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HYDROLOGY OF THE BERYL-ENTERPRISE AREA, ESCALANTE DESERT, UTAH, WITH EMPHASIS ON GROUND WATER

by

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With a Section on Surface Water

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CONVERSIONS FACTORS

Most values in this report are given in inch-pound units followed by metric units. The conversion factors are shown to four significant figures. In the text, however, the metric equivalents are shown only to the number of significant figures consistent with the accuracy of the value in inch-pound units.

Inch-pound Unit (Multiply)	Inch-pound Abbreviation	(by)	Metric Unit (to obtain)	Metric Abbreviation
Acre	--	0.4047	Square hectometer	hm^2
		0.004047	Square hectometer	km^2
Acre-foot	acre-ft	0.001233	Cubic hectometer	hm^3
		1233	Cubic meter	m^3
Cubic foot per second	ft^3/s	0.02832	Cubic meter per second	m^3/s
Foot	ft	0.3048	Meter	m
Foot per mile	ft/mi	0.1894	Meter per kilometer	m/km
Gallon per minute	gal/min	0.06309	Liter per second	L/s
Inch	in.	25.40	Millimeter	mm
		2.540	Centimeter	cm
Mile	mi	1.609	Kilometer	km
Square foot	ft^2	0.0929	Square meter	m^2
Square mile	mi^2	2.590	Square kilometer	km^2
Micromho	µmho	1	Microsiemen	mS

Chemical concentration and water temperature are given only in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million.

Water temperature is given in degrees Celsius (^{o}C), which can be converted to degrees Fahrenheit (^{o}F) by the following equation: $^{o}F=1.8(^{o}C)+32$.

HYDROLOGY OF THE BERYL-ENTERPRISE AREA, ESCALANTE DESERT, UTAH, WITH EMPHASIS ON GROUND WATER

By R. W. Mower

ABSTRACT

The Beryl-Enterprise area consists of 1,920 square miles (4,970 square kilometers) in southwestern Utah, in the Basin and Range physiographic province. The project area consists of a valley bounded almost completely by mountains. The valley is underlain by unconsolidated to semiconsolidated sedimentary materials of Tertiary and Quaternary age. The mountains are composed of semiconsolidated to consolidated rocks of Cambrian through Tertiary age, except for local, thin, unconsolidated surficial deposits of Quaternary age.

Water use in the area is supplied by three small streams at the south end of the valley and by wells completed in the valley fill. The 1959-78 average annual reported diversions from the streams was 6,500 acre-feet [8.0 hm^3 (cubic hectometers)]. Withdrawals from wells for irrigation increased from 3,000 acre-feet (4 hm^3) during 1937 to 92,000 acre-feet (110 hm^3) during 1974, the maximum recorded; withdrawals were only 80,000 acre-feet (100 hm^3) during 1977.

The principal ground-water reservoir consists of saturated unconsolidated to semiconsolidated valley fill and ignimbrite in the general area about 2-12 miles (3-20 kilometers) north to northwest of Enterprise. The maximum estimated saturated thickness of the valley fill is 1,000 feet (300 meters) and of the ignimbrite 500 feet (150 meters).

Recharge to the principal ground-water reservoir during 1977 was estimated to be about 48,000 acre-feet (60 hm^3). The largest source of recharge was subsurface inflow from the mountains and infiltration from stream channels, 31,000 acre-feet (40 hm^3); the second largest was infiltration of irrigation water, 16,300 acre-feet (20 hm^3). Infiltration from precipitation on the valley floor contributed an estimated 500 acre-feet (0.6 hm^3), and subsurface inflow from outside the area was an estimated 320 acre-feet (0.4 hm^3).

Discharge from the principal ground-water reservoir during 1977 was estimated to be about 88,000 acre-feet (110 hm^3). Discharge was largely from wells, 81,000 acre-feet (100 hm^3), and by evapotranspiration by phreatophytes, 6,000 acre-feet (7 hm^3).

Prior to the construction of wells for irrigation, water in the principal ground-water reservoir moved from the main recharge areas near the mountains and hills bounding the valley to discharge areas of phreatophytes on the valley floor. Some water moved in the subsurface to the Milford area. By 1977, pumpage had so greatly exceeded recharge that a cone of depression had formed on the water table in the southern one-half of the area. All ground

water encompassed by the depression moves toward its lowest point, which is approximately midway between Beryl Junction and Enterprise. In the northern one-half of the area, water still moves in the subsurface toward the Milford area. The quantity of subsurface outflow is about 1,000 acre-feet (1 hm^3) annually.

The amount of water in storage in the principal ground-water reservoir during 1978 was about 72 million acre-feet (89,000 hm^3). A decline of 1 foot (0.3 meter) from the ground-water levels during the spring of 1978 would have released about 100,000 acre-feet (120 hm^3) of water from storage. This quantity per unit decline is not a constant value, however, and it decreases with depth. At 100 feet (30 meters) below the levels during the spring of 1978, the quantity of water released by a 1-foot (0.3-meter) decline would have been about 80,000 acre-feet (100 hm^3).

The temperature of ground water from irrigation wells ranges from 11° Celsius (52° Fahrenheit) near Enterprise to 97° Celsius (207° Fahrenheit) near Newcastle.

The concentration of dissolved minerals in ground water in most of the Beryl-Enterprise area is less than 1,000 milligrams per liter. The dissolved-solids concentrations decrease with depth. The dissolved-solids concentration in water in many parts of the area is increasing with time, however, apparently as a result of recycling of irrigation water.

Two simulations were made by a digital-computer model of the principal ground-water reservoir for 1978-92. Assuming that all conditions of recharge and discharge existing during 1969-77 would continue unchanged, the first simulation indicated that water levels will continue to decline to 1992, but at a slightly slower rate than they did during 1969-77. The second simulation shows that dewatering an ore body during 1978-92 would cause a relatively small increase of water-level decline near the mine and a relatively small decrease of water-level decline in the water-disposal areas.

INTRODUCTION

An investigation of the water resources of the Beryl-Enterprise area, Escalante Desert, Utah (pl. 1), was made during 1976-78 as part of a cooperative program with the Utah Department of Natural Resources, Division of Water Rights. Wells were the most important source of water for all purposes in the Beryl-Enterprise area during 1978, but it has not always been so. For nearly a century after the first settlers arrived in about 1860, streams supplied most of the irrigation water and springs supplied much of the water for domestic and stock use. A few shallow wells were dug by the early settlers for domestic and stock water, but the widespread use of ground water did not start until the 1920's when shallow wells were first dug to supply irrigation water. Ground-water withdrawals from wells, principally for irrigation, have increased nearly every year since the 1920's. The quantity withdrawn from wells surpassed that diverted from surface sources during the mid-1940's and was about eight times that amount during the 1970's. As a result, water levels have declined measurably throughout the area resulting in administrative water-rights problems.

The primary purpose of this report is to describe the water resources with emphasis on ground water. The surface-water resources are evaluated only as they pertain to the understanding of the ground-water resources. A secondary purpose is to discuss the extent and effects of the development of ground water in order to provide the hydrologic information needed for the orderly and optimum development of the resource and for the effective administration and adjudication of water rights in the area. The hydrologic data on which this report is based are given in a companion report by Mower (1981).

Well- and spring-numbering system

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well or spring, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake Base Line and Meridian, and these quadrants are designated by uppercase letters as follows: A, northeast; B, northwest; C, southwest; and D, southeast. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section, and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section,--generally 10 acres (4 hm^2);[1] the quarters of each subdivision are designated by lowercase letters as follows: a, northeast; b, northwest; c, southwest; and d, southeast. The number after the letters is the serial number of the well or spring within the 10-acre (4-hm^2) tract; the letter "S" preceding the serial number denotes a spring. Thus (C-36-16)36add-1 designated the first well constructed or visited in the SE¼SE¼NE¼ sec. 36, T. 36 S., R. 16 W. If a well or spring cannot be located within a 10-acre (4-hm^2) tract, one or two location letters are used and the serial number is omitted. Other sites where hydrologic data were collected are numbered in the same manner, but three letters are used after the section number and no serial number is used. The numbering system is illustrated in figure 1.

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[1]Although the basic land unit, the section, is theoretically 1 mi^2 (2.6 km^2), many sections are irregular. Most of such sections are subdivided into 10-acre (4-hm^2) tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

The northern row of sections (1 through 6), in T. 36 S., Rs. 16-20 W., is about 2 mi (3.2 km) long north to south. Wells in the northern one-half of each section are numbered using lot numbers rather than the quarter-quarter-quarter section. Thus (C-36-16)6L13-1 designates the first well constructed or visited in lot 13, sec. 6, T. 36 S., R. 16 W. Wells in the southern one-half of the section are designated in the usual manner.

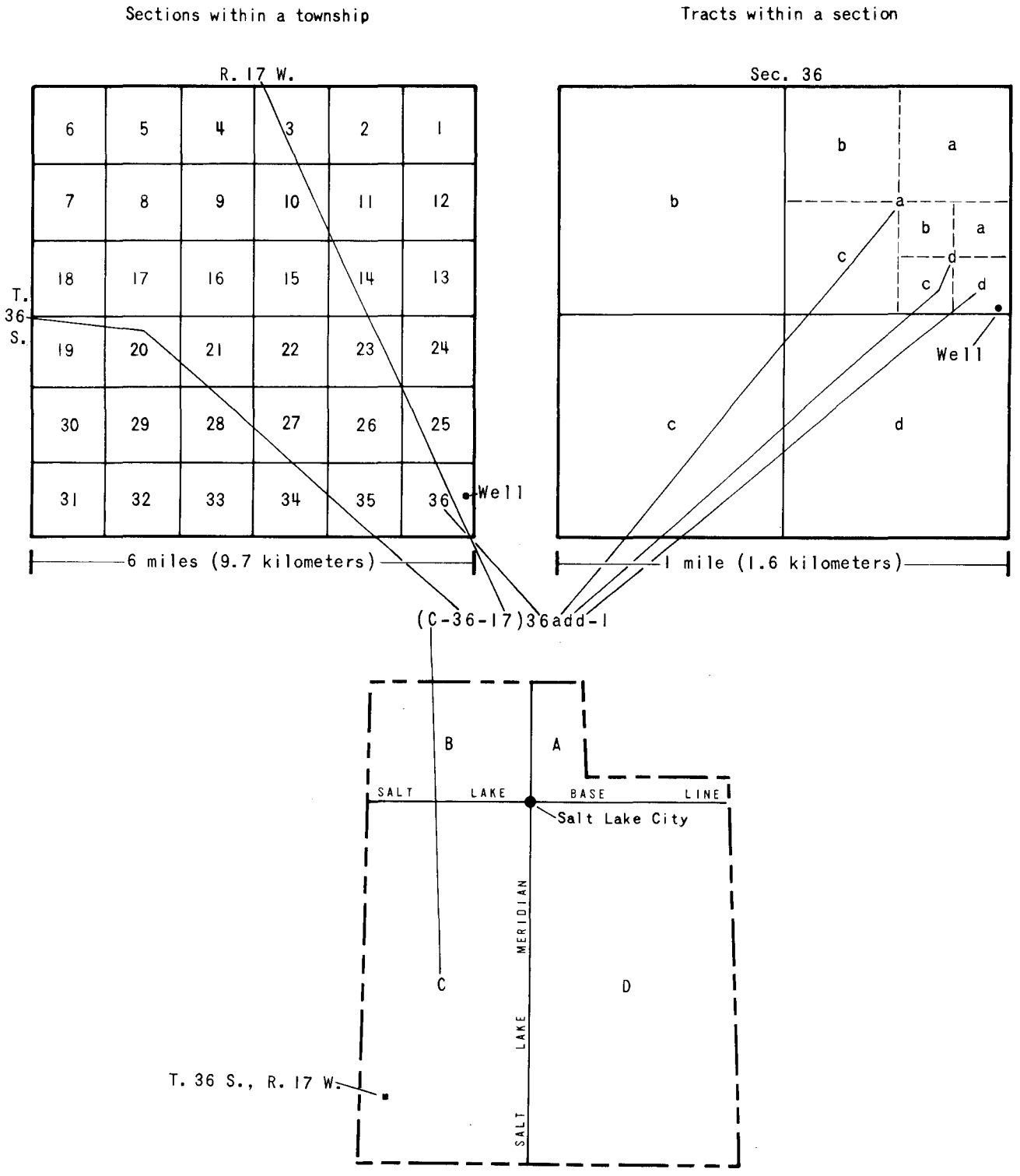

Figure 1.— Well-, spring-, and other data site-numbering system used in Utah.

Physiography and drainage

The Beryl-Enterprise area is in the Great Basin section of the Basin and Range physiographic province (Fenneman, 1931). The central part of the area is a desert valley, whose floor is mostly between altitudes of 5,075 and 5,500 ft (1,547 and 1,676 m) above the National Geodetic Vertical Datum of 1929.[1] The valley is bounded by mountains and hills which are mostly at altitudes below 8,000 ft (2,440 m). However, Rencher Peak, in the Pine Valley Mountains along the southern margin of the area, has an altitude of 8,788 ft (2,679 m) and an unnamed peak in the Indian Peak Range along the northwestern margin of the area has an altitude of slightly more than 9,040 ft (2,755 m).

The study area consists of 1,920 mi^2 (4,970 km^2) in southwestern Utah--1,600 mi^2 (4,140 km^2) in Iron County, 250 mi^2 (650 km^2) in Washington County, and 70 mi^2 (180 km^2) in Beaver County (pl. 1). The area encompasses what previous investigators have called the Beryl-Enterprise and Lund districts (Sandberg, 1966). An additional 105 mi^2 (270 km^2) in eastern Nevada also drains to the Beryl-Enterprise area, but it was not included in this study.

The area studied is bounded by drainage divides, except (1) at the west, at the Nevada-Utah State line and (2) at the northeast, about 4 mi (6 km) south of the Beaver-Iron County line (pl. 1). This northeastern boundary was selected at the narrowest point between outcrops of bedrock in mountains on the east and west sides of the valley. The boundary follows the crest of a large alluvial fan, which extends eastward from the Wah Wah Mountains nearly to the westernmost outcrop in the Black Mountains (pl. 1).

Three perennial streams, Little Pine (a tributary of Shoal Creek), Mountain Meadow, and Pinto Creeks, drain the mountains along the southern boundary and supply irrigation water to the valley. The area contains many ephemeral streams, and after heavy rainstorms, floodflows in several of these streams may exceed 1,000 ft^3/s (30 m^3/s). Such floods sometimes carry boulders weighing several hundred pounds and mature juniper a few miles onto the valley floor.

Mud Spring Canyon and Iron Springs Canyon (pl. 3) are two gaps in the mountains along the east side of the study area where surface flow enters the study area from Cedar City Valley, which is east of the study area. No surface water currently flows through these gaps, except for floods that result from intense local rainstorms or from local snowmelt. No information is available concerning the quantities of water that flowed through these gaps before diversion for irrigation depleted the streamflow in Cedar City Valley. The poorly developed channels and the lack of trees near the gaps indicate that there may never have been much flow through the gaps. Perhaps the only flow then, as now, was occasional floodwater from spring snowmelt and intense rainstorms.

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[1] A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean sea level."

The central lowland part of the area is about 45 mi (72 km) long and about 40 mi (64 km) wide, and it is underlain mainly by unconsolidated deposits of Quaternary age eroded by streams from the surrounding mountains. The average northeastward gradient of the land surface is 5 ft/mi (2 m/km). The generally smooth surface is broken by ephemeral stream channels as much as 10 ft (3 m) deep eroded by cloudburst floods, by sand dunes as much as 25 ft (8 m) high, and by depressions as much as 17 ft (5 m) deep caused by wind erosion.

The Beryl-Enterprise area is part of the Beaver River drainage basin, but there is no trace of a surface channel in the lowest part of the area, northeast of Lund. Thus, the Beryl-Enterprise area probably has had no surface outflow for centuries. Excess surface water flows into shallow closed depressions in the valley floor where the water evaporates. The largest of these depressions is north of Lund. The depression is a maximum of about 17 ft (5 m) deep and encompasses 11,300 acres (4,570 hm^2). Only floodflows from ephemeral streams have reached any of the depressions since reservoirs were constructed on the major perennial streams. About every 20 years, the reservoirs cannot store all the runoff and the excess flows down the stream channel where most of it infiltrates the valley fill.

Hydrogeology

The Beryl-Enterprise area is underlain by consolidated rocks ranging in age from Cambrian to Tertiary and by unconsolidated and semiconsolidated rocks of Quaternary age (pl. 1). Unconsolidated to partly consolidated rocks, consisting of stream, lake, and wind deposits constitute most of the valley fill. The lithologic units in the valley and mountains are combined in three hydrologic units in table 1 and plate 1. Unit 1 and part of unit 2 compose the principal ground-water reservoir.

The percentage of sand and gravel in the valley fill is an indication of the water-yielding potential. The percentage of sand and gravel in the upper 200 ft (61 m) of the unconsolidated deposits (unit 1 and in table 1) was determined from drillers' logs, and the areal distribution of the percentages are shown on plate 2. Most of the principal ground-water reservoir contains less than 25 percent of sand and gravel. The reservoir contains more than 50 percent of sand and gravel in five relatively small areas: (a) along an ephemeral stream channel east of Modena; (b) north of Enterprise, along Shoal Creek (three areas); and (c) near Newcastle, along Pinto Creek.

Table 1.--Hydrogeologic units and their qualitative hydrologic properties

Hydrologic units			Qualitative hydrologic properties
Unit	Geologic age	Lithology	
1	Quaternary	Unconsolidated to semi-consolidated gravel, sand, silt, and clay.	Forms most of the principal ground-water reservoir. Coarse-grained deposits, which crop out mainly around the perimeter of the area, probably accept large quantities of recharge from ephemeral flow resulting from storms. The sand and gravel, which generally are within 500 feet (152 meters) of the surface, readily yield water to wells. Clay and silt deposits restrict vertical movement, but they are not so extensive or impermeable as to prevent vertical movement between the coarser deposits. Thickness ranges from zero near the edge of the valley to probably more than 1,000 feet (305 meters) in the central part of the valley. The semiconsolidated deposits generally form the lowermost part of the principal ground-water reservoir. The semiconsolidated deposits are similar in most respects to the overlying unconsolidated deposits, and usually it is difficult to distinguish between them.
2	Tertiary	Andesitic-latitic ignimbrite	Between Modena and Enterprise considered as an undeveloped part of the principal ground-water reservoir. Probably accepts a moderate rate of recharge where fracture zones underlie saturated unconsolidated deposits or are crossed by ephemeral streams. Would yield water to wells at varying rates depending upon the number and interconnection of the fractures intersected.
3	Quaternary to Cambrian	Limestone, siltstone, shale, sandstone, basalt, intrusive igneous rocks, unconsolidated to semi-consolidated sedimentary deposits.	Bounds the principal ground-water reservoir. The Quaternary unconsolidated materials are thin surficial deposits; in places the older rocks contain well developed and interconnected open joints. Probably accepts moderate to large quantities of recharge and contributes large quantities of water to the principal ground-water reservoir at the southern margin of the valley and small to moderate quantities at the other margins. Would yield water to wells at varying rates, depending upon the number and interconnection of the fractures intersected.

Vegetation

Vegetation in the Beryl-Enterprise area may be grouped into five classes according to the source of water used:

1. Vegetation on the mountains and hillsides that depends entirely on local precipitation

2. Vegetation along stream channels in the mountains that depends on perennial streamflow or water in underlying saturated materials

3. Vegetation on the valley floor that depends entirely on local precipitation

4. Vegetation, usually on the lower-lying parts of the valley floor, that depends on water in underlying saturated fill--the water table is usually within 11 ft (3.4 m) of the land surface

5. Cultivated crops that are irrigated.

Only the vegetation in classes 4 and 5 have a major direct effect on the water supply of the area, and this will be discussed below in the section on evapotranspiration.

Climate

The climate of the Beryl-Enterprise area is characterized by mild summers and cool winters. Daytime temperatures rarely exceed 38°C (100°F). Winter temperatures at night usually are less than 0°C (32°F) but seldom are less than -25°C (-13°F). The mean annual temperature at Modena, the only climatological station in the area with a long record, is 9.4°C (48.9°F). The average length of the growing season is about 120 days, from mid-May to mid-September.

The normal annual precipitation (1931-60) is less than 12 in. (305 mm) in most of the irrigated parts of the areas and ranges from about 8 to about 30 in. (203 to 762 mm) in the mountains (pl. 3) (U.S. Weather Bureau, 1963). The cumulative departure from average annual precipitation for 1935-78 is shown in figure 2. The departure curve trends downward during periods of less than normal precipitation and upward during periods of greater than normal precipitation. Annual precipitation at Modena during 1935-78 ranged from a low of 4.17 in. (106 mm) during 1950 to a high of 16.28 in. (414 mm) during 1941. The annual average for the period was 9.75 in. (248 mm), which is slightly greater than the 1931-60 normal annual of 9.53 in. (242 mm).

The monthly variation of precipitation at Modena for 1931-78 is shown in figure 3. About 55 percent of the precipitation falls during May-October and 45 percent during November-April. The range in average mean precipitation is from 0.46 in. (12 mm) during June to 1.28 in. (33 mm) during August. In contrast, the range between minimum and maximum precipitation for all months is more than 2 in. (51 mm) and more than 6 in. (152 mm) for August.

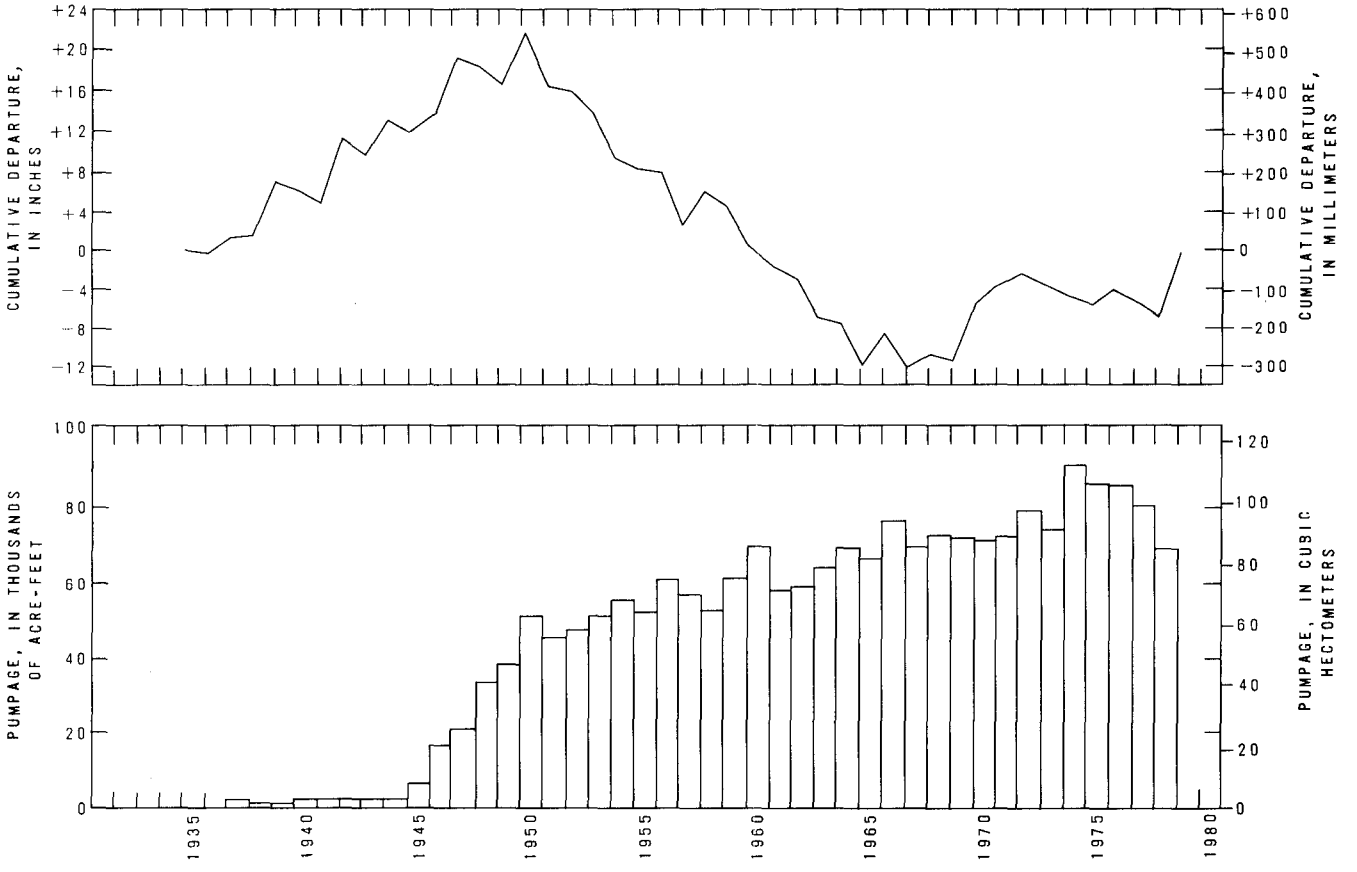

Figure 2.— Annual pumpage for irrigation and cumulative departure from the average annual precipitation at Modena, 1935-78.

