STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

Technical Publication No. 98

GROUND-WATER HYDROLOGY OF PAHVANT VALLEY AND ADJACENT AREAS, UTAH

By

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Prepared by the
United States Geological Survey
in cooperation with the
Utah Department of Natural Resources
Division of Water Rights

1990

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
acre	0.4047	hectare
	4,047	square meter
acre-foot	0.001233	cubic hectometer
	1,233	cubic meter
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
foot per day	0.3048	meter per day
foot squared per day	0.0929	meter squared per day
gallon	0.06308	liter per second
	0.00006308	cubic meter per second
gallons per minute	0.063	liters per second
inch	25.40	millimeter
	0.0254	meter
mile	1.609	kilometer
pound	1.121	kilogram per hectare
square mile	2.590	square kilometer

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. Specific conductance is given in microsiemens per centimeter (μs/cm) at 25 degrees Celsius.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8\,(°C) + 32.$$

The term acre-feet per year is also used in this report. To obtain acre-feet per year, divide cubic feet per second by 0.00138.

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

The primary ground-water reservoir in Pahvant Valley and adjacent areas is in the unconsolidated basin fill and interbedded basalt. Recharge in 1959 was estimated to be about 70,000 acre-feet per year and was mostly by seepage from streams, canals, and unconsumed irrigation water and by infiltration of precipitation. Discharge in 1959 was estimated to be about 109,000 acre-feet and was mostly from springs, evapotranspiration, and wells.

Water-level declines of more than 50 feet occurred in some areas between 1953 and 1980 because of less-than-normal precipitation and extensive pumping for irrigation. Water levels recovered most of these declines between 1983 and 1986 because of reduced withdrawals and record quantities of precipitation.

The quality of ground water in the area west of Kanosh has deteriorated since large ground-water withdrawals began in about 1953. The cause of the deterioration probably is movement of poor quality water into the area from the southwest and possibly the west during periods of large ground-water withdrawals and recycling of irrigation water. The quality of water from some wells has improved since 1983, due to increased recharge and decreased withdrawals for irrigation.

Water-level declines of more than 80 feet in some parts of Pahvant Valley are projected if ground-water withdrawals continue for 20 years at the 1977 rate of about 96,000 acre-feet. Rises of as much as 58 feet and declines of as much as 47 feet are projected with withdrawals of 48,000 acre-feet per year for 20 years. The elimination of recharge from the Central Utah Canal is projected to cause water-level declines of up to 8 feet near the canal.

INTRODUCTION

The Utah Department of Natural Resources, Division of Water Rights; local irrigation companies; and other water users in Pahvant Valley and adjacent areas need information on the ground-water system to enable them to better manage water resources. More specifically, information is needed on how changes in irrigation diversions and practices or possible future changes in ground-water withdrawals and recharge might affect the ground-water system. In order to address these concerns, the U.S. Geological Survey, in cooperation with the Utah Division of Water Rights, evaluated the ground-water hydrology of Pahvant Valley and adjacent areas during 1985-88.

Purpose and Scope

This report describes the ground-water hydrology of Pahvant Valley and adjacent areas and discusses the effects of possible future changes in ground-water withdrawals and recharge. Data on ground-water recharge, movement, discharge, hydraulic properties, water-level fluctuations, storage, and water quality in the unconsolidated basin fill and interbedded basalt are presented. Results of a computer simulation, which was used to project the effects of future ground-water withdrawals and loss of recharge from the Central Utah Canal, also are described in this report.

Previous Studies and Acknowledgments

Previous studies of the ground-water hydrology of Pahvant Valley and adjacent areas include those by Meinzer (1911), Livingston and Maxey (1944), Dennis and others (1946), Nelson and Thomas (1953), Mower (1965 and 1967), Handy and others (1969), Hamer and Pitzer (1978), and Holmes (1983 and 1984). Previously published compilations of basic data include those by Mower (1963), Mower and Feltis (1964), Hahl and Cabell (1965), Enright and Holmes (1982), and Thiros (1988). Other data on changes in water levels and ground-water withdrawals are in a series of annual ground-water reports prepared by the U.S. Geological Survey, the most recent being that by Cordy and others (1988). Records from surface- and ground-water data-collection networks in Utah are published in a series of annual hydrologic data reports, the most recent being that by ReMillard and others (1988). A water-budget analysis for the Sevier River basin was published by the U.S. Department of Agriculture (1969).

This study could not have been completed without the cooperation of local well owners, irrigation companies, municipalities, utility companies, and the Utah Division of Water Rights and the Division of Wildlife Resources. Access to wells and springs, and data supplied by well owners and other agencies are appreciated.

Numbering System for Hydrologic-Data Sites

The system of numbering wells, springs, and other hydrologic-data sites in this report, illustrated in figure 1, is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the site, describes its position in the land net. By the land-survey system, the State of Utah is divided into four quadrants by the Salt Lake Base Line and Meridian, and these quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. 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[1]; the letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well or spring within the 10-acre tract; the letter S preceding the serial number denotes a spring. The letters following the serial number denote W, a stream or X, a slough. Thus, (C-21-5)21aba-1 designates the first well constructed or visited in the NE$\frac{1}{4}$, NW$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 21, T. 21 S., R. 5 W.

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[1]Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular. Such sections are divided into 10-acre 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.

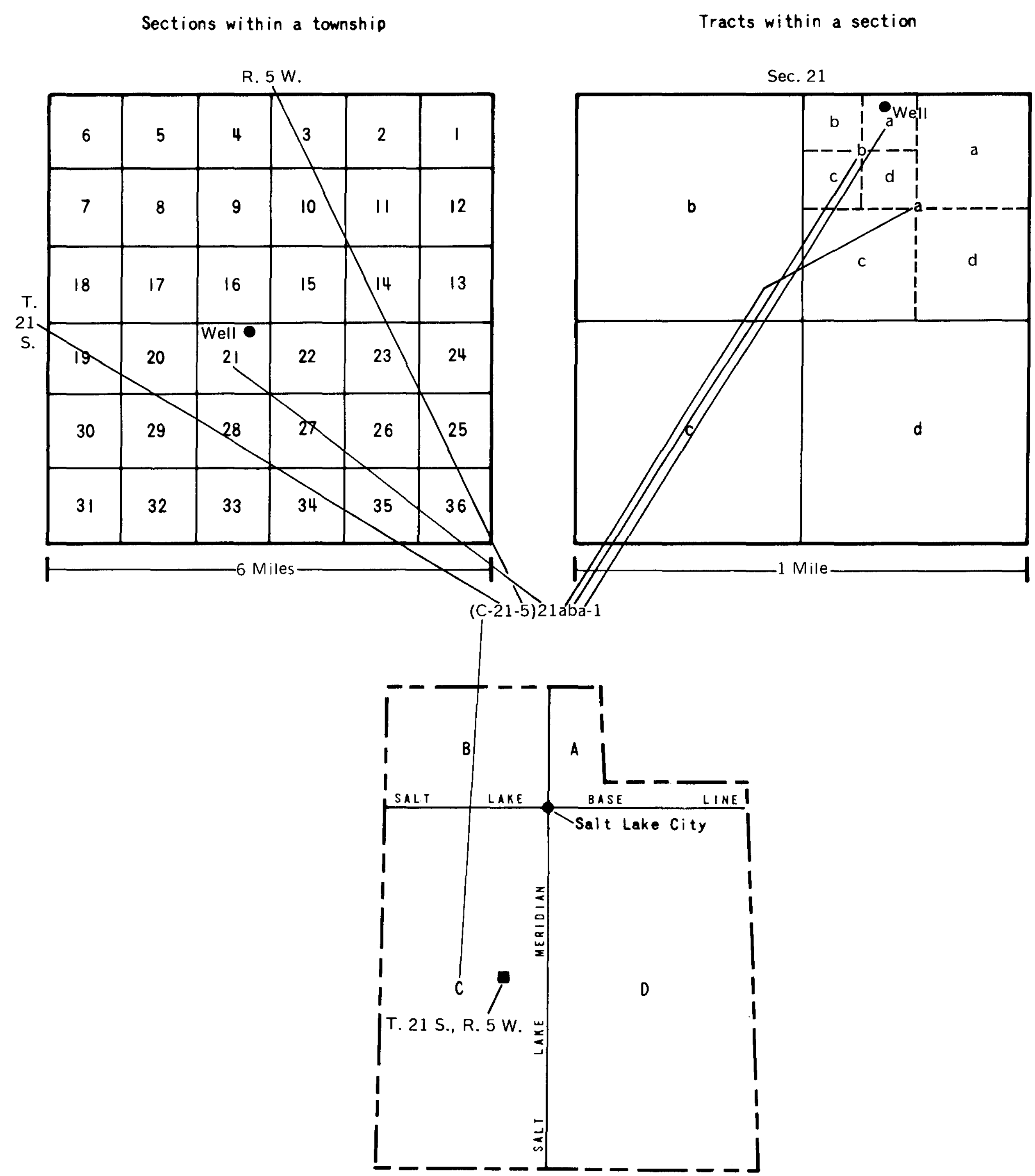


Figure 1.--Numbering system used in this report for hydrologic-data sites.

Description of the Study Area

Physiography

The study area is located in Millard County in west-central Utah (fig. 2) and is part of the Great Basin section of the Basin and Range province (Fenneman, 1931). The area encompasses about 1,600 square miles and includes Pahvant Valley on the east and the southern part of the Sevier Desert on the west. The highest point in the study area is Mine Camp Peak in the Pahvant Range with an altitude of 10,222 feet, and the lowest point is on the Beaver River channel at the northwest boundary of the study area with an altitude of about 4,560 feet.

The area is bounded on the east by the Canyon Mountains and the Pahvant Range, on the south by a topographic divide separating Pahvant Valley and the Sevier Desert from the Cove Creek drainage and the Milford area, and on the west by the Cricket Mountains. The northern boundary of the study area does not represent a topographic or ground-water divide. The boundary was located such that the study area included Clear Lake Springs, which is the primary natural ground-water discharge area for Pahvant Valley (pl. 1).

Geology

The rocks in the study area range from Precambrian to Holocene in age. The generalized geology of the study area is shown on plate 1.

The Pahvant Range, the eastern boundary of the study area, is generally considered to be part of the eastern edge of the Basin and Range physiographic province, and consists of consolidated rocks of Paleozoic to Cenozoic age. The stratigraphy of the Canyon Mountains, in the northeastern part of the study area, is similar to that of the Pahvant Range but includes rocks of Precambrian age.

Mitchell and McDonald (1987, p. 547) concluded from seismic data that normal Basin-and-Range-type faulting does not bound the Pahvant Range on the west or the Cricket Mountains on the east as was previously believed. The Sevier Desert basin was formed by normal movement (westward) along the deep-seated Sevier Desert detachment beginning in Paleocene to Eocene time. The Sevier Desert detachment has an average dip of 11 degrees west (Von Tish and others, 1985, p. 1082) and extends the length of the study area. Deposits of Tertiary age in the deepest part of the Sevier Desert basin within the study area may be more than 11,000 feet thick (Mitchell and McDonald, 1987, p. 539). The Cricket Mountains, the western edge of the study area, consist mainly of allochthonous Cambrian strata underlain by the Sevier Desert detachment. Crone and Harding (1984, p. 293) determined that recent high-angle normal faults near Clear Lake Springs either merge with or are truncated by this detachment.

Tertiary sedimentary deposits, chiefly fanglomerates and alluvium (Morris, 1978, p. 3), underlie most of the younger Cenozoic unconsolidated deposits in the study area and crop out at the base of the Pahvant Range and Canyon Mountains and as hills within Pahvant Valley. The Sevier River Formation of Pliocene to Miocene age (Steven and Morris, 1983, p. 2) consists of interlayered fine- to coarse-grained sediment deposited by fluvial and

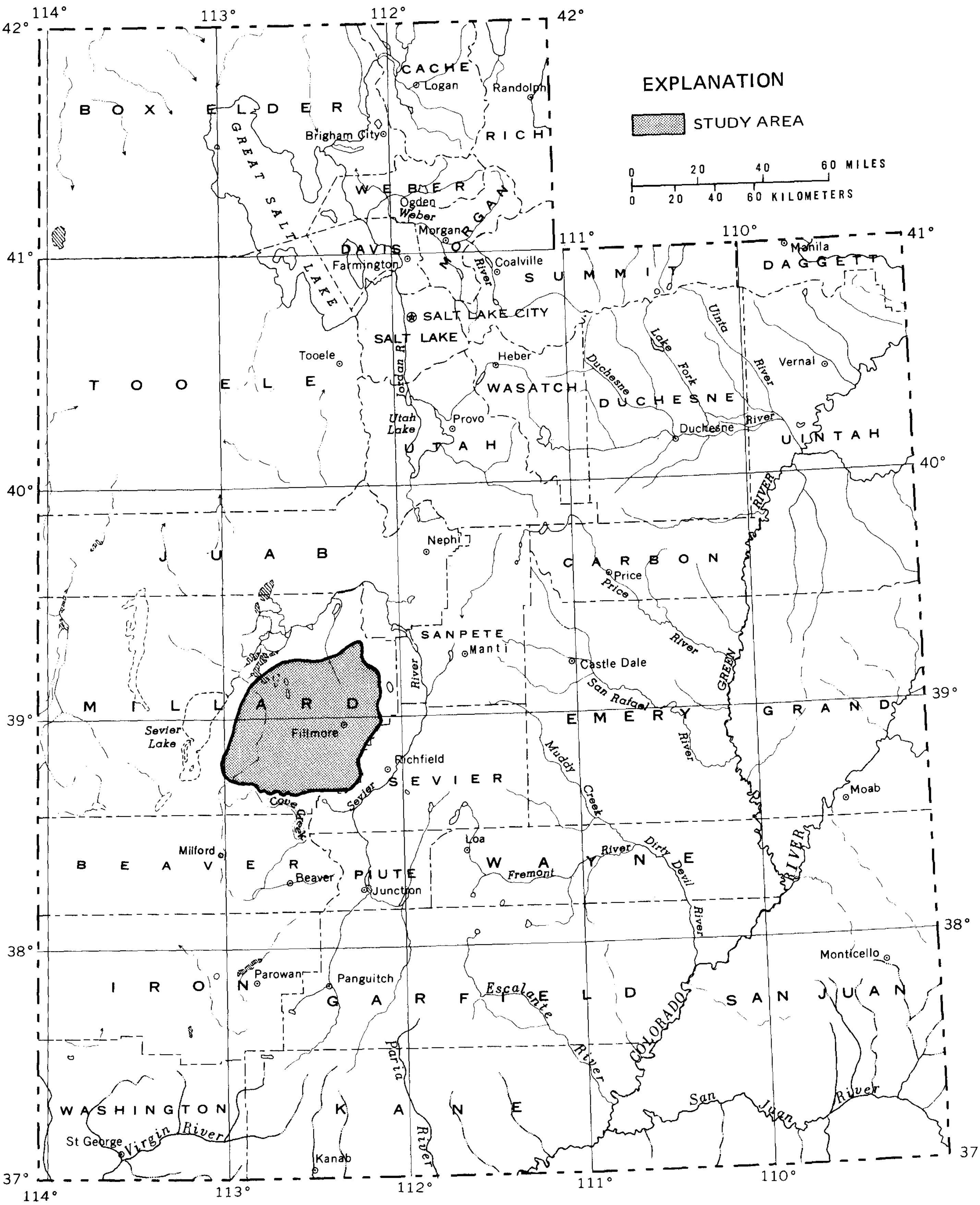


Figure 2.--Location of study area.

lacustrine processes. This unit is poorly to moderately consolidated and is largely impermeable to ground water occurring in the overlying unconsolidated deposits (Mower, 1965, p. 20). A disconformity separates the irregular surface of the Sevier River Formation from the younger lacustrine deposits. Exposed and possibly buried hills composed of the Sevier River Formation may influence or control the ground-water system of the area.

Alluvial fans which developed along the mountain fronts, predominantly during Quaternary time, were deposited synchronously with sediments laid down by intermittent lakes. The fans extended into the basin where they interfingered with lakebed deposits consisting of gravel, sand, silt, and clay. These deposits are unconsolidated and form one of the principal aquifers in Pahvant Valley. Pleistocene Lake Bonneville, the last of the intermittent lakes to inundate the area, existed between approximately 30,000 to 10,000 years B.P. (Oviatt and Currey, 1987, p. 259). Bars, spits, and beaches formed by Lake Bonneville can be found at or below the Provo substage level of 4,830 feet in Pahvant Valley.

Basaltic and rhyolitic volcanic rocks were deposited in the study area during late Tertiary and Quaternary time, the result of extension within the Basin and Range province (Hoover, 1974, p. 38). Silicic volcanism, which formed rhyolite domes and volcaniclastic deposits, took place in the central and southern part of the study area with White Mountain, a small silicic dome in Pahvant Valley, being extruded less than 1 million years ago (Hoover, 1974, p. 19). The name White Mountain is derived from the white gypsiferous sand deposits blown against the dome's base from the surrounding playa.

Basaltic rocks, found near or at the surface in the study area, were deposited during the past one million years. Basalt flows extend from 100 to 800 feet above the valley floor, forming a north-south-trending ridge which divides the study area into Pahvant Valley on the east and the Sevier Desert on the west. Hoover (1974, p. 5) divides these eruptive events into three episodes based on composition and age relations.

The Beaver Ridge and Kanosh volcanic fields, ranging in age from 918,000 to 536,000 years B.P., comprise episode 1. The eastward extent of the Beaver Ridge basalts is unknown because of normal faulting and a veneer of alluvium that obscures the outcrops. The Kanosh field consists of several cones, including the Black Rock Volcano, and lava flows that also have been subsequently covered by alluvium.

Episode 2 is composed of the Pahvant volcanic field which ranges in age from about 130,000 to 30,000 years B.P. Extruded subaerially, the basalt flows of this field are the most extensive in the study area. The flows contain abundant pressure ridges, lava tubes, and polygonal joints (Condie and Barsky, 1972, p. 338). The final eruptive stage in the Pahvant field was contemporaneous with Lake Bonneville and, therefore, was subaqueous. Pahvant Butte, a 750-foot-high tuff cone, rests unconformably upon the older Pahvant field basalts.

The last eruptive episode occurring in the area consisted of the Tabernacle and the Ice Springs volcanic fields. The subaqueous Tabernacle field basalts mainly were extruded during the Provo substage of Lake Bonneville (less than 12,000 years B.P.) from the base of a tuff cone called

Tabernacle Hill (Condie and Barsky, 1972, p. 339). The lack of Provo-substage-level terraces and the occurrence of pillow-like structures at the outer edges of the flows indicate a subaqueous eruption. The cinders, spatter cones, and lava of the Ice Springs field, about 3 miles west of Flowell, disconformably overlie Lake Bonneville sediments with an estimated age between 4,000 to 1,000 years B.P. (Hoover, 1974, p. 20). Ice Springs lavas also overlap the southern part of the Pahvant field.

Travertine ridges and deposits located west of Hatton are still being formed at hot and warm springs in the area. The travertine deposits follow the same northward trend along which the Kanosh and Ice Springs volcanic fields and Pahvant Butte are located.

Climate

The climate of the study area ranges from semiarid on the basin floor to subhumid at the higher altitudes in the mountains. Daytime temperatures on the basin floor during summer often exceed 40 °C and minimum temperatures during winter can be less than -20 °C. The 1951-80 normal annual temperature at Fillmore is about 11 °C (U.S. Department of Commerce, 1985).

The 1951-80 normal annual precipitation at Fillmore is 14.51 inches (U.S. Department of Commerce, 1985). February, March, and April are the wettest months while June, July, and August are the driest months. Precipitation generally was less than average during 1946-63 and 1974-77, near average during 1964-73, and above average from 1978-86. The 1982-85 average annual precipitation was 21.80 inches, 7.29 inches greater than the 1951-80 normal, and was the wettest four-year period on record (U.S. Department of Commerce, 1982-1985). The cumulative departure from average annual precipitation at Fillmore for 1946-86 is shown in figure 3.

The estimated annual evaporation for 1931-70 from bodies of fresh water was 69.52 inches at Milford, Utah, about 30 miles south of the study area (Waddell and Fields, 1977, table 12). The lower parts of the study area are topographically similar to the Milford area. Thus, the estimated annual evaporation from freshwater lakes in the lower altitudes of Pahvant Valley and adjacent areas is estimated to be about 70 inches.

Vegetation

The vegetation in uncultivated parts of Pahvant Valley and the Sevier Desert primarily consists of phreatophytes including greasewood, saltgrass, and rabbitbrush, with lesser amounts of saltcedar where the water table is near the surface and sagebrush where the water table is deeper. The vegetation in the higher areas primarily consists of sagebrush, juniper, pinyon pine, and oak on the foothills and low mountains, and pine, fir, aspen, oak, and sagebrush in the high mountains.

Irrigated croplands are restricted to Pahvant Valley in the eastern part of the study area. The main irrigated crops are alfalfa, grains, corn, and potatoes. In 1960, 35,300 acres of cropland were irrigated in Pahvant Valley of which 11,400 acres were irrigated exclusively with ground water (Mower, 1965, table 2). The Clear Lake Migratory Waterfowl Refuge, west of Pahvant

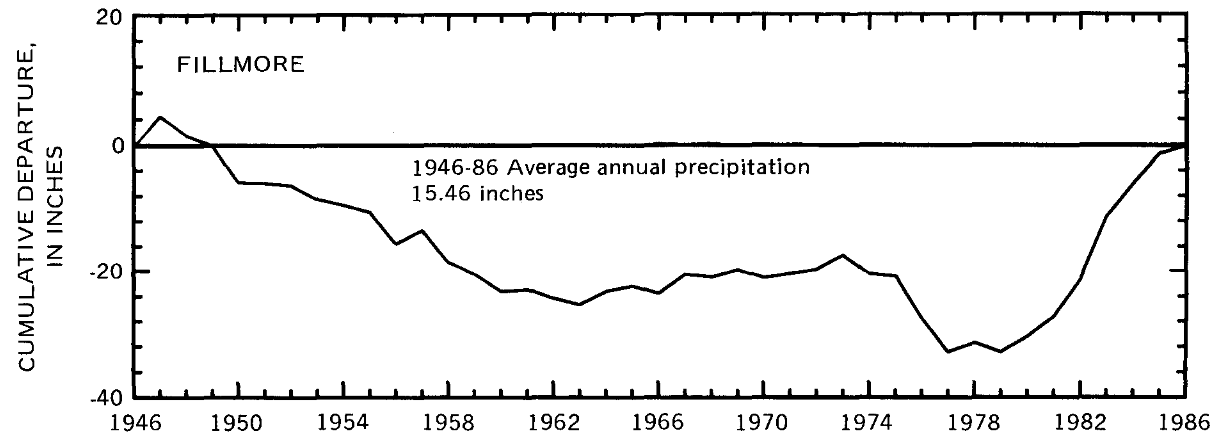


Figure 3.--Cumulative departure from average annual precipitation, 1946-86, at Fillmore, Utah.

Valley in the northern part of the study area, has more than 5,000 acres of lakes and marshes that are dependent on the flow of Clear Lake Springs.

Surface Water

The major sources of surface water in the study area are streams originating in the Canyon Mountains and the Pahvant Range along the eastern border of the study area and water imported from the Sevier River in the Central Utah Canal. The larger streams in the study area undergo many diversions for irrigation after leaving the mountain fronts. There has been no surface-water outflow from the study area since about 1914. With the exception of 1983-84, the Beaver River, which enters the study area on the southwest corner and leaves the study area on the northwest corner, has been dry within the study area since 1914. During 1983-84, however, some water in the Beaver River channel entered the study area and reached an earthen dam located about 6 miles south of Clear Lake Springs (Red Wilson, Beaver County News, oral commun., May 1985).

Chalk Creek is the largest stream in the study area. Gaging station 10232500, Chalk Creek near Fillmore, Utah, was operated by the U.S. Geological Survey during 1945-71. The average annual flow for 27 years of record was 22,000 acre-feet. Before irrigation began in Pahvant Valley (probably before 1900), much of the water in Chalk Creek flowed northwest across the valley to The Sink (pl. 1), a low-elevation area about 3 miles north of Flowell, where it percolated into underlying basalt (Mower, 1965, p. 12).

Corn Creek is in the southeast corner of the study area. Gaging station 10233500, Corn Creek near Kanosh, Utah, was operated by the U.S. Geological Survey during 1966-75, and the average annual flow for 10 years of record was 12,900 acre-feet. Some water from Corn Creek probably flowed to The Sink before irrigation began in Pahvant Valley.

Meadow Creek is east of the town of Meadow (pl. 1). Gaging station 10233000, Meadow Creek near Meadow, Utah, was operated by the U.S. Geological Survey during 1966-75, and the average annual flow for 10 years of record was 5,100 acre-feet.

The average annual flow from all other streams tributary to Pahvant Valley was estimated by Mower (1965, table 5) to be about 61,000 acre-feet. The estimate did not include flow from ephemeral streams in the Cricket Mountains which discharge into the Sevier Desert in the western part of the area.

Mower (1965, table 5) estimated the flow for the mountain area west of Corn Creek to be 100 acre-feet per 1,000 acres. The average elevation of the Cricket Mountains is about 1,000 feet lower than the average elevation for the mountain area west of Corn Creek, and the average annual precipitation is less than 10 inches, so the average annual flow from streams in the Cricket Mountains is probably less than 100 acre-feet per 1,000 acres. Assuming an average annual flow of 50 acre-feet per 1,000 acres, and an area of about 72,000 acres, which represents the area of the Cricket Mountains tributary to the study area above an altitude of 5,000 feet, the estimated annual average flow from the Cricket Mountains is 3,600 acre-feet.

The average annual inflow to the study area from the Central Utah Canal, based on data collected at a gaging station located about 2 miles east of McCornick during 1966, 1970-73, and 1975-77, is about 8,900 acre-feet (Roger Walker, Sevier River Commissioner, written commun., July 1985).

GROUND-WATER HYDROLOGY

Ground water in the study area is present in both consolidated rocks and unconsolidated basin fill. The primary ground-water reservoir is the unconsolidated basin fill, but consolidated basalt flows crop out and are interbedded with the unconsolidated fill in some parts of the study area and are considered part of the primary ground-water reservoir. Water in consolidated rocks in the mountains surrounding the study area provides the baseflow of perennial streams and springs, but these rocks are not considered part of the primary ground-water reservoir.

Unconsolidated Basin Fill and Interbedded Basalt

The primary ground-water system in the study area is the unconsolidated basin fill and the interbedded basalt. The fill consists of alluvial-fan and lacustrine deposits of gravel, sand, and silt near the mountains and lacustrine deposits of gravel, sand, silt, and clay interbedded with basalt in the central part of the study area. The fill becomes finer grained toward the central part of the area.

