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REEVALUATION OF THE GROUND-WATER RESOURCES OF TOOELE VALLEY, UTAH

By

Joseph S. Gates

Geologist

U. S. Geological Survey

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CONTENTS

CONTENTS—Continued

ILLUSTRATIONS

TABLES

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ABSTRACT

Tooele Valley is in northwestern Utah, about 30 miles southwest of Salt Lake City, and its drainage basin includes an area of about 400 square miles.

The valley is a structural depression bordered by uplifted mountain ranges which are largely composed of marine deposits of Paleozoic age. The valley is filled with alluvial, colluvial, lacustrine, and possibly volcanic deposits of Tertiary and Quaternary age, which at one place are probably as thick as 7,100 feet. Five faults in the valley were redefined or defined during this investigation — the Mill Pond, Occidental(?), Fishing Creek, Warm Springs, and Sixmile Creek faults.

Ground water occurs under both water-table and artesian conditions, but almost all of the 1,300 wells in the valley tap artesian aquifers. The principal artesian aquifer in the northern part of the valley is from 80 to 130 feet thick, and the depth to the top of this aquifer ranges from 50 to 300 feet.

Recharge to the artesian aquifer system is from precipitation, seepage from streams, seepage from irrigated land, underflow from the canyons in the mountains, and seepage from the bedrock of the mountains. Recharge to the artesian aquifers is about 100,000 acre-feet per year.

Ground water in the valley moves northward toward Great Salt Lake, generally parallel to the slope of the land surface. Discharge from the artesian aquifer system in 1962 included 21,000 acre-feet from wells, most of the 15,000 acre-feet discharged from springs, most of the 40,000 acre-feet discharged by evapotranspiration from an area of phreatophytes in the northern part of the valley, and most of the ground water discharged by subsurface flow to Great Salt Lake. Between 1938-40 and 1962, discharge from wells has more than tripled, whereas discharge from springs decreased by about one-fourth.

Coefficients of transmissibility obtained from aquifer tests in the valley range from 120,000 to 1,300,000 gallons per day per foot, and storage coefficients range from 0.0002 to 0.0042.

Five of the ground-water districts in the valley — the Lake Point, Erda, Marshall, Grantsville, and Burmester districts — were redefined, and two new districts — the Mill Pond and Tooele districts — were defined during this investigation. Each district is either

partly hydraulically separate from the other districts or has distinct hydrologic characteristics.

In 1941, the valley contained an estimated 1,050 wells. Of these, only 13 were 8 inches or more in diameter and only two were equipped with turbine pumps. From 1941 through 1963, about 256 additional wells were constructed, of which 91 were 8 inches or more in diameter. In 1962, 62 wells were pumped for irrigation, municipal, military, and industrial supplies.

Water levels in the valley declined between 1950-52 and 1963. The water level in an observation well in the Erda district declined 20 feet, and the water level in a well in the Grantsville district declined 17 feet. Water levels declined from 5 to 11 feet from 1958 to 1963 in the Erda and Grantsville districts, whereas water levels in other parts of the valley declined lesser amounts. Below-normal precipitation since 1950-52 has caused part of the decline and led to an increase in pumping which actually caused most of the decline.

Most of the ground water in the valley contains less than 1,000 parts per million of dissolved solids and can be used for most purposes, although it commonly is hard. The ground water from the Erda, Grantsville, and Tooele districts and parts of the Mill Pond and Marshall districts is generally suitable for irrigation. Ground-water development has not caused any major changes in water quality, but some poor-quality water may be moving into areas of better-quality water in the Mill Pond and Marshall districts.

Normal ground-water temperatures range from 53°F at a depth of 50 feet to about 63° at a depth of 640 feet. Above-normal temperatures near Mill Pond and Dunne's Pond Springs, Fishing and Sixmile Creeks, and Warm Springs indicate that saline water rises along faults in these three areas.

A tentative hydrologic budget for the valley south of a reference line through the Mill Pond, Erda, Marshall, and Grantsville districts included an annual water gain of 200,000 acre-feet from precipitation and annual water losses of 80,000 acre-feet by evapotranspiration in the recharge area and adjacent mountains, 10,000 acre-feet by streamflow, 10,000 acre-feet by discharge of springs, drains, and wells, and 100,000 acre-feet by underflow past the reference line.

Future development of ground water in Tooele Valley will reduce losses by evapotranspiration and subsurface flow to Great Salt Lake. Concurrent with these benefits, however, water levels will decline, many wells will stop flowing, the discharge of some springs may decrease, and water of poor quality may migrate into areas of water of good quality. Careful planning and management of ground-water development would minimize these harmful effects.

INTRODUCTION

Purpose and scope

This study of the geohydrology of Tooele Valley, Utah, was made by the U.S. Geological Survey in cooperation with the Utah State Engineer during the period 1958-63. The purpose of the study was to update an earlier investigation of ground water in Tooele Valley made by the Geological Survey during 1940-42 (Thomas, 1946). The construction of approximately 256 wells in the valley since 1940, many of which are large-diameter pumped wells drilled since 1950, made available new data on water levels, well discharge, and chemical quality for interpretation of ground-water conditions. New data also were available on spring discharge, streamflow, aquifer characteristics, and geologic, geophysical, and climatic conditions. The earlier report by Thomas (1946) was freely used during the preparation of this report.

Geologic work was done only where additional investigation or evaluation of recent geologic work would help in the interpretation of the hydrology. Some new interpretations of the geology were made, using hydrologic and geophysical data collected since 1942.

The ground-water hydrology of Tooele Valley was reanalyzed wherever analysis of data from the period 1943-63, combined with earlier information, would add to an understanding of the hydrologic system. Discharge of ground water was measured or estimated and the effects of this discharge on water levels and water quality were determined. Water-level, water-quality, temperature, geologic, and gravity data were used to make new interpretations of faults and ground-water district boundaries. A tentative hydrologic budget was made for the artesian aquifer system. The chemistry of the ground water in the valley was reevaluated on the basis of all data collected since 1940, and the thermal gradient in the valley was determined from temperature measurements of water from wells.

Thomas' (1946) discussion of future development of ground water in each ground-water district of the valley was updated, and the hydrologic data that will be needed in the future for proper management of the water resources of the valley were listed.

The investigation was conducted by H. D. Goode and the writer from March 1958 to October 1958 and by the writer on a part-time basis from October 1958 through 1963. Goode and Gates (written communication, 1959) summarized the progress of the study through 1958. In reports prepared as a result of this investigation and related work Gates defined the Occidental(?) fault in the Erda area (1962), compiled the basic data used in preparing this report (1963b), and reported on the hydrogeology of Middle Canyon in the Oquirrh Mountains (1963a).

Previous investigations

Thomas (1946) described the ground water in Tooele Valley, discussed the geology of the valley and adjacent mountains, and studied some aspects of the hydrology of the valley in detail.

Before Thomas' study, Carpenter (1913) made a ground-water reconnaissance that included Tooele Valley, Gilbert (1890) reported on Pleistocene Lake Bonneville and discussed the deposits of the lake in the valley, and Gilluly (1932) mapped the southern part of the Oquirrh Mountains, southeast of the valley. Kearney and others (1914) investigated the vegetation of Tooele Valley; and unpublished studies were made of the soils of the valley by A. T. Strahorn of the Bureau of Soils, U. S. Department of Agriculture, in 1922 and by the Soil Conservation Service in 1935.

Since Thomas' study, Rigby (1958) and Cook (1961) edited Utah Geological Society guidebooks for the Stansbury Mountains and the northern Oquirrh Mountains, respectively; Tooker and Roberts (1961) mapped the northern end of the Oquirrh Mountains; and W. W. Johnson (written communication, 1958)[1] made a gravity survey in Tooele, Rush, and southern Skull Valleys.

[1]Johnson, W. W., 1958, Regional gravity survey of part of Tooele County, Utah: Utah Univ. M.S. thesis, 38 p.

Geography

Location, topography, and water resources

Tooele Valley is at the eastern edge of Tooele County in northwestern Utah (fig. 1) and is about 30 miles southwest of Salt Lake City. The valley proper includes approximately 250 square miles bounded by Great Salt Lake and the foot of the steep slopes of the Oquirrh Mountains, South Mountain, the Stansbury Mountains, and Stansbury Island. The area of investigation included the entire 400 square miles of the drainage basin except for about 12 square miles south of Stansbury Island. (See fig. 1.) The latter area was not included because it is not shown on any large-scale topographic maps and is mostly saltflat.

Altitudes of the drainage basin range from about 4,200 feet at the lakeshore to 10,350 feet in the Oquirrh Mountains and 11,031 feet in the Stansbury Mountains.

Lakes filled Tooele Valley at different times during the Pleistocene Epoch. The best known and most recent of the lakes, Lake Bonneville, greatly influenced the existing topography of the valley. Shorelines of Lake Bonneville are well exposed on the western side of the Oquirrh Mountains, and the highest shoreline is at an altitude of 5,250-5,280 feet. Deposits of the lake, such as the Stockton bar (see fig. 2) and spits in the southwest corner of Tooele Army Depot, also are prominent in the valley.

The mountains that border Tooele Valley are drained by several perennial and many intermittent streams. Perennial streams are in parts of Settlement Canyon in the Oquirrh Mountains and in North and South Willow Canyons in the Stansbury Mountains. None of the perennial streams reach Great Salt Lake because they are diverted, and perhaps only South Willow Creek reached the lake before the valley was settled.

Numerous springs, many of which are perennial, are in the mountains. Several of these springs furnish perennial streamflow for short distances. Four spring areas that each yield over 1,000 gpm (gallons per minute) are in the northern part of the valley — Mill Pond Spring, Dunne's Pond Springs, and the springs that feed Sixmile and Fishing Creeks (fig. 2). The flow from these large springs originally may have reached the lake, but it is now diverted. Several small unnamed springs also are in the northern part of the valley.

Water in Tooele Valley is used chiefly for irrigation. Settlement Creek is diverted for irrigation and public supply. The flow of North and South Willow Creeks, combined with that of the intermittent streams in Davenport and Box Elder Canyons, is used around Grantsville for irrigation. Some of the springs in the mountains are unused; others supply water for stock, public supply, or industry. In the northern part of the valley the water from the large springs is used for irrigation or industrial supply, and the water from the small springs is used for irrigating pasture or by stock.

Wells, which are another major source of water in the valley, produce water for irrigation, industry, public supply, use at military installations, domestic use, and stock.

Climate

Tooele Valley is semiarid, but the higher parts of the Oquirrh and Stansbury Mountains receive enough precipitation to be classified as humid. The only substation of the U.S. Weather Bureau in Tooele Valley that has long-term records is at Tooele (fig. 2), where

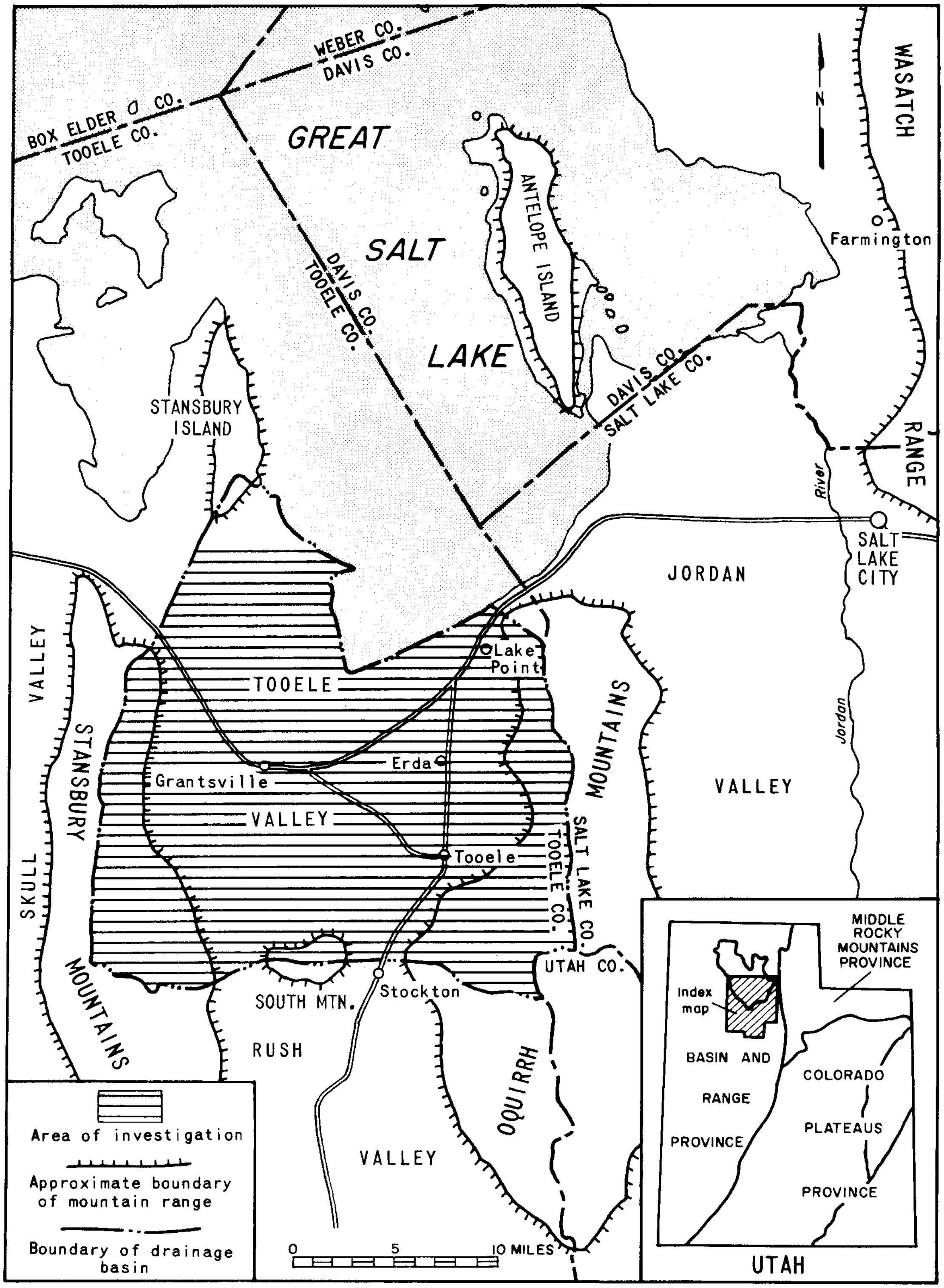

Figure 1.-Index map showing the location of the Tooele Valley drainage basin and the area of investigation.

the normal (1931-60) annual precipitation is 15.48 inches. A substation has been intermittently operated at Grantsville (present location shown in fig. 2) and a substation was at Grantsville Power House (fig. 2) from October 1942 through April 1956.

E. L. Peck, of the U.S. Weather Bureau, prepared a map of the normal (1931-60) annual precipitation over the valley (fig. 2). The map shows that precipitation on the western side of the valley is less at the same altitude on the eastern side because the Stansbury Mountains create a rain shadow.

Precipitation in the drainage basin from October through April contributes more to the local water supply than that from May through September. At Tooele, normal precipitation from October through April is 10.69 inches, or 69 percent of the annual precipitation. Rates of transpiration and evaporation are greatest during the May-September period; thus, less water remains for streamflow and ground-water recharge.

Precipitation at Tooele follows an irregular pattern of alternating periods of relatively wet and dry years. Each period of wet years, however, includes individual dry years, and each period of dry years includes individual wet years. Figure 3 shows cumulative departure from the average annual precipitation for the period 1897-1963 and cumulative departure from the average October-April precipitation for the period October 1896-April 1963. Lines trending upward indicate periods of above-average precipitation, and lines trending downward indicate periods of below-average precipitation.

The normal (1931-60) mean annual temperature at Tooele is 51.5°F. The minimum mean monthly temperature is 28.5° in January and the maximum is 76.6° in July. The annual freeze-free period at Tooele is 209 days (Criddle, Harris, and Willardson, 1962, p. 11).

Vegetation

The most common native plants in the valley are sagebrush, juniper, rabbitbrush, white sage, shadscale, greasewood, saltgrass, pickleweed, and samphire (Kearney and others, 1914). The depth to the water table, salinity of soil and ground water, soil moisture, and soil texture determine which species is dominant in particular parts of the valley.

In the mountains the vegetation differs in response to altitude and exposure. Juniper commonly grows on the foothills and lower mountain slopes. Southern slopes at all altitudes are covered with scrub oak and various species of brush. Northern slopes at high altitudes are covered with yellow pine, Douglas-fir, spruce and aspen.

Population and economy

The population of Tooele Valley in 1960 was about 13,000. The most populated centers were Tooele with 9,133 people and Grantsville with 2,166 people. The population of the valley and of Tooele and Grantsville has approximately doubled since 1940.

The economy of Tooele Valley is based on agriculture, industry, and a military installation. Crops are raised both with and without irrigation. Alfalfa is the chief irrigated crop; lesser acreages of wheat, oats, barley, and pasture also are irrigated. Grain is the major crop grown on the dry farms, most of which are along the eastern side of the valley. The chief marketed agricultural product in the valley is cattle and sheep to which most of the alfalfa and much of the grain is fed locally.

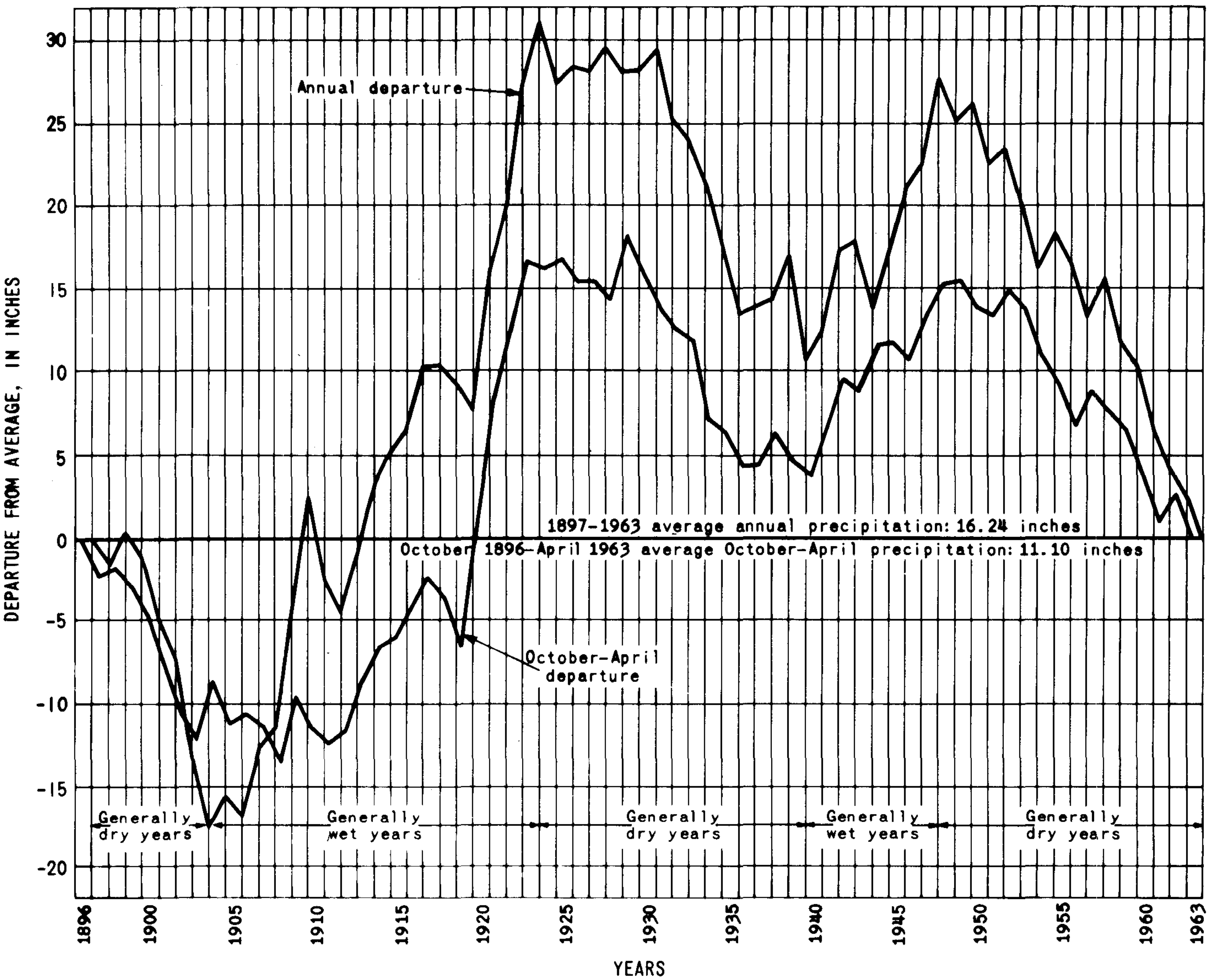

Figure 3.— Cumulative departure from average annual precipitation for 1897-1963 and from average October-April precipitation for 1896-1963 at Tooele.

International Smelting and Refining Co. has a smelter northeast of Tooele, and Combined Metals Reduction Co. has a plant just north of the Stockton bar that was largely unused during the period of this study. Solar Salt Co. and Leslie Salt Co. have plants in the northwest and northeast corners of the valley, respectively, that produce salt from water from Great Salt Lake. Utah Lime and Stone Co. has a quarry in the northwest corner of the valley and a processing plant just northwest of the valley. Tooele Army Depot, west of Tooele, probably employs more people than all the industries in the valley.

Acknowledgments

The following persons or organizations furnished data on wells, springs, and tunnels; permitted the collection of hydrologic data; and permitted the collection of water samples: individual well owners; Tom Mander, North Willow Irrigation Co.; Sidney Noble and Arthur Garner, city of Tooele; Marvin Johnson, city of Grantsville; W. H. Thompson and Lynn Elkington, Tooele Army Depot; Royal Anderson, Kennecott Copper Corp.; International Smelting and Refining Co.; Combined Metals Reduction Co.; the Anaconda Co.; Leslie Salt Co.; Solar Salt Co.; and Utah Lime and Stone Co.

Utah Power and Light Co. supplied power-consumption data for pumped wells. The Tooele office of the Soil Conservation Service furnished streamflow records for Settlement Creek. Well drillers, including Robinson Drilling Co., J. S. Lee and Sons Drilling Co., Melvin Church, Ivan Hale, Jess Long, and B. B. Gardner, supplied data on wells. E. L. Peck of the U.S. Weather Bureau prepared maps of precipitation in Tooele Valley. L. T. Liddell and Evan Sandberg operated water-level recording gages on observation wells at Erda and Grantsville, respectively.