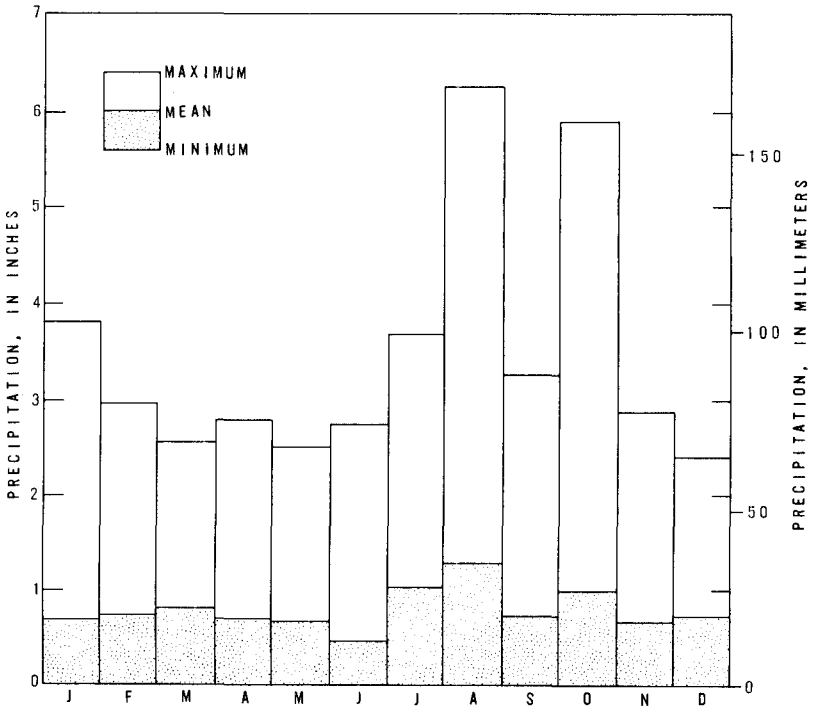

Figure 3.—Monthly variations of precipitation at Modena, 1935-78. The bars show maximum, mean, and minimum values for each month. The minimum for all months is trace or zero.

Average yearly pan evaporation during April-October 1953-78 at Milford, about 65 mi (105 km) northeast of Modena, was 78 in. (1,981 mm). Evaporation in the Beryl-Enterprise area should be about the same as at Milford because both areas are similar in physiography, altitude, and wind conditions. Water-surface evaporation was computed to be 63.87 in. (1,622 mm) at Milford and about 65.89 in. (1,674 mm) at Beryl by the U.S. Department of Agriculture (1973a, table 9, p. 27).

Previous investigations

Gilbert (1890) studied the geology of the northern part of the Beryl-Enterprise area as part of his classic study of ancient Lake Bonneville. More recent workers have concentrated largely on the geology of the mountains in the area.

The earliest ground-water investigation by the U.S. Geological Survey began in 1923 (White, 1932). The study focused mainly on the discharge of ground water by native vegetation in the Milford area, but the extent of water-consuming vegetation and estimates of water usage and water levels in selected wells were reported for the Beryl-Enterprise area.

During 1936-38, Clyde (1941) made a study to determine the extent and success of agricultural development using ground water near Beryl and to determine the cost of water to the farmer. His report contains some information about irrigated acreages, quantities of pumpage, and number of pumping plants.

The U.S. Geological Survey has measured water levels in selected wells in the area annually since 1935. Many of the water-level measurements were reported in the Survey's annual series of Water-Supply Papers for the years 1935-55 and in the 5-year series for the years 1956-75.

Chemical-quality and pumpage data have been gathered intermittently in the area by the Geological Survey since 1923. The chemical-quality data through September 1955 were reported by Connor, Mitchell, and others (1958).

B. E. Lofgren prepared three progress reports that described ground-water conditions in the Beryl-Enterprise area through 1953 and that were included in reports by Fix and others (1950, p. 146-180), Thomas and others (1952, p. 40-48), and Waite and others (1954, p. 48-74).

Sandberg (1966) reported on ground-water conditions in the area through 1962. Much of the hydrologic data available at the time, including well data, well logs, water-level measurements, and water analyses, were compiled in a separate report (Sandberg, 1963).

The U.S. Department of Agriculture (1973b, p. 9) made a study "***to inventory the water and related land resources, to define resource-related problems, to evaluate needs, and to determine opportunities for resource development." The report "***consisted mostly of an accumulation and evaluation of previously recorded data, both published and unpublished***." It included much useful hydrologic information.

Since 1963, the Geological Survey has issued an annual report that includes a brief discussion of current ground-water conditions in the Beryl-Enterprise area. The latest report in the series is by Price and others (1979).

Acknowledgments

The writer wishes to express appreciation to all who aided in this study. Well drillers and pump companies supplied logs and information related to the drilling and testing of wells. Personnel from the Utah Division of Water Rights, especially Gerald Stoker, provided much information about wells and pumpage, assisted on aquifer tests and with the compilation of historical pumpage, and made many valuable suggestions. Many well owners granted permission for the measurement of water levels in their wells and supplied useful information; special appreciation is due those who allowed their wells to be pumped or used for observing water-level fluctuations during pumping tests.

PRECIPITATION

The average annual precipitation on the Beryl-Enterprise area is about 1,200,000 acre-ft (1,500 hm^3). About 800,000 acre-ft (990 hm^3) falls on the mountain and foothill areas--approximately the area above the 10-in. (254-mm) annual precipitation line on plate 3. The other 400,000 acre-ft (490 hm^3) falls on the valley floor--approximately the area below the 10-in. (254-mm) annual precipitation line. The volume of precipitation, which was computed from a map of Utah, scale 1:500,000, showing normal annual precipitation for 1931-60 (U.S. Weather Bureau, 1963) is only approximate, but it indicates the correct order of magnitude.

Much of the precipitation that eventually supplies water that becomes available for appropriation or managed use falls as snow in the mountains along the southern margin of the area during November-March. Runoff from the snowmelt is during March-June. Most of this runoff is collected in three small reservoirs--Upper Enterprise, Lower Enterprise, and Newcastle Reservoirs--before being diverted for irrigation. Little of the precipitation on the mountains along the other margins of the area, on the foothills, or on the lowlands becomes available for managed use. However, precipitation does supply some water to irrigated fields and provides some recharge to the ground-water reservoir as described in following sections of this report. All the precipitation not available for managed use evaporates or replenishes the soil moisture used by native vegetation--none leaves the study area in surface streams.

SURFACE WATER

by G. W. Sandberg

Surface water in the Beryl-Enterprise area results from runoff from precipitation within the drainage basin and from one transmountain diversion. Most of the runoff is in direct response to rainfall or from snowmelt, although some mountain streams have a small base flow originating from spring discharge.

When precipitation is not intense, there is little runoff except when rain falls on a snow cover, causing snowmelt. Conversely, intense rains may cause flooding, which contributes large quantities of water to reservoir storage, especially when the rain falls on a thick snowpack, resulting in rapid melting. Estimates of runoff (White, 1932, p. 15) at the headwaters of Shoal Creek indicate that from 0 to 3 percent of the precipitation runs off during the summer and fall and 15 to 25 percent during the spring. The percentages of runoff in other mountain areas probably are about the same. The only long-term streamflow measurements in the area are for a gage on a transmountain diversion from the Santa Clara River to Pinto Creek.

Perennial streams

The only perennial streams in the area are Little Pine (a tributary of Shoal Creek), Mountain Meadow, and Pinto Creeks. Partial records of diversions from and to these streams for 1959-78 (table 2) are available from irrigation companies. Streamflow records are not available during the nonirrigation season, for floodflows not diverted, nor for irrigation diversions that are made at times when the diversions are not charged against irrigators' accounts, such as during periods when streamflow exceeds

Table 2.--Diversions from and to perennial streams, 1959-78, in acre-feet

[From unpublished Water Commissioners' reports to the Utah State Engineer, except for the transmountain diversion, which is from U.S. Geological Survey published records]

Little Pine Creek: Based on releases from Upper and Lower Enterprise Reservoirs.
Pinto Creek: Based on releases from Newcastle Reservoir.

Calendar year	Little Pine Creek	Trans-mountain diversion to Pinto Creek	Pinto Creek (includes transmountain diversion)	Mountain Meadow Creek	Total reported diversions (rounded)
1959	4,095	40	612	584	5,300
1960	2,444	1,130	1,004	507	4,000
1961	620	2,490	2,790	485	3,900
1962	3,980	--	4,020	--	[1]8,000
1963	2,870	--	1,060	376	4,300
1964	1,040	--	2,280	365	3,700
1965	3,650	--	3,050	485	7,200
1966	3,750	--	3,200	405	7,400
1967	3,950	--	4,400	400	8,800
1968	3,750	--	2,400	460	6,600
1969	6,550	--	6,300	590	13,400
1970	3,800	298	1,300	480	5,600
1971	4,010	1,460	2,020	465	6,500
1972	4,180	2,180	1,510	441	6,100
1973	4,660	6,360	4,910	480	10,000
1974	3,586	581	2,833	480	3,300
1975	2,832	3,070	3,416	421	6,700
1976	3,772	1,400	1,708	460	5,900
1977	483	319	479	401	1,400
1978	3,210	8,560	2,772	486	6,500
Average (rounded)	3,400	--	2,600	460	6,500

[1]Plus an unknown quantity from Mountain Meadow Creek.

diversions. The diversion records may account for more than 90 percent of the streamflow for most years; except for Mountain Meadow Creek where the diversions are mainly base flows, thus the recorded diversions reflect only about one-half of the annual flow. During extremely wet years, however, such as 1978, recorded diversions represented a smaller part of the total streamflow. Runoff during the spring of 1978, which was the greatest in the memory of local residents,[1] resulted from warm spring rains on a thick snowpack. A record of runoff during February-May 1978, as determined in or near the canyon mouths of five streams, is presented in table 3.

Table 3.--Runoff from selected streams during February-May 1978, in acre-feet

Stream: Measuring sites are shown on plate 3.

Stream	February	March	April	May	Total runoff (rounded)
Mountain Meadow Creek[1]	30	800	600	-	1,400
Pinto Creek, site P-1[1]	0	0	500	1,200	1,700
Pinto Creek, site P-2	0	0	300	900	1,200
Pinto Creek, site P-3	0	0	50	200	250
Spring Creek[1]	30	1,700	1,000	10	2,700
Shoal Creek[1,2]	100	10,000	6,000	600	17,000
Cottonwood Creek	10	100	100	1	200
					23,000

[1]Additional unknown quantities were diverted for irrigation during March, April, and May.

[2]Figures for Shoal Creek include those listed for Spring Creek.

The Upper and Lower Enterprise Reservoirs on Little Pine Creek store water for irrigation in the valley below. The upper reservoir was completed during 1909 with a capacity of about 10,000 acre-ft (12 hm^3); and the lower reservoir was completed in its present state about 1950 with a capacity of about 2,400 acre-ft (3.0 hm^3). The dam at the lower reservoir was at varying lower heights prior to 1950.

[1]Runoff during the spring of 1980 is reported to have exceeded that of 1978.

Some of the runoff that enters Little Pine Creek downstream from the reservoirs and runoff in Shoal Creek can be diverted for irrigation. Most of the runoff in Shoal Creek is not diverted, however, because it is mostly unpredictable flow of short duration. Most of the water in Shoal Creek usually infiltrates the channel a few miles upstream or downstream from Enterprise. When the flow exceeds about 200 ft^3/s (6 m^3/s) at Enterprise for periods longer than about 1 day, however, some water is impounded in small flood-retention ponds about 4 mi (6 km) north of Enterprise. When the flow greatly exceeds this quantity for more than a few days, the ponds overflow and the water inundates nearby farms. The approximate area that was flooded during the spring of 1978, when flow exceeded and sometimes greatly exceeded 200 ft^3/s (6 m^3/s) for several days, is shown on plate 3.

Most of the diversions from Little Pine Creek are direct releases from the Lower Enterprise Reservoir into a canal about 1.5 mi (2.4 km) downstream from the reservoir. The canal is about 11 mi (17.7 km) long, with about 6.5 mi (10.5 km) of the lower part being concrete lined. Two seepage runs, which were made on August 16, 1976, and May 11, 1977, indicate that there are no significant overall gains or losses in the unlined part of the canal. The locations of the measuring sites used for the seepage runs are shown on plate 3.

The base flow of Mountain Meadow Creek is diverted into a ditch and pipeline system about 2 mi (3.2 km) upstream from the mouth of the canyon. The water flows to a small pond near the mouth of the canyon where it is released into ditches for irrigation. Estimates of diversions are listed in table 2.

Five seepage runs were made on Mountain Meadow Creek and the diversion ditch during 1976 and 1977. Data from these runs are tabulated below:

Measuring site	Discharge: Cubic feet per second					Acre-feet		Distance between sites (miles)
	Sept. 20, 1976	Feb. 10, 1977	Apr. 13, 1977	June 24, 1977	Sept. 8, 1977	Estimated 1977	Gain (+) or loss (-)	
M-1	1.19	1.20	1.03	0.91	0.85	720		
							+320	1.3
M-2	1.56	2.00	1.38	1.30	1.09	1,040		
							-190	.7
M-3	1.33	1.16	1.01	1.39	1.18	850		
							-10	1.0
M-4	1.24	1.28	.97	1.18	1.23	840		

Discharge increased between sites M-1 and M-2 during all seepage runs and decreased between sites M-2 to M-4 during four of the runs. The locations of the gaging sites are shown on plate 3.

Pinto Creek is regulated by Newcastle Reservoir, which was completed during 1956 with a capacity of 3,200 acre-ft (3.9 hm^3) and was enlarged during 1975 to a capacity of 5,200 acre-ft (6.4 hm^3). Water from the reservoir is released into a concrete-lined canal and then to various ditches for irrigation near Newcastle. The measured quantity of water released for irrigation during 1959-78 is given in table 2.

An unknown quantity of the flow in Pinto Creek is diverted into six ditches for irrigation of small farms and meadows upstream from the reservoir. Some of this water returns to the creek as seepage from the irrigated areas upstream from the reservoir and, thus, becomes available for reuse downstream.

Almost all the flow in Pinto Creek is stored in Newcastle Reservoir. When it fills, however, such as during 1969, 1973, and 1978, the excess water spills into Pinto Creek. About 1,700 acre-ft (2.1 hm^3) spilled during the spring of 1978 (table 3); no other records of spill for other years are available.

The water that spills into Pinto Creek flows in a northerly direction for several miles along the east side of the valley, where most of it infiltrates into the ground. The remainder flows into an area of brushland and fields in the north-central part of T. 35 S., R. 15 W. During 1978, temporary gages were installed to measure seepage at three sites along Pinto Creek (pl. 3). The quantity of water that flowed past each gage is given in table 3. Approximately 29 percent of the water passing site P-1 infiltrated between sites P-1 and P-2 and about 56 percent infiltrated between sites P-3 and P-3. The remaining water flowed past site P-3 for a distance of 1.5 mi (2.4 km) where it overflowed brushlands and fields in which it eventually evaporated or infiltrated into the soil.

Intermittent streams

Intermittent streams enter the valley from the east, south, and west sides. The base flow in these streams is mainly from springs that yield less than 0.5 ft^3/s (0.01 m^3/s) of water, most of which usually infiltrates the ground a short distance downstream from the springs. Most of the flow in the intermittent streams is from rainstorms or snowmelt, and this water may flow for several miles out onto the valley floor before infiltrating the ground or evaporating.

The two largest intermittent streams, Spring and Shoal Creeks, are near Enterprise. Springs supply water to short reaches of both streams, but much of the springflow is diverted for public supply or irrigation. Prior to such diversion, both streams probably were perennial upstream from Enterprise. Flows during 1946-78 that reached as far downstream as Enterprise occurred only during 1946, 1952, 1966, 1969, 1973, and 1978, according to local residents. All flows resulted from rapid snowmelt and flash floods from rainstorms and all occurred during the spring of the year except for one during October 1946 and one during December 1966, when intense rains caused flash floods. The approximate quantity of water in the two creeks near Enterprise during the spring of 1978 is given in table 3.

Much of the water in Shoal Creek infiltrates the channel near Enterprise. Shoal Creek was flowing 103 ft^3/s (2.9 m^3/s) on March 27, 1978, in the north part of Enterprise in the SW¼ sec. 11, T. 37 S., R. 17 W.; but the flow was only 32 ft^3/s (0.9 m^3/s) about 2.4 mi (3.9 km) downstream at the north edge of sec. 1, T. 37 S., R. 17 W. The peak rate of flow in Shoal Creek in the north part of Enterprise during the spring of 1978 was about 1,700 ft^3/s (50 m^3/s) on March 5.

Ephemeral streams

Ephemeral streams enter the valley from drainages ranging in size from a small fraction of a square mile to nearly 100 mi^2 (260 km^2). Flow is from rainstorms and snowmelt and is usually of short duration. In any particular stream, flow may occur several times a year or it may not occur for several years. The distance water flows before it infiltrates the ground or evaporates depends on the intensity and duration of the rainstorm or snowmelt period, the type of material in the streambed, and the gradient. Most flows are small and of short duration, thus they dissipate near the valley edge where the sediments are coarse. Flows in larger streams reach several miles onto the valley floor before disappearing.

Volume of inflow

The average annual inflow from streams to the Beryl-Enterprise area was estimated by a channel-geometry method described by Fields (1975). Measurements were made in all large drainage basins and in selected small drainage basins. The results of the small-basin measurements were then extrapolated to the remainder of the study area. The location of measuring points and estimated average annual flow are shown on plate 3. The estimated total average annual inflow to the area is about 30,000 acre-ft (40 hm^3).

GROUND WATER

Ground water occurs in the subsurface throughout the Beryl-Enterprise area (fig. 4). Some of the ground water in the mountainous areas discharges by evapotranspiration, some discharges at springs to mountain streams, and the remainder moves directly into the principal ground-water reservoir.

The principal ground-water reservoir

The principal ground-water reservoir in the Beryl-Enterprise area includes unconsolidated to semiconsolidated deposits, which have an estimated maximum saturated thickness of 1,000 ft (300 m), and the ignimbrite in a generally triangular-shaped area about 2-12 mi (3-20 km) north to northwest of Enterprise (pl. 1) which has an estimated thickness of 500 ft (150 m). Insufficient data are available to warrant inclusion of any of the other consolidated rocks in the area in the principal ground-water reservoir. However, the digital model included the Table Butte area (an outcrop of rhyolitic ignimbrite) as transmissive material. The model simulated historical water-level changes more closely with the Table Butte area included.

Extensive hydraulic continuity may not exist everywhere within the ground-water reservoir because of the lenticular nature of the unconsolidated deposits. This is indicated on plate 4, which shows the horizontal and vertical variability of the deposits.

Despite the variability between deposits, however, aquifer tests have shown that a hydraulic connection exists between different strata in the ground-water reservoir. This was demonstrated when pumping one well caused water-level declines in other wells completed in different strata. During relatively short tests (less than 1 week of continuous pumping), the magnitude

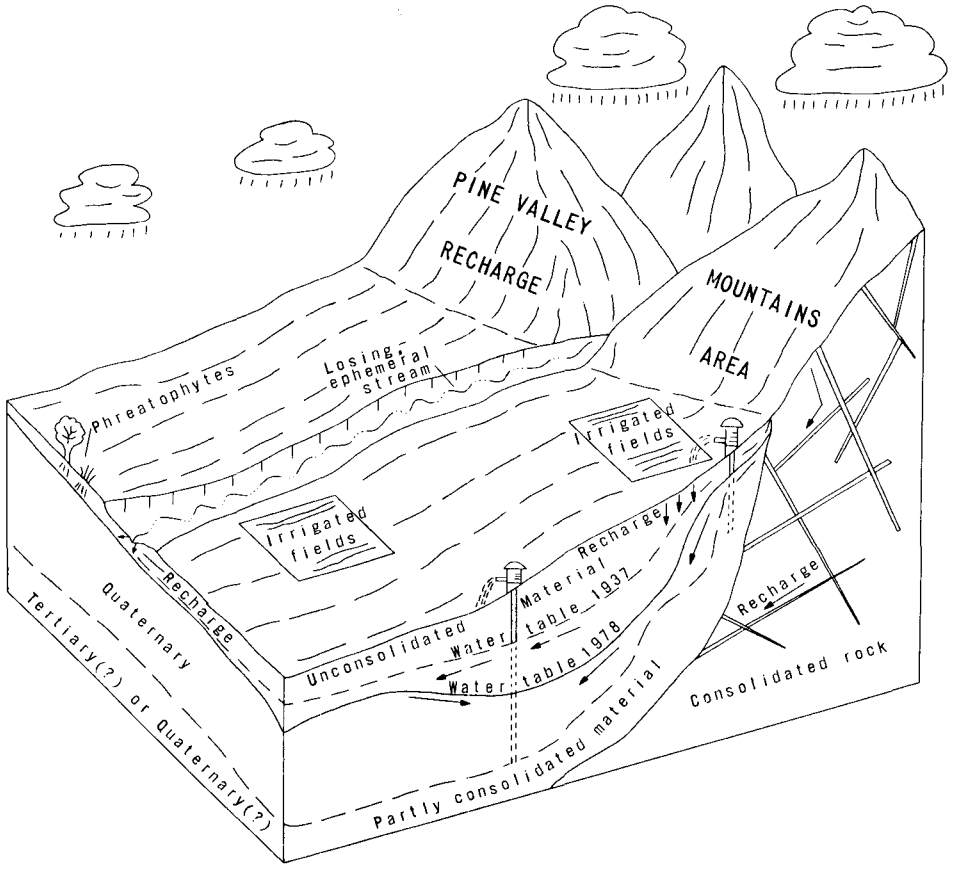

Figure 4.— Sketch illustrating general location of recharge areas, types of occurrence, location of the water table during 1937 and 1978, direction of ground-water movement during 1937 and 1978, and discharge points in the Beryl-Enterprise area. Wells withdraw water mainly from the unconsolidated material although they also may be open to the partly consolidated material.

of the effects in most observation wells varied inversely with the vertical distance between beds open to the pumped well and to the observation wells. An effect was observed even when observation wells were completed several hundred feet shallower or deeper than the pumped well.

During relatively long tests (several months or longer of continuous or intermittent pumping or of continuous nonpumping), the hydraulic head in all components of the ground-water reservoir is affected. For long-term analyses, therefore, the principal ground-water reservoir, including the ignimbrites near Enterprise, needs to be treated as a unit.

Hydraulic properties of the ground-water reservoir

The capacity of the ground-water reservoir in the Beryl-Enterprise area to transmit and store water is determined by the transmissivity (T)[1] of the reservoir, which is dependent on the saturated thickness and hydraulic conductivity (K)[2] of the water-bearing material, and on the specific yield (Sy)[3] of the reservoir. Knowledge of these hydraulic properties allows prediction of hydraulic response of the reservoir under specified pumping or other stresses.

Values for T and Sy can be determined from aquifer tests in which a well is pumped at a known rate and the drawdowns in nearby wells are measured periodically during the pumping period. T also may be estimated where K can be calculated from lithologic logs and the saturated thickness of the ground-water reservoir is known. The values for K in table 4 were derived largely from data obtained from aquifer tests in the area and partly from experience in the adjoining Milford area (Mower and Cordova, 1974, p. 13).

Data from the aquifer tests were analyzed by the Theis equation (1935) or a modification of this equation. During an aquifer test, a well was pumped at a known constant rate for periods ranging from about 8 hours to 30 days; and water levels were measured periodically in 1 to 10 observation wells at distances from the pumped well ranging from 298 to 3,750 ft (91 to 1,143 m).

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[1]Transmissivity (T) is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. The units for T are cubic feet per day per foot [$(ft^3/d)/ft$], which reduces to feet squared per day (ft^2/d). The term transmissivity replaces the term coefficient of transmissibility, which was formerly used by the U.S. Geological Survey and which was reported in units of gallons per day per foot. To convert a value for coefficient of transmissibility to the equivalent value of transmissivity, divide by 7.48; to convert from transmissivity to coefficient of transmissibility, multiply by 7.48.

[2]The hydraulic conductivity (K) of a water-bearing material is the volume of water that will move through a unit cross section of the material in unit time under a unit hydraulic gradient. The units for K are cubic feet per day per square foot [$(ft^3/d)/ft^2$], which reduces to feet per day (ft/d). The term hydraulic conductivity replaces the term field coefficient of permeability, which was formerly used by the U.S. Geological Survey and which was reported in units of gallons per day per square foot. To convert a value for field coefficient of permeability to the equivalent value of hydraulic conductivity, divide by 7.48; to convert from hydraulic conductivity to coefficient of permeability, multiply by 7.48.

[3]Specific yield (Sy) is defined as the ratio (sometimes expressed as a percentage) of the volume of water that an aquifer will yield by gravity to the volume of the aquifer dewatered. For practical purposes, Sy can be considered equal to the storage coefficient for unconfined aquifers.

Table 4.--Estimated average values of hydraulic conductivity of materials described in drillers' logs of wells

Drillers' description	Hydraulic conductivity K (feet per day)
Gravel	500
Sand, gravel, and boulders	400
Gravel and boulders	400
Boulders	250
Sand and gravel	125
Sand	50
Sand, clay, and gravel	20
Sand and clay	5
Hardpan and cemented materials	5
Clay or silt	1

Values calculated for T from the aquifer tests range from 200 to 120,000 ft^2/d (19 to 11,000 m^2/d) (table 5). The largest T value was observed about midway between Enterprise and Beryl Junction. Most of the pumped and observation wells used in aquifer tests penetrated less than one-half the full saturated thickness of the aquifer. Jacob (1963, p. 272) pointed out that such wells are less efficient than fully penetrating wells. Transmissivity computed from aquifer tests on wells open only to the upper part of the aquifer commonly will be too low. If an observation well is at a distance from the pumped well equal to or greater than twice the aquifer thickness times the square root of the ratio of horizontal to vertical permeability, then water levels in the observation well will be equal to the levels that would be generated if the pumped well fully penetrated the aquifer (Jacob, 1963, p. 274). In this case, values of transmissivity computed from test data would be reasonably correct. Because most of the pumped wells penetrated only part of the aquifer and because most tests either had observation wells too close to the pumped well or had observation wells that did not yield usable data, it is likely that transmissivity values from field tests are too low. In addition, if vertical permeability is much less than horizontal permeability, tests using pumped and observation wells that penetrate less than one-half the aquifer essentially may indicate transmissivity for only that part penetrated, and be less than for the full aquifer thickness.