Previous studies have divided the ground-water system into an unconfined and an artesian system (Dennis and others, 1946, p. 40-49, and Mower, 1965, p. 32-33). The unconfined system includes about 50 feet of the saturated unconsolidated fill in most of the area and about 100 feet or less of basalt that is interbedded with the fill in the central part of the area. The confined system, in the Flowell area, is encountered at a depth of between 140 and 200 feet and is separated from the unconfined system by 15 to 75 feet of clay under weak artesian conditions (Dennis and others, 1946, p. 44).

Previous studies also divided the ground-water system into six ground-water districts (Mower, 1965, p. 31). The principal purpose of the division was to delineate areas having similiar characteristics and common sources of recharge and areas of discharge. Ground-water movement between districts may occur and withdrawals in a district may affect water resources in adjacent districts. Because the districts are not completely hydrologically independent, they are not used in this report.

The thickness of the unconsolidated basin fill varies from a few feet near the mountain fronts to at least 1,400 feet as shown by a driller's log of the Neels Well (T. 20 S., R. 8 W.) reported by Meinzer (1911). The fill is underlain by and abuts against the Sevier River Formation of low permeability in the eastern part of the study area (Mower, 1965, p. 20). Tertiary volcanic rocks mark the southern boundary of the basin fill, and consolidated rocks in the Canyon Mountains, Pahvant Range, and Cricket Mountains form the eastern and western boundaries of the fill. Basin fill on the northern and northwestern edge of the study area is not bounded by consolidated rocks.

Basalt flows are interbedded with the unconsolidated basin fill in most of the study area. Basalt flows from the Kanosh and Pahvant volcanic fields crop out or are at shallow depths on the west side of Pahvant Valley near the central part of the study area. Other basalt flows have been identified at depths of more than 2,000 feet in the Gulf 1 Gronning Test Well (McDonald, 1976, pl. 3), north of the study area near Delta, and (using seismic-reflection data) near the northern boundary of the study area (Von Tish and others, 1985, fig. 3). The deeper basalt flows are of Pliocene age, and the flows at the surface or at shallow depths are of Pleistocene age. The deeper flows have been truncated by high-angle normal faults, are discontinuous in the subsurface, and are not considered to be part of the principal ground-water reservoir.

The basalt flows of Pleistocene age, some of which are only about 5,000 years old, also are faulted by north-trending, high-angle faults, but the degree of displacement in the subsurface is uncertain. The basalt flows are jointed and fractured, contain numerous lava tubes, and are permeable. They form an important part of the ground-water reservoir near Flowell and west of Kanosh. They also are the source for water discharging at Clear Lake Springs.

Recharge

Recharge to the principal ground-water reservoir in the study area is by seepage from streams, canals, and unconsumed irrigation water; infiltration of precipitation; and subsurface inflow from the Milford area. Subsurface inflow from consolidated rocks along the mountain fronts probably is small (Mower, 1965, p. 20). Total recharge varies from year to year and was estimated to be about 70,000 acre-feet in 1959. The methods and data used to calculate recharge are discussed in the following sections.

Seepage from streams

Recharge by seepage from streams in the study area is estimated to average about 20,000 acre-feet per year. Most of this recharge comes from streams on the east and south sides of Pahvant Valley, and was estimated to be 18,000 acre-feet in 1959 (Mower, 1965, table 9). Chalk and Corn Creeks contribute most of the recharge, but all major tributaries contribute some recharge (Mower, 1965, p. 46). In addition, it is estimated that 2,000 acre-feet recharge the ground-water reservoir from the Cricket Mountains on the west side of the study area, an area not included in Mower's study.

Recharge from streams in 1983 and 1984 was much larger due to the unusually high flows and long duration of the spring runoff period. Chalk Creek had peak flows of more than 1,000 cubic feet per second and sustained flows of more than 500 cubic feet per second in the spring of 1983 and 1984 (Jack McBride, Chalk Creek Irrigation Company, oral commun., November 1986). An estimated 51,000 acre-feet of water entered The Sink area, north of Flowell, between March 10 and July 17, 1983, increasing to an estimated 62,000 acre-feet between March 17 and July 17, 1984 (Garth Swallow, Chalk Creek Irrigation Company, oral commun., December 1986). Estimates for the remainder of the irrigation season after July 17, 1983, and 1984 were not available. Most of the water ponded and eventually moved into the basalt that underlies the area at shallow depths. The quantity of water that actually recharged the basalt north of Flowell could not be measured, but based on limited data may have been as much as 60,000 acre-feet in 1983 and 70,000 acre-feet in 1984.

In May of 1984, a dam on Corn Creek, about 2 miles southeast of Kanosh, washed out and allowed an estimated 900 cubic feet per second of flow down the old Corn Creek channel for about 30 days (Cloyd Day, U.S. Department of Agriculture, Soil Conservation Service, oral commun., November 1986). Most of the water ponded on land at lower elevations about 7 miles west of Kanosh where round, symmetrical sinkholes, with diameters of about 20 to 40 feet and depths of 10 feet or greater, formed, draining the water into the underlying basalt in a few days. Recharge to the basalt west of Kanosh may have been as much as 50,000 acre-feet.

In 1984, part of the flood water from Corn Creek drained to the north and ponded against a basalt flow in sec. 25, T. 21 S., R. 6 W. In addition to the flow of Corn Creek, water from sloughs at the mouth of Pine Creek and Meadow Creek, as well as a number of uncontrolled flowing wells began discharging into channels that ponded against the basalt at this location in 1984. Flood-control measures to contain the water included channeling and diking which forced the flood waters to discharge into the permeable basalt flows at this location. Milo Anderson, a landowner in Flowell, estimated 125 cubic feet per second entered the basalt for most of the winter of 1984-85. Additional water entered the basalt south of the channeling and diking projects where the water had ponded against the basalt. Based on conversations with local landowners and measurements at the point of diversion into the basalt, [Thiros, 1988, table 8, location (C-21-6)24cdd-1X)], recharge to the basalt may have been as much as 40,000 acre-feet in 1984 and 30,000 acre-feet in 1985.

<u>Seepage from the Central Utah Canal</u>

Recharge by seepage from the Central Utah Canal has been estimated to be about 3,300 acre-feet per year (Mower, 1965, table 10). The 3,300 acre-feet per year was included in an estimated 27,000 acre-feet of recharge from unconsumed surface irrigation water (Mower, 1965, p. 48). Most of the seepage was thought to occur between the northern boundary where the Central Utah Canal enters the study area near McCornick and where the canal passes west of Cedar Mountain near the center of Pahvant Valley.

A seepage study of this reach of the Central Utah Canal, conducted by the U.S. Geological Survey during the summer of 1986, showed an average loss of 36 cubic feet per second (Enright, 1987). Assuming the canal was in operation for 90 days, the loss from the canal for 1986 would have been about 6,500 acre-feet out of about 16,000 acre-feet delivered or about a 40-percent loss. This agrees with estimates by Mower (1965, table 10) of 3,300 acre-feet per year out of an average flow of about 8,900 acre-feet per year, or 37 percent losses, based on data from 1966, 1970-73, and 1975-77 (Roger Walker, Sevier River Commissioner, written commun., July 1985).

Seepage from unconsumed irrigation water

Mower (1965, p. 48) had estimated recharge from unconsumed irrigation water to be 39,000 acre-feet per year in 1959--27,000 acre-feet from surface water (including seepage from the Central Utah Canal) and 12,000 acre-feet from ground water. Recharge has probably increased since 1959 because withdrawals of ground water for irrigation have increased. The quantity of ground water withdrawn in Pahvant Valley has increased from 60,000 acre-feet in 1959 to almost 100,000 acre-feet in 1977 (Cordy and others, 1988, table 3). Assuming that 25 percent of the increase in ground- and surface-water withdrawals in 1977 (10,000 acre-feet) was returned to the ground-water reservoir as recharge (Mower, 1965, p. 49), and recharge from other ground- and surface-water sources was the same as in 1959 (39,000 acre-feet), the value for unconsumed irrigation water may have been as large as 50,000 acre-feet.

Recharge primarily occurs on the alluvial fans at the mountain front on the east side of Pahvant Valley where irrigated fields are underlain by relatively permeable material susceptible to large seepage losses. Some recharge from unconsumed irrigation water occurs in the lower parts of Pahvant Valley such as The Sink, north of Flowell, and the area west of Kanosh, where permeable basalt flows are at or near the surface.

Infiltration of precipitation

Recharge by infiltration of precipitation is estimated to average about 11,000 acre-feet per year. About 8,000 acre-feet of recharge (5 percent of the precipitation) infiltrates in the upland parts of Pahvant Valley between the altitudes of 4,800 and 6,000 feet (Mower, 1965, p. 46), and 3,000 acre-feet per year of recharge (17 percent of the precipitation) occurs on the basalt outcrops in the central part of the study area (Mower, 1967, p. E27). Recharge from precipitation during periods of greater-than-normal rainfall is probably much larger than the 5 or 17 percent during average years because consumptive use by plants and soil moisture retention do not increase proportionally and, thus, more of the precipitation is available for recharge.

The average annual precipitation on the western side of the study area in and near the Cricket Mountains (not covered by previous reports), is less than 10 inches per year. Therefore, the area probably does not contribute substantial recharge from precipitation to the ground-water reservoir.

Subsurface inflow from the Milford area

Recharge by subsurface inflow from the Milford area was estimated by Mower (1974, table 9 and p. 33) to be 8 acre-feet per year. The estimate is based on an average transmissivity of 75 feet squared per day, a hydraulic gradient of 0.003, and a cross-sectional length of 4,000 feet. For the purposes of this report, this small quantity of recharge is insignificant.

Movement

Ground water in the study area generally moves from major recharge areas near the mountains on the east and south toward discharge areas in the lower parts of Pahvant Valley and the Sevier Desert. Some ground water leaves the study area along the northwest boundary, but the quantity is small. Plate 2 shows the potentiometric surface in the unconsolidated basin fill and interbedded basalt in spring 1986. The direction of ground-water movement is generally at right angles to the contour lines.

Ground-water movement has been affected in local areas by large withdrawals for irrigation. Handy and others (1969, fig. 4) show an area west of Kanosh where the direction of ground-water movement was reversed due to large ground-water withdrawals in 1967. The same condition existed in 1986 (pl. 2) and probably has occurred during other years when large quantities of ground water were pumped for irrigation. Mower (1965, pl. 4) showed a large, relatively flat area on the potentiometric surface near Flowell, which he attributed to large withdrawals for irrigation (Mower, 1965, p. 41).

Ground-water movement to the west in the unconsolidated basin fill is restricted both laterally and vertically, beginning at the western border of Pahvant Valley, by the fine-grained silts and clays in the subsurface. Mower (1967, p. E11) referred to a ground-water dam that laterally confines subsurface water to the permeable beds in the unconsolidated deposits within the valley. The result of the restricted flow to the west is water levels greater than 50 feet above land surface in the area near Flowell (Thiros, 1988, table 3). Some water probably leaks upward into the permeable basalt layers that are interbedded with the fine-grained unconsolidated basin fill.

The movement of ground water from Pahvant Valley through the basalt to the west and north toward Clear Lake Springs is not well understood. Mower (1967, p. E16) states that although the hydraulic gradient in the basalt is only about 1 foot per mile, the movement of water may be fast due to the large permeability of the basalt aquifer. In addition, Mower (1967, p. E16) noted a transition zone of small permeability near the southern boundary of T. 21 S., R. 6 W., where the basalt from the older Beaver Ridge and Kanosh volcanic fields is in contact with basalt from the Pahvant field.

The rate of ground-water movement in the basalt can be estimated based on responses in the discharge at Clear Lake Springs to changes in the recharge to the basalt in Pahvant Valley. Several areas of Pahvant Valley have contributed substantial amounts of recharge to the basalt between 1983 and continuing through 1987 (see section on recharge by "Seepage from streams").

Surface water was diverted to control flooding, beginning in the spring of 1983, from Corn and Meadow Creeks and Pine Creek and Meadow Creek sloughs into the basalt southwest of Flowell. The flood waters entered and disappeared into the basalt of the Ice Springs volcanic field where it apparently found a path into the underlying Pahvant basalt flow. The basalt flows in the area have been cut by a number of high-angle normal faults (pl. 1). The faults and related fractures probably provide a permeable conduit for ground water to move to Clear Lake Springs. In addition, the springs probably mark the western boundary of the Pahvant basalt flow. West of the springs, ground-water movement is restricted by relatively impermeable lake sediments. Therefore, water moving through the permeable basalts toward the northwest encounters the relatively impermeable lake sediments, and is forced to the surface at Clear Lake Springs.

Recharging water also enters and moves through basalt at The Sink, about three miles northwest of Flowell, and at an area about seven miles west of Kanosh in T. 23 S., R. 6 W., sec. 8. Flood waters from Chalk Creek collected in The Sink in 1983 and 1984 and eventually disappeared, much of it into the ground. In 1984, flood waters from Corn Creek collected and formed a lake in the topographically low area about 7 miles west of Kanosh and disappeared into a series of sinkholes that opened and drained the lake. Both areas are underlain by permeable basalt at depths of less than 50 feet. The potentiometric-surface contours (pl. 2) indicate that water entering the basalt at these locations will move toward Clear Lake Springs.

Mower (1967, p. E27) developed an empirical relationship between October-April precipitation on the basalt, ground-water withdrawals, and low flow of the springs. Since most of the precipitation on the basalt occurs in March and April, the time lag between precipitation and discharge of the spring is about six or seven months. In addition, Mower (1967, p. E23) states that water-level changes in observation wells in Pahvant Valley and changes in the discharge of the springs are directly related; however, changes in the discharge of the springs lag behind the changes in the water levels by one to two months.

The ground-water velocity in the basalt can be estimated using the equation:

$$v = KI/\Theta$$

where v = velocity of ground water,
K = hydraulic conductivity of basalt,
I = hydraulic gradient, and
Θ = porosity of the basalt.

Assuming K is 10,000 feet per day, I is 0.001, and Θ is 0.05, the average velocity is about 200 feet per day.

To gain a better understanding of the travel time in the basalt, a dye study was conducted. On October 29, 1985, 50 pounds of Rhodamine WT[1] dye was injected into water being diverted into the basalt west of Flowell, a distance of about 12 miles from Clear Lake Springs. Daily samples, collected at Clear

[1]Use of the trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Lake Springs through the end of February 1987, did not contain detectable concentrations of dye. Although the dye study did not confirm that ground water was moving to the springs, it is possible that the concentration was too small to be detected. Another possibility is that the flow path and time of travel was greater than the time of the study period.

Discharge

Discharge from the ground-water reservoir in the study area is by springs, evapotranspiration, subsurface outflow, and wells. Discharge varies from year to year and was estimated to be about 109,000 acre-feet in Pahvant Valley in 1959.

Springs

Most of the discharge from springs is from Clear Lake Springs. Prior to any ground-water development in Pahvant Valley (about 1915), the discharge of the springs was probably between 14,000 and 22,000 acre-feet per year. Numerous measurements by the Utah Division of Wildlife Resources from 1959 through 1985 and streamflow records collected by the U.S. Geological Survey from 1985 to 1987 as part of this study, are shown in figure 4.

The discharge of Clear Lake Springs varied from 13 to 30 cubic feet per second until the fall of 1983. In the fall of 1983, the discharge of the springs began to increase rapidly and measurements from November 1984 to August 1985 showed discharges of more than 80 cubic feet per second (fig. 4). The increase in discharge of the springs is due to increased recharge to basalt north and southwest of Flowell and west of Kanosh. (See section on recharge by "Seepage from streams" previously discussed in this report.)

Springs and seeps in an area west of Meadow were estimated to be discharging about 3,000 to 3,500 acre-feet per year in the early 1940's (Dennis and others, 1946, p. 78-79). Numerous other springs and seeps were discharging water over broad meadowlands and playas west of Meadow. The discharge of many of the springs and seeps is collected in natural and man-made drains and was measured as part of this study and reported in Thiros (1988, table 7). Data are insufficient to determine if the discharge of these springs and seeps has substantially changed under the current (1987) hydrologic conditions.

Evapotranspiration

Discharge by evapotranspiration in the study area is estimated to be about 29,000 acre-feet per year. Mower (1965, p. 54) estimated evapotranspiration in Pahvant Valley to be 24,000 acre-feet per year. Evapotranspiration in the area not covered by previous studies (west of Pahvant Valley) is estimated to be about 5,000 acre-feet per year. This estimate is based on about 50,000 acres of phreatophytes, primarily greasewood, with an average density of 10 percent, and an annual consumptive use of 0.1 foot per year.

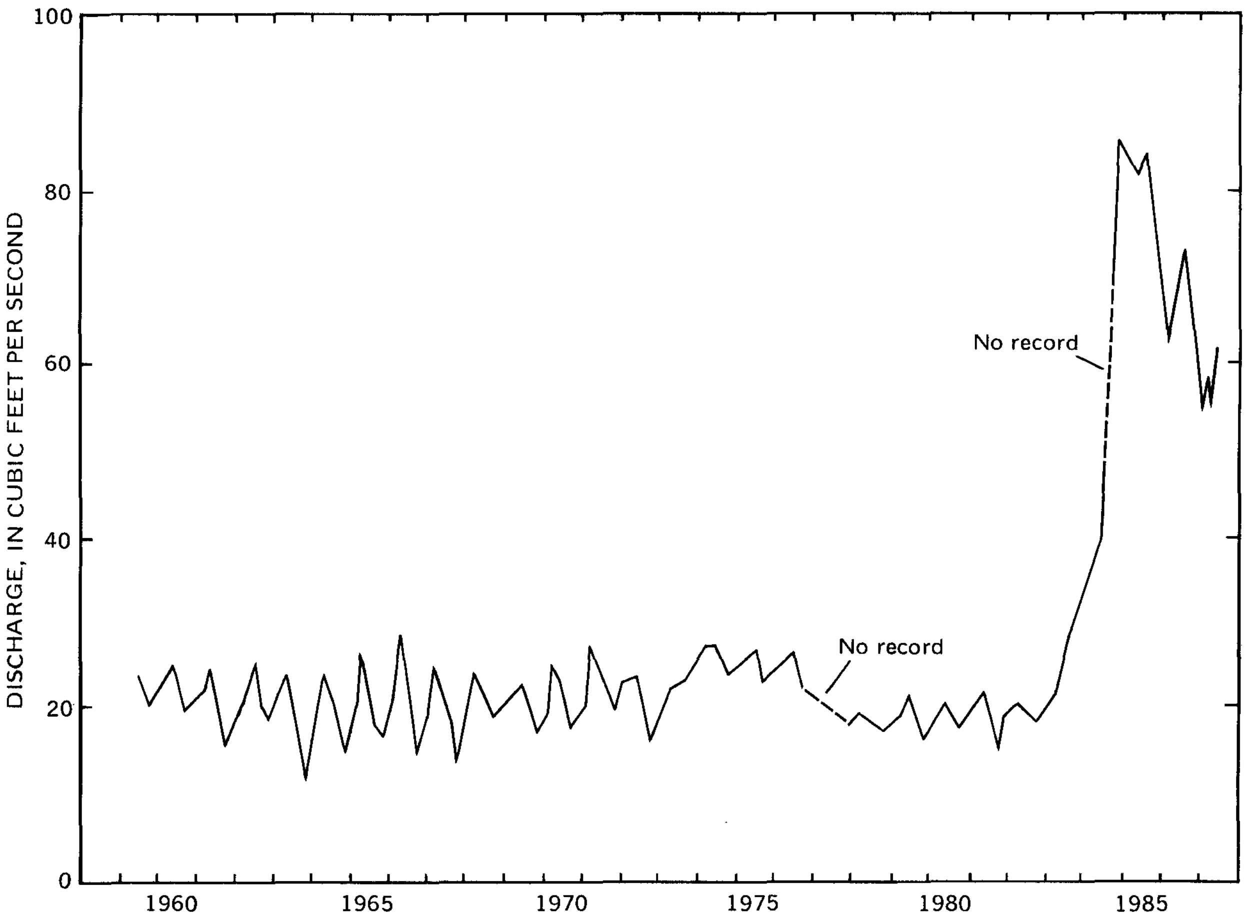


Figure 4.--Discharge of Clear Lake Springs, 1959-86.

Subsurface outflow

Subsurface outflow from the study area occurs along the northwestern border. The ground-water gradient along the border is estimated to be about 0.001, the transmissivity is estimated to be about 500 feet squared per day, and the distance across the boundary is about 16 miles. Therefore, using Darcy's Law, the estimated subsurface outflow is about 400 acre-feet per year.

Wells

Discharge by wells in the study area has varied considerably since the first successful wells were drilled near Flowell in about 1915. Estimated annual ground-water withdrawals from pumped and flowing wells in Pahvant Valley during 1946-86 is shown in figure 5. Discharge primarily was from flowing wells until the availability of electricity in 1952-53. With increased withdrawals from pumping wells after 1953, the discharge of flowing wells decreased, and from 1966 through 1983 was estimated at less than 1,000 acre-feet per year. Withdrawals from flowing wells increased to 9,500 acre-feet in 1984, 23,000 acre-feet in 1985, and 22,000 acre-feet in 1986 because of record quantities of precipitation and reduced withdrawals from pumped wells.

Ground-water withdrawals from wells reached a maximum in 1977 when withdrawals were about 96,000 acre-feet. Since that time, withdrawals have decreased as a result of greater-than-normal precipitation and availability of additional surface water, better irrigation practices, and the increasing cost of electricity. The 1972-81 estimated average annual withdrawal of ground water was 84,000 acre-feet while the 1982-85 average annual withdrawal was about 54,000 acre-feet. Most of the wells are completed at depths of between 200 and 500 feet in unconsolidated basin fill or between 100 and 200 feet in basalt.

Hydraulic Properties of the Basin Fill and Interbedded Basalt

Hydraulic coefficients of the ground-water reservoir in Pahvant Valley were reported by Mower (1965, tables 8 and 11 and p. 52). The transmissivity of the unconsolidated basin fill ranges from about 2,000 to 40,000 feet squared per day, and the transmissivity of the basalt ranges from about 24,000 to 3,000,000 feet squared per day. The storage coefficient of the ground-water reservoir under artesian conditions ranges from 0.001 to 0.0001. The estimated specific yields for geologic units include 0.10 to 0.25 for the unconsolidated deposits, 0.06 for the basalt, and 0.12 for the combined unconsolidated basin fill and basalt.

Water-Level Fluctuations

Water levels fluctuate in response to changes in the balance between recharge and discharge. Prior to development of the ground-water resources in the study area, water-level fluctuations were due primarily to changes in recharge from precipitation and surface-water infiltration. Ground-water withdrawals for irrigation, beginning in about 1915, have caused additional water-level fluctuations, both on a seasonal, as well as a long-term basis. Mower (1965, pl. 5) shows an area near Flowell where water-level declines from March to September 1960, were more than 45 feet as a result of ground-water withdrawals for irrigation during the summer months. Hydrographs of four representative wells showing seasonal water-level fluctuations during this study are shown in figure 6.

Water levels in wells (C-20-5)13daa-1 and (C-21-6)26aac-1 have large seasonal fluctuations because of surface-water infiltration. Well (C-20-5)13daa-1 is located near the Central Utah Canal. The highest water levels occur during the summer months when the canal is in use and losses from

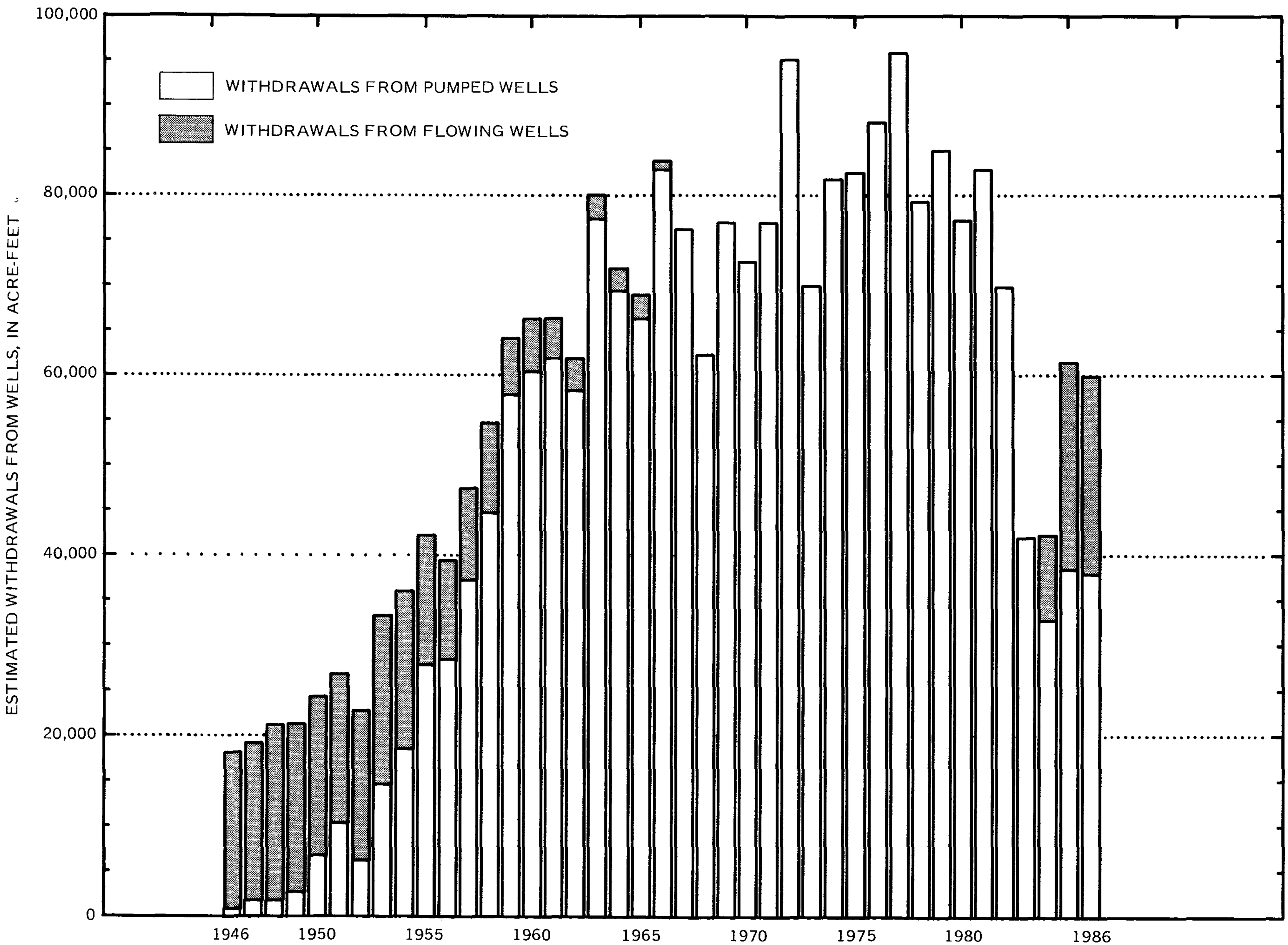


Figure 5.--Estimated annual ground-water withdrawals, 1946-86, from pumped and flowing wells.