Well-numbering system used in Utah

The system of numbering wells in Utah is based on the cadastral land-survey system of the Federal Government. The well number, in addition to designating the well, locates its position to the nearest 10-acre tract in the land net. By this system the State is divided into four quadrants by the Salt Lake base and meridian, and these quadrants are designated by the capital letters A, B, C, and D. A is the northeast quadrant, B is the northwest, C is the southwest, and D is the southeast. Numbers designating the township and range follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses designates the section, and the lowercase letters give the location of the well within the section. The first letter indicates the quarter section, which is generally a tract of 160 acres, the second letter indicates the 40-acre tract, and the third letter indicates the 10-acre tract. The number following the letters indicates the serial number of the well within the 10-acre tract. Thus, well (C-2-4)31dad-2, in Tooele County, is in the SE¼NE¼SE¼ sec. 31, T. 2 S., R. 4 W., and is the second well constructed or visited in that tract. Figure 4 shows the method of numbering wells as described above. In this report springs and sampling sites are also located using this system, but the designation number within a 10-acre tract is omitted.

If a well is listed in this report by number, it is shown in figure 5, unless otherwise indicated.

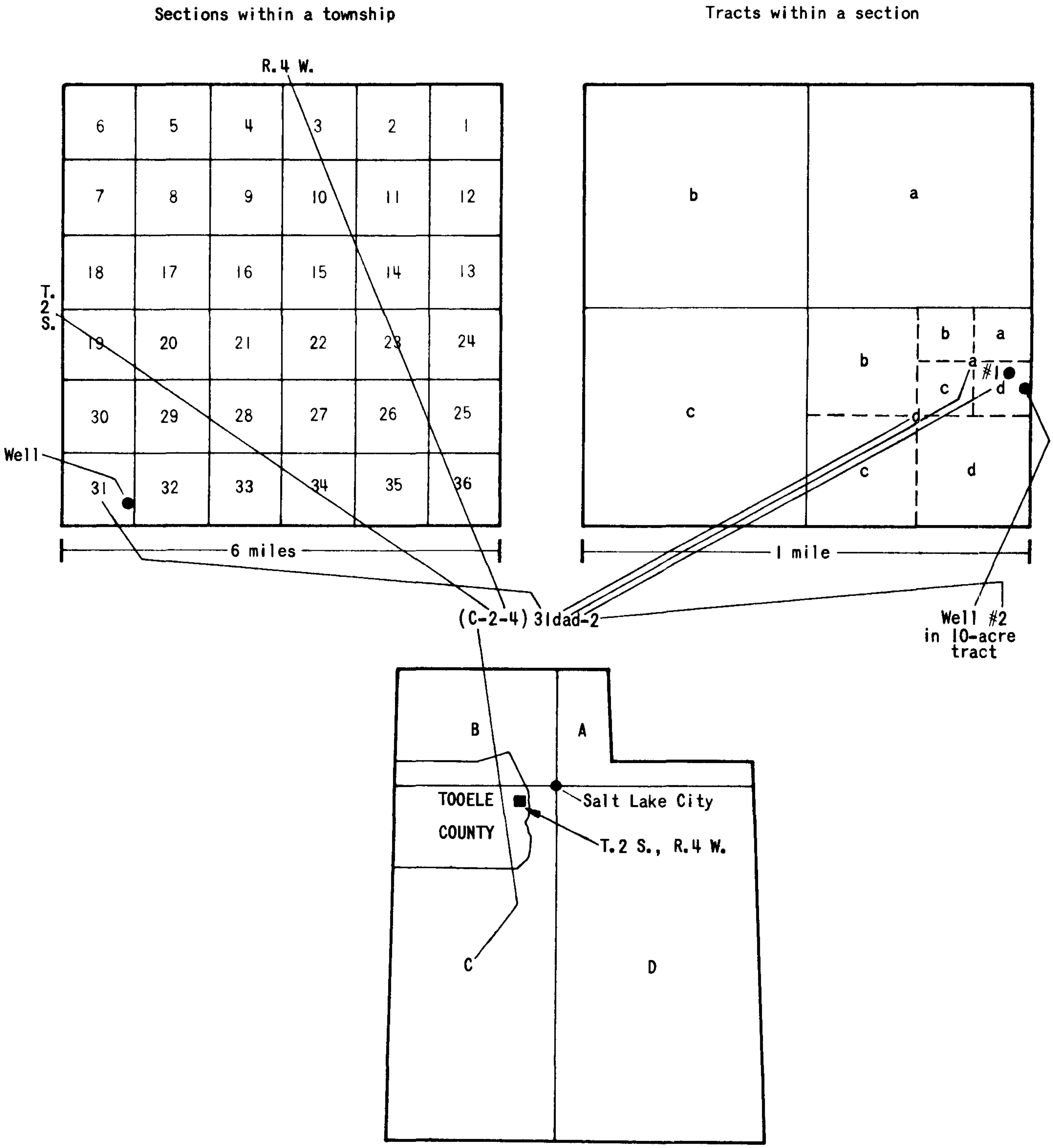

Figure 4.—Well-numbering system used in Utah.

GEOLOGY

Summary of stratigraphy and structure

Tooele Valley is a structural depression bordered on three sides by mountain ranges, which are composed mainly of limestone and quartzite of Paleozoic age. The valley is filled with alluvial, colluvial, lacustrine, and possibly volcanic deposits of Tertiary and Quaternary age.

Rocks in the Oquirrh Mountains range in age from Cambrian to Tertiary, but that part of the mountains that borders Tooele Valley is composed mostly of the Oquirrh Formation of Early, Middle, and Late Pennsylvanian and Early Permian age. The range has been described by Gilluly (1932, p. 91) as a block, uplifted on its western edge and tilted to the east. The Oquirrh Mountains were uplifted during late Tertiary and early Quaternary time (Roberts and Tooker, 1961, p. 47) and probably were tilted to the east during the same period. In their southern and central parts, the mountains consist of a series of broad, northwest-trending folds, but in their northern part (Roberts and Tooker, 1961, p. 37) the rocks have been folded along east- and northeast-trending axes and cut by thrust, tear, and steep normal and reverse faults. Most of the folding probably occurred during Cretaceous and early Tertiary time.

South Mountain is composed of rocks of the Oquirrh Formation which have been folded into an anticline whose axis trends northwestward (Gilluly, 1932, pl. 12).

The Stansbury Mountains are composed of rocks ranging in age from Cambrian to Tertiary. The Tintic Quartzite of Early and Middle Cambrian age and the Oquirrh Formation are the thickest formations in the range. The Tintic is exposed along most of the crest of the range, and the Oquirrh crops out over a large area adjacent to the southwestern corner of Tooele Valley. The Stansbury Mountains are essentially a north-trending, doubly plunging anticline, with smaller folds along its northern and southern ends (Rigby, 1958, p. 61). Rigby (1958, p. 61) also noted that a major synclinal axis parallels the range on its eastern side and is separated in part from the main structure of the range by a reverse fault. The range, similar to the Oquirrh Mountains, is also a large block, faulted and uplifted along its western edge and tilted to the east (Rigby, 1958, p. 93 and fig. 16).

The valley fill in Tooele Valley consists of the Salt Lake Formation of Pliocene age, pre-Lake Bonneville alluvium (probably includes deposits of lakes older than Lake Bonneville) of Pleistocene age, Lake Bonneville deposits of Pleistocene age, and deposits of Recent age which include alluvium, lake beds, and dunes (Thomas, 1946, p. 116-133). The valley fill is unconsolidated, whereas rocks older than the Salt Lake Formation probably are consolidated.

The unconsolidated rocks mainly consist of alluvial, colluvial, and lacustrine deposits, all of which have a range of size, shape, and permeability. Most alluvial deposits are bedded, partly sorted, discontinuous elongate bodies of silt, sand, gravel, and boulders. Stream-channel deposits usually are very permeable whereas stream-bank deposits are less permeable. Most colluvial deposits were laid down by mud-rock flows near the mountains. They are irregular and poorly sorted masses of silt, sand, and larger fragments, and they generally have low permeability. The lacustrine deposits are fairly continuous, well sorted, elongate to tabular bodies of clay, silt, sand, and gravel. Fine-grained lake-bottom beds generally have low permeability whereas lakeshore or nearshore deposits may be coarse, well sorted, and highly permeable.

Subaerial and lacustrine conditions of deposition alternated several times during Tertiary and Quaternary history of the basins, producing, correspondingly, stream and colluvial deposits or lake-bottom and lakeshore deposits. The valley stratigraphy is complex because these various deposits alternate and intertongue, making it difficult to correlate beds from one place in the valley to another. The Salt Lake Formation, the pre-Lake Bonneville alluvium, and the Lake Bonneville deposits are not easily distinguishable in well logs. No attempt, therefore, was made during this study to differentiate the unconsolidated deposits in the valley.

The thickness of the valley fill is known in only a few places. In the southern part of the valley, thicknesses range from 207 feet at well (C-3-4)23ccd-1 in the southeastern corner to more than 763 feet at well (C-3-5)36ddd-1 in the central part, and more than 780 feet at well (C-3-6)36aac-1 in the southwestern part. (Well locations are shown in fig. 5). Just north of the Stockton bar, well (C-4-5)13bbd-1 reportedly reached bedrock at 460 feet, and two other wells in the same section reportedly reached bedrock at depths of 195 and 240 feet. In the northern part of the valley, only two water wells have reached bedrock — (C-2-4)3ccc-1 at 290 feet and (C-2-4)9cda-1 at 668 feet. Two deep water wells in the northern part of the valley did not reach bedrock — (C-1-6)22ddc-1, 630 feet deep, and (C-2-4)-31dad-2, 747 feet deep. Interpretation of electric logs indicates that in the northern part of the valley the Hickey Oil Co. Cassity No. 1, (C-2-5)13bcd, penetrated bedrock at about 4,830 feet. The Hickey Oil Co. Cassity No. 2, (C-2-5)13bca-1, was drilled to a total depth of 3,540 feet without reaching bedrock, and the Walker-Wilson Drilling Co. Woodlay-Garson No. 1, (C-2-5)14cab-1, penetrated what may be bedrock at about 7,100 feet.

Tooele Valley has been interpreted as the eastern part of the tilted Stansbury fault block which has been buried by unconsolidated deposits. By using gravity data, however, W. W. Johnson (written communication, 1958) interpreted the general structure of the valley to be a broad graben which contains two subsidiary grabens, one within the other, in the north-central part of the valley. The lowest part of the structural basin is a northeast-trending trough which extends from Grantsville toward, and probably beneath, Great Salt Lake. Johnson stated that gravity data indicated a normal fault along the eastern edge of the Stansbury Mountains, adjacent to Tooele Valley. Both interpretations of the structure of Tooele Valley may be correct. The mountains may be uplifted and tilted blocks, whereas the valley may be a graben.

Redefinition of faults in the valley fill

Thomas (1946, p. 146-152) defined several basin-and-range type faults of Tertiary and Quaternary age in Tooele Valley, based largely on hydrologic data. Johnson (written communication, 1958) inferred several faults using gravity data and, where possible, correlated them with the faults defined by Thomas. Using the interpretations of Thomas and Johnson and recent hydrologic data, five faults were outlined in the valley. They are the Mill Pond, Occidental(?), Fishing Creek, Sixmile Creek, and Warm Springs faults (fig. 5).

The Mill Pond fault was first located by Thomas (1946, p. 149 and fig. 10) on the basis of the location of Mill Pond and Dunne's Pond Springs, topography, and geology[2]. Johnson (written communication, 1958) correlated a gravity anomaly with the Mill Pond fault, but his anomaly does not coincide exactly with the trace of Thomas' fault. The Mill Pond fault shown in figure 5 is an interpretation by the writer based on all available information. The fault passes through Dunne's Pond and Mill Pond Springs and then trends southeastward and passes southwest of outcrops of the Oquirrh Formation in the SE¼ sec. 15, T. 2 S., R. 4 W. The northward extension of the Mill Pond fault is not known, but it may trend northeastward to the front of the Oquirrh Mountains as indicated by Johnson, and roughly enclose a pediment where bedrock underlies the land surface at shallow depth.

The Occidental(?) fault (fig. 5) was named by Gates (1962) on the basis of a gravity anomaly described by Johnson and topographic, quality-of-water, and water-level data. It was tentatively correlated with the Occidental fault in the Oquirrh Mountains. The northward extent of the Occidental(?) fault is not shown, and its trace in the Oquirrh Mountains is not shown in figure 5 because this map only shows faulting in the valley fill.

The Fishing Creek fault (fig. 5) passes through the springs that are the sources of Fishing and Sixmile Creeks. Water-quality and temperature data collected during this study indicated a fault through these springs (p. 54), and Johnson (written communication, 1958) inferred a fault through this area based on a gravity anomaly. Johnson's gravity data indicate that to the east the Fishing Creek fault joins the Occidental(?) fault and to the west it traces an arc that successively trends northwestward, northward, and then northeastward. These extensions are not indicated by hydrologic data and are not shown in figure 5. Thomas (1946, p. 150-151) also mapped the Box Elder Canyon fault through the springs at Fishing Creek and Sixmile Creek. The Box Elder Canyon fault is discussed below.

The Sixmile Creek fault (fig. 5) was located using data from electric logs for three oil tests (fig. 5). Beds penetrated by (C-2-5)13bca-1 and 13bcd, east of the fault, can be correlated, but they cannot be correlated with beds penetrated by (C-2-5)14cab-1, west of the fault. In addition, oil test (C-2-5)13bcd reached bedrock at a depth of about 4,830 feet, whereas (C-2-5)14cab-1 reached beds tentatively identified as bedrock at about 7,100 feet. This difference is likely the result of fault displacement. Johnson (written communication, 1958) also inferred a fault through the area based on a gravity anomaly. Although no hydrologic data indicate the Sixmile Creek fault, the data from the electric logs and the gravity study are conclusive enough to locate the fault approximately as shown in figure 5.

The Warm Springs fault (fig. 5) was inferred using chemical-quality and temperature data (p. 54). Johnson (written communication, 1958) also inferred a fault that passes through this area and along the eastern front of the Stansbury Mountains. Available hydrologic data, however, only indicate a fault in the vicinity of Warm Springs.

Both Thomas (1946) and Johnson inferred other faults in the alluvium of Tooele Valley, none of which could be located using hydrologic data collected during this study. Although these faults may exist, they are not shown in figure 5. Two of these faults, the Erda and Box Elder Canyon faults, were partly or wholly defined by Thomas on the basis of hydrologic data.

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[2]The Mill Pond fault, as defined by Thomas, was coincident with the eastern boundary of Thomas' Erda ground-water district. This boundary and other boundaries of the ground-water districts defined by Thomas are shown in figure 5.

About 3½ miles west of his Mill Pond fault, Thomas (1946, p. 150) inferred the north-south Erda fault, the location of which was misprinted in his report as "2½ miles west of * * * the Mill Pond fault." The Erda fault was located on the basis of a ground-water barrier shown by a map of the piezometric surface of the principal aquifer (Thomas, 1946, fig. 10) and marked the western boundary of Thomas' Erda district (fig. 5). The interpretation of a barrier, however, was largely based on the water level in one well that did not reach the principal aquifer (p. 21). The water level in this well probably was not representative of the pressure in the principal aquifer; and, therefore, the barrier may not exist. The gravity data of Johnson and the piezometric surface in 1962 (fig. 6) do not suggest a fault along the trace of Thomas' Erda fault.

Thomas (1946, p. 150-151 and pl. 1) mapped a major fault in Box Elder Canyon and named it the Box Elder Canyon fault. He projected this fault northeastward across Tooele Valley, through the springs that head Fishing and Sixmile Creeks, to a point just south of Dunne's Pond Springs. This fault formed the northern boundary of both the Erda and Marshall districts and the southeastern boundary of the Grantsville district as he defined them. Johnson (written communication, 1958) inferred faults approximately through the springs that head Fishing and Sixmile Creeks and in Box Elder Canyon, but his gravity data do not indicate that the faults are part of a single fault that crosses the valley. Therefore, Thomas' fault is not shown in figure 5, and the fault through the springs at Fishing and Sixmile Creeks has been renamed the Fishing Creek fault.

GROUND WATER

Occurrence

Ground water in Tooele Valley and the adjacent mountains occurs in both consolidated rocks and unconsolidated deposits. The Salt Lake Formation and younger sediments are classified as unconsolidated deposits; older Tertiary rocks and rocks of pre-Tertiary age are classified as consolidated.

Consolidated rocks

Few data are available on water in the consolidated rocks around and underlying Tooele Valley. Ground water probably moves through fractures and fault zones in various types of rock and through solution openings in limestone.

No wells in the valley are known to obtain water from the bedrock which underlies the valley fill. The only information on water in rock has been obtained from tunnels and mines in the mountains. Thomas (1946, p. 157-159) discussed the Honerine and Elton tunnels in the Oquirrh Mountains and Gates (1963a, p. K32-K33) presented data on the Utah Metals tunnel southeast of Tooele (fig. 5).

Discharge from the Elton tunnel has had a significant effect on ground-water conditions in the valley fill. (See p. 38.) It was constructed from May 1937 to August 1941, and Thomas (1946, p. 158) compiled records of water discharged from the tunnel through June 1946. He stated that much of the water discharged during the first few years probably was withdrawn from storage and that a sustained flow of about 5 cfs (cubic feet per second), or about 3,600 acre-feet per year, could be expected. His prediction was borne out by data on outflow from the Elton tunnel collected since 1946 by the Anaconda Co. These data are shown below:

Year	Acre-feet	Year	Acre-feet
1946	3,905	1952	2,285
1947	3,710	1953	965
1948	3,720	1954	505
1949	3,720	1955	75(?)
1950	3,755	1956	30(?)
1951	3,380	1957	--------
		1958	0

The annual flow from the tunnel remained fairly steady during 1947-50, but it started to decline in 1951 when parts of the tunnel caved and the flow was dammed.

Unconsolidated deposits

Ground water occurs under both water-table (unconfined) or artesian (confined) conditions in Tooele Valley. Because few wells tap unconfined water, little is known about the water table in the valley. Almost all wells tap artesian aquifers, and of the 1,300 wells in the valley, about 1,100 flow or have flowed at one time.

Water-table conditions

Water is under water-table conditions in deep beds near the Oquirrh and Stansbury Mountains and in the southern end of the valley. Little is known about the unconfined water in these areas. Recharge undoubtedly is by percolation from the surface or by direct movement of water from the consolidated rock of the mountains, and the beds transmit water onward to the artesian aquifers in the central part of the valley. Some wells in the Tooele district may tap unconfined aquifers which probably will yield more water to wells than will the shallow beds in the northern part of the valley.

Water in the shallow beds in the northern part of the valley also is unconfined. These beds include an interval from the land surface to a depth of about 50 feet, and mostly contain water that has leaked upward from the underlying artesian aquifers. Few wells in the valley tap the shallow beds, and it is believed that the beds have low permeability and contain water of poor quality. The shallow beds do not yield enough water to wells to be termed an aquifer, so they are called the "water-table zone" in this report.

Artesian conditions

Artesian aquifers are the most important sources of water in Tooele Valley. Ground water is confined in the coarser beds of the valley fill by overlying and underlying fine-grained beds that are mostly lake-bottom deposits. Permeable beds in the southern part of the valley probably are only poorly confined; but the fine-grained beds appear to develop toward the northern part of the valley, where they are thicker, more extensive, and confine the water more completely. The various aquifers are sufficiently connected hydraulically that they can be considered a single hydraulic system, and in this report, the aquifers collectively are termed "the artesian aquifer system."

Principal aquifer.—The artesian aquifer penetrated by most of the wells in the northern part of the valley was defined by Thomas (1946, p. 145-146, 173) as the "principal aquifer." Wells in the southern part of sec. 34, in sec. 35, and in most of sec. 36, T. 2 S., R. 5 W., apparently do not penetrate the principal aquifer; thus it is not continuous. Thomas (1946, p. 146) believed that even though the aquifer is not continuous, it consists of material that was deposited at the same time and under similar conditions. Therefore, he included the main water-yielding zone in both the east and west sides of the valley within the same "principal aquifer."

Thomas' definition of the principal aquifer applied to an area along a line from Erda to Grantsville where most of the wells in Tooele Valley were drilled prior to this study (Thomas, 1946, fig. 3). During this investigation some modification was made in Thomas' description of the depth and thickness of the aquifer, and the principal aquifer was defined in other parts of the valley. The definition usually was based on fewer data than are available along Thomas' line of reference, and the interpretations are less reliable. In the following paragraphs, the aquifer is described in reference to the ground-water districts defined during this study (fig. 5).

In the Lake Point district the principal aquifer is estimated to be from 150 to 250 feet below the land surface. In the Mill Pond district, it is estimated to be from 50 to 170 feet deep. The aquifer in the Mill Pond district is on the upthrown side of the Occidental(?) fault and is shallower than it is in the adjacent Erda district.

In the southeastern part of the Erda district (in secs. 33, 34, and 35, T. 2 S., R. 4 W.) the principal aquifer is about 100 to 190 feet deep. From sec. 32, T. 2 S., R. 4 W., to the center of sec. 36, T. 2 S., R. 5 W., it includes beds between depths of 160 and 270 feet. In the western half of sec. 36 the principal aquifer apparently is not present. North and northwest of Erda, between the town and U.S. Highway 40, the principal aquifer is between depths of 150 and 230 feet. North of the highway, in the northern tip of the Erda district and in the eastern part of the Burmester district, the aquifer is estimated to be 240 to 350 feet deep. The valley fill in this area mostly is fine grained, however, and the principal aquifer may not continue as a definite zone this far north.

In the northeastern part of the Marshall district (in the southern part of sec. 34 and in sec. 35, T. 2 S., R. 5 W.) the principal aquifer may not exist. In the northwestern corner of the Marshall district (in secs. 32 and 33 and the northern part of sec. 34, T. 2 S., R. 5 W.) the aquifer is from 180 to 310 feet deep, and probably is continuous with the principal aquifer in the adjacent Grantsville district.

In the Grantsville district, the principal aquifer includes beds between depths of 180 and 310 feet at the eastern edge of Grantsville and between 90 and 210 feet in the southwestern part of Grantsville. Just north of Grantsville the principal aquifer is probably 170 to 300 feet below the land surface, and between Grantsville and Warm Springs, it is estimated to be between 70 and 200 feet. The aquifer has been tentatively traced through the northern end of the district to the southern edges of secs. 5 and 6, T. 2 S., R. 5 W., in the Burmester district, where it may include beds between 300 and 420 feet. In this latter area most of the valley fill is fine grained, however, and the principal aquifer may not exist as a definite zone.

The principal aquifer may not exist as a definite zone in most of the Burmester district and in the northeastern tip of the Marshall district because the sediments are mostly fine grained.

The principal aquifer was not defined in the southern part of the Grantsville and Marshall districts and in the Tooele district. In these areas the valley fill is mostly coarse grained, and the principal aquifer may not exist as a separate zone.

Other aquifers.—Some artesian wells obtain water from aquifers above or below the principal aquifer, but little is known about these other aquifers. The shallower aquifers do not yield as much water to wells as the principal aquifer, but the deeper aquifers yield large amounts of water.