The calculated T values in table 5 were used as a starting point in the construction of the digital-computer model for this study. The final T values used during the modeling process are shown on plate 5. The final values of T were obtained by the following steps: (1) The values of T from aquifer tests were converted to hydraulic conductivities by dividing by the approximated saturated thickness of aquifer penetrated by the test well, (2) the hydraulic conductivities derived from aquifer tests or estimated from data in table 4

Table 5.--Hydraulic coefficients of the principal ground-water reservoir determined from aquifer tests

Pumped well	Well depth (feet)	Transmissivity T (feet squared per day)	Apparent specific yield Sy
(C-32-13)9aac-1	308	8,400	0.004
(C-34-13)8abd-1	242	200	-
(C-34-16)18cdc-2	230	8,100	-
22bad-1	-	6,700	-
(C-35-15)2cdb-2	512	13,000	-
(C-35-16)7ccc-2	234	26,000	-
33bdc-2	191	55,000	.025
(C-35-17)14ccc-1	173	3,000	-
22bcb-3	280	4,000	-
(C-36-15)17bba-1	417	33,000	.033
(C-36-16)5L10-2	254	41,000	.037
20dcc-1	340	120,000	.0014
(C-36-17)36aad-1	363	70,000	.016
(C-37-17)14bdb-1	249	23,000	-
14dcd-2	152	14,000	-

were multiplied by the estimated total saturated aquifer thickness to compute the transmissivity of the entire aquifer, (3) the estimated T values were used as initial values in the digital model, and (4) were modified to the final values during model calibration. The values from table 5 are applicable only for analyses of effects of short-term pumping from part of the aquifer (as much as 1 month), and the values from plate 5 may be applicable to analyses of long-term pumping which affects the full thickness of the aquifer.

Values for Sy calculated from the aquifer tests range from 0.0014 to 0.037. When pumping begins at a well completed in an unconfined aquifer, most of the early discharge is derived from compaction of the aquifer materials and expansion of the water in the affected area around the well. As pumping progresses, an increasing percentage of the discharge is derived from the partly dewatered materials around the well. Water may continue to drain from partly dewatered fine sediments or from coarse sediments that are interbedded with fine sediments, such as in the ground-water reservoir in the Beryl-Enterprise area, for several years. Thus, Sy values that were determined from relatively short aquifer tests are approximate, and they become larger and more accurate as pumping continues. The length of the pumping period needed to obtain an accurate Sy value is usually much longer than an irrigation season and sometimes even longer than 20 years (Mower and Cordova, 1974, p. 15).

Studies were made with a neutron-radiation meter in the Milford area to determine Sy in materials that had been dewatered since pumping began there (Mower and Cordova, 1974, p. 15). The average measured approximate long-term value of Sy for all the materials tested in the Milford area, which ranged

from silty clay to gravel, was 0.20. Fine-grained material dewatered during the 1972-irrigation season had a lower Sy value--0.04 for clayey silt. The ground-water reservoirs in both the Beryl-Enterprise and the Milford areas were formed concurrently under the same geological processes, and much of the valley fill constituting the reservoirs has derived from similar sources. For these reasons, the maximum value of Sy determined for the Milford area was used as an initial estimate in analysis of the ground-water reservoir in the Beryl-Enterprise area. The final Sy values derived from calibration of the digital-computer model are shown on plate 6.

The values of Sy are lowest in areas of largest decline in water levels during 1937-78 (pls. 6 and 10). Because on the order of one-half of the decline occurred in the last 15 years of the period 1937-78, it is likely that incomplete drainage is reflected in the lower Sy values. Additional evidence for incomplete drainage is that water in several wells can be heard falling from shallow perforations to the water surface during nonpumping periods, indicating that some shallow zones are not completely drained.

Recharge

Recharge to the principal ground-water reservoir in the Beryl-Enterprise area is from five major sources (table 6). The water for four of the sources is from precipitation that falls directly on the drainage basin, whereas the fifth source represents precipitation on an adjoining drainage basin.

Every few years, recharge occurs at flood-retention ponds about 4 mi (6 km) north of Enterprise. The quantity is unknown, but it may be as much as several hundred acre-ft when water in Shoal Creek flows this far into the valley. The average annual recharge from this source is unknown; however, it is likely to be quite small, hence in this report it is disregarded.

Table 6.--Summary of estimated average annual recharge to the principal ground-water reservoir, 1977

Source	Average annual quantity (acre-feet)
Subsurface inflow from--	
Outside the area	320
Bedrock in the mountains	31,000
Infiltration from--	
Stream channels	
Farms	16,300
Precipitation on the valley floor	500
Total (rounded)	48,000

Subsurface inflow from outside the area

The annual subsurface outflow from Cedar City Valley toward the Beryl-Enterprise area was estimated by Thomas and Taylor (1946, p. 103-104) to be 20 acre-ft (0.02 hm^3) at Mud Springs Wash and 500 acre-ft (0.6 hm^3) at Iron Springs Gap. All outflow from Cedar City Valley at Mud Springs Wash is inflow to the nterprise area. No data collected since the study of Thomas and Taylor indicate that there has been any appreciable change in the quantity of subsurface flow, therefore, subsurface inflow at Mud Springs Wash during 1977 was estimated to be 20 acre-ft (0.02 hm^3) per year.

Only part of the subsurface outflow from Cedar City Valley at Iron Springs Gap is subsurface inflow to the Beryl-Enterprise area. The outflow during 1977 probably was about what it was during the study of Thomas and Taylor, but about 80 percent is discharge at springs near the boundary between the two areas. About one-half of the springflow infiltrates and returns to the ground-water reservoir. It is estimated, therefore, that subsurface inflow to the Beryl-Enterprise area at Iron Springs Gap is 300 acre-ft (0.4 hm^3) per year.

Subsurface inflow from bedrock in the mountains and infiltration from stream channels

The amount of subsurface inflow from bedrock in the mountains and hills bounding the area probably has not changed significantly since the area was first settled. The amount could not be calculated directly from onsite measurements, but it was determined during the modeling process discussed in a later section of this report.

Infiltration from stream channels near the valley edge occurs at virtually the same place as the subsurface inflow from bedrock. Recharge from the two sources are considered as one item for modeling and other purposes of this study. The average annual inflow from both sources is about 31,000 acre-ft (40 hm^3).

Infiltration from farms

Infiltration from farms was not determined directly because of the lack of accurate historical records of surface-water diversions. The infiltration was assumed to be similar to that determined by Willardson and Bishop (1967) in the Milford area on the basis that soil and water conditions and cropping and irrigation practices are similar in the two adjoining areas. Willardson and Bishop (p. 35) concluded that "***a 60 percent water-application efficiency (40 percent loss) is probably attainable under most conditions." They suggest, however, that the average irrigation efficiency attainable by the furrow-flooding methods commonly in use during the study at Milford is between 60 and 80 percent (loss between 40 and 20 percent). Assuming additional seepage from reservoirs and ditches, the total loss probably averaged about 40 percent. Similar irrigation efficiencies are assumed to be applicable to the Beryl-Enterprise area.

The installation of sprinkler-irrigation systems on some farms during recent years has resulted in improved irrigation efficiencies, and by 1977 the average total loss by infiltration was reduced to an estimated 20 percent. Recharge from water pumped from wells, therefore, was 20 percent of 80,000 acre-ft (100 hm^3) (fig. 2), or 16,000 acre-ft (20 hm^3), and recharge from surface-water diversions was 20 percent of 1,400 acre-ft (1.7 hm^3) (table 2), or 300 acre-ft (0.4 hm^3).

Infiltration from precipitation on the valley floor

The average annual precipitation on most of the valley floor is less than 10 in. (254 mm) (pl. 3), which is less than the optimal annual requirement of all cultivated crops and many native plants. Therefore, except during some storms, direct infiltration from precipitation on the valley floor is negligible.

If precipitation falls on irrigated fields that are saturated through the root zone, some water will move down beyond the root zone and recharge the ground-water reservoir. During the April-September irrigation season, the root zone is assumed to be always saturated in 10 percent of the irrigated area of 26,000 acres (10,500 hm^3). It was assumed further that only precipitation in excess of 0.25 in. (6 mm) during any storm would cause water to move beyond the root zone. Smaller quantities would be evaporated. Precipitation during 1977 totaled 3.86 in. (98 mm) for six storms during April-September, for an effective total of 2.36 in. (60 mm). The estimated recharge, therefore, was 0.10 x 26,000 acres x 2.36 in./12 in. = 500 acre-ft (0.6 hm^3), which is assumed to be the average annual recharge from precipitation on the valley floor.

Movement

Prior to the construction of wells for irrigation, ground water in the principal aquifer moved from the main recharge areas near the mountains and hills to discharge areas on the valley floor or northeast to the Milford area. The general direction of such movement is indicated on plates 3 and 7 for 1937. Subsequent pumping for irrigation has modified the direction of flow, as indicated on plates 3 and 8 for 1978.

The potentiometric-surface contours on plates 7 and 8 are based on water-level measurements in wells ranging from about 12 to 700 ft (4 to 210 m) in depth. Most well casings are perforated from the water table to the bottom of the well; thus, the measured water level in a well is an average for the section of the ground-water reservoir penetrated by the well. The water-level measurements used for the contour maps were made during the spring before large-scale pumping had begun for irrigation; thus, water levels were approximately at a yearly high.

Movement within the principal ground-water reservoir usually is from deeper zones, which have greater hydrostatic pressure, through semiconfining beds to shallower zones, which have less hydrostatic pressure. However, the direction may be reversed if pumping decreases the hydrostatic pressure sufficiently in the deeper zones or if local recharge increases the hydrostatic pressure sufficiently in the shallower zones. Differences in altitudes of the water level in neighboring wells of different depths may result from either of these causes.

The rate of lateral movement of ground water is extremely slow in comparison to the rate of flow of surface streams. The rate of movement (velocity) of ground water, V is governed by the hydraulic conductivity, K, and porosity, θ, of the saturated materials and the hydraulic gradient, I, in accordance with the equation:

$$V = KI/\theta$$

Data for 1937 applicable to a line along the central bottom part of the valley from about the Iron-Washington County line to the north edge of the Beryl-Enterprise area indicate that K is 40 ft/d (12 m/d), I is 0.00049 (pl. 7), and θ is estimated to average 0.35. Hence,

$$V = \theta(40 \text{ ft/d}) \times (0.00049)\theta/0.35$$
$$V = 0.056 \text{ ft/d } (0.017 \text{ m/d})$$

This average horizontal velocity of 0.056 ft/d (0.017 m/d), or about 20 ft/yr (6 m/yr), was typical of ground-water velocities in the lower parts of the valley before large ground-water withdrawals appreciably changed the configuration of the potentiometric surface. Since 1937, the hydraulic gradient has been reduced in the northern one-half of the area and the direction of the gradient has been reversed in much of the southern one-half (pl. 8).

Large variations in the rate of ground-water movement are to be expected in different parts of the area because of variations in the hydraulic gradient or the hydraulic conductivity. The hydraulic gradient is steepest in the younger alluvial-fan deposits around the perimeter of the area, where the ground-water reservoir is generally thinnest and the materials are coarsest, and flattest in the alluvium in the lower central parts of the area. For example, areal variations of the hydraulic gradient are indicated by the difference in spacing of the potentiometric contours on plate 7. The hydraulic gradient in the spring of 1937 ranged from about 40 ft/mi (8 m/km) near Enterprise to about 1.2 ft/mi (0.23 m/km) in the west-central part of the area, about midway between Beryl and Modena. From near the north edge of Enterprise to near the Iron-Washington County line, beds of gravel may have hydraulic conductivities of about 500 ft/d (150 m/d), whereas fine-grained deposits in the lower parts of the valley may have hydraulic conductivities of less than 5 ft/d (1.52 m/d). The range of hydraulic conductivities of the materials shown in table 4 is from 1 to 500 ft/d (0.3 to 150 m/d). Thus, a combination of a steep hydraulic gradient and a large hydraulic conductivity, as near Enterprise, tends to produce velocities as fast as 4,000 ft/yr (1,200 m/yr), and a consequent rapid movement of water from the recharge areas to the thicker parts of the reservoir. Conversely, flatter hydraulic gradients in combination with small hydraulic conductivities result in velocities less than 1 ft/yr (0.3 m/yr) in the lower-lying and northern parts of the area.

Ground-water withdrawals since 1937 have greatly modified the ground-water regimen, principally in the south-central one-third of the area. Water levels have declined as much as 70 ft (21 m) near the central part of the intensively pumped area, and lesser declines extend outward for a distance of several miles. The configuration of the potentiometric surface changed considerably between 1937 and 1978. (Compare pls. 7 and 8.) The direction of movement has been reversed in much of the southern one-half of the area, and some of the water that formerly moved northward now moves southward toward the lowest part of a ground-water depression. The depression is expanding, and it will continue to do so until it intercepts sufficient natural discharge to counterbalance the withdrawals within the area of depression.

Water-level fluctuations

The principal water-level fluctuations in the Beryl-Enterprise area reflect recharge to or withdrawals from the ground-water reservoir and indicate changes in ground-water storage. Fluctuations resulting from other causes are of short duration or have small magnitudes and do not indicate changes in storage.

Water levels in the Beryl-Enterprise area have been measured periodically in observation wells since 1935. Long-term water-level trends and seasonal water-level fluctuations are shown in figures 5 and 6. The locations of the observation wells are shown on plate 9. Mower (1981) includes water-level measurements for other wells and localities in the study area.

A downward trend of water levels in parts of the area began about 1940 and accelerated about 1947. The largest declines were near the south-central part of the main irrigated area and are represented by the hydrograph for well (C-36-17)36add-1 in figure 5. The declines are progressively smaller at increasing distances from the center of pumping. Although the highest water levels were measured during the late 1930's, water levels may have declined when streams were first diverted during the 1800's. As the irrigated lands replaced the stream channels as a major recharge area, the ground-water system apparently reached a new equilibrium by the 1930's.

The water-level decline during 1940-46 occurred when precipitation was greater than normal but withdrawals for irrigation were slowly increasing (fig. 2). The accelerated decline started about 1947 when withdrawals for irrigation began to increase rapidly, although the average annual precipitation continued to be greater than normal. Since 1947 withdrawals have increased and water levels have declined, regardless of variations in precipitation.

Water levels in most wells reach an annual high during the spring, immediately preceding the beginning of a new irrigation season. The annual low is near the end of the irrigation season during the fall, depending largely on the distance from pumped irrigation wells. (See fig. 6.)

The declines in water level from 1937 to 1978 for the principal ground-water reservoir are shown on plate 10. The largest declines are near the center of pumping for irrigation. A similar pattern of decline, but of lesser magnitude, is occurring on an annual basis as depicted by the water-level-change map for March 1977-March 1978 (fig. 7). This general pattern and magnitude of water-level decline may be expected to continue indefinitely under the 1977 pumping and irrigation regimen.

Storage

The amount of water in storage in the principal ground-water reservoir was estimated from the volume of saturated deposits and their water content. The volume of saturated deposits during the spring of 1978 was estimated from the saturated thickness and areal extent of the reservoir to be 190 million acre-ft (230,000 hm^3). The estimate was for a maximum saturated thickness of 1,000 ft (305 m). The ground-water reservoir is deeper in places, but the reliability of the data do not warrant deeper estimates.

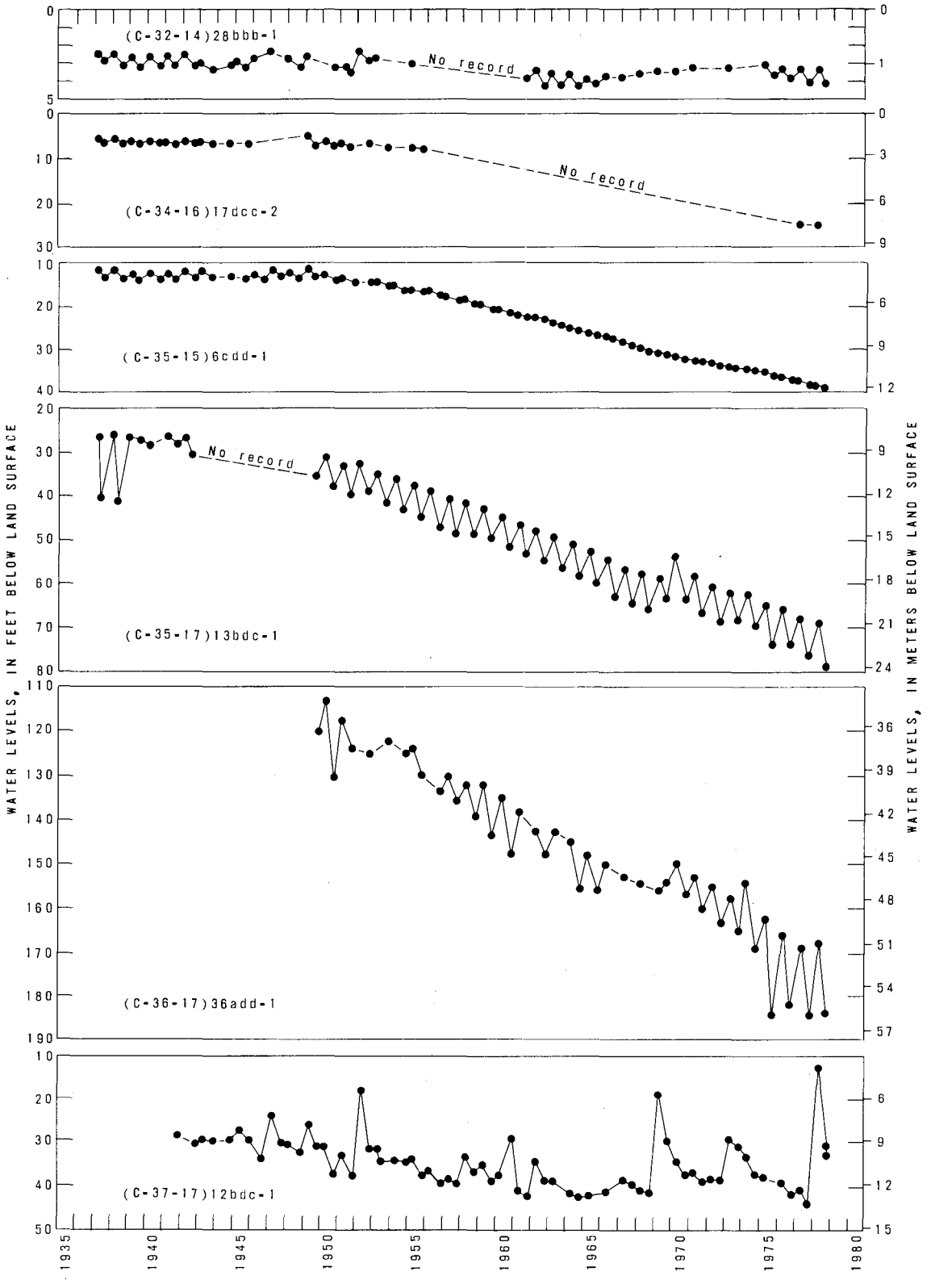

Figure 5.—Water levels in selected wells, 1937-78.

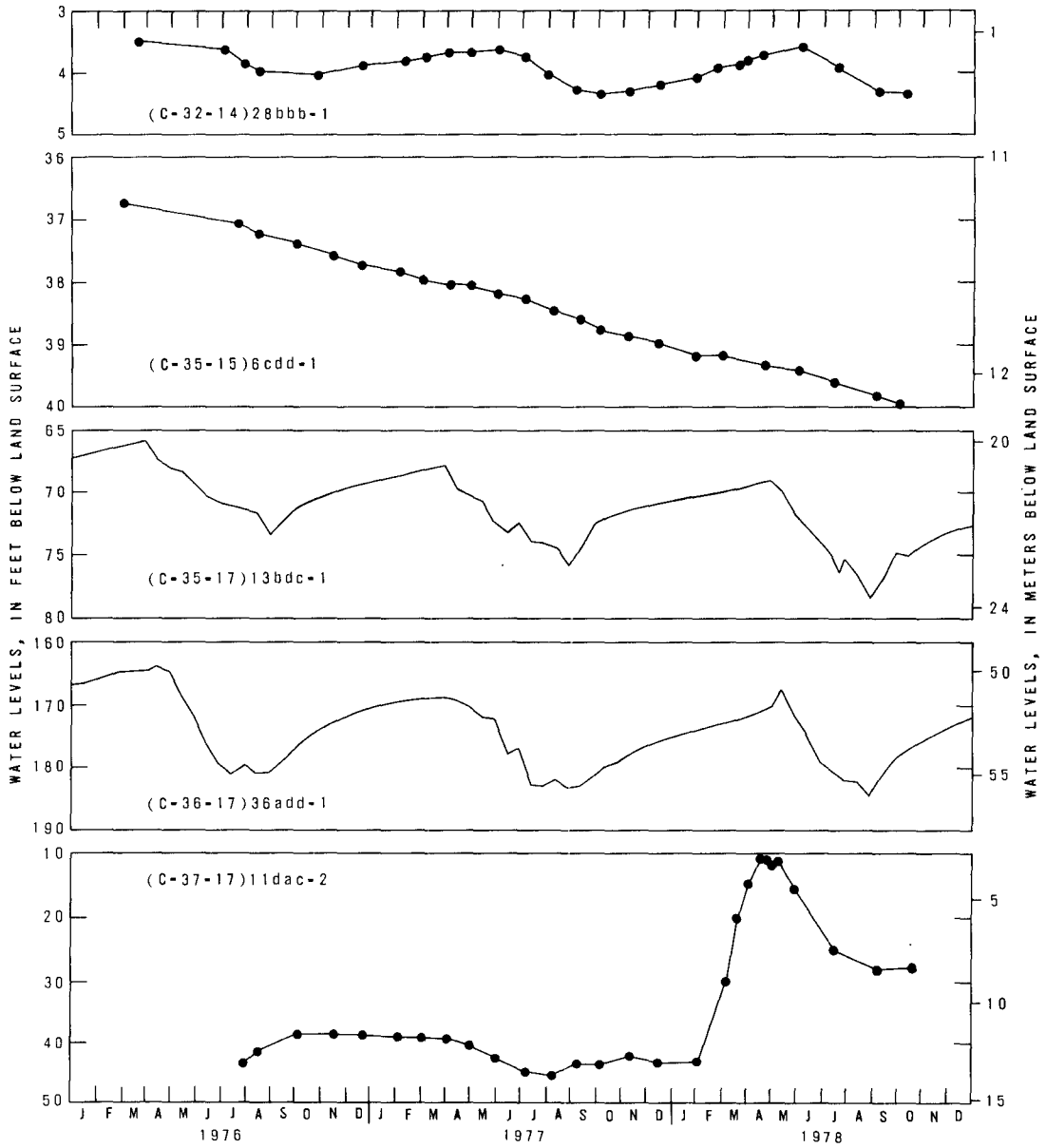

Figure 6.— Seasonal water-level fluctuations in selected wells, 1976-78.

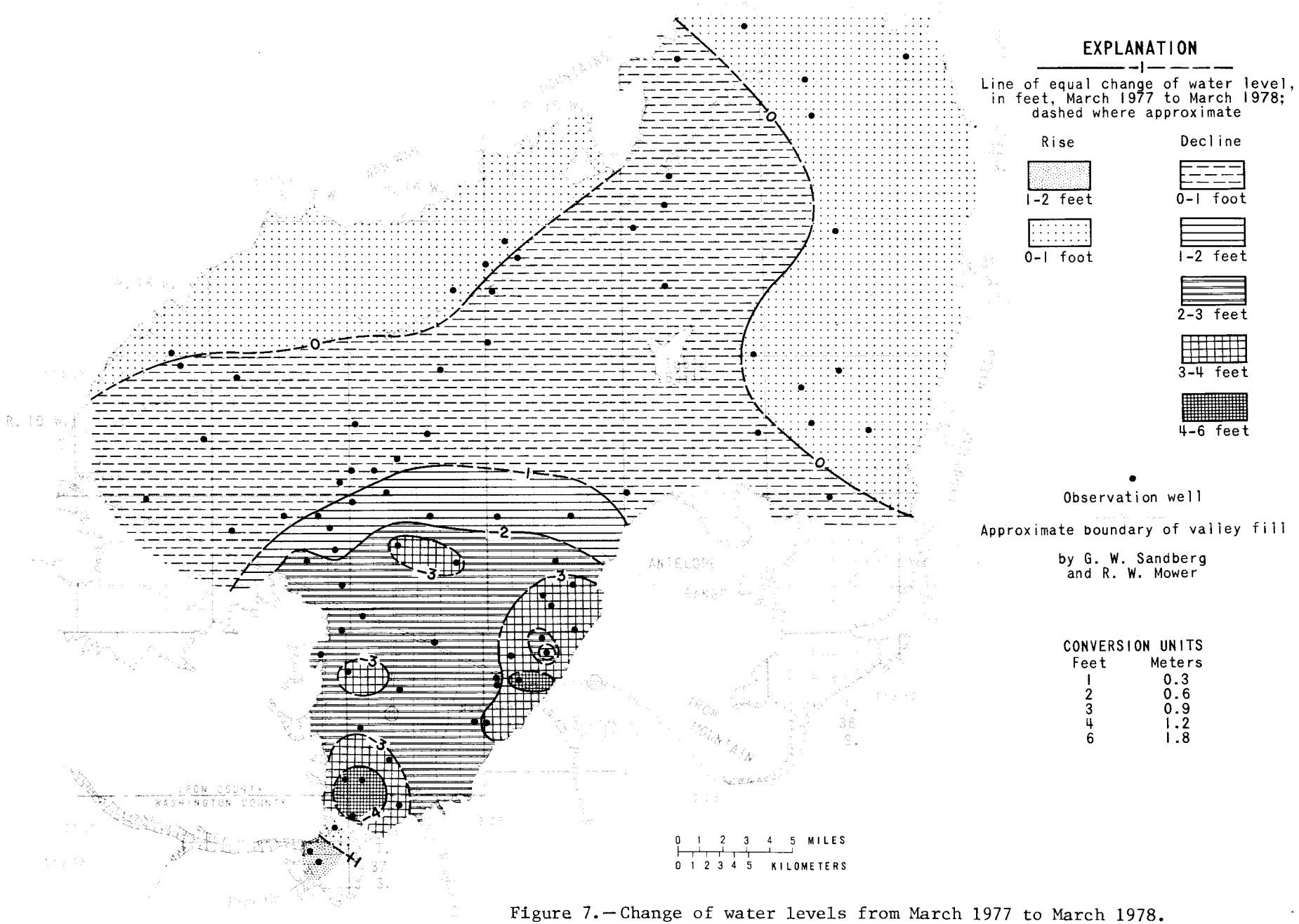

Figure 7.—Change of water levels from March 1977 to March 1978.