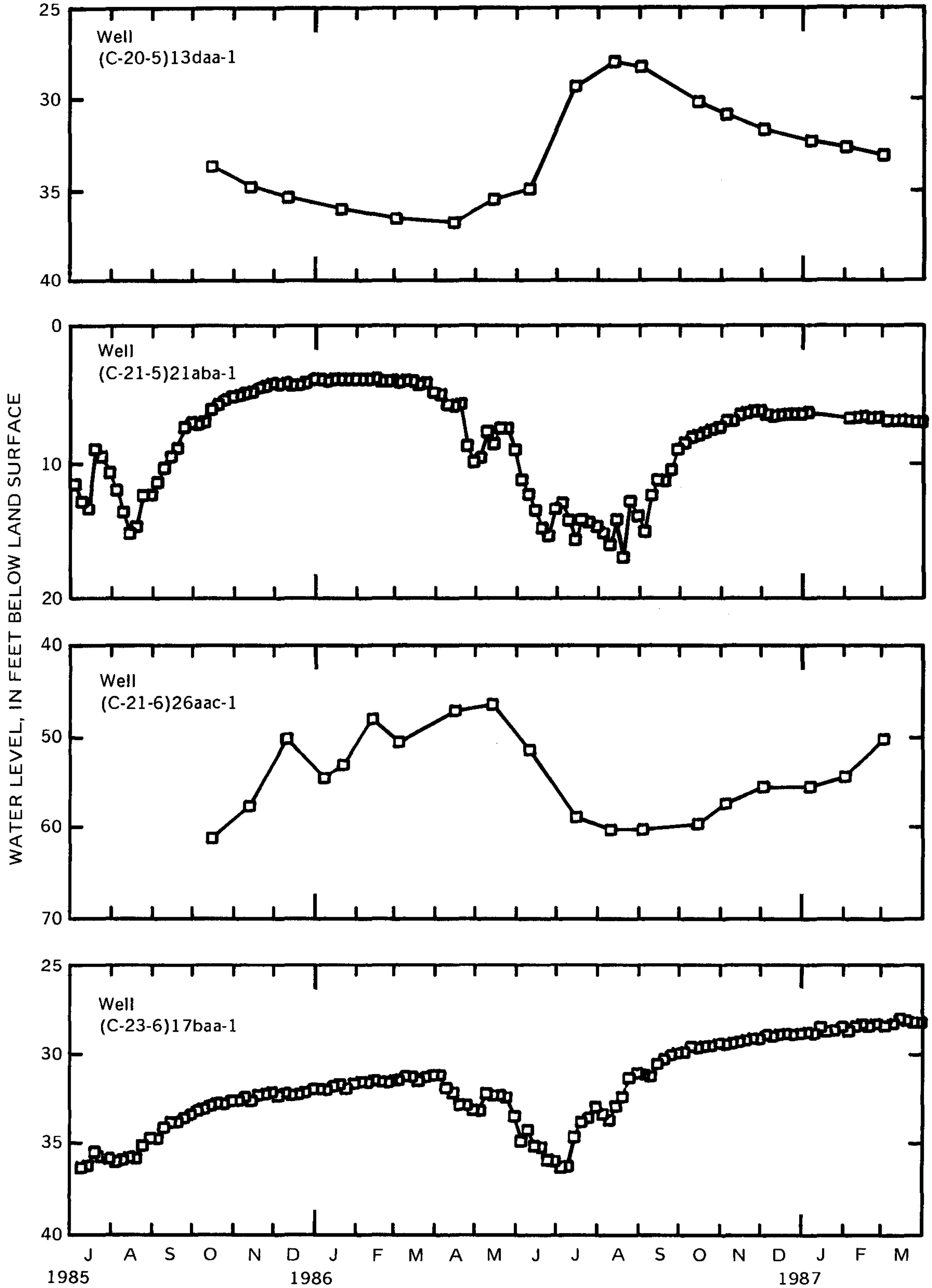


Figure 6.--Seasonal water-level fluctuations, July 1985 to April 1987, in four wells.

the canal are large (Enright, 1987, p. 3). Well (C-21-6)26aac-1 is located west of Flowell where water is diverted into the basalt. The highest water levels occur in the winter or spring when the quantity of water diverted into the basalt reaches its maximum.

Water levels in wells (C-21-5)21aba-1 and (C-23-6)17baa-1 have large seasonal fluctuations because of ground-water withdrawals for irrigation. Water levels in the two wells reach their highest levels at the end of March, and begin declining after the first part of April when irrigation begins. The water levels continue to decline through the summer months until the end of the main part of the irrigation season, normally between August and September. Water levels recover during the winter and early spring until the next irrigation season begins.

During the period of extensive pumping of ground water from the early 1950's to about 1980, a period of generally less-than-normal precipitation (fig. 3), water levels in some areas did not fully recover between irrigation seasons. Water-level declines of more than 50 feet occurred between 1953 and 1980 in some areas of Pahvant Valley. Most water levels recovered between 1983 and 1986 as a result of reduced withdrawals for irrigation and record quantities of precipitation. Hydrographs of eight representative wells showing long-term water-level fluctuations are shown in figure 7. Water-level changes from March 1960 to March 1986 are shown on plate 3.

Water levels in well (C-18-5)16bbc-1 near the northern boundary of the study area, about 3 miles north of McCornick, show only small fluctuations (less than 7 feet) over a period of 27 years. Water levels in well (C-19-4)30dab-1 show an almost steady decline from 1951 until about 1980 due to large withdrawals for irrigation. Water levels began to rise in 1983 due to record quantities of precipitation and less-than-normal withdrawals, and by 1986 more than one-half of the declines had been recovered.

In two wells near Flowell, (C-21-5)7cdd-2 completed in the basalt, and (C-21-5)21aba-1 completed in the unconsolidated basin fill, and one well near Meadow, (C-22-5)28dbd-1, the water levels generally declined until about 1965, they remained fairly consistent until 1983, then rose rapidly and fully recovered between 1983 and 1986. In well (C-21-6)26aac-1, completed in the basalt about 3.5 miles southwest of Flowell, water levels generally remained unchanged until 1983 when flood waters were diverted into the basalt near the well causing water levels to fluctuate with the quantity of water diverted into the basalt.

Water levels in well (C-23-6)10bdd-1, about 4.5 miles west-northwest of Kanosh, declined from 1953 to about 1968; they remained fairly constant other than seasonal fluctuations until about 1983, then rose rapidly in response to large amounts of recharge until 1986 when the water level was higher than predevelopment water levels. Water levels in well (C-23-6)20ccc-1, about 7 miles west of Kanosh, are similiar except that the water level has not fully recovered to the predevelopment level. Most of the recharge to this area is from Corn Creek to the east. Well 10bdd-1 is closer to the recharge area than well 20ccc-1 and, thus, has shown the largest rise.

Water-level measurements in Pahvant Valley in the spring of 1986 are generally higher than measurements in the spring of 1960 (pl. 3). Two areas

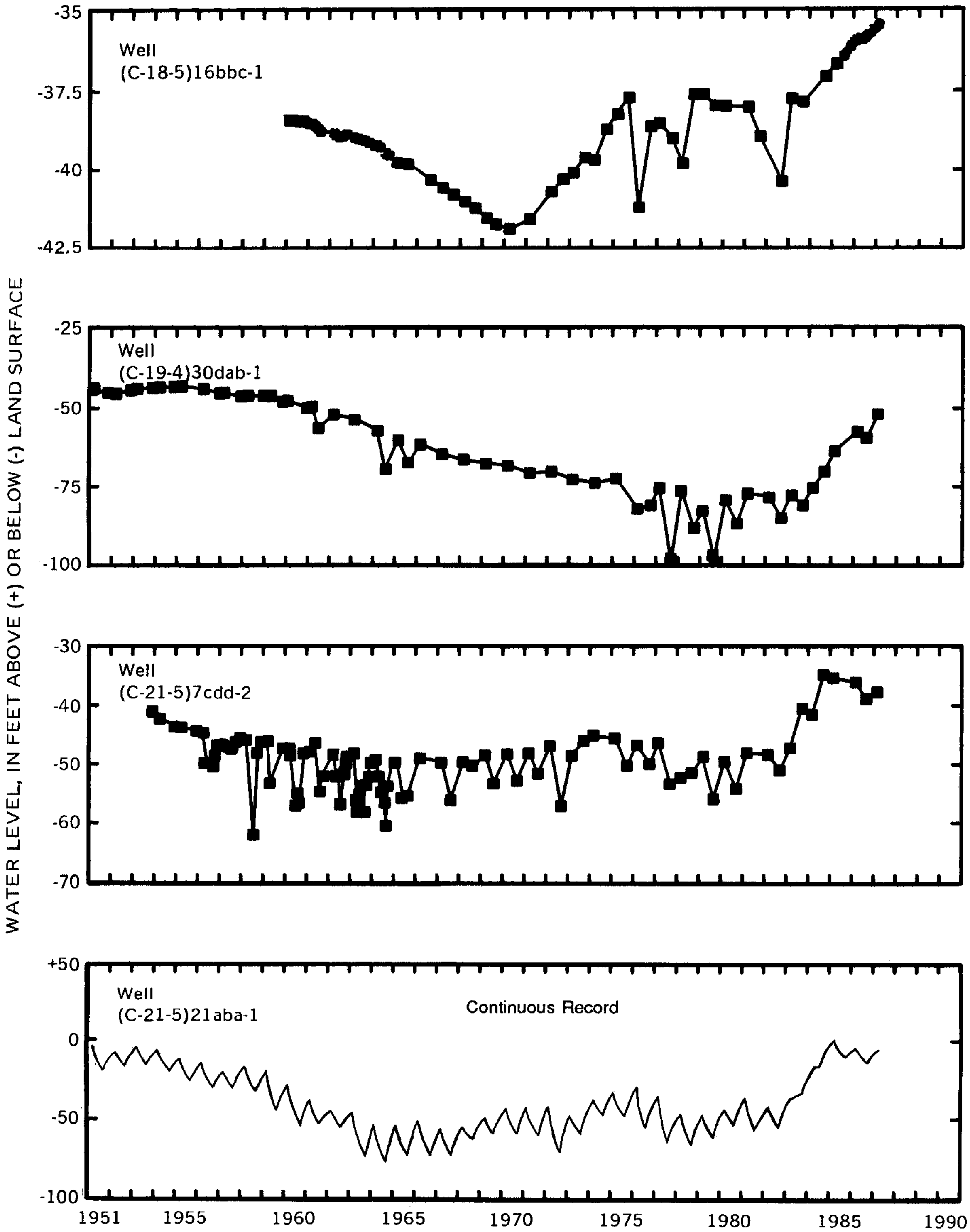


Figure 7.--Long-term water-level fluctuations, 1951-86, in eight wells.

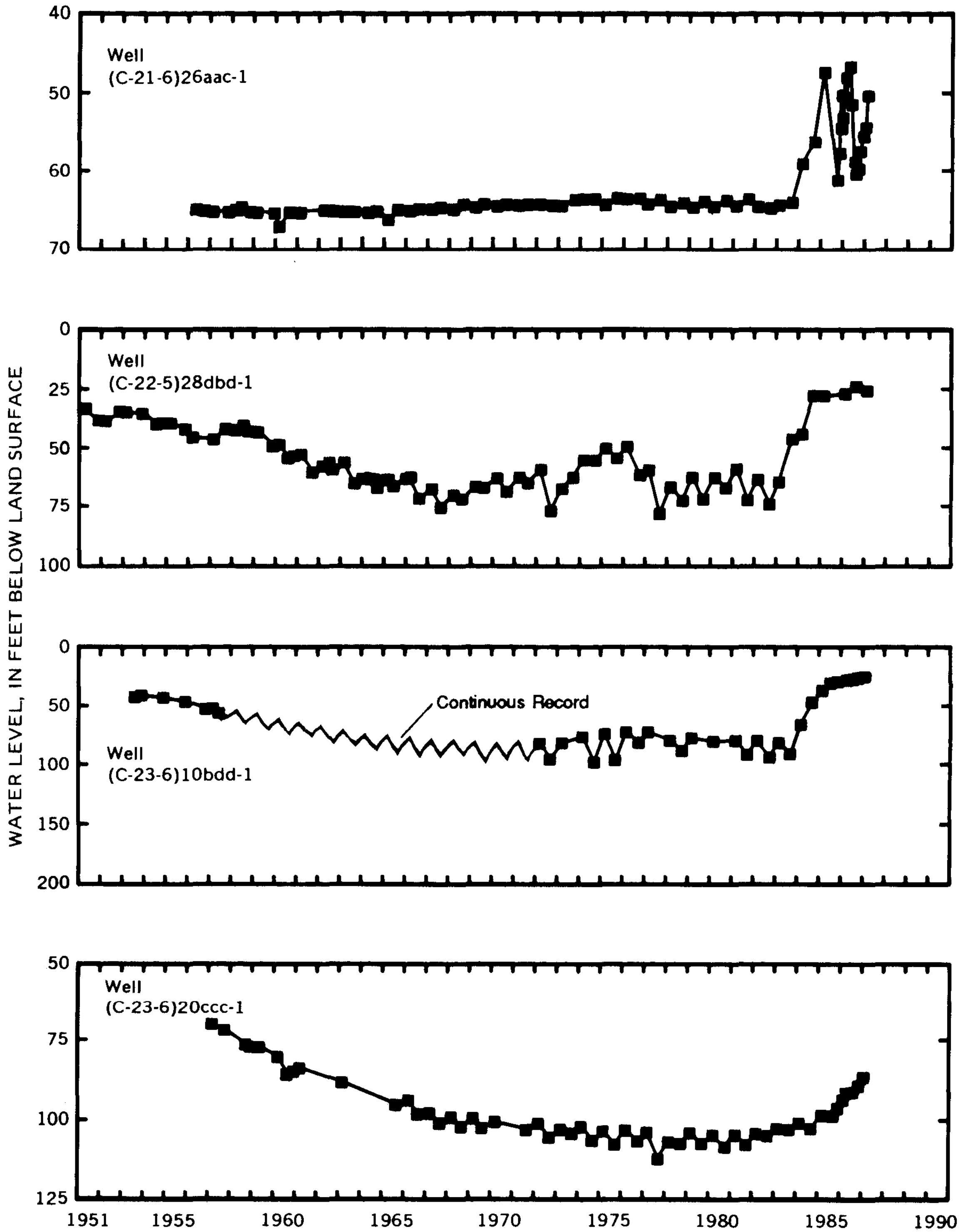


Figure 7.--Long-term water-level fluctuations, 1951-86, in eight wells--Continued.

of exception are in the northern part of Pahvant Valley near McCornick and in a small area west of Kanosh, where water levels have not fully recovered from large withdrawals during previous years. Water-level declines of similiar magnitude to those in the past (fig. 7), can be expected in the future with normal precipitation and large ground-water withdrawals.

Storage

The quantity of ground water in storage in the study area could not be determined with available data. Mower (1965, table 11) estimated 11,000,000 acre-feet of total ground water in storage in Pahvant Valley. Data for the area covered during this study, which is a much larger area than that used by Mower, are insufficient to make a meaningful estimate. Also, much of the ground water in the central and western parts of the study area is of poor quality and limited value, and is in fine-grained material which would yield little water to wells.

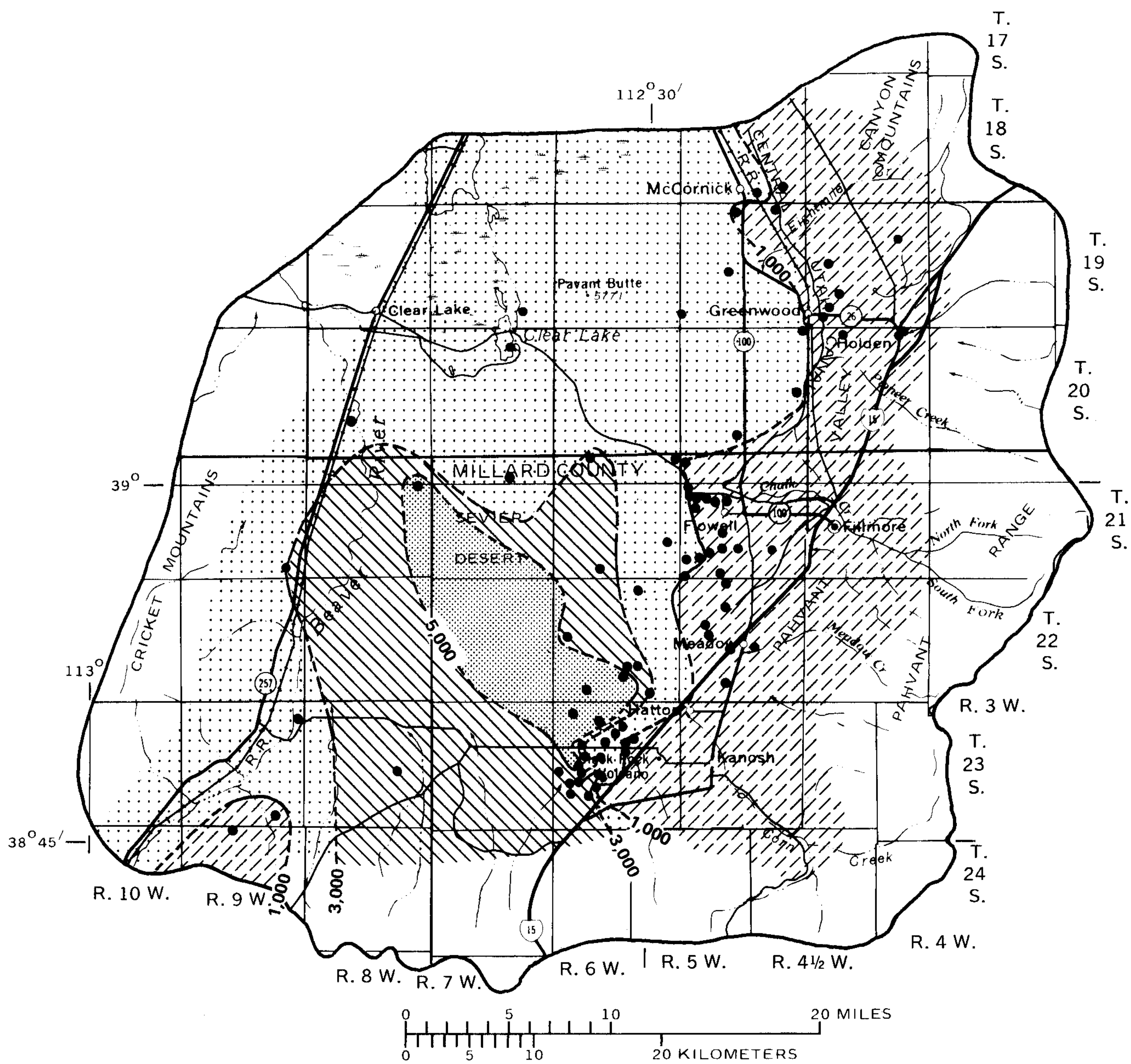
Quality of Ground Water

The chemical quality of water samples collected from ground-water sites in the study area is reported in Thiros (1988, tables 6 and 9). The quality of the water in the ground-water reservoir varies considerably.

Dissolved solids in water ranged from 300 milligrams per liter in well (C-19-4)17ccb-1 to 9,000 milligrams per liter in spring (C-22-6)34abd-S1. The water in the eastern part of the study area generally has dissolved-solids concentrations less than 1,000 milligrams per liter, while water in most of the remaining area has concentrations ranging from about 1,000 to 5,000 milligrams per liter. The largest concentrations of dissolved solids in wells in Pahvant Valley occur in the Kanosh farming district, about five miles west of the town of Kanosh, and in the area to the northwest of the farming district, where concentrations exceed 5,000 milligrams per liter. The water with smaller concentrations of dissolved solids is generally of the calcium magnesium bicarbonate type, while water with larger concentrations of dissolved solids is generally of the sodium chloride or sodium chloride sulfate type. Dissolved-solids concentrations in water samples from ground-water sites in 1985-87 are shown in figure 8.

The quality of ground water in some areas of Pahvant Valley has changed since large-scale withdrawals for irrigation began in about 1953. The largest changes have occurred in the Kanosh farming district, where dissolved-solids concentrations increased from about 2,000 to more than 6,000 milligrams per liter in water from some wells. The increase in the dissolved solids primarily is the result of an increase in sodium, chloride, and sulfate. Dissolved-solids concentrations in water from most wells in the district have decreased since 1983 as a result of greater-than-average precipitation and decreased ground-water withdrawals. Dissolved-solids concentrations in well (C-23-6)21bdd-1, located 5.25 miles west of the town of Kanosh, are shown in figure 9.

Handy and others (1969, p. D230) attributed the increase in dissolved solids in the Kanosh farming district to the recirculation of irrigation water, estimated to account for between 25 and 50 percent of the water that is pumped from wells; or the movement of poor quality water into the area from



EXPLANATION

—5,000- - - LINE OF EQUAL DISSOLVED-SOLIDS CONCENTRATION--Dashed where approximately located. Interval, in milligrams per liter, is variable

DISSOLVED-SOLIDS CONCENTRATION

- 300 - 1,000 milligrams per liter
- 1,000 - 3,000 milligrams per liter
- 3,000 - 5,000 milligrams per liter
- 5,000 - 9,000 milligrams per liter
- NO DATA

• GROUND-WATER SITE--From which water was analyzed for dissolved-solids concentration

Figure 8.--Dissolved-solids concentrations in water samples from ground-water sites, 1985-87.

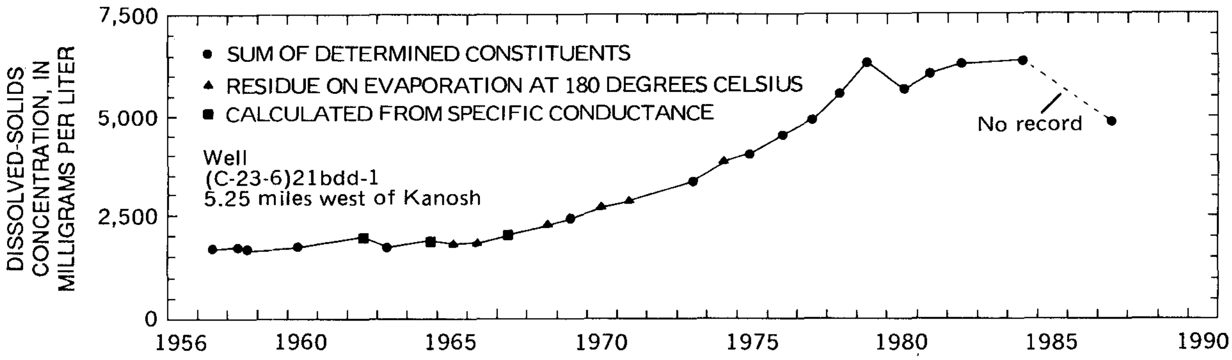


Figure 9.--Dissolved-solids concentrations in water from well (C-23-6)21bdd-1 near Kanosh, 1957-87.

north and west of the farming district. Hans Claassen and others (U.S. Geological Survey, written commun., 1987) also attributed the movement of poor quality water into the area from north and west of the farming district as the most likely explanation for the increase in dissolved solids. Water-level data were not available during the pumping season to verify the possibility.

In an effort to provide a better understanding of the source or cause of the increase in dissolved solids in the Kanosh area, water samples were collected as part of this project, and analyzed for major dissolved ions, dissolved nitrate plus nitrite, and hydrogen, oxygen, and carbon isotopes. Selected chemical analyses and results of the radioisotope analyses are given in table 1. The other analyses, as well as the historic water-quality data, are presented by Thiros (1988, tables 5-7 and 9).

The relation of sulfate and chloride in 136 ground-water samples collected in the Kanosh farming district between 1957 and 1987 is shown in figure 10. The data can be divided into three groups that describe linear relations of sulfate and chloride in three general areas, the southeastern, northern, and southwestern parts of the district. The division of the farming district into these three areas containing ground water with similar sulfate to chloride ratios, and the direction of ground-water movement in the spring of 1986 are shown in figure 11.

Ground water in the southeastern part of the district represents subsurface recharge water moving into the district from the Corn Creek area on the east. The water generally has small concentrations of dissolved solids (less than 1,000 milligrams per liter) and a sulfate to chloride ratio of about 1.2. Ground water in the southwestern part of the area generally has large concentrations of dissolved solids (greater than 1,500 milligrams per liter) and a sulfate to chloride ratio of about 0.34. Ground water in the northern part of the area, including discharge from warm springs in the northeastern part, generally has large dissolved-solids concentrations and a sulfate to chloride ratio of about 0.52. There are no water-quality samples from wells west of the farming district.

Table 1.--Chemical analyses for sulfate, chloride, nitrogen, and radioisotopes in water from selected wells and springs

[mg/L, milligrams per liter; permil, parts per thousand; pCi/L, picocuries per liter; --, no data; <, less than]

Location: For an explanation of the numbering system, see section on numbering system for hydrologic-data sites. Dashes (--), no data

Location	Date	Sulfate, dis-solved (mg/L as SO_4)	Chlo-ride, dis-solved (mg/L as Cl)	Nitro-gen, NO_2+NO_3 dis-solved (mg/L as N)	C-13 / C-12 Stable isotope ratio per-mil	H-2 / H-1 Stable isotope ratio per-mil	O-18 / O-16 Stable isotope ratio per-mil	Tritium, total (pCi/L)
(C-20-7) 2ccd-S1	08-29-85	--	--	--	--	--	--	11
	08-29-85	--	--	--	--	--	--	18
(C-21-5)31cdd- 2	08-29-85	--	--	--	--	--	--	8.0
(C-21-6) 1ddb- 1	08-29-85	--	--	--	--	--	--	84
(C-21-8)12dcc- 1	07-30-87	1,300	4,200	0.360	-7.5	-112.0	-13.5	<0.3
(C-22-6)35ddb-S1	09-10-85	--	--	--	--	--	--	<1.0
(C-23-6)10ccc- 2	07-29-87	310	480	0.980	-6.5	-122.0	-16.2	<0.3
(C-23-6)15baa- 1	07-30-87	170	300	3.60	-9.1	-119.0	-15.9	55
(C-23-6)15bda- 1	07-29-87	68	130	3.80	-9.3	-119.0	-16.1	13
(C-23-6)17cdc- 1	07-29-87	1,000	2,800	1.90	-5.1	-119.0	-15.4	6.0
(C-23-6)17dad- 1	08-29-85	--	--	--	--	--	--	15
(C-23-6)21bdd- 1	07-29-87	390	1,700	21.0	-6.5	-120.0	-15.6	17
(C-24-4.5)4abb- 1	07-29-87	47	65	0.380	-10.3	-122.0	-16.4	33

The relation of sulfate and chloride in three wells in the northern, southeastern, and southwestern parts of the Kanosh farming district are shown in figure 12. The sulfate to chloride ratio in each of the wells has generally remained unchanged since sampling began in 1957, even though the sulfate and chloride concentrations have increased dramatically. A linear relation between sulfate and chloride in all three areas suggests the water has undergone evaporative concentration.