Source

The source of almost all the ground water in Tooele Valley is precipitation on its drainage basin. The amount of water diverted to Tooele Valley from Jordan Valley and Rush Valley by mining tunnels was negligible during 1958-63. The only other possible water source of any significance is underflow from Rush Valley, and available data do not indicate that a large amount of water moves from Rush Valley to Tooele Valley.

Rush Valley is separated from Tooele Valley by South Mountain and by low divides between South Mountain and the Stansbury and Oquirrh Mountains. Little water could be moving through South Mountain, and it is unlikely that water moves through the western divide. Rocks of Paleozoic age crop out just north of the divide between South Mountain and the Stansbury Mountains (Gilluly, 1932, pl. 12, and Rigby, 1958, pl. 2), and bedrock probably is at shallow depth under the divide.

The divide between South Mountain and the Oquirrh Mountains is formed by the Stockton bar (see fig. 5), a large gravel deposit built by Lake Bonneville. Ground-water levels differ greatly on either side of the bar. On the southern side of the bar, a flowing well, 2½ miles southwest of the bar, at an altitude of about 4,960 feet; Rush Lake, about 2 miles south of the bar; and several square miles of wetland around the lake, all indicate that the piezometric surface is above the land surface. In contrast, in well (C-4-5)13bbd-1, about half a mile north of the bar, the water level was at an altitude of about 4,650 feet — about 300 feet lower than south of the bar. Four wells have been drilled in the same area north of the bar. They were unused, probably because they would yield only small amounts of water. The steep hydraulic gradient beneath the bar and the low yields of the wells north of the bar suggest low permeability and indicate that little water moves from Rush Valley to Tooele Valley. This conclusion agrees with Thomas (1946, p. 194-195) who believed that the material beneath the Stockton bar transmits little water to the north. Before the Stockton bar was built by Lake Bonneville, however, Rush Valley probably drained to Tooele Valley (Gilbert, 1890, p. 184) and some permeable stream-channel deposits may underlie the bar. Until data are available on the permeability of the material beneath the bar, therefore, the possibility of underflow from Rush Valley to Tooele Valley cannot be completely discounted.

Recharge

Thomas (1946, p. 193-196) listed and discussed four sources of recharge in Tooele Valley — direct penetration of precipitation, seepage from streams, underflow beneath stream channels in the mountains, and penetration of unconsumed irrigation water. In addtion to these, water probably moves directly in the subsurface from the consolidated rock of the mountains into the valley fill.

The most significant areas of recharge probably are in the southeastern and southwestern corners of the valley in the Grantsville and Tooele districts. The major water-producing canyons in the mountains — Middle, Settlement, Box Elder, South Willow, North Willow, and Davenport Canyons — enter the valley through the two districts; and they are a focus for recharge by seepage from streams, underflow beneath stream channels, and penetration of unconsumed irrigation water.

The approximate minimum recharge area for the artesian aquifer system was determined mostly from topographic and geologic maps and is shown in figure 2. The upper edge of the area essentially coincides with bedrock outcrops, as they are shown in maps by Gilluly (1932, pl. 12), Thomas (1946, pl. 1), Rigby (1958, pls. 1 and 2), and Tooker and Roberts (1961). Where data from these maps were insufficient, the bedrock-valley fill contact was interpreted from topographic maps.

The lower edge of the recharge area shown in figure 2 is related to fine-grained bottom deposits of Lake Bonneville and was placed between the 5,250-foot and the 5,100-foot topographic contours in most of the valley. The highest levels of Lake Bonneville noted in Tooele Valley are between 5,250 and 5,280 feet (Crittenden, 1963, fig. 3). Thus below 5,250 feet, lake-bottom deposits may prevent recharge of underlying artesian aquifers; but in some places, the land surface is so steep that clay beds likely were not deposited above 5,100 feet. Where the bedrock-valley fill contact is below the 5,250-5,100 foot zone, such as at the northern margins of the Stansbury and Oquirrh Mountains, recharge is probably limited to a narrow zone of coarse material adjacent to bedrock. In other places, however, the upper edge of the fine-grained deposits also may be below the 5,250-5,100 foot zone, such as along the western margin of the valley where Lake Bonneville deposits are thin or absent. For example, artesian aquifers in the Erda area are known to have been recharged by water discharging from the Elton tunnel at an altitude of 5,080 feet. The recharge area, therefore, may be considerably larger than that shown in figure 2.

A quantitative estimate of the recharge to the artesian aquifers was made by means of a hydrologic budget and is about 100,000 acre-feet per year. (See p. 55-59.)

Movement

After entering the aquifers in Tooele Valley water moves generally toward Great Salt Lake, perpendicular to the contours of the water table or piezometric surface. Figure 6 shows the piezometric surface of the principal aquifer in March-April 1962. Data from aquifers other than the principal artesian aquifer in the valley were not used in the figure because the other aquifers have different piezometric surfaces. The aquifers above the principal aquifer have lower water levels and those below have higher water levels than the principal aquifer. In the southern part of the valley, however, there are probably no separate aquifers and all water-level data from this latter area were used to help prepare figure 6. Owing to the few data available, contours in the southern part only show a possible configuration of the piezometric surface or water table.

The decrease in pressure with decreasing depth in the artesian aquifer system is caused by a loss of head as water moves upward through the fine-grained deposits separating the aquifers. This has previously been noted in Utah by Hunt, Varnes, and Thomas (1953) and others. Thus, in addition to the direction of movement indicated in figure 6, the ground water in Tooele Valley also moves upward into and out of the principal artesian aquifer.

The only known barrier to ground-water movement in the valley fill is the Occidental(?) fault (fig. 6). Gates (1962, p. D79) inferred this barrier because the altitude of the piezometric surface northeast of the fault is lower than that on the southwest side.

Discharge

Ground water is discharged in the Tooele Valley drainage basin by wells, springs, drains, evapotranspiration, and subsurface flow to Great Salt Lake. During this investigation, data were collected on the discharge of wells and springs in the valley and an estimate was made of evapotranspiration from the area of phreatophytes in the northern end of the valley. Estimates also were made of ground-water discharge in the mountains by evapotranspiration and from wells, major springs, and major drains. The data from the valley are included in this section; data from the mountains are included in the section on the hydrologic budget of the artesian aquifer system (p. 55-59).

Discharge from wells and springs

Wells

About 21,000 acre-feet of water was discharged from wells in Tooele Valley in 1962. The total discharge was determined on the basis of measurements and statistical correlation for those wells constructed prior to 1941 and measurements and estimates for those wells constructed since 1940. The determination was made for 1962 because data for that year were more complete than for the other years of this study.

Wells constructed before 1941.—During 1938-40, the discharge of practically every well in the valley was measured one or more times by the Utah State Engineer. During those years almost all the discharge was by natural flow. On the basis of the measurements, Thomas (1946, p. 230) estimated that the discharge of the wells drilled before 1941 ranged from 6,400 acre-feet in 1940 to 7,000 acre-feet in 1939.

The discharge in 1962 of wells constructed before 1941 was determined by estimating the changes in discharge since 1938, the year in which records for Tooele Valley were most complete. The sum of the discharge in 1938 of all wells that still were flowing in 1962 was multiplied by 0.54. This factor was determined by measuring the flow of 17 wells in 1962 and 1963 and comparing the results with their flow in 1938. Of the 17 wells, 8 are in the Erda district, 2 are in the Marshall district, 4 are in the Grantsville district, and 3 are in the Burmester district. The flow of these wells in 1962-63 ranged from 27 to 86 percent of their flow in 1938, but 12 of the 17 wells discharged from 46 to 66 percent of their flow in 1938. The average flow in 1962-63 was 54 percent of the flow in 1938.

The total discharge in 1962 of wells constructed before 1941 was 2,500 acre-feet (table 1).

An overall decline in water levels from 1938 to 1963 (fig. 7) probably caused most of the decline in discharge. In 1963, for example, the height of the water level above the discharge point for 8 of the 17 wells averaged 60 percent of its height in 1941; the 1941 water levels in the other 9 wells are not known. The loss in head is about the same percentage as the loss of discharge and probably accounts for most of it. Some decline in discharge also may have been caused by deterioration of well casing and silt accumulation in the wells.

Wells constructed since 1940.—Wells constructed since 1940 were divided into three categories: wells pumped for irrigation, municipal, industrial, or military supply; flowing wells used mostly for irrigation, stock-watering, and domestic supply; and wells used only for domestic and stock supply.

The discharge of 62 wells pumped in and adjacent to the valley for irrigation and municipal, industrial, or military supplies in 1962 was tabulated by Gates (1963b, p. 20). Of these 62 wells, 7 which are outside Tooele Valley — 4 in Pine Canyon and 3 in Middle Canyon — discharged about 650 acre-feet in 1962. The discharge of the other 55 wells is summarized in table 1. Although 8 of the 55 wells were constructed before 1941, their discharge was included with that of the other pumped wells in table 1.

All the pumps are driven by electric motors, and most were rated as to the amount of water discharged per 1,000 kilowatt hours of electricity used in 1962. The annual discharge of each well was then calculated from power-consumption records. When a well could not be rated, the annual discharge was calculated either from water-meter readings, estimated from information supplied by well owners, or obtained by estimating the acreage irrigated and assuming that about 3½ acre-feet of water per year is used to irrigate an acre. Alfalfa in Tooele Valley requires 3½ to 4 acre-feet of water (Criddle, Harris, and Willardson, 1962, p. 41 and table 4).

The pumpage of 10,500 acre-feet in 1962 probably was a little less than the average for the 1958-63 period. Precipitation from October 1961 through April 1962 was above average (fig. 3), and many pumps were not used until summer. The pumpage in the valley in 1961 and in 1963, about 13,000 acre-feet, is probably nearer the average for the 1958-63 period.

About 115 flowing wells were constructed from 1941 through 1963 to supply water mostly for irrigation, stock, and domestic use. Of these wells, 107 were in use in 1962, but 12 were used only for domestic purposes and 2 were pumped and not allowed to flow. The discharge in 1962 of the 93 other wells was 8,200 acre-feet, and was estimated from spot measurements or from the initial discharge reported by the driller and is summarized in table 1.

Of the 93 wells, 32 were measured both by the driller when the well was completed and by the writer during the period September 1961 through August 1963. The 32 wells are distributed over the northern part of the valley. The flows measured ranged from 8 to 100 percent of the initial flow, and averaged 44 percent. The flow of 26 wells was originally more than 100 gpm, and in 1961-63 these had an average flow of 49 percent of their initial flow. The flow of the other 6 wells was originally less than 100 gpm, and in 1961-63 these had an average flow of only 24 percent of their initial flow.

The flow of the 32 wells diminished mainly because their water levels declined since construction and, to a lesser extent, because of casing deterioration and silt accumulation in the wells. Because the driller probably measured the flow before equilibrium was reached between the water level and the discharge, the reported initial flow was higher than later flows. In addition to local water-level declines, water levels in general have declined since 1941 (figs. 8 and 9). Maximum declines are in areas where several large-diameter flowing wells were drilled.

Some of the discharge measurements at the 32 flowing wells were made in 1961 or 1963, but they were probably close to the 1962 values. Many of the wells are in the Burmester district, where water levels, and therefore discharge, did not change greatly from 1958 to 1963 (fig. 9). From the 1961-63 measurements and an estimate of the amount of time each well flowed during the year, the total discharge in 1962 of the 32 wells was calculated.

Measurements or estimates of the discharge of 19 other flowing wells were made during 1961-63. These 19 wells were mostly those for which no initial measurement had been reported by the driller or for which the initial reported measurement was obviously inaccurate. Thus, the total discharge in 1962 of 51 wells is known, and it probably amounts to more than 90 percent of the water yielded by flowing wells constructed from 1942 through 1962.

Estimates of the discharge from 42 other wells were made by assuming that their discharge in 1962 was about 40 percent of their initial reported discharge. This factor was used because most of the 42 wells are of small diameter, and as previously stated, the discharge of small-diameter wells decreased more than average.

From 1941 through 1963, 73 wells, mostly of small diameter, were constructed and used for domestic and stock supply. A rural family uses about three-fourths of an acre-foot per year (Criddle, Harris, and Willardson, 1962, p. 23), so these wells probably produced about 50 acre-feet in 1962. Essentially all of this 50 acre-feet was used in the Lake Point district.

Springs

Thomas (1946, p. 234) stated that in 1938-40, springs in Tooele Valley yielded about 20,000 acre-feet per year. In 1962 the spring discharge had decreased to about 15,000 acre-feet (table 1).

Many of the small springs in the valley were dry in 1962 or probably had greatly diminished in flow since the 1938-40 period. Most of the spring flow probably is derived from the water-table zone. The below-average precipitation since 1947 evidently has caused lowering of the water table and thus decrease in spring discharge. Although no discharge measurements were made, it was estimated that in 1962 small springs yielded about 100 acre-feet in the Lake Point district, about 100 acre-feet in the Erda district, and about 500 acre-feet in the Grantsville district. Several of the springs defined by Thomas to be in the Burmester district are outside of Tooele Valley as it was defined during this study. The springs now included in the Burmester district probably yielded about 1,000 acre-feet in 1962.

The flow of the four large spring areas — Mill Pond Spring, Dunne's Pond Springs, and the sources of Fishing Creek and Sixmile Creek — apparently has also decreased since 1940 although the 1938-40 and 1962 estimates are not accurate enough to give the amount of the decrease. Most of the water from these springs is thought to rise along faults from artesian aquifers, and, therefore, the general decline in artesian water levels since 1941 may have caused a decline in discharge.

Measurements of the flow of Mill Pond Spring in 1962 and spot measurements of Dunne's Pond Springs in 1963, both by Kennecott Copper Corp., indicate that they discharge about 4,200 and 4,400 acre-feet per year, respectively. Their flows apparently fluctuate significantly, however, and these annual discharge figures are only estimates. The flow of Fishing Creek, which was measured four times in 1962, varied from 1,500 to 1,800 gpm, thus the total discharge in 1962 of the springs heading the creek was about 2,700 acre-feet. The flow of Sixmile Creek was measured once in 1963, and it was estimated that the springs heading the creek discharge 2,400 acre-feet per year. The two spring areas in the Marshall district, therefore, discharged a total of about 5,000 acre-feet in 1962.

Summary

The total discharge of wells and springs in Tooele Valley in 1962 is shown in table 1. The total of 36,000 acre-feet represents an increase of 10,000 acre-feet from the 26,000 acre-feet per year estimated by Thomas (1946, p. 234). Most of this increase represents water pumped from wells for irrigation, municipal, military, and industrial supplies. In 1938-40, the amount of water pumped for uses other than domestic was negligible, but in 1962, it was 10,500 acre-feet. This amount was produced from only 55 wells, but it was greater than all of the 1,050 existing flowing wells yielded in 1938-40.

Table 1.—Discharge from wells and springs in Tooele Valley in 1962

District	Discharge from wells constructed before 1941 (acre-feet)	Discharge from wells constructed after 1940: Pumped wells (domestic wells excluded) (acre-feet)	Discharge from wells constructed after 1940: Flowing wells (domestic wells excluded) (acre-feet)	Discharge from wells constructed after 1940: Wells for domestic and stock use (acre-feet)	Discharge from all wells (acre-feet)	Discharge from springs (acre-feet)	Total discharge from wells and springs (acre-feet, rounded)
Lake Point	30	80	130	50	290	100	400
Mill Pond	60	910	0	0	970	8,600	9,600
Erda	1,520	3,310	1,290	0	6,120	100	6,200
Tooele	0	1,630	0	0	1,630	0	1,600
Marshall	230	1,830	1,050	0	3,110	5,000	8,100
Grantsville	350	2,630	1,520	0	4,500	500	5,000
Burmester	300	140	4,180	0	4,620	1,000	5,600
Totals (rounded)	2,500	10,500	8,200	50	21,200	15,000	36,000

Discharge by evapotranspiration

Ground water is discharged by evapotranspiration in the area of phreatophytes at the northern end of Tooele Valley (fig. 14), where the water table is at or near the land surface. South of this area the water is too deep to be a source for most plants. The amount of evapotranspiration is about 40,000 acre-feet per year and is summarized in table 2. It was estimated by dividing the area into units of different types of cover and applying use factors that were developed during detailed studies in another area.

Table 2. — Water lost by evapotranspiration from the area of phreatophytes in the northern part of Tooele Valley

	Vegetative cover	Area (acres)	Annual evaporation or transpiration (feet)	Water lost (acre-feet)
Area of scanty vegetation	Pickleweed and greasewood	1,600	2.6	4,000
	None	30,400	.09	3,000
Area of thicker vegetation	Saltgrass	6,400	3.0	19,000
	Greasewood and rabbitbrush	3,200	2.1	7,000
	Pickleweed	1,600	3	5,000
	None	20,800	.09	2,000
			Total	40,000

R. W. Mower and the writer, in a reconnaissance of the northern end of the valley on November 7, 1963, outlined the area of phreatophytes and identified the most common species (fig. 14). Most of the area is north of U.S. Highway 40 and coincides with an area where significant amounts of artesian water leak upward to the water table. The area of evapotranspiration was divided into two subareas (fig. 14), each of which covers about 50 square miles, one with scanty vegetation and one where vegetation is thicker.

About 5 percent of the scantily vegetated area is covered by pickleweed and greasewood; and about 95 percent is bare ground and salt and mud flats near Great Salt Lake. About 65 percent of the other subarea is bare and about 35 percent is covered by vegetation; 20 percent by saltgrass, 10 percent by greasewood and rabbitbrush, and 5 percent by pickleweed.

Several small stands of saltcedar are in Tooele Valley. This notorious phreatophyte probably has moved into the valley in recent years and is not yet widespread. If the saltcedar is not eradicated and spreads over large areas in the northern end of the valley, just as it has in many parts of the southwestern United States, it will use large amounts of ground water.

The rates of water consumption from the areas of phreatophytes in Tooele Valley were taken from a report by Mower and Nace (1957, p. 21) for Malad Valley, Idaho. This valley is about 100 miles north of Tooele Valley, and the rate of consumption in both valleys should be similar. For growths of 100 percent density, pickleweed is assumed to consume 3 acre-feet per acre per year, greasewood 2.25 acre-feet per acre, saltgrass 3 acre-feet per acre, and rabbitbrush 2 acre-feet per acre.

The rate of evaporation from unvegetated land, including the salt and mud flats around Great Salt Lake, was taken from a report by Feth and Brown (1962). They determined that the annual rate of evaporation from the saltflats on the eastern shore of the lake, about 40 miles northeast of Tooele Valley, was about 0.09 acre-feet per acre.

Discharge to Great Salt Lake

Some ground water moves into Great Salt Lake, mostly through artesian aquifers, but the amount cannot be calculated because the transmissibility of the valley fill and the hydraulic gradient at the lakeshore are not known.

Hydraulic characteristics of the artesian aquifer system

The hydraulic characteristics of the artesian aquifer system were obtained from 11 aquifer tests made using pumped wells. Coefficients of transmissibility[3] and storage[4] obtained and other data from these tests are given in table 3. The locations of the pumped and observation wells used are shown in figure 14. Pumped wells were used to determine the aquifer characteristics because they commonly are perforated in a significant thickness of water-bearing material, whereas flowing wells were not used because they commonly are unperforated.

[3]The coefficient of transmissibility of an aquifer is the rate of flow of water, in gallons per day, at the prevailing water temperature, through a vertical strip of the aquifer 1-foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 100 percent.

[4]The coefficient of storage of an aquifer is the volume of water released or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Table 3. — **Data from aquifer tests in Tooele Valley**

Pumped well	Observation well (P, pumped well used as observation well)	Date of test	Length of pumping period	Length of recovery period	Discharge (gpm)	Method of calculation[1]	Coefficient of transmissibility (gallons/day/ft)	Coefficient of storage	Distance from pumped well to observation well (ft)	Aquifer[2]
(C-2-4)21add-1	P	9-12-62	6-8 hr	3 hr	750	M	900,000	....	....	P
28aac-1	(C-2-4)28aab-1	4-11-62	9 hr 42 min	....	1,000	N	340,000	$4.2x10^{-3}$	1,400	P
31bdc-3	31cda-2	3-19-62	8 hr 25 min	....	1,080	N	190,000	$2.0x10^{-4}$	1,670	P,D
31cda-2	P	9- 7-62	12+ hr	3 hr 20 min	1,080	M	120,000	....	....	P,D
33aab-1	P	7-27-62	28± hr	3 hr 40 min	1,760	M	190,000	....	....	D
33add-1	P	7-18-62	12+ hr	3 hr	575	M	990,000	....	....	S,P
(C-2-5)33dcd-1	P	10-19-62	24+ hr	3 hr 20 min	550	M	240,000	....	....	S,P
(C-2-6)23cdc-2	P	9-14-62	8± hr	2 hr 20 min	1,460	M	770,000	....	....	P,D
(C-3-4)30aac-1	P	6-20-63	12± hr	4 hr	630	M	520,000	....	....	?
(C-3-5)4bbb-2	(C-3-5)5aba-1	3-29-62	10 hr 13 min	....	1,100	N	390,000	$1.9x10^{-3}$	1,500	P,D
(C-3-6)1bdb-1	P	7-26-62	24+ hr	3 hr 20 min	1,620	M	1,300,000	....	....	D
							Average	$2x10^{-3}$		

[1]M, modified nonequilibrium formula; N, nonequilibrium formula (Ferris and others, 1962, p. 92-110).

[2]S, aquifer above principal aquifer; P, principal aquifer; D, aquifer below principal aquifer.

Two types of tests were made: in three of the tests a well was pumped and the drawdown of the water level was measured in a nearby well that was perforated in the same aquifer, and in eight of the tests a well was pumped and the recovery of the water level in the well was measured after the pump was turned off. Coefficients of transmissibility and storage were calculated from data of the first type of test by the nonequilibrium formula (Ferris and others, 1962, p. 92-98), and coefficients of transmissibility were calculated from data of the second type of test by the modified nonequilibrium formula. Coefficients of transmissibility ranged from 120,000 to 1,300,000 gallons per day per foot, and storage coefficients ranged from 2×10^{-4} to 4.2×10^{-3} and averaged 2×10^{-3}.

The map of the piezometric surface (fig. 6) also indicates hydraulic characteristics of the aquifers. The spacing of the piezometric contours is proportional to permeability[5] if the rate of flow of ground water and the cross-sectional area through which it moves remain constant. Widely spaced contours indicate higher permeability than closely spaced contours. For example, the aquifer tests indicated large transmissibilities (suggesting high permeability) south of Grantsville and Erda, where the piezometric contours are widely spaced (fig. 6).

North of Grantsville and north and west of Erda the contours are closely spaced. Although few data for transmissibility are available in these areas, comparison of well logs in the areas of widely and closely spaced contours indicates that the steepening of the hydraulic gradient probably is caused by an increase in fine-grained material and thus a decrease in permeability.

Well (C-3-5)7dcc-1, south of Grantsville, penetrated about 86 feet of clay in a total thickness of 395 feet (22 percent clay); whereas well (C-2-5)30dcc-1, north of Grantsville, penetrated about 328 feet of clay in a total of 510 feet (64 percent clay) (Gates, 1963b, p. 16-17).

