types grown on the plots (chiefly aspen, oak, brush, and herbaceous plants) often grow in much shallower soils with correspondingly less water-holding capacity. Hence the basinwide average soil-moisture depletion may be somewhat less than the amounts derived from the experimental data.

Returning to the concept of estimating evapotranspiration from computed water losses, a few basins in northern Utah might be expected to have negligible subsurface outflow even though such outflow is common. Unfortunately, few records of unregulated streamflow in northern Utah outside of Salt Lake County are long enough for determination of normal runoff corresponding to the normal precipitation (fig. 4). However, Reid and others (1968) made correlative estimates that enable such determinations for a few additional areas. The five stations at which the least normal water losses were found are listed below. All areas are in counties adjacent to Salt Lake County and in the Jordan River drainage except Holmes Creek near Kaysville which discharges into Great Salt Lake.

Gaging station	Water loss, in inches
Holmes Creek near Kaysville, Davis County	11.8
Provo River near Kamas, Summit County	11.9
Dry Creek near Alpine, Utah County	10.7
Fort Creek near Alpine, Utah County	14.1
Summit Creek near Santaquin, Utah County	14.6

Evapotranspiration tends to be low where precipitation is low because of the small supply of moisture. Even with due consideration of such tendency, however, all the losses listed above are less than the evapotranspiration shown in table 31. The three areas with the least losses are characterized by steep slopes, thin soils or bare rock, and sparse vegetative cover. Hence, runoff probably is greater than average (and water loss less than average) for areas of similar size and with similar precipitation. Nevertheless, the five listed losses considered together suggest that basinwide averages of evapotranspiration are somewhat less than those calculated by Cook and Jensen.

An average error of 1 inch in the estimated evapotranspiration from the Wasatch Range in Salt Lake County corresponds to an error of 12,800 acre-feet. On the basis of all the information discussed above, the writers estimate the evapotranspiration to be about 1 inch less than that shown in table 31, and the subsurface outflow computed by this method to be about 110,000 acre-feet per year. Comparision of this figure with a corresponding figure for subsurface outflow computed by the method of Darcy's law results in a mean value of 106,000 acre-feet per year (see p. 121) which is applied to the budget in table 32.

The estimates for the Oquirrh Mountains are less reliable than those for the Wasatch Range because of a paucity of information on both runoff and evapotranspiration. These results are compared with other information in the discussion of ground-water recharge (p. 121).

Jordan Valley

Evapotranspiration from areas within Jordan Valley varies markedly with the nature and use of the land. Annual rates range from a few inches in areas that are mostly covered by buildings and pavement to about 56 inches in waterfowl-management areas described later. Where the only moisture available to plants is from local precipitation, the annual evapotranspiration rate is equal to or less than the annual precipitation; but where additional water is naturally available to plant roots or is applied by irrigation, the rate often exceeds the annual precipitation.

Land use varies greatly, even with small areas; but the generalized map in figure 79 shows the areas in which certain uses predominate. Because of the complexity of the detailed pattern of land use, continual change of pattern, and lack of information about evapotranspiration for certain types of land use, estimates of consumptive use from some parts of Jordan Valley would be of dubious value. Estimates for certain other parts and for the valley as a whole, however, are significant for this investigation.

The best estimate of the loss by evapotranspiration from the entire valley is obtained from a water budget, in which evapotranspiration is the only significant item that cannot be measured or satisfactorily estimated by other means. The budget is shown in table 32.

Table 32.—Water budget for Jordan Valley, 1964-68

[Mean annual quantities, in acre-feet.]

Surface inflow (table 18)	463,000
Subsurface inflow (see table 21)	
At Jordan Narrows	2,500
From bedrock	135,000
In channel fill	1,500
Precipitation on valley floor (derived from fig. 5)	464,000
Total inflow	1,066,000
Increase in ground-water storage	3,000
Surface outflow (table 19)	324,000
Subsurface outflow (see p. 136-137)	4,000
Evapotranspiration (inflow minus storage increase minus outflow)	735,000
Total outflow	1,063,000

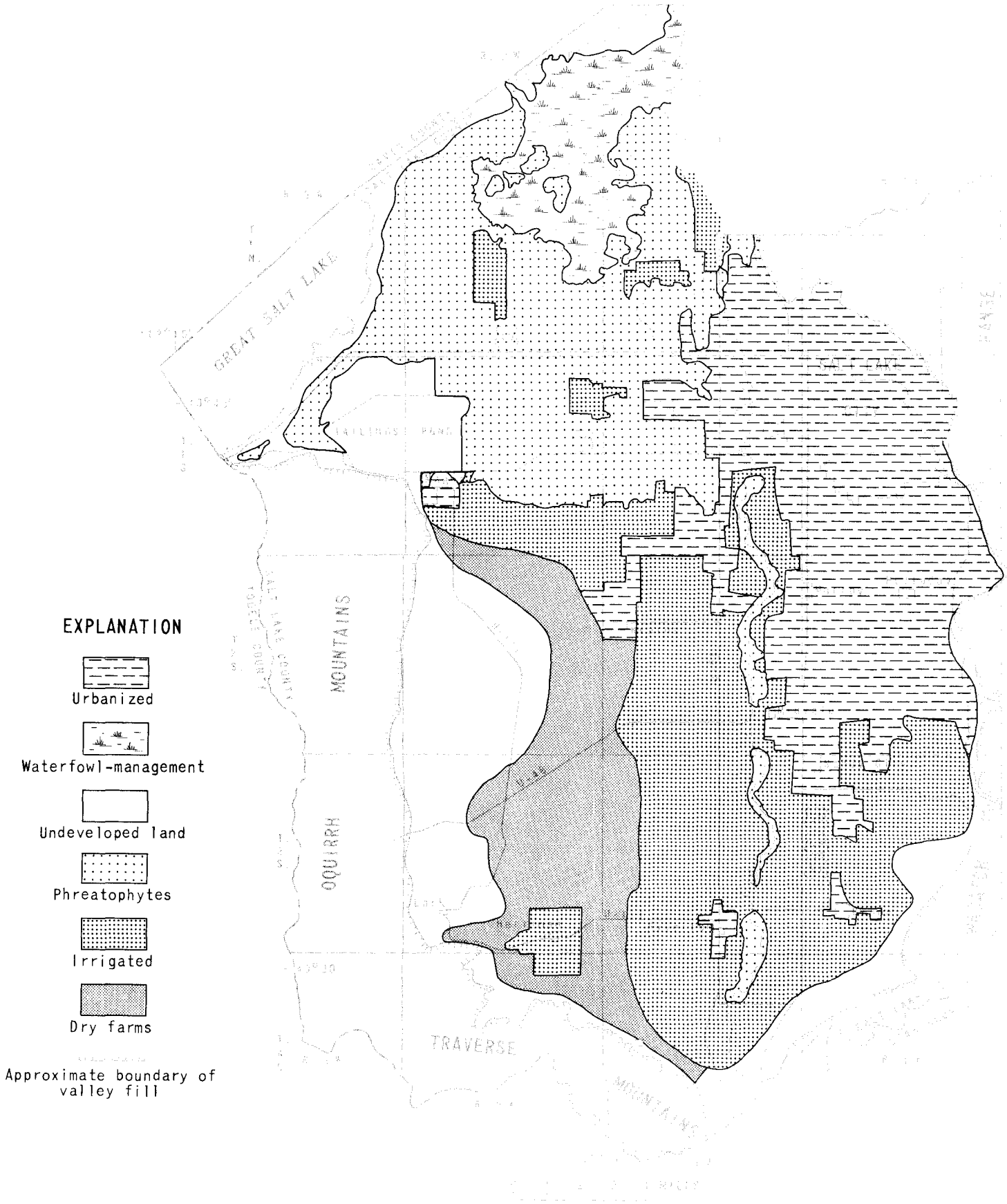


Figure 79.—Generalized pattern of dominant land uses in Jordan Valley, 1964-68.

The total inflow in this budget is the approximate amount of water that reached the valley from all sources. This was disposed of by surface and subsurface outflow, an increase in ground-water storage, and evapotranspiration. Net changes in storage in surface reservoirs and soil moisture are considered negligible. Thus, the evapotranspiration equals the total inflow minus the surface and subsurface outflow and the increase in ground-water storage. This quantity of evapotranspiration is equivalent to an average depth of 2.3 feet (about 28 in.) on the budget area of about 320,000 acres (area of valley fill).

Evapotranspiration from the parts of Jordan Valley, where the loss is of particular hydrologic significance, is discussed in following sections.

Areas of evapotranspiration of ground water

In the northern part of Jordan Valley and along the Jordan River farther south, the water level in the shallow unconfined aquifer is so close to the land surface that ground water is lost by evapotranspiration. Such loss, totaling 60,000 acre-feet per year (table 33), is significant because it is part of the ground-water discharge (table 22) and also because a part of the loss could be prevented by effective management of the ground-water reservoir. Much of the loss is associated with native vegetation of low economic value or with waterfowl-management areas. The low-value vegetation generally consumes more water than common cultivated crops.

The areas where the average depth to water in August 1968 was 15 feet or less are shown in figure 80. Water-level fluctuations in these areas during 1964-68 (figs. 71-73) were relatively minor; therefore, figure 80 is reasonably representative of depths during the entire period. The areas where ground water was lost by evapotranspiration and several categories of land use and vegetal types within these areas are shown on plate 5.

Plants that grow in saturated soils or shallow water are classified as hydrophytes; those that usually grow where the water table is appreciably below the land surface but within reach of roots are classified as phreatophytes. The quantities of water consumed vary with plant species, depth to water, and density of the foliage. Because of these variations, reliable estimates of the amounts of water consumed require a variety of information on land use and vegetal types as described in the following section.

Classification and mapping of the areas

The entire area of evapotranspiration of ground water was divided into five major categories, as shown in table 33, by field inspection and by using aerial photographs and topographic maps. The phreatophyte category was further subdivided by dominant plant species or groups of species; the different species generally were easily distinguished on the photographs. The photographs were taken during 1964, and the field inspection was made during the summer of 1968. Hence, the results are representative of the 1964-68 period. As relatively little change in these areas has occurred since 1931, the results probably are fairly representative of the longer period also.

Nearly two-thirds of the area is in the phreatophyte category, which is most amenable to computation of evapotranspiration. The category includes a few tracts that were once cultivated but later abandoned. Also, a few tracts of meadow receive about one irrigation per year when surplus river water is available.

Bare ground, as used in table 33, does not include the shore of Great Salt Lake below an altitude of 4,205 feet. Ground-water discharge below this level has been included as part of the

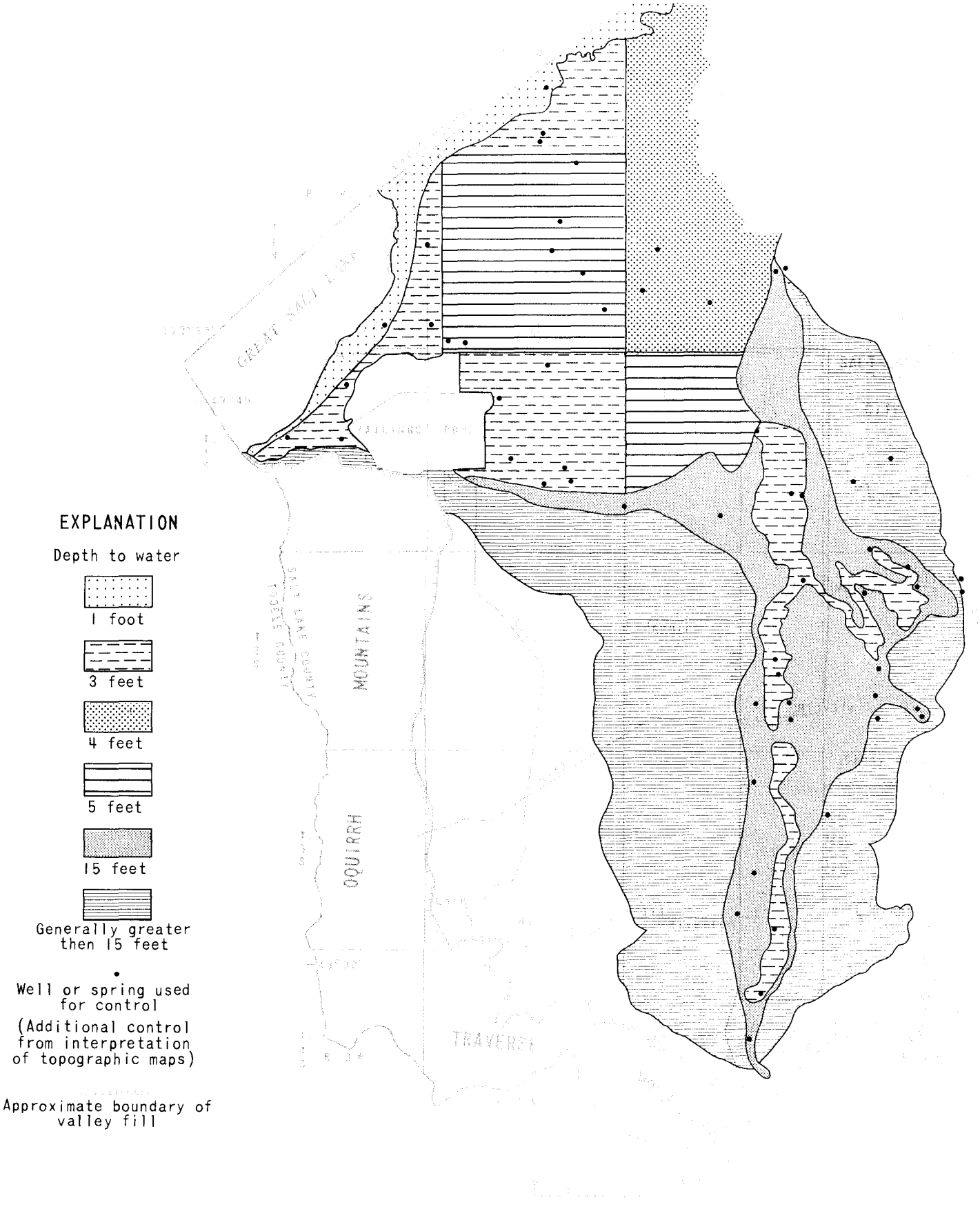


Figure 80.—Average depths to water in the shallow unconfined aquifer, August 1968. Data generalized for input to analog model.

Table 33.—Summary of seasonal evapotranspiration of ground water, by land category and township, 1964-68

Township	Phreatophytes		Bare ground		Cultivated		Urbanized		Waterfowl-management		Total	
	Area (acres)	Evapotranspiration (acre-feet)	Area (acres)	Evapotranspiration (acre-feet)	Area (acres)	Evapotranspiration (acre-feet)	Area (acres)	Evapotranspiration (acre-feet)	Area (acres)	Evapotranspiration (acre-feet)	Area (acres)	Evapotranspiration (acre-feet)
T. 1 N., R. 1 W.	8,390	6,370	0	0	1,600	610	1,600	610	1,700	1,290	13,290	8,880
T. 1 N., R. 2 W.	15,180	10,260	800	540	1,400	470	0	0	5,400	3,610	22,780	14,880
T. 1 N., R. 3 W.	1,830	1,510	900	740	0	0	0	0	0	0	2,730	2,250
T. 2 N., R. 1 W.	1,510	1,420	0	0	0	0	0	0	4,000	3,760	5,510	5,180
T. 2 N., R. 2 W.	820	790	600	580	0	0	0	0	2,500	2,410	3,920	3,780
T. 1 S., R. 1 W.	7,050	6,180	0	0	400	170	1,200	510	0	0	8,650	6,860
T. 1 S., R. 2 W.	11,270	12,050	100	110	900	480	100	50	0	0	12,370	12,690
T. 1 S., R. 3 W.	1,210	1,610	100	150	0	0	0	0	0	0	1,310	1,760
T. 2 S., R. 1 W.	1,040	1,320	0	0	600	380	100	60	0	0	1,740	1,760
T. 3 S., R. 1 W.	850	1,000	0	0	100	60	0	0	0	0	950	1,060
T. 4 S., R. 1 W.	530	930	0	0	0	0	0	0	0	0	530	930
T. 1 S., R. 1 E.	0	0	0	0	0	0	200	100	0	0	200	100
T. 2 S., R. 1 E.	0	0	0	0	0	0	1,400	700	0	0	1,400	700
Total (rounded)	49,700	43,000	2,500	2,100	5,000	2,200	4,600	2,000	13,600	11,100	75,400	60,000

discharge to Great Salt Lake. Perennial vegetation covers less than 10 percent of the area classed as bare ground, but dense growths of pickleweed seedlings cover parts of it at times.

Cultivated crops (mostly alfalfa and small grains) receive part of their water by irrigation with water diverted from the Jordan River, but they use some ground water that under natural conditions would be used by phreatophytes.

Some of the area formerly occupied by phreatophytes has been urbanized in recent years, and drains have been installed in parts of it to lower the ground-water level. Some evapotranspiration of ground water still occurs in these areas.

The waterfowl-management category, as used in table 33, is applied to an area that receives most of its water supply from the Jordan River. Hence, the total consumptive use is treated in a separate section of this report. The estimate of consumptive use of ground water, however, is based on data developed in this section.

The common phreatophytes and their characteristics have been described by Robinson (1958). Those that are significant in Jordan Valley are described briefly below, and their distribution is indicated on plate 5 and table 34.

Greasewood (*Sarcobatus vermiculatus*) is by far the most common phreatophyte in the valley and grows either alone or in association with almost all other phreatophytes. The range of depths to ground water in areas of greasewood is about 3-15 feet.

Saltgrass (*Distichlis stricta*) grows in low-lying areas and provides forage for livestock. It thrives on all but the most saline soils in the valley and often is associated with greasewood and pickleweed. The most dense growths were observed in areas where the water level was less than 2 feet below the land surface, and sparse growths were observed in some areas where the average depth to water was 10 feet.

Saltcedar (*Tamarix gallica*) has become firmly established along streams and shorelines of ponds and lakes. There are no mature stands in the valley, but the density is increasing and the plants are spreading into some areas where the average depth to water is less than 15 feet below the land surface. Although not native to the southwest, this species has proved to be an aggressive invader that has posed serious problems in many flood plains of the region.

Pickleweed (*Allenrolfea occidentalis*) grows chiefly where the depth to water is less than 5 feet, usually in association with saltgrass and greasewood.

Rabbitbrush (*Chrysothamnus nauseosus*) usually grows in association with saltgrass where the depth to water is 5-10 feet.

The collective term "meadow" has been applied to one of the phreatophyte subdivisions. About 75 percent of the vegetation is saltgrass; about 20 percent is threadleaf sedge (*Carex* sp.), Nebraska sedge (*Carex nebraskensis*), and alkali sacaton (*Sporobolus airoides*); and about 5 percent is other common species of phreatophytes or hydrophytes. The most vigorous meadow is associated with depths to water of less than 3 feet and with low to moderate soil and water salinity. Some tracts where the depth to water is greater than 5 feet are irrigated at times.

Other phreatophytes that grow in sparse stands, usually in association with more common species, include cottonwood (*Populus* sp.), Russian olive (*Eleagnus angustifolia*), and willow

Table 34.—Acreages, by township, of phreatophyte species and groups in Jordan Valley, 1968

Township	Greasewood	Saltgrass	Pickleweed	Meadow	Greasewood and saltgrass	Greasewood and pickleweed	Greasewood, saltgrass, pickleweed	Greasewood, saltgrass, rabbitbrush	Saltgrass and pickleweed	Saltgrass and saltcedar	Saltgrass and rabbitbrush	Saltcedar and rabbitbrush	Totals
T. 1 N., R. 1 W.	210	1,520	630	240	2,220	980	680	0	1,880	0	0	30	8,390
T. 1 N., R. 2 W.	3,210	760	1,430	0	1,790	5,360	1,640	0	910	80	0	0	15,180
T. 1 N., R. 3 W.	0	103	440	0	0	570	720	0	0	0	0	0	1,830
T. 2 N., R. 1 W.	0	0	340	0	0	100	0	0	1,070	0	0	0	1,510
T. 2 N., R. 2 W.	160	0	0	0	0	660	0	0	0	0	0	0	820
T. 1 S., R. 1 W.	60	1,310	180	1,300	2,690	0	180	180	950	160	40	0	7,050
T. 1 S., R. 2 W.	2,170	800	2,020	1,360	3,050	540	160	200	460	210	230	70	11,270
T. 1 S., R. 3 W.	0	0	0	380	0	30	800	0	0	0	0	0	1,210
T. 2 S., R. 1 W.	0	0	0	1,040	0	0	0	0	0	0	0	0	1,040
T. 3 S., R. 1 W.	0	0	0	850	0	0	0	0	0	0	0	0	850
T. 4 S., R. 1 W.	0	0	0	530	0	0	0	0	0	0	0	0	530
Totals	5,810	4,490	5,040	5,700	9,750	8,240	4,180	380	5,270	450	270	100	49,680
Percent of phreatophyte area	11.7	9.0	10.1	11.5	19.6	16.6	8.4	0.8	10.6	0.9	0.5	0.2	100

(*Salix* sp.). These were not mapped separately but were included with the major species in determining foliage density. Most stands were observed in areas where the water level was 3-15 feet below the land surface.