Water from some wells located near the boundaries of the areas shown in figure 11, such as well (C-23-6)21bdd-1, have fluctuating sulfate to chloride ratios (Thiros, 1988, table 6). During periods of less-than-normal precipitation and large ground-water withdrawals, such as 1975-77, water from well (C-23-6)21bdd-1 had a sulfate to chloride ratio of less than 0.4, while during periods of greater-than-normal precipitation and small ground-water withdrawals, such as 1982-85, the water had a sulfate to chloride ratio of greater than 0.5. During periods of less-than-normal precipitation and large ground-water withdrawals, more ground water from the southwest and possibly the west, with a lower sulfate to chloride ratio, moves into the aquifer at this location, causing a decline in the sulfate to chloride ratio.

The isotopic relation between deuterium and oxygen 18, carbon 13 and chloride, oxygen 18 and chloride, deuterium and chloride, and tritium and chloride is shown in figure 13 for five samples collected in the Kanosh farming district in 1987. The deuterium and oxygen 18 data for the Kanosh farming district plots to the right of the Colorado meteoric water line (Claassen, 1986) and the best-fit line describing the data has a slope of

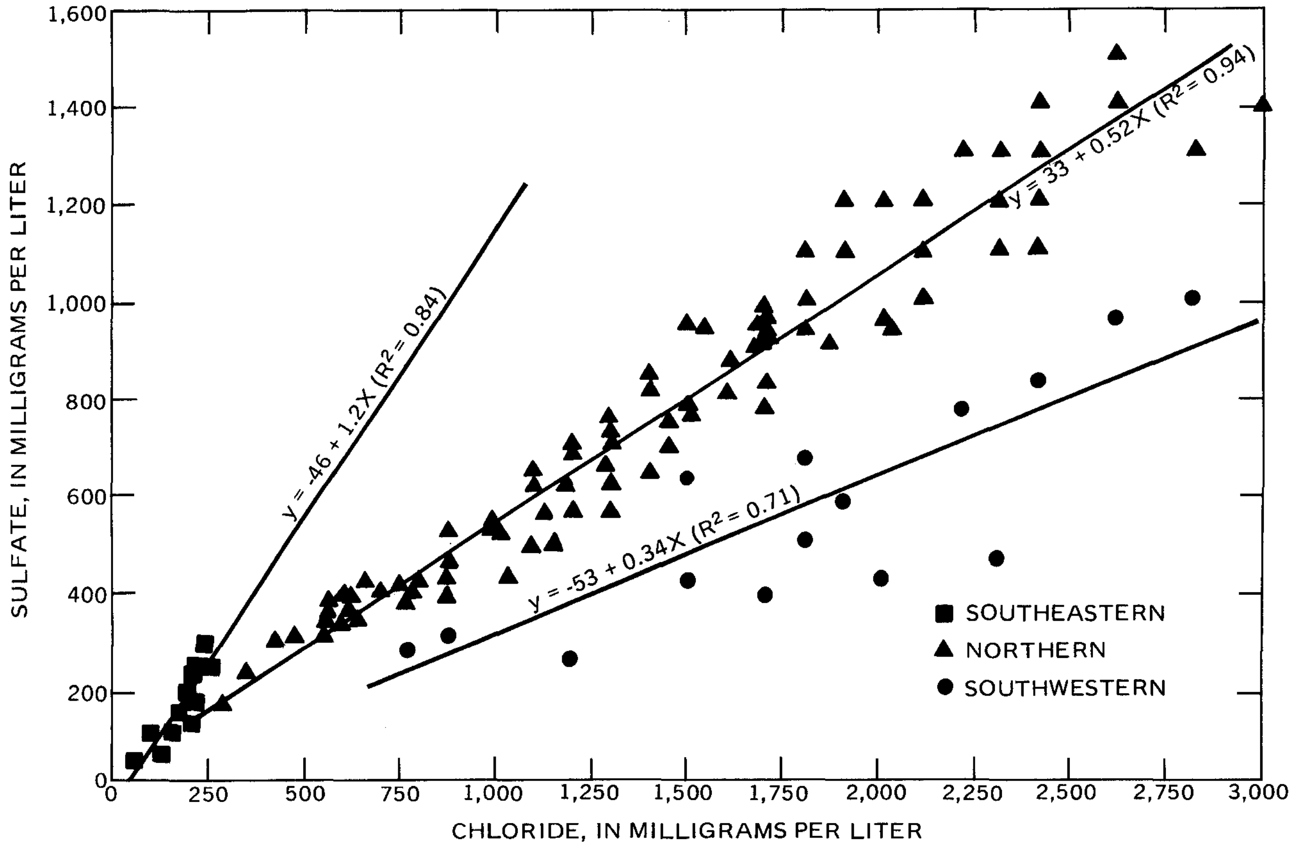


Figure 10.--Relation of sulfate and chloride in ground-water samples from the southeastern, northern, and southwestern parts of the Kanosh farming district.

about two, which is consistent with surface water that has undergone evaporation (Tyler Coplen, U.S. Geological Survey, written commun., 1987). The regression lines of carbon 13 and chloride, oxygen 18 and chloride, and deuterium and chloride show increasing isotopic weight along the general direction of ground-water flow (fig. 11).

Large amounts of tritium were added to the atmosphere from 1952 to the mid-1960's, produced by the atmospheric testing of thermonuclear weapons. By 1963, tritium levels had increased by approximately three orders of magnitude over that of prebomb natural levels of about 26 picocuries per liter (pCi/L) (Thatcher and others, 1977, p. 8). It was concluded by Coplen (written commun., 1987) that water with a tritium content less than 3.2 pCi/L was not recharged to an aquifer after 1952. An increase in tritium concentrations along the ground-water flow direction would be expected if recycling of irrigation water since the mid-1950's were the primary cause of the increased dissolved solids. The tritium concentrations in five samples ranged from less

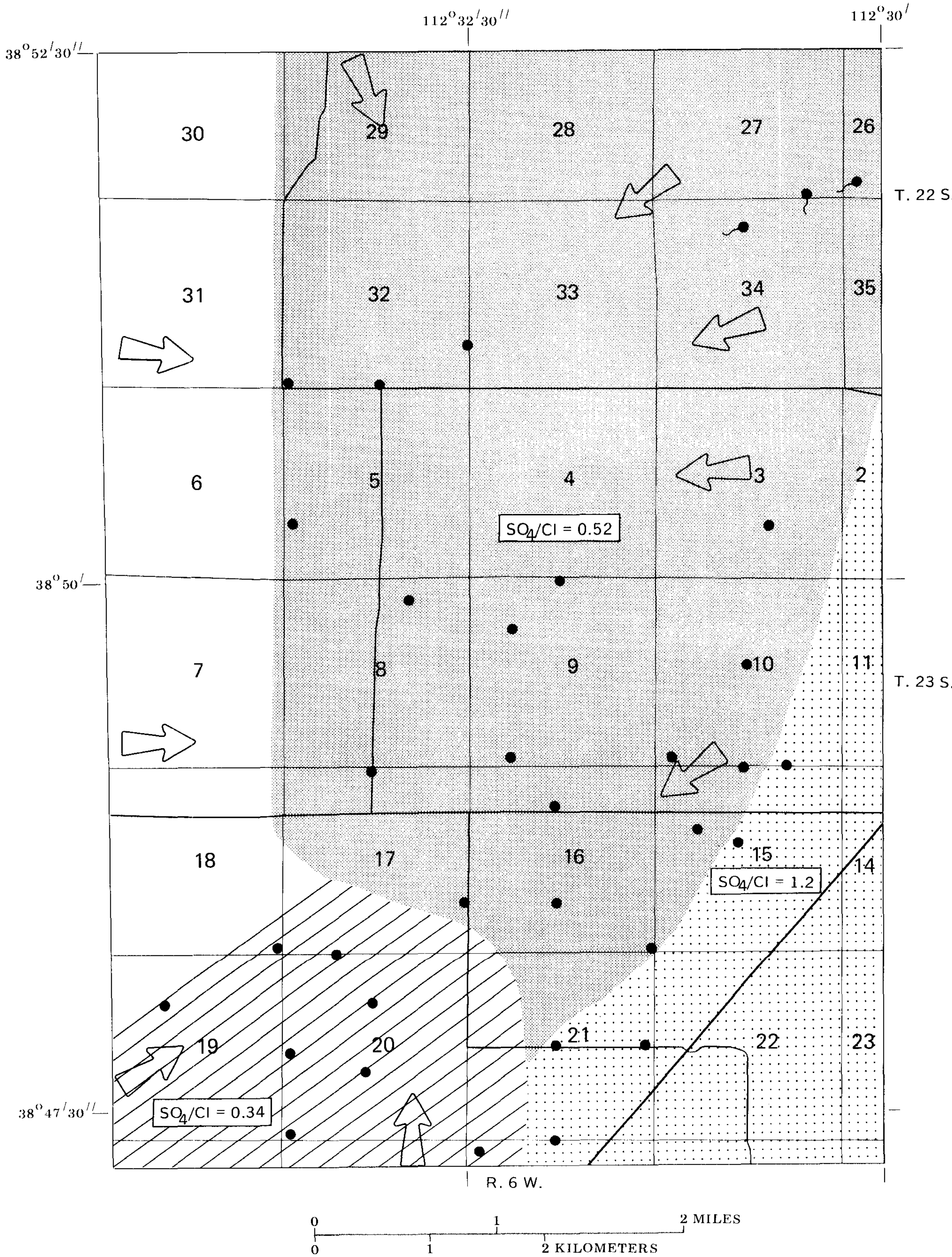


Figure 11.--Areas of generally similar sulfate to chloride ratios (SO_4/Cl) and arrows showing direction of ground-water flow in the spring of 1986, in the Kanosh farming district.

EXPLANATION FOR FIGURE 11

AREA WHERE SULFATE TO CHLORIDE RATIO IS ABOUT 0.34

AREA WHERE SULFATE TO CHLORIDE RATIO IS ABOUT 0.52

AREA WHERE SULFATE TO CHLORIDE RATIO IS ABOUT 1.2

WELL FROM WHICH SULFATE TO CHLORIDE RATIO HAS BEEN CALCULATED

SPRING FROM WHICH SULFATE TO CHLORIDE RATIO HAS BEEN CALCULATED

DIRECTION OF GROUND-WATER FLOW IN SPRING 1986

ROAD

than 0.3 to 55 pCi/L and generally decreased as the water moved down the hydraulic gradient (fig. 13). Thus, the relation of tritium and chloride does not indicate evaporative concentration of post-1952 irrigation water.

Nitrogen, from the application of fertilizers, can sometimes be used as an indicator of recycled irrigation water. Results from eight samples collected in the southeastern part of the district indicate increases in chloride may be related to increases in dissolved nitrate plus nitrite. In the southwestern part (9 samples) and northern part (49 samples) of the area, where the largest increases in dissolved solids have occurred, results do not indicate any relation between the increase in chloride and an increase in dissolved nitrate plus nitrite. This would indicate that irrigation return flow in the southwestern and northern parts of the district is not the dominant cause of an increase in dissolved-solids concentrations in water from wells.

Water from some wells in the southwestern and northern parts of the district contained greater than 10 micrograms per liter of dissolved selenium. Water from wells sampled in the southeastern part of the district contained dissolved selenium concentrations of less than 10 micrograms per liter. A relation between selenium and chloride was not indicated by these limited data.

Based on the above observations, it is probable that the primary cause of deterioration in water quality in the southwestern and northern parts of the Kanosh farming district is the movement of water from the southwest and possibly the west into the aquifer during periods of large ground-water withdrawals. The water contains large concentrations of dissolved solids and selenium, small concentrations of nitrogen, and very little tritium. The deterioration of water quality in the southeastern part of the area may be the result of concentration by recycling of irrigation water and mixing of recharge water from the east with isotopically heavy water from the southwest and possibly the west.

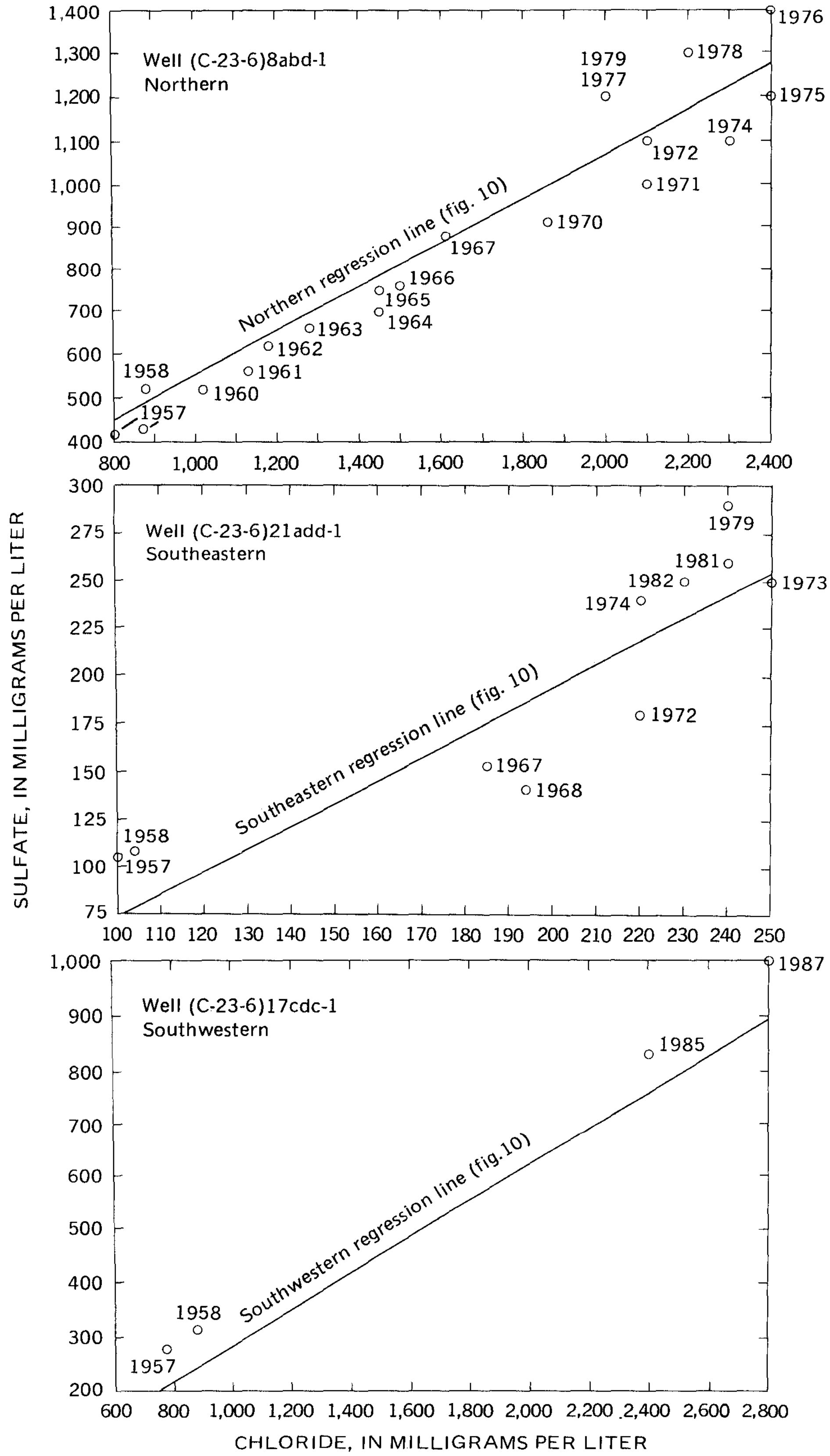


Figure 12.--Relation of sulfate and chloride in water samples from three wells in the northern, southeastern, and southwestern parts of the Kanosh farming district, showing year sample was taken.

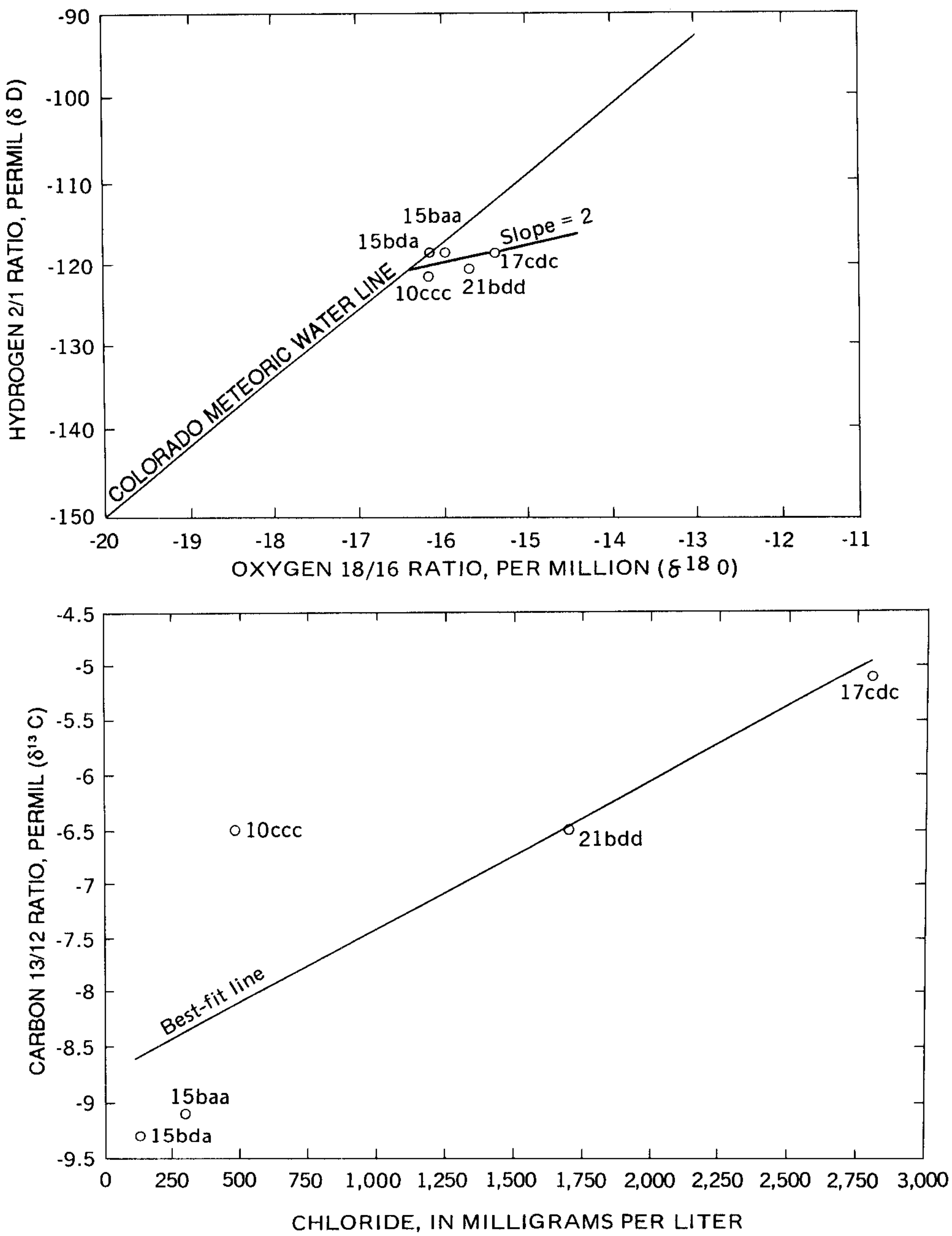
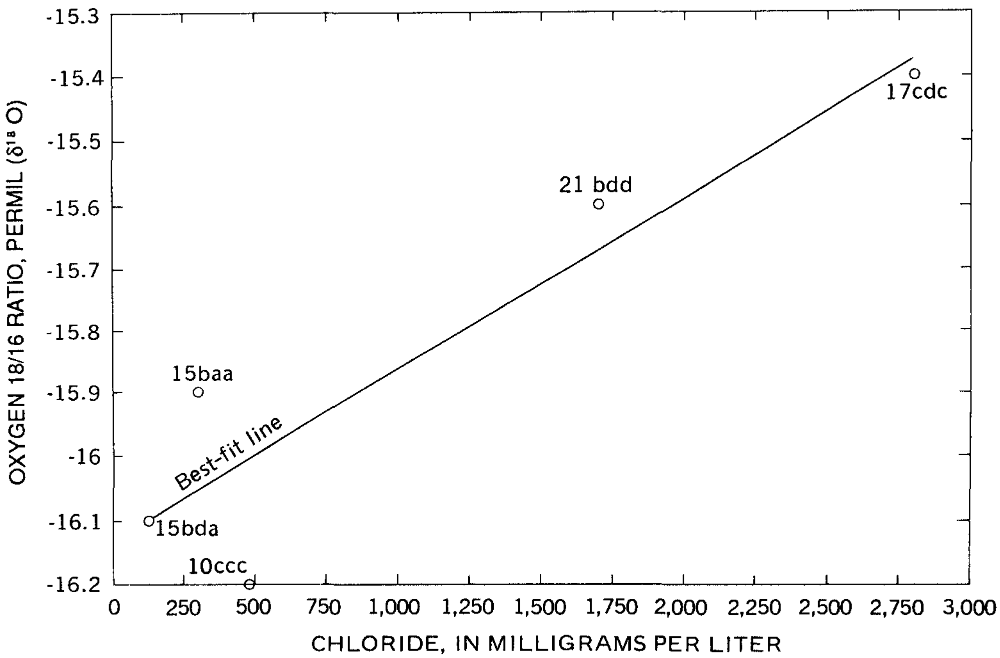


Figure 13.--Relation of deuterium to oxygen 18, and carbon 13, oxygen 18, deuterium,and tritium to chloride from sampled wells in the Kanosh farming district (T. 23 S., R. 6 W.).



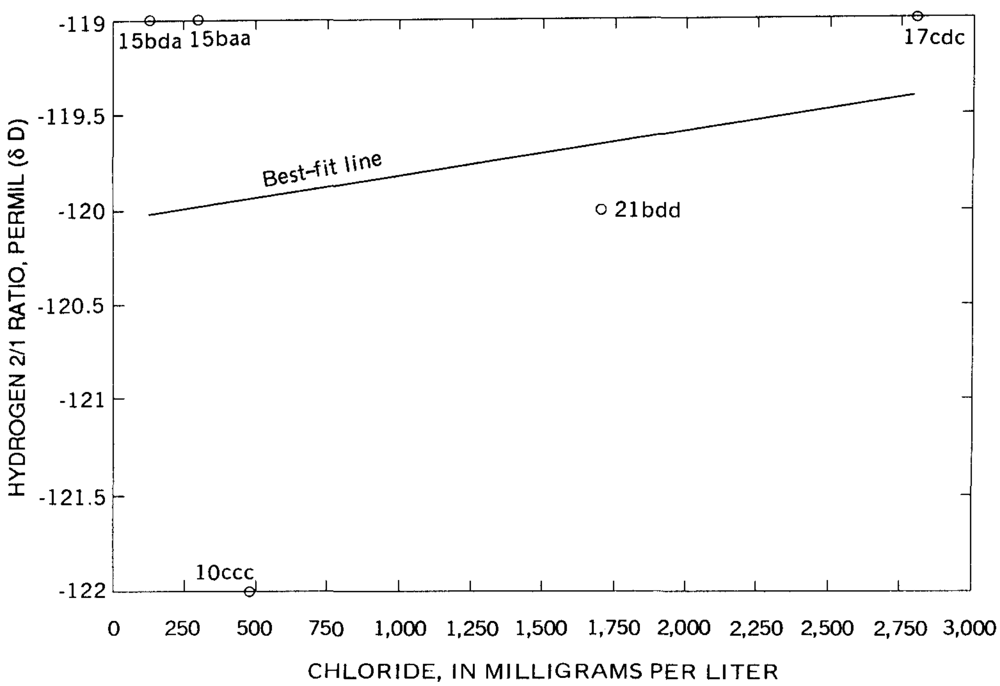


Figure 13.--Relation of deuterium to oxygen 18, and carbon 13, oxygen 18, deuterium, and tritium to chloride from sampled wells in the Kanosh farming district (T. 23 S., R. 6 W.)--Continued.

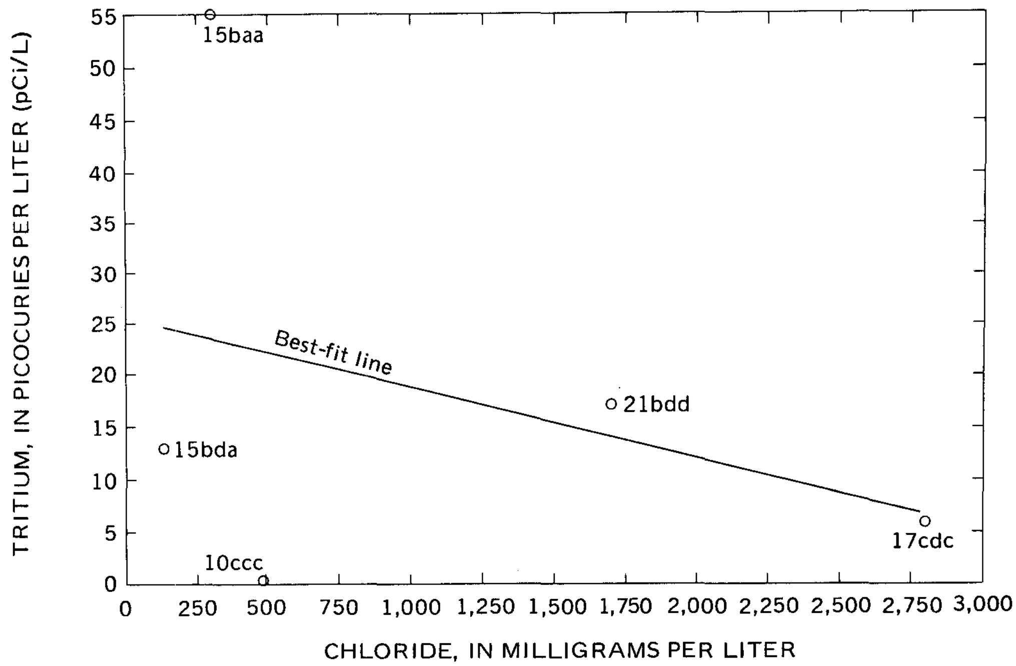


Figure 13.--Relation of deuterium to oxygen 18, and carbon 13, oxygen 18, deuterium, and tritium to chloride from sampled wells in the Kanosh farming district (T. 23 S., R. 6 W.)--Continued.