North of the areas where the gradient of the piezometric surface is steep near Grantsville and Erda, the gradient flattens slightly toward Great Salt Lake. This flattening probably is not caused by an increase in permeability because the valley fill becomes finer grained toward the lake, and the permeability probably is smaller. Well (C-2-5)17bcd-3, north of the area of steep gradient, penetrated about 418 feet of clay in a total thickness of 435 feet (96 percent clay) (Gates, 1963b, p. 16). The decrease in hydraulic gradient is caused by a decrease in the rate of flow and possibly a slight increase in the saturated cross section. The flow is less because a significant amount leaks upward to the water table through the confining beds. The saturated cross section may be larger because of a slight widening of the valley and an increase in the thickness of the valley fill.

The closely spaced contours near Tooele likely do not reflect low permeability. In this area, the steep hydraulic gradient may indicate that ground water flows down a steep bedrock surface, and the saturated thickness probably is small.

Specific capacities[6] of 31 selected perforated wells in Tooele Valley are shown in figure 14. The specific capacity of a well is generally proportional to transmissibility, but it is also affected by other factors, including type of well construction. Most wells in Tooele Valley

[5]The field coefficient of permeability is equal to the coefficient of transmissibility divided by the thickness of the aquifer.

[6]The specific capacity of a well is its rate of yield per unit of drawdown, expressed in gpm per foot.

are constructed similarly, and a marked change in specific capacity generally indicates a change in transmissibility. Specific capacities in Tooele Valley range from 4 to 118 gpm per foot for wells ranging from 6 to 20 inches in diameter. The larger values are in areas in the Mill Pond, Erda, Tooele, and Grantsville districts where transmissibility is high, and the smaller values are in areas in the Lake Point, Marshall, Grantsville, and Burmester districts where the transmissibility probably is low.

Ground-water districts and other localities that include wells

Carpenter (1913, p. 78) informally defined the Erda and Grantsville flowing-well areas in Tooele Valley, and Thomas (1946, p. 161-162) later divided the northern part of the valley into five ground-water districts. Using additional hydrologic and geologic data not available to Thomas, the boundaries of these districts were modified and two new districts were defined during this investigation.

The five ground-water districts defined by Thomas are the Lake Point, Erda, Marshall, Grantsville, and Burmester districts. Within each of the districts, the ground water has a common source, a fairly consistent direction and rate of movement, and similar chemical characteristics (Thomas, 1946, p. 161). The boundaries of the districts, both as defined by Thomas and as modified during this study, are shown in figure 5. The Erda and Grantsville districts essentially correspond to the two flowing-well areas noted by Carpenter, and although the boundaries defined by Thomas have been changed, they include virtually the same areas. The Mill Point and Tooele districts, also shown in figure 5, were defined during this study.

Many of the approximate district boundaries along the mountain fronts mark the upper (topographically highest) limits of thick alluvial deposits. Beyond these boundaries, bedrock or the Salt Lake Formation is at shallow depth, and probably neither contains significant amounts of ground water.

Lake Point district

The eastern and southern boundaries of the Lake Point district (fig. 5) are the approximate upper limit of thick alluvial deposits. The western boundary was arbitrarily defined along a north-south line from the northern end of the Mill Pond fault.

The low northern end of the Oquirrh Mountains discharges little runoff to the district. This condition apparently also existed during deposition of the valley fill, because most of the valley fill is fine grained. As an example, the driller's log of well (C-1-4)34bab-1 indicated that 98 percent of the 400 feet of material penetrated by the well was mud or clay.

Recharge to the Lake Point district is mostly from the bedrock of the Oquirrh Mountains to the east, although part may come from bedrock of the pediment (see p. 18) to the south. The ground water then moves northwestward, either to Great Salt Lake or into the Burmester district.

Well yields in the district are small, because of the fineness of the unconsolidated deposits. The largest yield recorded during this study was 120 gpm, and most of the wells in the district are domestic wells that yield less than 50 gpm. A total of 400 acre-feet was discharged in 1962 from wells and springs in the district. Other discharge of ground water within the district is by evapotranspiration in the northern and western parts of the district, where the water table is at or near the land surface.

Mill Pond district

The Mill Pond district (fig. 5) was named by Goode and Gates (written communication, 1959), largely because water levels in this area fluctuated less than in the adjacent Lake Point and Erda districts. Gates (1962) later noted that the Occidental(?) fault forms a ground-water barrier which physically separates ground water in the Mill Pond and Erda districts. The fault is here defined as the western and southwestern boundary of the Mill Pond district.

The eastern boundary of the Mill Pond district is defined along the approximate upper limit of thick alluvial deposits. The northern part of this boundary is east of the Mill Pond fault, and the southern part of the boundary coincides with the Mill Pond fault. The pediment between the Mill Pond and Lake Point districts, where bedrock is at shallow depth, probably physically separates the ground water in these two districts. The northern boundary of the Mill Pond district was arbitrarily drawn to include the northernmost area in which ground water is believed to be contaminated by water rising along the Mill Pond fault (see p. 54).

Recharge to the Mill Pond district is from the mountains and the pediment to the east as discharge directly from bedrock or as underflow from Bates Canyon and other small drainages. The ground water then moves generally northwestward into the Burmester district.

Some of the few wells that have been constructed in the district yield large quantities of water, whereas others yield little water. Well (C-2-4)28aac-1, in the southern part of the district, yields about 1,000 gpm; whereas well (C-2-4)9cda-1, at the northern end of the district, reportedly yielded only 35 gpm. A total of 9,600 acre-feet was discharged in 1962 from wells and springs in the district (table 1), of which 90 percent was from Mill Pond and Dunne's Pond Springs. Other discharge is by evapotranspiration in the northern part of the district.

Erda district

New boundaries were defined for the Erda district during this study (p. 17-19). The eastern boundary of the Erda district is the Occidental(?) fault (fig. 5) and the mountain front south of the point where the fault extends into the Oquirrh Mountains.

The northern boundary and the northern half of the western boundary were drawn on the basis of chemical quality of the ground water (fig. 11). The Erda district includes those areas in which ground water contains less than 300 ppm (parts per million) of chloride, whereas ground water in the Burmester and Marshall districts contains more than 300 ppm of chloride. Part of the western boundary, however, cuts off a part of sec. 35, T. 2 S., R. 5 W., in which ground water contains less than 300 ppm of chloride (fig. 11). The well yields in this area are small, and the unconsolidated deposits are predominantly fine grained. Thus the area is more logically included in the Marshall district to the west (p. 34-35). The western boundary of the Erda district extends south to an exposure of bedrock in sec. 24, T. 3 S., R. 5 W., (fig. 5).

The southern boundary was somewhat arbitrarily drawn to extend from the exposure of bedrock, northeastward to the mountain front. The boundary is generally parallel to the gravity contours interpreted by Johnson (written communication, 1958), and it may coincide with a deeply buried bedrock ridge.

Ground water moves generally northwestward into the Erda district from the Tooele district and then moves into the Marshall and Burmester districts.

Yields of wells in the Erda district differ, but many yields are large. Five pumped wells in the southern half of the district yield more than 1,000 gpm each; and one of these wells, (C-2-4)33aab-1, yields 1,760 gpm. Both the wide spacing of the piezometric contours (fig. 6) and analysis of a pumping test at well (C-2-4)33add-1 (table 3) indicates that deposits in the southeastern corner of the district have high permeability. Individual flowing wells in the district, however, do not yield large quantities of water, and in the northern part of the district they yield less than 15 gpm. The total discharge from wells and springs in the district in 1962 was 6,200 acre-feet (table 1). Other discharge includes evapotranspiration from an area of phreatophytes in the northern part of the district.

Tooele district

The Tooele district was named by Goode and Gates (written communication, 1959). This district is discussed in more detail than the other districts because few data on this area have been included in earlier reports.

The northern boundary of the Tooele district coincides with the southern boundary of the Erda district, and the eastern and southern boundaries of the district are the approximate upper limit of thick alluvium. East and south of these boundaries, except in stream channels in the mountains, bedrock or the Salt Lake Formation is shallow and likely would not yield significant amounts of water to wells.

The western and southwestern boundaries were drawn on the basis of well yields. Successful wells have been drilled within these boundaries; whereas five apparently unsuccessful wells have been drilled beyond them. The valley fill in the Tooele district probably contains more coarse-grained material than does fill west of the district, because most of the major streams from the Oquirrh Mountains enter the valley through the district.

Recharge enters the Tooele district from the east and southeast, mostly as underflow from canyons or seepage from the bedrock of the Oquirrh Mountains. The ground water probably moves northwestward through the district and into the Erda and Marshall districts.

Yields of wells in the Tooele district differ but commonly are moderate to large. Fourteen wells were drilled in the district through 1963; seven were successful and one, (C-3-4)-14adb-1, reportedly was successful. The seven known successful wells yield from about 350 to 1,000 gpm. The total discharge of wells in the district in 1962 was 1,600 acre-feet.

Of the six unsuccessful wells, three were on the eastern side of the district in an area where the bedrock surface probably is above the water table (fig. 5). These three wells encountered bedrock at depths of from 207 to 325 feet, and the shallowest water level in the successful wells in the district is 349 feet below the land surface in well (C-3-4)28cdc-1. The gravity contours interpreted by Johnson (written communication, 1958) suggest a northwest trending buried nose of bedrock in this vicinity, and any well drilled within the lined area shown in figure 5 probably would reach bedrock above the water table. Two of the other unsuccessful wells probably were not drilled deep enough to reach water. The third well, which was drilled about 1,000 feet southwest of and to a greater depth than successful well (C-3-4)28cdc-1, evidently did not yield enough water to warrant installing a pump.

Additional interpretations of the thickness of the valley fill in the Tooele district were made using gravity and well-log data. In the vicinity of the bedrock outcrop in the NE¼ sec. 24, T. 3 S., R. 5 W., the bedrock probably is above the water table (fig. 5). Well (C-3-4)30aac-1, about 2 miles southeast of the outcrop, reached bedrock at 494 feet; and two wells in the southwestern corner of the district penetrated 701 and 763 feet of unconsolidated deposits without reaching bedrock. These data suggest that on the western side of the Tooele district, the bedrock surface is deeper to the south. In the eastern half of the district, gravity contours suggest a shallow basin in the bedrock surface in the western half of sec. 13 and the eastern half of sec. 14, T. 3 S., R. 4 W. The only well in the area, (C-3-4)-14adb-1, penetrated 656 feet of unconsolidated sediments without reaching bedrock.

Localities southeast of the Tooele district

Several wells have been drilled into alluvium in the canyons adjacent to the Tooele district. In Pine Canyon, four wells, 130 to 285 feet deep, yield from 120 to 320 gpm; and in Settlement Canyon, the city of Tooele has a well that reportedly produces 3 to 4 gpm. In Middle Canyon, the city of Tooele drilled seven wells to depths of about 50 to 140 feet in the NE¼ sec. 35, T. 3 S., R. 4 W. Three of these wells were in use in 1962 and together produced 200-300 gpm. North of the Tooele wells in Middle Canyon, an unsuccessful well was drilled to a depth of 245 feet in the SW¼ sec. 26. The total yield in 1962 of all wells discharging from alluvium in the canyons was 650 acre-feet.

Wells drilled southeast of the Tooele district, but away from stream channels, have not yielded large amounts of water. An unsuccessful well, 390 feet deep (probably mostly in the Salt Lake Formation), was drilled on the terrace southwest of Middle Canyon, in the center of sec. 35, T. 3 S., R. 4 W. Well (C-4-4)7aaa-1, 425 feet deep (probably through colluvium and alluvium), southeast of State Highway 36, reportedly yielded only 6 gpm.

Marshall district

The Marshall district, as defined by Thomas (1946, p. 162), was partly bounded by structural features that probably do not exist. In this report, however, the name is retained because the district includes an area that has distinct hydrologic characteristics and can be conveniently classed as a unit. Well yields and quality of ground water in the district differ greatly, and these differences sharply contrast with the more uniform ground-water conditions in the adjacent Erda, Grantsville, and Burmester districts.

As now defined (fig. 5), the eastern boundary of the Marshall district coincides with the western boundaries of the Erda and Tooele districts. The eastern half of the northern boundary is the northern limit of an area in which ground water contains more than 600 ppm of chloride (fig. 11). The western half passes north of an area where the valley fill mostly is fine grained and includes the springs heading Fishing Creek. The northern one-fourth of the western boundary passes east of ground water in the Grantsville district that contains less than 100 ppm of chloride. Along the southern three-fourths of the boundary, no data were available to define the boundary, so it was projected south to the western end of South Mountain. The southern boundary of the district is the approximate upper limit of thick alluviam.

Some recharge may move into the Marshall district from the consolidated rock of South Mountain and as underflow from Rush Valley, but most of the ground water probably moves into the district from the Tooele and Erda districts. Water then moves generally northward or northeastward toward the Burmester district. Large quantities of ground water discharge from the springs heading Fishing and Sixmile Creeks, and some water discharges by evapotranspiration in the northern part of the district.

Yields differ greatly from well to well in the northern end of the Marshall district. In the northeastern part, well-log data indicate that the valley fill is mostly fine grained, and wells there do not yield large amounts of water. As an example, well (C-2-5)35add-1 penetrated 513 feet of material, of which about 300 feet was described as clay, silt, or hardpan (Gates, 1963b, p. 16). West of this area of low permeability, however, wells yield large quantities of water and presumably penetrate more coarse-grained material. Well (C-3-5)-4bbb-2 yields 1,300 gpm. A total of 8,100 acre-feet was discharged in 1962 from wells and springs in the district (table 1). About 60 percent of this discharge was from the springs heading Fishing and Sixmile Creeks.

The valley fill in the district is mostly fine grained, probably because no large streams drained into the Marshall district during the deposition of the valley fill, except the stream that may have drained from Rush Valley. In the northwestern part of the Marshall district, however, where well yields are large, much of the valley fill may have been derived from the Stansbury Mountains.

Ground-water conditions in the southern three-fourths of the Marshall district are mostly unknown. Only five wells have been drilled in this area — a shallow well in the SE¼ sec. 35, T. 3 S., R. 5 W., and four wells in sec. 13, T. 4 S., R. 5 W. Apparently these wells did not have enough yield to warrant installation of pumps.

Grantsville district

The boundaries of the Grantsville district were only slightly modified during this investigation. They were defined, using the same criteria used by Thomas (1946, p. 162), to include the area in which there is free circulation of ground water of good quality from the major drainages in southwestern Tooele Valley (North and South Willow Creeks). The entire northern boundary of the district is the northern limit of ground water that contains less than 100 ppm of chloride (fig. 11); that part of the northwestern boundary between the southwestern corner of sec. 23, T. 2 S., R. 6 W., and the mountain front is approximate. The eastern boundary was defined under the discussion of the Marshall district. The southern and western boundaries of the district are the approximate upper limit of thick alluvium.

Recharge enters the Grantsville district mostly as underflow from Box Elder, South Willow, North Willow, and Davenport Canyons and directly from the consolidated rock of the Stansbury Mountains. The ground water then moves generally northeastward and northward into the Burmester district.

Yields of wells in the Grantsville district differ considerably. In the southern end of the district, coarse sediments probably make up a significant part of the valley fill, and the permeability in this area should be as high as that farther north. Wells in the east-central part of the district, extending from the northern edge of Grantsville to the southern edge of sec. 7, T. 3 S., R. 5 W., yield large quantities of water. Three wells in this area yield from 1,500 to 1,600 gpm each. In the northern end of the district, individual small-diameter flowing wells yield as much as 10 gpm each. The total discharge from wells and springs in 1962 in the district was 5,000 acre-feet. Other discharge includes evapotranspiration from an area of phreatophytes in the northern end of the district.

Burmester district

The Burmester district includes that part of Tooele Valley west of the Lake Point district and north of the Mill Pond, Erda, Marshall, and Grantsville districts. A small part of the northern end of the district was not included in this investigation. Other than the common boundaries with the other districts, the Burmester district is bounded on the north and northwest by the shoreline of Great Salt Lake, bedrock outcrops on Stansbury Island, and the northwestern boundary of Tooele Valley. The southwestern boundary of the district, west of Warm Springs, is the approximate upper limit of thick alluvium.

Ground water moves into the Burmester district from the Lake Point, Mill Pond, Erda, Marshall, and Grantsville districts, and across its southwestern boundary directly from the consolidated rock of the Stansbury Mountains. Ground water then moves in a northerly direction toward Great Salt Lake.

Well yields in the Burmester district generally are small, because the unconsolidated deposits of the district are predominantly fine grained. Gates (1963b) reported yields of 21 wells in the district, 5 of which are pumped at rates of 15 to 300 gpm. The other 16 wells flow at rates of 1 to 900 gpm, but yields of 10 of them are 30 gpm or less and average only 8 gpm.

In that part of the Burmester district in T. 1 S., Rs. 5 and 6 W., little is known about ground water. In this area, however, the permeability probably is low and well yields would be small.

The total discharge from wells and springs in the district in 1962 was 5,600 acre-feet. The district is the major area of natural discharge of ground water in the valley, because much of it is covered by phreatophytes that discharge large quantities of water by evapotranspiration. Most of the artesian water that moves upward through the confining beds in the northern part of Tooele Valley reaches the land surface in the Burmester district.

Ground-water development and water-level changes

The best tools for study of ground-water development and its effect on the hydrologic system are accurate data on well discharge and water-level changes. Discharge data were collected in Tooele Valley only during the periods 1938-40 and 1961-63. Since 1935, however, water levels have been measured periodically in selected wells; and during 1958-63 water levels in 131 wells were measured several times (Gates, 1963b, table 2).

Status of development in 1941

When Thomas (1946, p. 225-234) studied the status of ground-water development in Tooele Valley in 1941, about 1,050 wells had been constructed; of these, 630 flowed, 160 were equipped with small pumps, and 250 were unused or abandoned. Most of the wells were jetted and are 2 to 3 inches in diameter; fewer than 50 are 6 inches or more in diameter, and only 13 are 8 inches or more in diameter. Almost all the wells in the valley in 1941 tapped artesian aquifers, and nearly half were in the Grantsville and Erda districts. Only two wells, both used for irrigation, were then equipped with turbine pumps.

Development from 1941 through 1963

Much of the ground water developed since 1940 has been used as a supplement to irrigate land that had been irrigated in the past exclusively by surface water or by other sources of ground water. Some new land has been irrigated, especially in the Mill Pond district, in the western part of the Erda district, and south and northwest of Grantsville. Ground water also has been developed since 1940 for industrial supplies in the northern part of the valley by the Solar and Leslie Salt Cos. and the Utah Lime and Stone Co., and by the International Smelting and Refining Co., northeast of Tooele. Since 1950, the city of Grantsville has drilled two wells for municipal supply, and wells have been drilled in the Tooele district to supply the city of Tooele and the Tooele Army Depot. Although new uses have been found for ground water and additional land is now irrigated, ground water has been developed since 1940 primarily because surface-water supplies were below average and ground-water discharge had declined.

About 256 wells were constructed in Tooele Valley from January 1941 through 1963. Of these, 52 replaced older wells. About 115 of the 256 wells flowed and 27 others were abandoned as unsuccessful. The most significant fact about ground-water development in the valley since Thomas' study was that, although the number of wells constructed per year has not increased since 1940, a larger proportion of large-diameter (8 inches or more) wells has been drilled and equipped with pumps. In 1941, only 13 wells (about 1 percent of the wells in the valley) were of large diameter; whereas since 1940, 91 large-diameter wells (more than one-third of the total constructed) have been drilled and about half of these have been equipped with turbine or submersible pumps.

For the purpose of studying ground-water development and water-level changes in Tooele Valley, the period 1941-63 can be conveniently divided into subperiods 1941-49 and 1950-63. Most of the post-1940 development was in the latter subperiod, because most of the large-diameter pumped wells have been drilled since 1950, as shown below:

Construction period	Prior to 1941	1941-49	1950-63
Number of large-diameter wells pumped in 1963	10	7	47

New wells were drilled in the early part of 1950-63 because supplemental water was needed. Below-average precipitation had diminished surface-water supplies and had caused lower ground-water levels. (See fig. 3.) Additional development of ground water in Tooele Valley continued through the latter part of 1950-63, both because precipitation still was below average and because the practicality of using large-diameter pumped wells had been demonstrated.

Water-level changes

Water levels in wells fluctuate principally in response to changes in recharge to or discharge from the ground-water reservoir. Minor fluctuations in artesian wells also are caused by changes in atmospheric pressure, temporary aquifer loading, earth tides, and earthquakes. The principal water-level changes can be conveniently classified into annual and long-term changes, which, in Tooele Valley, were studied by preparing hydrographs of water levels in observation wells (fig. 7), and by preparing maps of changes in water levels for selected periods of time (figs. 8 and 9).

Little is known about water-level changes in Tooele Valley before 1935. Thomas (1946, p. 183-184) used data supplied by well owners to estimate that water levels in 1941 in the Grantsville and Erda districts were 8 to 12 feet below previous known highest levels.

Changes shown by hydrographs

Hydrographs of water levels for the period 1937-63 in two observation wells in Tooele Valley are shown in figure 7. The fluctuations in well (C-2-4)33add-1 in the Erda district are representative of water-level fluctuations in the eastern part of Tooele Valley, and in well (C-2-6)36dcc-1 in the Grantsville district are representative of fluctuations in the western part.

The water level in the Erda well reaches its maximum altitude in the late winter or spring and then declines sharply to a minimum in the late summer or fall (fig. 7). The decline begins when the flowing wells are opened and when pumping begins. It continues until the flowing wells are closed or the pumps are stopped in the fall. The water level then rises until the cycle begins again the next spring. The hydrograph of the Erda well, therefore, is essentially a drawdown and recovery curve caused by withdrawal of water from wells in the district. However, some of the recovery each year is caused by recharge.

The hydrograph of the Erda well also shows the effect of long-term changes in recharge and discharge. The trends of yearly high water levels approximate the trends in amount of annual precipitation — downward from 1938 to 1939, upward from 1939 to 1950, and downward from 1950 to 1963.

The October-April precipitation from October 1940 to April 1949 was above average (fig. 3), and water from the Elton tunnel, which was used for irrigation in the southeastern corner of the valley, recharged the artesian aquifers in the Erda area from about 1938 to 1950.

In the period 1950-63, the yearly high water level in the Erda well declined steadily, until in 1963 it was 6 feet below its previous low in 1939 and 20 feet below its peak in 1950. This decline was caused both by the increased withdrawal of water from large-diameter wells and by decreased recharge — because of below-average precipitation and damming of the Elton tunnel.

The hydrograph of the well in Grantsville (fig. 7) also shows an annual cycle with a yearly water-level high in the spring or early summer and a low in the period from fall to early spring. Goode and Gates (written communication, 1959) concluded that the differences between the annual fluctuations in this well prior to 1954 and since 1955 were caused by an increase of pumpage in and near Grantsville.