Quantitative estimates

Several partly empirical methods of estimating the evapotranspiration from vegetated areas have been developed. The reliability of results varies, depending on the type, completeness, and accuracy of the data used. In a comparative study of six of the most commonly used methods, Cruff and Thompson (1967, p. M27) concluded that the method developed by Blaney and Criddle (1962) is the most practical for use with the data generally available. Hence, this method has been used to estimate the consumptive use of water in the phreatophyte areas of Jordan Valley.

The Blaney-Criddle formula for consumptive use during an entire growing season is:

$$U = KF \tag{7}$$

where, U = consumptive use or evapotranspiration, in inches;

K = an empirical coefficient for the particular species of vegetation;

and F = a factor based on climatic characteristics.

The seasonal climatic factor, F, is the sum of monthly factors computed from normal monthly temperatures and the monthly percentage of the annual daytime hours. At the Salt Lake City International Airport F = 39.22 (Criddle, Harris, and Willardson, 1962, p. 11), and this value is applicable to the entire area with negligible error.

Values of K have been determined by experiments for several cultivated crops and species of native vegetation, generally at densities of approximately 100 percent. However, K depends on the availability of water to the plants as well as on the species. Values for cultivated crops generally apply when an adequate supply is available at all times, as in most irrigated fields. Values for phreatophytes vary with the depth to the water table.

Rantz (1968) made a study of the literature on values of K for phreatophytes and developed a family of curves showing the approximate relations of K to the depth to the water table for each of six common phreatophytes. Two of these curves are reproduced in figure 81 and were used in selecting values of K for Jordan Valley. Values of K for other phreatophytes were selected on the basis of the writers' experience and review of the literature.

The consumptive use of water also varies with density of foliage. The coefficient K generally is determined for cultivated crops or dense growths of phreatophytes. When the density is much less than the maximum, the value of K must be adjusted to reflect the lesser density. Rantz (1968) recommended that 0.85 K be used for medium growth and 0.70 K be used for sparse (light) growth. However, an objective method of estimating density is required.

The volume density, described by Gatewood and others (1950, p. 25), is an index of the phreatophyte's ability to consume water and is the product of the areal and vertical densities observed in the field. The areal density is the percentage of the land in a given parcel that is shaded by foliage when the sun is directly overhead. The vertical density is the percentage of the optimum depth of foliage for a particular species that is occupied by the actual foliage. When all densities are 100 percent, new growth generally is balanced by death of older foliage.

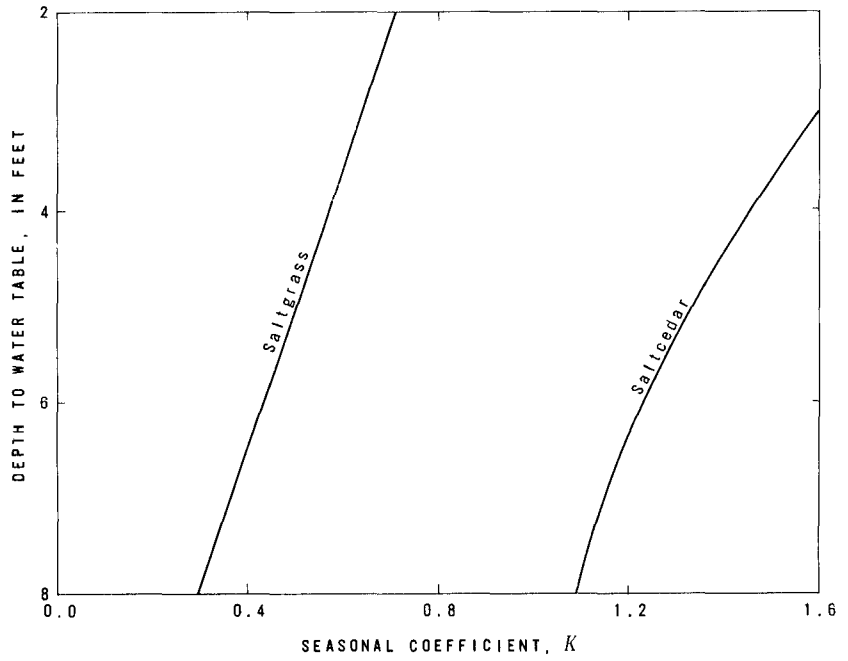


Figure 81.—Relations of the Blaney-Criddle coefficient, *K*, for saltgrass and saltcedar (under conditions of maximum use) to depth to the water table.

Vertical densities for all species in Jordan Valley except saltcedar were assumed to be 100 percent because the plants generally have been undisturbed for many years. The average vertical density of saltcedar was estimated to be 75 percent. The relations between these density indicators and the consumptive-use coefficient as used herein are shown below.

Adjective density	Volume density, in percent	Adjusted consumptive-use coefficient
Dense	Over 75	*K*
Medium	50-75	0.85 *K*
Sparse (or light)	Less than 50	0.70 *K*

The computation of seasonal evapotranspiration in the phreatophyte area is summarized by township and density class in table 35. For this purpose the meadow category (table 34) was considered as a separate class because of the different species and *K* values involved. The consumptive use, *U*, includes water from all sources but does not include evapotranspiration

Table 35.—Average seasonal evapotranspiration from phreatophyte areas, by townships, 1964-68

[Computed by equation 6. *U* is April-October evapotranspiration; *K* is a weighted average for each township representing all the species of significant density, and it is adjusted when necessary for effects of density; *F* is 39.22 at Salt Lake City International Airport. Evapotranspiration from ground water and irrigation water is (*U-Pe*)/12 times the area, where *Pe* is the effective precipitation, 9.6 inches. Figures in parentheses are estimated amounts of irrigation water, in acre-feet.]

Township	Density class	Area, in acres	Depth to water, in feet	*K*	Adjusted *K*	*U*, in inches	*U-Pe*, in acre-feet
T. 1 N., R. 1 W.	Dense	560			0.63	24.7	700
	Medium	1,540	4.3	0.63	.54	21.2	1,490
	Sparse	6,050			.44	17.3	3,880
	Meadow	240	3	.75	.75	29.4	400 (100)
T. 1 N., R. 2 W.	Dense	340			.61	23.9	400
	Medium	2,870	4.8	.61	.52	20.4	2,580
	Sparse	11,970			.43	16.9	7,280
T. 1 N., R. 3 W.	Dense	40			.70	27.4	60
	Medium	60	3.8	.70	.60	23.5	70
	Sparse	1,730			.49	19.2	1,380
T. 2 N., R. 1 W.	Medium	950	3.9	.67	.57	22.3	1,010
	Sparse	560			.47	18.4	410
T. 2 N., R. 2 W.	Medium	160	3.6	.74	.63	24.7	200
	Sparse	660			.52	20.4	590
T. 1 S., R. 1 W.	Dense	210			.65	25.5	280
	Medium	1,280	4.3	.65	.55	21.6	1,280
	Sparse	4,260			.46	18.0	2,980
	Meadow	1,300	3	.75	.75	29.4	2,140 (500)
T. 1 S., R. 2 W.	Dense	830			.73	28.6	1,310
	Medium	3,440	3.3	.73	.62	24.3	4,210
	Sparse	5,640			.51	20.0	4,890
	Meadow	1,360	3	.75	.75	29.4	2,240 (600)
T. 1 S., R. 3 W.	Medium	150	2.7	.74	.63	24.7	190
	Sparse	680			.52	20.4	610
	Meadow	380	2	.9	.9	35.3	810
T. 2 S., R. 1 W.	Meadow	1,040	3	.75	.75	29.4	1,720 (400)
T. 3 S., R. 1 W.	Meadow	850	3	.75	.75	29.4	1,400 (400)
T. 4 S., R. 1 W.	Meadow	530	2	.9	.0	35.3	1,130 (200)
Total (rounded)		49,700					45,000
Irrigation water applied (rounded)							2,000
Net evapotranspiration from ground water (rounded)							43,000

during the winter months. The last column in table 35 shows the evapotranspiration from ground water plus the small amount of irrigation water applied to meadows.

The effective precipitation, subtracted from the seasonal consumptive use, is an estimate of the amount of precipitation consumed by vegetation. As a rough approximation, the effective precipitation has been assumed equal to the average April-October precipitation at Salt Lake City International Airport during 1964-68, which was 9.6 inches. Some of this probably ran off and some may have infiltrated to the water table, but this may be approximately balanced by consumptive use of winter precipitation.

The use of 43,000 acre-feet of ground water by 49,700 acres of phreatophytes represents an average of about 10.4 inches. All this water is lost from the shallow aquifer; but as the net annual change of water levels is practically unaffected by the loss, most of the water must be replaced by upward leakage from the confined aquifer. The loss from ground water ceases in the winter, but the upward leakage continues. The observed fluctuations of water level are the net result of evapotranspiration and upward leakage.

Evapotranspiration from dense vegetation with an abundant water supply is similar to the corresponding evaporation from water surfaces, which in turn is approximately 0.71 times the pan evaporation (see the discussion of evaporation in the section on climate). Estimates of evapotranspiration thus can be based on pan-evaporation data. The relation involved is very similar to equation 6, pan evaporation (Ep) replacing F and a different crop factor (K') replacing K. At present the method cannot be considered independent of the Blaney-Criddle method because most published values of K' are derived from results of estimates by the Blaney-Criddle method. For those who are interested in using evaporation as an index, however, the following comparison is presented. From table 35, F is 39.2 and the depth of evapotranspiration from irrigation and ground water is (45,000 acre-ft/49,700 acres) x 12 = 10.9 inches. Adding the effective precipitation (9.6 inches), the total evapotranspiration (U) is 20.5 inches. The average pan evaporation during April-October in Jordan Valley is 57.8 inches (table 2), which is assumed to be applicable to the phreatophyte area. With F, U, and Ep determined, average values of K and K' can be computed. The respective equations and their components are compared as follows:

Method	Blaney-Criddle	Pan-evaporation
Formula	$U = K\,F$	$U = K'\,Ep$
Solution	20.5 = (0.524) (39.2)	20.5 = (0.355)(57.8)

When sufficient information is available, the use of distinct values of K and K' for different vegetal types rather than the average values derived above, provides more reliable results.

A summary of the evapotranspiration of ground water in all areas is shown in table 33. The computed amounts for the phreatophyte area were used as a basis for estimating the amounts consumed in other areas. For bare ground (where the water table or capillary fringe was at the land surface during most of the year or where the surface was covered with shallow water) and waterfowl-management areas (which were phreatophyte areas or areas covered with shallow water prior to their designation as waterfowl-management areas), the evapotranspiration of ground water was assumed to be at the same rate as in nearby phreatophyte areas (generally in the same township).

For cultivated and urbanized areas the rate was assumed to be half of that for nearby phreatophyte areas because of the effects of slightly higher ground (greater depths to water), artificial drains, buildings, and pavements. For example, in T. 1 N., R. 1 W. (first line of table 33), the average evapotranspiration in the phreatophyte area is 6,370 acre-feet from 8,390 acres or 0.76 foot. The same rate was used to compute values for bare ground and waterfowl-management areas, and 0.38 foot was used for cultivated and urbanized areas.

Although waterfowl-management areas are a part of the previously described area of evapotranspiration of ground water, the largest part of their water supply is from the Jordan River. They occupy 13,600 acres at the northern end of Salt Lake County (table 33) and about 6,000 acres in Davis County. Small streams in southern Davis County also contribute water to the management area there.

The consumption of water in waterfowl-management areas can be only approximated because of the variety of water sources, the complex system of dikes and weirs, leakage through dikes, and ever-changing areas of open water, marsh, and dry land. In an effort to obtain information on the water requirements of a management area that would be applicable to similar areas near the shore of Great Salt Lake, Christiansen and Low (1970) conducted studies at the Howard Slough Waterfowl Management Area about 20 miles north of Salt Lake City.

By measuring the surface inflow, precipitation, surface outflow, and the changes in surface storage, Christiansen and Low determined an amount of consumptive use that does not include any ground-water contribution. Their field data from piezometer clusters showed that the entire area was under artesian pressure; but efforts to determine the magnitude of the ground-water contribution were unsuccessful, and they considered it negligible.

Ground-water conditions at Howard Slough are similar to those in northern Jordan Valley, however, where the seasonal evapotranspiration of ground water is about 10 inches. Hence, this value probably applies to Howard Slough also.

On the basis of data for 3 years (1960, 1962, and 1963), Christiansen and Low (1970, table 5) computed the average March-November consumptive use of surface water and precipitation as 45.1 inches. Adding 10 inches for consumption of ground water makes a total seasonal use of 55 inches. An additional small amount of winter evaporation must be added to obtain an annual total. For the three winter months, pan evaporation is 3.4 inches (table 2), the corresponding evaporation from ponds and lakes is 2.4 inches, and the estimated evaporation from management areas (of which only parts are open water and parts are sheltered from wind by dormant vegetation) is about 1 inch. Thus the estimated total annual evapotranspiration is 56 inches.

During 1964-68 in the lower Jordan Valley about 16 inches of the annual total evapotranspiration was supplied by precipitation and 10 inches by ground water, leaving 30 inches that was supplied by streamflow. This depth of water on the total waterfowl-management area of 19,600 acres is 49,000 acre-feet. Assuming the contribution of small streams in Davis County to be 10,000 acre-feet, the depletion of Jordan River by use in the management areas was 39,000 acre-feet per year.

The amount of water consumed in a management area should not be confused with its total water requirement. Enough water must flow through the area to prevent excessive salinity of the water (see table 39), which would limit growth of mature vegetation and prevent propagation. Christiansen and Low (1970, p. 85-90) described a method of estimating the additional water requirement to prevent excessive salinity.

Projected use

The pattern of dominant land uses in Salt Lake County is expected to remain much as it is (fig. 79) for the forseeable future, except for the increasing density of population and commercial and industrial establishments in present suburban areas (Salt Lake County Planning Commision, 1965, p. 3). Urbanization and industrial development will be encouraged within the areas largely committed to such development but containing considerable agricultural and idle land. The irrigated acreage is expected to decline slightly as additional land is urbanized, but the largest tracts in the southern part of the valley probably will remain practically unchanged. Although the large area now in dry farms could be irrigated if water and the right to use it were available and economic conditions justified the cost, most of the increase in usable water supply probably will be for municipal and industrial users because such users can better afford the higher costs usually associated with additional supplies.

Projections of water requirements for municipal and industrial use necessarily are less reliable than the projections of population and industrial activity on which they depend. Municipal requirements are closely related to population, but industrial requirements are strongly influenced by the type of industry, the extent of reuse after previous withdrawal and discharge, and the extent of recycling within a plant before discharge. Although recycling usually involves additional costs because of the need to cool or purify the used water, it is becoming more common because of increasing costs of new water supplies and nationwide pressure for conservation of quantity and quality of water supplies.

Despite the uncertainty of future requirements, projections are necessary planning aids. In regions where water is scarce, the demand probably will reach any reasonable projection, if not by the forecast date, then at some later date. Some projections of future water requirements for Salt Lake County are listed in table 36.

Table 36.—Projections of population and annual water requirements for Salt Lake County

[Data from Templeton-Linke and Alsup, Consulting Engineers (1966, tables II and III). Projections by Bureau of Economic and Business Research, University of Utah. The requirements shown are for total withdrawal—not consumptive use.]

		Water requirements, in acre-feet	
Year	Population	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 of Salt Lake County exceed those listed in table 36 because the table does not include withdrawals for irrigation or domestic use, which totaled about 350,000 acre-feet per year during 1964-68. The requirements for domestic supply, 30,000 acre-feet per year in 1964-68, probably will decline as public supply systems are extended into new areas. Increasing urbanization will cause a slight reduction of irrigated acreage unless new areas are developed. If an abundant regulated supply of water becomes available, however, the requirements for the remaining acreage may increase. Some of the present irrigation diversions are subject to junior rights which provide for water only during short periods when water surplus to all senior rights is available. Presumably changes in the present system of water rights would accompany any change to a regulated water supply. Thus, the combined requirement for irrigation and domestic use may remain near 350,000 acre-feet per year. If so, the requirement for all uses except waterfowl management in the year 2020 would be near 1,200,000 acre-feet.

Part of the total requirement will be met by return flows from irrigation and industries where such flows enter the Jordan River above the Surplus Canal. Below that point, the quality of the water is too poor for many uses, but this situation may improve with improvements in the treatment of wastes before discharge to the river. The study of gains in the Jordan River suggests that about 20 percent of the water diverted for irrigation in Salt Lake County returns to the river. Most of the large industrial uses of water consume only a small part of the quantity diverted—commonly less than 10 percent. The water returned is available for reuse unless its quality is too badly impaired. However, water diverted to industries in the Garfield-Magna area is discharged to drains entering Great Salt Lake. Hence, there is opportunity for recycling (in addition to that now done) but not reuse after discharge. The net quantity of water available for reuse is highly conjectural, but in the year 2020 it might amount to a few hundred thousand acre-feet of the 1,200,000 acre-foot requirement.

Other changes in water use or water loss (such as evapotranspiration of ground water) are discussed in the next section on alternatives for future development.

Relation of water use and quality

The utilization of water depends in part upon the quantities and kinds of dissolved constituents present and certain physical properties such as color, turbidity, dissolved-oxygen content, temperature, and suspended-sediment content. An unlimited supply of water is of little consequence if its chemical composition or physical properties preclude its intended use.

Use of water for most purposes results in degradation of its quality so that reuse is limited unless the quality requirements for subsequent use are lower. Quality degradation may be due to the addition of contaminants, excessive increase in the dissolved-solids content, or excessive increase in temperature.

A small part of the water used for municipal and domestic purposes, (other than irrigation of lawns and gardens) is consumed, but most of it is returned to a stream or aquifer with an increased dissolved-solids content in addition to organic and bacterial contaminants. The increases in the concentration of the major constituents and the dissolved-solids content resulting from use of water in four communities and two improvement districts are shown in table 37.

Table 37.—Estimated chemical quality of public water supply and sewage of selected communities in Jordan Valley, 1965-66

[Concentration of dissolved constituents and dissolved solids given in milligrams per liter. Sodium (Na) and potassium (K) computed and reported as sodium (Na). Chemical quality of public water supply estimated from chemical analyses of individual sources and percent of total production, 1964-68. Chemical quality of sewage estimated from five analyses of sewage discharge from communities other than Salt Lake City, 1965-66. Data furnished by Utah State Department of Health. Estimate for Salt Lake City is weighted average for sewage canal, 1964 water year.]

	Salt Lake City		Murray		Midvale		Sandy City		Kearns		Granger-Hunter	
	Supply	Sewage	Supply	Sewage	Supply	Sewage	Supply	Sewage	Supply	Sewage	Supply	Sewage
Calcium (Ca)	50	134	48	82	30	74	29	66	43	46	44	94
Magnesium (Mg)	14	64	14	43	4.7	29	4.8	39	13	15	14	51
Sodium (Na)	11	548	12	142	8.1	120	6.2	142	16	108	57	326
Bicarbonate (HCO_3)	169	402	166	318	98	230	88	343	151	205	155	342
Sulfate (SO_4)	45	497	42	202	14	158	20	127	44	87	93	342
Chloride (Cl)	17	668	22	151	13	135	9.1	149	17	99	47	348
Nitrate (NO_3)	.6	2.5	1.7	8.0	2.3	27	1.7	14	.7	15	.3	33
Dissolved solids	236	2,130	225	784	134	693	128	783	225	520	353	1,390
Sewage facilities												
Population served[1]	198,000		20,000		17,612		8,994		20,000		24,600	
Average daily flow (cfs)	54		4.6		3.9		1.5		1.5		1.2	
Increase in dissolved solids	1,890		559		559		655		295		1,020	
Dissolved-solids load												
Tons per year	100,700		3,880		2,150		967		434		1,250	
Tons per year per 1,000 population	508		194		122		108		22		51	

[1] *From "Municipal waste water facilities in Utah - 1966 inventory" Utah State Department of Health.*

In irrigation practice, a part of the water diverted is lost by evaporation from canals, ponds, and the land surface, a part is lost by transpiration of vegetation, and a part is lost through incorporation in plant tissue. These losses of relatively pure water tend to increase the concentration of dissolved constituents in the remaining water. Also, soluble salts made available through accelerated chemical weathering of tilled soils or from fertilizers and soil amendments are leached by precipitation or excess irrigation water, thus increasing the dissolved-solids content of the drainage from fields. Increases in the dissolved-solids content in several streams, due in part to the drainage from irrigated fields, are shown in table 9.