The water content of the saturated deposits was estimated from well logs by assigning an estimated water content to various lithologic types (table 7). The values in table 7 were based partly on a laboratory and field study by Mower and Cordova (1974, p. 24-27) of soil moisture in the adjacent Milford area and partly on a similar but smaller study in the Beryl-Enterprise area. Lithologic logs were examined for all wells drilled to the base of the ground-water reservoir and for all wells deeper than 300 ft (90 m). From examination of drillers' logs and from the data in table 7, it was estimated that the ground-water reservoir contains an average of 38 percent water by volume. The amount of ground water in storage during the spring of 1978, therefore, was 0.38 times 190 million acre-ft (230,000 hm^3), or about 72 million acre-ft (89,000 hm^3).

The quantity of water that can be removed from storage by lowering water levels was determined from the volume of material through which the water levels declined and the specific yield of that material. Assuming an average specific yield of 0.20, an average decline of 1 ft (0.3 m) (pl. 8) over and area of 1 mi^2 (2.6 km^2) would result in a change in ground-water storage of 128 acre-ft (0.16 hm^3). For the entire area underlain by the principal ground-water reservoir, a 1-ft (0.3-m) decline from the levels in the spring of 1978 represents a change in storage of about 100,000 acre-ft (123 hm^3). (See fig. 8.)

The volume of water recoverable from storage per foot of decline decreases as water levels decline because the areal extent of the saturated fill decreases with a decrease in saturated thickness. If water levels were at an average of 100 ft (30 m) below the spring of 1978 levels, an additional 1 ft (0.3 m) of decline would represent a decrease in storage of about 80,000 acre-ft (100 hm^3).

Table 7.--Estimated water content of saturated deposits of the principal ground-water reservoir

Lithologic material as described by drillers	Water content (percent)
Clay; clay and silt	50
Clay and sand; sandy clay	40
Sand	30
Gravel	25
Gravel and sand	20
Hardpan; conglomerate; other cemented material	10

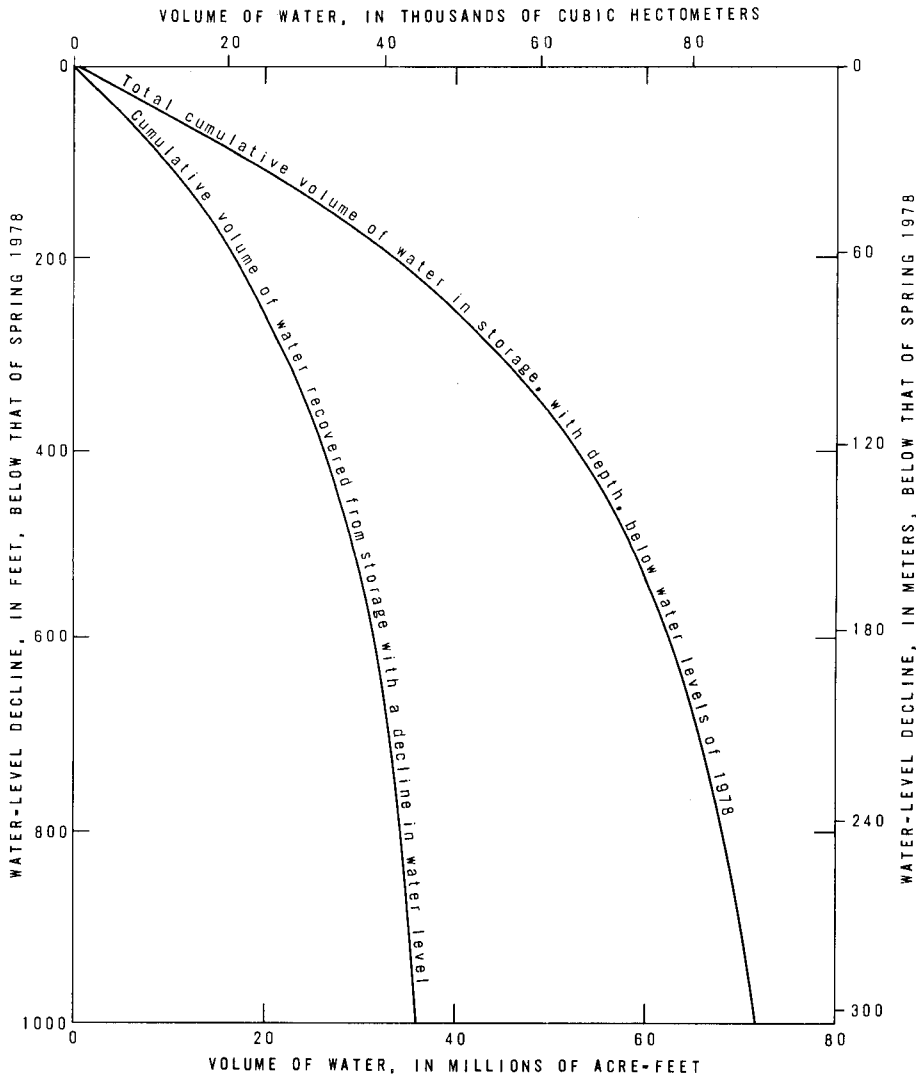

Figure 8.— Approximate total cumulative volume of water in storage with depth, in the principal ground-water reservoir and the approximate volume that can be withdrawn with uniform lowering of water levels below the levels of spring 1978.

The decrease in storage for 1937-78 was estimated to be 1.5 million acre-ft (1,800 hm^3). This estimate is based on a specific yield of 0.20 for basin fill and 0.03 for consolidated rock and the volume of dewatered materials represented by the water-level declines shown on plate 10. Another, and probably more realistic estimate of the water actually removed from storage was derived by using the values of specific yield given on plate 6, in conjunction with the volume of dewatered material as derived from plate 10; and it totaled 1.3 million acre-ft (1,600 hm^3). More than 90 percent of the decrease is concentrated in less than 10 percent of the ground-water reservoir in the southern parts of the area.

Discharge

Ground water in the Beryl-Enterprise area is discharge by springs, evapotranspiration, wells, and subsurface outflow. The discharge in the area from the principal ground-water reservoir is summarized in table 8 and discussed in detail in the following sections.

Springs

Although many springs discharge in the mountains (Mower, 1981, table 2), none issued from the principal ground-water reservoir during 1977, nor apparently at any time since the area was settled. The source of the water at most of the springs is local precipitation.

More than three-fourths of the springs discharge less than 1 gal/min (0.06 L/s); the largest discharge was estimated to be about 200 gal/min (13 L/s) at (C-38-17)4acb-S1. About one-half the springs have improvements, such as pipelines, water troughs, or small reservoirs. The towns of Enterprise, Newcastle, and Modena obtain some water from springs. Some spring water is used for irrigation, but most of the spring water is used for stock watering.

Evapotranspiration

Evapotranspiration directly from the principal ground-water reservoir during 1977 was by native vegetation, but in the past there has been more evapotranspiration by cultivated crops. Evapotranspiration during 1977 was estimated to be 6,000 acre-ft (7 hm^3).

Table 8.--Summary of the ground-water discharge from the principal ground-water reservoir, 1977

Source	Quantity (acre-feet)
Springs	0
Evapotranspiration	6,000
Wells	
Domestic and stock	750
Public supply and industrial	295
Irrigation	[1]80,000
Total wells (rounded)	81,000
Subsurface outflow	1,000
Total discharged	[1]88,000

[1]The reported withdrawals for irrigation may be as much as 25 percent higher, as discussed in the following section "Withdrawal from wells."

Phreatophytes.--There were 90,000 acres (36,000 hm^2) of phreatophytes in the Beryl-Enterprise area during 1977 (pl. 11). Phreatophytes are plants that obtain water by extending their roots to the water table or to the overlying capillary fringe. In addition to ground water, they can obtain water from precipitation, irrigation wastewater, and floodwater. Greasewood, (*Sarcobatus vermiculatus*), which is by far the most predominant phreatophyte, occupies practically all the phreatophytic lands, usually as the sole phreatophyte. Greasewood occupies about 5 percent of the area where it is in association with saltgrass (*Distichlis stricta*) and pickleweed (*Allenrolfea occidentalis*). This association is on the lowest parts of the valley floor where the soils are fine grained and usually where the water table is within about 5 ft (1.5 m) of the land surface. A greasewood and rabbitbrush (*Chrysothamnus nauseosus*) association occupies less than 1 percent of the area of phreatophytes where the surface soil is well drained and the depth to the water table usually exceeds about 5 ft (1.5 m). Other phreatophytes were observed in the valley, but the areas of growth were too small or growth densities too sparse to have any significant effect on the ground-water supply.

The areas of phreatophytes were mapped during 1927 (White, 1932, pl. 1) and during 1977 (pl. 11). Although no information is available concerning the distribution of phreatophytes during 1937, it is likely that the area covered then was about the same as during 1927. The mapping during 1927 was done on an early topographic base using various cultural and natural features for control. The mapping during 1977 was more complete and accurate because of the availability of better base maps and the use of aerial photographs for control.

Differences between the areas of phreatophytes shown on plate 11 for 1927 and 1977 are due largely to the more accurate mapping during 1977 and to the replacement of phreatophytes by farms since 1927. That process is in flux, however, because some farms that replaced areas of phreatophytes during the 1920's and 1930's have been abandoned in recent years. Most of the abandoned farms remain virtually devoid of phreatophytes; but phreatophytes have returned, usually at a sparse-growth density, to some of the lower-lying and northernmost abandoned farms.

White mapped 83,000 acres (33,000 hm^2) of phreatophytes during 1927; but on the basis of the 1977 survey, there were probably 93,000 acres (38,000 hm^2) during 1927. During 1977 there were probably 93,000 acres (38,000 hm^2) of phreatophytes plus 3,000 acres (1,200 hm^2) of farmland that had formerly supported phreatophytes. No areas were observed during 1977 where it appeared that phreatophytes had died as a result of declining water levels. The plants in some tracts of greasewood, however, had many dead branches and few leaves, which were pale in color. Apparently, many years are required for greasewood to die because of declining water levels.

Evapotranspiration was estimated by White (1932, p. 92-93) in the Beryl area, which is approximately the area of phreatophytes from about the latitude of Beryl on the north to near the center of T. 35 S. on the south. White reported that greasewood was the only important phreatophyte in the Beryl area, that the depth to water ranged from 7 to 30 ft (2 to 9 m), and that evapotranspiration was 2 in. (51 mm) per year. He assumed that the effective area of phreatophytes included 30,000 acres (12,000 hm^2); thus, he estimated annual evapotranspiration in the Beryl area to be "***approximately 5,000 acre-feet (6 hm^3)."

White's original estimates of evapotranspiration were modified, using his original rates of evapotranspiration for various species and various depths-to-water and using data collected during this study for growth density, soil-moisture measurements, known depth to the water table throughout the area, and more detailed mapping of species distribution. It is now estimated that during 1927 evapotranspiration was 5 in. (127 mm) from 30,000 acres (12,000 hm^2) and 2.5 in. (64 mm) from 63,000 acres (25,000 hm^2). The total annual evapotranspiration from the entire areas of phreatophytes during 1927, therefore, was 26,000 acre-ft (32 hm^3). Estimates for 1977 are 2.5 in. (64 mm) from 5,000 acres (2,000 hm^2), 1 in. (25 mm) from 60,000 acres (24,000 hm^2) and virtually zero from 25,000 acres (10,000 hm^2). Total annual evapotranspiration from areas of phreatophytes during 1977 therefore was 6,000 acre-ft (7 hm^3).

The reduction of 20,000 acre-ft (25 hm^3) in annual evapotranspiration from 1927 to 1977 was caused by the decline of water levels due primarily to pumping for irrigation. Evapotranspiration in the areas of phreatophytes will continue to diminish as long as water levels continue to decline. Eventually, if the present pattern and rates of ground-water withdrawals continue, evapotranspiration from phreatophytes may become negligible. This may not happen for several decades, however, at points such as Lund which are distant from the center of pumping.

Cultivated crops.--The amount of ground water consumed directly by cultivated crops in 1977 was negligible. The only cultivated phreatophyte is alfalfa, but even in the alfalfa fields in the lowermost parts of the valley, the water table is so far beneath the land surface that the plants would not be able to use appreciable quantities of water. This was not so, however, when farming began during the 1920's and for about 20 years thereafter. The water table then at some of the lowest fields was close enough to the land surface so that alfalfa could probably have used as much ground water as the phreatophytes which it replaced.

Withdrawal from wells

The first wells in the Beryl-Enterprise area were dug during the latter one-half of the 19th century and early part of the 20th century to obtain domestic and stock-water supplies. Annual withdrawals probably never exceeded 50 acre-ft (0.06 hm^3) before 1920.

Since the early 1920's, most domestic and stock wells have been drilled. The pumps at most wells near the settled areas are driven by electric motors, whereas in outlying areas they are mostly driven by windmills or gasoline engines. During 1977 the total withdrawal from domestic and stock wells was estimated at 750 acre-ft (0.92 hm^3).

The first public-supply well was drilled in Enterprise during 1928 to provide water mainly as a supplement for irrigating yards. The first use of well water for household use in Enterprise was during 1955, supplementing the supply from springs. Water from industrial wells at Beryl, Lund, Modena, and Zane also has been used for public supply at various times. Prior to 1976 the total withdrawal from wells for public supply probably never exceeded 100 acre-ft (0.12 hm^3) per year. Enterprise was the only town that used well water during 1977 when 270 acre-ft (0.33 hm^3) was withdrawn.

The first industrial wells were drilled during 1906 by the Los Angeles and Salt Lake Railway at the towns of Beryl, Lund, Modena, and Zane to provide water for steam locomotives and culinary use. The annual withdrawal peaked at about 200 acre-ft (0.25 hm^3) during the early 1940's and by 1977 had diminished to about 25 acre-ft (0.03 hm^3).

The first irrigation well was dug about 1919, and the average annual withdrawal from wells for irrigation during 1919-36 was estimated to be 2,200 acre-ft (2.7 hm^3). At least 80 wells had been dug or drilled by 1937 when the pumpage was about 3,000 acre-ft (4 hm^3). Annual withdrawals remained relatively constant until 1945 when they began to increase sharply (fig. 2), eventually reaching a maximum of 92,000 acre-ft (110 hm^3) during 1974. Withdrawals have decreased since 1974, partly because of the increased use of sprinkler-irrigation systems. As additional sprinkler-irrigation systems are installed to replace flood-irrigation systems, the amount of annual withdrawal should be reduced further.

The withdrawals of water from individual irrigation wells during 1945-60 were determined by the U.S. Geological Survey from power-consumption or operating-time records and periodic discharge measurements. Since 1960, withdrawals have been metered at individual wells. The metered records for many of the wells are so imprecise or incomplete, however, that they can be considered only as estimates. As part of the data compilation for the digital-computer model (discussed in a later section of this report), personnel of the Utah Division of Water Rights compiled data on withdrawals for irrigation during 1961-77. Their evaluation of the data indicates that the metered withdrawals probably are as much as 25 percent less than actual withdrawals. If so, the values shown in figure 2 need to be increased by 25 percent. Thus, the maximum annual withdrawal of 92,000 acre-ft (110 hm^3) recorded during 1974 would be about 115,000 acre-ft (140 hm^3), and the quantity recorded for 1977 would be 100,000 acre-ft (120 hm^3) rather than the 80,000 acre-ft (100 hm^3) shown.

Subsurface outflow

Ground water moves northward out of the project area near Lund (pls. 7 and 8). The potentiometric-surface contours on plate 7 indicate that during 1937 the overall movement of ground water was toward a low point northeast of Lund. Most of the ground water actually was discharged by evapotranspiration before it reached the northern boundary. Withdrawals from wells since 1937 has resulted in a reversal of the direction of ground-water flow in the central part of the area. The potentiometric-surface contours for 1978, however, show little change from those of 1937 near the northern boundary (pl. 8). Thus, the volume of subsurface outflow has not been appreciably reduced by ground-water withdrawals.

The amount of subsurface outflow from the Beryl-Enterprise area was estimated by Mower and Cordova (1974, p. 16) to be 1,000 acre-ft (1 hm^3) per year. The amount estimated using the computer model, however, is 2,100 acre-ft (2.6 hm^3) per year (see p. 100). This volume probably is more accurate because it is based on more complete data.

Yield of wells

The yield of a well is determined by the characteristics of the well itself and the water-bearing strata that provide water to the well. The specific capacity of a well, as used in this report, is the yield in gallons per minute per foot of drawdown after pumping for 24 hours. Well characteristics that affect specific capacity include the depth of penetration of the well into and the length open to the water-bearing strata; method of well construction; the diameter of the well; the extent, type, and location of the perforations or screen; the degree of corrosion, encrustation, and plugging of the perforations or screen; and the effectiveness of well development. Proper well development removes the finer grained material from around the perforated casing or screen and for a short distance out into the aquifer, thereby forming a permeable pack of coarse-grained material close to the well. Thus, the effect of well development is similar to that of increasing the well diameter, and it increases the well efficiency.

The efficiency of a well is the ratio of the theoretical drawdown in a perfectly constructed and developed well to the actual drawdown multiplied by 100. In a well that is 100-percent efficient, the water in the well and the water immediately outside the casing, assuming that the casing has no thickness, are at the same level regardless of the amount of drawdown. In a well that is less than 100-percent efficient, however, when the well is pumped the water in the well is at a level below the water in the aquifer immediately outside the well casing.

An indication of poor well condition is the range in values of the ratio of transmissivity to specific capacity. Transmissivity is proportional to specific capacity (Bentall, 1963, p. 331), so their ratio should be fairly constant for wells of similar diameter. A large range in the value of the ratio may indicate large entrance losses which cause the pumping water level and specific capacity to be low and the ratio to be high. For 14 of the wells listed in table 5, the ratio of transmissivity, in feet squared per day, to specific capacity, in gallons per minute per feet, ranged from 1.5 (in dimensionless units) (which should be the most efficient well) to 18 (the least efficient well). Eight of the wells in table 5 have ratios greater than 6 and probably have lesser efficiencies.

Interference among wells

When a well flows or is pumped, the potentiometric surface in the ground-water reservoir around the well is lowered, forming a cone of depression. The cone expands and deepens with time until the ground-water system reaches a new equilibrium. The overlapping of cones of depression around discharging wells is called "interference," and it results in additional water-level declines at each affected well.

Theoretical graphs were constructed from solutions of the Theis equation (Theis, 1935) to provide a basis for estimating interference among wells and water-level declines due to pumping in wells (fig. 9). The graphs were prepared from computed water-level declines for commonly occurring combinations of coefficient of transmissivity and specific yield, and for distances of 0.01-10 mi (0.2-16 km) from a well pumping 1,000 gal/min (63 L/s) for 180 days. Values used for transmissivity are in the range of values shown

on plate 5. The values used for specific yield were 0.1, the approximate value for periods shorter than 180 days, and 0.2, for periods of greater than 1 year. The graphs are approximations because specific yield is not a constant value but increases with the length of the pumping period.

To illustrate use of the graphs, assume that four wells are in a straight line at 1-mi (1.6-km) intervals. Three wells (at either end of the line) will be pumped for 180 days, and there is no other discharge and no recharge within the area encompassed by the cones of depression to be formed at any of the wells. What will be the total drawdown at the fourth well? Assumptions for the problem are stated in table 9.

The drawdowns at well 4 caused by pumping at each of wells 1, 2, and 3 is obtained from figure 9. The total interference of 0.52 ft (0.16 m) is the sum of the effects of the three pumped wells.

Temperature of ground water

The temperature of ground water in the Beryl-Enterprise area varies areally and with depth, and the areal distribution is shown in figure 10. The temperature of ground water near the land surface is usually a degree or two above the mean annual air temperature, which at Modena is 9.4°C (48.9°F). Figure 10 is based on water temperatures for wells that range in depth from 100 to 400 ft (30 to 120 m) and are perforated through most of the saturated section penetrated. The temperature of the water pumped from such wells is an approximate average for the entire perforated section. The temperature of ground water in most of the Beryl-Enterprise area generally ranges from 10°-15°C (50°-59°F), which is considered normal for the area.

Table 9.--Approximate interference for hypothetical problem

[Transmissivity = 100,000 feet squared per day and specific yield = 0.20]

Pumping well	Average pumping rate during 180 days (gallons per minute)	Distance from pumped well to well 4 (miles)	Interference at well 4 at end of 180 days (feet)
1	1,000	1	0.4
2	500	2	.1
3	100	3	.02
	Total computed interference at well 4		0.52

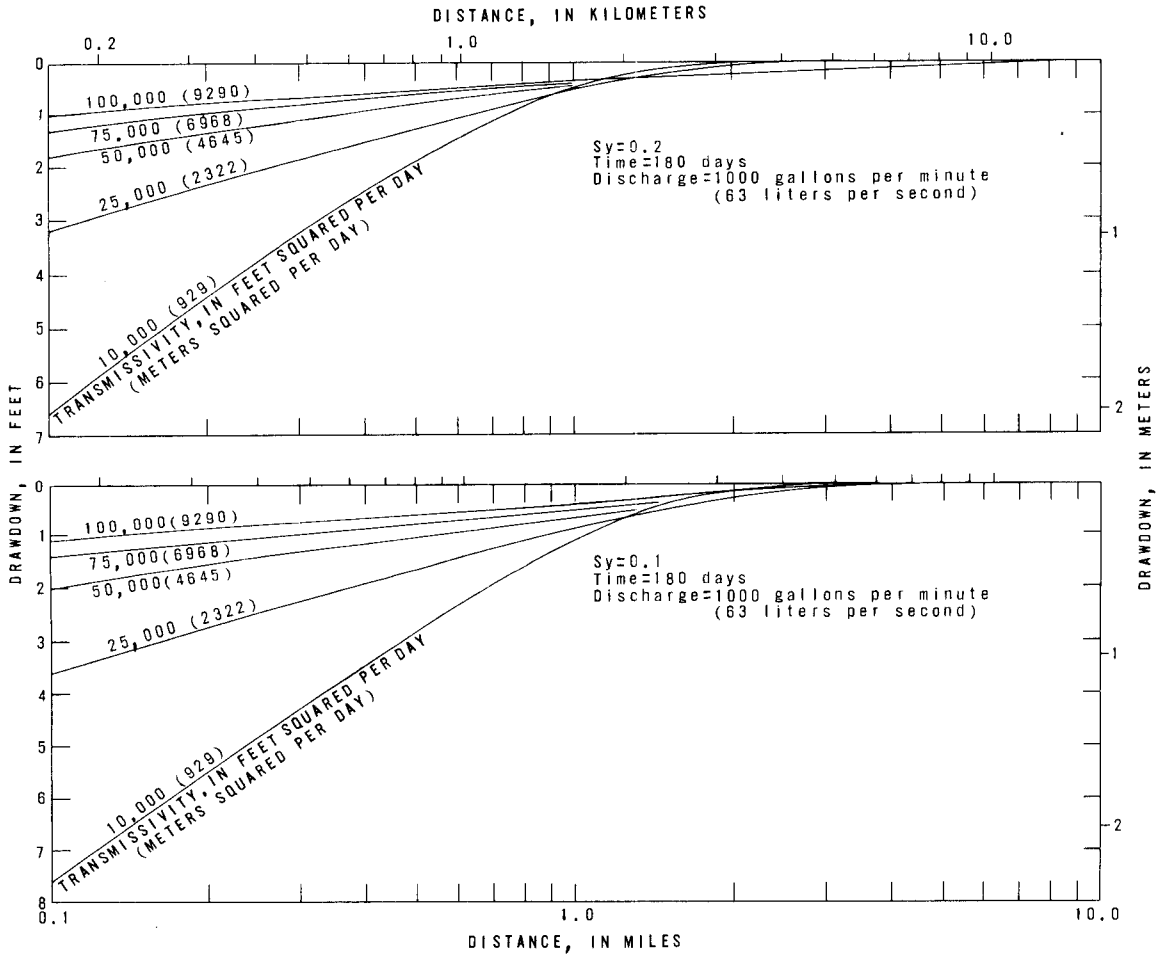

Figure 9.— Distance-drawdown graphs for the principal ground-water reservoir.