Prior to 1954, the yearly high water level in the Grantsville well generally was in or near June, which about coincides with the period of maximum stream runoff and, therefore, with the period of maximum recharge. In 1963, for example, the peak flow in both North and South Willow Creeks was in May and June, and the peak flow of Settlement Creek during 1949-60 ranged from May 18 to June 9 (fig. 7). The yearly low water level was in November or later, when recharge was at a minimum. Before 1954 the difference between yearly high and low water levels averaged less than 3 feet. Since 1955, the yearly high water level

Figure 7.—Hydrographs of two wells in Tooele Valley, 1937-63, and discharge of Settlement Creek 1949-60.

has been as early as March in 4 of 8 years, the yearly low has been in September or October, and the difference between them has ranged from 6 to more than 8 feet.

All the pumped wells in the Grantsville district were drilled after 1952, and of the 12 wells that were pumped in 1962, 5 were drilled in 1954-55. These 5 wells yielded about 56 percent of the water pumped in the district in 1962. Apparently when pumping began at these 5 wells in 1954-55, the annual water-level cycle changed in the Grantsville observation well.

The yearly high level since 1955 has been just before pumping starts, but when spring precipitation is great or the surface-water supply is adequate, pumping may not start until summer. Thus the water level may reach its yearly high at the time of maximum recharge, as it did before 1954. The highest water level each year, therefore, is lower now than it would be if there were no pumped wells. The water level drops during the summer, is lowest just before pumping stops in the fall, and then recovers until the next spring. The annual range of fluctuations in the water level has doubled since 1955 because pumping has increased the total withdrawal from wells. The hydrograph of annual fluctuations in the Grantsville district now is largely a drawdown and recovery curve resulting from pumping, although some of the recovery in the late winter and spring is caused by recharge.

The hydrograph of the Grantsville well also shows a long-term trend. From 1941 to 1951, the yearly high changed very little. From 1952 to 1963, however, the yearly high declined 17 feet. The decline was due to a combination of pumping in the district and decreased recharge (fig. 3).

Maps of changes in water levels

Figures 8 and 9 show changes in water levels in Tooele Valley from 1941 to 1958 and 1958 to 1963, respectively. In addition, figure 8 shows the large-yield (more than 100 gpm) pumped and flowing wells drilled during the period 1941-57, and figure 9 shows all the large-yield pumped wells in the valley in 1962 and the large-yield flowing wells drilled during 1958-62.

Figure 8 shows approximate water-level changes from the spring of 1941 to the spring of 1958. The changes are approximate because in 1958 the water levels could not be measured from the same point at the wells as in 1941, and the difference between the measuring points usually could not be determined. However, the water-level changes are accurate to within 2 feet.

Water levels declined from 0 to 5 feet from 1941 to 1958 in most of the northern part of the valley. The only large area of rise was in the Erda district where water from the Elton tunnel (fig. 5) recharged aquifers. Any declines caused by pumping southeast of Erda were masked by the general rise of water levels in the district.

In three areas of significant size, southwest of Erda, near Sixmile Creek, and north of Grantsville, water levels declined more than 5 feet. Only two pumped wells and no large-yield flowing wells were drilled during 1941-57 near the area southwest of Erda, so the cause for the decline there is not apparent. However, in the area near Sixmile Creek, four large-yield flowing wells were drilled from 1953 to 1955. Much of the decline in the area north of Grantsville may have been caused by pumping from wells in and southeast of this area and by flow from five wells drilled during 1941-57 just northeast of the area in secs. 28 and 29, T. 2 S., R. 5 W. Water levels probably declined near the five flowing wells in secs. 28 and 29 and near the pumped wells south and east of Grantsville, but no data are available to substantiate these declines.

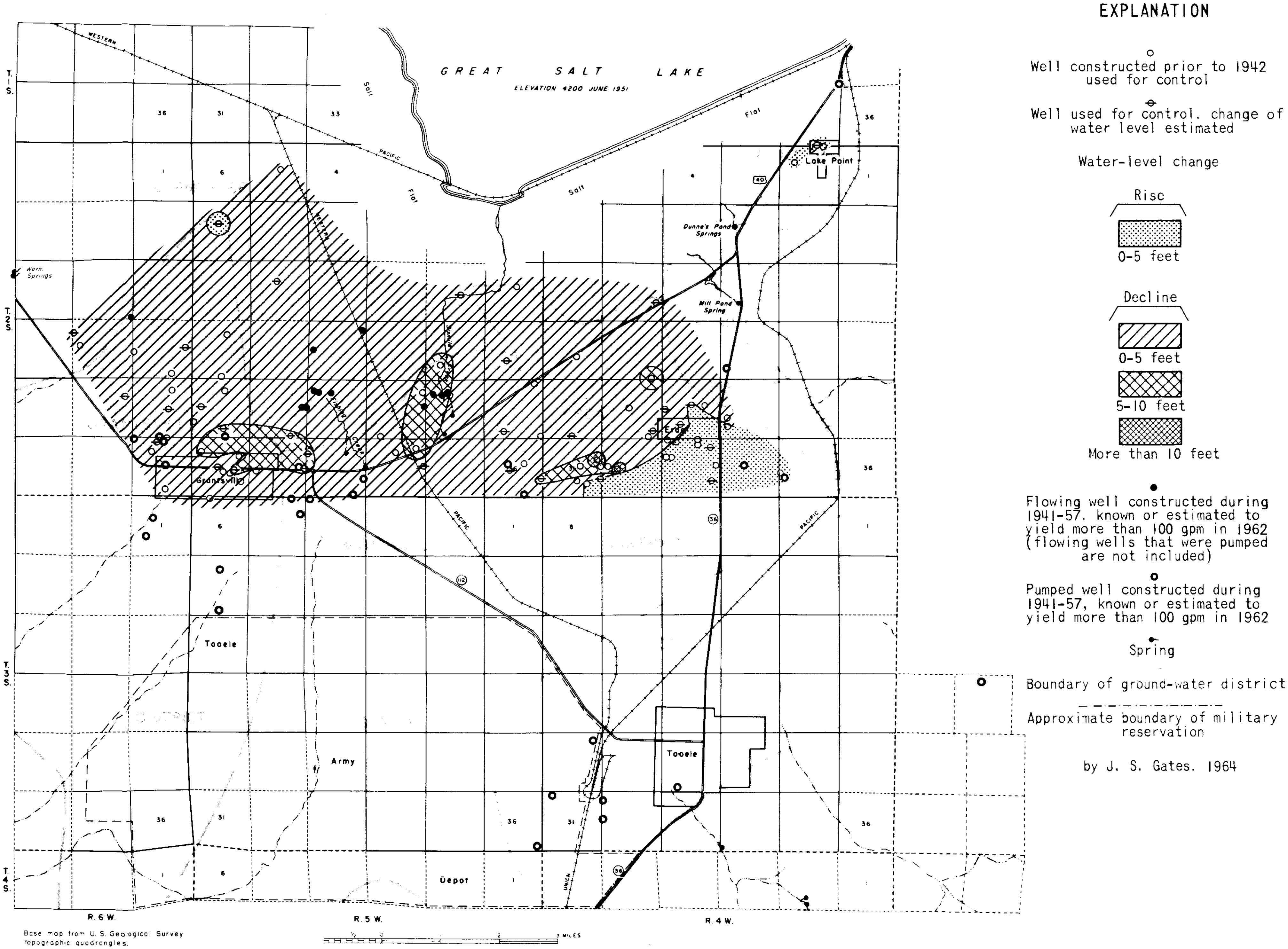

Figure 8.—Map of Tooele Valley showing approximate change of piezometric head, February-March 1941 to March-April 1958.

Six wells were drilled during 1941-57 in and west of Tooele. Although the pumping of these wells may have lowered water levels locally, no data are available to indicate declines.

Figure 9 shows water-level changes from the spring of 1958 to the spring of 1963. Water levels in more than half the area where data are available declined 2 feet or less, but water levels in large areas near Erda and Grantsville declined from 5 to 11 feet. Much of the water moving through the valley is discharged before it reaches the northern edge of T. 2 S., so that water levels in the northern part of the Burmester district are not affected much by recharge or pumpage.

Figure 9 shows the 53 wells in the valley that could be pumped at more than 100 gpm in 1962. Of these 53 wells, 10 are in areas where water-level measurements in observation wells could not be made during the 1958-63 period. Of the other 43 wells, 5 are in areas where water levels declined 0-2 feet, 15 are in areas where water levels declined 2-5 feet, and 23 are in areas where water levels declined 5-11 feet. Seven of the 10 wells that could be pumped at more than 1,000 gpm are in areas of 5-11 feet of decline.

Water-level declines of more than 2 feet during 1958-63 were caused directly by pumping and indirectly by below-average precipitation. Because water levels in much of the northern part of the valley declined 0-2 feet, the deficiency in precipitation may have caused up to 2 feet of decline. The areas of more than 2 feet of decline near Erda and Grantsville include most of the large-yield pumped wells. Pumping, therefore, caused the declines of more than 2 feet. Many of the pumped wells were drilled because of deficient precipitation, however, and, therefore, most of the water-level decline in the valley has been caused at least indirectly by below-average precipitation.

Flowing wells constructed since 1941 discharged almost as much water in 1962 as did the pumped wells (table 1). Although flowing wells constructed during 1941-57 near Sixmile Creek lowered water levels significantly during 1941-58 (p. 40 and fig. 8), in general figures 8 and 9 indicate that discharge from the large-yield flowing wells drilled since 1941 has not greatly affected water levels.

Discharge from flowing wells affects water levels differently than discharge from pumped wells. The water level and discharge of a well that flows continuously are relatively stable because they are interdependent. A decline in the water level will cause the discharge to the decrease, and that in turn will lessen the rate of water-level decline. Therefore, after a group of flowing wells are drilled and the local water levels and their discharge are in approximate equilibrium, water levels then will fluctuate through a relatively small range. In an area of pumped wells, however, if the discharge is large, water levels may continue to decline throughout the pumping period because the cone of depression around the wells does not reach equilibrium with the discharge. Thus, although flowing wells discharge a significant percentage of the total amount of water withdrawn from wells in Tooele Valley, their discharge has not lowered water levels greatly since 1958 and has only locally lowered water levels since 1941, mostly near newly drilled wells.

Water levels probably declined south of the Erda and Grantsville areas during the 1958-63 period, but no data are available to indicate the amount of change. The decline likely was progressively less southward, however, similar to the declines north of the areas of pumping. Water levels probably declined in and west of Tooele because of pumping from the six wells in this area, but the amount of decline is unknown. Pumping the wells in Pine Canyon, outside of the valley, probably does not have a measurable effect on water levels in the valley.

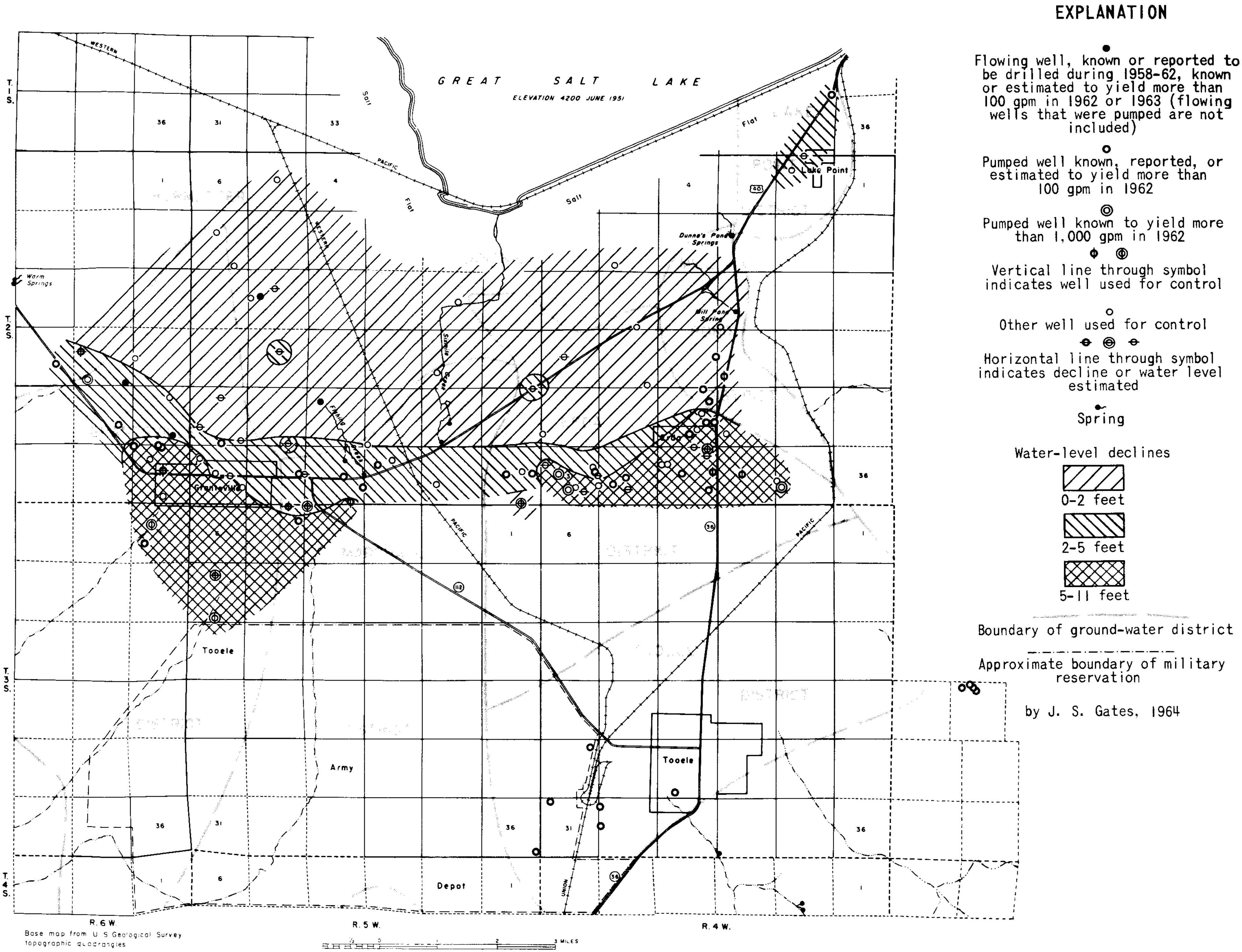

Figure 9.—Map of Tooele Valley showing decline of piezometric head, March-April 1958 to March 1963

Indications of changes in storage

Water-level changes indicate changes in the amount of water stored in aquifers. The difference between the amount of water in storage in 1941 and in 1958 in the artesian aquifers of northern Tooele Valley was estimated using an average coefficient of storage of 2×10^{-3} (table 3). Areas of different water-level change, in acres, were measured with a planimeter and were multiplied by the average change within the areas, in feet, to obtain a figure in acre-feet for each area. These figures then were multiplied by the coefficient of storage, to obtain the amounts of water, in acre-feet, removed from or added to storage. The total amount removed from storage within areas where water levels declined was subtracted from the total amount added to storage within areas where water levels rose, to obtain the net change in storage. From 1941 to 1958, less than 200 acre-feet was removed from storage in the artesian aquifers of the northern part of the valley.

From 1958 to 1963 about 200 acre-feet again was removed from storage in the northern part of the valley. Although the amount of water that was taken from storage during 1958-63 in the artesian aquifers of the southern part of the valley could not be estimated, the amount withdrawn from artesian storage in the entire valley probably was less than 400 acre-feet.

CHEMICAL QUALITY AND TEMPERATURE OF WATER

Chemical quality

Thomas (1946, p. 201-216) discussed the chemical quality of water in Tooele Valley, based on complete analyses[7] of water from 13 wells, 8 springs, and 1 stream, and partial analyses of water from 102 wells and springs. During this investigation, samples were collected from 100 wells, 4 springs, 5 streams, and 1 tunnel (Gates, 1963a, table 1, and 1963b, table 4). Of the 100 samples from wells, complete analyses were made of 71 samples and partial analyses were made of 29 samples. Complete analyses were made of the spring, stream, and tunnel samples.

Thomas' conclusions were substantiated by the data collected during this study and are summarized as follows. Ground water in Tooele Valley is either of the calcium bicarbonate type with a relatively small dissolved-solids content, the sodium chloride type with a larger dissolved-solids content, or a mixture of the two types. Surface water in the mountains probably is typical of the water that recharges the ground-water reservoir of the valley and is of the calcium bicarbonate type that contains little dissolved matter. As it enters and moves through the valley fill the water dissolves mineral matter from the unconsolidated sediments. Most of the additional mineral matter dissolved is sodium chloride.

Chloride content

All samples of water from Tooele Valley were analyzed for chloride content. Because sodium and chloride are predominant constituents in much of the water, chloride content is approximately proportional to dissolved-solids content. Figure 10 shows the relation

[7]A complete analysis includes determinations of calcium, magnesium, sodium and potassium, bicarbonate, sulfate, chloride, hardness, and dissolved solids; and it may include additional constituents. A partial analysis includes determination of fewer constituents.

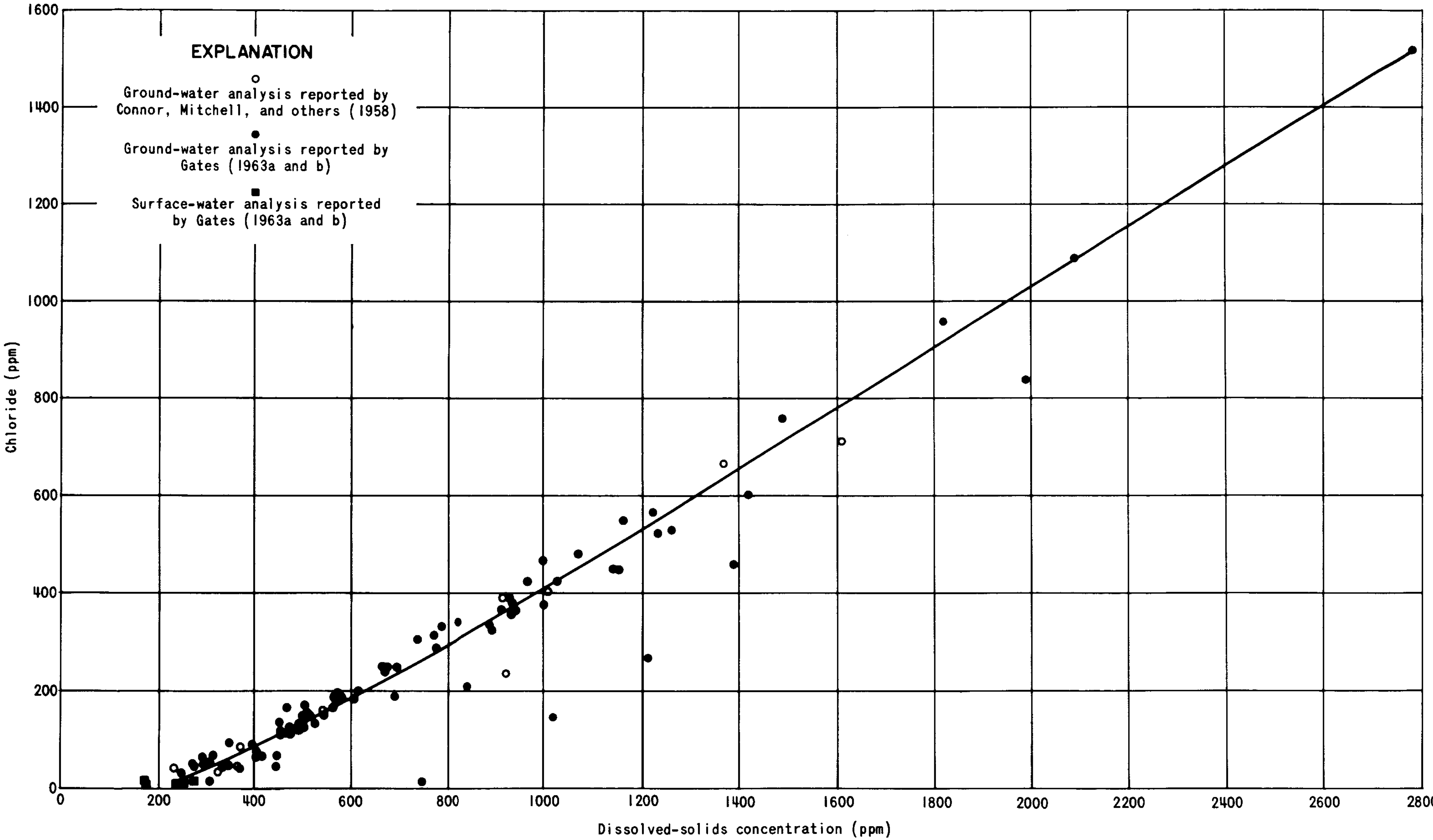

Figure 10.—Relation of chloride to dissolved-solids concentration.

between dissolved solids and chloride in water from Tooele Valley, and it can be used to estimate the dissolved-solids content of water if the chloride content is known.

A map (fig. 11) showing the chloride content of ground and surface water in the valley was prepared using the analyses reported by Gates (1963a and b) and, where additional data were needed, analyses reported by Connor, Mitchell, and others (1958).

Data from springs and wells of all depths were used to prepare figure 11; in small areas where more than one sample was collected, the chloride content of water from the principal aquifer was used, if available. If data only for the principal aquifer had been used, figure 11 probably would not be greatly different, because the known difference between chloride content of water from deep and shallow aquifers commonly is less than 50 ppm.

The quality of ground water in the southern part of the valley is unknown except in the few small areas shown in figure 11. It is expected, however, that the water in the southeastern and southwestern corners of the valley is of excellent quality. These areas, which include the Tooele district and the southern end of the Grantsville district are the major areas of recharge to the artesian aquifer system (p. 23). The surface water in the Oquirrh and Stansbury Mountains, which probably is chemically typical of the recharge water, contains less than 20 ppm of chloride (fig. 11); and ground water in and near the recharge area along the mountain front also may be low in chloride content and dissolved solids. After the ground water has traveled a few miles northward, it dissolves additional mineral matter and its quality may resemble that of water in the northern parts of the Erda and Grantsville districts. In the south-central part of the valley, however, the sediments in the Marshall district are fine grained; and the ground water may be of poorer quality than that at the sides of the valley.

Figure 11 shows that two large areas yield ground water of relatively good quality (containing less than 300 ppm of chloride), one large area yields water of poorer quality (containing 300-600 ppm), and smaller areas yield water of generally poor quality. The two large areas of good-quality water are essentially the northern parts of the Erda and Grantsville districts, and they extend valleyward from the areas of greatest recharge (see p. 23). They coincide with areas of relatively permeable sediments. Because the sediments include a larger proportion of stream-channel deposits, they are coarser and less soluble than the fine-grained deposits in the central and northern parts of the valley. Furthermore, water moves through the coarser deposits faster than through fine deposits and consequently has less time to dissolve mineral matter. Alluvium in the Grantsville district is less soluble than that in other parts of the valley because deposits in the district include a large proportion of quartzite derived from the Stansbury Mountains.