Various standards have been devised to determine the suitability of water for specific uses. Some of these standards are rigid and mandatory; others are goals to be met if possible. The following sections describe some of the standards and the suitability of the principal supplies in Salt Lake County for various uses.

The only nationwide standards for drinking water are those established by the U.S. Public Health Service (1962) for use by interstate carriers and others subject to Federal quarantine regulations. These standards are summarized in table 38. Concentrations of chemical constituents that exceed the recommended limits are undesirable for domestic use, but these limits often are exceeded in both domestic and public supplies when water of better quality is not available.

Table 38.—Recommended limiting concentrations of chemical substances in drinking water

[These limits, recommended by the U.S. Public Health Service (1962), should not be exceeded except when water of the specified quality is unavailable.]

Substance	Concentration, in milligrams per liter
Chloride	250
Fluoride [1]	1.2
Iron	.3
Manganese	.05
Nitrate	45
Sulfate	250
Dissolved solids	500

[1] Recommended limits vary with the average of the maximum daily air temperatures. The value shown is for Jordan Valley; the corresponding limit for Brighton is about 1.7 milligrams per liter.

Hardness of water—a measure of its tendency to form soap curd or scum—is caused principally by calcium and magnesium. Other constituents such as aluminum, boron, iron, strontium, and free acidity, if present, contribute to hardness. The hardness classification used by the U.S. Geological Survey (S.K. Love, written commun., 1962) is as follows:

Hardness as calcium carbonate, in milligrams per liter	Rating	Usability
0–60	Soft	Suitable for many uses without softening.
61–120	Moderately hard	Usable except in some industrial applications, Softening profitable for laundries.
121-180	Hard	Softening required for laundries and some other industries.
Over 180	Very hard	Softening desirable for most purposes.

Standards of quality for water used in industries vary widely from industry to industry and even from process to process within a particular industry. Some processes require water of unusually high quality and some require nearly constant composition of the dissolved solids. On the other hand, sea water with a dissolved-solids content of about 35,000 mg/l can be used for cooling (the largest of all industrial uses) in plants equipped to handle such water and brines with higher concentrations can be used for ore processing. Use of better water, however, results in lower costs or fewer problems. Specific standards have been described by the American Water Works Association (1950, table 3-4).

The quality of water required for successful irrigation depends on many factors, including soluble minerals in the soil, physical structure of the soil, climate, the crops grown, soil drainage, and irrigation practices. For example, near the shore of Great Salt Lake continual upward movement of ground water carries large amounts of dissolved solids to the surface where they are left when the water evaporates. Consequently, only salt-tolerant vegetation grows there. In the principal irrigated areas in the southern part of Jordan Valley, however, there is no upward transport of dissolved solids to the surface and the excess of applied water over plant-growth requirements plus the winter precipitation is sufficient to prevent excessive accumulations of dissolved solids from the irrigation water.

The hazards involved in using water with various concentrations of dissolved-solids (the salinity hazard) and various concentrations of sodium relative to calcium and magnesium (the sodium-adsorption ratio, SAR, which is a measure of the sodium hazard) have been described quantitatively by the U.S. Salinity Laboratory Staff (1954).

Bicarbonate concentrations in excess of the concentration of calcium and magnesium may increase the sodium hazard of irrigation water through precipitation of relatively insoluble calcium and magnesium carbonates, thus increasing the relative concentration of sodium. Eaton (1950) introduced the concept of residual sodium carbonate (RSC), expressed as milliequivalents per liter (meq/l), to indicate the bicarbonate value of the irrigation water. The U.S. Salinity Laboratory Staff (1954) has shown that waters containing less than 1.25 meq/l RSC are probably safe, those containing 1.25-2.50 meq/l RSC are marginal, and those containing more than 2.50 meq/l RSC are not suitable.

The harmful accumulations of salts can be prevented or decreased by applying extra water to leach the soils, but excessive leaching removes desirable as well as undesirable minerals. The process of removing undesirable minerals, chiefly sodium, is sometimes aided by the addition of calcium (in the form of gypsum) to the irrigation or leaching water. The objective of applying gypsum is to provide enough calcium to promote favorable chemical reactions. A method of determining the amounts of leaching and gypsum required to maintain good crop yields with various types of irrigation water has been developed by Eaton (1954).

Christiansen and Low (1970), in a study of water requirements for waterfowl management, found that water with a dissolved-solids content of less than 1,900 mg/l produced the best growth of all plants in flooded or swampy areas except sago pondweed *(Potamogeton pectinatus)* tubers which showed greatest growth in water containing 3,000 mg/l of dissolved solids. Paradoxically, the least desirable plant—cattail (*Typha latifolia*)—grew best in water containing less than 640 mg/l of dissolved solids. Christiansen and Low (1970) give the tentative classification of water quality for waterfowl management shown in table 39.

California State Water Pollution Control Board (1963, p. 112), summarizing a report by the Western Australia Department of Agriculture (1950), listed the following threshold dissolved-solids content for use in watering stock and poultry.

	Threshold dissolved-solids concentration, in milligrams per liter
Poultry	2,860
Swine	4,290
Horses	6,435
Cattle, dairy	7,150
beef	10,000
Sheep, adult without young)	12,900

Table 39.—Tentative classification of water quality for waterfowl-management areas in northern Utah

[From Christiansen and Low (1970)]

Class	Rating	Dissolved-solids content mg/l	Specific Conductance
1	Excellent	0-640	Less than 1,000
2	Good	640-1,280	1,000-2,000
3	Fair	1,280-2,560	2,000-4,000
4	Poor	2,560-5,120	4,000-8,000
5	Restrictive	More than 5,120	More than 8,000

Suitability of surface water

Municipal and domestic use. —Water from the Wasatch streams in Salt Lake County and from Deer Creek Reservoir and Provo River are suitable for municipal and domestic use with the usual treatments of settling or filtration and chlorination to control bacteria. Concentrations of dissolved solids and most constituents are well below the recommended limits for drinking water (table 38) except that the dissolved-solids content of Emigration Creek exceeds 500 mg/l during periods of low flow. The waters range from moderately hard to very hard and softening is desirable for household use.

Water from the Jordan River is unsuitable for municipal or domestic use. The dissolved-solids content of the river water greatly exceeds the recommended limits for drinking water, it is organically polluted, and it contains very fine sediment (some of it colloidal) which is difficult to remove.

Industrial use. —The sources described as suitable for municipal and domestic use are also suitable for most industries that require water of moderately good quality. Softening would be necessary for some uses and special treatment would be required for others with exacting requirements.

For uses such as cooling and ore processing, the quality requirements are not stringent but the quantities required are large. The Jordan River water is acceptable for most such uses. Other possible sources include the Salt Lake City Sewage Canal, Goggin Drain, Lee Creek, and Kennecott Drain. The chemical quality of water in the drains is much poorer than that of Jordan River water and would be suitable for only those uses with the lowest quality requirements.

Irrigation.—All the major surface-water sources in the county have been used successfully for irrigation. Water from the Salt Lake City Sewage Canal also is suitable for irrigation of some crops, but it is not presently (1970) used for irrigation. The suitability of water from the various sources can be inferred from table 40. All the surface-water sources listed in the table except the Salt Lake City Sewage Canal contain sufficient calcium so that addition of gypsum is not necessary. The leaching requirements for waters from the Wasatch streams are negligible, being far below the leaching resulting from ordinary irrigation practices. The leaching requirements for Jordan River water are much greater, being about 12 to 20 percent of the irrigation water. However, part of the required leaching may occur naturally as a result of winter rain and snowmelt.

The sodium hazard is low for all waters except Jordan River at 9400 South where it is medium. The salinity hazard is low to medium for water from the Wasatch streams and is high to very high for Jordan River water.

Stock watering.—Water from the seven Wasatch streams, the Jordan River system, and streams in the Oquirrh Mountains (except Bingham Creek) is of suitable chemical quality for stock watering. During low-flow periods, water from Goggin Drain, which has a dissolved-solids content as high as 18,900 mg/l, would be unsuitable. Water from Kennecott and Garfield Drains and Lee Creek is chemically unsuitable because of acidity, high dissolved-solids content, and the probable presence of toxic heavy metals. The water from the Jordan River may be unsafe for stock watering because of organic pollution.

Suitability of ground water

Municipal and domestic use.—Ground water from the principal aquifer is used for municipal and domestic purposes throughout much of Jordan Valley without any treatment except softening. The concentrations of dissolved solids, chloride, and sulfate in water from many wells, however, exceed the limits recommended by the U.S. Public Health Service (see table 38). Table 41 lists 58 wells that are used for municipal and domestic supply and which yield water containing more dissolved solids than the recommended limit of 500 mg/l. Table 41 also gives the chloride and sulfate concentrations that exceed the recommended limit of 250 mg/l. The wells are scattered throughout the valley, but most are west of the Jordan River. In the eastern part of the valley the recommended limit for sulfate is exceeded in water from a few wells; the limit for chloride is not exceeded in any of the wells. In the western part of the valley, the recommended limit for chloride or sulfate or both is exceeded in about half the wells.

Industrial use.—Ground water of chemical quality suitable for the diversity of industrial requirements is available in most parts of Jordan Valley. Treatment of the water is not necessary for most uses; softening and other special treatment would be necessary for uses with rigid quality requirements. Ground water in the west-central and northern parts of the valley is suitable only for those industrial uses where quality standards are not exacting. The relatively high temperature of ground water in parts of the northern section of the valley may reduce its usefulness for cooling purposes.

Irrigation.—Most of the water from the principal aquifer in the northern part of Jordan Valley (Tps. 1 N. and 1 S., R.2W.)—is not suitable for irrigation except under special conditions.

Table 40.—Chemical parameters indicating suitability of surface water for irrigation, 1964-68 water years

[Based on discharge-weighted average chemical analyses; see tables 8 and 13. Negative calcium requirements indicate that the water contains more calcium than needed]

Source	Specific conductance, in micromhos/cm at 25°C	Sodium-adsorption ratio	Percent sodium	Salinity hazard (C)	Sodium hazard (S)	Residual sodium carbonate (RSC), in meq/l	Calcium requirement, in meq/l	Gypsum requirement, in lb/acre-ft	Leaching requirement, in percent of irrigation water
Little Cottonwood Creek	202	0.3	14	Low	Low	0	-0.15	0	0.5
Big Cottonwood Creek	319	.2	8.9	Medium	do	0	-.34	0	.6
Mill Creek	576	.2	4.8	do	do	0	-2.10	0	.6
Parleys Creek	647	.6	16	do	do	0	-.93	0	1.8
Emigration Creek	727	.7	16	do	do	0	-1.29	0	2.6
Red Butte Creek	621	.5	14	do	do	0	-.69	0	1.3
City Creek	481	.3	10	do	do	0	+.03	0	.6
Provo River	368	.3	11	do	do	0	-.55	0	.8
Jordan River									
at narrows	1,740	3.9	47	High	do	0	-2.31	0	14
at 9400 South	2,480	4.0	42	Very high	Medium	0	-6.81	0	20
at 5800 South	2,210	3.7	41	High	Low	0	-5.70	0	16
at 2100 South	1,850	3.3	41	do	do	0	-4.35	0	13
at Cudahy Lane	1,080	3.4	43	do	do	0	-3.28	0	12
Surplus Canal at Cohen Flume	1,850	3.5	42	do	do	0	-3.86	0	14
Salt Lake City Sewage Canal[1]	3,210	9.7	67	Very high	High	0	+2.18	510	43

[1] Based on weighted-average analysis for 1964 water year. No data after construction of Salt Lake City Sewage Plant.

Table 41.—Dissolved-solids, chloride, and sulfate contents of water from selected wells which exceed the recommended limits for drinking water.
[Chemical data in milligrams per liter]

Well number	Chloride	Sulfate	Dissolved solids
(B-1-1)5ddd-1	490	----	1,060
6cca-1	----	----	567
9aba-1	898	----	1,730
(B-1-2)11dca-4	----	----	612
(C-1-1)2abc-1	----	----	584
24cdc-2	----	482	1,240
24dab-18	----	----	664
24dac-10	----	----	578
24dac-11	----	----	525
24dac-12	----	280	738
24dad-22	----	264	684
24dbd-2	----	273	556
34cdc-2	----	----	798
(C-1-2)20cbc-1	498	278	1,510
22bcd-4	270	----	856
23cdd-8	312	----	1,170
23ddb-2	280	----	976
23ddc-1	270	----	1,020
27abc-1	325	338	1,430
28aaa[1]	412	484	1,730
28cdd-1	300	373	1,320
35ada-2	315	----	1,140
36abb-5	280	----	1,020
36abc-1	298	----	1,110
(C-2-1)3cdd-4	----	----	661
14caa-1	315	525	1,430
32dca-1	----	----	780
(C-3-1)4ddd-1	368	579	1,640
6cac-1	328	----	928
(C-3-1)6dbc-2	260	441	1,240
13bab-1	----	----	908
24bcc-1	450	----	1,080
31aaa-1	----	----	691
32abb-1	----	----	559
32cdc-1	----	----	519
(C-3-2)5aac-1	----	----	636
5acb-1	----	----	719
34daa-1	----	----	553
(C-4-1)6dad-1	----	319	978
11ccc-1	----	----	825
22dbd-1	----	----	689
(D-1-1)4adc-1	----	----	548
4cac-2	----	----	527
7abd-6	----	----	644
19bac-4	----	----	609
19bac-24	----	286	653
19bdc-21	----	264	610
19cdb-17	----	----	622
19dbc-1	----	----	608
20cbc-1	----	262	634
20cca-2	----	----	562
20ddd-1	----	289	691
21ddd-1	----	----	625
25ccb-2	----	----	599
26bbc-1	----	387	794
(D-2-1)4bcc-1	----	284	642
17bcc-7	----	----	515
(D-4-1)6bdd-1	----	----	659

[1]Composite of wells (C-1-2)28aaa-4, 28aaa-5, 28aaa-6, and 28aaa-7.

The computed leaching requirement[1] of water from selected wells in that area, as indicated in figure 82, ranges from about 0 to 240 percent and averages about 50 percent. Leaching requirements in the upper part of this range would necessitate an extensive drainage system and the use of fertilizers to replace essential plant nutrients lost through leaching. Application of from 70 to about 3,200 pounds of gypsum per acre-foot of applied water would be required (fig. 82). However, addition of large amounts of certain types of fertilizers and of gypsum may not be feasible because it would increase the salinity hazard of the water, which ranges from high to very high, in most of the northern part of the valley (fig. 83). The sodium hazard of water from the principal aquifer in the northern part of the valley ranges from low to very high, and residual sodium carbonate (RSC) ranges from 0 to 8.44 meq/l. Wells that yield water containing residual sodium carbonate are listed below.

Well number[1]	Residual sodium carbonate (meq/l)	Well number	Residual sodium carbonate (meq/l)
(B-1-1)6cca-1	6.41	(B-1-2)15bcd-2	3.54
16ccc-1	6.36	19aca-1	6.39
19baa-3	4.42	21abb-1	1.47
19baa-5	2.22	21acd-1	3.19
20bab-1	8.33	21bbb-2	.64
27cdd-3	5.37	21dcd-1	2.11
27dcb-2	8.44	22bdb-1	3.59
(B-1-2)2dac-2	3.20	22cdb-1	3.17
3bdc-1	2.00	23bbd-1	4.41
8abd-1	.06	28bdd-1	.41
11dca-4	5.23	28cad-1	3.90

[1]See appendix for explanation of numbering system.

Water from the principal aquifer south of T. 1 N. (excluding T. 1 S., R. 2 W.) is generally suitable for irrigation. The leaching requirement of the water ranges from about 0 to 20 percent and averages about 5 percent. The necessary amount of leaching ordinarily will occur under normal irrigation practice as return flow from irrigation commonly equals or exceeds 25 percent of the applied water in most of the valley. The application of gypsum is not recommended except in the southeastern part of the valley and near Murray (fig. 82).

Most of the water in the principal aquifer south of T. 1 N. (excluding T. 1 S., R. 2 W.) is of medium to high salinity hazard and low sodium hazard (fig. 83). In several small areas in the southwestern part of the valley, the water has a very high salinity hazard; and near Magna the water has very high salinity and sodium hazards. None of the water from the principal aquifer in the southern part of the valley contains any residual sodium carbonate.

[1]Leaching requirement is defined as the percentage of the applied irrigation water in excess of the crop requirement that is needed to control soil salinity (U.S. Salinity Lab. Staff, 1954, p. 37).

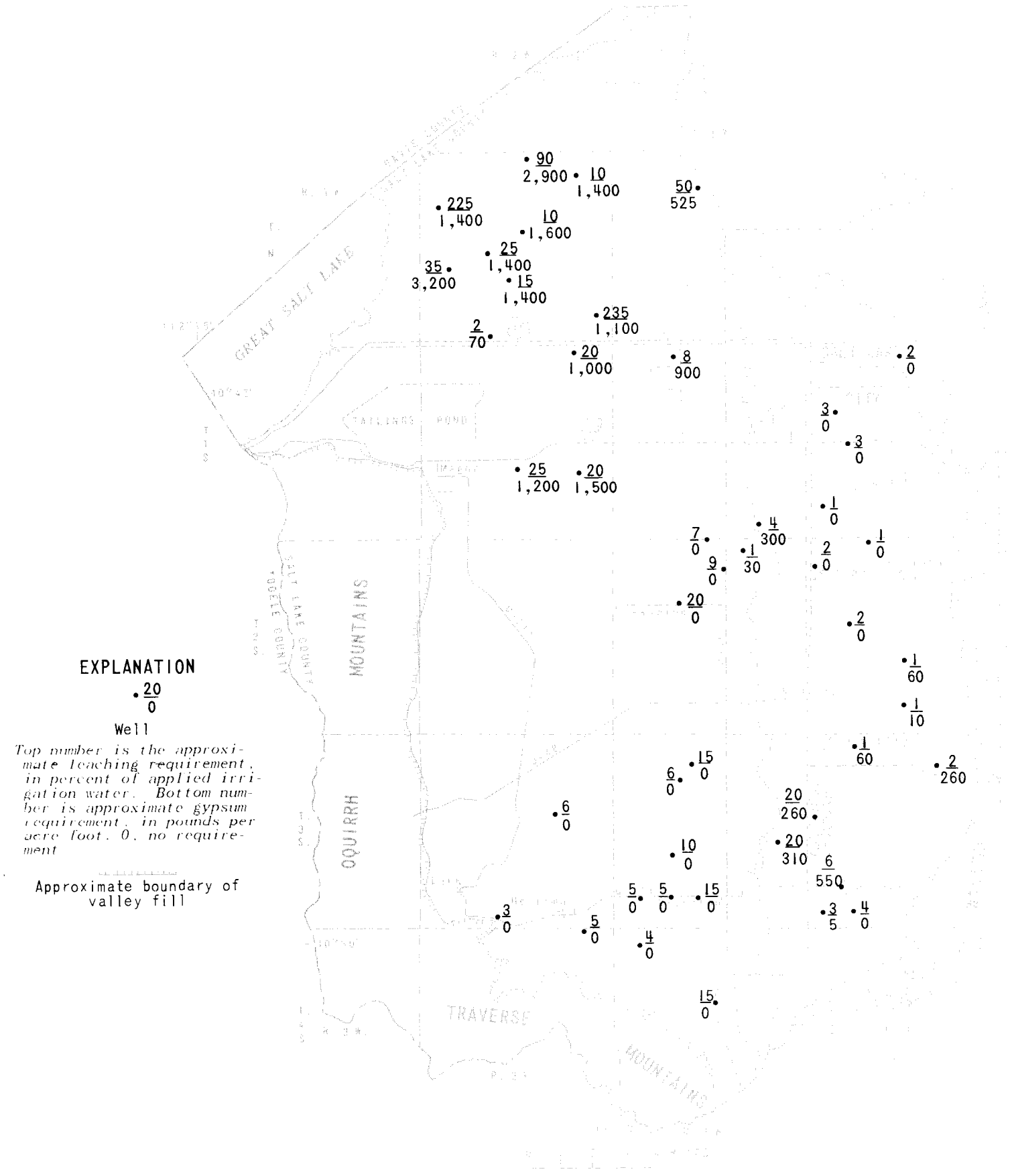


Figure 82.—Leaching and gypsum requirements for use of irrigation water from selected wells in the principal aquifer in Jordan Valley.