Ground-water temperature increases with depth because of the geothermal gradient, and wells deeper than 400 ft (120 m) yield water with temperatures as much as 5°C (9°F) warmer than the temperatures indicated in figure 10. (See Mower, 1981, table 1.) The presence of an underground heat source, such as a body of recently emplaced (in terms of geologic time) volcanic rocks, tends to increase the temperature of ground water. Areas where the hottest ground water occurs are north of Beryl (maximum temperature 28.5°C or 83°F) and near Newcastle (maximum temperature 97°C or 206.5°F) (fig. 10). F. E. Rush (U.S. Geological Survey, written commun., 1979) estimated that thermal water near Newcastle may have temperatures as hot as 170°C (338°F).

CHEMICAL QUALITY OF WATER

The general chemical quality of ground water in the Beryl-Enterprise area is indicated on plate 12, which is based on the specific conductance of water pumped from numerous wells. The water measured at each well, however, is a composite water sample because most wells are perforated from the water table to the bottom of the well. The specific conductance of the water generally is greatest at the water table and decreases with depth. The rate

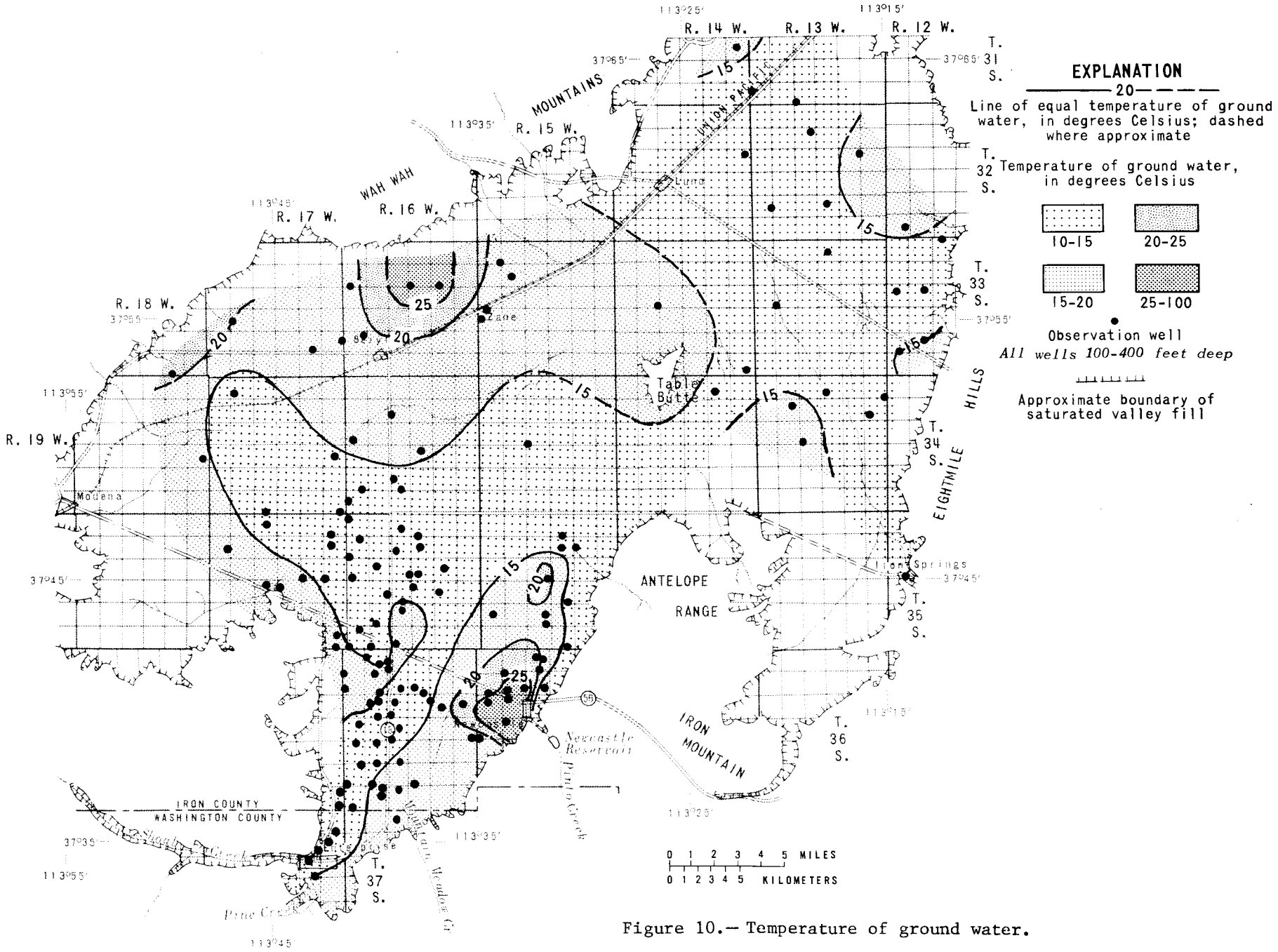

Figure 10.— Temperature of ground water.

of change varies widely, at different locations, but generally water at or within a few feet of the water table has a specific conductance two to three times as great as shown on plate 12; and water at depths greater than 400 ft (120 m) (the greatest depth represented on the map) has a specific conductance of about one-half that shown on plate 12. Thus, plate 12 is only a general guide to the quality of water at specific locations.

The relation between specific conductance and the concentration of dissolved solids in the water is shown by the graph in figure 11. The graph indicated that the dissolved-solids concentration is about 0.75 times the specific conductance. The concentration of dissolved minerals in ground water in most of the Beryl-Enterprise area thus is calculated to be less than 1,000 mg/L (specific conductance about 1,400 µmho micromhos per centimeter at 25°C). The concentration is slightly less than 500 mg/L (specific conductance about 700 µmho) in a narrow belt mainly between Enterprise and Beryl.

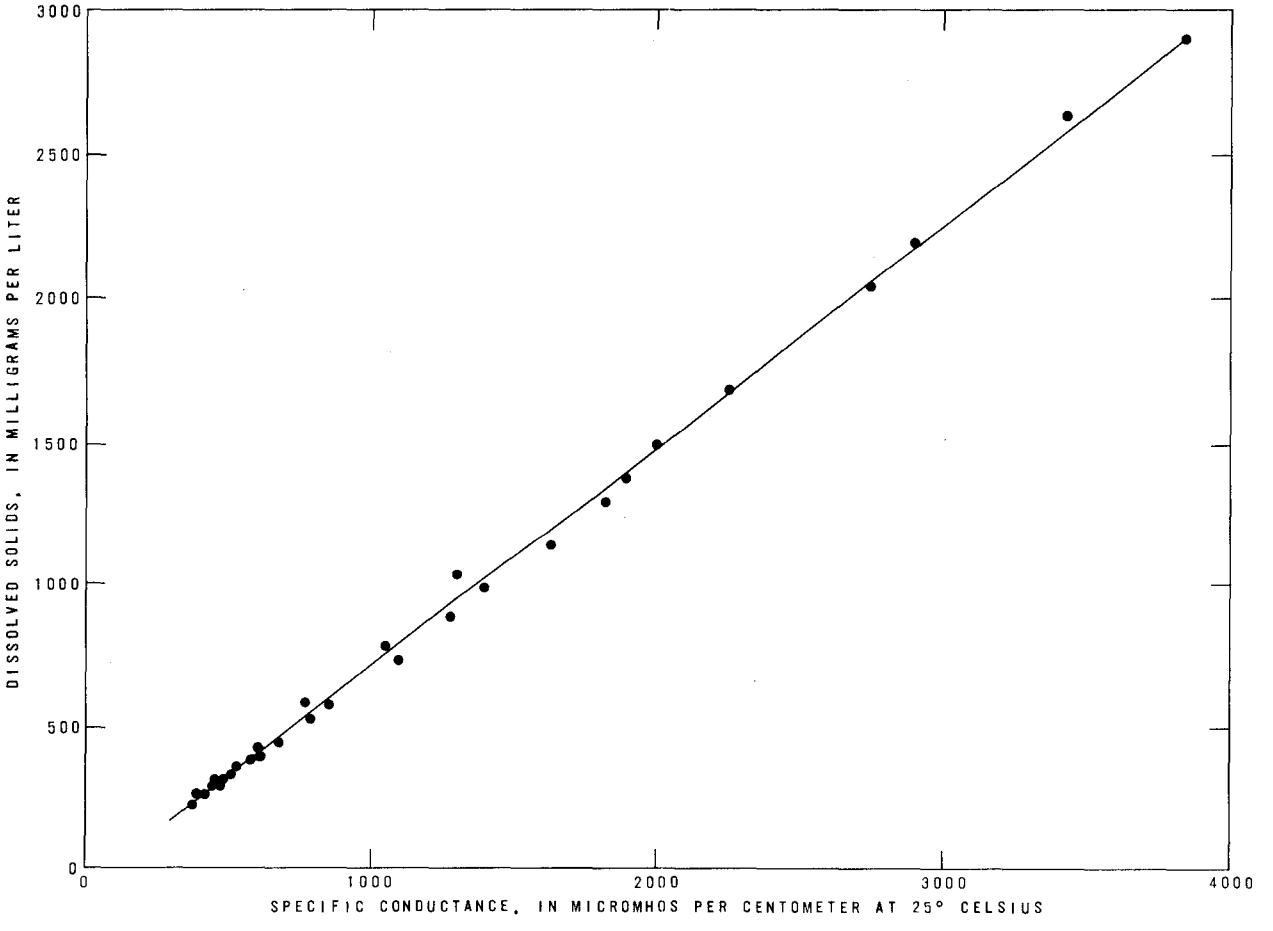

Figure 11.— Relation of specific conductance to dissolved solids in ground water.

Quality in relation to use

Domestic supply

The U.S. Environmental Protection Agency (1976) stated quality standards for drinking water, a partial list of which follows:

Constituent	Milligrams per liter	
	Recommended maximum limit	Mandatory maximum limit
Sulfate	250	--
Chloride	250	--
Nitrate	--	10

Sulfate and chloride concentrations in water from wells sampled at various locations north of the latitude of Newcastle exceed the recommended maximum limits. Nitrate exceeding the mandatory maximum limit was noted at five wells, all in the southern part of the valley (Mower, 1981, table 4).

The U.S. Environmental Protection Agency (1976, p. 206) did not set an upper limit for dissolved-solids concentration, recognizing that such a limit was influenced primarily by considerations of taste and acclimation. The data on plate 12 indicate that water with the greatest dissolved-solids concentrations is in four relatively small areas centered: (1) About 5 mi (8 km) northeast of Beryl, (2) about 8 mi (13 km) north of Newcastle, (3) about 2 mi (3 km) northwest of Newcastle, and (4) about 5 mi (8 km) northeast of Lund.

Hardness of water, which results mainly from the concentrations of calcium and magnesium, is an important quality consideration for domestic use. The following classification is used in this report:

Rating	Hardness as calcium carbonate (milligrams per liter)
Soft	0- 60
Moderately hard	61-120
Hard	121-180
Very hard	More than 180

According to the data in Mower (1981, table 4), the water in most wells in the Beryl-Enterprise area is hard to very hard. Hardness increases as the water moves from the recharge areas through the ground-water reservoir.

Irrigation

The characteristics of water that are most important in determining its suitability for irrigation are: (1) Concentration of soluble salts, (2) relative proportion of sodium to other cations, (3) the bicarbonate concentration as related to the concentration of calcium plus magnesium, and (4) concentration of boron or other minor elements that may be toxic (U.S. Salinity Laboratory Staff, 1954, p. 69). When classifying water for irrigation, it should be kept in mind that the suitability of the water is affected by soil drainage, water management, and application of soil amendments. Also, the presence of gypsum and calcium in the soil tends to counteract the effects of sodium.

The concentration of soluble salts can be expressed in terms of specific conductance. The specific conductance of water from nearly 500 wells in the Beryl-Enterprise area has been measured by the Geological Survey since 1923. The specific conductance from 24 representative wells is plotted in figure 12 to indicate the salinity hazard of the water according to the method of the U.S. Salinity Laboratory Staff (1954). Most of the water in the area has a medium- to high-salinity hazard.

Water with a large proportion of sodium in relation to other cations tends to break down the friable, granular nature of soil and cause it to become less permeable. In contrast, water containing large proportions of calcium and magnesium in relation to sodium maintains good tilth and texture in soil. The sodium hazard can be expressed in terms of the sodium-adsorption ratio (SAR), where:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

The concentrations of sodium, calcium, and magnesium in the formula are expressed as milliequivalents per liter (meq/L). Most of the water in the study area has a low-sodium hazard (fig. 12) except for an area from about Newcastle northward to about Table Butte where the sodium hazard is greater.

Another expression of the sodium hazard in water used for irrigation is the residual sodium carbonate (RSC), where

$$RSC = (CO_3^{-1} + HCO_3^{-1}) - (Ca^{+2} + Mg^{-2})$$

The concentrations of carbonate (CO_3), bicarbonate (HCO_3), calcium (Ca), and magnesium (Mg) are expressed in milliequivalents per liter (Eaton, 1950, p. 127). Residual sodium carbonate is a measure of the tendency of water to become more alkaline when calcium and magnesium carbonates precipitate as the water is transpired by plants. This contributes to the soil condition referred to as black alkali. Residual sodium carbonate greater than 2.5 meq/L is considered to make water unsuitable for irrigation (U.S. Salinity Laboratory Staff, 1954, p. 81). In the Beryl-Enterprise area, only the ground water in the south-central part of the area (fig. 13) is known to contain more than 2.5 meq/L of residual sodium carbonate.

None of the ground water in the Beryl-Enterprise area is known to contain concentrations of boron or other minor elements that are toxic to crops grown in the area.

Ground water near the recharge areas usually is more suitable for irrigation than water considerably farther downgradient because percolating water dissolves and takes into solution salts from the materials through which it passes. Additional concentration is caused by evapotranspiration in the bottom-land areas where plants consume pure water and leave the dissolved minerals in the soil. This is illustrated by a comparison of the quality of water from well (C-37-16)4bdd-1 in the recharge area and the water from well (C-35-15)3ddc-1 about 3 mi (5 km) downdip from the main recharge area. Water from well (C-37-16)4bdd-1 has a low-sodium hazard and a medium-salinity hazard, whereas water from well (C-35-15)3ddc-1 has a medium-sodium hazard and a very high salinity hazard.

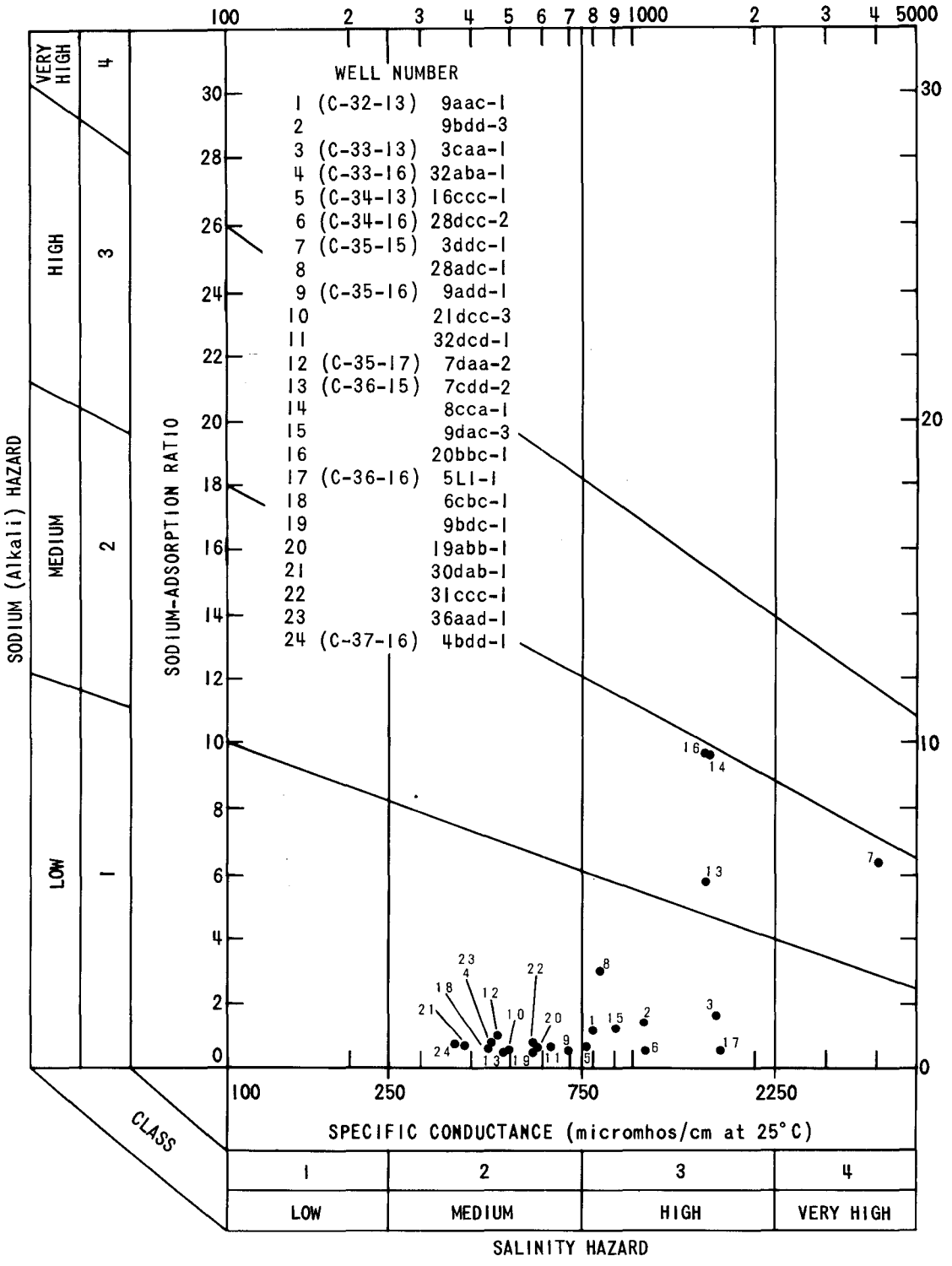

Figure 12.— Classification of irrigation water (method of the U.S. Salinity Laboratory Staff, 1954).

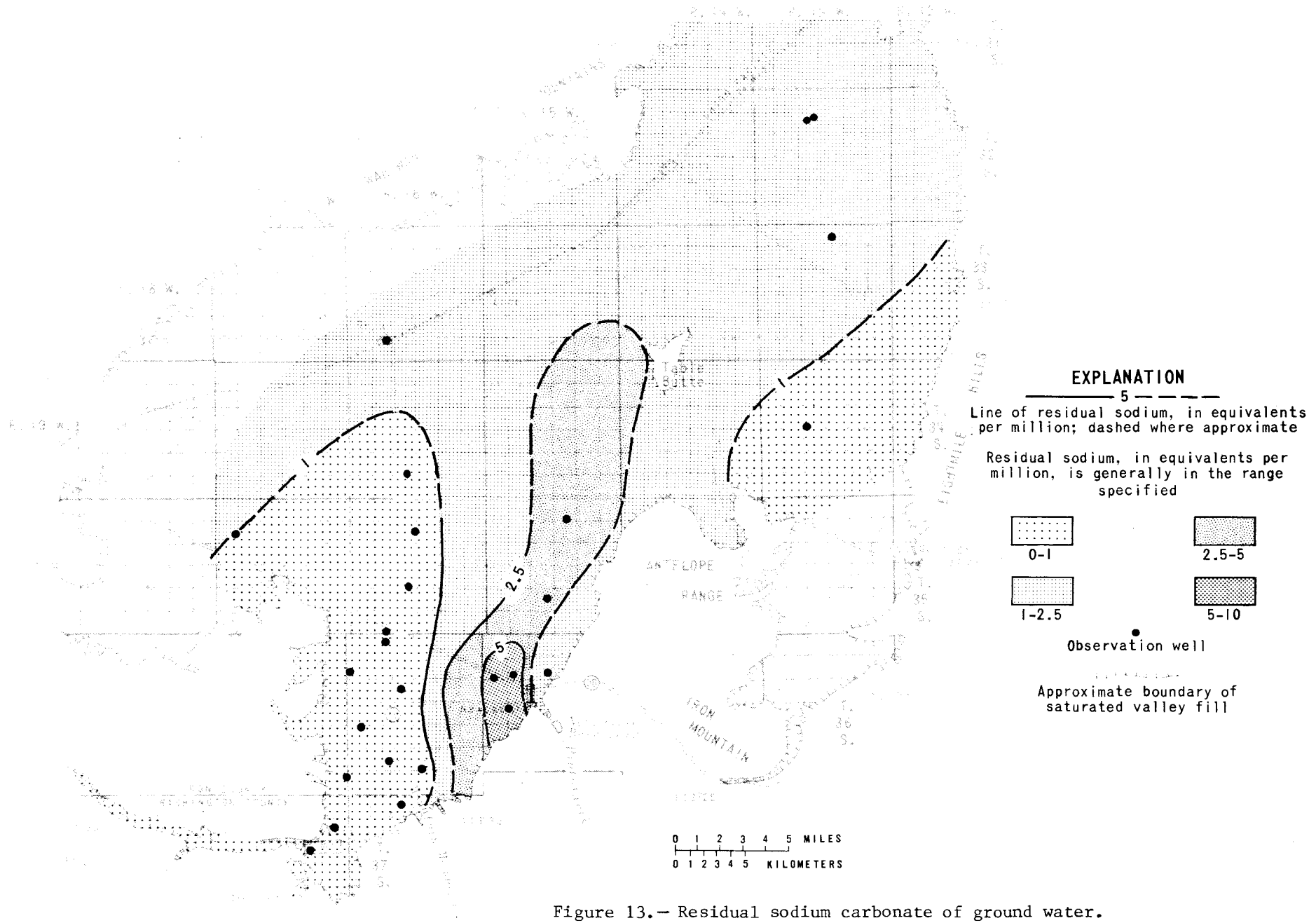

Figure 13.— Residual sodium carbonate of ground water.

Changes of chemical quality

The concentration of dissolved solids in ground water is increasing in many parts of the Beryl-Enterprise area as indicated by the graphs in figure 14 showing changes of specific conductance of the water at 10 selected sites. The changes in chemical quality probably are caused by recycling of irrigation water and induced flow to wells of water of different chemical quality.

When plants transpire water, most of the dissolved minerals are left behind. The minerals accumulate in the soil unless additional water exceeds the field capacity of the soil, thus flushing the minerals down to greater depths. If the dissolved minerals reach an underlying unconfined aquifer, they increase the concentration in the water in the aquifer. This is happening at well (C-34-16)28dcc-2 (fig. 14), north of Beryl Junction, ant at other wells in the area where the reversal of the water-level gradient (compare pls. 7 and 8) has resulted in the recycling of ground water. By contrast, the change in chemical quality at well (C-37-17)14bac-1, near Enterprise, has been slight. This is an area of appreciable natural recharge where the water-level gradient has not only been reversed, but it has been steepened, and the dissolved minerals are moved northward out of the area instead of being recycled.

Part of the increased concentration at well (C-34-16)28dcc-2 (fig. 14) is the result of induced flow of naturally occurring water containing relatively large concentrations of dissolved solids. About 1 mi (1.6 km) north of Newcastle at well (C-36-15)9dac-3, the change in direction of movement from northward to westward has caused a decrease in dissolved-solids concentrations. The well obtains some water from a bedrock fault that trends northward from near the west edge of Newcastle, west of this well. The water moving up the fault contains a greater dissolved-solids concentration than does water in the valley fill (F. E. Rush, U.S. Geological Survey, written commun., 1979). The water that formerly moved northward from the fault now moves westward away from the well and water in the valley fill is moving toward the well. The dissolved-solids concentration is increasing in water west of the fault and decreasing in water east of the fault.

DIGITAL-COMPUTER MODEL OF THE GROUND-WATER RESERVOIR

A digital-computer model was prepared to simulate the ground-water reservoir and its response to imposed stresses. The model can be used to indicate probable water-level changes and changes in natural discharge from the ground-water reservoir due to various assumed conditions of future recharge and discharge.

Description of the digital-comupter model

The digital-computer model used in the study of the Beryl-Enterprise area uses a finite-difference program based on the work of Trescott (1973) and Trescott, Pinder, and Larson (1976). In this study, the special water-table equation for unconfined aquifers was solved. A rectangular grid of node points was superimposed on a map of the ground-water reservoir in the Beryl-Enterprise area, and physical dimensions and hydraulic characteristics of the reservoir were modeled at each node.