The large area that yields water of poorer quality includes parts of the Mill Pond, Marshall, and Burmester districts and much of the Lake Point district. In these areas, deposits are mostly fine grained, and they probably contain more soluble material than do the deposits in the Grantsville and Erda districts. Ground water moves through these fine sediments slowly and dissolves large amounts of mineral matter.

In several small areas, the ground water contains more than 600 ppm of chloride (fig. 11). In some of these areas such as in sec. 26, T. 1 S., R. 4 W., in the Lake Point district, and in sec. 36, T. 2 S., R. 5 W., in the Erda district, wells may tap aquifers that contain large amounts of soluble material. In two areas, in sec. 34, T. 1 S., R. 4 W., in the Lake Point district, and in secs. 5 and 6, T. 2 S., R. 5 W., in the Burmester district, ground water that contains large amounts of chloride may be partly connate water that was trapped in sediments of Great Salt Lake, Lake Bonneville, or older lakes, and partly water that has dissolved a large amount of salts from fine-grained deposits of these lakes.

In most places, water from the shallower aquifers contains more dissolved solids than that from the principal and deeper aquifers. This increase in dissolved solids with decreasing depth was noted by Thomas (Hunt, Varnes, and Thomas, 1953, p. 89) in northern Utah Valley, about 40 miles southeast of Tooele Valley. In both northern Utah and Tooele Valleys, water moves upward through fine-grained confining beds that contain soluble material. Because of this upward movement of water, the unconfined water in the northern part of Tooele Valley probably contains more dissolved solids than does the shallow artesian water. The poor quality may be one reason why the unconfined water has not been developed.

Water from great depths in the valley also may be saline. Electric logs of the three oil tests in the valley (fig. 5) indicate that in this locality fresh water may be present to depths as great as 1,600 feet, and that below 1,600 feet, all water is saline.

Water from deep aquifers in a few places in Tooele Valley contains more dissolved solids than does the shallower water. In three of the small areas, near Dunne's Pond Springs, between the heads of Fishing and Sixmile Creeks, and near and southeast of Warm Springs ground water contains from 300 to more than 5,000 ppm of chloride. Water in these areas has been contaminated by saline water rising from deep zones along faults (p. 54), and this saline water may have contaminated nearby deeper aquifers more than it has contaminated the shallow aquifers. As an example, well (C-2-6)23cbb-1, 210 feet deep and near the Warm Springs fault, yields water that contains 295 ppm of chloride; whereas nearby well 23cbb-2, 95 feet deep, yields water that contains only 139 ppm of chloride. The water from the faults may be similar to that at depths below 1,600 feet as indicated by the electric logs of the oil tests. The source of the chloride in this water is not known, but it probably is connate water or from deposits of soluble material.

Little is known about the quality of ground water in much of the northern part of the Burmester district. The valley fill in this area, however, probably is fine grained and contains much soluble material; thus, it is expected that the water would be of poor quality.

Suitability of water for various uses

Chemical analyses of water indicate its suitability for many uses. Water containing less than 500 ppm of dissolved solids is satisfactory for most uses; water containing from 500 to 1,000 ppm of dissolved solids commonly is usable; but water with more than 1,000 ppm is likely to be unsuitable for domestic use or public supply because of taste, hardness, corrosiveness, or other reasons. However, water with more than 1,000 ppm of dissolved solids can be used for some purposes. Range cattle in the western United States can drink water containing more than 5,000 ppm of dissolved solids (Hem, 1959, p. 241), and water containing about 35,000 ppm of dissolved solids is commonly used for cooling purposes in coastal areas.

Of 84 sources of natural water that were analyzed for dissolved solids (Gates, 1963b, table 4), only 18 yielded water containing more than 1,000 ppm of dissolved solids. Figure 11 shows the known distribution of dissolved solids in the ground water in the valley.

The water in Tooele Valley commonly is very hard and should be softened to make it desirable for domestic use. Of 85 sources that were analyzed for hardness (Gates, 1963b, table 4), none yielded soft water (60 ppm or less of hardness), 2 yielded moderately hard water (61-120 ppm), 14 yielded hard water (121-180 ppm), and 69 yielded very hard water (more than 180 ppm).

The suitability of water for irrigation can be judged by using a classification devised by the U. S. Salinity Laboratory Staff (1954). Irrigation water is classified in regard to salinity hazard and sodium hazard by plotting its specific conductance against its sodium-adsorption ratio (fig. 12). Water with low salinity and sodium hazards can be used to irrigate most crops, but crops irrigated with water of high salinity hazard should be salt tolerant and may require excess water to provide leaching. Land irrigated with water of high sodium hazard may require addition of gypsum to maintain adequate soil permeability.

Figure 12 shows the salinity and sodium hazards of 75 ground-water sources from the districts in Tooele Valley and of 4 surface-water sources from the Oquirrh and Stansbury Mountains. Data were obtained from table 4 of Gates (1963b). The best water for irrigation is from the streams in the mountains, and ground water from the Grantsville district is almost as good in quality. Next best is water from the Erda district, the Tooele district, the southeastern edge of the Mill Pond district, and the northwestern corner of the Marshall district. Water from the Lake Point district, the northeastern part of the Marshall district, and most of the Burmester district generally is unsuitable for irrigation.

Changes in quality

Thirty-three wells and two springs in Tooele Valley were sampled from 2 to 10 times during 1941-62. Table 4 gives the chloride and dissolved-solids content and the specific conductance of these samples, and it was prepared to determine if the water quality in the valley has changed. The analyses of samples from a single source may vary somewhat because of differences in sampling procedure or analytical error, and samples from pumped wells may show small changes in quality if the rate or length of the pumping period changes. Periodic samples, however, will indicate if water has been polluted by man or mixed with other water of different quality.

The chief potential cause of change of water quality in Tooele Valley is movement of poor-quality water into areas of good-quality water. Such movement would necessitate a source of poor-quality water and a decline of water levels adjacent to the source. The poor-quality water exists in the valley along the shore of Great Salt Lake, near the Mill Pond, Fishing Creek, and Warm Springs faults, and below depths of 1,600 feet.

The data in table 4 do not show any marked changes in water quality, but analyses of samples from a spring and four wells in the valley showed increases in chloride content which may be significant. In the Mill Pond district, the chloride content of water from Mill Pond Spring, (C-2-4)15cac, increased 18 percent from 1941 to 1958. Water levels near the spring did not change greatly during this period so the reason for the increase is not apparent. Water from well (C-2-4)22ccb-4 increased 11 percent in chloride from 1959 to 1962. Increased pumping may have lowered water levels enough to move poor-quality water outward from the Mill Pond fault.

In the Tooele district, water from well (C-3-4)31bba-1 increased 13 percent in chloride content from 1954 to 1960, and water from well (C-3-4)32bcc-1 increased 10 percent from 1956 to 1962. The significance of these increases in chloride content cannot be evaluated, because no water-level measurements were made in the district before 1962.

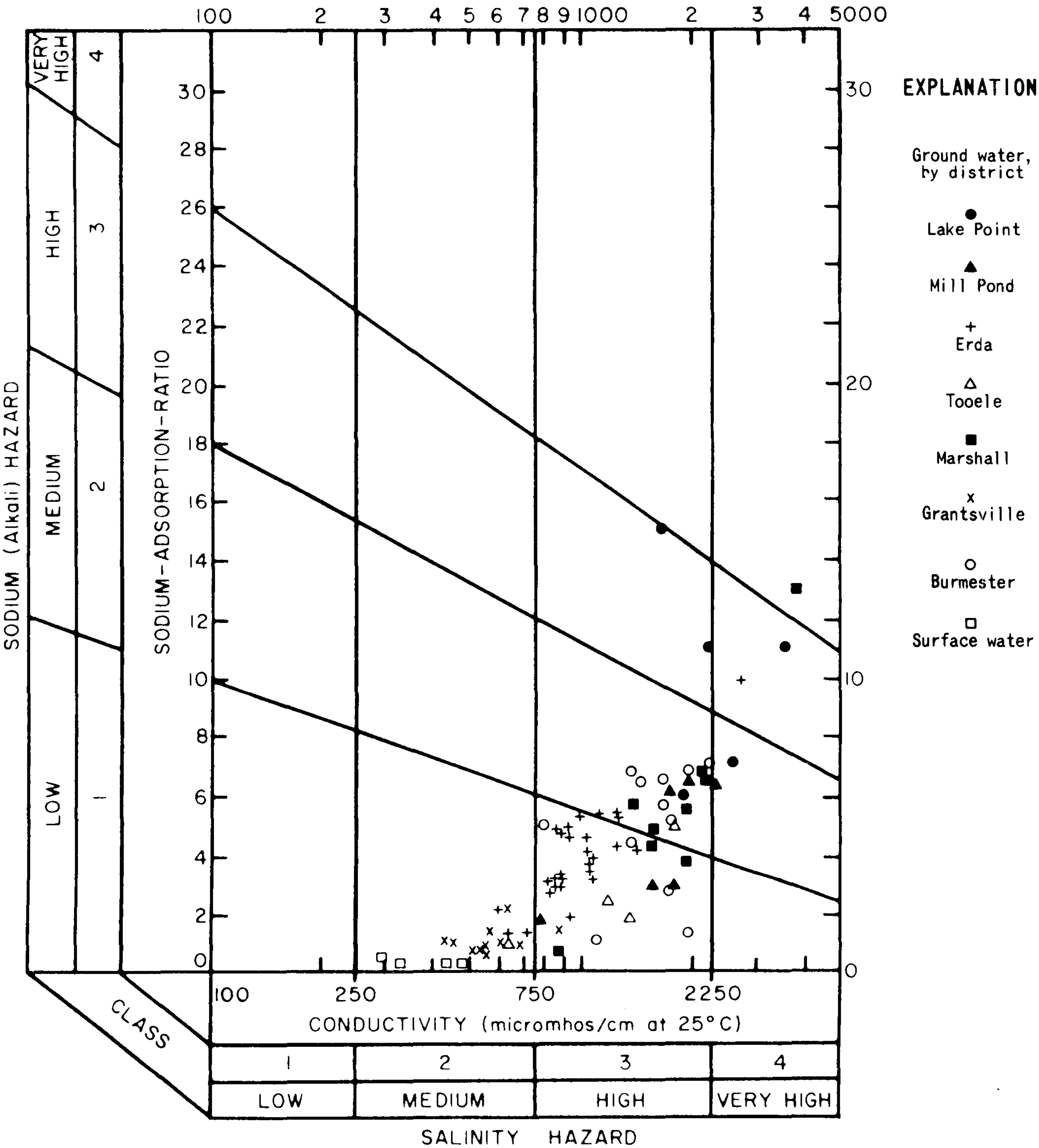

Figure 12.—Classification of water for irrigation.

Table 4. — Chemical quality of water from wells and springs in Tooele Valley that have been sampled more than once[1]

Well or spring number and ground-water district	Date of collection	Depth of well (feet); S indicates spring	Chloride (ppm)	Dissolved solids[2] (ppm)	Specific conductance (micromhos/cm at 25°C)
(C-1-4)26ddd-1 Lake Point	12-28-60	227	975	1,890	3,490
	5-31-61		935	....	3,400
	11-24-61		960	1,820	3,550
(C-2-4)2aba-1 Lake Point	3-23-59	232	352	922	1,660
	7- 1-59		350	929	1,670
	9-23-59		350	927	1,680
	12-29-59		355	916	1,670
	3-30-60		358	938	1,660
	10- 4-60		355	933[3]	1,670
(C-2-4)8cdc-1 Burmester	3-26-59	345	333	738	1,370
	6-29-59		342	762	1,390
	9-24-59		325	715	1,370
	12-30-59		335	731	1,370
	4- 5-60		340	751	1,370
	10- 5-60		338	786[3]	1,360
(C-2-4)15cac Mill Pond	4- 4-41	S	382	1,100[3]	....
	8-22-58		450	1,150	1,990
(C-2-4)22ccb-4 Mill Pond	6-11-59	96	242	1,130	1,760
	4-12-61		246	1,050	1,670
	10- 3-61		238	1,100	1,670
	6-19-62		268	1,210[3]	1,840
(C-2-4)28acd-3 Erda	3-23-59	190	43	413	702
	6-29-59		44	422	700
	9-23-59		48	420	709
	12-29-59		43	408	709
	3-30-60		45	397	671
	10- 4-60		44	442[3]	709
(C-2-4)29bcd-1 Erda	10-28-41	300	215	....	....
	8-20-58		182	574	1,030
(C-2-4)31ada-1 Erda	8-20-58	200	124	491	843
	3-23-59		122	497	883
	7- 1-59		124	516	889
	9-23-59		124	485	878
	12-29-59		127	493	891
	3-30-60		126	507	874
	10- 4-60		122	475	836
(C-2-5)31bbd-3 Grantsville	3-26-59	125	138	459	860
	6-29-59		147	451	854
	9-24-59		144	480	873
	12-29-59		144	470	862
	4- 4-60		146	469	869
	10- 5-60		146	505[3]	865
(C-2-5)33dad-3 Marshall	4-11-61	400	454	1,080	1,940
	9-26-61		428	1,050	1,870
	5- 1-62		452	1,140[3]	1,940
(C-2-5)34add-1 Marshall	8-26-41	440	330	....	....
	8-18-58		318	752	1,380
	3-24-59		312	739	1,380
	7- 1-59		315	770	1,390
(C-2-5)36add-2 Erda	9- 2-41	310	178	....	....
	8-18-58		192	578	1,070
(C-2-5)36dad-1 Erda	9- 2-41	259	245	....	....
	8-22-58		249	696	1,220
(C-2-5)36dcd-1 Erda	8-20-58	325	760	1,490	2,710
	6-12-59		....	....	2,700
	9-23-59		....	....	3,010
(C-2-6)23cbb-1 Burmester	5-31-61	210	337	822[3]	1,470
	8-22-62		295	774[3]	1,360
(C-2-6)24cbb-2 Grantsville	9- 4-41	150?	46	....	....
	12-29-60		47	265[3]	454
	6- 1-61		46	....	458
	10-24-61		46	274[3]	456
(C-3-4)30aac-1 Tooele	10-29-47	515	52	334[3]	589
	11- 3-49		50	354[3]	631
	9-14-50		50	346[3]	620
	4-12-51		51	351[3]	618
	9-10-52		52	352[3]	630
	10-27-52		....	....	633
	9- 3-53		51	350[3]	621
	2-13-57		48	345[3]	628
	7-29-59		50	348[3]	621
	11- 1-60		53	362[3]	635
(C-3-4)31bba-1 Tooele	4- 8-54	701	160	644[3]	1,100
	10-18-54		185	653[3]	1,110
	2-13-57		192	691[3]	1,160

(C-2-4)31bcb-1	8-18-58	343	198	586	1,090
Erda	12-28-60		198	605[3]	1,080
	5-31-61		196	....	1,070
	10-24-61		191	604[3]	1,060
(C-2-4)33aab-1	12-18-59	403	46	333	601
Erda	9- 7-62		....	....	612
(C-2-4)33bbb-1	8-25-41	277	190	....	....
Erda	8-20-58		128	496	885
	12-28-60		136	497	897
	5-31-61		136	....	904
	10-24-61		144	516[3]	926
(C-2-4)33bcb-1	8-25-41	283	215	....	....
Erda	8-20-58		130	499	909
(C-2-5)7bdd-1	4- 4-41	300	47	278	....
Grantsville	10-11-61		47	....	442
(C-2-5)13bca-1	11- 8-55	3,540?	595	1,200	2,130
Burmester	5- 5-61		510	....	1,910
(C-2-5)14dbb-1	10-28-41	300	410	....	....
Burmester	3-12-58		380	935	1,680
(C-2-5)17bcc-1	3-26-59	356	268	592	1,140
Burmester	7- 1-59		270	609	1,160
	9-24-59		270	589	1,170
	12-29-59		252	570	1,110
	4- 4-60		245	560	1,070
	10- 5-60		252	675[3]	1,090
(C-2-5)26cdc	9- 5-41	S	1,070	2,070	....
Marshall	8-22-58		1,090	2,090	3,770
	7-29-59		178	664[3]	1,120
	11- 1-60		181	664[3]	1,110
(C-3-4)32bbc-1	11- -54	720	84	559	....
Tooele	12- 9-54		93	397	....
	8-24-55		66	418	....
(C-3-4)32bcc-1	9-28-56	710	364	914	....
Tooele	10-17-62		400	....	1,760
(C-3-5)4bbb-2	5-11-59	410	402	882	1,640
Marshall	8-22-62		468	1,000	1,910
(C-3-5)7dcc-1	7-12-57	395	52	309	520
Grantsville	6-29-59		51	292	510
(C-3-5)36ddd-1	10-29-47		222	834[3]	1,340
Tooele	11- 3-49	763	205	785[3]	1,280
	9-14-50		210	822[3]	1,340
	4-12-51		204	784[3]	1,270
	9-10-52		202	760[3]	1,280
	9- 3-53		210	780[3]	1,280
	11-23-54		228	871[3]	1,400
	2-13-57		210	843[3]	1,330
	7-29-59		212	805[3]	1,320
	11- 1-60		222	860[3]	1,340
(C-3-6)1bdb-1	6-29-59	418	97	356	633
Grantsville	4- 6-61		98	371[3]	638
	9-26-61		93	399[3]	634
(C-3-6)1cbd-1	8-25-53	305	44	233	....
Grantsville	9-29-61		44	....	432
(C-3-6)36aac-1	3-22-56	780	69	392[3]	686
Grantsville	2-14-57		68	403[3]	675
	7-29-59		70	380[3]	670
	11- 1-60		69	376[3]	658

[1]Additional chemical-quality data for these wells and springs are in Connor, Mitchell, and others (1958), in Gates (1963b), and in the files of the Geological Survey.

[2]Calculated from determined constituents except as noted.

[3]Residue on evaporation.

In the Marshall district, water from well (C-3-5)4bbb-2 increased 16 percent in chloride content from 1959 to 1962. This pumped well is near six others and all of them are southwest of the poor-quality water associated with the Fishing Creek fault. Water-level declines around the wells during the period of sampling may have caused movement of high-chloride water toward the wells. More data are needed to show if there is any extensive migration of poor-quality water.

In contrast to the deterioration of water quality, analyses of samples from six wells in the valley showed decreases in chloride content which may be significant. In the Erda district, water from three wells, (C-2-4)29bcd-1, 33bbb-1, and 33bcb-1, decreased from 15 to 40 percent in chloride content during the perod 1941-58. The reason for this change in quality is not known, but it is possible that the change is due to recharge from the Elton tunnel during 1938-50 (p. 38). In the Tooele district, water from well (C-3-4)32bbc-1 decreased 21 percent in chloride content from 1954 to 1955, and in the Burmester district, water from well (C-2-6)23cbb-1 decreased 12 percent in chloride from 1961 to 1962. Both are pumped wells, and pumping may be drawing in water of better quality. Also in the Burmester district, water from oil test (C-2-5)13bca-1 decreased 14 percent in chloride content from 1955 to 1961. There is no apparent cause for the decrease in chloride content in water from this well.

In summary, chemical-quality data from Tooele Valley do not clearly indicate that ground-water development is causing deterioration or improvement in water quality, but slight contamination may have occurred in the Mill Pond and Marshall districts. Water quality may change in the future if water levels change enough, and the quality should be checked periodically in areas where changes might be expected.

Temperature

Temperature data were collected during this study mainly to help locate faults in the valley fill. Temperatures in the earth increase with depth, and the rate of change is normally almost constant within the depths usually penetrated by water wells. Artesian water that leaks upward along faults from considerable depth will be warmer than normal at a given shallower depth. Wells or springs near a fault that transmits water upward may yield water of above-normal temperature and thus indicate the approximate location of the fault.

Temperatures of water from flowing wells and a few pumped wells in Tooele Valley were measured in 1962 and 1963 to determine the normal thermal gradient. These temperatures were measured in areas where the ground water was known to contain less than 300 ppm of chloride because such water is not contaminated from faults. Only one thermometer was used to make the measurements; and only unperforated wells or wells that had single, small perforated zones were included in the survey, in order to insure that the water was from a single depth. The normal gradient is shown in figure 13.

In figure 13, the scatter of the points that determine the normal thermal gradient is partly caused by errors in the reported depths of wells. The flow of some of the wells may have been too small to permit obtaining the true temperature, and some corroded well casings may admit water from a zone other than that assumed. Because of the scatter of

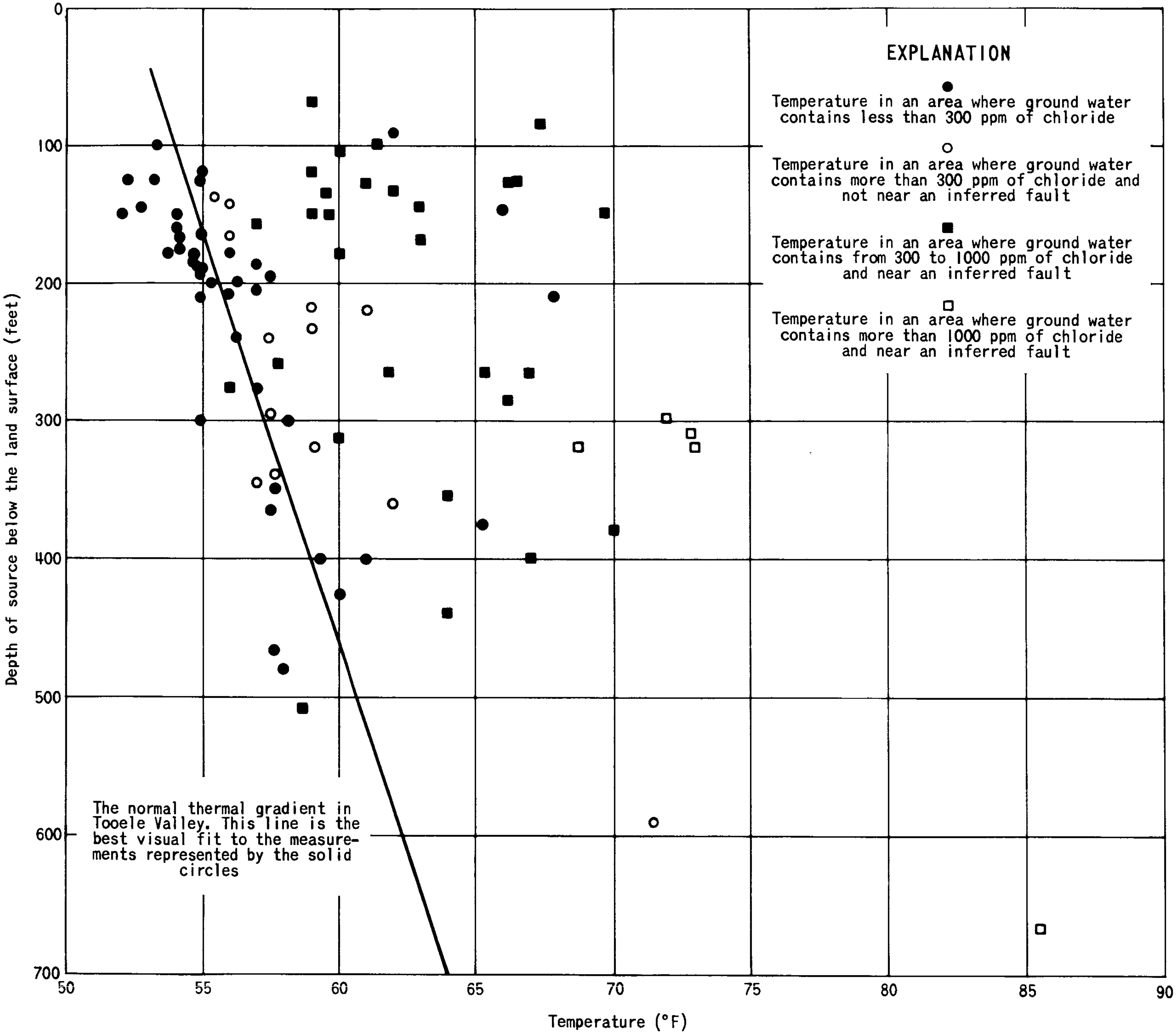

Figure 13.—Relation between temperature and depth of source of water from wells.

points, a temperature was not considered "abnormal" unless it was 5°F or more different from the normal gradient.