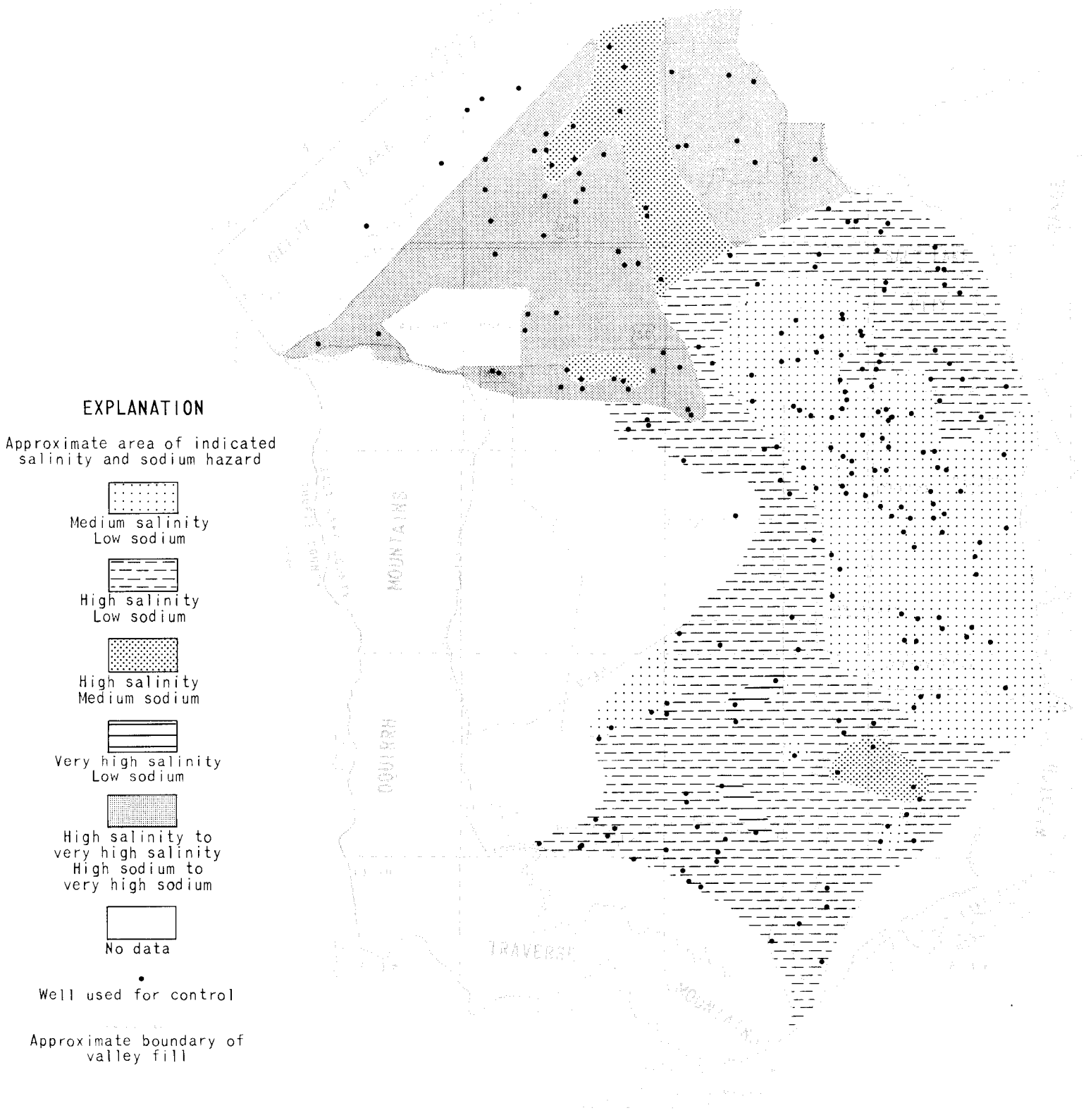


Figure 83.—Areal distribution of the salinity and sodium hazards of water from the principal aquifer in Jordan Valley. Classifications according to method of the U.S. Salinity Laboratory Staff (1954, p. 79-81).

Stock watering.—Most of the ground water in Jordan Valley is suitable for stock watering. However, the high sodium and chloride content of water from some wells in the northern part of the valley may make this water unpalatable to animals at first use.

SELECTED PROGRAMS FOR GROUND-WATER DEVELOPMENT

Results of model tests

After the previously described analog model of the ground-water reservoir in Jordan Valley was completed and verified, it was used to determine the probable effects of 22 idealized alternative programs of ground-water development on the hydrologic regimen in Jordan Valley. The following seven of the 22 programs were selected for discussion:

1. Pumpage after 1968 continued at approximately the 1959-68 rate.
2. Pumpage after 1968 at approximately double the 1959-68 rate.
3. Pumpage after 1968 at approximately triple the 1959-68 rate.
4. Pumpage after 1968 from existing well fields at approximately the 1959-68 rate and also from a postulated well field.
5. Pumpage after 1968 continued at approximately the 1959-68 rate and recharge augmented artificially.
6. Pumpage after 1968 at approximately double the 1959-68 rate and recharge augmented artificially.
7. Pumpage after 1968 at approximately triple the 1959-68 rate and recharge augmented artificially.

The effects of the four programs that involve no artificial recharge of the aquifers are summarized in table 42; and the effects of the three programs that include artificial recharge are summarized in table 43.

Some of the idealized programs tested are feasible from a practical hydrologic standpoint; others are not or would result in undesirable effects or impractical situations. For example, a large increase in withdrawal of ground water at the north end of the Oquirrh Mountains would induce recharge from Great Salt Lake, which would be undesirable for most uses of the water but probably not prohibitive for its use in ore processing. Also, in the eastern half of Salt Lake City, the aquifer is too thin (fig. 64) to allow large amounts of artificial recharge or more than moderate increases in withdrawals. Thus, the aquifer imposes physical limitations on water-level fluctuations, but the model imposes no similar limitations on the simulated fluctuations.

For most of the model programs, it was assumed that (1) withdrawals would be from existing wells or new wells in their vicinity, and (2) rates of withdrawal from existing pumping centers (consisting of one or more wells) would be at rates approximately equal to, double, or triple the 1959-68 rates. Most of the existing large-capacity wells are used only intermittently during a few months each year, and a large part of the increased demand could be met by using them for longer periods. Most of the wells are located where the demand is expected to increase; therefore, the locations of the pumping centers are not expected to change appreciably by the year 2020.

The locations of the centers of ground-water withdrawals during 1932-68 are shown in figure 84. The locations of the principal changes of recharge during 1932-68 (modeled as recharge wells) and of assumed changes of recharge and discharge after 1968 (also modeled as wells), used in the model tests, are shown in figure 85.

Table 42.—Summary of the effects of pumping ground water at selected rates during selected periods.

[All quantities are mean annual amounts, in acre-feet, and all except those in the last line are increases over the corresponding amounts for 1931. All quantities are derived from measurements in the analog model. The pumpage increase in the heading differs slightly from the sum (next to last line) because of errors inherent in operation of the model or reading the oscilloscope]

	Program 1			Program 2			Program 3			Program 4		
Source of pumpage increase	Pumpage increase, 67,700			Pumpage increase, 125,000			Pumpage increase, 194,800			Pumpage increase, 120,800 including 51,700 from postulated well field		
	1969-80	1981-2000	2001-20	1969-80	1981-2000	2001-20	1969-80	1981-2000	2001-20	1969-80	1981-2000	2001-20
Increased recharge from irrigation water	11,800	11,800	11,800	13,100	13,100	13,100	12,200	12,200	12,200	11,900	11,900	11,900
Increased recharge from urbanized areas and tailings pond	16,900	16,900	16,900	18,800	18,800	18,800	17,600	17,600	17,600	16,600	16,600	16,600
Decreased evapotranspiration of ground water	12,800	14,600	15,000	33,800	39,200	40,500	43,300	49,500	50,400	41,500	46,500	46,500
Decreased ground-water discharge to streams	5,200	8,300	9,800	17,200	29,100	32,000	35,000	53,000	61,500	6,700	10,200	12,000
Decreased ground-water discharge to Great Salt Lake	2,200	2,200	2,200	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Induced recharge from Great Salt Lake	0	0	0	3,400	4,400	4,800	6,500	9,500	10,200	300	400	400
Decreased discharge from flowing wells	4,800	5,800	6,100	10,200	12,200	13,400	13,600	18,800	19,900	5,800	7,800	8,400
Decreased ground-water discharge to or induced recharge from waterfowl-management areas	5,100	5,100	5,200	(1)	(1)	(1)	(1)	(1)	(1)	8,800	11,900	12,600
Decreased storage in the shallow unconfined aquifer	6,500	1,700	500	26,800	11,000	7,600	49,500	18,200	8,900	19,800	5,400	2,700
Decreased storage in the principal aquifer	1,800	1,100	700									
Sum	67,100	67,500	68,200	127,300	131,800	134,200	181,700	182,800	184,700	115,400	114,700	115,100
Total withdrawal of ground water[2]	100,900	99,900	99,600	152,800	150,800	149,600	219,200	214,000	212,900	153,000	151,000	150,400

[1]Not modeled. Amount included in evapotranspiration of ground water and storage in the shallow unconfined aquifer.

[2]The total withdrawal is the 1931 withdrawal (38,000 acre-ft) plus the pumpage increase less the amount derived from the discharge of flowing wells.

Table 43.—Summary of the effects of pumping ground water at selected rates during selected periods, with artificial recharge.

[All quantities are mean annual amounts, in acre-feet, and all except those in the last line are increases over the corresponding amounts for 1931. All quantities are derived from measurements in the analog model. The pumpage increase in the heading differs slightly from the sum (next to last line) because of errors inherent in operating the model or reading the oscilloscope.]

Source of pumpage increase	Program 5			Program 6			Program 7		
	Pumpage increase, 74,000 Artificial recharge, 25,600			Pumpage increase, 136,000 Artificial recharge, 26,700			Pumpage increase, 203,700 Artificial recharge, 24,900		
	1969-80	1981-2000	2001-20	1969-80	1981-2000	2001-20	1969-80	1981-2000	2001-20
Increased recharge from irrigation water	11,600	11,600	11,600	12,700	12,700	12,700	11,900	11,900	11,900
Increased recharge from urbanized areas and tailings pond	16,000	16,000	16,000	17,600	17,600	17,600	16,900	16,900	16,900
Decreased evapotranspiration of ground water	12,500	13,800	13,800	28,200	32,700	34,400	30,000	36,500	39,100
Decreased ground-water discharge to streams	1,200	-1,800	-2,500	17,300	25,400	29,000	33,200	53,700	55,100
Decreased ground-water discharge to Great Salt Lake	2,200	2,200	2,200	4,000	4,000	4,000	4,000	4,000	4,000
Induced recharge from Great Salt Lake	0	0	0	2,000	4,400	4,600	8,200	11,900	11,800
Decreased discharge from flowing wells	2,500	1,300	1,000	7,700	9,400	10,500	12,800	17,000	18,300
Decreased ground-water discharge to or induced recharge from waterfowl-management areas	4,600	3,100	3,100	6,500	7,400	7,500	8,800	10,900	11,800
Decreased storage in the shallow unconfined aquifer	-5,800	-900	0	20,100	4,100	1,100	43,000	12,000	6,200
Decreased storage in the principal aquifer				2,100	2,100	1,800	7,700	5,400	4,800
Sum [1]	70,400	70,900	70,800	144,900	146,500	149,900	201,400	205,100	204,800
Total withdrawal of ground water [2]	109,500	110,700	111,000	166,300	164,600	163,500	228,900	224,700	223,400

[1] Includes the amount of artificial recharge shown in the headings.

[2] The total withdrawal is the 1931 withdrawal (38,000 acre-ft) plus the pumpage increase less the amount derived from discharge of flowing wells.

Figure 84.—Locations of the centers for withdrawal of ground water used in the analog model for the period 1932-68. A center consists of one or more flowing or pumped wells and represents a point on the analog model where withdrawal was simulated.

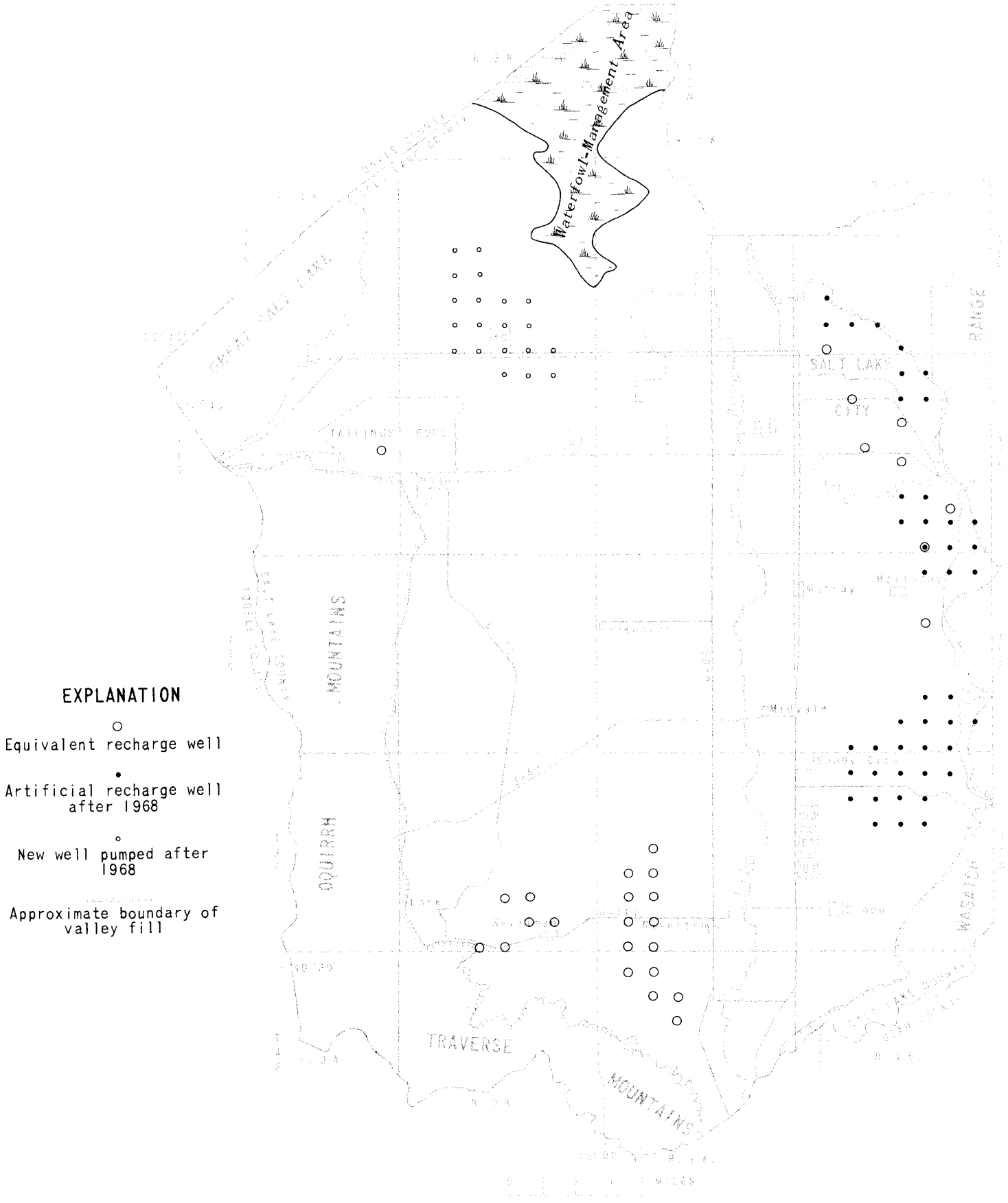


Figure 85.—Locations of the principal changes of ground-water recharge, 1932-68, and of assumed changes of recharge and discharge after 1968, as used in the analog model. The "equivalent recharge wells" represent recharge resulting from the effects of irrigation, urbanization, and the tailings pond.

Early model tests verified the assumption that the ground-water regimen was essentially in equilibrium in 1931, when the total annual withdrawal was 38,000 acre-feet. Hence, this condition was used as a base, and all results read from the model are expressed as changes since 1931. The last lines in tables 42 and 43 (total withdrawal), include the 1931 base rate of 38,000 acre-feet.

The sources and quantities of water available to pumped wells are summarized in the following table.

Potential source of water pumped from wells	Quantity available at the beginning of 1969 (acre-ft per yr)	Remarks
Seepage of irrigation water	11,800	This is the average annual increase since 1931. (See table 26.) Accumulated total for this source since 1931 is 127,000 acre-feet.
Recharge from urbanized areas and tailings pond	15,000	This is the average annual increase since 1931 (table 26) and the total for this source.
Evapotranspiration of ground water	60,000	See table 33.
Ground-water discharge to streams	196,000	See table 22.
Ground-water discharge (through seeps, springs, and drains) to Great Salt Lake	4,000	Do.
Ground-water discharge by flowing wells	38,000	See p. 140.
Induced recharge from waterfowl-management areas	205,000	This is the amount of surface water diverted to waterfowl-management areas. (See table 19.)
Ground-water storage in the shallow unconfined and principal aquifers	60,000,000 acre-feet	

The rate of pumping from wells was held constant throughout each model program. Continuous pumping generally causes a decline of water levels, which in turn results in a decrease in the discharge by flowing wells. Thus, the total withdrawal from pumped and flowing wells is expected to decline as indicated by the values in the last line of tables 42 and 43.

Large increases of the net withdrawal would cause declines in the ground-water discharge to streams in Jordan Valley. If such declines occurred during seasons of dormant vegetation and relatively low-water demand, they would represent salvage of water which would otherwise be wasted to Great Salt Lake. Such declines during the growing season, however, would represent a reduction of the usable supply of surface water. It is estimated that approximately half the indicated reductions of ground-water discharge to streams in line 4 of tables 42 and 43 would be reductions of usable surface-water supply. Thus the overall increase of water withdrawn in the valley would be correspondingly smaller than is indicated by the total withdrawals shown in the last line of tables 42 and 43.

The analog model was so constructed that all the simulated increase in withdrawal from wells was derived from induced recharge in the valley, from increases in recharge resulting from man's activities, from a reduction in other modes of discharge, or taken from storage within the valley. No additional recharge from outside the valley was induced in the model.

Nine individual sources of the additional water withdrawn from wells were monitored during most of the model programs: (1) increased recharge from irrigation water, (2) increased recharge from urbanized areas and tailings pond, (3) decreased discharge of ground water by evapotranspiration in low-lying parts of the valley (excluding the waterfowl-management area), (4) decreased discharge of ground water to streams, especially the Jordan River and Big Cottonwood and Little Cottonwood Creeks, (5) decreased ground-water discharge to Great Salt Lake and induced recharge from Great Salt Lake, (6) decreased discharge from flowing wells, (7) decreased ground-water discharge to waterfowl-management area or, at times (in program 4), induced recharge from ponded surface water in the area, (8) decreased storage in the shallow unconfined aquifer, and (9) decreased storage in the principal aquifer.

The apparent recharge resulting from the tailings pond was discussed in the section on ground-water recharge. (See p. 127.) To enable completion of the estimate of recharge (table 21), the apparent recharge from the tailings pond was separated into actual recharge and an effect due to weight of the tailings on water levels, which was indistinguishable in the model from actual recharge. In tables 42 and 43, no separation was attempted because the relative amounts are unknown and probably variable, and the effects of weight are small relative to the effects of the pumpage increase.