Projected Effects of Future Ground-Water Withdrawals and Loss of Recharge from the Central Utah Canal Using a Digital-Computer Model

A digital-computer model was used to simulate the principal ground-water reservoir of Pahvant Valley and the surrounding area. The model is a finite-difference ground-water flow model documented in McDonald and Harbaugh (1988), including a complete program listing. The model was used to project future changes in the ground-water system assuming various ground-water development options. In addition, the model was used to project the effects of the loss of recharge from the Central Utah Canal.

Model Design and Construction

A block-centered grid with variable grid spacing was used to model Pahvant Valley and the surrounding area. The grid consisted of 58 rows and 35 columns. Four layers were used to represent the unconsolidated basin fill and interbedded basalt making a total of 8,120 nodes of which about 6,360 were active. The area covered by individual nodes ranged from 0.25 square mile where many observation wells were located or where the change in water levels over a short distance is large, to about 4.3 square miles where data were sparse or water-level changes and withdrawals were minimal. The model grid and information on the uppermost model layer are shown in plate 4, a generalized geologic section showing lithology and divisions of the ground-water reservoir into model layers in the Flowell area is given in figure 14, and the boundaries of each layer are shown in figures 15 to 18.

The first layer of the model initially represents the approximate upper 50 feet of saturated deposits. The water in the first layer is unconfined and the layer serves as a temporary storage reservoir for areally distributed recharge which may move into lower aquifers or be discharged from the layer by evapotranspiration or discharge to drains or springs. Changes in the balance between recharge and discharge can cause the saturated thickness to vary from the initial 50 feet.

The second layer of the model represents the next 100 feet (depth of 50 to 150 feet) of saturated deposits. Near the mountain fronts and extending for several miles toward the central part of the basin, the layer represents more permeable material. In the central part of the study area, the layer represents basalt that is interbedded with the unconsolidated basin fill. In areas adjacent to and extending for several miles west of the basalt, the layer represents a fine-grained confining unit.

The third layer of the model represents basin fill at depths of between 150 and 350 feet. Most ground-water withdrawals in the study area are from depths represented by the third layer in the model.

The fourth layer generally represents the poorly to moderately consolidated, somewhat permeable part of the Sevier River Formation. The aggregate thickness of the formation probably exceeds 800 feet (Mower, 1965, p. 19), which, except in some areas where the deposits have been reworked (Mower, 1965, p. 31), is relatively impermeable. The formation crops out at several locations within Pahvant Valley and may occur at very shallow depths at other locations.

The boundaries of the model include no-flow boundaries on the southwest, northeast, and east, represented by zero values of hydraulic conductivity or transmissivity in figures 15 to 18, and a no-flow boundary at the base of the model that corresponds approximately to the contact between the permeable, unconsolidated basin fill and reworked Sevier River Formation, and the relatively impermeable lower part of the Sevier River Formation (fig. 14 and Mower, 1965, p. 20). A number of no-flow nodes located in the interior of the model represent outcrops of the Sevier River Formation which forms the cores of several hills in the central part of Pahvant Valley. No-flow boundaries on the southern and southwestern borders of the study area represent consolidated rocks, which are relatively impermeable and do not contain substantial quantities of water (Mower, 1965, p. 20). The northwestern boundary of the model is a constant-head boundary (pl. 4) that simulates flow from the study area, primarily through fine-grained unconsolidated basin fill of low permeability, toward the areas of lower elevation in the Sevier Desert.

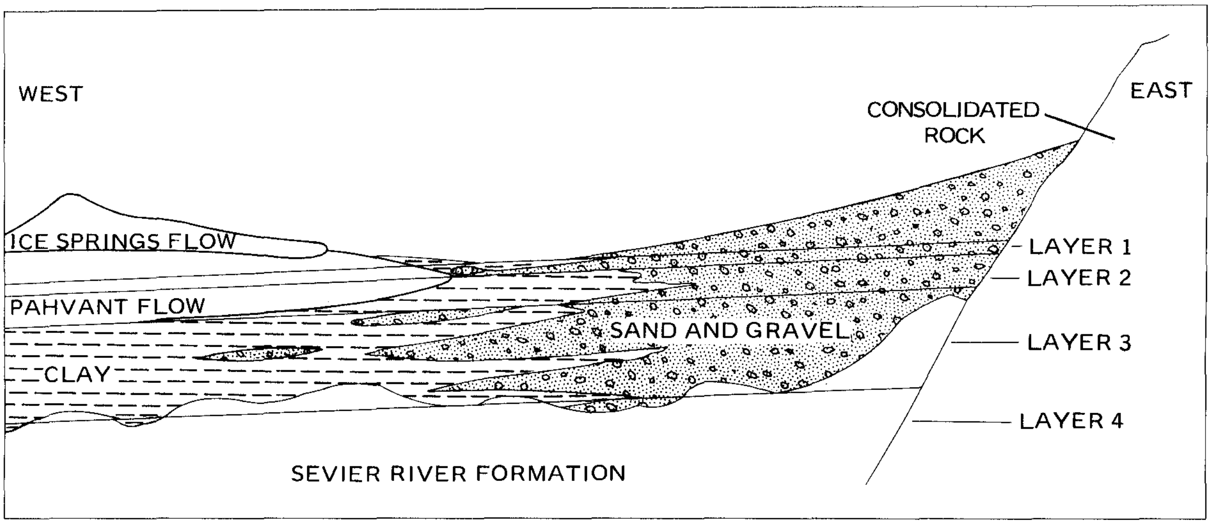


Figure 14.--Generalized geologic section showing lithology and divisions of the ground-water reservoir into model layers in the Flowell area.

Data Input

Data input to the model include initial water levels, areally distributed recharge, transmissivity or hydraulic conductivity, storage properties, confining-bed properties, evapotranspiration rates and depths of extinction, conductance terms for the interface between drains and porous material, and well discharge.

Initial water levels from wells in Pahvant Valley, representing conditions prior to about 1952 before large-scale withdrawals of irrigation water, were obtained primarily from Dennis and others (1946, pl. 1 and p. 85-96). Data from Livingston and Maxey (1944) and Mower (1965), as well as water levels reported in drillers' logs, also were used for initial water levels.

Areally distributed recharge used in the model includes seepage from streams, the Central Utah Canal, unconsumed irrigation water, and infiltration from precipitation. The quantities of recharge from these sources primarily are based on estimates reported for 1959 by Mower (1965, table 9). Recharge from unconsumed irrigation water increased after 1959 because of increased irrigation. The distribution of recharge from the various sources used in the steady-state model is shown on plate 4.

Hydraulic properties of the basin fill are based on results of aquifer tests reported by Mower (1965, table 8), Dennis and others (1946, p. 65), and descriptions of materials from drillers' logs. The simulated values do not always agree with the reported values derived from aquifer tests. The simulated values represent an average for a specific node and layer, which may not be the same interval represented by the aquifer test.

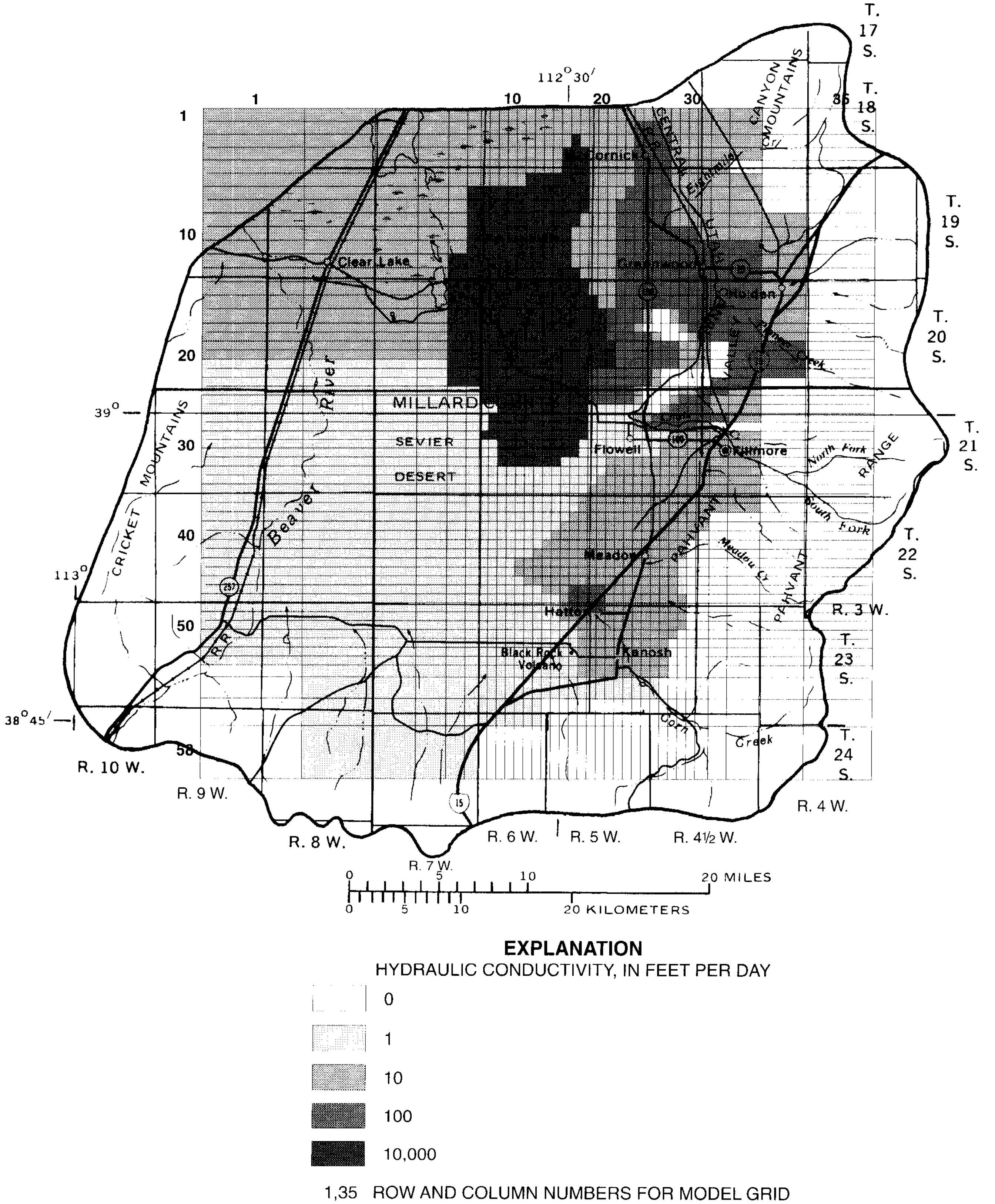


Figure 15.--Distribution of hydraulic conductivity used in layer 1 of the digital-computer model.

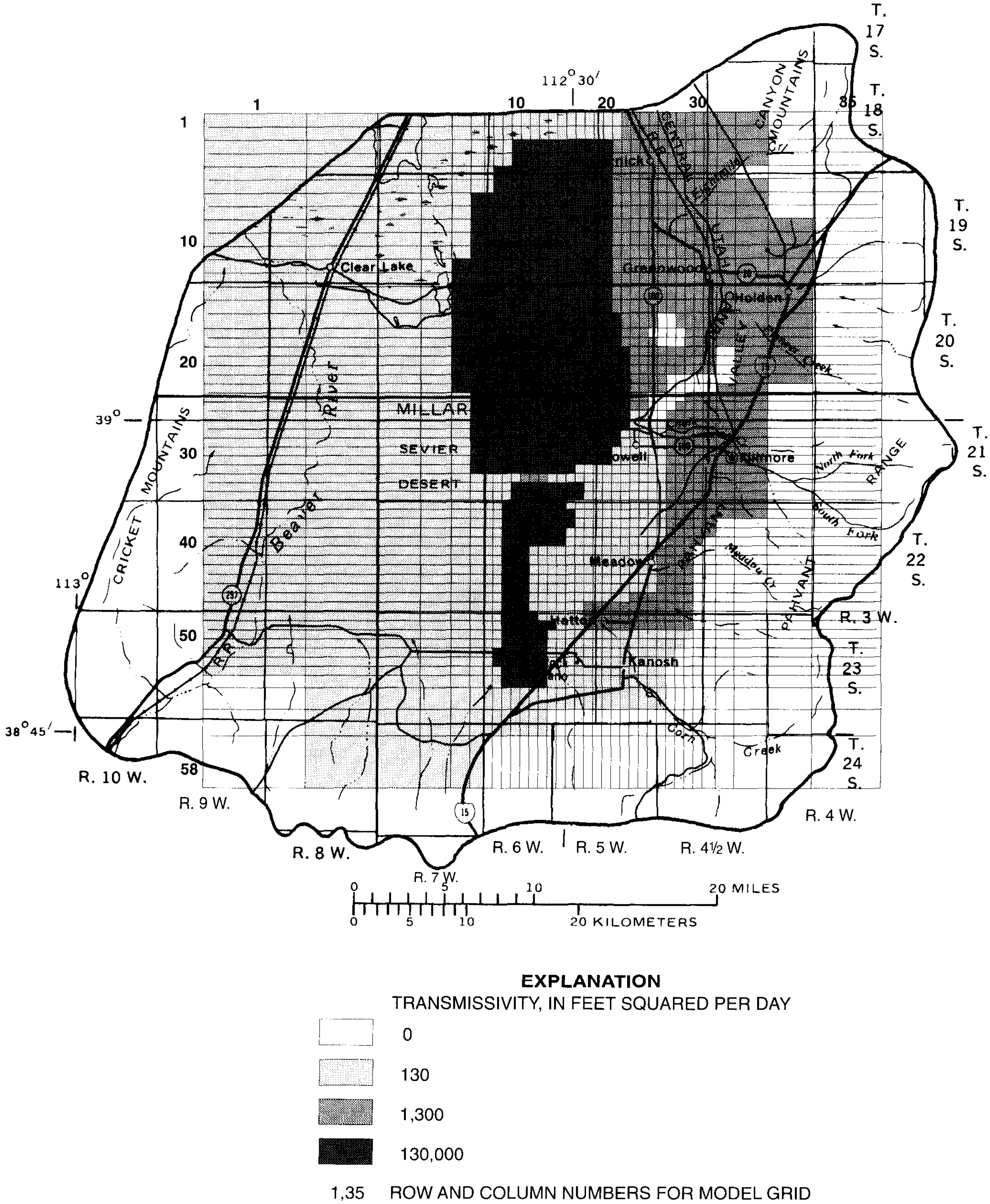


Figure 16.--Distribution of transmissivity used in layer 2 of the digital-computer model.

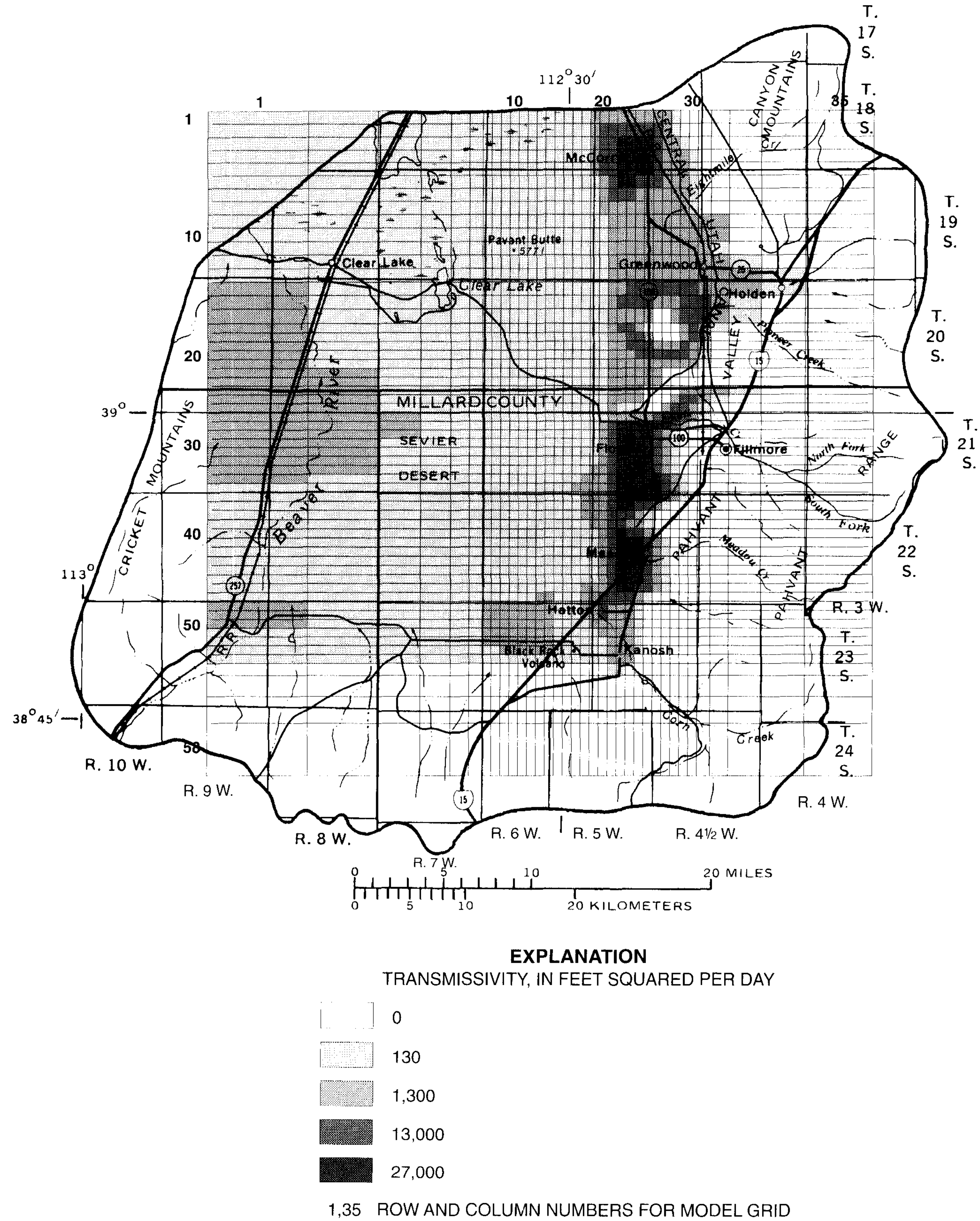
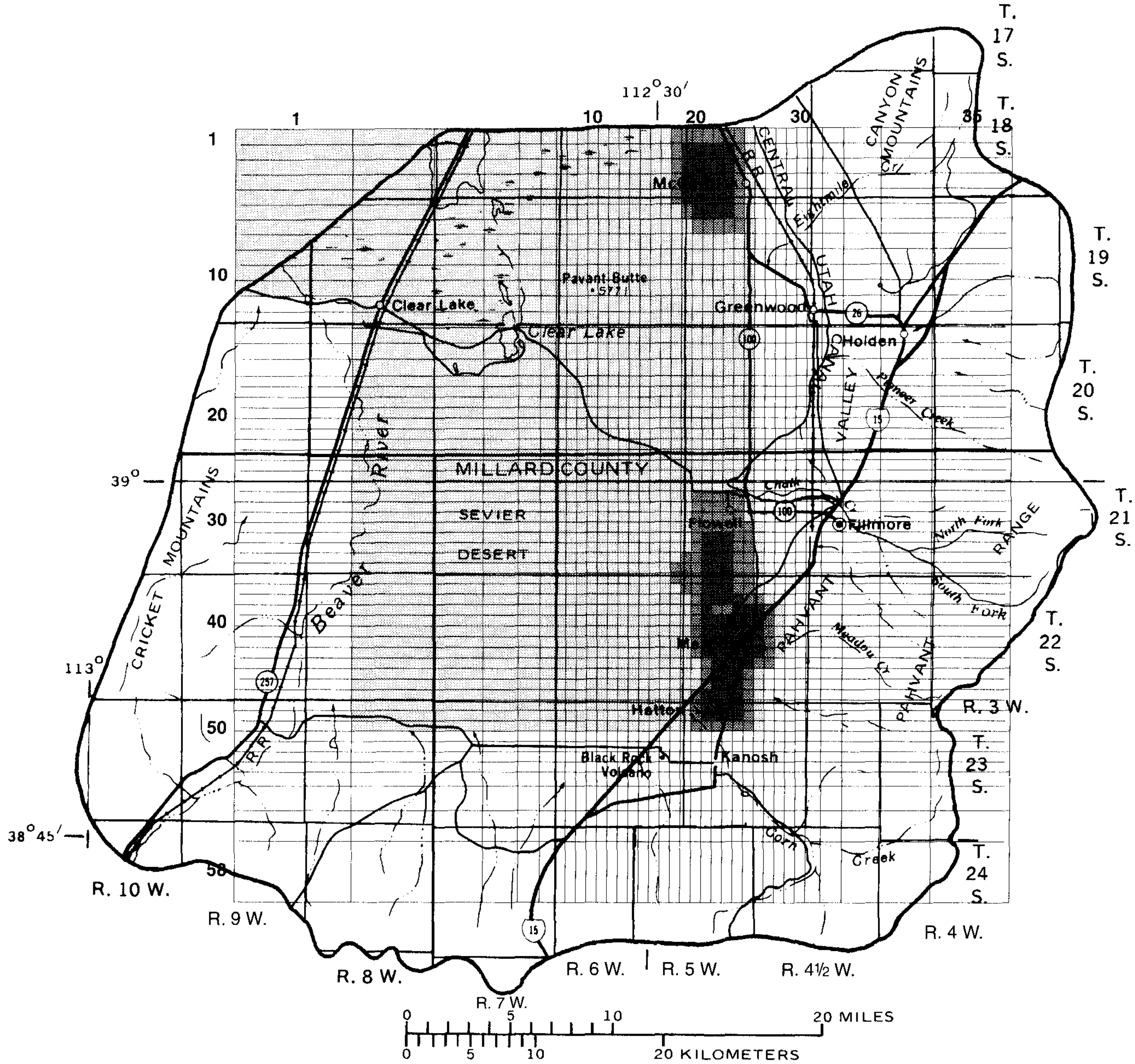


Figure 17.--Distribution of transmissivity used in layer 3 of the digital-computer model.



EXPLANATION

TRANSMISSIVITY, IN FEET SQUARED PER DAY

- 0
- 130
- 1,300
- 13,000

1,35 ROW AND COLUMN NUMBERS FOR MODEL GRID

Figure 18.--Distribution of transmissivity used in layer 4 of the digital-computer model.

The hydraulic conductivity values used in the model for layer 1 (fig. 15) were generally set at 1 foot and 10 feet per day in most of the study area where the basin fill consists of clay, silt, or fine sand. A value of 10,000 feet per day was used where the fill was basalt, and 10 and 100 feet per day was used near the mountain fronts where the fill was mostly sand and gravel.

The transmissivity of layer 2 (fig. 16) in most of the area was set at 130 feet squared per day. In the basalt, the transmissivity was set at 130,000 feet squared per day, and near the mountain fronts, the transmissivity was set at 1,300 feet squared per day.

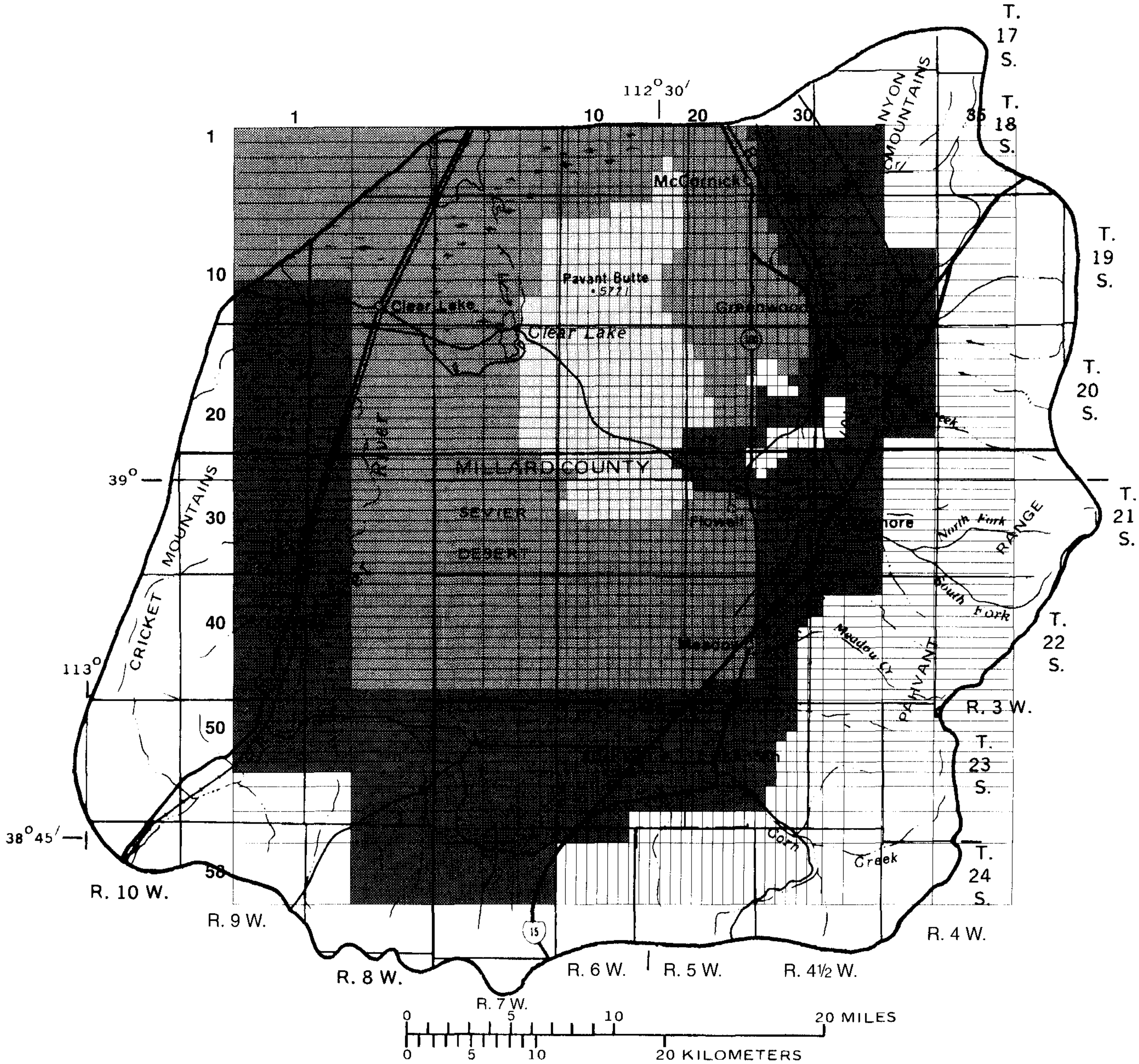
The transmissivity of layer 3 (fig. 17) was generally set at 13,000 and 27,000 feet squared per day in the central part of Pahvant Valley where the basin fill is generally well sorted sand and gravel; 130 feet squared per day west of Pahvant Valley; and 130 and 1,300 feet squared per day on the eastern side of Pahvant Valley. Layer 3 represents the most heavily pumped part of the basin fill.