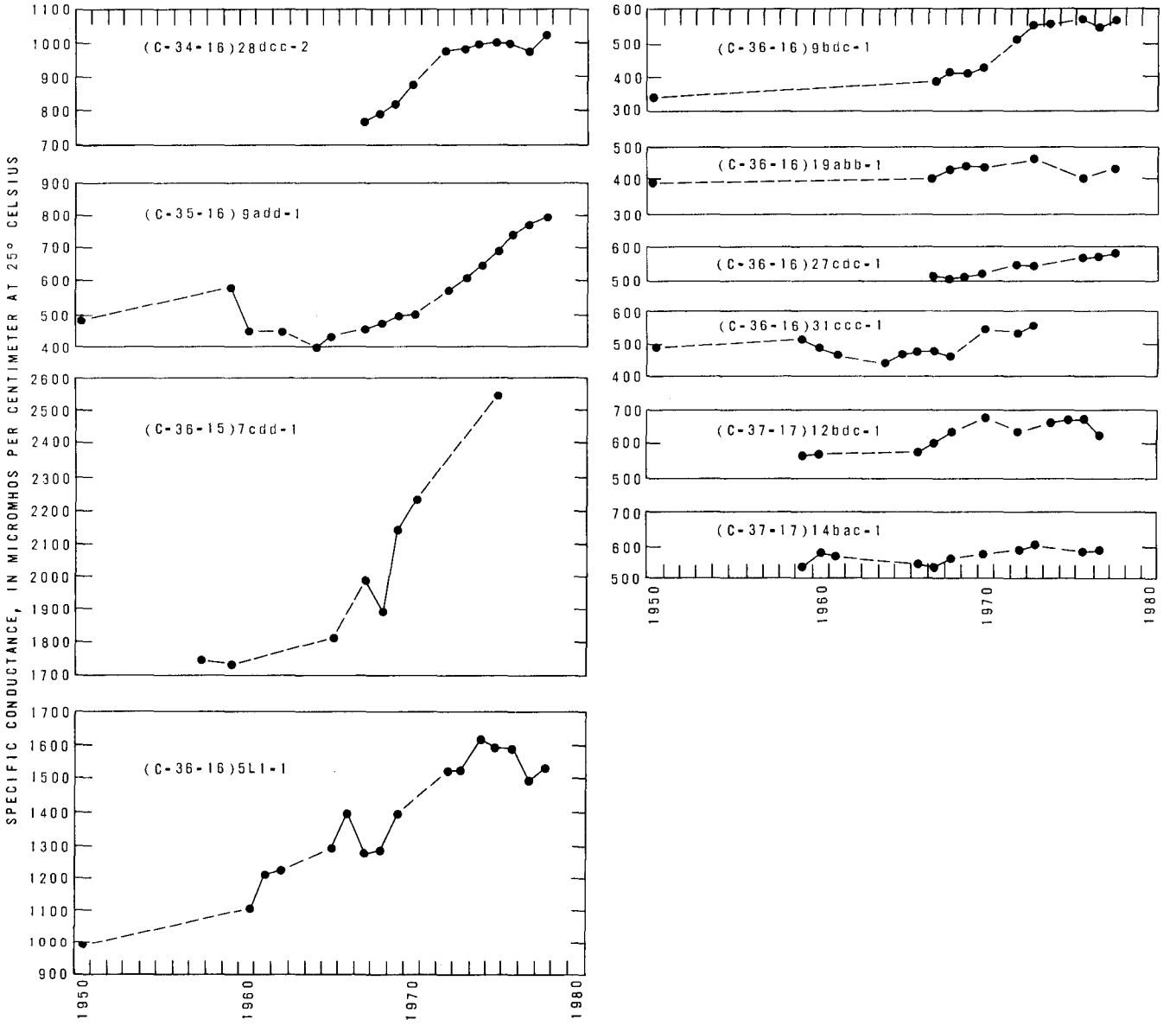

Figure 14.— Specific conductance of water from selected wells.

The boundary of the modeled ground-water reservoir, with several exceptions, was placed approximately at the contact between saturated valley fill and older, partly consolidated to consolidated rocks (Stokes, 1964). One exception was the ignimbrite west to northwest of Enterprise, which is included as part of the ground-water reservoir. Others are small tributary valleys or areas on the southeast and southwest sides of the model. Another is the north end of the study area, where the reservoir is conformably contiguous with the ground-water reservoir in the Milford area. The Table Butte rhyolitic-ignimbrite area was also included in the active part of the model.

The modeled area is shown on plate 13. The spacing of the rectangular grids used for the model data arrays ranged from 2,000 ft (610 m) in areas of greatest withdrawals to 15,000 ft (4,570 m) in areas of little or no withdrawals. To simulate the boundary of the model, the node immediately outside the last node representing the principal ground-water reservoir was assigned a value of zero hydraulic conductivity. At the boundary between the Beryl-Enterprise area and the Milford area, where the valley fill below the water table was saturated on both sides of the boundary, an artificial boundary was defined with zero conductivity nodes.

The perimeter of the model, except where it joins the Milford area, is treated as a constant recharge boundary, and the recharge is simulated by recharge wells at most of the first nodes inside the boundary. Underflow to the Milford area is simulated by wells discharging at a constant rate at the boundary. The average annual underflow into and out of the study area was determined in a steady-state phase by holding discharge within the basin and the hydraulic head constant (at the 1937 level) at the first node on each row and column immediately inside the model boundary. Inflow was thus determined to be about 31,000 acre-ft (40 hm^3) and outflow about 2,100 acre-ft (2.6 hm^3).

The base of the ground-water reservoir was determined from well logs and geologic outcrops for a small part of the reservoir; but because of lack of data, assumptions were necessary for most of the reservoir. The maximum saturated thickness was assumed to be 1,000 ft (300 m).

The top of the reservoir was represented by the potentiometric-surface contours for 1937 (pl. 7). The transient effects of pumping and the effects of recharge from surface water used for irrigation on the configuration of the potentiometric surface during 1937 were judged to be insignificant.

Hydraulic conductivity was obtained from aquifer tests, estimates based on drillers' logs, extrapolations where field data were sparse or lacking, and adjustments during calibration of the model, particularly at places where no aquifer-test data were available. The hydraulic conductivity used in the model ranged from 10-250 ft/d (3-76 m/d).

Initial estimates of transmissivity were made by multiplying hydraulic conductivities derived from aquifer-test data or from drillers' logs by the total saturated thickness of the ground-water reservoir. The transmissivity used in the model ranged from zero to slightly more than 100,000 ft^2/d (9,290 m^2/d) (pl. 6).

Evapotranspiration of ground water by phreatophytes was computed at nodes where the water table is within 11 ft (3.4 m) of the land surface. The altitudes of the land surface, which were used in the computation of evapotranspiration, were taken from topographic maps having a contour interval of 5 ft (1.5 m) on the valley floor. The maximum error in the modeled land surface, therefore, should be one-half a contour interval, or 2.5 ft (0.76 m). The rate of evapotranspiration used in the model ranged from the calculated maximum potential of 40 in. (1,016 mm) per year for localities where the water table is at the land surface, to zero where it is greater than 11 ft (3.4 m) below the land surface.

A preliminary specific yield of 0.20 was assigned to all the valley fill on the basis of tests made in the Milford area to the north, but it was adjusted by trial and error during the course of model calibration. The specific yield value of 0.20 was retained where the reservoir materials are mostly coarse grained and where water-level declines during 1937-78 were less than about 2 ft (0.60 m). However, the specific yield value decreases progressively to 0.10 toward the area of greatest water-level decline (pl. 6), where the dewatered aquifer is only partly drained because much of the decline occurred during the last 20 years. A specific yield value of 0.05 was assigned to the Tertiary ignimbrite, where it is assumed to be part of the ground-water reservoir. This value was selected on the basis of estimated porosity by inspection of several outcrops and verified by model testing.

Method of analysis

The ground-water reservoir and its response to both past and future pumping was simulated in three phases: (1) Steady-state calibration phase, the equilibrium conditions existing in 1937, (2) transient-state calibration phase, the response to pumping during 1937-77, and (3) predictive phase, probable response to anticipated pumping after 1977.

Analysis during the calibration phases provided insight about the nature of the reservoir and was a means of evaluating and thus adjusting the data used in the model. The model was calibrated under transient-state conditions so that the simulated hydraulic heads, water-level changes, and distribution of evapotranspiration agreed reasonably well with measured values. Reservoir thickness, hydraulic conductivity, recharge, subsurface outflow, and rate of and effective depth of evapotranspiration were adjusted during the steady-state calibration phase. Specific yield and recirculation of pumped water were adjusted during the transient-state calibration phase.

Simulations during the predictive phase were made to determine changes that might occur under several possible pumping regimens after 1977.

Equilibrium condition.--The potentiometric surface during the spring of 1937 (pl. 7) was assumed to represent equilibrium conditions. It was used for the steady-state calibration of the model to produce a set of hydraulic-head values and recharge and discharge rates that were in numerical balance. Recharge and discharge rates simulated by the model during calibration agree reasonably well with known information. These hydraulic-head values and recharge and discharge rates were used initially for the transient-state calibrations which began with the 1937 pumping season.

Response to pumping during 1937-77.--The response to pumping during 1937-77, which was simulated during the transient-state calibration phase, was considered in five pumping periods. The annual pumpage during 1937-77 is shown in figure 2 and the average modeled rate for each of the periods is given in table 10.

Some of the water pumped for irrigation was assumed to return to the ground-water reservoir and become available for pumping again. During the transient phase, the simulated quantity of water that returned to the reservoir ranged from 5 to 35 percent of the pumpage. A value of 5 percent was ultimately used everywhere in this phase except in T. 35 S., R. 15 W., where 35 percent was used. The valley fill in T. 35 S., R. 15 W., generally is much coarser and more permeable than in most other parts of the study area. The actual amount of water recycled in most of the area probably exceeds 5 percent of the rate shown in table 10 because the pumpage shown in figure 2 probably is about 25 percent less than actual pumpage.

The simulated declines in the potentiometric surface from the spring of 1937 to the spring of 1977 are shown on plate 6. The declines shown on plate 6 generally are similar to those on plate 10, which shows the measured declines during the same period. Most of the differences probably are caused by different drainage rates resulting from variations in permeability in the valley fill. For this reason, the simulated water-level declines are slightly smaller than the measured declines in places where the permeability is relatively large, while in other places where the permeability is relatively small, the simulated declines are slightly larger than the measured declines. The model as a whole, however, represents the ground-water reservoir well, and it can be used to predict changes due to imposed stress. The degree of agreement between measured and simulated hydraulic heads at 75 nodes where measured information was available for comparison is illustrated in figure 15.

Response to pumping after 1977.--The model can be expected to yield a reasonably dependable depiction of future water-level changes if there is little or no change in the magnitude and distribution of pumping and the efficiency of use of the water. The model is not applicable for periods longer than 30 years or if the distribution of pumpage is greatly different than that during 1969-77, except for determining gross trends.

Table 10.--Pumpage data used for transient-state calibration phase of the digital-computer model

Pumping periods	Time interval	Number of nodes used as pumping centers	Average aggregate pumping rate	
			Cubic feet per second	Acre-feet per year
1	1937-45	33	3.4390	2,490
2	1946-49	129	38.2560	26,700
3	1950-64	175	71.6480	51,870
4	1965-68	174	91.2654	66,350
5	1969-77	190	101.8387	73,730

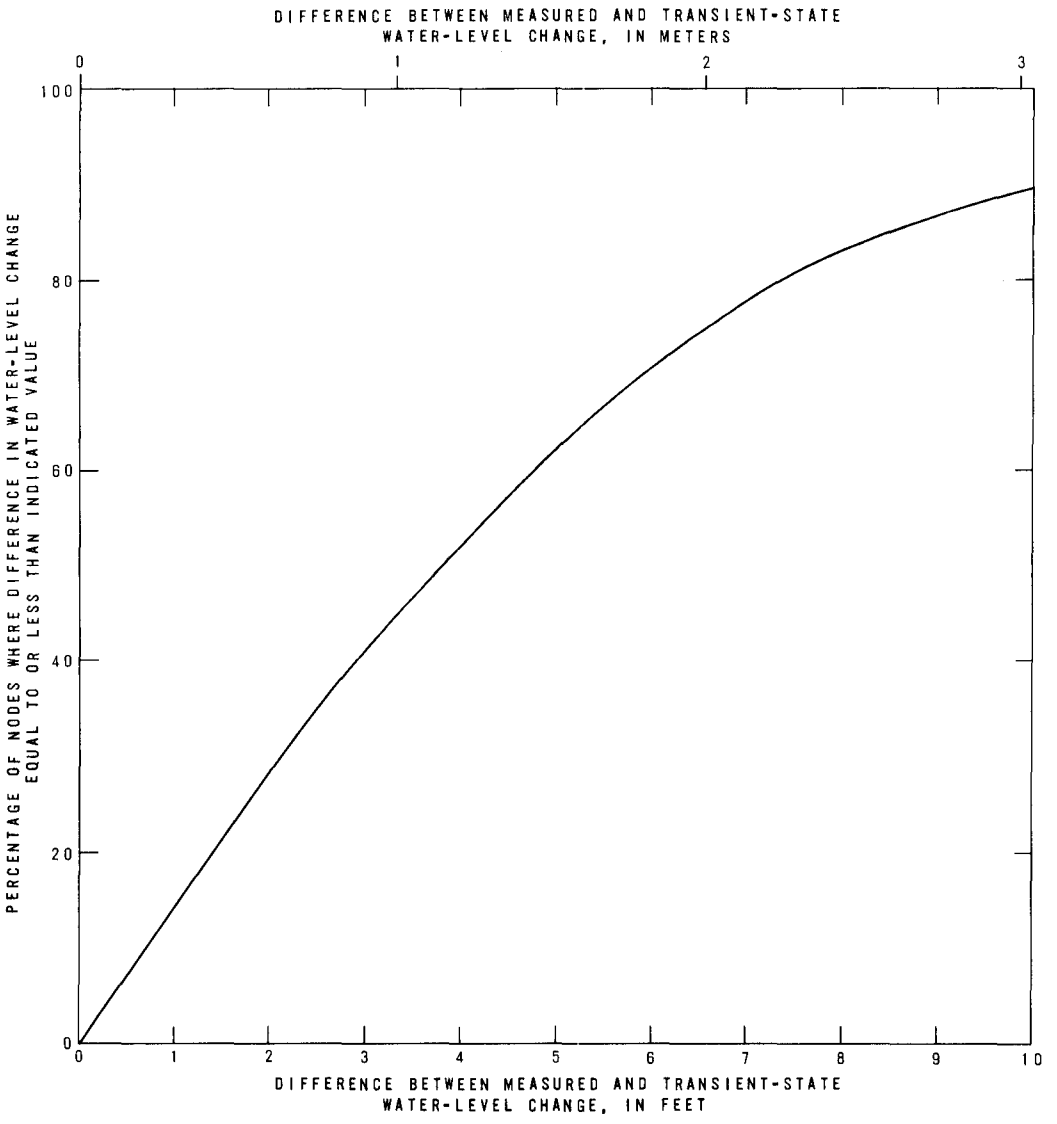

Figure 15.— Relation between measured and transient-state simulated water-level changes, 1937-78.

A simulation was made spring of 1978 to spring of 1992, assuming that all conditions of recharge and discharge existing during 1969-77 would continue unchanged. Simulated water-level declines ranged from zero at about the latitude of Lund to slightly more than 20 ft (6 m) in a small area centered about 3 mi (5 km) northeast of Enterprise (fig. 16). The simulated declines were 15-20 ft (5-6 m) in most of the area that contains irrigation wells. The average annual simulated rate of decline is slightly less than that measured during 1969-77, primarily because the expanding cone of depression in the intensively pumped area would capture increasing quantities of recharge.

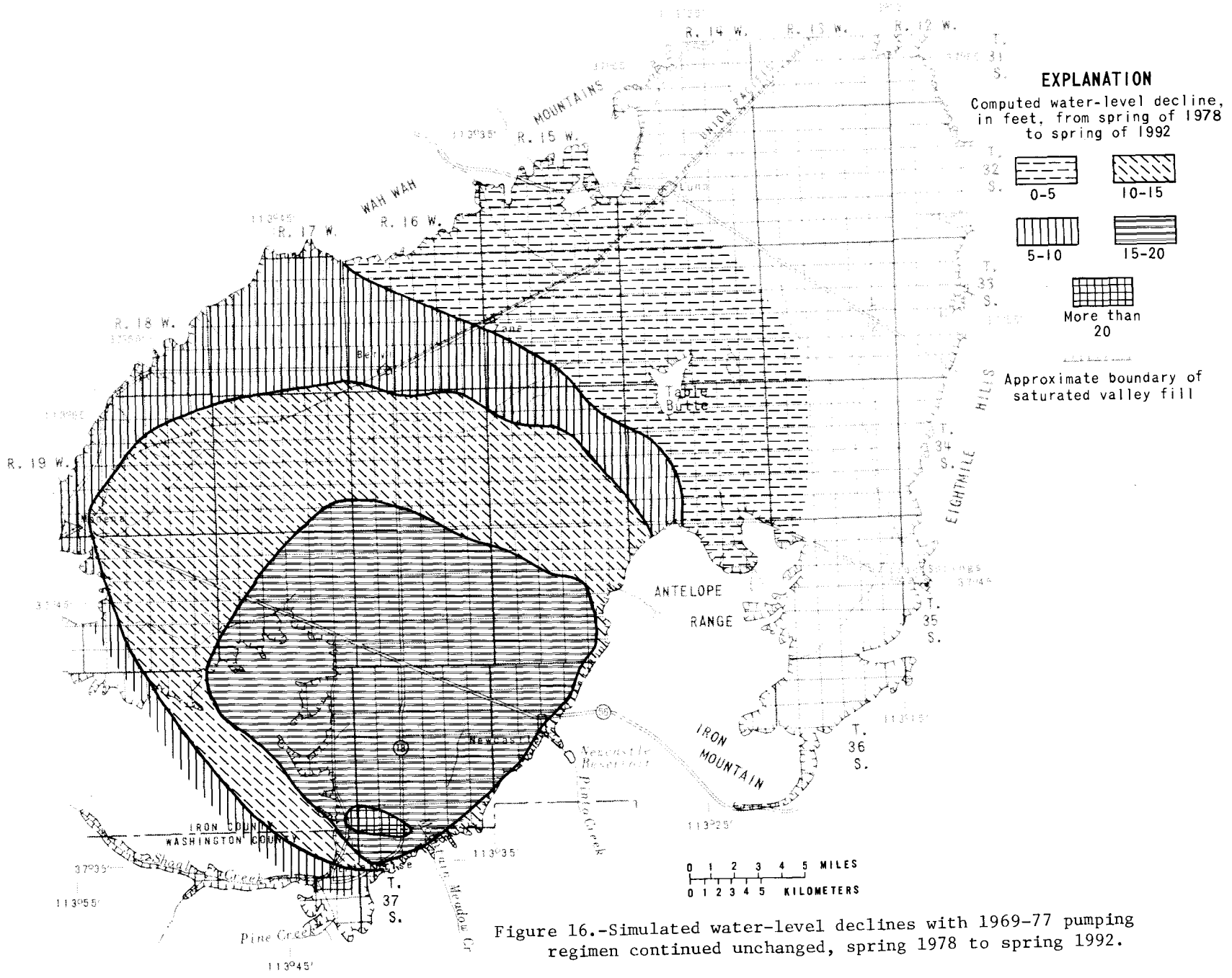

Figure 16.-Simulated water-level declines with 1969-77 pumping regimen continued unchanged, spring 1978 to spring 1992.

A second simulation was made for the same time period, assuming the pumping of wells to dewater a silver mine in sec. 2, T. 36 S., R. 17 W. Dewatering of the silver mine was planned to begin in 1979 by pumping about 9,000 gal/min (370 L/s) from a series of wells. The pumping rate will be increased progressively to a maximum of about 20,000 gal/min (1,300 L/s) by 1991, shortly before anticipated termination of mining. Part of the pumped water will be used for irrigation in the valley and part will be diverted by canals to Shoal Creek in sec. 25, T. 36 S., R. 17 W. It is expected that all water not diverted for irrigation will infiltrate the beds of the canals or Shoal Creek and return to the ground-water reservoir within about 4 mi (6 km) of the mine.

During the second simulation, the following assumptions were made: (a) The dewatering rate was 20,000 gal/min (1,300 L/s); (b) of that, 10,000 gal/min (630 L/s) was used for irrigation 6 months of the year; (c) about 500 gal/min (30 L/s) of the water used for irrigation recharged the ground-water reservoir; and (d) pumping from existing irrigation wells in the valley was reduced by 10,000 gal/min (630 L/s). The model analysis indicated that most of the effects of dewatering the mine will be in the area about 0.5-4 mi (0.8-6 km) southeast of the mine (fig. 17). The actual drawdown of the mine wells was not computed, but it will be much greater than the maximum drawdown shown in figure 17.

Accuracy of the model results

The model produces precise results, but the accuracy of the results is limited by the accuracy of the data input to the model. For example, in most parts of the study area the thickness and lateral extent of the ground-water reservoir must be inferred, and adequate hydraulic data are available only for a few small areas. The assumptions used in the formulation of the model, consequently, introduce some degree of uncertainty in the model results. The fact that a good fit was obtained between measured and simulated hydraulic heads does not mean that equally good matches could not be obtained using other combinations of modeled data. In theory, the good fit that simulated the 1937 conditions could be obtained by an infinite number of data combinations. For this reason, during the calibration phase the sensitivity of each type of data was tested by simulations during which the data were changed by a selected amount while all others were held at set values.

The model is relatively insensitive to moderate changes in all data related to the physical and hydraulic characteristics of the ground-water reservoir except at two or three nodes immediately within and around most of the boundary perimeter. At these nodes, moderate changes in either hydraulic conductivity or reservoir thickness cause moderate deviations from the accepted fit. The fact that moderate deviations from the calibrated values usually results in only small hydraulic-head changes indicates that the model is a reasonable representation of the real system except near the reservoir boundary. The reliability of the model is not known in that part of the reservoir consisting of ignimbrite.

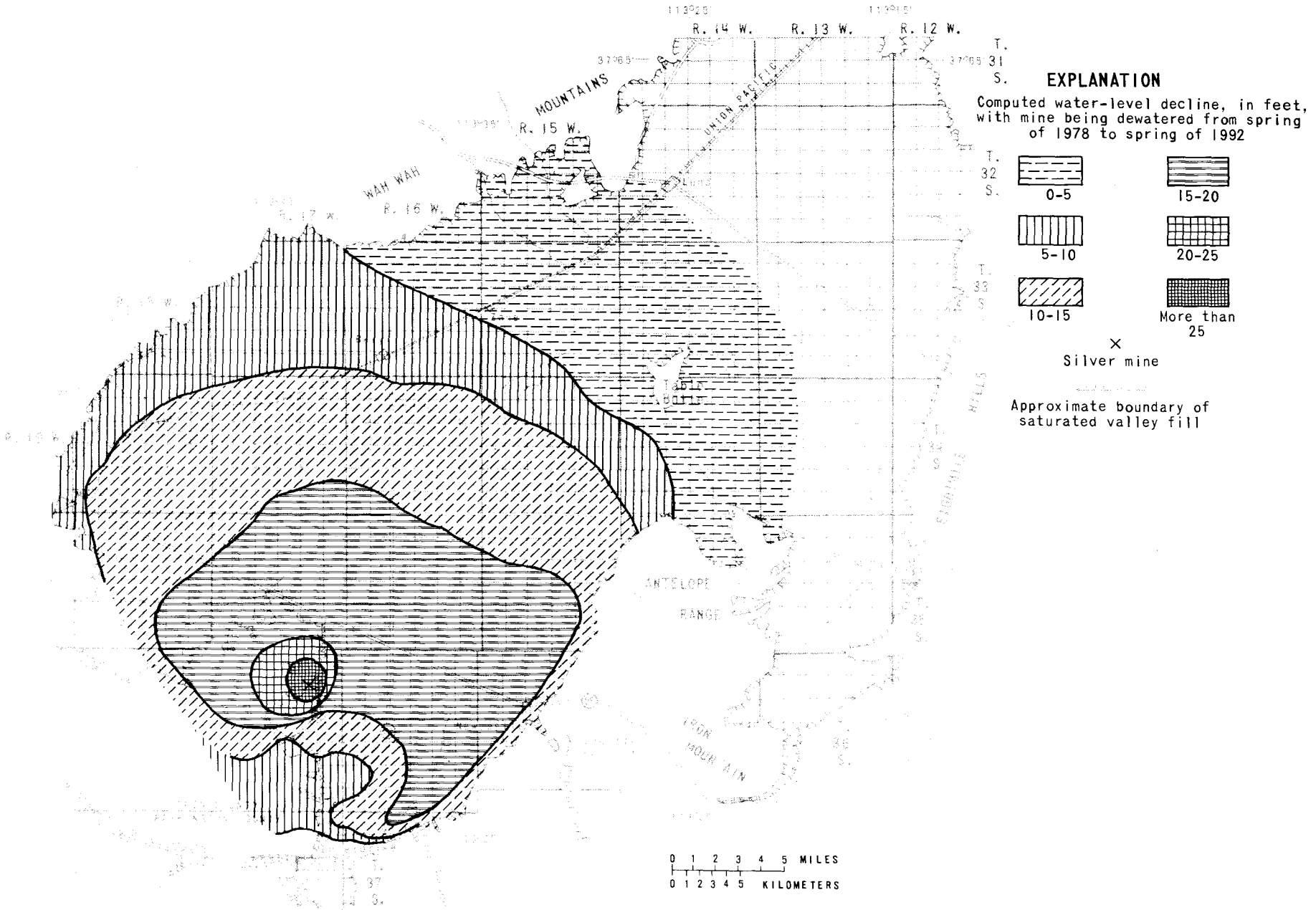

Figure 17.-Simulated water-level declines with 1969-77 pumping regimen continued and mine dewatering added, spring 1978 to spring 1992.

SUMMARY

Water used in the Beryl-Enterprise area is 7 percent surface water and 93 percent ground water. About 99 percent of the water is used for irrigation.

The principal ground-water reservoir includes saturated valley fill with a maximum thickness of 1,000 ft (300 m) and ignimbrite with a maximum thickness of 500 ft (150 m).

The ground-water reservoir was in approximate hydrologic equilibrium during 1937, but since then ground-water withdrawals have exceeded recharge, resulting in the withdrawal of water from storage. The amount of ground water in storage during the spring of 1978 was 72 million acre-ft (89,000 hm^3). A 1-ft (0.3-m) average change of water level in the principal ground-water reservoir from the level in the spring of 1978 would result in a change in storage of 100,000 acre-ft (120 hm^3).

The decline in water level during 1937-78 ranged from more than 60 ft (18 m) near the center of the pumped area to zero in the northern one-half of the Beryl-Enterprise area. The average annual decline in the central pumped area is as much as 2 ft (0.6 m).