Source 7 was not modeled in programs 2 and 3. Consequently, sources 3 and 8 appear to yield more water than they actually would because of the close relation of these three sources in the vicinity of the waterfowl-management area. Also for programs 2-5, sources 8 and 9 were not monitored separately but were read as total storage depletion in the ground-water reservoir.

Maps showing the change in water levels between 1931 and the programed date (1980, 2000, or 2020) were derived from the model for each of the seven programs in tables 42 and 43. These maps indicate the general nature of the pattern of water-level change. Significant differences between the actual and simulated water levels occur locally, however, because the model was constructed using averages of the observed values of transmissivity and storage coefficient. These averages may differ from actual averages, especially where the available data are not sufficient to define precisely the variations of physical characteristics of the actual aquifer. Although the time periods are different, comparison of figures 63 and 86 reveals such a discrepancy between the observed and simulated water-level declines between Holladay and Murray for the same pumping program.

Variables that were intended to be the same in two or more programs differ slightly in the various programs because of limitations of the accuracy of the values obtained from the model. However, such differences generally are less than 10 percent of the values modeled, and most are less than 5 percent. The values used in and resulting from the model analysis are reported to the nearest 100 acre-feet in order to show adequately their significance, thus appropriate consideration must be allowed in any other application of the values.

One general conclusion from the model studies is that land subsidence does not pose a serious problem in any of the programs investigated. In the central and northern parts of Jordan Valley, where aquifers contain thick beds of fine-grained sediments and are most susceptible to compaction, with consequent land subsidence, water levels would not decline more than 50 feet for any of the programs. In the eastern part of the valley, where future declines may exceed 50 feet, the deposits are mostly coarse grained. Here the aquifers are susceptible to only slight compaction.

The probable effects of the seven individual programs are discussed below.

Program 1 (pumpage increase of 67,700 acre-ft annually over the 1931 base withdrawal of 38,000 acre-ft). —According to the model study, the largest source of the total withdrawal after 1968 would be man-caused recharge (seepage of irrigation water, and seepage from urbanized areas and the tailings pond). This would amount to 28,700 acre-feet (table 26) or 29 percent of the total withdrawal, an amount assumed to be constant through the 1969-2020 period. (See table 42.)

The amount of water taken from storage in the ground-water reservoir would be relatively small, ranging from about 8 percent of the total water pumped during 1969-80 to about 1 percent during 2001-20. Conversely, the amount of ground water diverted from discharge to the Jordan River and tributaries would increase from about 5 percent of the total withdrawal during 1969-80 to about 10 percent during 2001-20. The gain from ground-water seepage into these streams (170,000 acre-ft, table 22) would be reduced by 3 and 6 percent, respectively, for the two periods. Each of the other items in table 42 would be a relatively small and stable quantity during 1969-2020.

The model shows that for program 1, water-level changes in the principal aquifer would range from rises of more than 20 feet to declines of more than 20 feet from the 1932 level by the years 1980, 2000, and 2020 (fig. 86). The average change would be a decline of 2.0 feet during 1932-80, 1.6 feet during 1981-2000, and 0.7 foot during 2001-20. Local declines exceeding 20 feet would occur west of Magna and east of Sandy City by 1980, southeast of Salt Lake City by 2000, and in the eastern part of Salt Lake City by 2020. The total areas encompassed by the lines of 20-foot decline would increase nearly 10 times between 1968 and 2020, but in no place would the declines reach 30 feet by 2020 (fig. 86). Water levels in the southern part of the valley rose a maximum of 29 feet by 1969 (fig. 63); and a rise exceeding 20 feet would remain until 2020, although there would be a small decrease in the size of the area of rise. Recharge would apparently approximately balance discharge in this part of the valley during the period 1969-2020. The area of no change in water level at the north end of the valley would be kept static by induced recharge from the ponds in the waterfowl-management area, which are supplied largely by streamflow (see table 19).

The chemical quality of the water in the principal aquifer in most of the valley would not change significantly under program 1. However, continuing recharge with water from the Jordan River used for irrigation would cause a continued degradation of the quality in the Herriman-Riverton area. On the other hand, recharge with good quality water used to water lawns probably would cause a slight improvement of quality in the eastern part of Salt Lake City. The large withdrawals northwest of Magna have already caused a marked degradation of quality, and continued withdrawals at the same rate might induce greater degradation.

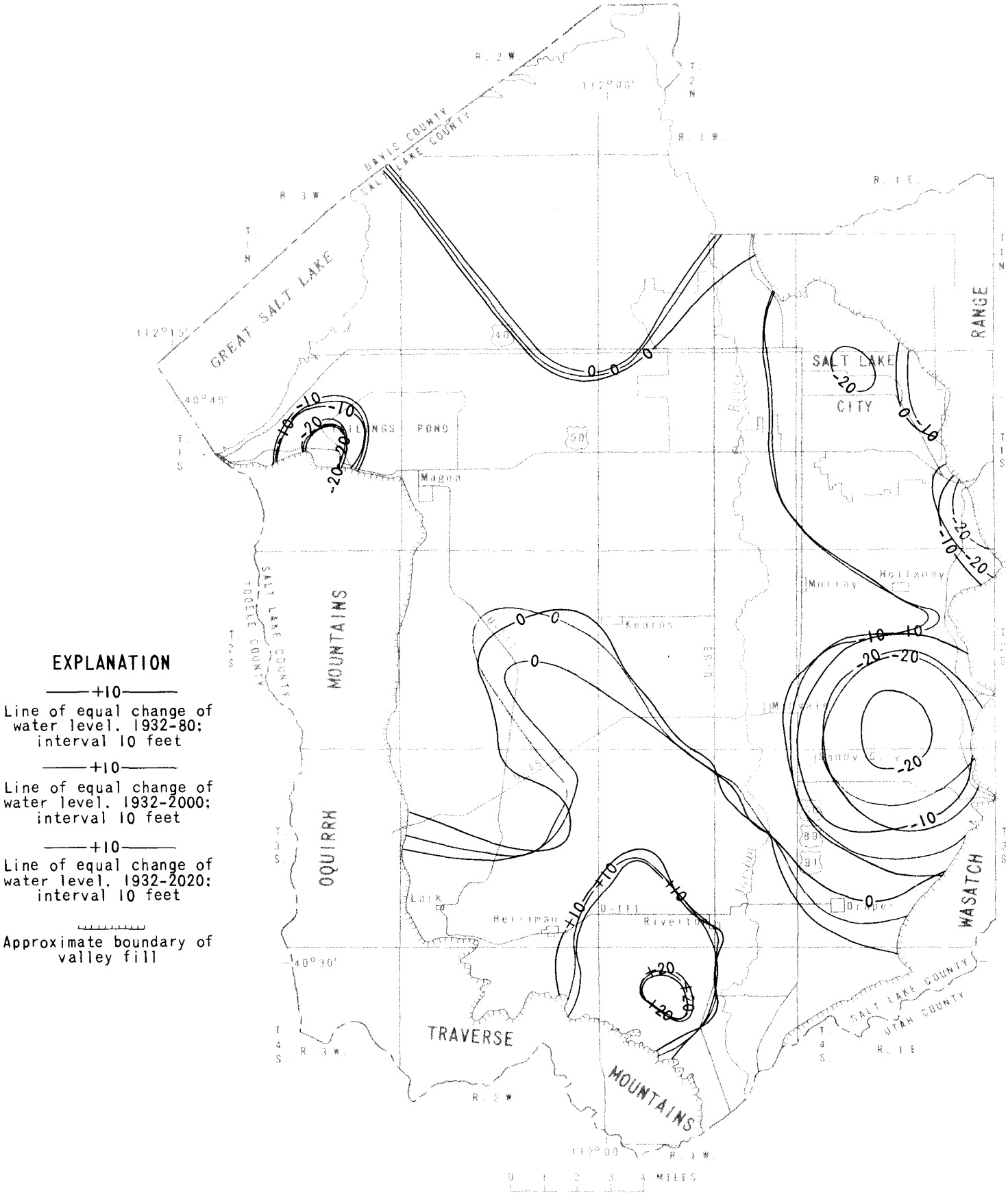


Figure 86.—Water-level changes for program 1—pumpage after 1968 continued at approximately the 1959-68 rate.

Program 2 (pumpage increase of 125,000 acre-ft annually over the 1931 base withdrawal of 38,000[1] acre-ft).—In this program, the amounts derived from sources other than man-caused recharge would increase markedly (table 42). The amounts derived from man-caused recharge (first two lines) theoretically remain constant, and the differences in these items between programs 1 and 2 in table 42 are due to model error.

As in program 1, the amounts derived from storage would decrease sharply with time. This decrease would be balanced by increases in the amounts derived from other sources, chiefly evapotranspiration of ground water and discharge to streams. A relatively small amount of recharge would be induced from Great Salt Lake (table 42) northwest of Magna.

The average water level in the principal aquifer would decline about five times as much between 1932 and 1980 as it would if withdrawals were not increased above the 1959-68 rate. The average decline of water level in the valley would be 10 feet during 1932-80, an additional 2.2 feet during 1981-2000, and an additional 0.8 foot during 2001-20 (fig. 87). Locally declines exceeding 40 feet in the eastern part of Salt Lake City and east of Sandy City would occur by 1980, and declines of 60 feet southeast of Salt Lake City would occur by 2000. Water levels in the southern part of the valley, which rose a maximum of 29 feet by 1969 (fig. 63), would decline; but a small area of rise exceeding 20 feet would remain until 2020. Discharge apparently would be only slightly greater than recharge in the small area of rise during 1969-2020. Water levels at the north end of the valley would remain essentially unchanged because of the relatively small amount of ground water withdrawn by wells in this part of the valley and because of the ponded water in the waterfowl-management area that would supply recharge.

The chemical quality of the water in the principal aquifer would not change significantly under program 2. The major effect would be continued and accelerated degradation of quality west of the tailings pond due in part to induce recharge from Great Salt Lake (table 42).

Program 3 (pumpage increase of 194,800 acre-ft annually over the 1931 base withdrawal of 38,000 acre-ft).—In this program the amounts derived from most sources (table 42) would be greater than those for program 2. The amounts derived from storage would decrease considerably with time, and this decrease would be balanced by increases from other sources, particularly discharge to streams.

The average water level in the principal aquifer would decline almost 10 times as much between 1932 and 1980 as it would have if withdrawals were not increased above the 1959-68 rate. The average decline in the valley would be 19 feet during 1932-80, an additional 4.4 feet during 1981-2000, and an additional 1.4 feet during 2001-20 (fig. 88). Locally, declines exceeding 80 feet east of Sandy City and more than 100 feet in Salt Lake City would occur by 2000 according to the model. The area of rise in the southern part of the valley would disappear by 2000.

[1] Only 5,000 acre-feet of the 38,000 acre-feet withdrawn in 1931 was pumped. Consequently, doubling the pumpage increase since 1931 is roughly equivalent to doubling the 1959-68 pumpage rate.

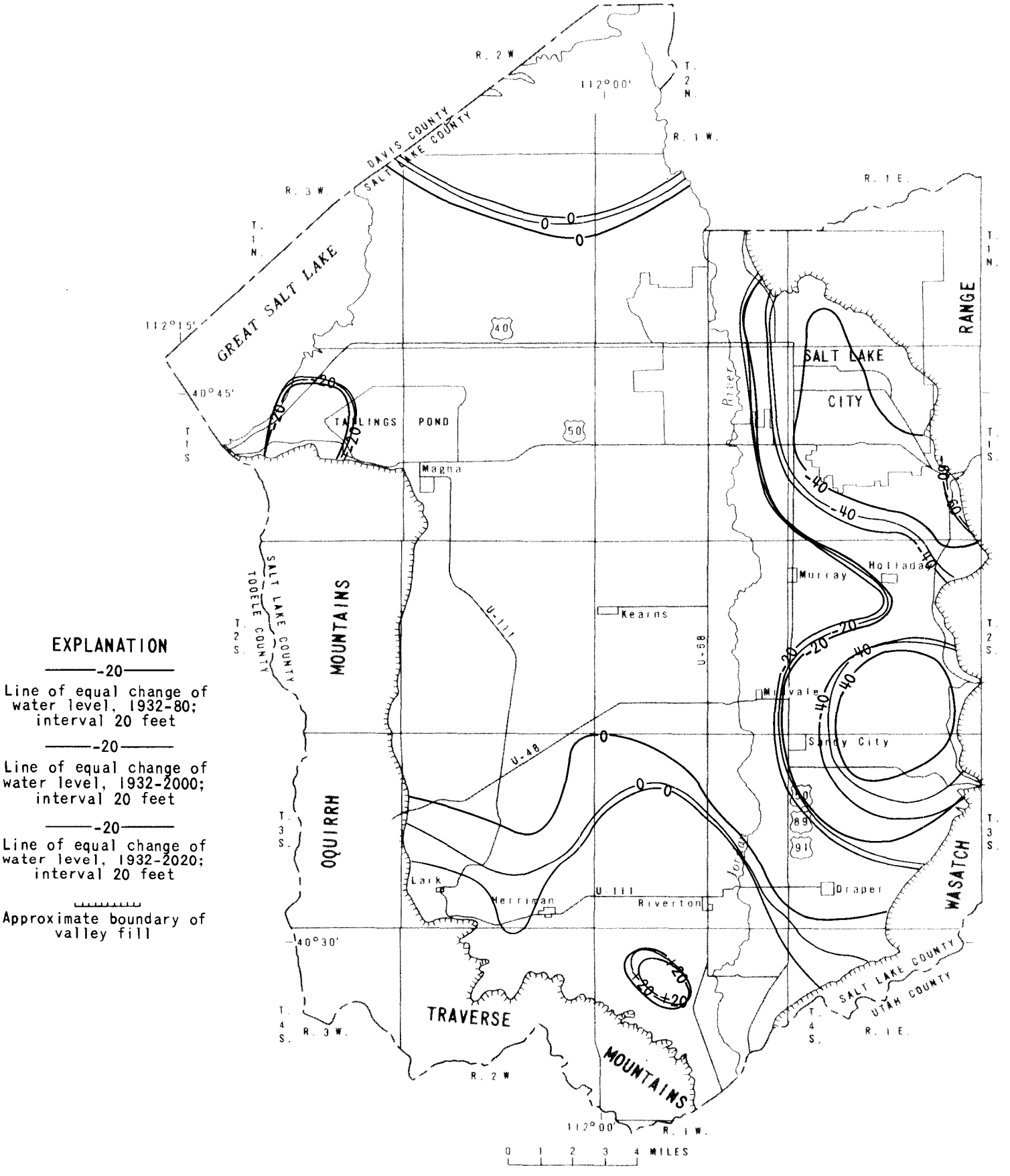


Figure 87.—Water-level changes for program 2—pumpage after 1968 at approximately double the 1959-68 rate.

The declines indicated in figure 88 in the eastern part of Salt Lake City exceed the saturated thickness of the principal aquifer. Consequently, it would not be possible to triple pumpage in that area. Declines in the remainder of the valley are not known to exceed the saturated thickness. Thus, from a hydrologic point of view, tripling the pumping rates would be feasible in all areas except eastern Salt Lake City.

Under present conditions, ground-water gradients toward the Jordan River from both east and west restrict ground-water movement from one side of the river to the other, and thus prevent contamination of water on the east side by water of poorer quality from the west side. This situation would be changed under program 3, and the gradient would reverse before 2020 in some places east of the river. The resulting migration of Jordan River water and ground water from west of the river into wells east of the river would cause serious degradation of the quality. Although a tripled pumping rate with no augmentation of the recharge could not be sustained for periods of 30 or more years without serious degradation of chemical quality, such rates could be sustained for shorter periods without degradation.

The induced recharge from Great Salt Lake would be greater under this program than under program 2, and the quality of the water would degrade more.

Program 4 (pumpage increase of 120,800 acre-ft annually over the 1931 base withdrawal, including 51,700 acre-ft from a postulated well field).—The postulated well field consists of 20 wells in the northern part of the Jordan Valley (fig. 85), in an area where future industries will probably require large amounts of water and where withdrawals would enable the maximum salvage of ground water now wasted by evapotranspiration. The pumping rate at the postulated well field was selected so that the drawdown at the southwest corner of the field would be 30 feet by 1980 (fig. 89). This limit was established in order to obtain the maximum pumpage without causing excessive aquifer compaction or the encroachment of saline water from Great Salt Lake.

In program 4, the amount of water salvaged from evapotranspiration of ground water would be nearly as great as that obtained by the tripled pumpage of program 3 (table 42); but the streamflow would be depleted much less. About 56 percent of the withdrawal from the postulated well field during 1969-80 would be from evapotranspiration of ground water, but the amount of water from this source would only increase by about 10 percent by 2020. The remainder of the withdrawal would be obtained from all other sources except man-caused recharge.

The average water level in the principal aquifer would decline about four times as much between 1932 and 1980 as it would have if there had been no pumping in the postulated well field. Most of this increased decline would be in the northern part of the valley (fig. 89). Declines in the valley would average 8.0 feet during 1932-80, but declines exceeding 40 feet would occur at the center of the postulated well field. Water levels in the southern third of the valley would not be affected by pumping in the postulated well field, and they would be affected only slightly in the northeastern part of the valley (compare figs. 86 and 89).

Water-level changes for the years after 1980 are not shown in figure 89 because the model showed that water levels would nearly reach equilibrium by 1980.

The effects of program 4 on the chemical quality of the water would be similar to those described for program 1, except for the effects of a small amount of induced recharge from Great Salt Lake northwest of Magna. Lowering the water level in the shallow unconfined aquifer would reduce the loss by evapotranspiration and consequently tend to improve the quality of the water in the shallow aquifer. Pumping from the principal aquifer in the postulated well field, however, would eventually cause some degradation of the chemical quality of the water in that aquifer because of the induced downward movement of water from the shallow aquifer.

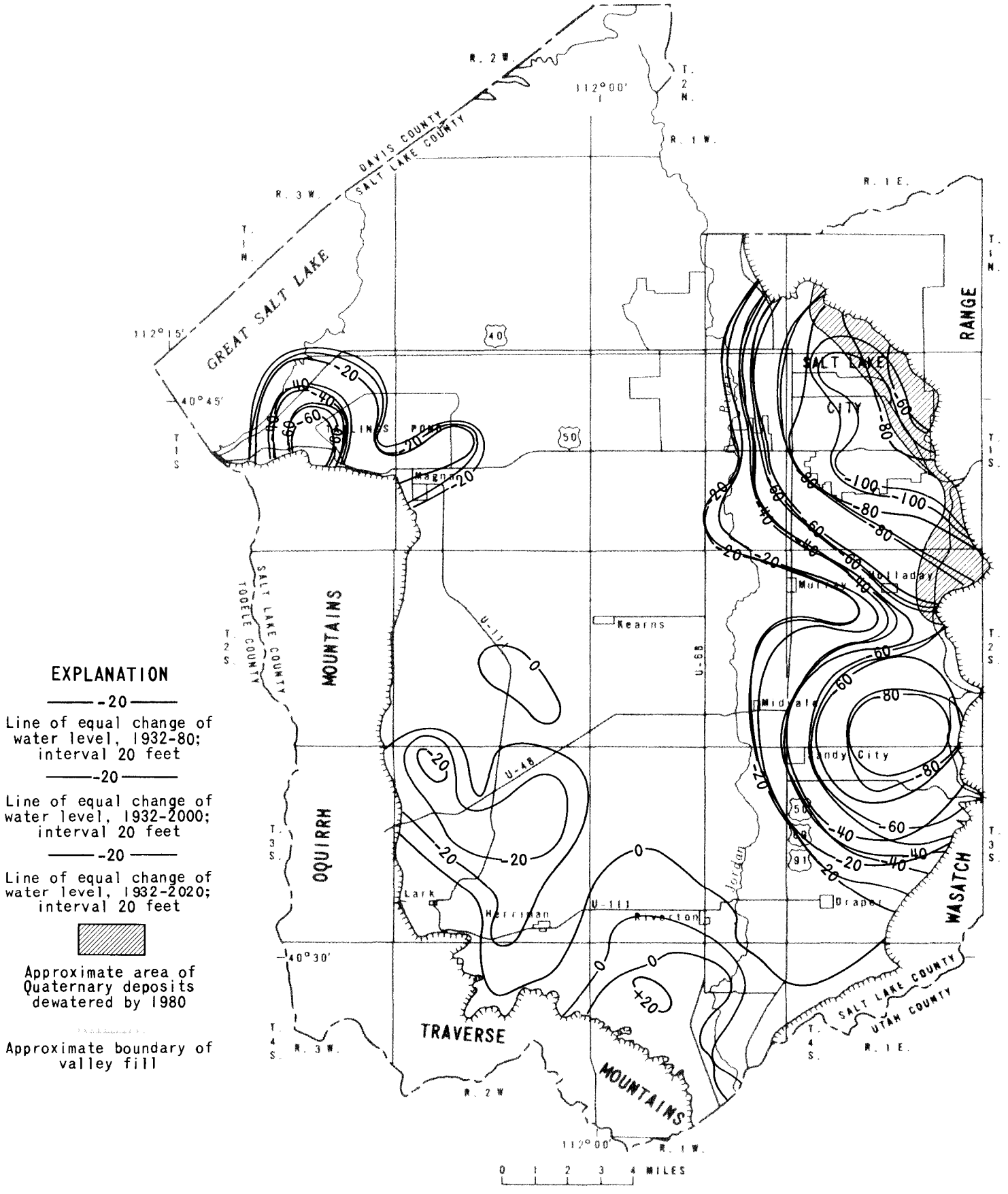


Figure 88.—Water-level changes for program 3—pumpage after 1968 at approximately triple the 1959-68 rate.