The transmissivity of layer 4 (fig. 18) was generally set at 130 feet squared per day, which is thought to represent the upper part of the Sevier River Formation. Two areas were assigned values of 1,300 and 13,000 feet squared per day and are thought to be more permeable reworked material from the Sevier River Formation.

The specific yield in layer 1 (fig. 19) was set at 0.30 above an elevation of about 4,800 feet, where the materials primarily consist of sand and gravel. Below an elevation of 4,800 feet in layer 1, where the materials primarily are silt and clay, a specific yield of 0.20 was used. Below an elevation of about 4,800 feet, where the materials are primarily basalt of the Pahvant flow, a value of 0.06 was used.

The primary storage coefficient in layer 2 was set at an artesian value of 0.001. When the water level in a confined cell in layer 2 falls below the top of the cell, the model uses a secondary storage term representing specific yield. The secondary storage terms representing specific yield were set equal to the specific yield in layer 1 (fig. 19). The storage coefficient of layer 3 and layer 4 was set at an artesian value of 0.00005.

The vertical conductance terms used in the model were initially estimated from aquifer tests in the Sevier Desert, about 30 miles north of the study area (Holmes and Wilberg, 1982). These values were adjusted during the calibration procedure. Vertical conductance is calculated within the model by multiplying the vertical leakance term, which incorporates both vertical hydraulic conductivity and thickness, and the horizontal cell area (McDonald and Harbaugh, 1988, p. 5-12). The final values of vertical leakance in active nodes ranged from a low of 7.7×10^{-11} sec^{-1} in the central part of the area between layers 2 and 3 to a high of 3.1×10^{-6} sec^{-1} near the mountain fronts between layers 1 and 2. The vertical leakance between layers 3 and 4 was set at 2.3×10^{-7} sec^{-1} throughout the modeled area. The final distribution of vertical leakance between layers 1 and 2 and between layers 2 and 3 is shown in figures 20 and 21.



EXPLANATION

SPECIFIC YIELD

0

0.06

0.20

0.30

1,35 ROW AND COLUMN NUMBERS FOR MODEL GRID

Figure 19.--Distribution of specific yield used in layer 1 of the digital-computer model.

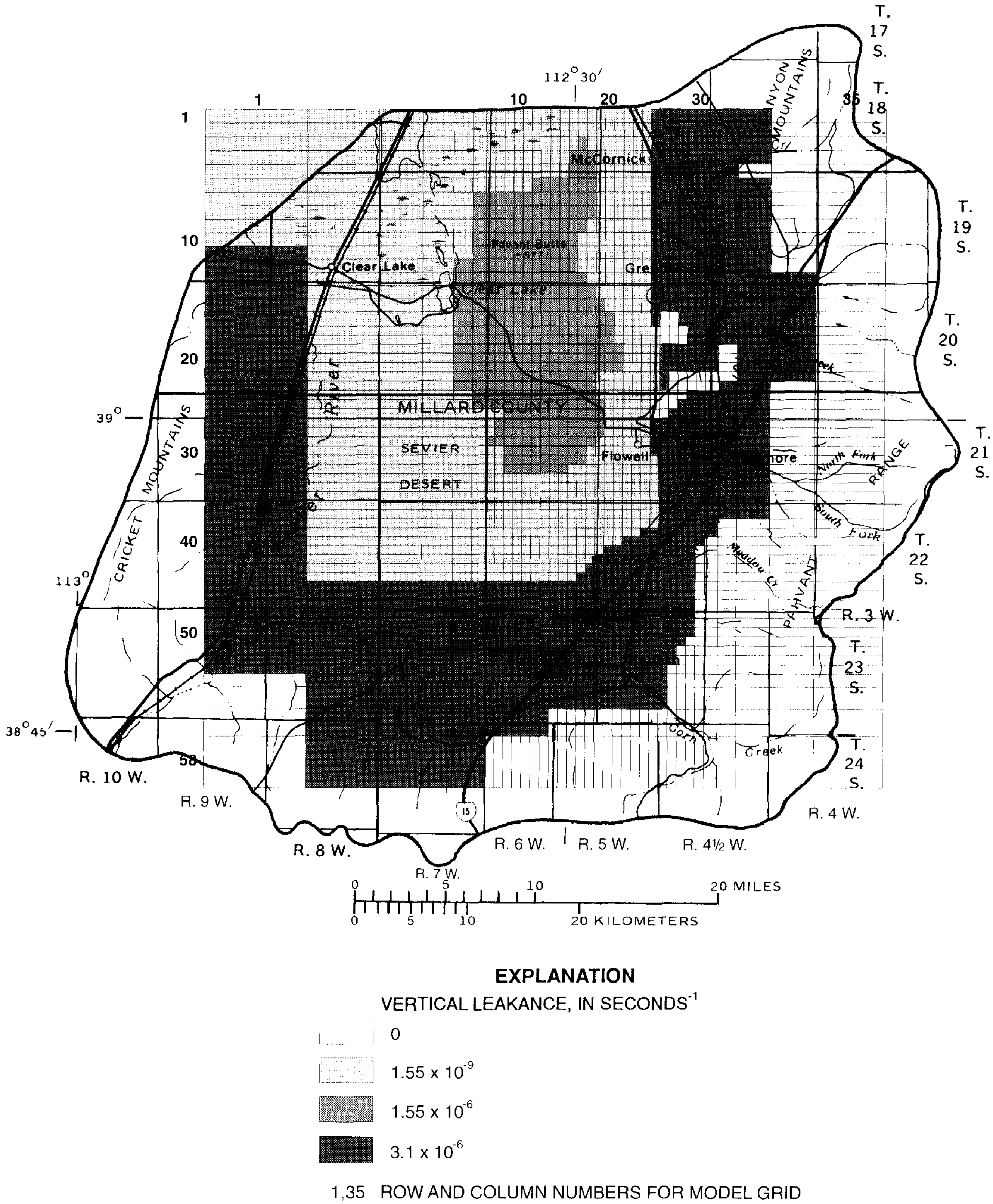
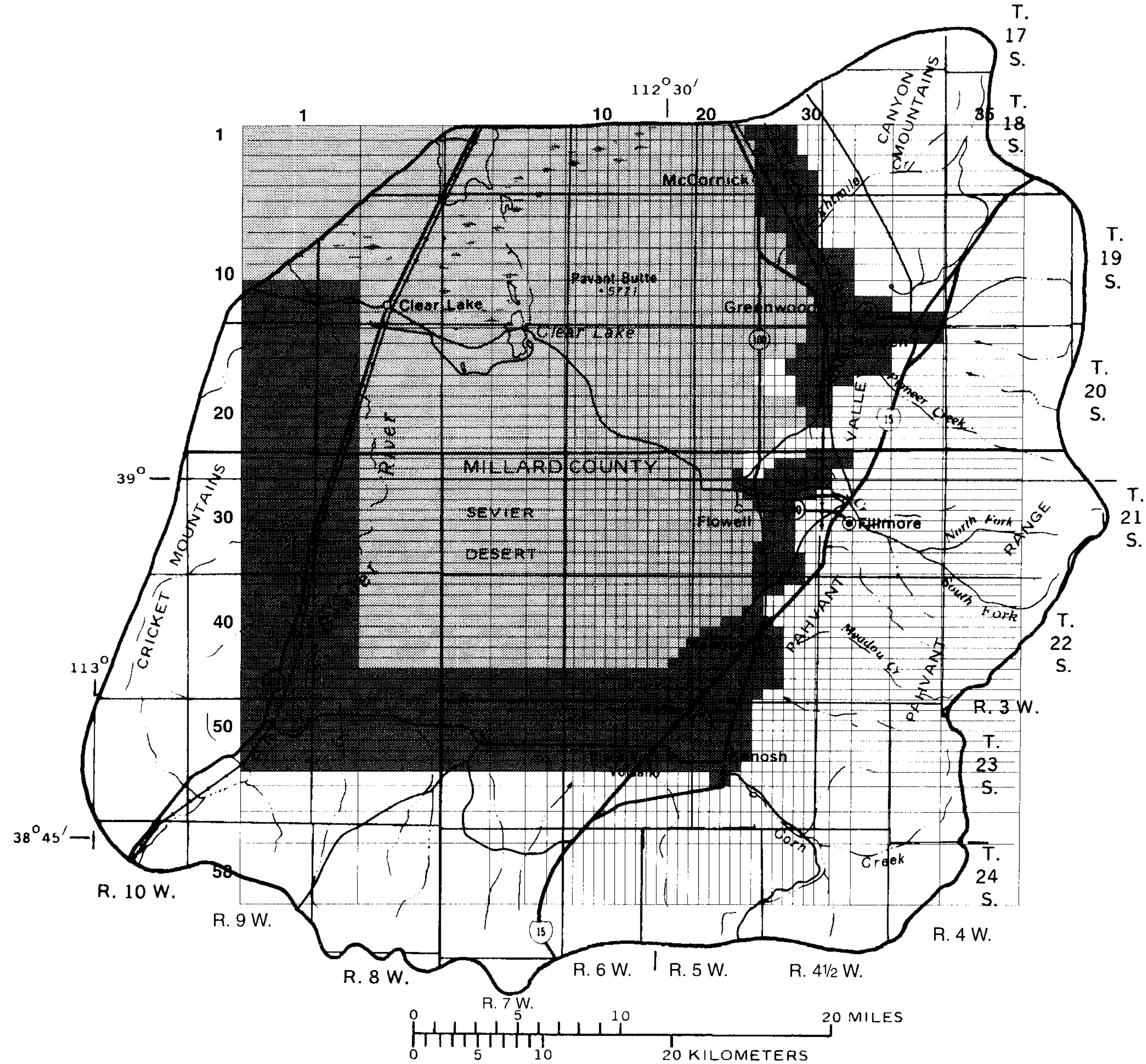


Figure 20.--Distribution of vertical leakance between layers 1 and 2 used in the digital-computer model.



EXPLANATION

VERTICAL LEAKANCE, IN SECONDS^{-1}

(white)	0
(light shading)	1.55×10^{-11}
(dark shading)	7.7×10^{-7}

1,35 ROW AND COLUMN NUMBERS FOR MODEL GRID

Figure 21.--Distribution of vertical leakance between layers 2 and 3 used in the digital-computer model.

Discharge from evapotranspiration, drains, wells, subsurface outflow, and springs are represented in the model. In the model, evapotranspiration (pl. 4) is head-dependent and requires the input of a maximum evapotranspiration rate and a depth of extinction (McDonald and Harbaugh, 1988, p. 10-8). The maximum evapotranspiration rate used was 2 feet per year, and the depth of extinction was set at 10 feet.

Simulation by the model of discharge from drains (pl. 4) is head-dependent and requires a conductance value for the interface between the cell and the drain, and the elevation of the drain (McDonald and Harbaugh, 1988, p. 9-7). A value of 10 feet squared per second was used for the conductance in all drains. This value was determined during the steady-state calibration of the model.

In the model, discharge from wells is based on records of ground-water withdrawals in the files of the U.S. Geological Survey in Salt Lake City. Ground-water withdrawals from the unconsolidated basin fill were simulated in layer 3, and withdrawals from the basalt were simulated in layer 2.

In all layers, discharge from constant-head nodes along the northwest side of the model (pl. 4) represents subsurface flow out of the modeled area. Discharge from an interior constant-head node in layer 1 (pl. 4) was used to simulate flow from Clear Lake Springs (pl. 1).

Steady-State Calibration

Steady-state calibration involved comparing model-computed water levels, computed discharge of Clear Lake Springs, and discharge of drains or sloughs to actual measured values, and adjusting some model parameters to obtain the best overall agreement with measured values. Steady-state conditions were assumed for the period prior to 1947, although 17,000 acre-feet per year was being withdrawn from flowing wells between 1930 and 1945 (Dennis and others, 1946, p. 80). Most of the flowing wells were drilled prior to 1935, and water levels and discharge from flowing wells remained fairly stable from 1935 through 1946.

Water-level measurements from 204 wells, most of which cover the period from 1940 to 1943, were used in the steady-state calibration and are reported by Dennis and others (1946, p. 85). A few more recent water levels were used for wells in remote areas, away from the effects of pumping. Nine of the water levels represent layer 1, 23 represent layer 2, 138 represent layer 3, and 34 represent layer 4. The relation between water levels computed by the model and those measured in wells is shown in figure 22. Model-generated water levels generally are in close agreement with the observed water levels, with maximum differences of about 25 feet for a single point. The largest differences occurred near Flowell, where a steep hydraulic gradient (pl. 2) was difficult to model. The potentiometric surface of layer 3 computed by the model for steady-state conditions is shown in figure 23.

The discharge of Clear Lake Springs varied from about 13 to 85 cubic feet per second and averaged about 25 cubic feet per second during 1959-85 (fig. 4). Disregarding the extremely large discharges during 1984-85, the average is about 21 cubic feet per second. The discharge of the springs has been reduced because of large ground-water withdrawals in Pahvant Valley (Mower,

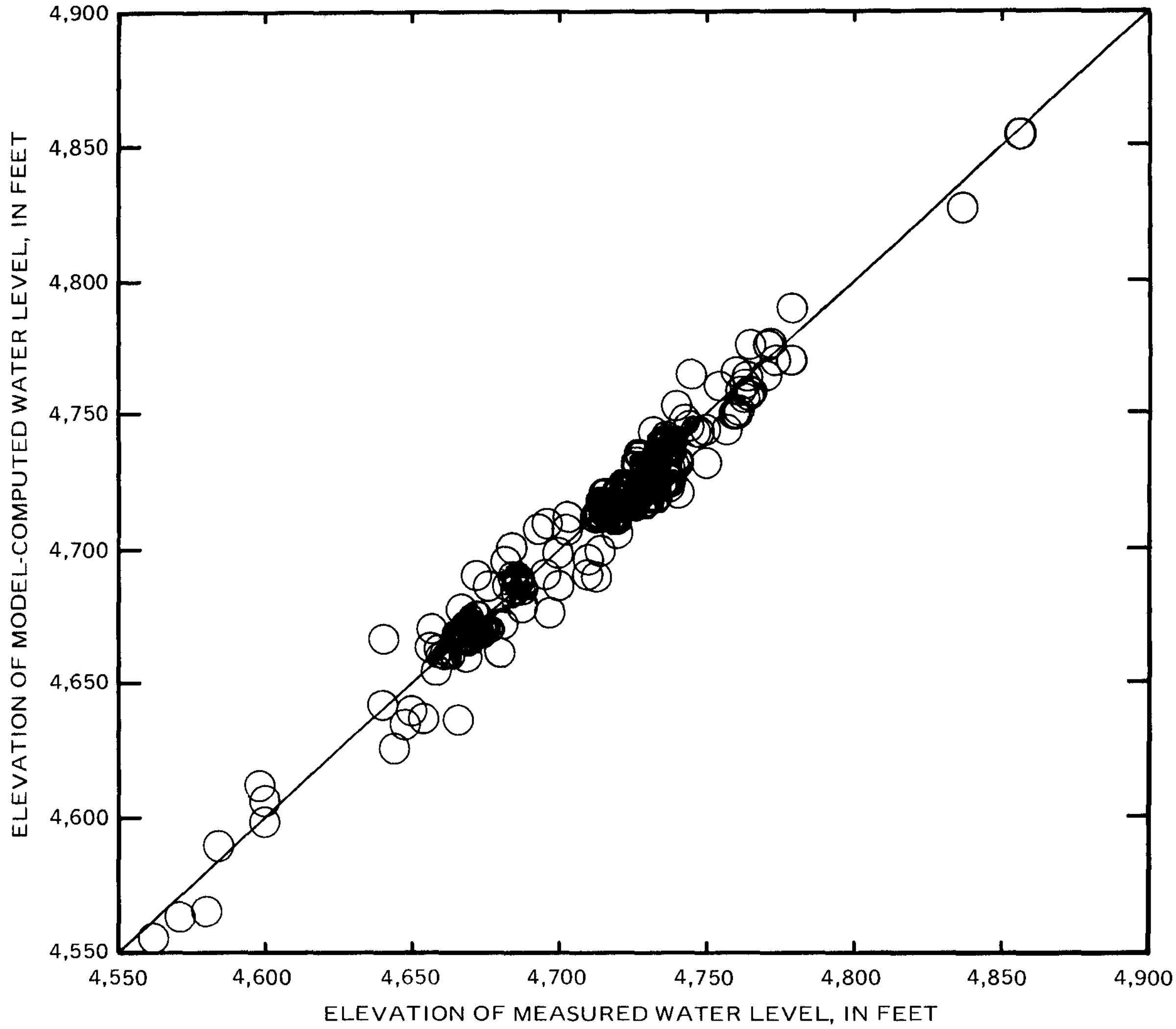
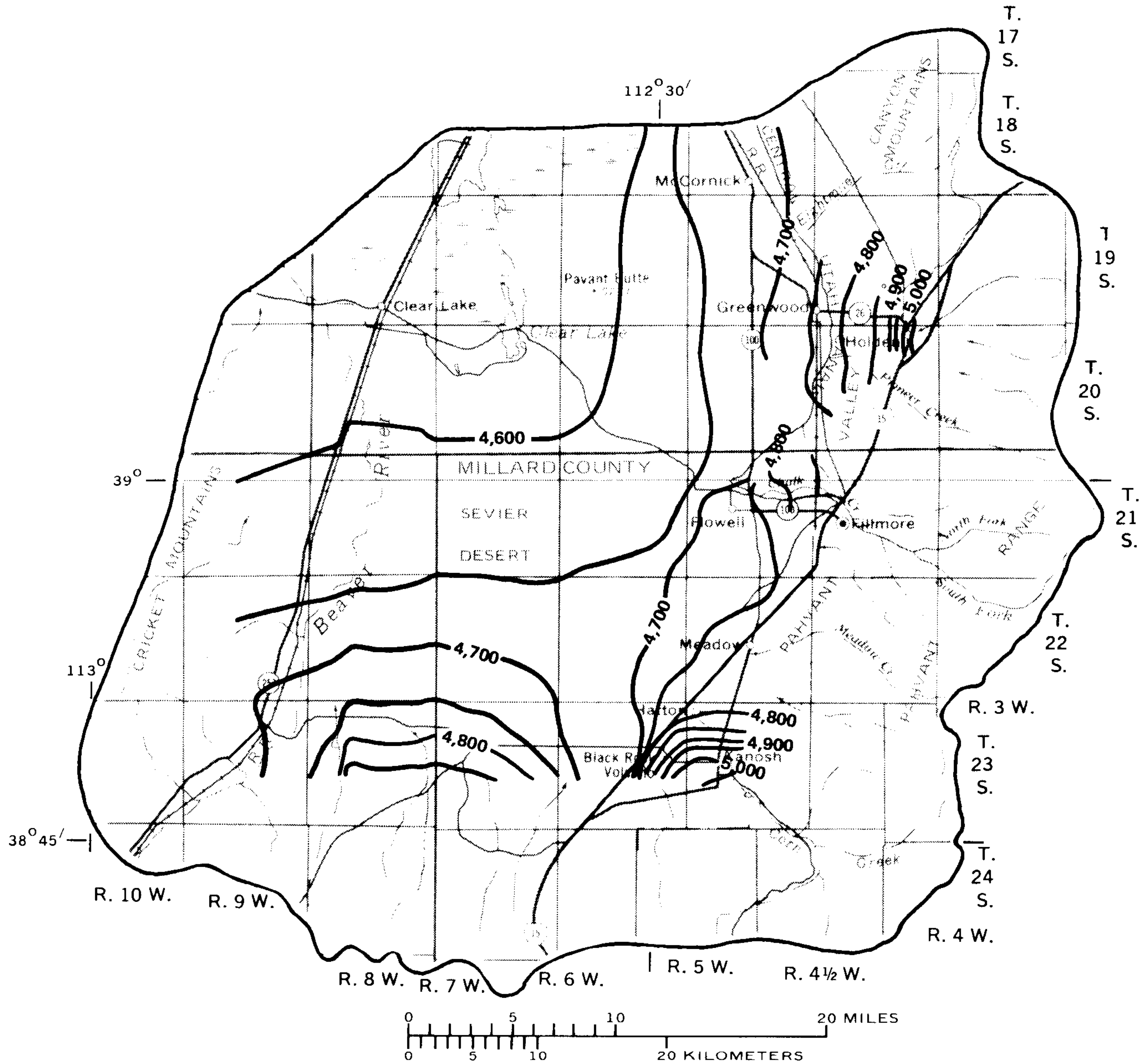


Figure 22.--Relation between measured and model-computed steady-state water levels in model nodes that include observation wells.

1967, p. E23). Prior to large-scale ground-water development, which began in about 1950, the discharge was probably between 25 to 30 cubic feet per second. The steady-state discharge calculated by the model was about 27 cubic feet per second, within the range of discharge estimated from the available data.

Dennis and others (1946, p. 55) reported the discharge of Meadow Creek slough in section 1, T. 22 S., R. 6 W. to be 4.6 cubic feet per second on June 20, 1944, and 5.1 cubic feet per second on April 12, 1945. Both reported measurements were in the spring or early summer, when maximum discharge might



EXPLANATION

—— 4,600 —— POTENTIOMETRIC CONTOUR--Shows altitude of the computed potentiometric surface. Contour interval 50 feet. National Geodetic Vertical Datum of 1929

Figure 23.--Model computed steady-state potentiometric surface of layer 3.

be expected, and both measurements may have included some flowing-well discharge. Also, in 1945, the artesian pressures were near historically large values, and many previously dry springs began to flow into Meadow Creek slough (Dennis and others, 1946, p. 55). Because the conditions in 1944-45 were conducive to greater-than-average flow, the model-computed flow of 1.8 cubic feet per second, represented by drain nodes, is probably a reasonable representation of long-term steady-state discharge. The steady-state ground-water budget computed by the digital model is shown in table 2.

Transient-State Calibration

Transient-state calibration was done by simulating ground-water withdrawals that were recorded during 1947-85 (39 yearly stress periods) and comparing measured water-level changes and measured changes in discharge at Clear Lake Springs, to computed water-level changes and computed changes in the discharge of Clear Lake Springs. Some minor adjustments to model parameters were made to improve the agreement of model-computed values of water levels and discharge at Clear Lake Springs with measured values.

During the transient calibration, it became apparent that varying the quantity of annual recharge produced model-computed values closer to the measured values than were the values obtained using a constant quantity of recharge equal to the long-term average. The best results were obtained when long-term average annual recharge was multiplied by a factor related to the percentage that the annual precipitation was greater than or less than the 1947-85 average. The factor was computed using the relation:

$$F = \left\{ [(P/P_{avg}) - 1] \times 4 \right\} + 1.0,$$

where P is the precipitation for the year and P_{avg} is 15.31. The lower limit of F was 0.5.

For example, in 1957, the precipitation at Fillmore was 17.52 inches, 2.21 inches or 14 percent greater than the 1947-85 average of 15.31 inches. The average recharge rate of about 66,000 acre-feet per year was multiplied by a factor of 1.56 [(0.14 X 4) +1], to obtain the recharge rate of about 103,000 acre-feet for 1957.

In addition, the distribution and average annual recharge in the model was increased after 1959 (stress period 13) from about 66,000 acre-feet per year to about 75,000 acre-feet per year. The additional recharge was added because increased irrigation, primarily from withdrawals of ground water for irrigation in the Kanosh and Meadow areas (Dennis and others, 1946, fig. 10 and Mower, 1965, pl. 10)(fig. 5), resulted in additional recharge from unconsumed irrigation water. Also, additional recharge from seepage from streams was simulated during 1983-85 (stress periods 37-39) when water was diverted into the basalt as a means of flood control or entered the basalt in flooded areas. (See sections entitled "Seepage from Streams" and "Movement"). The additional recharge from seepage from streams added during 1983-85 was varied during calibration. The final values were about 43,000 acre-feet during 1983, 139,000 acre-feet during 1984, and 28,000 acre-feet during 1985.

Table 2.—*Steady-state, reported, transient-state, and model-projected ground-water budgets for Pahvant Valley and surrounding areas, in acre-feet per year*

	Steady-state model	Reported by Mower (1965)	Transient-state model	Transient-state model	Projected using the 1977 rate of withdrawal for 20 years		
					x 1	x 0.5	Without recharge from the Central Utah Canal
			YEAR				
Budget element	(1946)	(1959)	(1977)	(1985)	(2005)	(2005)	(2005)
Recharge (precipitation, seepage from streams and canals, and unconsumed irrigation water)	66,000	[1]70,000	37,900	198,100	75,000	75,000	71,700
Discharge							
Clear Lake Springs	19,900	15,600	7,200	57,800	7,200	15,600	14,800
Wells	18,200	[2]64,000	95,900	61,500	95,900	48,000	48,000
Drains	1,300	not reported	700	3,300	1,000	1,500	1,500
Evapotranspiration	26,600	[3]29,000	15,400	23,500	13,000	19,000	18,100
Water going into (+) or out of (-) storage	0	-38,600	-80,700	+52,900	-41,500	-7,700	-9,600

[1]Includes 5,000 acre-feet of recharge from areas not included in previous studies.

[2]Revised from previously published value of 60,000 acre-feet (Mower, 1965, table 12).

[3]Includes 5,000 acre-feet of discharge from evaportranspiration from areas not included in previous studies.

The measured and computed water-level changes for 12 selected observation wells are shown in figure 24, and a comparison of the measured discharge at Clear Lake Springs with the computed discharge of the springs is shown in figure 25. The measured and computed water-level changes as well as the measured and computed discharge of Clear Lake Springs are in close agreement. Table 2 shows the ground-water budgets computed by the model at the end of 1977 and 1985 (stress periods 31 and 39).