Phreatophytes occupied about 93,000 acres (38,000 hm^2) during 1927 and during 1937 when they consumed 26,000 acre-ft (32 hm^3) of ground water. The area had decreased to 90,000 acres (36,000 hm^2) during 1977 and the consumption of ground water had decreased to 6,000 acre-ft (7 hm^3).

The concentration of dissolved solids in ground water in most of the area is less than 1,000 milligrams per liter. The greatest concentrations are found in small areas near Beryl, Lund, and Newcastle. Most of the ground water has a low-sodium hazard and a medium- to high-salinity hazard, and none of the water is known to contain concentrations of minor elements that are toxic to crops grown in the area.

Simulation by a digital-computer model of the principal ground-water reservoir indicates that water levels will continue to decline from 1978 to 1992 at a slightly slower rate than was occurring during the spring of 1978, assuming conditions of recharge and discharge similar to those for 1969-77.

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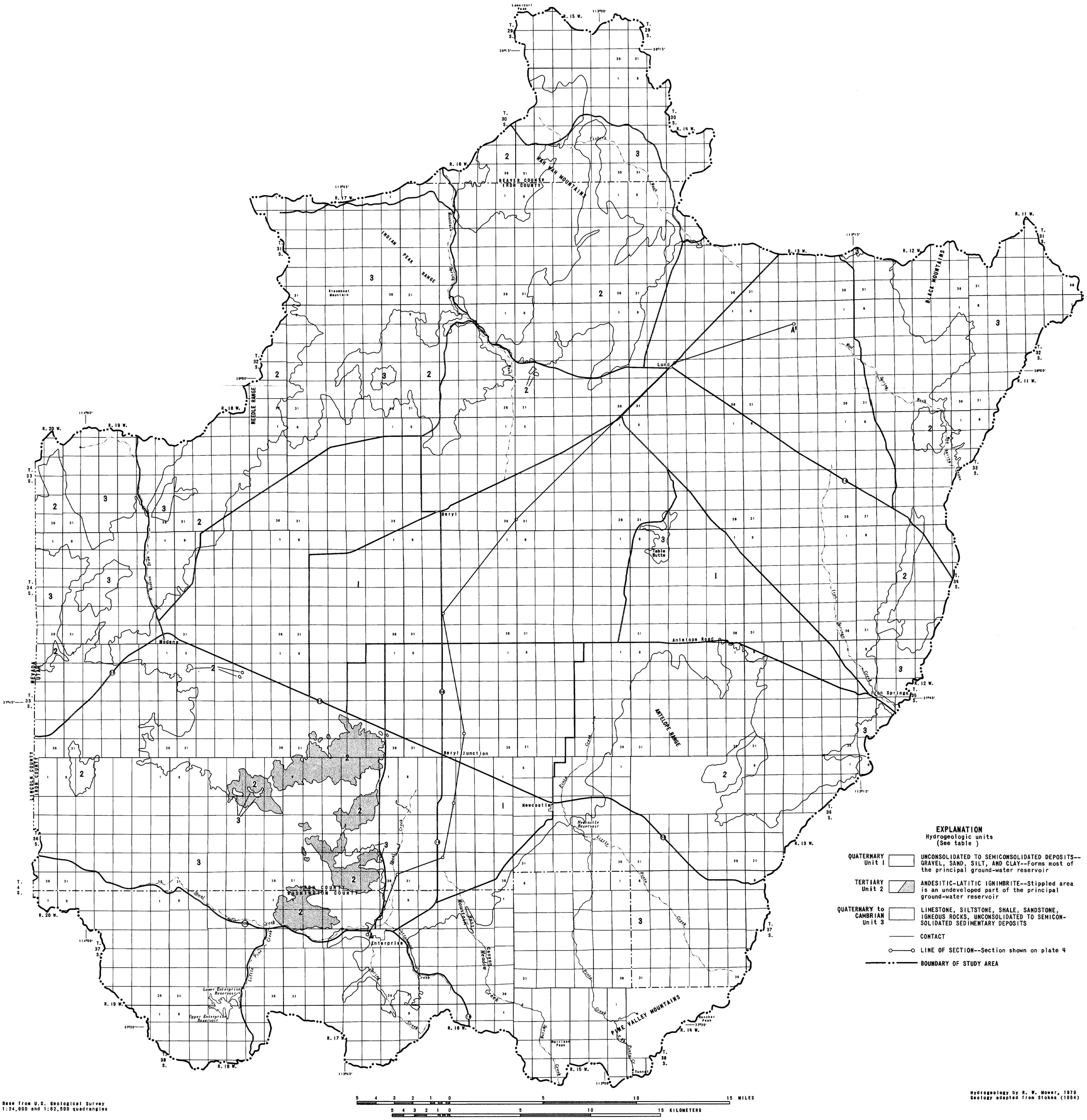
TECHNICAL PUBLICATION NO. 73
1982
PLATE I



MAP SHOWING AREAS OF HYDROGEOLOGIC UNITS IN THE BERYL-ENTERPRISE AREA, UTAH.

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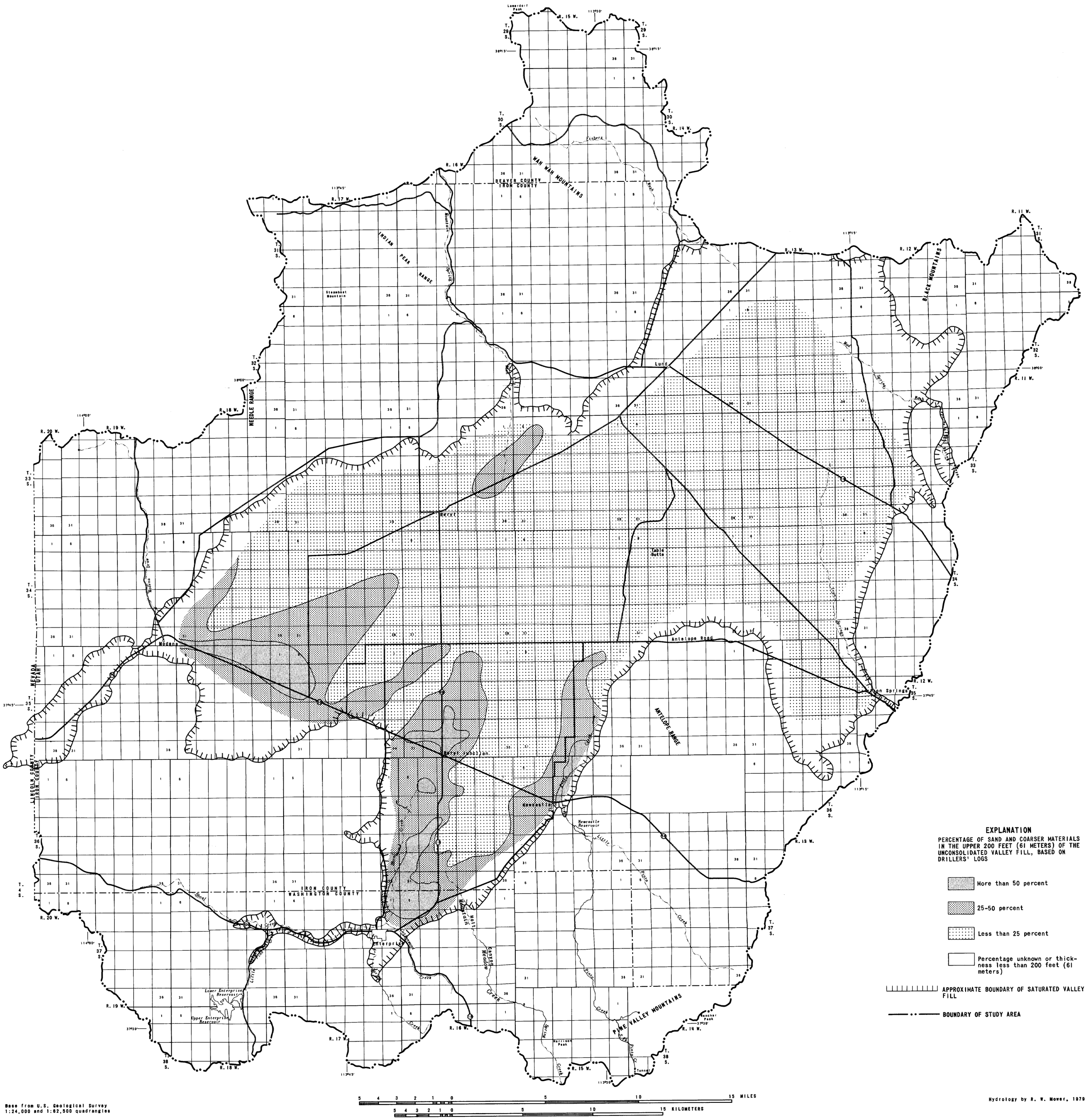

Base from U.S. Geological Survey
1:24,000 and 1:62,500 quadrangles

Hydrology by R. W. Mower, 1979

MAP SHOWING DISTRIBUTION OF SAND AND COARSER MATERIALS IN THE BERYL-ENTERPRISE AREA, UTAH.

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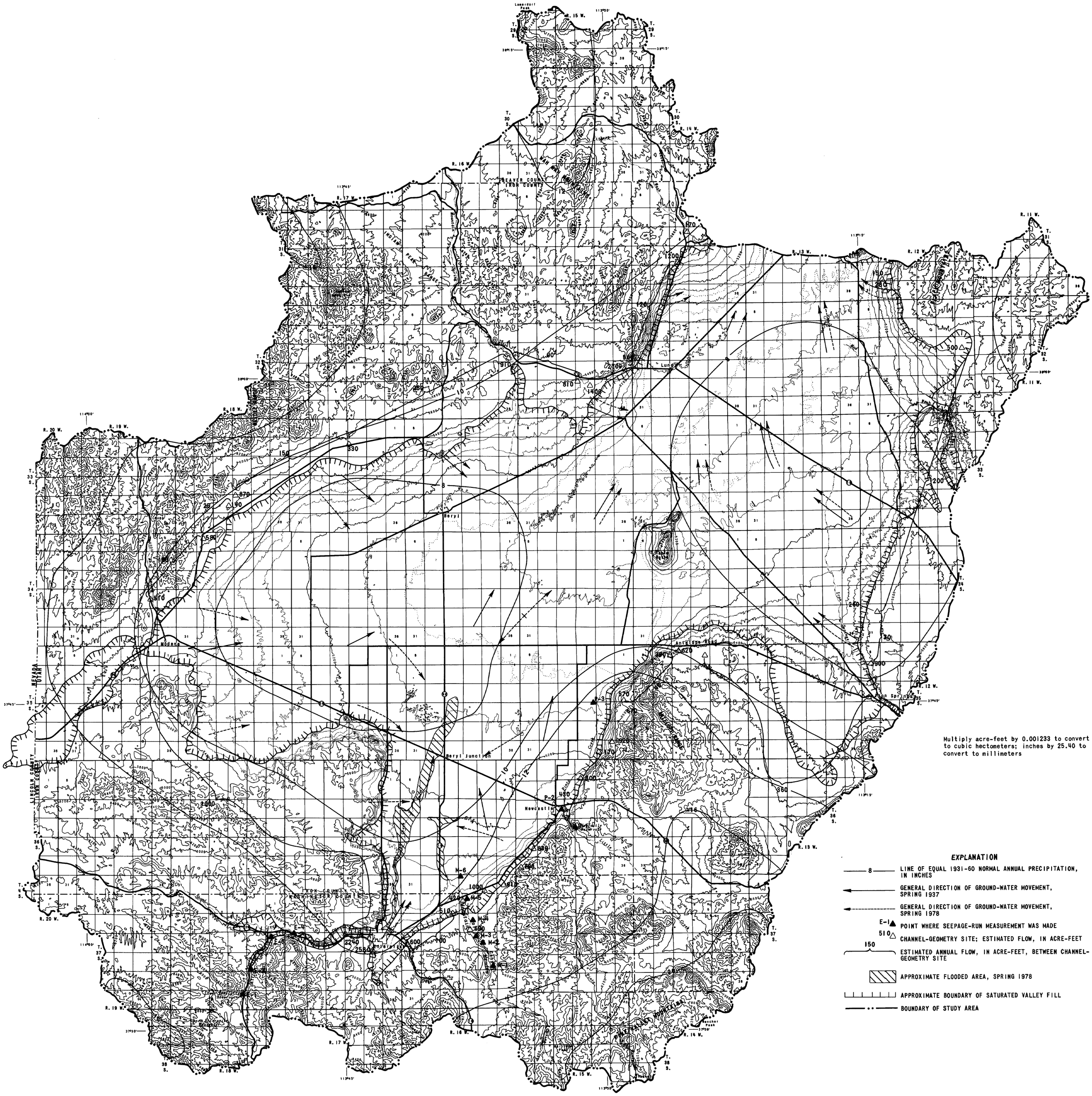

MAP SHOWING 1931-60 NORMAL ANNUAL PRECIPITATION AND GENERAL DIRECTION OF GROUND-WATER MOVEMENT DURING SPRING 1937 AND SPRING 1978, AND MEASUREMENT POINTS FOR SEEPAGE RUNS, CHANNEL-GEOMETRY SITES, ESTIMATED AVERAGE ANNUAL FLOW, AND APPROXIMATE FLOODED AREA, SPRING 1978, IN THE BERYL-ENTERPRISE AREA, UTAH.

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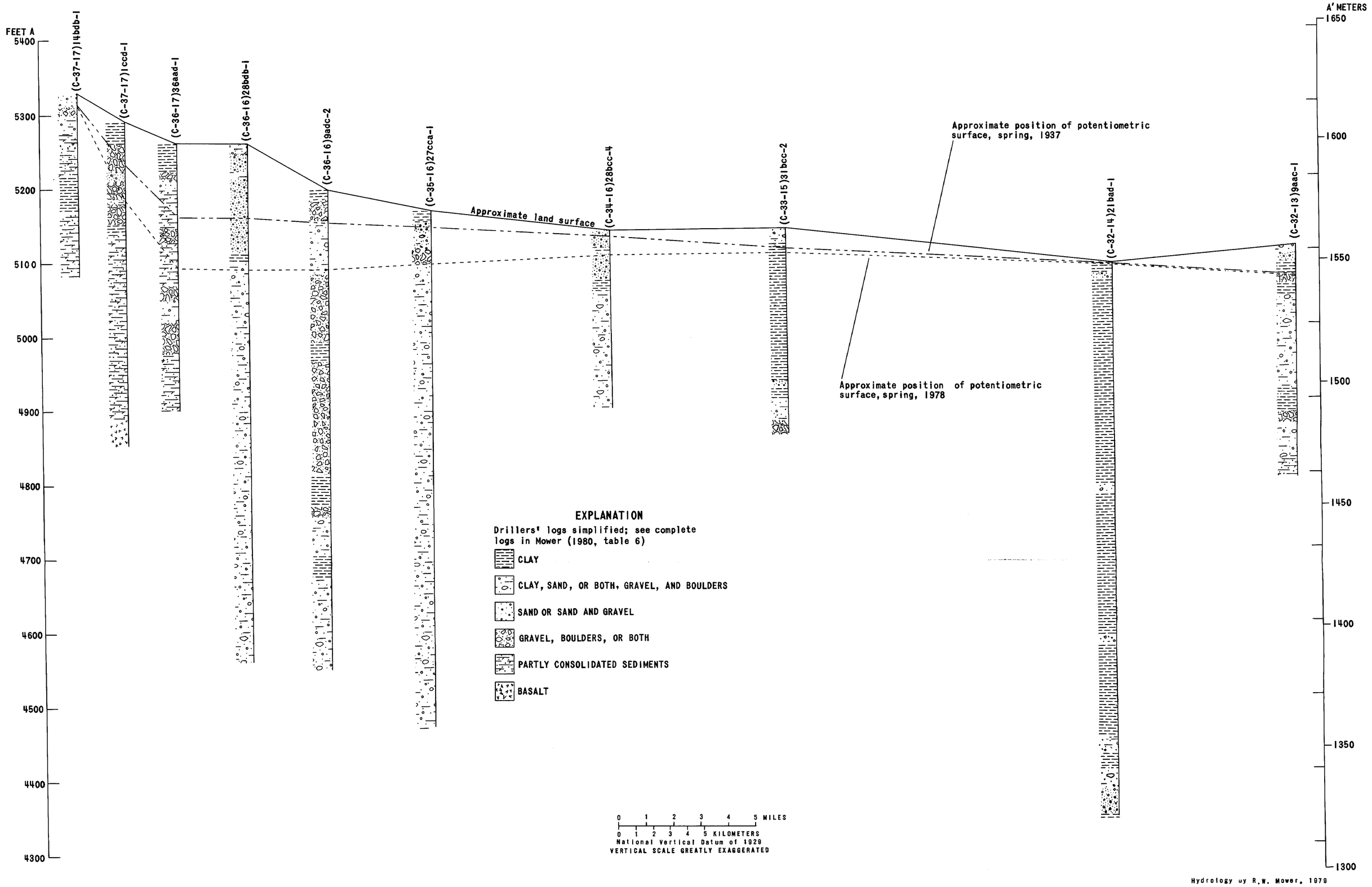

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LITHOLOGIC LOGS ALONG SECTION A-A', IN THE BERYL-ENTERPRISE AREA, UTAH.

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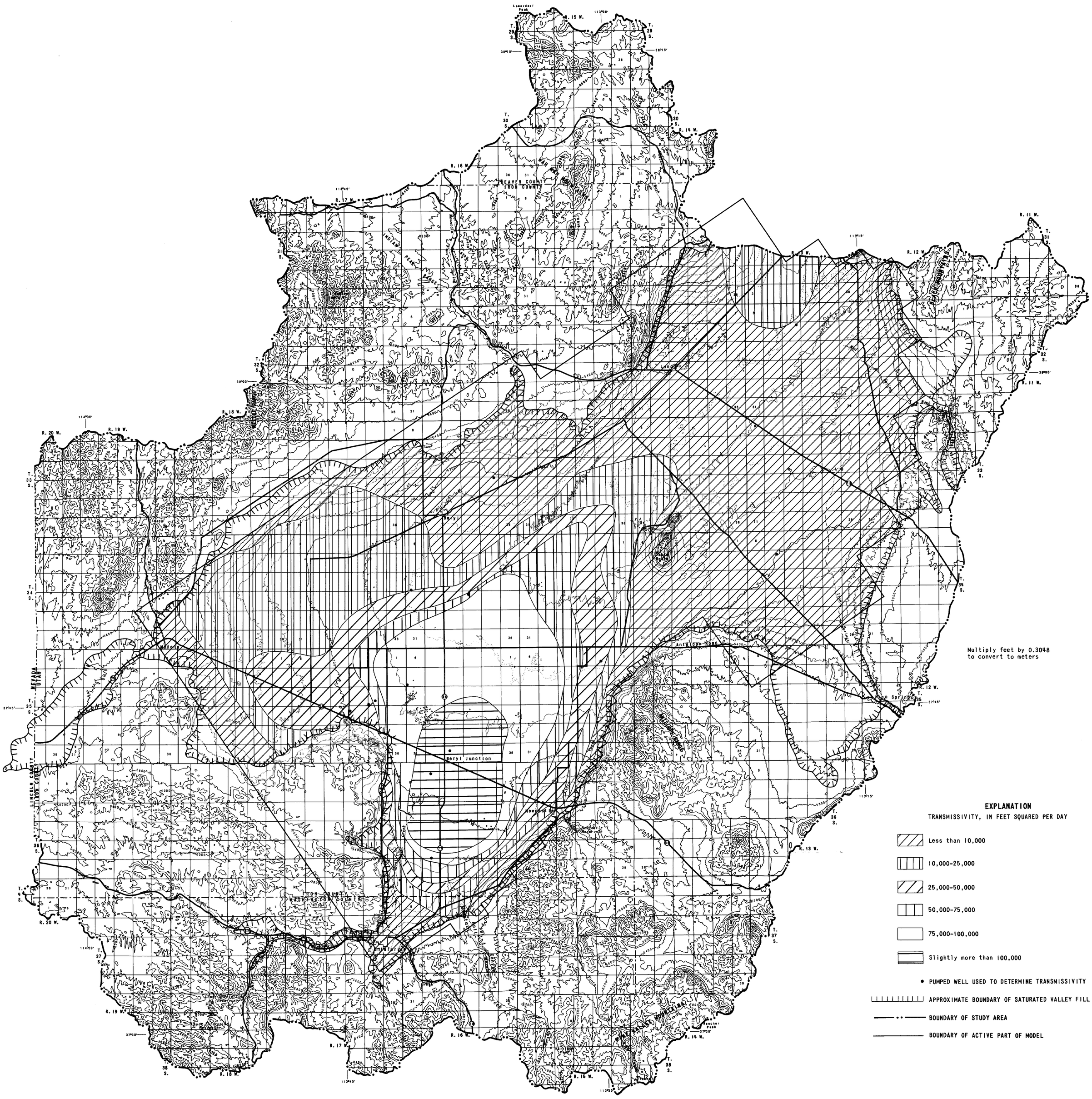

Base from U.S. Geological Survey
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Hydrology by R. W. Mower, 1979

MAP SHOWING TRANSMISSIVITY OF THE GROUND-WATER RESERVOIR AS USED IN THE DIGITAL-COMPUTER MODEL IN THE BERYL-ENTERPRISE AREA, UTAH.

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TECHNICAL PUBLICATION NO. 73
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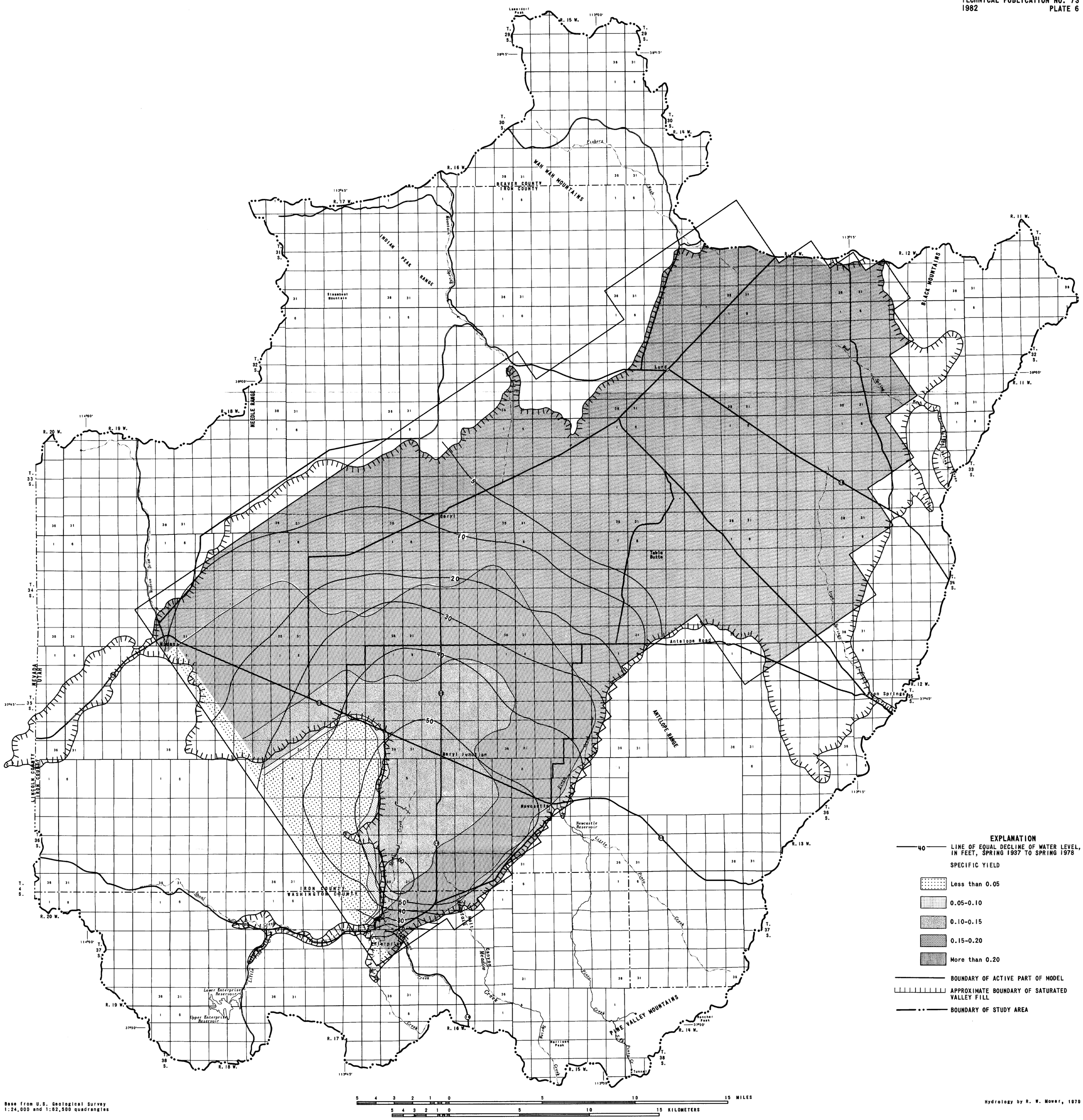
PLATE 6



MAP SHOWING SPECIFIC YIELD OF THE PRINCIPAL GROUND-WATER RESERVOIR AS USED IN THE DIGITAL-COMPUTER MODEL, AND SIMULATED DECLINES OF WATER LEVELS FROM SPRING 1937 TO SPRING 1978 IN THE BERYL-ENTERPRISE AREA, UTAH.