Figure 89.—Water-level changes for program 4—pumpage after 1968 from existing wells at approximately the 1959-68 rate and also from a postulated well field.

Program 5 (pumpage increase of 74,000 acre-ft annually over the 1931 base withdrawal; artificial recharge, 25,600 acre-ft annually). —The artificial recharge was programed through 44 hypothetical wells along the east side of Jordan Valley (fig. 85). Artificial recharge may be by methods other than through wells. If the locations and amounts of recharge remain the same as those modeled, however, the results would be unaffected.

Program 5 would cause an increase of the ground-water discharge to streams (indicated by the negative entries in table 43) by the year 2000. It would also cause an increase of the amount of water in storage until shortly after 1980, when the water levels would stabilize. Ground-water discharge to Great Salt Lake should be the same as for program 1.

The average water level in the principal aquifer would decline one-fifth as much between 1932 and 2000 as it would have without artificial recharge. The average decline in the valley during 1932-2000 would be 0.7 foot (fig. 90), but a local decline exceeding 20 feet would occur west of Magna. Rises exceeding 40 feet southeast of Sandy City and as much as 155 feet (not shown in fig. 90) in the eastern part of Salt Lake City were indicated by the model. Such large rises in the eastern part of Salt Lake City are not practical, however, because in parts of the area the unsaturated thickness of the aquifer is much less than 155 feet. This means that with no increase in pumping in this part of the valley, artificial recharge in the eastern part of Salt Lake City would have to be much less than the amount programed. Water levels west of the Jordan River would be affected only slightly by artificial recharge east of the river, because the river acts as a drain for ground water from each side of the valley.

Under program 5 the changes in chemical quality induced by changes in water level would be similar to those described for program 1. Mixing of native ground water at any place in Jordan Valley with water from the Wasatch streams or Deer Creek Reservoir would cause an improvement in quality in the area downgradient from the recharge area to the zone where practically all water used for artificial recharge would be withdrawn.

Artificial recharge may involve chemical-quality problems that are related to the chemical quality of the recharge water, the aquifer characteristics, and chemical reactions that may result from the process of recharge. Sources of water for artificial recharge in the eastern part of Jordan Valley include Deer Creek Reservoir and Little Cottonwood, Big Cottonwood, and Mill Creeks. Computations based on the weighted average concentrations of dissolved solids for water from Deer Creek Reservoir (p. 74) show that the equilibrium pH is 7.7, which is only slightly less than the measured value of 7.8. If the equilibrium pH of recharge water exceeds the measured pH by 0.5, the water is capable of dissolving calcium carbonate from the aquifer. Conversely, if the equilibrium pH is less than the measured pH by 0.5, the water is supersaturated with calcium carbonate, which will precipitate in the aquifer and reduce its permeability. Hence, if water from Deer Creek Reservoir should be used for artificial recharge in southeastern Salt Lake County, neither precipitation of calcium carbonate in the aquifer nor solution from the aquifer would be significant.

The pH values for the three Wasatch creeks are listed below:

	Equilibrium pH	Measured pH
Little Cottonwood Creek	8.2	7.4
Big Cottonwood Creek	7.2	7.8
Mill Creek	7.7	7.8

Thus, considering pH values, the water from Little Cottonwood and Mill Creeks would be the most suitable for artificial recharge.

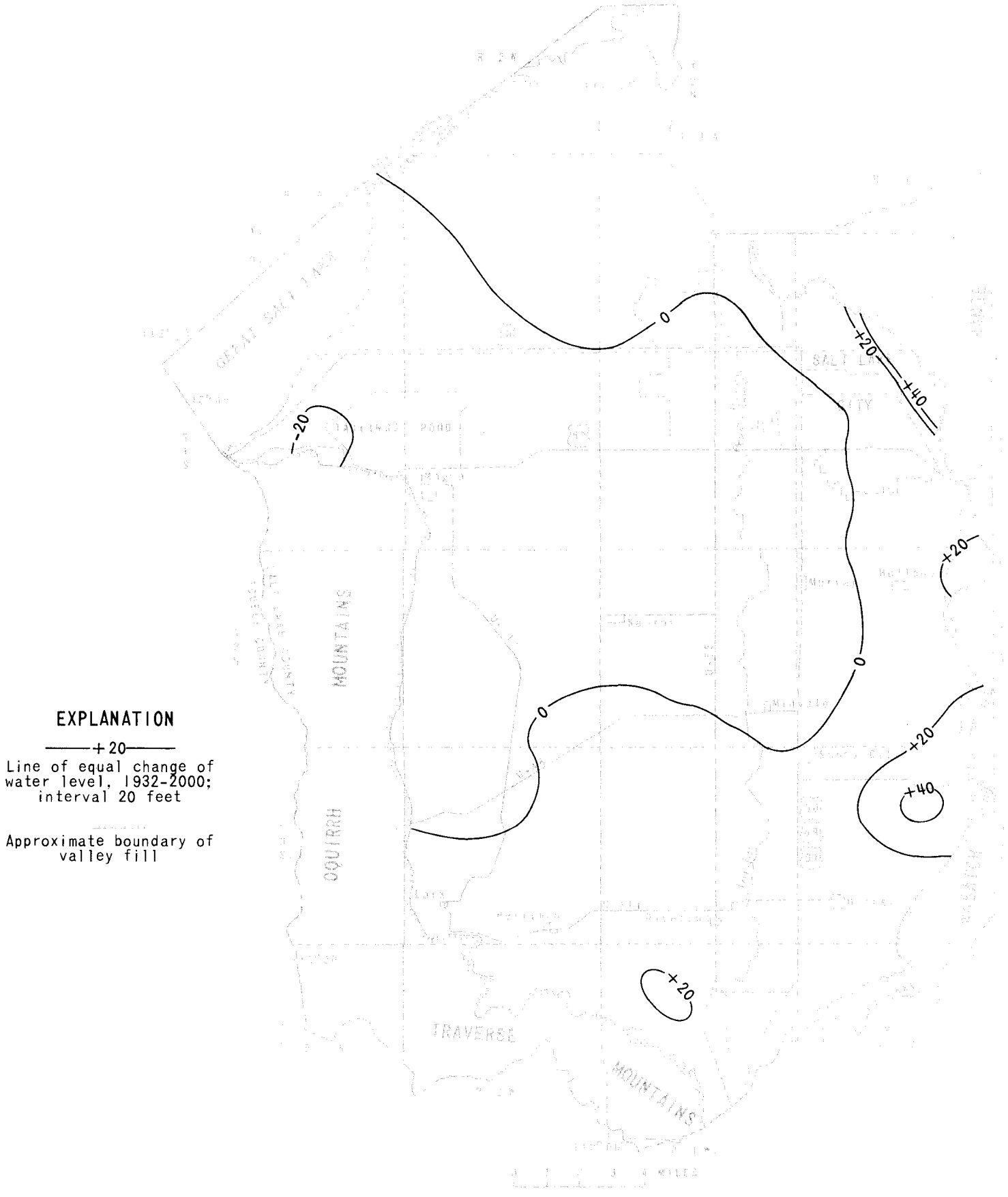


Figure 90.—Water-level changes for program 5—pumpage after 1968 at approximately the 1959-68 rate and recharge augmented artificially.

Artificial recharge may also involve sediment problems which may require additional research for solution. Water conducted from a reservoir through a pipeline or lined canal to the recharge site is best for artificial recharge because of its extremely low sediment content. The relative suitability of water from the Wasatch streams is indicated by the sediment loads in table 10. Although the concentrations of sediment in these streams is much less than the concentrations in many streams, the concentrations during periods when surplus water is available may be high enough to cause some clogging of recharge areas or wells.

Serious plugging of the aquifer can occur during artificial recharge by the precipitation of ferric iron. Generally, the Eh (redox potential) and pH of the native ground water would permit ferrous iron to remain in solution, but the Eh and pH of some surface water used for recharge could permit the complete oxidation of ferrous iron and precipitation as ferric hydroxide. Additional data on the iron content, Eh, and pH of the native ground water and the injected water should be collected during specific recharge experiments. Application of stability field diagrams (Hem, 1960, 1961b) would indicate the potential plugging by iron that might not be apparent for some time after recharge had started.

Program 6 (pumpage increase of 136,000 acre-ft annually over the 1931 base withdrawal; artificial recharge, 26,700 acre-ft annually). —The effects of program 6 are shown in table 43. The program would result in an average decline in water level between 1932 and 2000 of 11.4 feet, about five times as much as it would be with pumpage at the 1959-68 rate and no artificial recharge. Declines would exceed 60 feet northwest of Magna (fig. 91), resulting in induced recharge from Great Salt Lake. Declines would exceed 40 feet in parts of Salt Lake City, but water levels would rise more than 20 feet at the eastern edge of the city.

Except for the dilution of native ground water with water used for artificial recharge, program 6 would cause little change in the chemical quality of ground water. The artificial recharge would have no effect on the quality of ground water west of the Jordan River, where quality changes would be similar to those for program 2.

Program 7 (pumpage increase of 203,700 acre-ft annually over the 1931 base withdrawal; artificial recharge, 24,900 acre-ft annually). —The effects of program 7 are indicated in table 43. By the year 2000, the program would result in an average water-level decline of 20 feet between 1932 and 2000, almost 10 times as much as it would have if pumpage had remained at the 1959-68 rate and there were no artificial recharge. Local declines would exceed 60 feet east of Sandy City and 100 feet west of Magna[1] (inducing recharge from Great Salt Lake) and in parts of Salt Lake City (fig. 92). Slight rises would occur at the east edge of Salt Lake City, and the rise in the southern part of the valley that existed in 1969 would practically disappear by 2000.

The indicated declines in the eastern part of Salt Lake City are greater than the saturated thickness of the aquifer. Hence, sustained pumping at triple the 1959-68 rate would not be possible there even with the indicated amount of artificial recharge.

Artificial recharge as postulated for program 7 would result in improved quality of the water near the recharge area. Practically all the water used for artificial recharge would be intercepted by discharging wells east of the Jordan River. Consequently, the recharge would have little effect on the quality near the river or west of it. The quality changes there would be similar to those for program 3.

Discussion

The hydrologic objectives of managing the water resources in Salt Lake County, 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

[1]The differences between figures 88 and 92 in the area near Magna result from limitations of the model.

Figure 91.—Water-level changes for program 6—pumpage after 1968 at approximately double the 1959-68 rate and recharge augmented artificially.

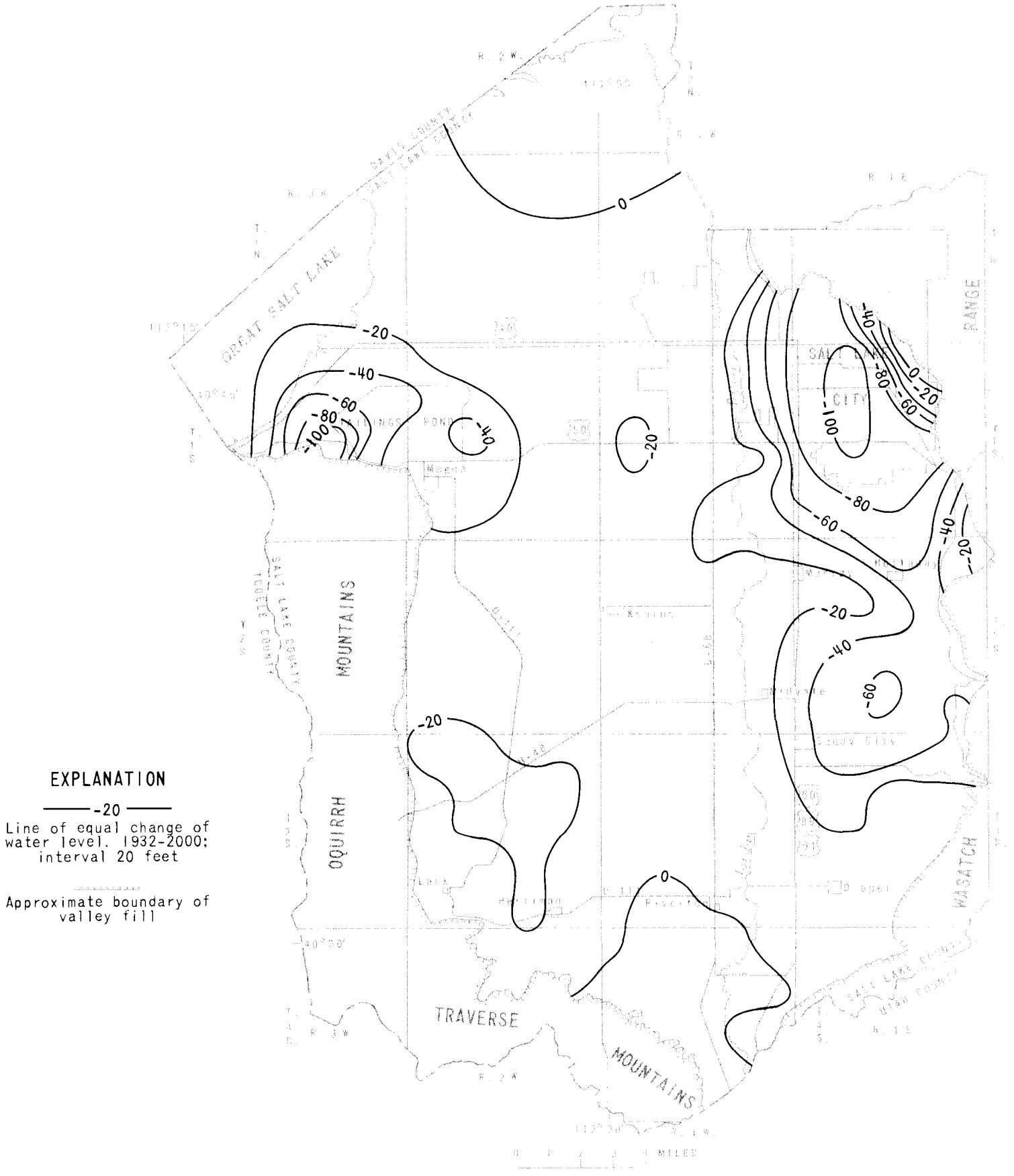


Figure 92.—Water-level changes for program 7—pumpage after 1968 at approximately triple the 1959-68 rate and recharge augmented artificially.

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 coordinated with the availability of surface-water supplies suitable for recharge.

It would be possible to lower the ground-water levels sufficiently to eliminate practically all waste of ground water through natural discharge. However, the drastic lowering which would be 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 was partly regulated in surface reservoirs and thus made available for longer periods. An estimate of the amount of surplus water available during 1964-68 water years is the difference between the amount of discharge (150,000 acre-ft) and the amount diverted (94,000 acre-ft), or 56,000 acre-feet per year.

Deer Creek Reservoir water could readily be used for artificial recharge, and such use would eliminate a major fault in the present system. As previously explained, rights of the Metropolitan Water District of Salt Lake City to water stored in the reservoir from previous years are nullified if runoff from the Provo River basin is sufficient to fill the reservoir. Such stored water could be transferred from the reservoir to an artificial recharge system during periods when the full capacity of the aqueduct is not needed for delivery of municipal supplies. The maximum amount of Deer Creek Reservoir water available to Salt Lake County during 1964-68 was 71,300 acre-feet per year (61,700 acre-ft plus 9,600 acre-ft per yr). The amount delivered averaged about 30,000 acre-feet per year (table 18). The difference of about 41,000 acre-feet is the approximate average annual quantity that could have been available for recharge.

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 assimilate 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.

The relation between the amount of water derived from ground-water storage and the duration of pumping for two assumed rates is shown in figure 93. The curves are defined by the

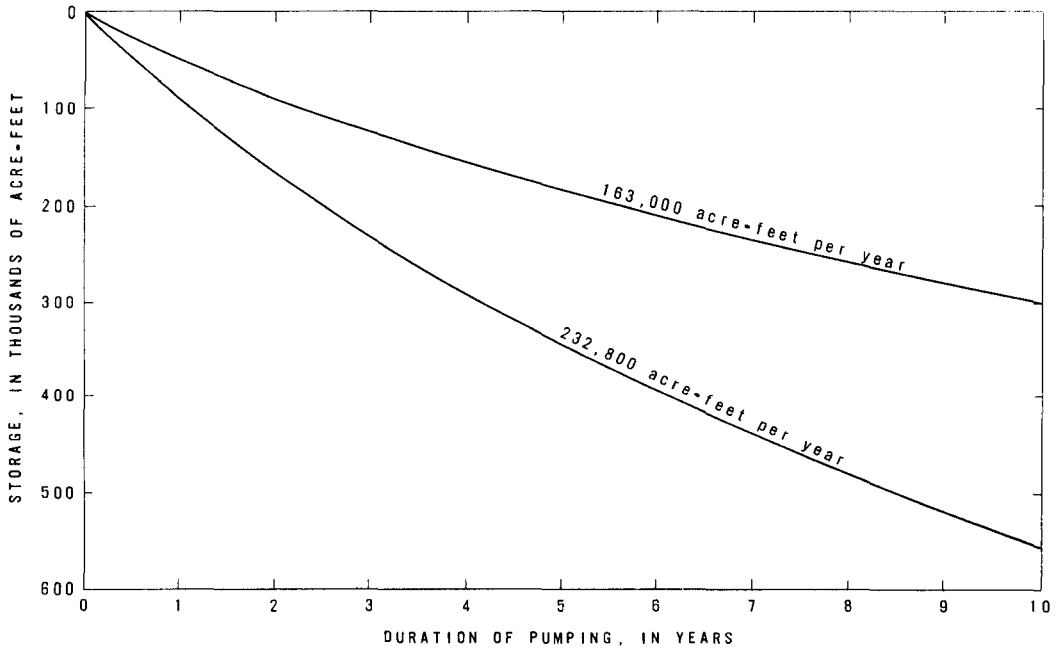


Figure 93.—Cumulative quantities of water derived from storage in the ground-water reservoir for two assumed pumping rates. The indicated pumping rates are approximately double and triple the 1958-69 rate superimposed on the 1931 base withdrawal rate of 38,000 acre-feet.

data from programs 2 and 3 of the analog model tests (table 42). If the pumpage increase over the 1931 rate of withdrawal were approximately triple the 1959-68 rate, for example, the amount of water withdrawn from storage in 2 years would be nearly 170,000 acre-feet—more than the storage capacity needed for complete regulation of the Wasatch streams within Salt Lake County.

The curves in figure 93, however, are based on storage in the entire ground-water reservoir and withdrawals from all existing pumping centers. In actual operation, a large part of the withdrawal and recharge might be concentrated in a much smaller area, and the storage capacity used would be less.

Data and discussions presented in this report indicate that full development of the water supply in the Wasatch streams would require considerable surface storage capacity and also that part of the total storage requirement could be met by use of the ground-water reservoir. The capacity of the ground-water reservoir that can be made available is sufficient to meet the needs for supplemental storage of water from these streams and also from Deer Creek Reservoir and other sources.