Model Simulations

The calibrated model was used to project the effects of ground-water withdrawals and changes in recharge on water levels; discharge from Clear Lake Springs, from drains, and by evapotranspiration; and changes in ground-water storage. Withdrawals equal to the 1977 rate of 95,900 acre-feet, one-half the 1977 rate (48,000 acre-feet), and the elimination of recharge from the Central Utah Canal were simulated. An average recharge rate of 75,000 acre-feet per year was used when simulating changes in withdrawals, and a rate of 71,700 acre-feet of recharge was used when simulating the elimination of recharge from the Central Utah Canal (table 2). The simulation period was 20 years, assumed to be 1985-2005, and the same well locations used in 1977 were also used for simulating withdrawals. Water-level-change maps were prepared that represent the difference between the computed water levels at the end of each

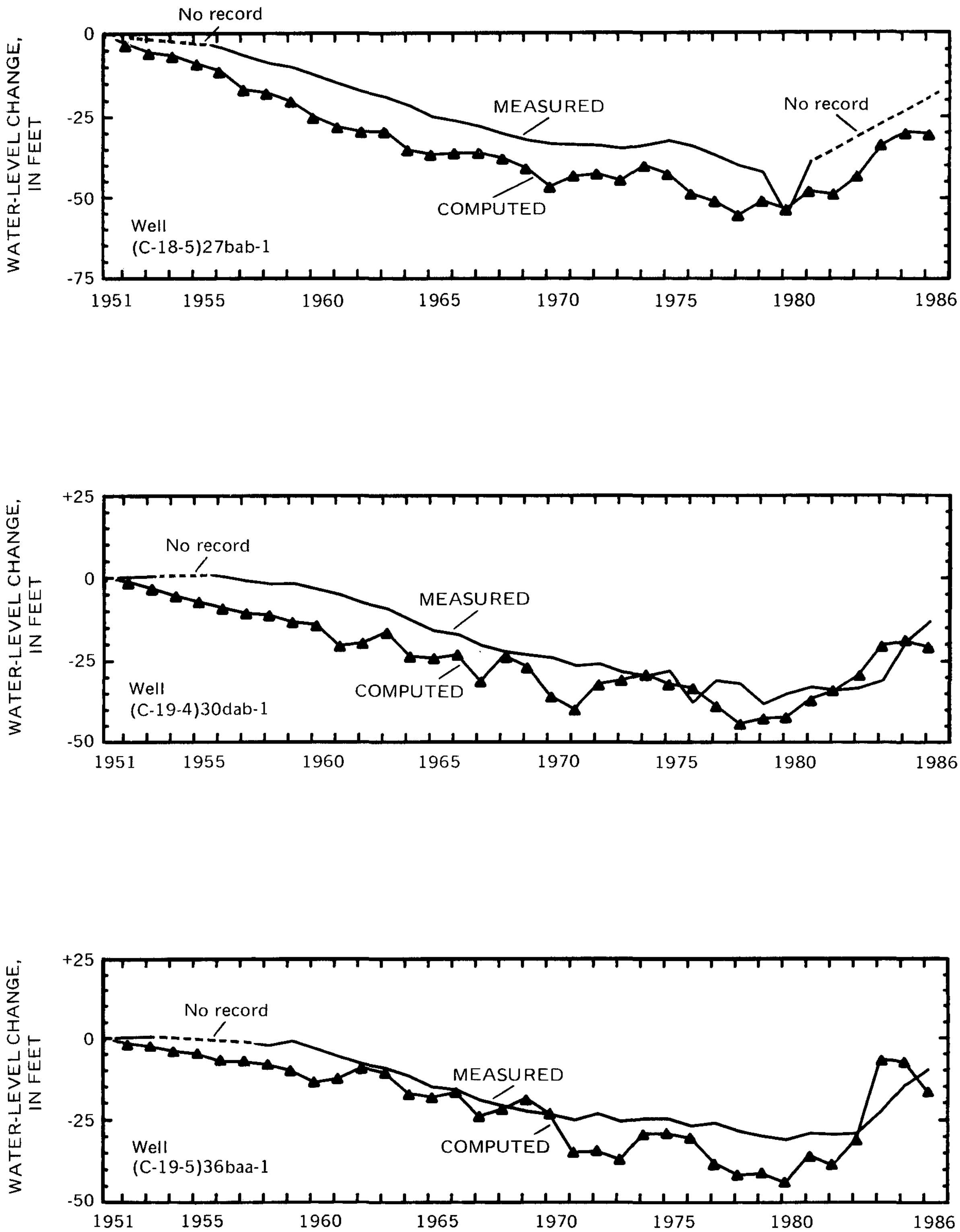
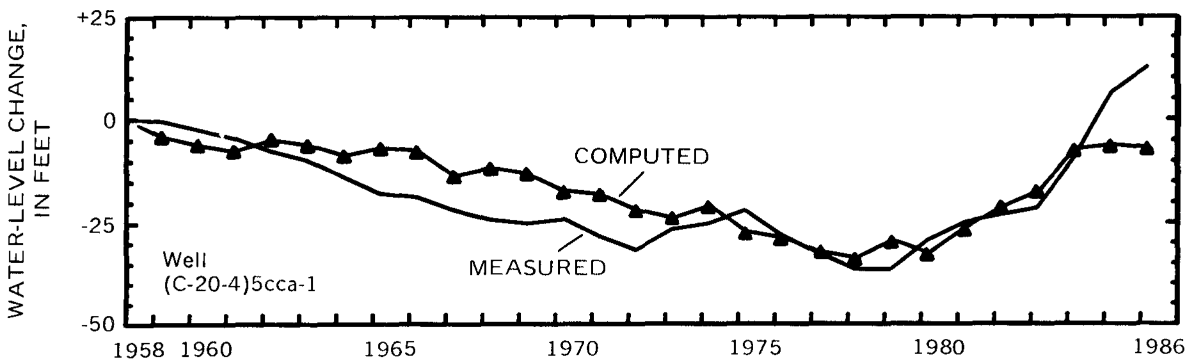
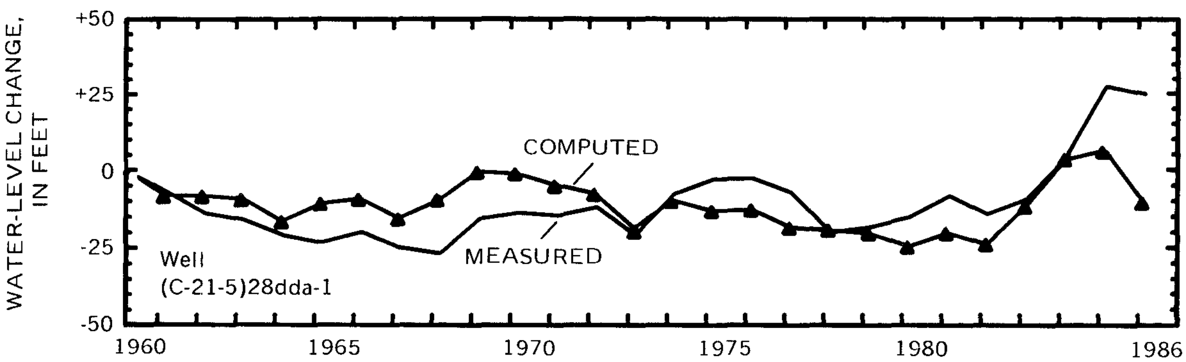


Figure 24.--Measured and computed water-level changes for 12 selected observation wells.





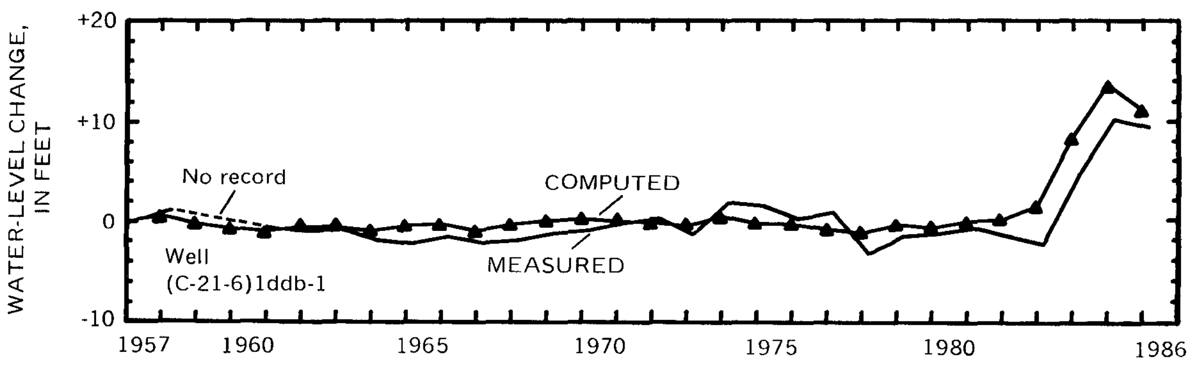
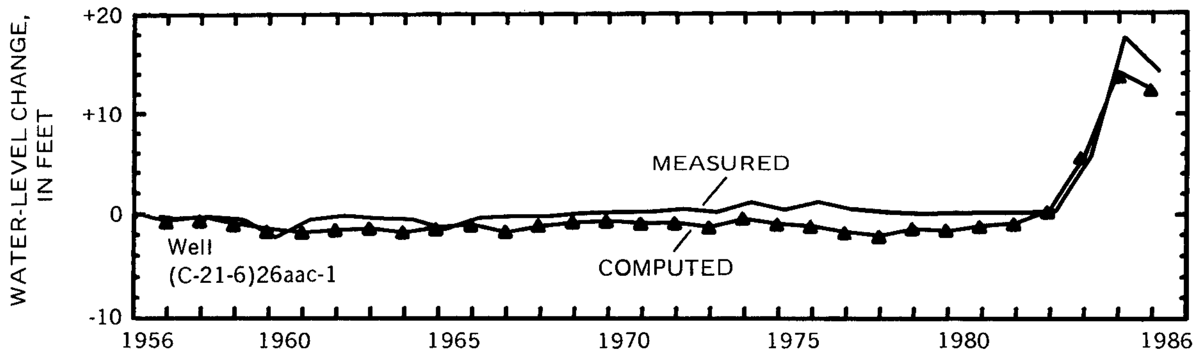
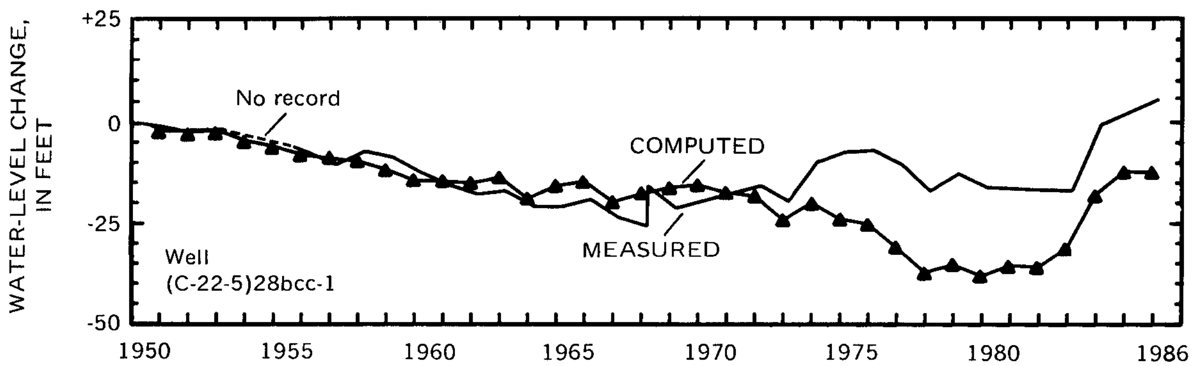


Figure 24.--Measured and computed water-level changes for 12 selected observation wells--Continued.





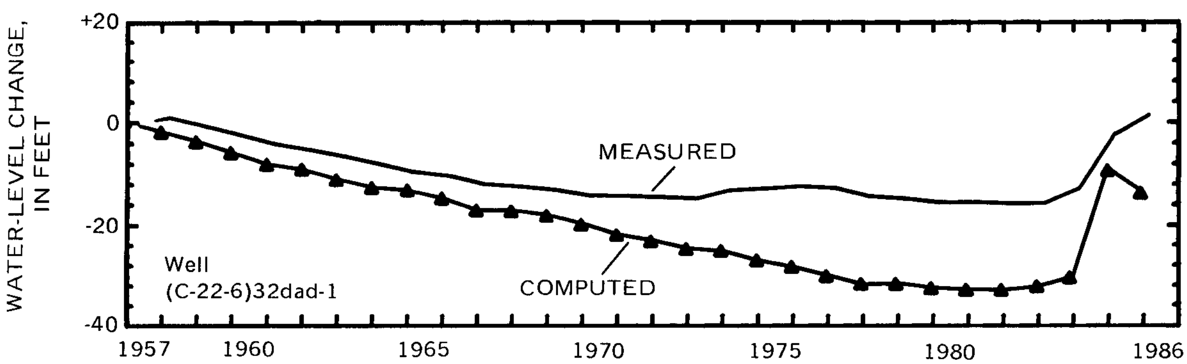
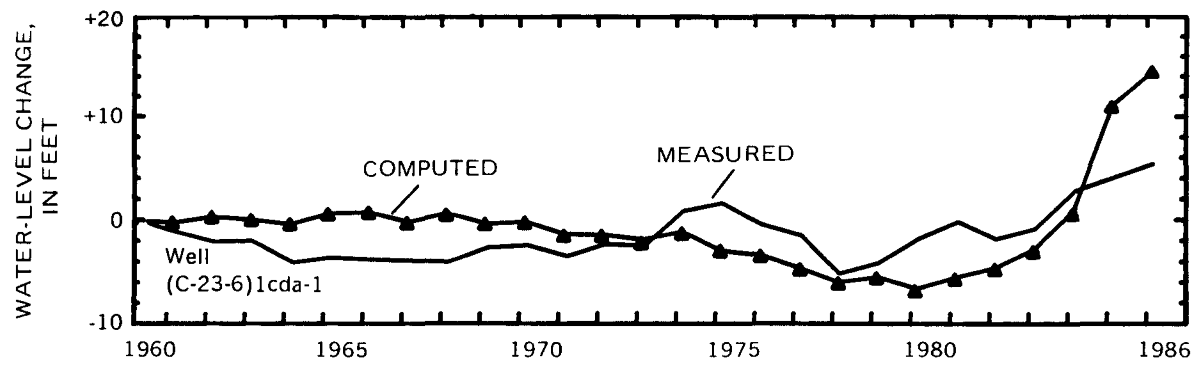
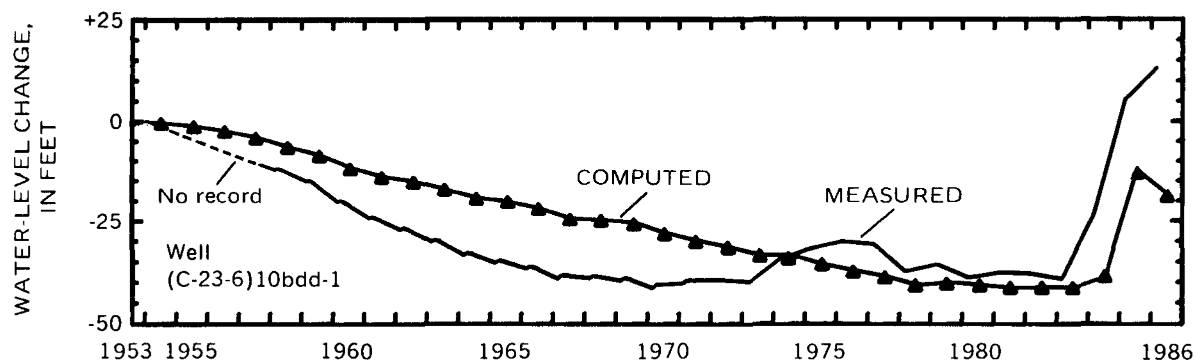


Figure 24.--Measured and computed water-level changes for 12 selected observation wells--Continued.





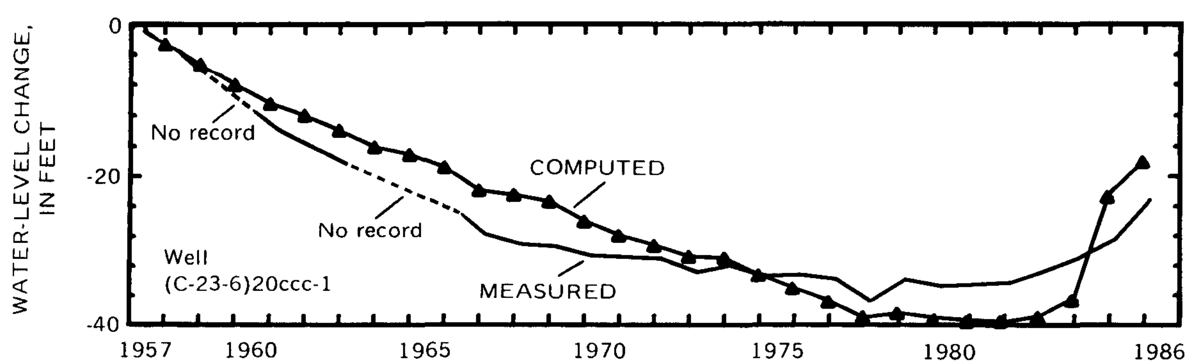


Figure 24.--Measured and computed water-level changes for 12 selected observation wells--Continued.

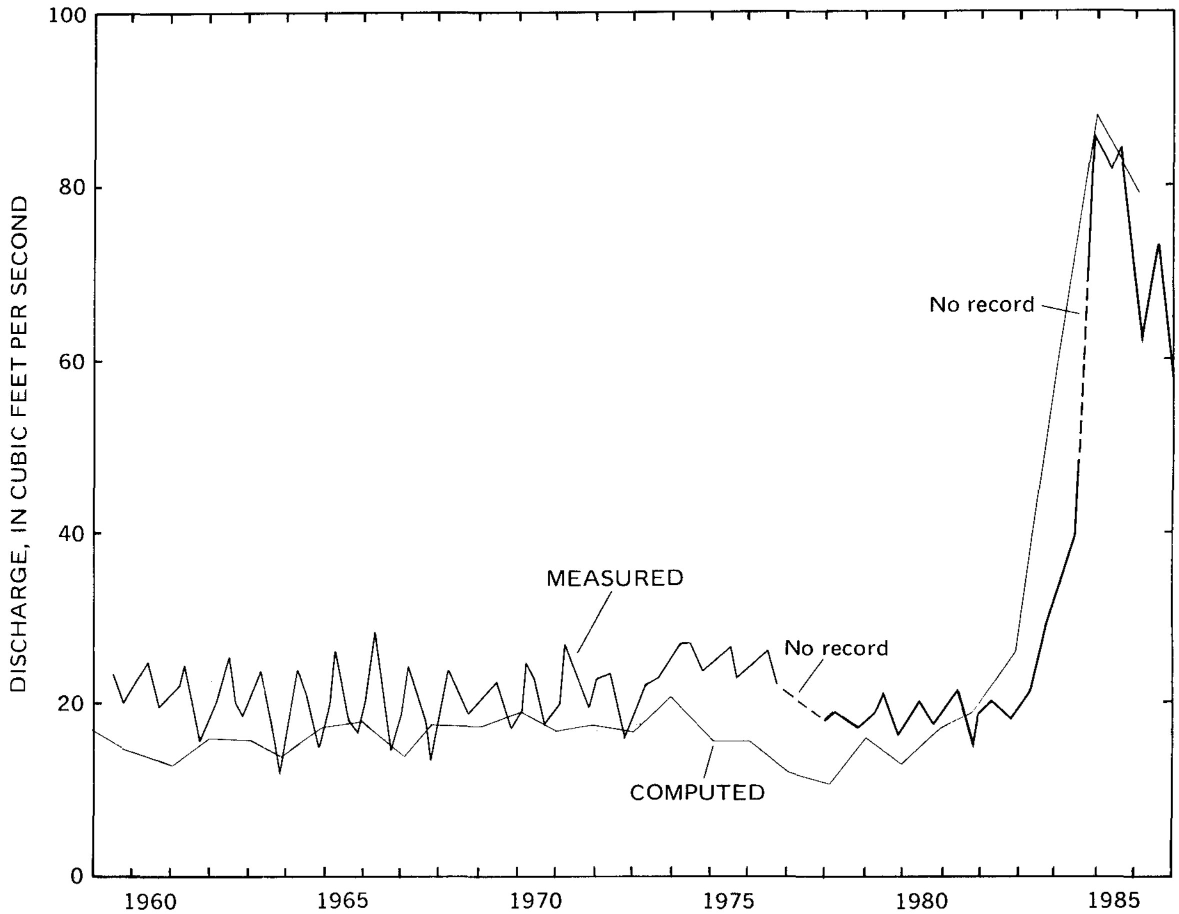
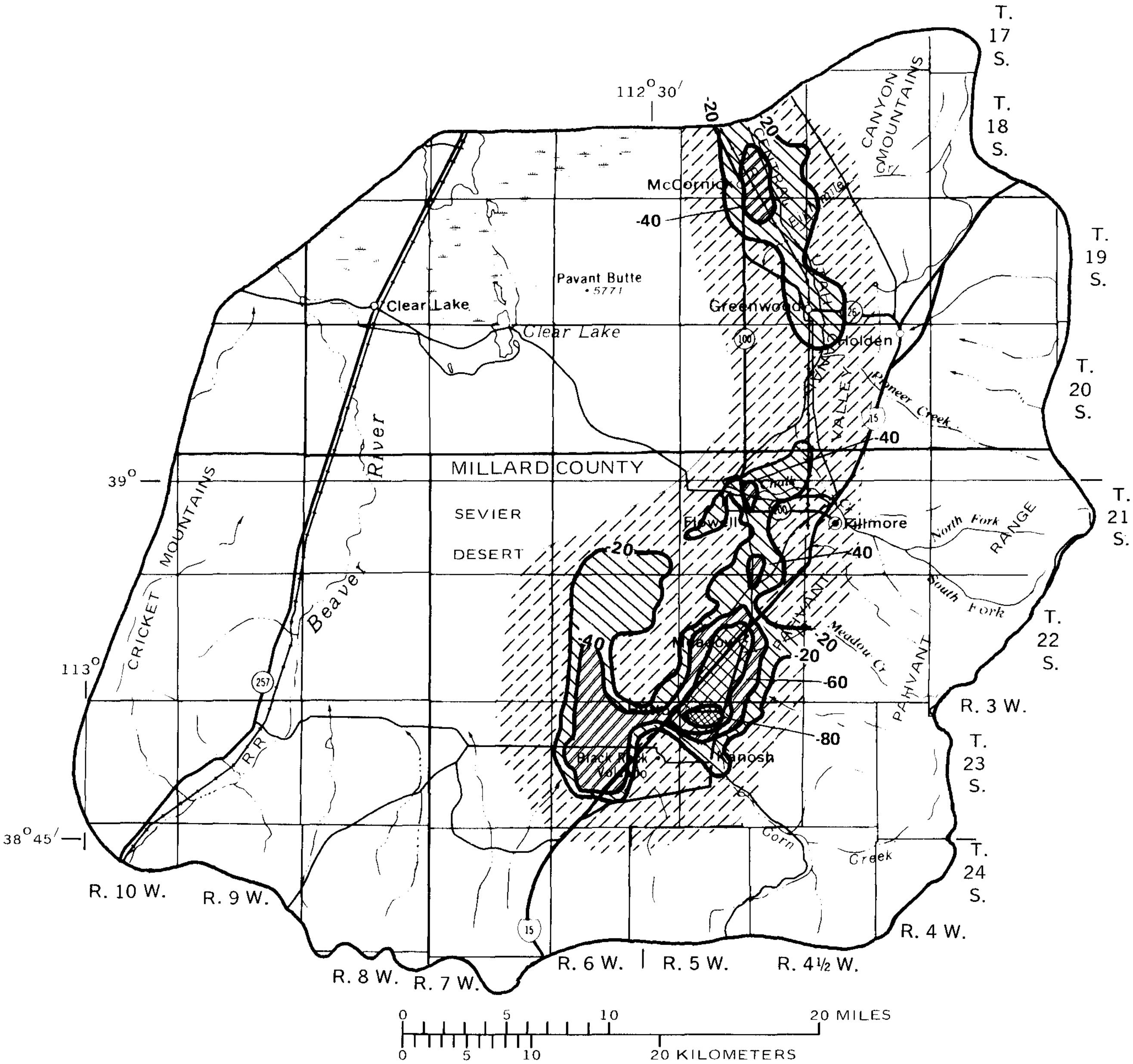


Figure 25.--Measured and computed discharge of Clear Lake Springs.

20-year simulation and the computed water levels at the end of 1985 in layers 2 and 3, the most heavily pumped part of the ground-water system. The results of the simulations are shown in figures 26 through 31.

Ground-water withdrawals equal to the 1977 rate for 20 years were projected to cause water-level declines of more than 80 feet in some parts of the modeled area in layers 2 and 3 (fig. 26 and 27). The ground-water budget at the end of the simulation is shown in table 2. Discharge from evapotranspiration, drains, and Clear Lake Springs were substantially reduced when compared with the budget for 1985. In addition, by the end of the 20-year simulation, about 41,500 acre-feet per year of ground water had been removed from storage.