Approximately half the measurements plotted in figure 13 are from areas where ground water contains less than 300 ppm of chloride. Of these, only four were 5°F or more above normal. All four are within 2 miles of Warm Springs, and their water temperatures range from 6 to 12°F above normal. The abnormally high temperatures may be due to an actual source of heat in the Warm Springs area, because the water apparently has not mixed with the high-chloride water rising along the Warm Springs fault.

Temperatures of water also were measured at 13 wells that are in areas where ground water contains more than 300 ppm of chloride but that are not near inferred faults. Only two of these wells yielded water that was 5°F or more above normal. These two wells, (C-1-4)26ddd-1 and (C-3-4)32bcc-1, may be near undefined faults.

Figure 13 also shows ground-water temperatures in areas where the chloride content is greater than 300 ppm and that are near inferred faults. Most temperatures in these areas were more than 5°F above the normal thermal gradient. Temperatures measured with various thermometers during the period 1941-63 were used, and wells perforated in more than one zone also were used. For the latter, temperatures were plotted against the maximum depth of the perforations, in order to show a minimum departure above normal.

Location of faults using chemical-quality and temperature data

In three areas of Tooele Valley — near Dunne's Pond Springs, Fishing and Sixmile Creeks, and Warm Springs — ground water generally contains more than 600 ppm of chloride (fig. 11) and ground-water temperatures are significantly above normal. In these three areas, ground water of high-chloride content leaks upward along faults and contaminates local ground water.

Near Fishing and Sixmile Creeks the source of high-chloride ground water must be local because the area is surrounded by ground water of better quality (fig. 11). Ground-water temperatures in this area are above normal. Figure 13 shows temperatures of water from 34 wells that yield water containing more than 300 ppm of chloride and that are near faults. Of these 34 wells, 25 are in the area of high-chloride water around Fishing and Sixmile Creeks. Of the 25 wells, 23 yield water of above-normal temperature and 16 of the latter yield water that is 5°F or more above normal. Four of the five wells in the valley that yield water containing more than 1,000 ppm of chloride are in this area, and the temperature of water from these four wells was from 11 to 15°F above normal. Thus, the high-chloride water probably is from deep sources and rises along a fault through the area.

The springs that are the sources of Fishing and Sixmile Creeks probably also discharge from the fault. The temperature of the water from one of the springs at the head of Fishing Creek is 62°F and from one of the springs at the head of Sixmile Creek is 65°F. Water from the Fishing Creek spring contains 810 ppm of chloride, and water from another one of the Sixmile Creek springs contains 1,090 ppm of chloride. An elongate area in which ground water contains more than 1,000 ppm of chloride extends between the two sets of springs (fig. 11). On these bases, the Fishing Creek fault has been inferred through the spring areas (fig. 5).

Near Dunne's Pond Springs, ground water contains large amounts of chloride and is above normal in temperature. Three wells near Dunne's Pond Springs yield water that contains more than 300 ppm of chloride and that is 5° or more above normal temperature. Water from one of these wells contains 1,520 ppm of chloride and has a temperature 22°

above normal. The temperature of the water from Dunne's Pond Springs ranges from 61° to 70°F, and at Mill Pond Spring it is 64°F. Water from one of the Dunne's Pond Springs contains 365 ppm of chloride, and water from Mill Pond Spring contains 450 ppm of chloride.

Five of six wells southeast of Warm Springs yield water that contains more than 300 ppm of chloride, and one of the Warm Springs discharges water that contains 16,700 ppm of chloride and has a temperature of 85°F. Thus on the basis of chemical-quality and temperature data, the Mill Pond fault (fig. 5) was inferred through Dunne's Pond Springs and Mill Pond Spring, and the Warm Springs fault (fig. 5) was inferred through Warm Springs.

The other two faults defined during this study, the Occidental(?) and Sixmile Creek faults (fig. 5), apparently do not transmit water upward. The Occidental(?) fault acts as a barrier to ground-water movement, but no chemical-quality or temperature anomalies were found along its length. The Sixmile Creek fault has no known effect on ground water.

TENTATIVE HYDROLOGIC BUDGET OF THE ARTESIAN AQUIFER SYSTEM

A hydrologic budget of the artesian aquifer system of part of Tooele Valley was prepared during this study. The budget includes water gains, water losses, and changes in storage in the aquifers south of a reference line that crosses the northern part of the valley through the Mill Pond, Erda, Marshall, and Grantsville districts (fig. 14). A budget for the entire hydrologic system of the valley was not prepared, mainly because few data are available for the water-table zone in the northern part of the valley, and because the quantity of water discharging from the valley in the subsurface to Great Salt Lake is not known.

The equation of the hydrologic budget is as follows: precipitation plus subsurface inflow equals change in ground-water storage, plus evapotranspiration, plus discharge by streamflow, plus discharge from springs, drains, and wells, plus subsurface outflow. These factors have been grouped into water gains, changes in storage, and water losses. The balance of gains and losses in the budget is fortuitous rather than an indication of accuracy.

The budget is summarized quantitatively below, and the various items are discussed in the following pages.

	Volume of water (acre-feet)
Water gains:	
Precipitation	200,000
Subsurface inflow	Assumed negligible
Total	200,000
Changes in storage:	Not fully known, assumed negligible
Water losses:	
Evapotranspiration	80,000
Streamflow	10,000
Spring, drain, and well discharge	10,000
Subsurface outflow	100,000
Total	200,000

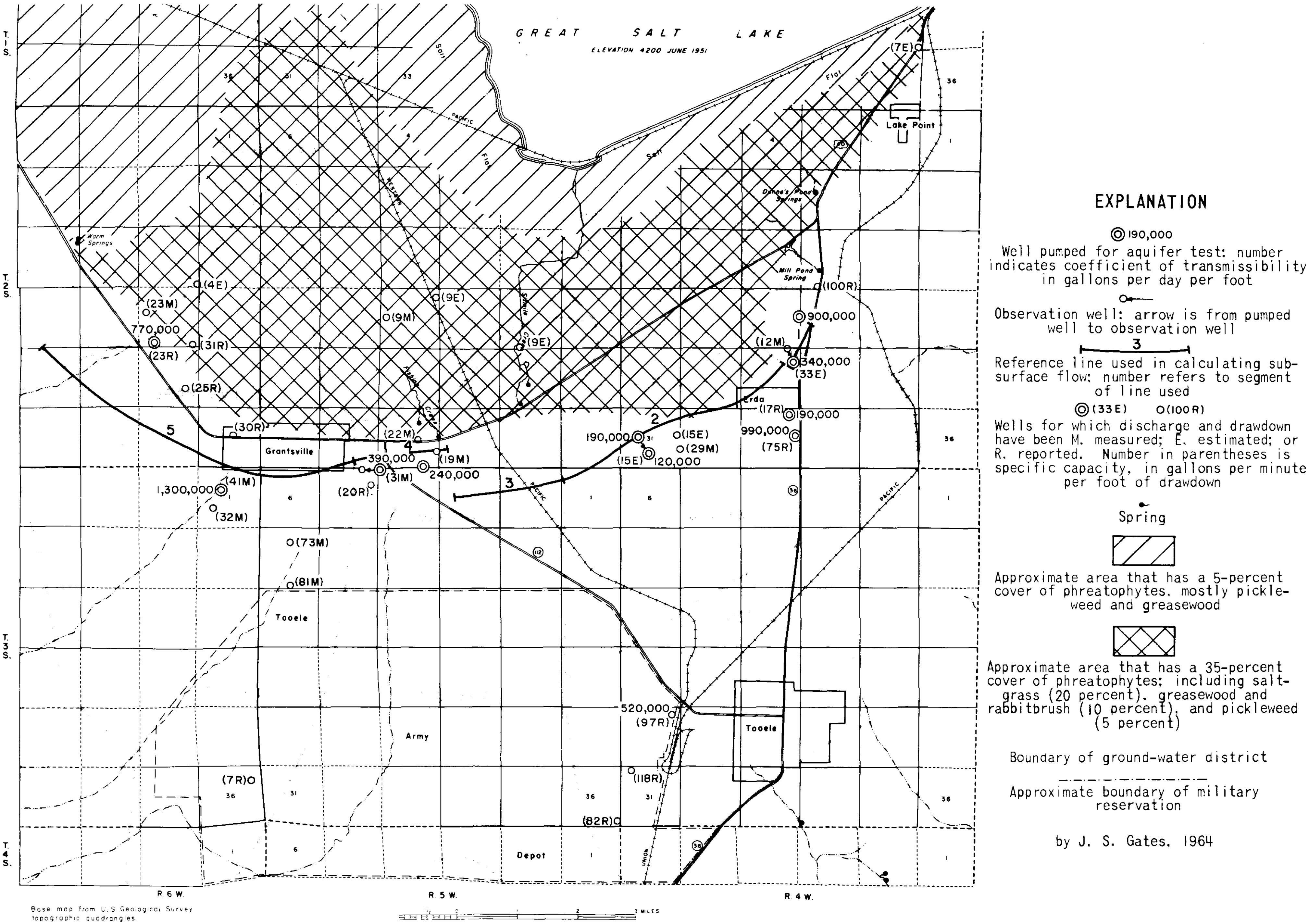

Figure 14.—Map of Tooele Valley showing wells used in aquifer tests, the line of reference used in calculating subsurface flow to the northern part of the valley, specific capacities of selected wells, and the approximate area of phreatophytes in the northern part of the valley.

Water gains

Precipitation

The normal annual precipitation over those parts of the adjacent mountains tributary to Tooele Valley and the recharge area in the valley (see p. 22-23) was determined from figure 2. It was assumed that precipitation at altitudes below the recharge area does not infiltrate to the artesian aquifer system; therefore, it was not included in the budget. The areas within successive isohyetal lines were measured by planimeter and multiplied by the average precipitation within the areas to obtain the amounts of precipitation. These amounts were then added to give the total annual precipitation over the recharge area and adjacent mountains. The normal annual precipitation in this area is about 200,000 acre-feet (table 5).

Table 5.—**Annual precipitation over these parts of the mountains tributary to Tooele Valley and the recharge area in the valley**

Interval of annual precipitation (inches)	Area (acres)	Average annual precipitation (feet)	Water gain from precipitation (acre-feet)
11-12	800	0.96	800
12-14	11,500	1.08	12,400
14-16	13,800	1.25	17,200
16-18	12,900	1.42	18,300
18-20	12,100	1.58	19,100
20-25	19,300	1.88	36,300
25-30	24,800	2.29	56,800
30-35	7,000	2.71	19,000
35-40	2,900	3.12	9,000
More than 40	1,600	3.54	5,700
		Total	194,600
		(Rounded:	200,000)

Subsurface inflow

Although some subsurface inflow may enter Tooele Valley from Rush Valley below the Stockton bar, there is no evidence that such flow is large; and it is assumed to be negligible (see p. 22).

Change in storage

The change in storage in the artesian aquifers in the valley during the period 1958-63 was estimated to be a loss of about 400 acre-feet, or about 80 acre-feet per year (see p. 44). This quantity is considered to be negligible, in view of the magnitudes involved in the water budget.

Water losses

Evapotranspiration

No data are available for evapotranspiration in the recharge area and in those parts of the mountains tributary to Tooele Valley. Rather than treat it as an unknown, however, an estimate of evapotranspiration was made using data collected by Croft and Monninger (1953) in Parrish Canyon, in the Wasatch Range east of Farmington, Utah (fig. 1).

Croft and Monninger (1953, p. 571) calculated that evapotranspiration consumed 35 percent of the total precipitation in areas covered only by herbaceous vegetation and 42 percent in areas covered by aspen and herbaceous vegetation. They (1953, p. 573) stated that their data could be applied to steep mountain watersheds between 7,000 and 10,000 feet in altitude that have vegetation, precipitation, and soil similar to Parrish Canyon. Much of the mountainous area tributary to Tooele Valley is similar and is above an altitude of 7,000 feet, but the recharge area in the valley is below 7,000 feet. Only about half the precipitation tabulated in table 5 falls on land at altitudes above 7,000 feet. However, for purposes of comparison a round figure of 40 percent for evapotranspiration was considered sufficiently accurate. Thus the evapotranspiration from the recharge area and from those parts of the mountains tributary to Tooele Valley is about 80,000 acre-feet per year.

Streamflow

Most of the flow in Davenport, North Willow, South Willow, Box Elder, Settlement, and Middle Canyons is diverted to irrigate land below the recharge area in the valley, and most of the diverted water crosses the recharge area in concrete ditches or pipelines. Consequently, most of the water that enters the valley in the six canyons is considered a water loss to the artesian aquifer system.

The average annual discharge from the canyons was estimated by comparing short-term discharge figures with 2-year periods of October-April precipitation. Correlations by Gates (1963a, fig. 5) indicated that a linear relation exists between the discharge from Middle Canyon during a given year and the October-April precipitation at the city of Tooele for the given year plus that of the preceding year. Similar correlations between precipitation and streamflow were assumed to exist for the other five canyons.

The total precipitation during October 1961-April 1962 and October 1962-April 1963 at Tooele was about 21.4 inches. The normal October-April precipitation for the period of record 1931-60 is 10.7 inches. Thus the 1961-63 period was one of average precipitation; and according to Gates' correlation, the discharge from the canyons during 1963 would be representative of the average annual discharge.

Spot measurements made from October 1962 to October 1963 indicated that Davenport and North Willow Canyons together yielded about 2,700 acre-feet during the year and South Willow and Box Elder Canyons together yielded about 3,800 acre-feet. Middle Canyon discharges about 1,100 acre-feet per year when the 2-year precipitation is about 21.4 inches (Gates, 1963a, fig. 5). A similar correlation for Settlement Canyon, based on streamflow records during 1949-60, indicates that the canyon discharges about 4,000 acre-feet per year when the 2-year precipitation is about 21.4 inches.

The total average annual discharge from the six canyons is about 12,000 acre-feet. Some of the land irrigated by water from Middle and Settlement Canyons may be in the recharge area of the artesian aquifer system, and it is assumed that 25 percent of the discharge from the two canyons, or about 1,300 acre-feet, recharges the artesian aquifers. Thus, the total amount of streamflow that is diverted across the recharge area and consequently lost to the artesian aquifer system is on the order of 10,000 acre-feet.

Spring, drain, and well discharge

Springs, drains, and wells discharge water south of the reference line, both in the valley and in the mountains. Discharge from small springs in the mountains is not known and is not included in the total. The flow of Big Spring in the mouth of Middle Canyon is included in the estimate of streamflow from the canyon and is not included in this section.

In and near the mountains, ground water is discharged in Middle, Pine, and Settlement Canyons. Springs, drains, and wells in Middle Canyon, excluding Big Springs, discharged about 1,100 acre-feet in 1947 (Gates, 1963a, p. K35); and this quantity is assumed to be the average discharge from these sources. Several springs and tunnels and four wells in Pine Canyon reportedly supplied about 1,000 acre-feet to the International Smelting and Refining Co. in 1962, about half of which was from the springs and tunnels and half from the wells. Springs in Settlement Canyon supply about 1,000 acre-feet to the city of Tooele, according to J. O. Reeve, Tooele City Engineer (oral communication, Sept. 1963). The total discharged in Middle, Pine, and Settlement Canyons is 3,100 acre-feet.

In the valley proper, south of the reference line, water is withdrawn from wells. In 1962, flowing wells south of the line discharged about 1,400 acre-feet in the Erda district; and pumped wells south of the line discharged 610 acre-feet in the Mill Pond district, 2,600 acre-feet in the Erda district, 1,630 acre-feet in the Tooele district, 1,520 acre-feet in the Marshall district, and 1,940 acre-feet in the Grantsville district. Thus in 1962 the total amount of water discharged in the valley by wells south of the reference line was 9,700 acre-feet.

The total amount of ground-water discharge south of the reference line both in and just outside of the valley was 12,800 acre-feet. This has been rounded to 10,000 acre-feet for use in the hydrologic budget on p. 55.

Some artesian water may leak upward to the water-table zone south of the line of reference, but the amount lost in this way was not determined. The amount lost probably is not large, however, and it was not estimated.

Subsurface outflow

The subsurface outflow past the line of reference was calculated using transmissibilities obtained from aquifer tests (fig. 14 and table 3) and hydraulic gradients from the map of the piezometric surface in March-April 1962 (fig. 6). In some places, specific capacities of wells (p. 30) were used to help estimate transmissibility.

The line of reference shown in figure 14 includes five segments, which were drawn parallel to piezometric contours near sources of hydraulic data. The transmissibility and gradient along each segment were assumed to be uniform.

Segment 1 crosses the Mill Pond district from the Occidental(?) fault to a point where the unconsolidated deposits probably are thin. The hydraulic gradient is about 30 feet per mile, and the coefficient of transmissibility of 340,000 gallons per day per foot was obtained from the aquifer test made at well (C-2-4)28aac-1.

Segment 2 crosses the Erda district where the hydraulic gradient is about 50 feet per mile. The coefficient of transmissibility assumed along this segment, 160,000 gallons per day per foot, is the average of values obtained from aquifer tests made on wells (C-2-4)31-bdc-3 and 31cda-2.

Segment 3 crosses the eastern part of the Marshall district, where the unconsolidated deposits are mostly fine grained (p. 35 and fig. 5). The transmissibility and hydraulic gradient along this segment are not known, but the coefficient of transmissibility was estimated to be 20,000 gallons per day per foot and the gradient was assumed to be equal to that in the western edge of the Erda district, or about 40 feet per mile.

Segment 4 crosses the western part of the Marshall district, where the unconsolidated deposits are coarser than they are in the eastern part. The hydraulic gradient is about 10 feet per mile, and the average coefficient of transmissibility of 320,000 gallons per day per foot was obtained from aquifer tests at wells (C-2-5)33dcd-1 and (C-3-5)4bbb-2. The line of reference, however, is north of these two wells. The hydraulic gradient probably is a little steeper along the line than it is near the tested wells; and, therefore, the transmissibility probably is smaller along the line. Along this segment, therefore, the coefficient of transmissibility was estimated to be about 250,000 gallons per day per foot.

Segment 5 crosses the Grantsville district where the hydraulic gradient is about 10 feet per mile. The transmissibility is not adequately defined because the only two aquifer tests made in the Grantsville district were at wells (C-2-6)23cdc-2 and (C-3-6)1bdb-1, neither of which is on the reference line. The coefficient of transmissibility of 1,000,000 gallons per day per foot assumed along this segment is the average of the values from these two tests.

The subsurface outflow beneath each segment of the line of reference was calculated using the formula:

$$Q = 0.00112TIW$$

where Q is the outflow, in acre-feet per year; 0.00112 is a factor that converts gallons per day to acre-feet per year; T is the coefficient of transmissibility, in gallons per day per foot; I is the hydraulic gradient, in feet per mile; and W is the length of the segment, in miles.

The data for the five segments are presented in the following table:

Segment (location shown on fig. 14)	Estimated coefficient of transmissibility (gallons per day per foot)	Hydraulic gradient (feet per mile)	Length of segment (miles)	Subsurface outflow past the segment (acre-feet per year)
1	340,000	30	0.8	9,000
2	160,000	50	4.2	38,000
3	20,000	40	1.8	2,000
4	250,000	10	1.6	4,000
5	1,000,000	10	5.8	65,000
			Total	118,000

Although the total annual subsurface outflow past the line of reference was calculated to be 118,000 acre-feet, this figure is only approximate. The estimate does not include outflow from the Lake Point district or from the northwestern corner of the valley because no data on which to base calculations are available in these areas. Outflow from these areas probably is not large, and omitting it probably does not introduce significant error.

Other sources of error in the estimate of subsurface flow include the values of transmissibility assumed. Data from longer aquifer tests might produce smaller values, an assumed value may not be representative of the entire length of a segment of the reference line, and the transmissibilities may be too small because they apply only to part of the saturated thickness of valley fill. Considering all sources of error, it was felt that the estimate of the subsurface outflow was accurate to only one significant figure. Thus it was reduced to 100,000 acre-feet for use in the hydrologic budget on p. 55.

FUTURE DEVELOPMENT

The possible effects and potential of future development in each ground-water district are discussed qualitatively in the following paragraphs.

In the Lake Point district, additional pumping from wells would cause water levels to decline greatly because the valley fill in most of the district has low permeability. A decline of water levels, however, would reduce losses in the western part of the district by evapotranspiration and subsurface flow to Great Salt Lake. Wells drilled near the northern and western edges of the district probably will penetrate fine-grained deposits and will yield small amounts of water of poor quality. Wells drilled along the eastern and southern edges, close to the mountain front to the east and to the pediment to the south, might penetrate a higher proportion of coarse material that would yield larger quantities of water of better quality.

In the Mill Pond district, pumping additional water would result in declines of water levels. This, in turn, would reduce losses in the northern part of the district by evapotranspiration and subsurface flow to the Burmester district. The best place to develop more water is in the southern part of the district, where well yields are large and water quality is good. However, large declines of water levels in the southern part of the district might cause water of poor quality to migrate southward into areas of water of good quality. A large increase in pumpage also might reduce the discharge of Mill Pond and Dunne's Pond Springs.

In the Erda district, pumping more water also would result in declines of water levels. This would reduce losses in the northern part of the district by evapotranspiration and subsurface flow to the Burmester district. Fifteen large-yield wells were being pumped in the center of the district by 1963, and water levels there declined about 2 feet per year from 1958 to 1963. A further increase in pumping would lower water levels more and many wells would stop flowing. Wells could be drilled and pumped in the northern part of the district, but the permeability there probably is low and well yields would not be large. Yields of wells drilled in the southern part of the district probably would be similar to those in the center of the district near Erda, but pumping lifts would be greater.