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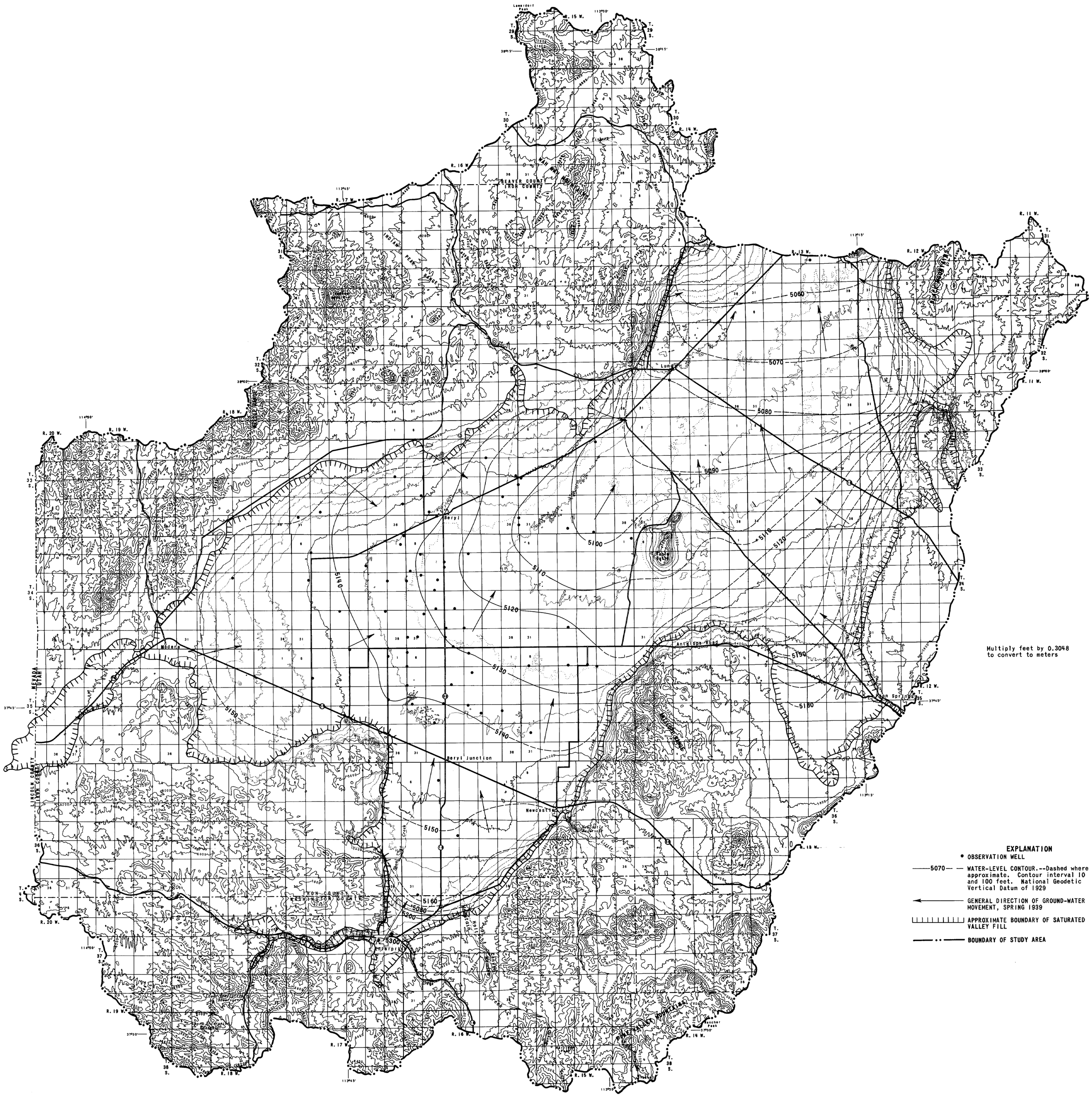

MAP SHOWING POTENTIOMETRIC-SURFACE CONTOURS AND GENERAL DIRECTION OF GROUND-WATER MOVEMENT, SPRING 1937, IN THE BERYL-ENTERPRISE AREA, UTAH.

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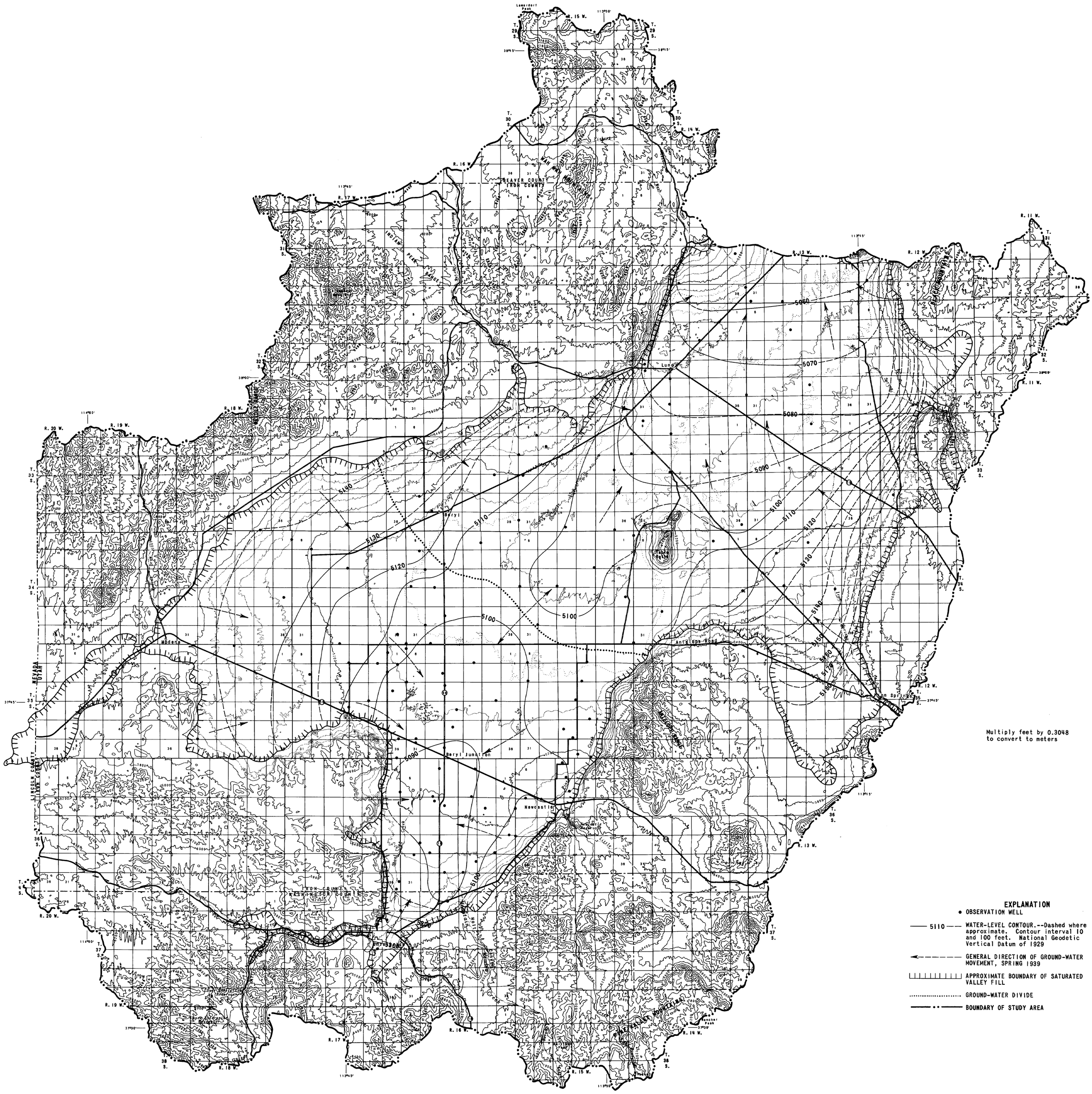
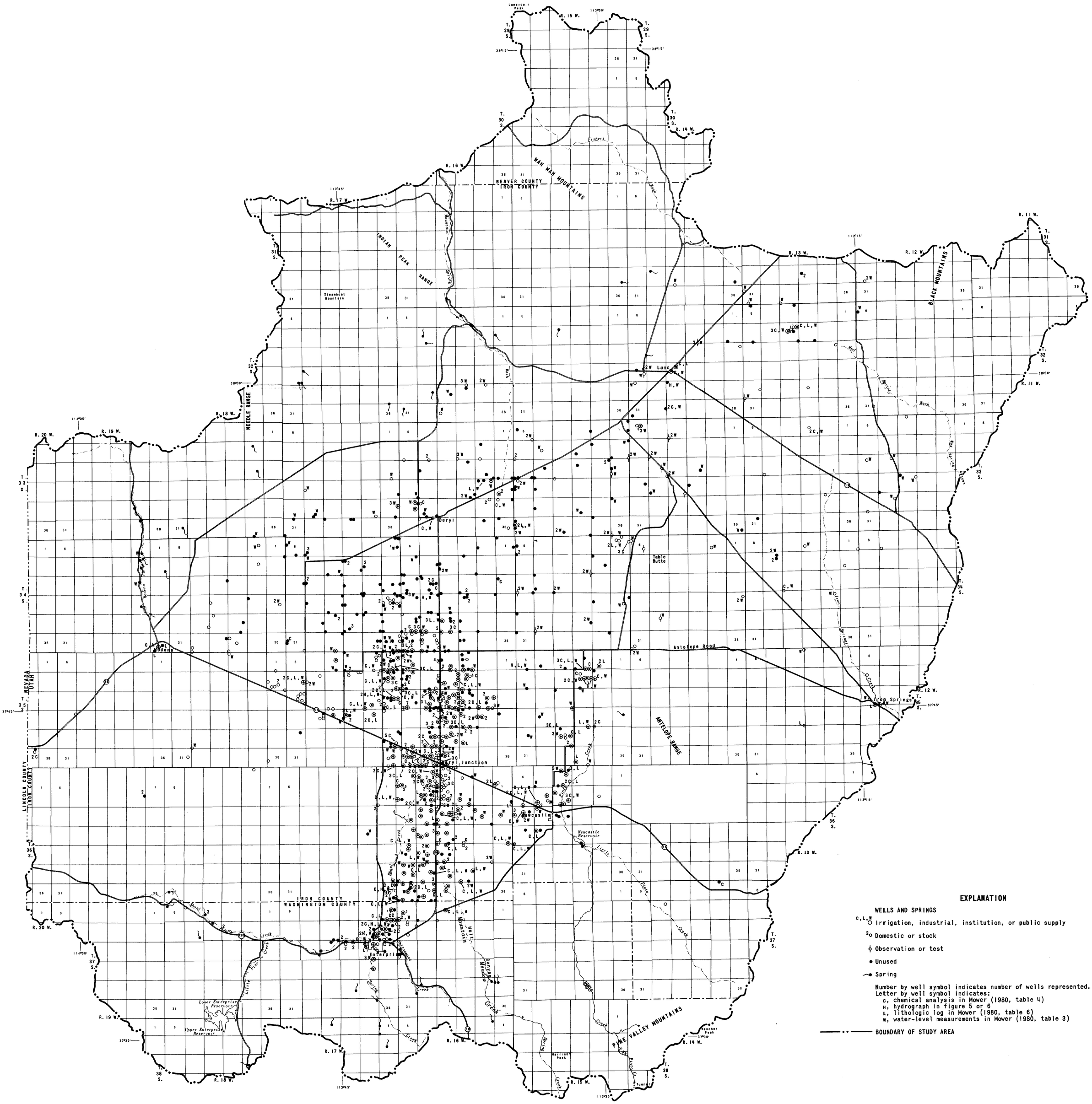


Base from U.S. Geological Survey
1:24,000 and 1:62,500 quadrangles

Hydrology by R. W. Mower, 1979

MAP SHOWING POTENTIOMETRIC-SURFACE CONTOURS AND GENERAL DIRECTION OF GROUND-WATER MOVEMENT, SPRING 1978, IN THE BERYL-ENTERPRISE AREA, UTAH.

Prepared in cooperation with the
STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES AND ENERGY

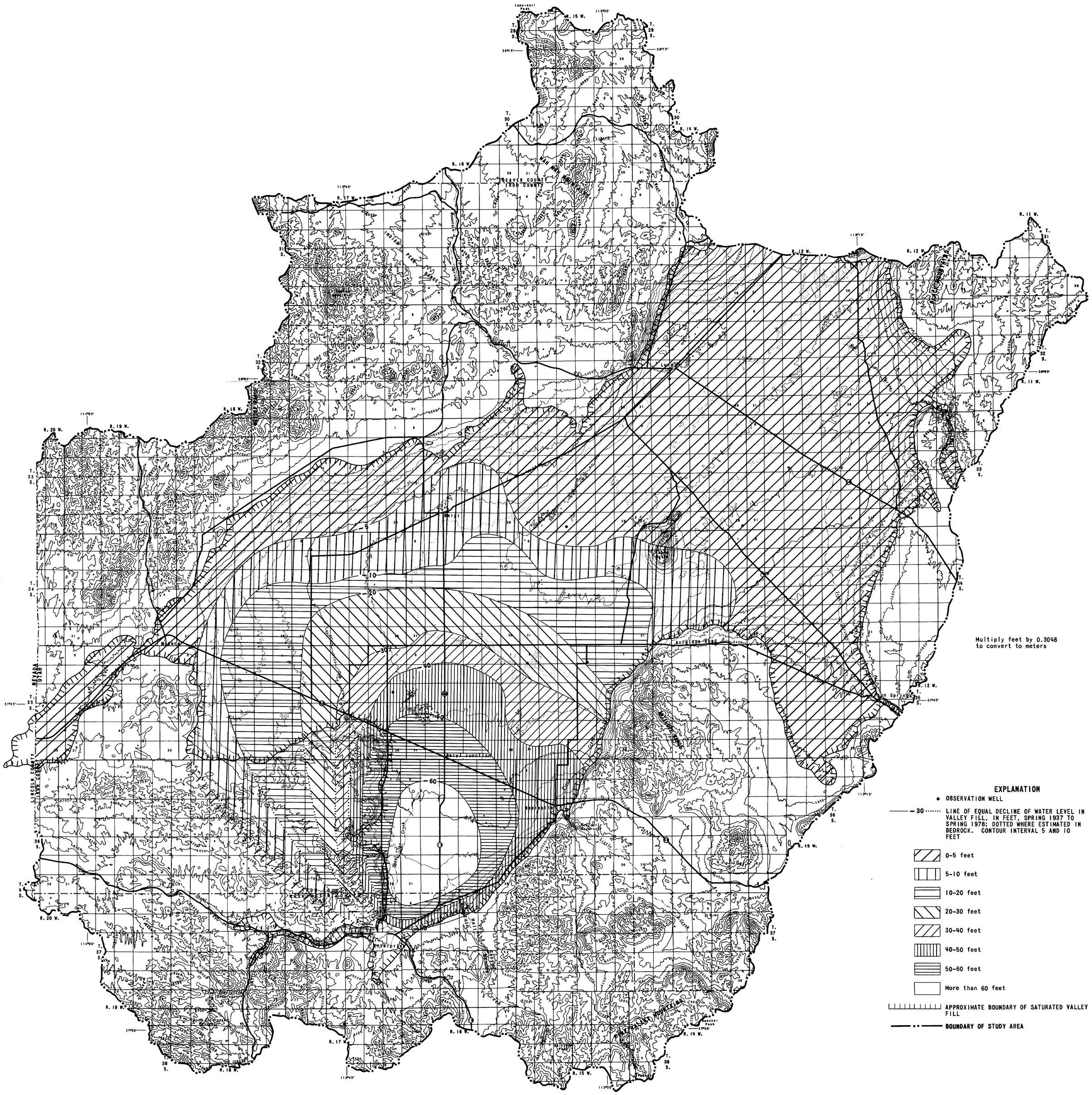


Base from U.S. Geological Survey
1:14,000 and 1:62,500 quadrangles

Hydrology by R. W. Mower, 1979

MAP SHOWING LOCATION OF SELECTED WELLS AND SPRINGS IN THE BERYL-ENTERPRISE AREA, UTAH.

Prepared in cooperation with the
STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES AND ENERGY


Multiply feet by 0.3048
to convert to meters
EXPLANATION
OBSERVATION WELL
30 LINE OF EQUAL DECLINE OF WATER LEVEL IN VALLEY FILL, IN FEET, SPRING 1937 TO SPRING 1978; DOTTED WHERE ESTIMATED IN BEDROCK. CONTOUR INTERVAL 5 AND 10 FEET
0-5 feet
5-10 feet
10-20 feet
20-30 feet
30-40 feet
40-50 feet
50-60 feet
More than 60 feet
APPROXIMATE BOUNDARY OF SATURATED VALLEY FILL
BOUNDARY OF STUDY AREA
BEAVER COUNTY
IRON COUNTY
LINCOLN COUNTY
NEVADA
UTAH
Beryl
Beryl Junction
Newcastle
Enterprise
Modena
Lund
Antelope Range
Antelope Road
Indian Peak Range
Lunigo
Cedar City
Iron Springs
Lower Kanarra Reservoir
Upper Kanarra Reservoir
Kanarra Creek
Shoal Creek
Little Creek
Pinto Creek
Rocky Ridge
Rocky Ridge Reservoir
Rocky Ridge Creek
Pinto Valley
Pinto Creek
Rocky Ridge Creek
Rocky Ridge Reservoir
Rocky Ridge Creek
Rocky Ridge Reservoir
Rocky Ridge Creek
Rocky Ridge Reservoir

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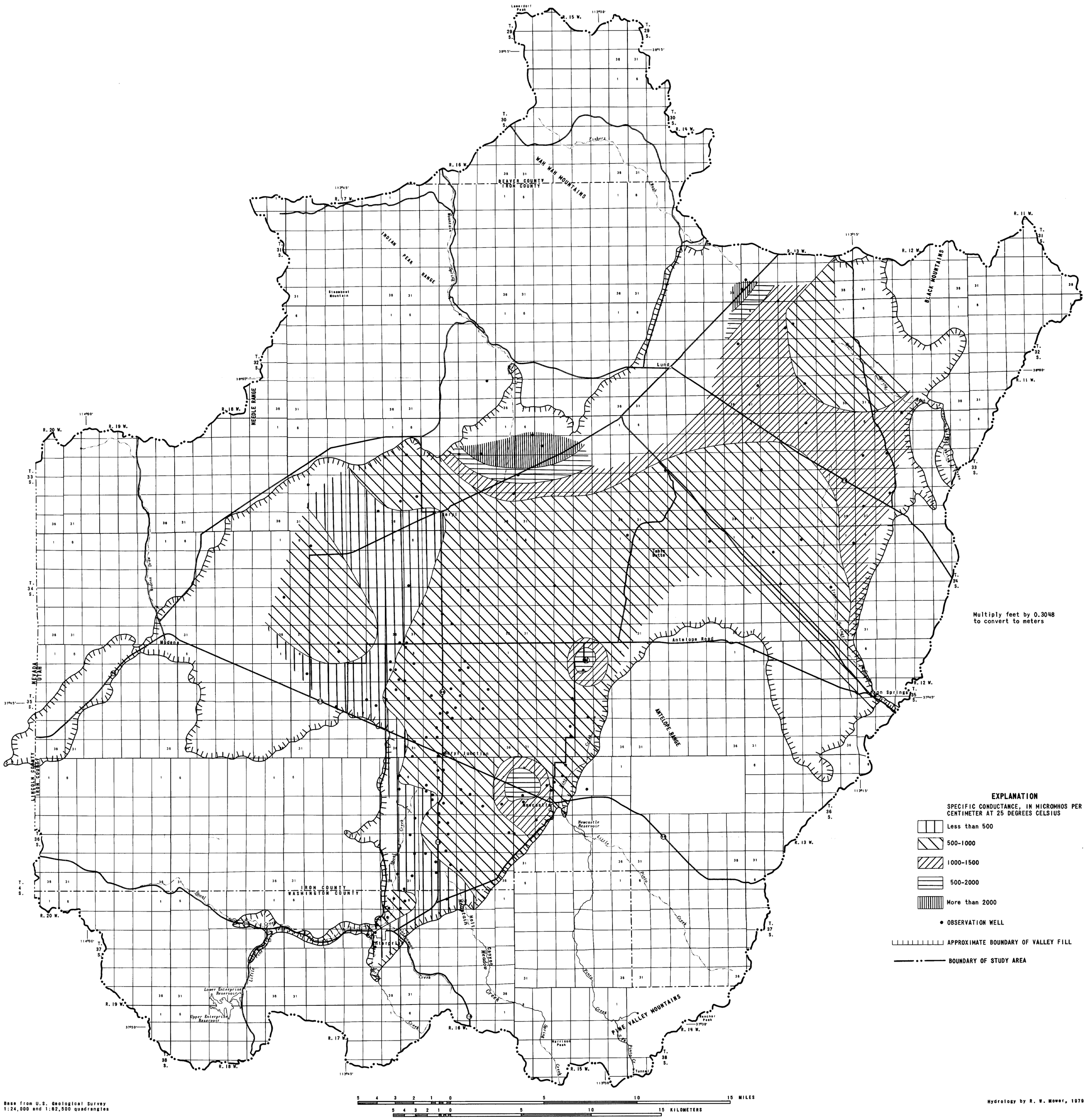
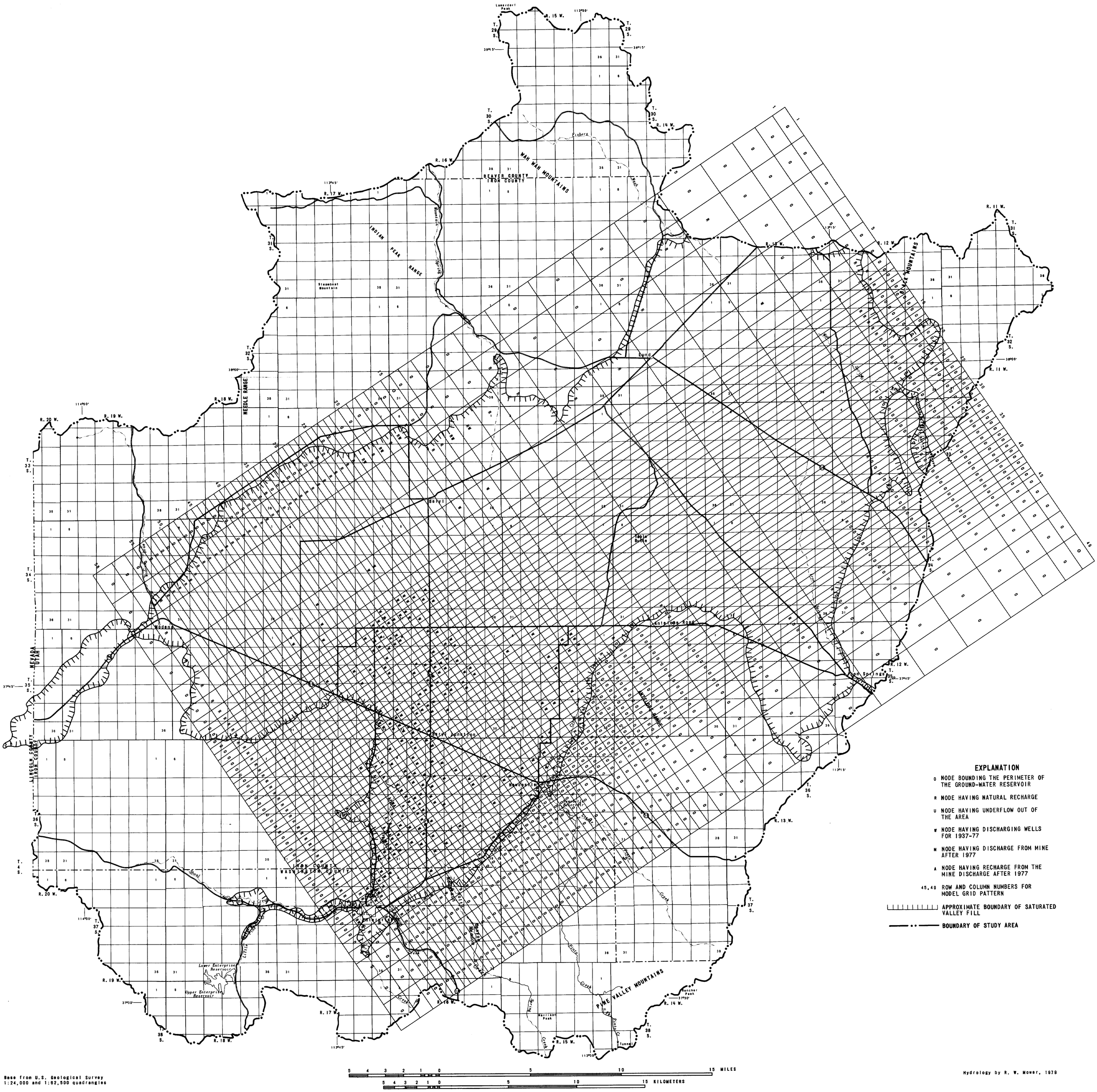


Base from U.S. Geological Survey
1:24,000 and 1:62,500 quadrangles

Hydrology by R. W. Mower, 1979

MAP SHOWING THE GENERAL CHEMICAL QUALITY OF GROUND WATER AS INDICATED BY SPECIFIC CONDUCTANCE, 1949-78, IN THE BERYL-ENTERPRISE AREA, UTAH.

Prepared in cooperation with the
STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES AND ENERGY



RECTANGULAR GRID USED WITH THE DIGITAL-COMPUTER MODEL OF THE GROUND-WATER RESERVOIR IN THE BERYL-ENTERPRISE AREA, UTAH.