The data also indicate that a long-term average pumping rate at least double that of 1959-68 can be maintained in most parts of Jordan Valley with no serious consequences (other than an increase in pumping lift). A rate triple that of 1959-68 could be maintained for shorter periods (from 1 to about 5 years) provided that the water levels are later allowed to recover either naturally or with the aid of artificial recharge.

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APPENDIX

Acknowledgements

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 Utah 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 the 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.

The work was conducted under the supervision of W.V. Iorns, project hydrologist, until February 1966 when he was succeeded by Allen G. Hely. Ground-water investigations were conducted by Reed W. Mower, and water-quality investigations by C. Albert Harr. Ted Arnow contributed the section on geology and served as geologic consultant. All work on the electric analog model was done in Phoenix, Ariz., under the direction of E.P. Patten, Jr.

Designation of station and well sites

Most sites or features in this report are described by reference to well known landmarks, the cadastral land survey by the U.S. Government, or the Salt Lake County coordinate system. The starting point for both the land survey and the coordinates is the intersection of the Salt Lake meridian and base line at Main and South Temple Streets in Salt Lake City.

The land survey established townships approximately 6 miles square, each township being designated by a township number north or south of the base line and a range number east or west of the meridian. Townships are subdivided into 36 sections numbered from the northeast section of the township as indicated in figure 94.

This survey is the basis for a system of numbering wells and springs in Utah that indentifies each well or spring and also locates it to the nearest 10-acre tract. The meridian and base line divide the State into four quadrants designated by the uppercase letters A, B, C, and D (fig. 94). Numbers designating the township and range, respectively, follow the quadrant letter, and the three are enclosed in parentheses. The number after the parentheses designates the section, and the lowercase letters designate the location within the section. The first letter indicates the quarter section (a tract of about 160 acres), the second letter indicates the 40-acre tract, and the third indicates the 10 acre-tract. The numbers that follow the letters indicate the serial number of the well or spring within the 10-acre tract. Thus, well (C-2-1)24adc-1 is in the SW¼SE¼NE¼ sec. 24, T. 2 S., R. 1 W., and is the first well assigned a number in that tract. (See fig. 94.) Springs are designated by the letter S preceding the serial number at the end of the location number.

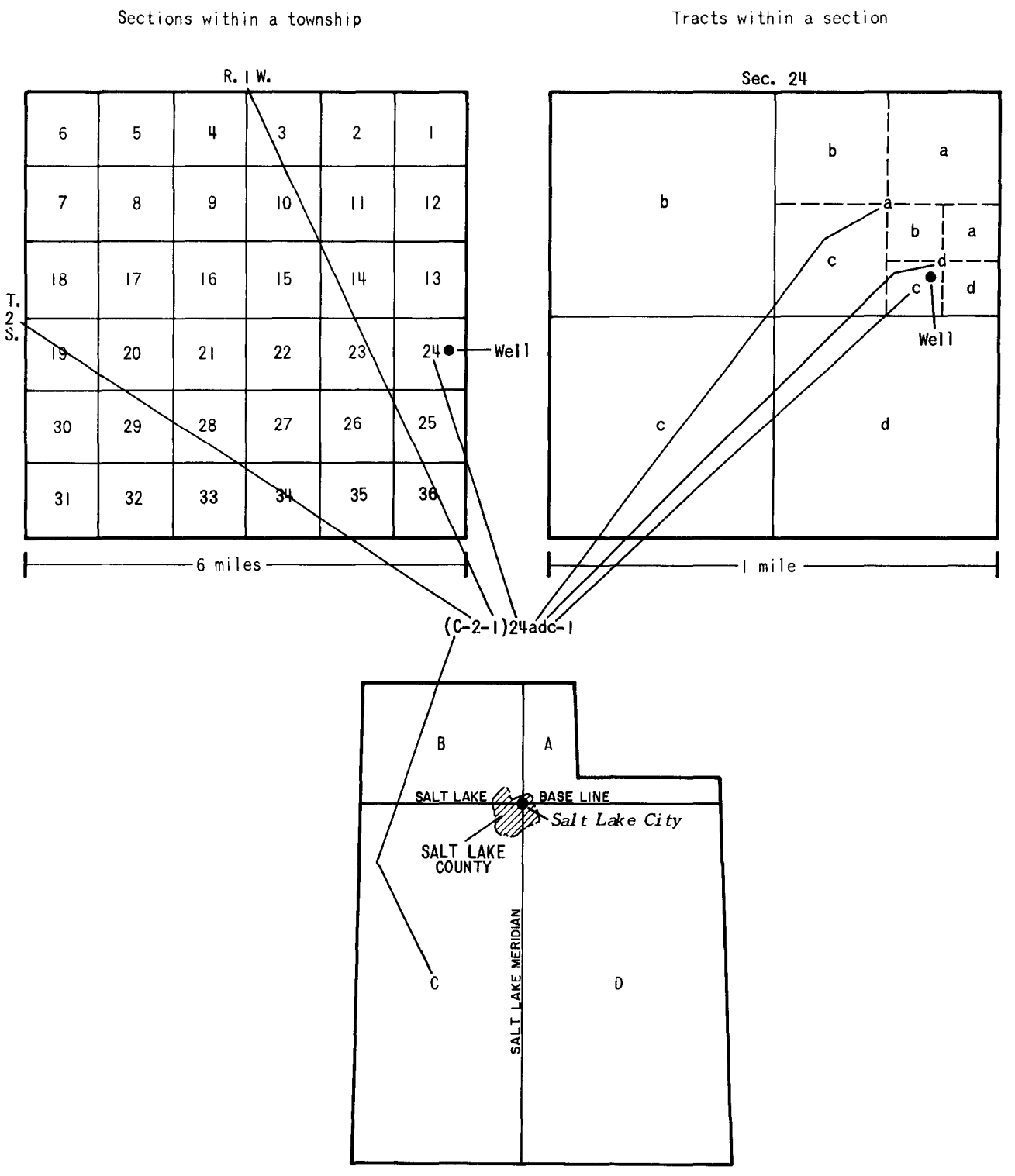

Figure 94.—Well- and spring-numbering system.

The county coordinate system, which is the basis for most street numbering in the county, indicates direction and approximate distance from the intersection of Main and South Temple Streets. For example, 27th East Street is 27 blocks east of Main and the corresponding coordinate number is 2700 East. Similarly, 21st South Street is 21 blocks south of South Temple and its coordinate number is 2100 South. However, west of Main Street and north of South Temple Street the numbers are 100 higher than the street names indicate, because West Temple Street is between Main and 1st West and North Temple Street is between South Temple and 1st North. Thus, 2nd West Street is three blocks west of Main, and its coordinate number is 300 West.

Units of measurement

In this report volumes of water (except in laboratory analyses) are expressed in acre-feet. One acre-foot is the volume of water required to cover one acre to a depth of one foot and equals 325,851 gallons.

Stream discharge is expressed in cubic feet per second (cfs). A steady discharge of 1.0 cfs for 1 day equals 1.983471 acre-feet.

Air temperatures are given in degrees Fahrenheit (°F) in accordance with long-standing practice of the Weather Bureau and other agencies. Water temperatures, however, are given in degrees Celsius (°C), formerly known as centigrade, in accordance with the adoption of metric units for reporting most water-quality data. Equivalent temperatures in the other units are often given to aid comparisons of air and water temperatures. (See accompanying temperature-conversion table.)

Concentrations of dissolved solids, constituents, and suspended sediment are given in milligrams per liter (mg/l) instead of the parts per million (ppm) formerly used. For nearly all concentrations discussed herein the results by the two systems are practically the same. The difference generally becomes significant only at dissolved-solids concentrations greater than 7,000 mg/l and sediment concentrations greater than 15,000 mg/l. Sediment discharge is reported in tons per day.

Concentrations of chemical constituents also may be given in milliequivalents per liter (meq/l). This unit, which expresses the concentration of chemical constituents in terms of chemical equivalence, better describes the composition of a water and the relationship of ions in solution. One milliequivalent of a postively charged ion (cation) will react with one milliequivalent of a negatively charged ion (anion). Milligrams per liter are converted to milliequivalents per liter by multiplying by the reciprocal of the combining weight of the ion. The following factors are used:

Cation	Factor	Anion	Factor
Calcium (Ca^{+2})	0.04990	Carbonate (CO_3^{-2})	0.03333
Magnesium (Mg^{+2})	.08226	Bicarbonate (HCO_3^{-1})	.01639
Sodium (Na^{+1})	.04350	Sulfate (SO_4^{-2})	.02082
Potassium (K^{+1})	.02557	Chloride (Cl^{-1})	.02821
		Nitrate (NO_3^{-1})	.01613

TEMPERATURE-CONVERSION TABLE

Temperatures in °C are rounded to nearest 0.5 degree. Underscored temperatures are exact equivalents. To convert from °F to °C where two lines have the same value for °F, use the line marked with an asterisk (*) to obtain equivalent °C.

°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
-20.0	-4	-10.0	14	0.0	32	10.0	50	20.0	68	30.0	86	40.0	104
-19.5	-3	-9.5	15	+0.5	33	10.5	51	20.5	69	30.5	87	40.5	105
-19.0	-2	-9.0	16	1.0	34	11.0	52	21.0	70	31.0	88	41.0	106
-18.5	-1	-8.5	17	1.5	35	11.5	53	21.5	71	31.5	89	41.5	107
-18.0 *	0	-8.0 *	18	2.0 *	36	12.0 *	54	22.0 *	72	32.0 *	90	42.0 *	108
-17.5	0	-7.5	18	2.5	36	12.5	54	22.5	72	32.5	90	42.5	108
-17.0	1	-7.0	19	3.0	37	13.0	55	23.0	73	33.0	91	43.0	109
-16.5	2	-6.5	20	3.5	38	13.5	56	23.5	74	33.5	92	43.5	110
-16.0	3	-6.0	21	4.0	39	14.0	57	24.0	75	34.0	93	44.0	111
-15.5	4	-5.5	22	4.5	40	14.5	58	24.5	76	34.5	94	44.5	112
-15.0	5	-5.0	23	5.0	41	15.0	59	25.0	77	35.0	95	45.0	113
-14.5	6	-4.5	24	5.5	42	15.5	60	25.5	78	35.5	96	45.5	114
-14.0	7	-4.0	25	6.0	43	16.0	61	26.0	79	36.0	97	46.0	115
-13.5	8	-3.5	26	6.5	44	16.5	62	26.5	80	36.5	98	46.5	116
-13.0	9	-3.0	27	7.0	45	17.0	63	27.0	81	37.0	99	47.0	117
-12.5	10	-2.5	28	7.5	46	17.5	64	27.5	82	37.5	100	47.5	118
-12.0 *	10	-2.0 *	28	8.0 *	46	18.0 *	64	28.0 *	82	38.0 *	100	48.0 *	118
-11.5	11	-1.5	29	8.5	47	18.5	65	28.5	83	38.5	101	48.5	119
-11.0	12	-1.0	30	9.0	48	19.0	66	29.0	84	39.0	102	49.0	120
-10.5	13	-0.5	31	9.5	49	19.5	67	29.5	85	39.5	103	49.5	121

For temperature conversions beyond the limits of the table, use the equation $C = 0.5556\ (F - 32)$ and $F = (1.8)(°C) + 32$. The formulae say, in effect, that from the freezing point of water (0°C, 32°F) the temperature in °C rises (or falls) 5° for every rise (or fall) of 9°F.

Sources of data

Climatologic data.—Most of the data herein are from publications of the U.S. Weather Bureau (no date, 1951-66, 1957, 1965) and corresponding publications in recent years by the U.S. Environmental Science Services Administration (1967-69, 1968). The U.S. Geological Survey in cooperation with the Weather Bureau maintained several additional evaporation and precipitation stations during the study period, 1964-68. These data are published in annual basic-data releases (Iorns and others, 1966a, 1966b; Hely and others, 1967-69). Several unpublished, partial records of precipitation are in files of the Weather Bureau and the Geological Survey.

Surface-water data.—Compilation reports by the U.S. Geological Survey (1960, 1963) contain records of monthly discharge at the principal streamflow stations from the beginning of record to 1960. Records of daily discharge for some of the same stations are contained in the Geological Survey's annual series on surface water (U.S. Geol. Survey, 1914-60, 1961-64 1965-68). Basic-data releases (Iorns and others, 1966a, 1966b; Hely and others, 1967-69) contain most of the data for 1964-68 used herein, including records for several temporary stations. Records of monthly flow of Red Butte Creek at Fort Douglas, 1942-62, are in files of the Post Engineer, Corps of Engineers, U.S. Army, and the U.S. Geological Survey.

During the period 1964-68, the Geological Survey participated in the operation of Salt Lake City's stations on the Wasatch streams at the canyon mouths and developed its own stage-discharge relations. Consequently, some of the records published by the Geological Survey differ somewhat from those in the city's files.

Annual reports of the Utah Lake and Jordan River Water Commissioner (Lofgren, 1934-35; Gardner, 1936-69) contain records of Utah Lake levels and evaporation and of diversions from Jordan River above 9400 South Street. These reports include summaries with data since 1900.

Records of flow in two tributaries to Mountain Dell Reservoir on Parleys Creek and gage-height records for Big Cottonwood Creek near a proposed damsite (Argenta) and at 2nd West Street are in files of the Salt Lake City Water Department. The same files also contain records of diversion from Big Cottonwood, Little Cottonwood, and Mill Creeks.

Records of deliveries through the Salt Lake City aqueduct are in files of the Metropolitan Water District of Salt Lake City, and those through the Provo Reservoir Canal are in files of the Provo River Water Users Association, Provo, Utah. Flow in Kennecott Copper Corp.'s pipeline from Tooele Valley was computed by the Geological Survey from gage-height records at the sources furnished by Kennecott Copper Corp.

Water-quality data.—Nearly all the water quality data used in this report are contained in basic-data releases by Marine and Price (1963), Iorns and others (1966a, 1966b), and Hely and others (1967-69). Other sources are acknowledged in the text.

Ground-water data.—Much of the data used herein pertaining to well construction, well characteristics, drillers' logs, water levels, and performance tests are from files of the Utah Division of Water Rights. Other similar data are from well drillers and well owners. These data are published in basic-data releases (Marine and Price, 1963; Iorns and others, 1966a, 1966b; Hely and others, 1967-69).

Records of most of the water levels measured in observation wells during 1935-65 are in reports by the U.S. Geological Survey (U.S. Geol. Survey, 1936-40, 1941-57, 1963, 1968). Basic-data releases (Iorns and others, 1966a, 1966b; Hely and others, 1967-69) contain most of the water-level measurements for 1964-68, including measurements made by the Geological Survey, Utah Division of Water Rights, and Salt Lake City Water Department.

During the period 1964-68, recording gages were maintained on 29 wells for periods ranging from 3 months to 5 years. Water levels were measured in about 100 wells at intervals ranging from 2 weeks to 2 months, and water levels were measured in about 100 other wells semiannually in February and September. Water levels were measured with a steel tape. Shut-in pressure heads in flowing wells were measured with a mercury manometer or with a transparent hose connected tightly to the discharge pipes. A standard lapse of 10 minutes was allowed between the time that the well was shut in and the time that the pressure was observed.

Pumpage from irrigation wells equipped with electric motors was determined by measuring the rate of consumption of electricity while pumping rates were being measured and then computing the annual pumpage from records of annual consumption. Pumpage from irrigation wells equipped with internal-combustion engines was determined from the duration of pumping or from annual fuel consumption.

Pumpage from most public supply and industrial wells, which are equipped with totalizing meters, was reported by the well owners. Pumpage from other wells was computed from records of the duration of pumping supplied by the owners. Pumpage from some public supply and industrial wells was computed by the method used in computing pumpage from irrigation wells.

The yields of about 75 selected flowing wells were measured 1 to 25 times a year by observing the time required to fill a container of known volume. The total yield from all flowing wells in a township was computed by estimating the average annual rate of discharge of the wells for which measurements had been made, and applying a modified rate (based on comparative water levels) to all flowing wells in the township.

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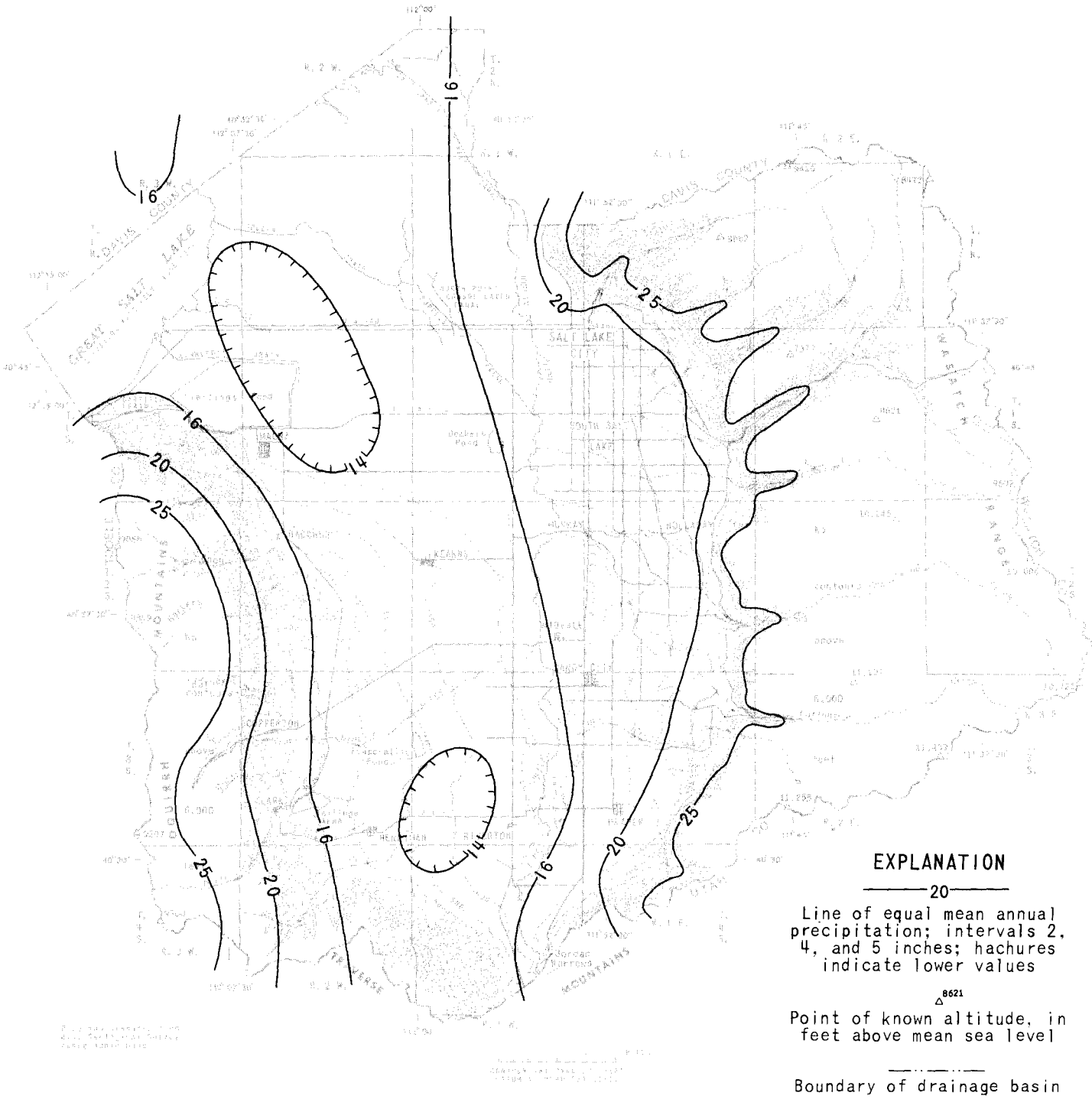

Figure 5.—Mean annual precipitation in Jordan Valley, October 1963 to September 1968. Isohyets above 25 inches not shown.