The effects of present pumping in the Tooele district are not known. A large increase in pumpage, however, would probably cause water levels to decline significantly. The water level in some parts of the district is below the bedrock surface (p. 33-34 and fig. 5), and wells drilled in these parts probably will not be successful. If any part of the surface-water supply in the district is unused, it could be used to recharge the ground-water reservoir artificially.

The potential for development of ground water in much of the Marshall district is not known. Few data are available in the southern four-fifths of the district, but it is believed that the permeability in most of this area is low and well yields would not be large. At the northern end of the district, additional pumping would result in declines of water levels, which in turn would decrease losses by evapotranspiration and subsurface flow to the Burmester district. The potential for future development at the northern end differs, and water quality commonly is poor. In the northeastern part (fig. 5), the valley fill is fine grained, well yields are small, and large amounts of additional water probably cannot be developed. On the western side of the northern end, however, the valley fill is more permeable, well yields are larger, and more water probably could be developed. Water levels in the western side declined almost 1 foot per year from 1958 to 1963, and increasing pumpage would increase this rate of decline. A large decline of water levels in a wide area might decrease the discharge of the spring sources of Sixmile and Fishing Creeks, and it might cause the ground water of poor quality near these springs to move southwestward into water of better quality.

The Grantsville district has the best potential for future development in the valley. Surface water is used in the district, and the use of surface and ground water could be integrated. In years when surface water is plentiful, water users could fully utilize it and conserve ground water; and when surface water is scarce, ground water could be used. Surplus surface water sometimes is available in the winter or spring and could be used to recharge the ground-water reservoir artificially.

From 1958 to 1963 water levels near large-yield wells declined about 1 to 2 feet per year, and increasing pumpage would increase the rate of decline and might cause many wells to stop flowing. The decline of water levels, however, would reduce losses by evapotranspiration in the northern end of the district and reduce subsurface flow to the Burmester district. The potential for development in the southern part of the district is not known, but wells there should yield as much as those in the center of the district. Pumping lifts in the southern part would be greater than near Grantsville. At the northern end of the district few large-diameter wells have been drilled, but well yields would not be large because of the low permeability. Pumping in this area might cause water of poor quality to migrate southward into the district.

The Burmester district also has potential for future development, chiefly because much of the natural ground-water discharge is from this district. If additional wells were drilled and pumped, the resulting decline of water levels would lessen evapotranspiration and discharge to the lake and might drain some waterlogged areas. There are several disadvantages to developing additional water in the district. Lowering water levels would lessen the density of saltgrass, which is used for pasture; many wells in the district would stop flowing; and poor-quality water might encroach upon better-quality water.

Most wells in the district are of small diameter, and their yields are small. Wells drilled along the mountain front in the southwestern corner of the district, however, might penetrate coarser alluvium and might yield significant amounts of water. Wells in T. 1 S., Rs. 5 and 6 W., probably would yield only small quantities of water of poor quality.

In summary, a large amount of water in Tooele Valley is wasted annually by vegetation and by subsurface flow to Great Salt Lake, and part of this waster water could be salvaged by pumping from wells. However, pumping additional water would cause a decline of water levels in some areas, would cause some wells to stop flowing, and might cause water of poor quality to move into areas where water quality is better.

Future development of ground water, therefore, should be managed carefully so that harmful effects are minimized. Well spacing should be regulated so that water-level declines and possible encroachment of saline water would be minimized, the use of surface and ground water for irrigation should be planned on an integrated basis, and the use of excess surface water for artificial recharge should be considered.

More hydrologic data should be collected in Tooele Valley so that water management can be entirely based on facts. A minimum program now being conducted by the U.S. Geological Survey in cooperation with the State of Utah includes measuring water-level changes, measuring annual well and spring discharge, and periodically determining water quality in areas of possible migration of saline ground water. In the future, it will be necessary to prepare an accurate hydrologic budget for the entire valley. At that time, the following minimum program will be necessary: precipitation stations should be installed in the valley and in the Oquirrh and Stansbury Mountains; evapotranspiration studies should be made in both the valley and mountains; test holes should be drilled to determine ground-water conditions where data are not now available (including test holes north of the Stockton bar, to determine if underflow moves from Rush Valley to Tooele Valley); additional aquifer tests should be made; and discharge of all streams, springs, and wells should be measured accurately.

SUMMARY

From 1948 through 1963, precipitation and surface-water supplies in Tooele Valley have been less than normal. During this period, many large-diameter wells were constructed and pumped to supplement surface- and ground-water supplies, to irrigate additional land, and for municipal and industrial use. The amount of water produced by all wells in 1962 was more than triple the amount produced in 1938-40. In 1938-40, flowing wells yielded almost all the water; whereas in 1962, large-diameter pumped wells yielded about half the water produced by wells.

From 1950-52 to 1963, water levels declined in the valley. Water levels have declined most in the Erda and Grantsville districts, where most of the large-diameter irrigation wells are pumped; and they have declined least in the Burmester district, where few wells are pumped. Most of the decline was caused by pumping, but declines of the magnitude of those in the Burmester district probably have been caused by below-normal recharge.

Water-level declines probably have resulted in a reduction of losses of ground water by evapotranspiration in the area of phreatophytes in the northern end of the valley and by subsurface flow to Great Salt Lake. The declines have caused no harmful effects through 1963, other than increasing pumping lifts slightly, causing some wells to stop flowing, and perhaps decreasing spring discharge. Additional ground-water development would further reduce losses by evapotranspiration and flow to Great Salt Lake; but would further lower water levels, further decrease spring discharge, cause more wells to stop flowing, and might cause saline water to migrate into areas of water of good quality.

If water development were carefully planned and managed, harmful effects would be minimized. Wells could be located so that declines in water levels and spring discharge would be minimized and migration of water of poor quality could be avoided. In addition, surface and ground water could be developed on an integrated basis and ground-water reservoirs could be recharged artificially.

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

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

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

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

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

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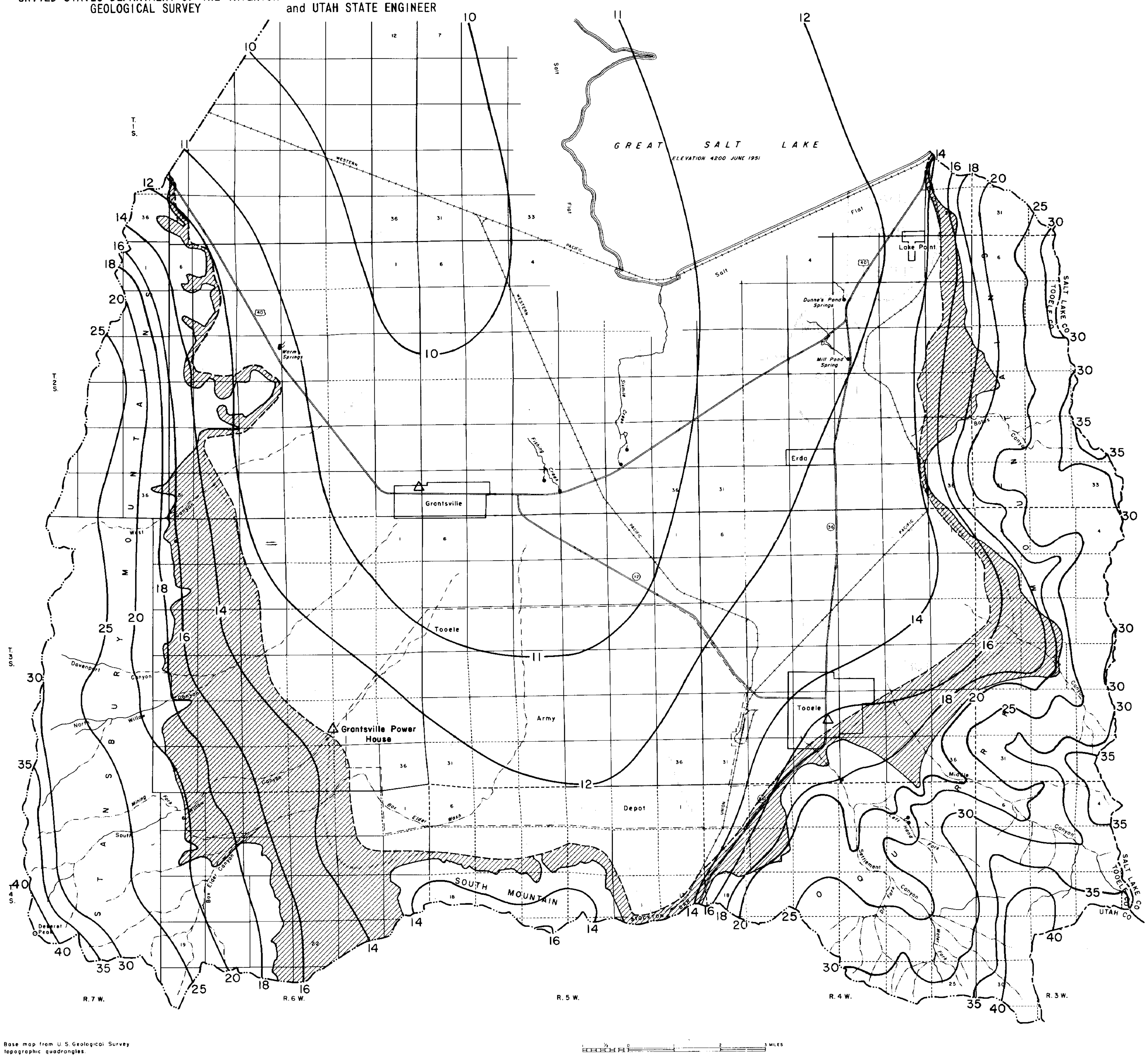
WATER CIRCULAR

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



EXPLANATION

——12——

Isohyetal average for 1931-60 period; contour intervals: 1, 2, and 5 inches

△

U.S. Weather Bureau substation

Approximate minimum recharge area of the artesian aquifers

Spring

Boundary of drainage basin, where not indicated by county boundaries

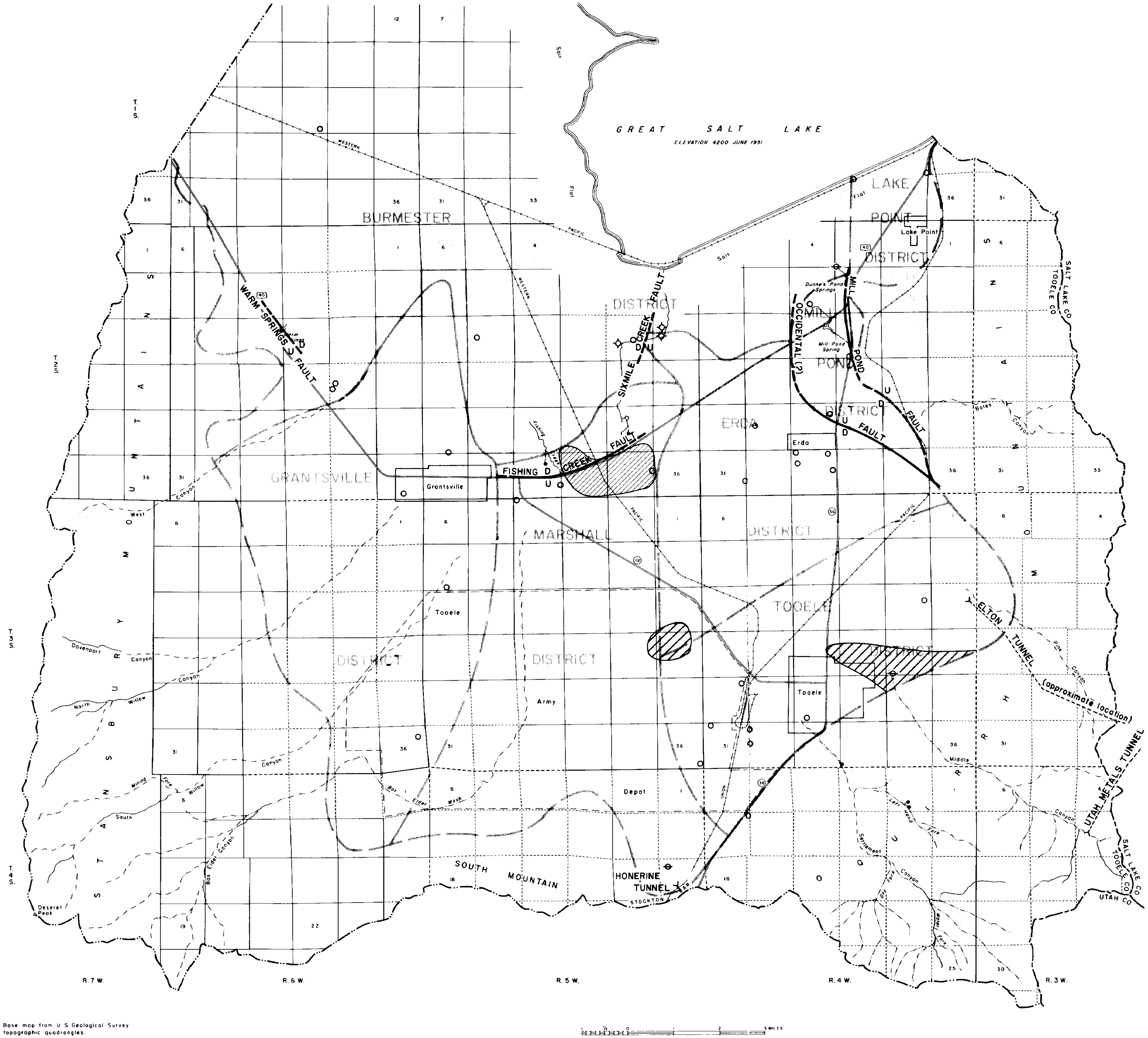
Boundary of ground-water district

Approximate boundary of military reservation

Recharge areas by J. S. Gates, 1963; contours of precipitation by E. L. Peck, U.S. Weather Bureau, 1963

Base map from U.S. Geological Survey topographic quadrangles.

Figure 2.—Map of Tooele Valley, Utah, showing normal annual precipitation, weather substations, and the approximate recharge area of the artesian aquifers.



EXPLANATION

Boundary of ground-water district as defined during this study, dashed where approximate

Boundary of ground-water district as defined by Thomas (1946)

Normal fault, dashed where inferred; U, upthrown side, D, downthrown side

Well mentioned in text

Abandoned well mentioned in text

Oil test

Spring

Tunnel

Area within a ground-water district in which the bedrock surface is known or inferred to be above the water table

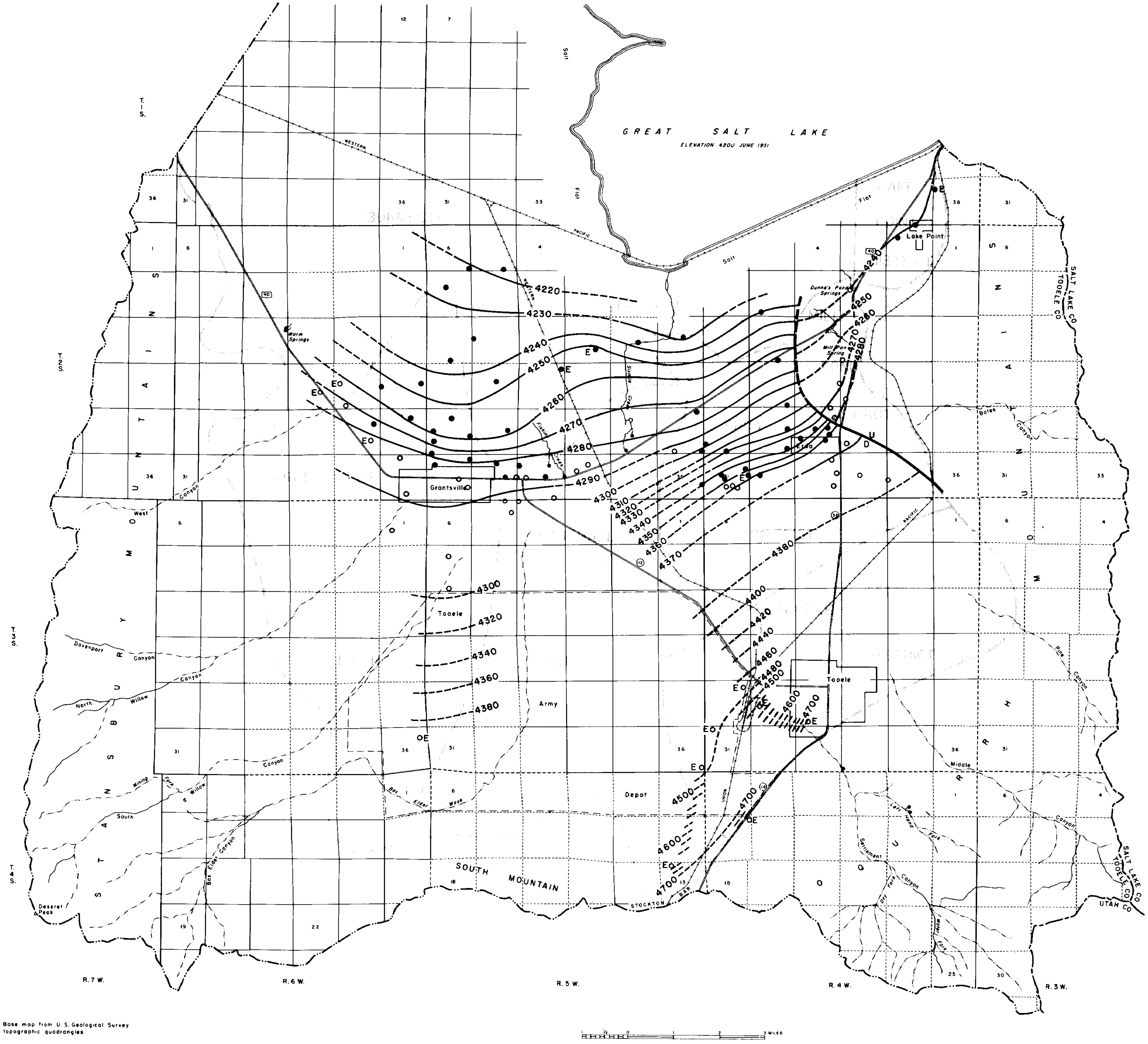
Area in the Marshall district in which the unconsolidated deposits are mostly fine grained

Boundary of drainage basin, where not indicated by county boundaries

Approximate boundary of military reservation

by J. S. Gates, 1964

Figure 5.—Map of Tooele Valley, Utah, showing ground-water districts, faults in the valley fill, and other hydrogeologic data.



EXPLANATION

Spring

Pumped well

Flowing well

Letter E indicates altitude of piezometric surface was estimated

4240

Piezometric contour, dashed where inferred; contour interval 10 feet (northern area), 20 feet (southern area); datum is mean sea level

U
D

Normal fault that is a barrier to ground-water movement, dashed where inferred; U, upthrown side, D, downthrown side

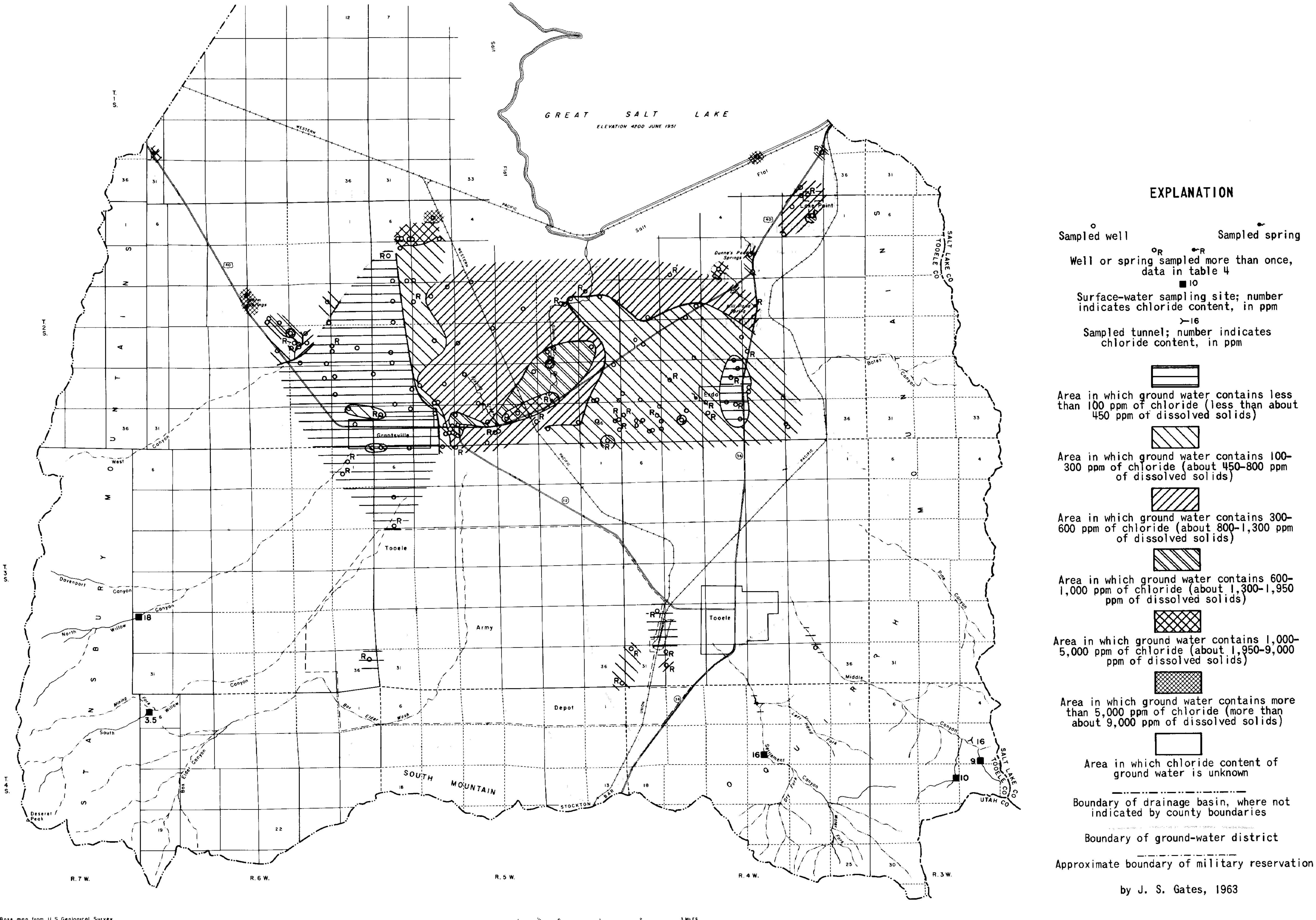
Boundary of drainage basin, where not indicated by county boundaries

Boundary of ground-water district

Approximate boundary of military reservation

by J. S. Gates, 1963

Figure 6.—Map of Tooele Valley, Utah, showing the piezometric surface of the principal aquifer in March-April 1962.



Base map from U.S. Geological Survey topographic quadrangles.

Figure 11.—Map of Tooele Valley, Utah, showing the chloride content of ground and surface water.