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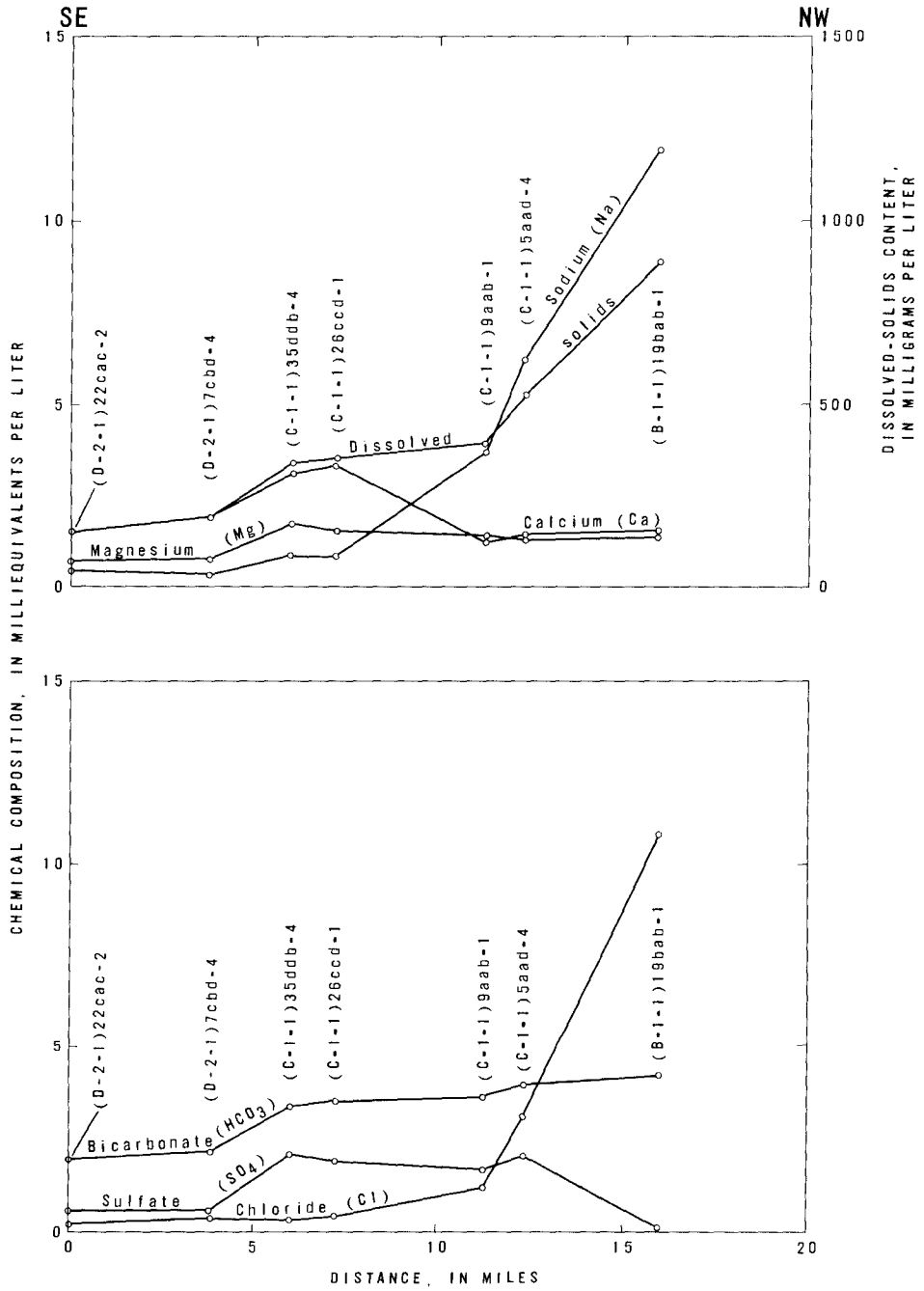

Figure 77.—Changes in the dissolved-solids content and chemical composition of ground water moving toward Great Salt Lake. Approximate flow line shown on plate 2.

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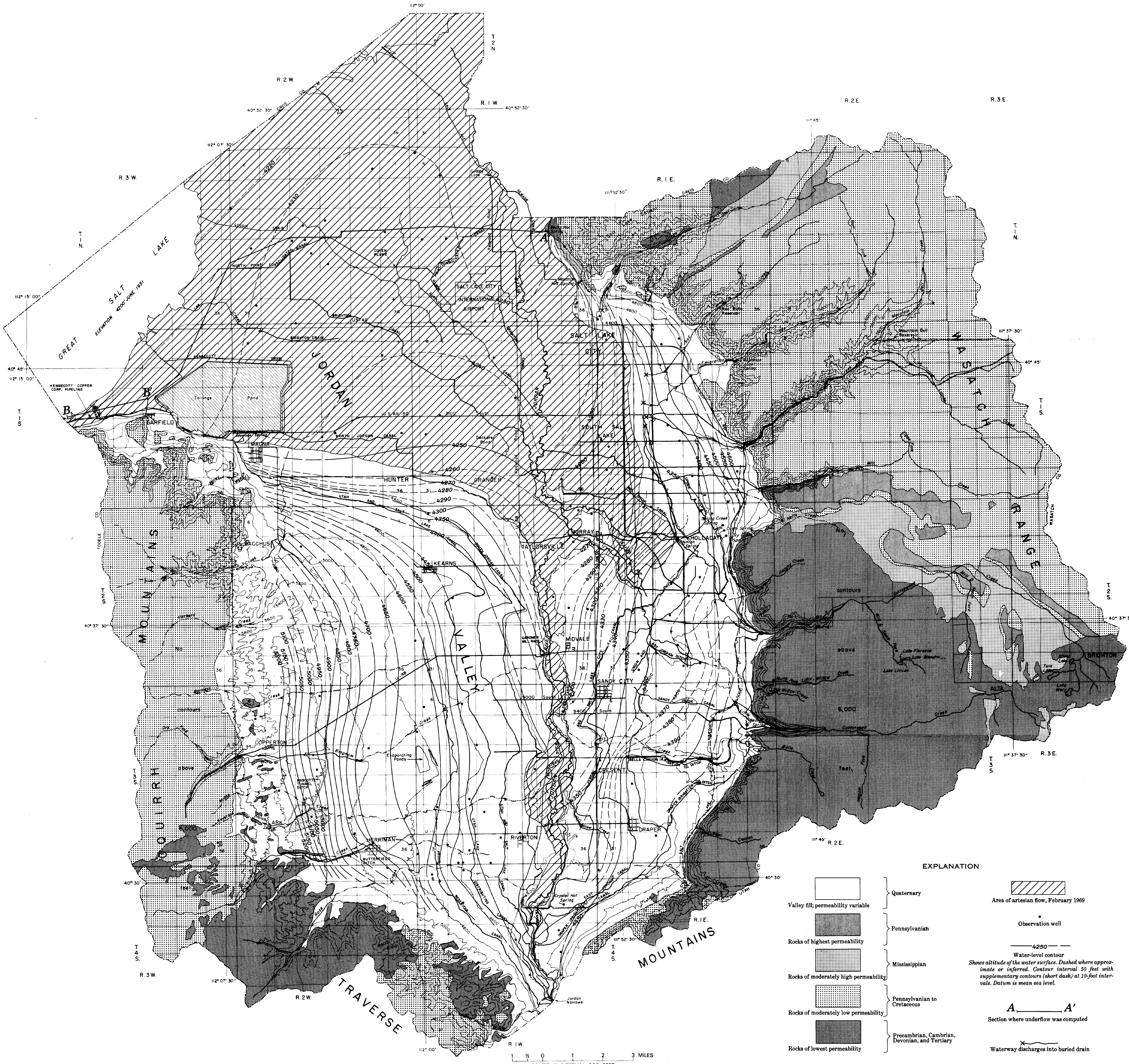
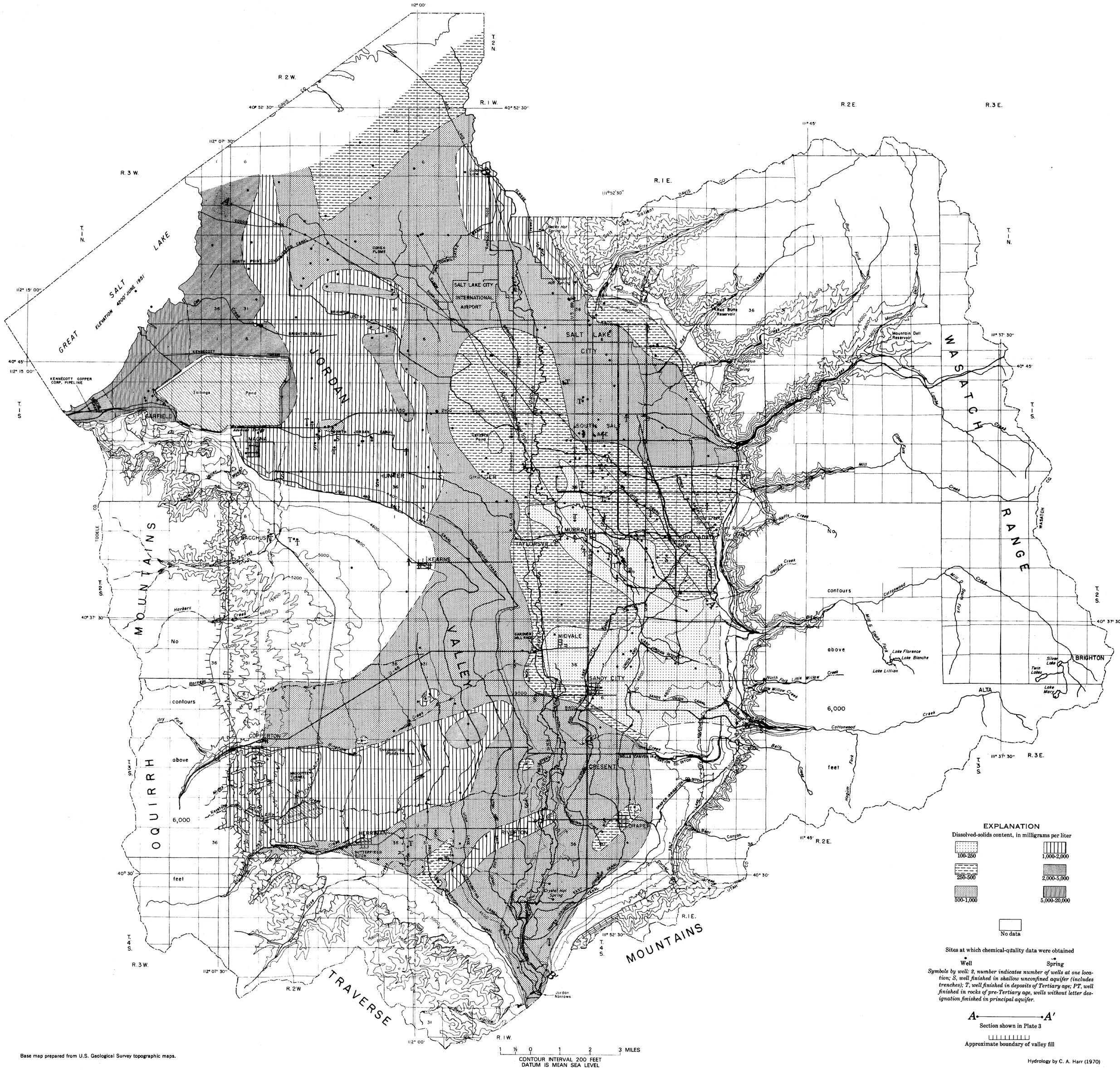


Base map prepared from U.S. Geological Survey topographic maps.

Hydrology by R. W. Mower and Ted Arnow, 1969; geologic boundaries adapted from Marsell and Threet (1960).

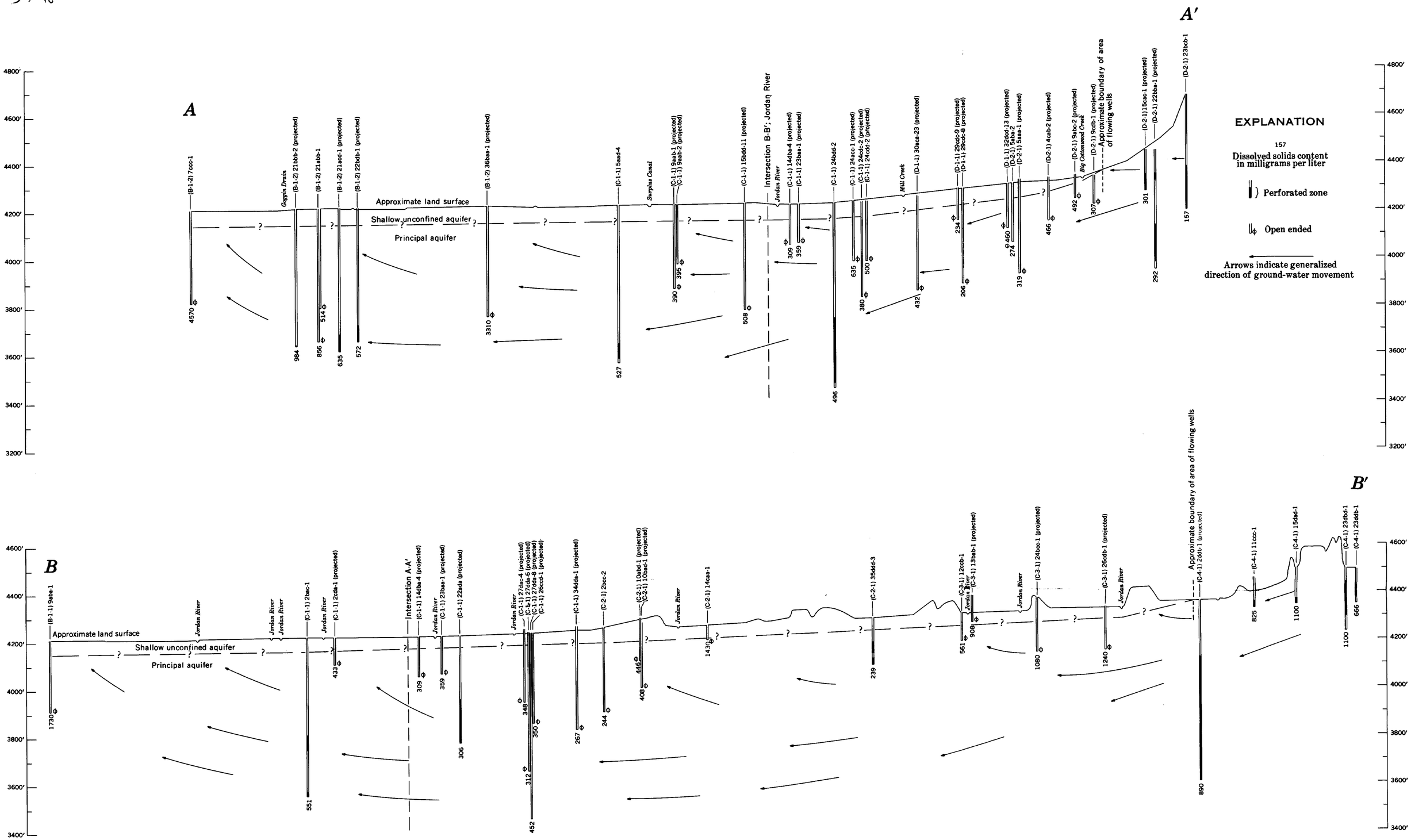
MAP SHOWING WATER-LEVEL CONTOURS FOR THE PRINCIPAL AQUIFER AND AREA OF ARTESIAN FLOW IN FEBRUARY 1969, WATER-DISTRIBUTION SYSTEM, AND GENERALIZED HYDROGEOLOGY OF SALT LAKE COUNTY, UTAH



Base map prepared from U.S. Geological Survey topographic maps.

Hydrology by C. A. Harr (1970)

MAP SHOWING DISSOLVED-SOLIDS CONTENT OF WATER IN THE PRINCIPAL AQUIFER IN THE JORDAN VALLEY, SALT LAKE COUNTY, UTAH, AND LOCATIONS WHERE SAMPLES FOR CHEMICAL ANALYSES WERE OBTAINED FROM WELLS, TRENCHES, AND SPRINGS



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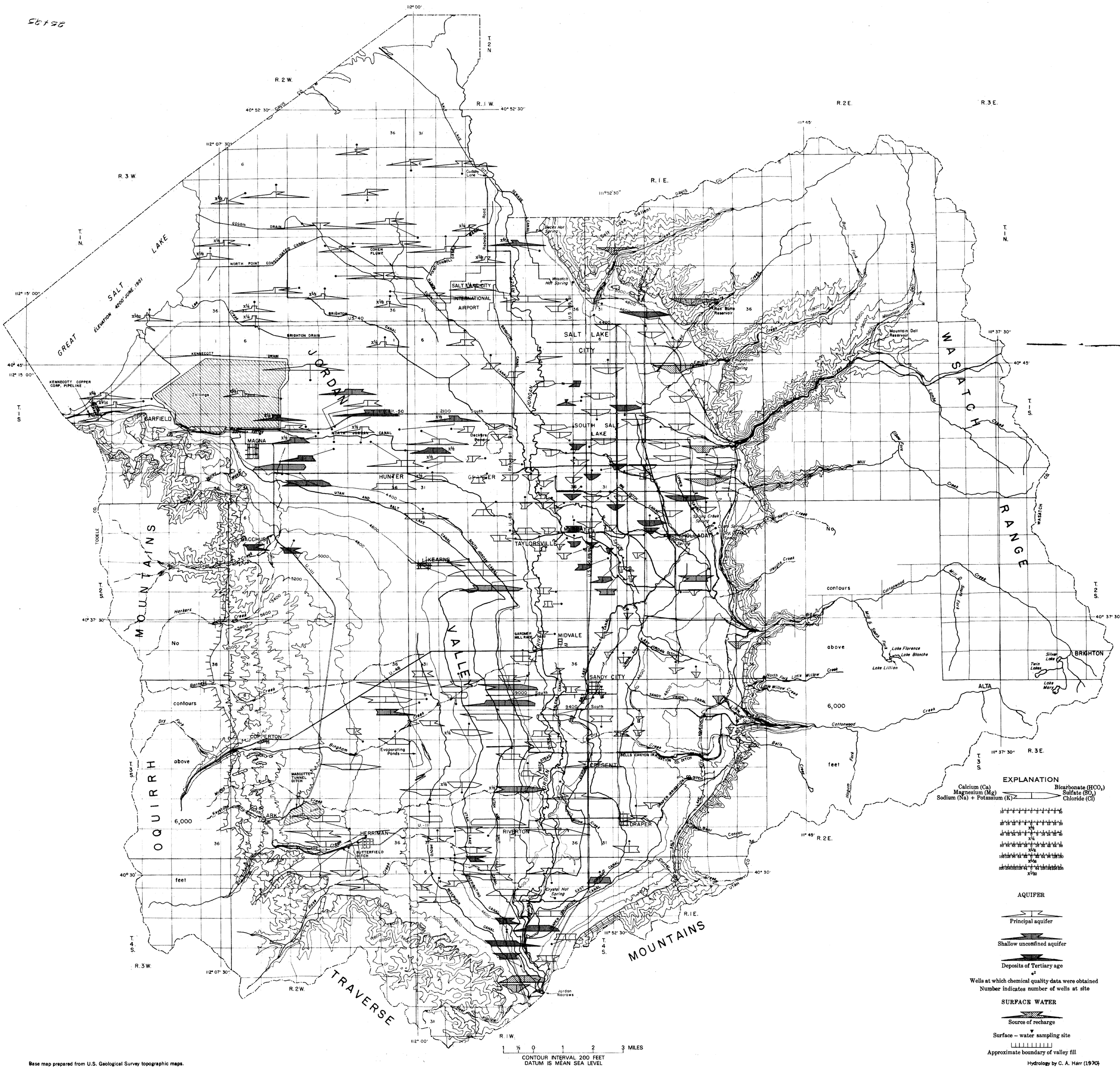
CROSS SECTION SHOWING GROUND-WATER FLOW PATTERN AND THE DISSOLVED-SOLIDS CONTENT OF WATER FROM VARIOUS LOCATIONS AND DEPTHS IN THE JORDAN VALLEY, SALT LAKE COUNTY, UTAH (THE LOCATIONS OF SECTIONS A-A' AND B-B' ARE SHOWN ON PLATE 2.)



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Hydrology by C. A. Harr (1970)

MAP SHOWING THE CHEMICAL COMPOSITION OF GROUND-WATER FROM SELECTED WELLS IN THE JORDAN VALLEY, SALT LAKE COUNTY, UTAH (THE COMPOSITION OF SURFACE WATER AT SOME POINTS AT THE EASTERN EDGE OF THE VALLEY IS INCLUDED BECAUSE IT REPRESENTS THE PROBABLE COMPOSITION OF A PART OF THE RECHARGE.)