EXPLANATION

——-20—— LINE OF EQUAL WATER-LEVEL DECLINE, IN FEET--Contour interval is 20 feet

DECLINE (feet)

0 - 20

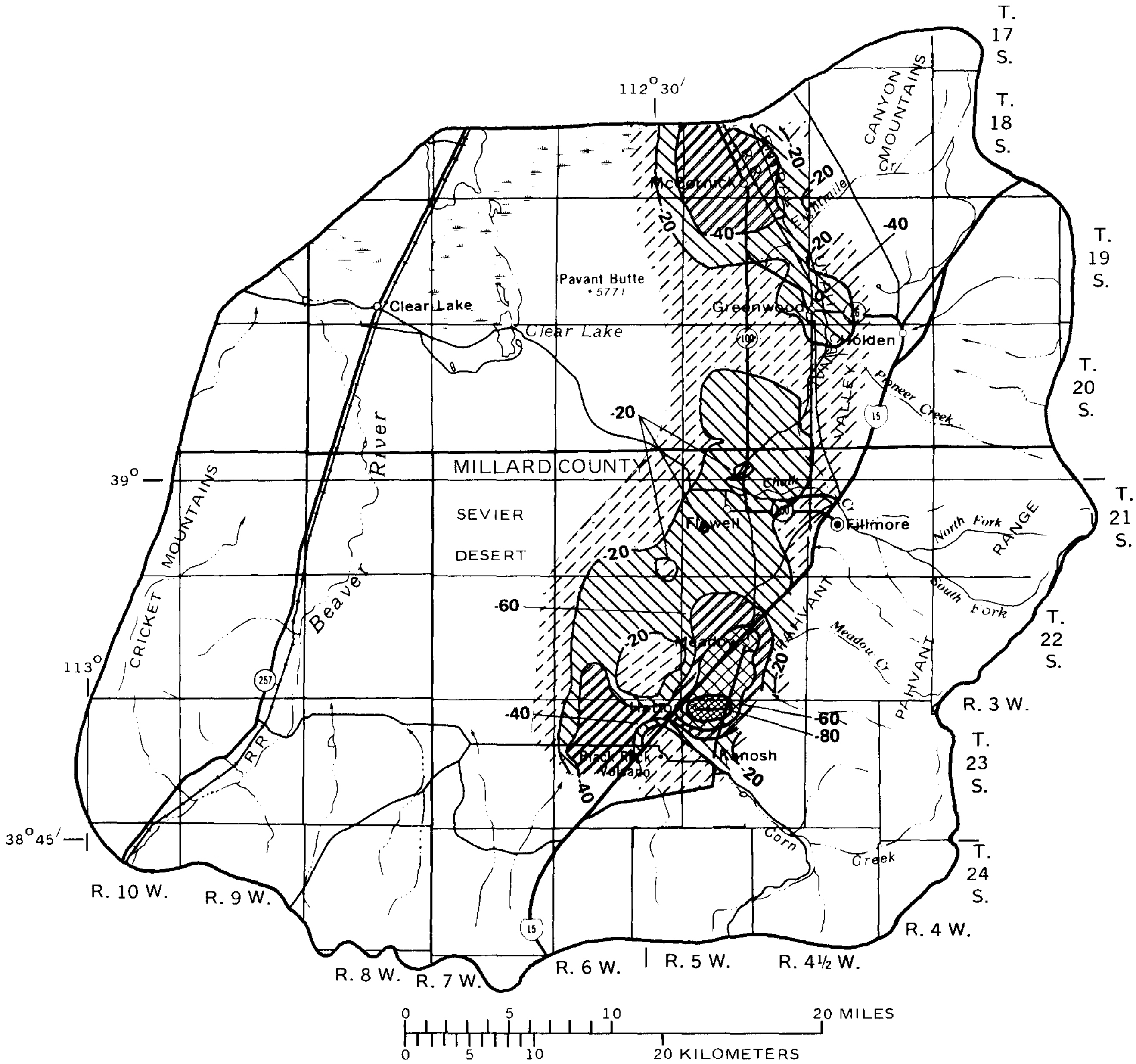
20 - 40

40 - 60

60 - 80

More than 80

Figure 26.--Projected water-level declines in layer 2 assuming ground-water withdrawals equal to the 1977 rate for a period of 20 years, 1985-2005.



EXPLANATION

——-20—— LINE OF EQUAL WATER-LEVEL DECLINE, IN FEET--Contour interval is 20 feet

DECLINE (feet)

- 0 - 20
- 20 - 40
- 40 - 60
- 60 - 80
- More than 80

Figure 27 --Projected water-level declines in layer 3 assuming ground-water withdrawals equal to the 1977 rate for a period of 20 years, 1985-2005.

Ground-water withdrawals equal to one-half the 1977 rate for 20 years were projected to result in water-level rises of as much as 33 feet in some parts of the area and water-level declines of as much as 47 feet in other parts of the area in layer 2 (fig. 28). Water-level rises of as much as 58 feet were projected for layer 3 (fig. 29). The ground-water budget at the end of the simulation (table 2) showed that discharge from evapotranspiration, drains, and Clear Lake Springs was more than the previous simulation. About 7,700 acre-feet per year of ground water had been removed from storage by the end of the simulation. Based on these results, it is projected that for every 1,000 acre-feet of increase or decrease in withdrawals in Pahvant Valley, the discharge at Clear Lake Springs will decrease or increase by about 130 acre-feet, respectively.

The elimination of recharge from the Central Utah Canal was projected to result in water-level declines of up to 8 feet in layer 2 near the canal (fig. 30) and up to 6 feet in layer 3 (fig. 31). Water levels in other parts of the area would not be affected. The loss of recharge from the canal is reflected in the ground-water budget by a decrease in discharge from Clear Lake Springs and from evapotranspiration, and an increase in the quantity of water being removed from storage (table 2) compared to values determined for projected withdrawals equal to one-half of the 1977 rate.

Limitations of Model

The ground-water model documented in this report has some limitations and simplifications. The use of a no-flow, northern boundary for the model, near McCornick, may cause the projected water-level declines in this area to be greater than might be expected if some ground-water movement across this boundary occurred. However, water levels in well (C-18-5)16bcc-1, located about 3 miles north of McCornick, do not show the effects of ground-water withdrawals, which indicates that the use of a no-flow boundary along the northern side of the model area is justified.

Recharge from all sources was varied with precipitation when, in fact, recharge from seepage from the Utah Central Canal or unconsumed irrigation water may not vary with precipitation. In addition, as more land came under irrigation, increased recharge from unconsumed irrigation water could not be estimated because data on increases in irrigated acreage were not available on a yearly basis nor were data showing changes in the surface-water distribution system. Changes in the model may be required if irrigation practices change, streamflow diversion patterns are altered, or the locations of ground-water withdrawals are changed.

Despite these limitations, the model should yield satisfactory results when projecting the effects on water levels and discharge using withdrawals of up to about 100,000 acre-feet per year for a period of about 20 years.

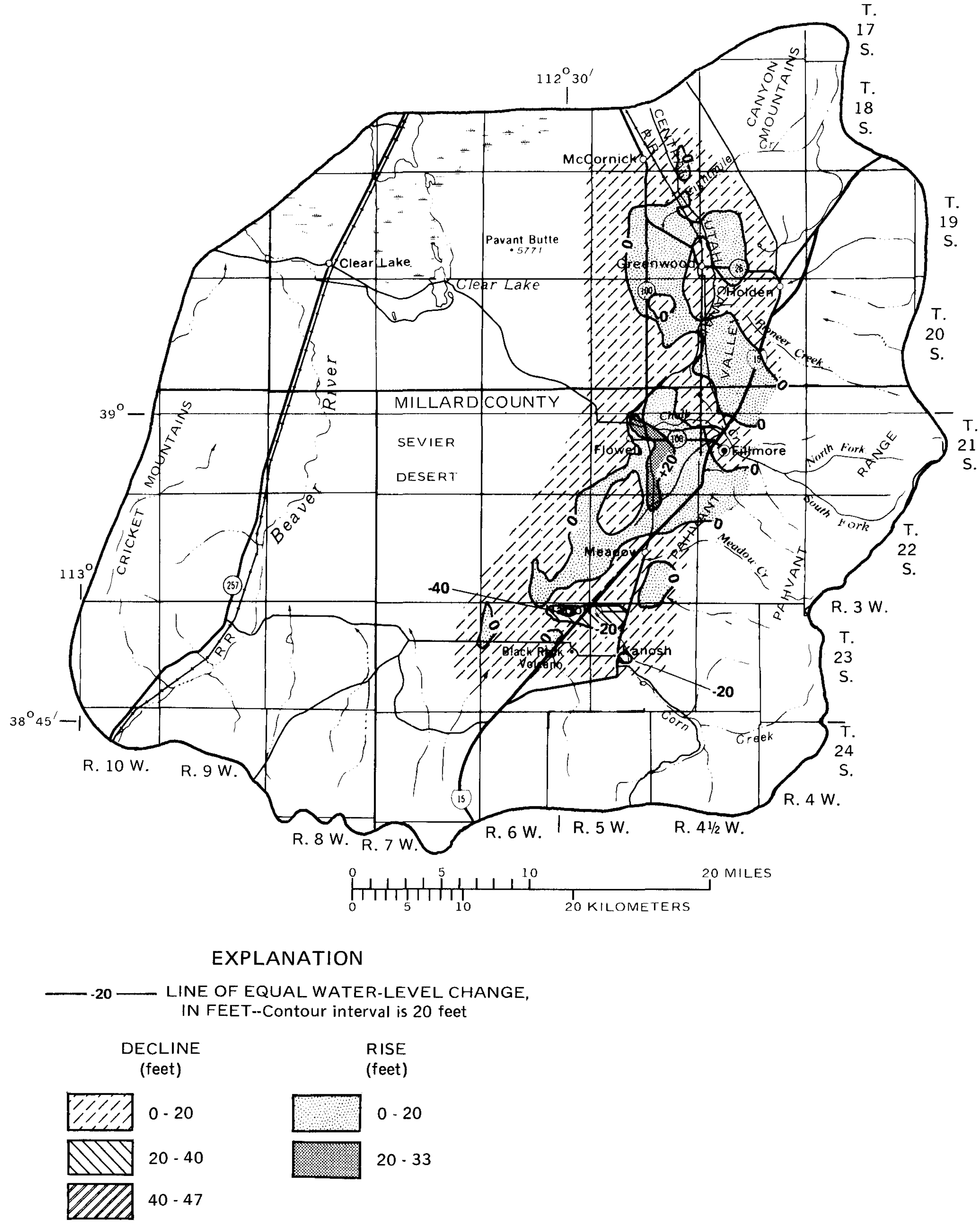


Figure 28.--Projected water-level changes in layer 2 assuming ground-water withdrawals equal to one-half the 1977 rate for a period of 20 years, 1985-2005.

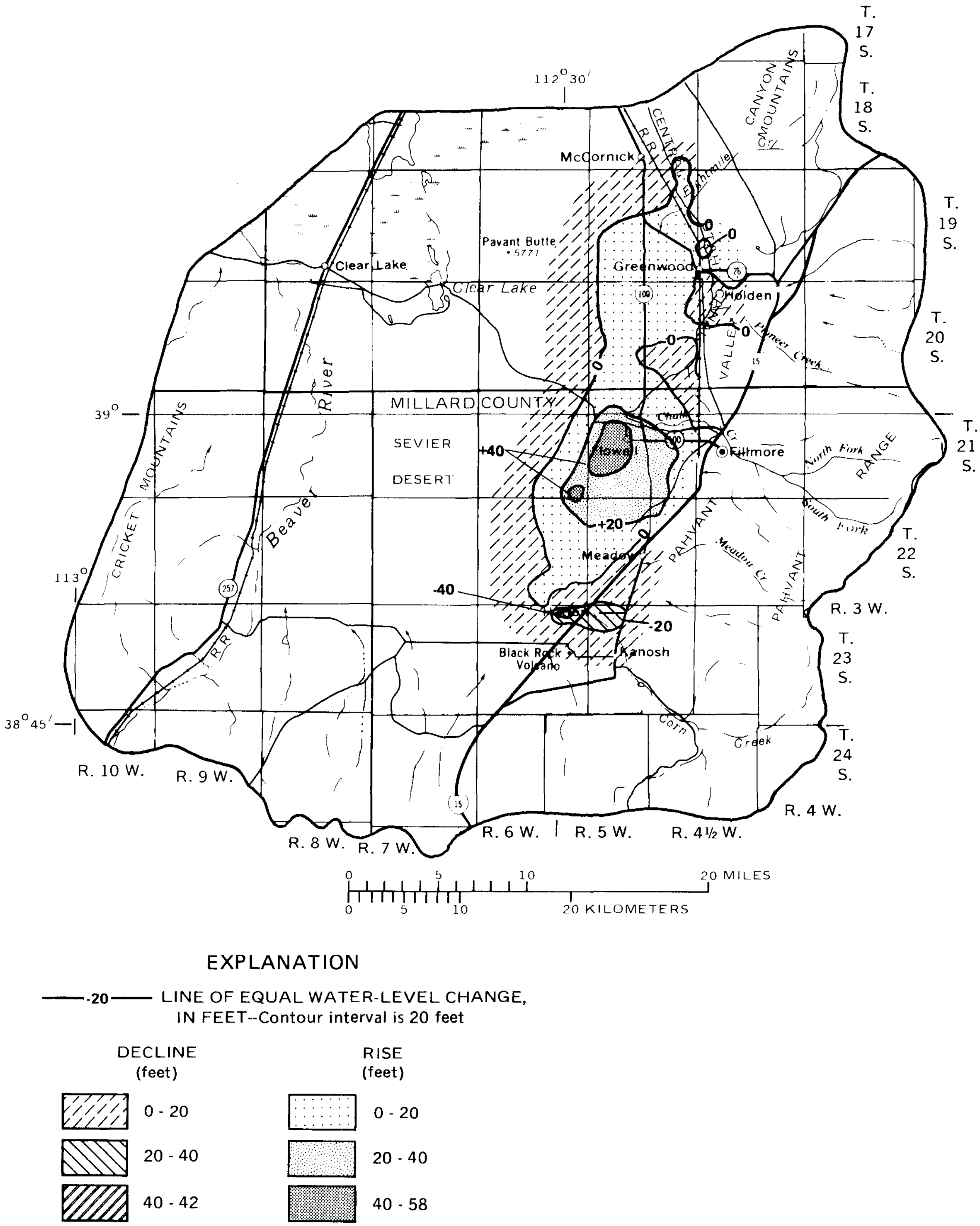


Figure 29.--Projected water-level changes in layer 3 assuming ground-water withdrawals equal to one-half the 1977 rate for a period of 20 years, 1985-2005.

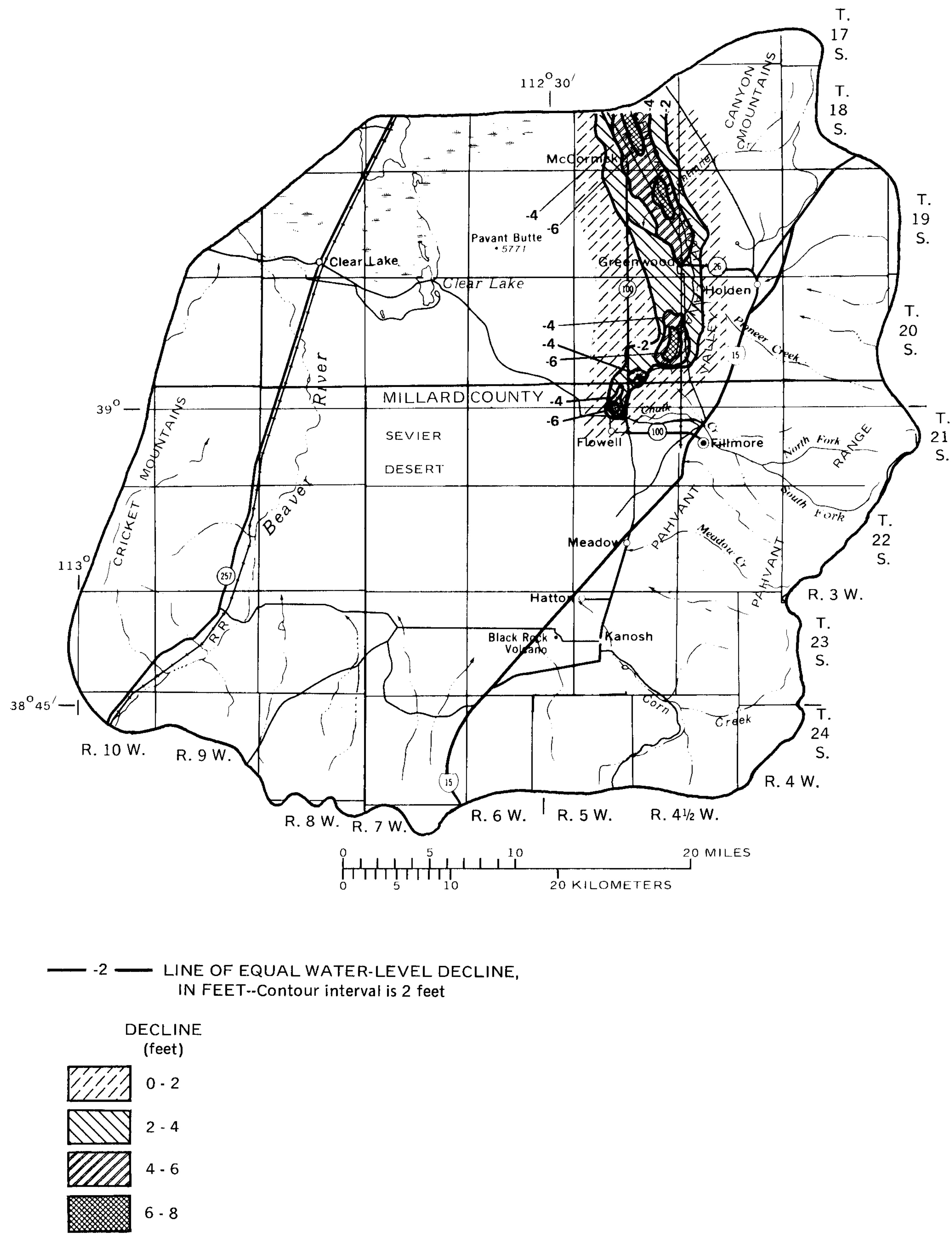
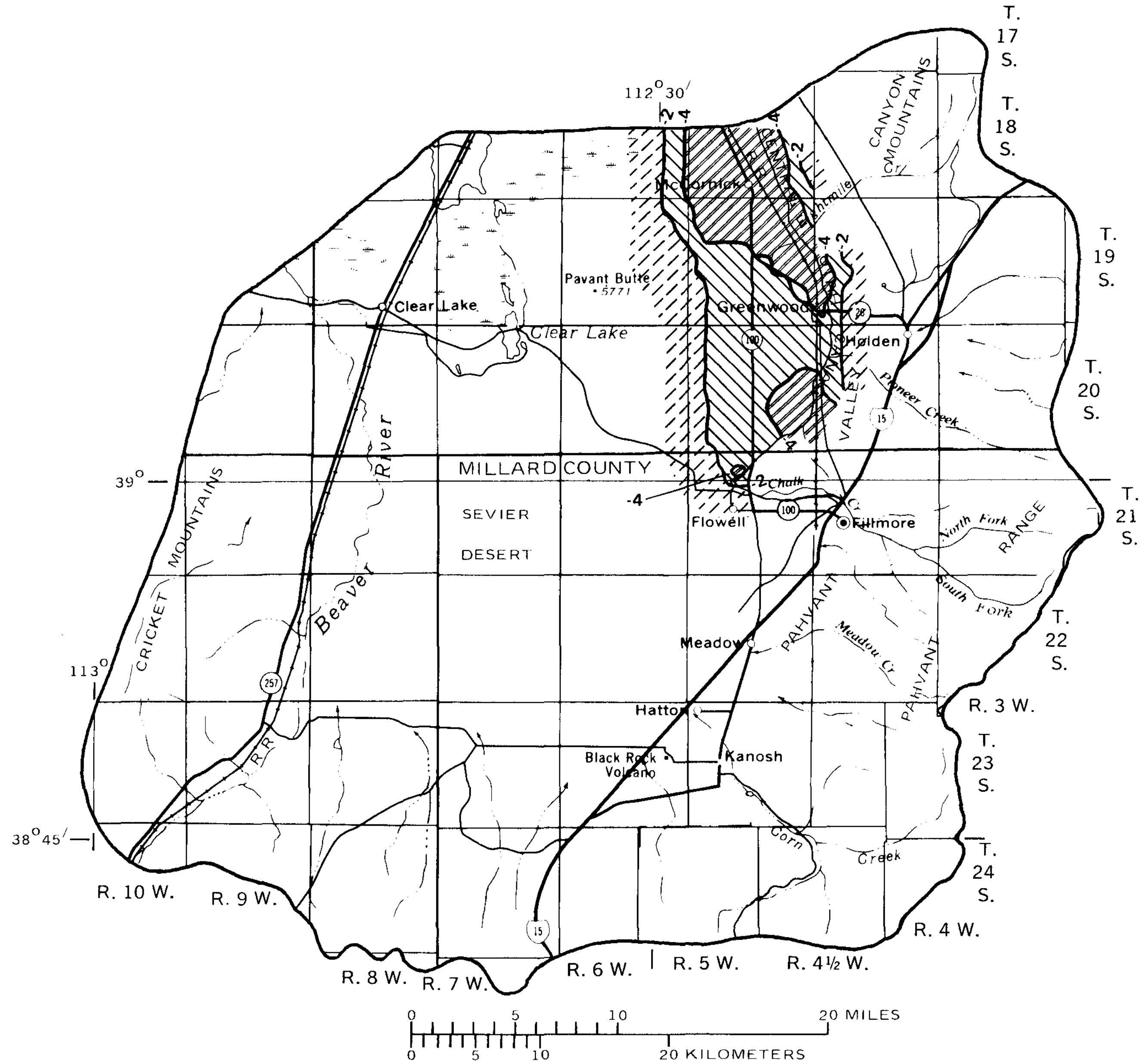


Figure 30.--Projected water-level declines in layer 2 assuming the elimination of recharge from the Central Utah Canal for a period of 20 years, 1985-2005.



EXPLANATION

—— -2 —— LINE OF EQUAL WATER-LEVEL DECLINE, IN FEET--Contour interval is 2 feet

DECLINE (feet)

- 0 - 2
- 2 - 4
- 4 - 6

Figure 31.--Projected water-level declines in layer 3 assuming elimination of recharge from the Central Utah Canal for a period of 20 years, 1985-2005.

SUMMARY

The primary ground-water system in Pahvant Valley and adjacent areas is that within the unconsolidated basin fill and interbedded basalt. The thickness of the unconsolidated basin fill varies from a few feet near the mountain fronts to at least 1,400 feet in the central part of the area.

Recharge to the basin fill in 1959, primarily from seepage from streams, canals, and unconsumed irrigation water and infiltration of precipitation, was estimated to be about 70,000 acre-feet. Movement of ground water is generally from recharge areas near the mountains on the east toward discharge areas in the central part of the study area. Some ground water moves out of the area along the northwestern boundary. Discharge from the ground-water system, primarily by discharge from springs, evapotranspiration, and wells, was estimated to be about 109,000 acre-feet in 1959.

Water-level declines of as much as 45 feet occur on a seasonal basis as a result of ground-water withdrawals for irrigation during the summer months. Water levels recover most of their decline during the winter and spring but spring water-level declines of more than 50 feet occurred between the early 1950's and 1980 due to extensive pumping and less-than-normal precipitation. Water levels recovered most of their declines between 1983 and 1986 because of record quantities of precipitation and reduced withdrawals for irrigation.

The quality of ground water is generally good, although west of Kanosh the quality of ground water in some wells has deteriorated from a dissolved-solids concentration of about 2,000 to more than 6,000 milligrams per liter. The deterioration in ground-water quality is probably caused by poor quality water from the southwest and possibly the west moving into the area during periods of large ground-water withdrawals and from the recycling of irrigation water.

A digital-computer model was used to project the effects of ground-water withdrawals and changes in recharge on water levels; discharge from Clear Lake Springs, drains, and evapotranspiration; and changes in ground-water storage. Ground-water withdrawals of about 96,000 acre-feet per year for 20 years are projected to cause water-level declines of more than 80 feet in some parts of Pahvant Valley, while withdrawals of about 48,000 acre-feet per year for 20 years are projected to cause water-level rises of as much as 58 feet and declines of as much as 47 feet. The elimination of recharge from the Central Utah Canal for 20 years is projected to cause water-level declines of up to 8 feet near the canal.

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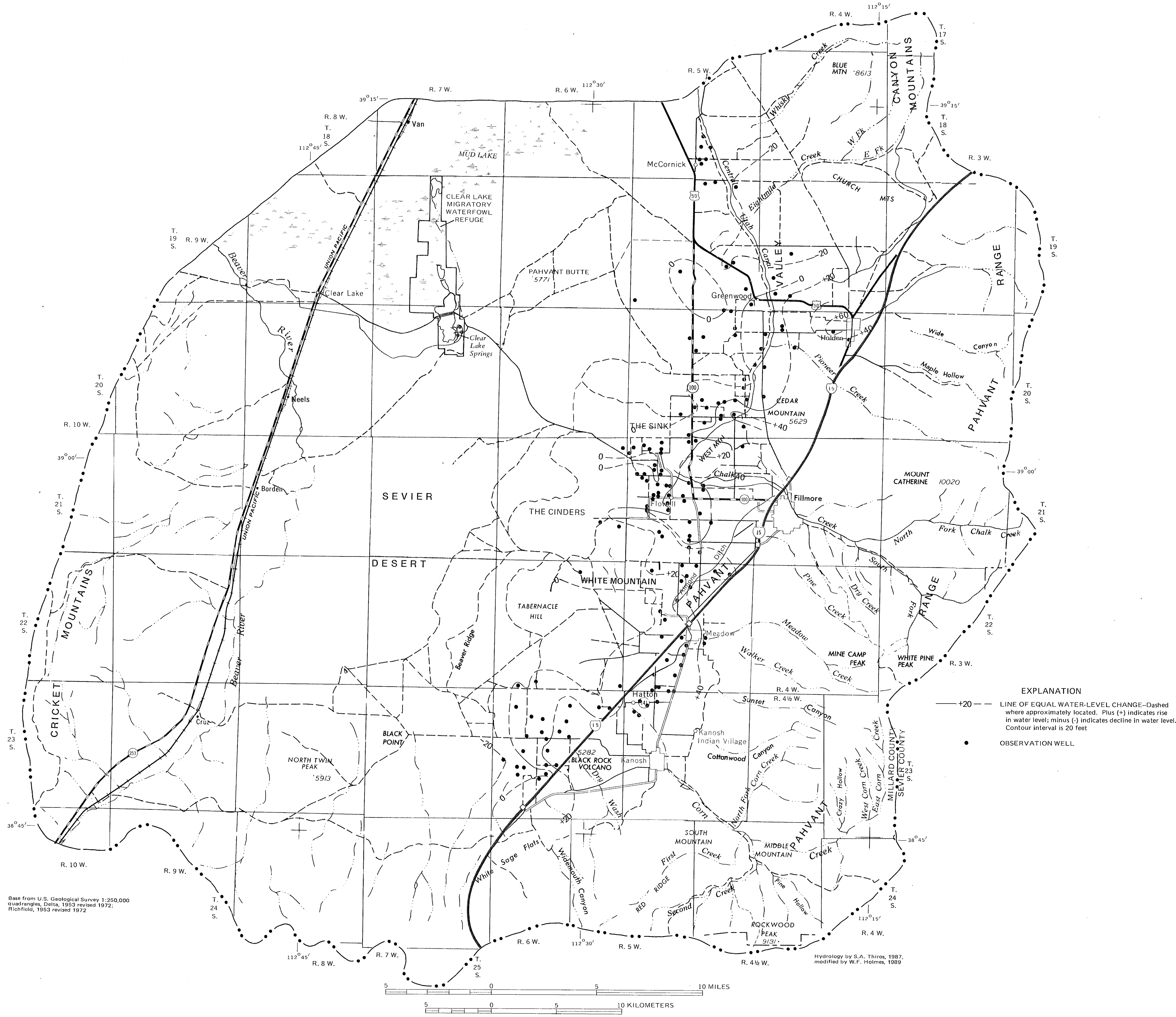

MAP SHOWING WATER-LEVEL CHANGES FROM SPRING 1960 TO SPRING 1986, PAHVANT VALLEY AND ADJACENT AREAS, UTAH

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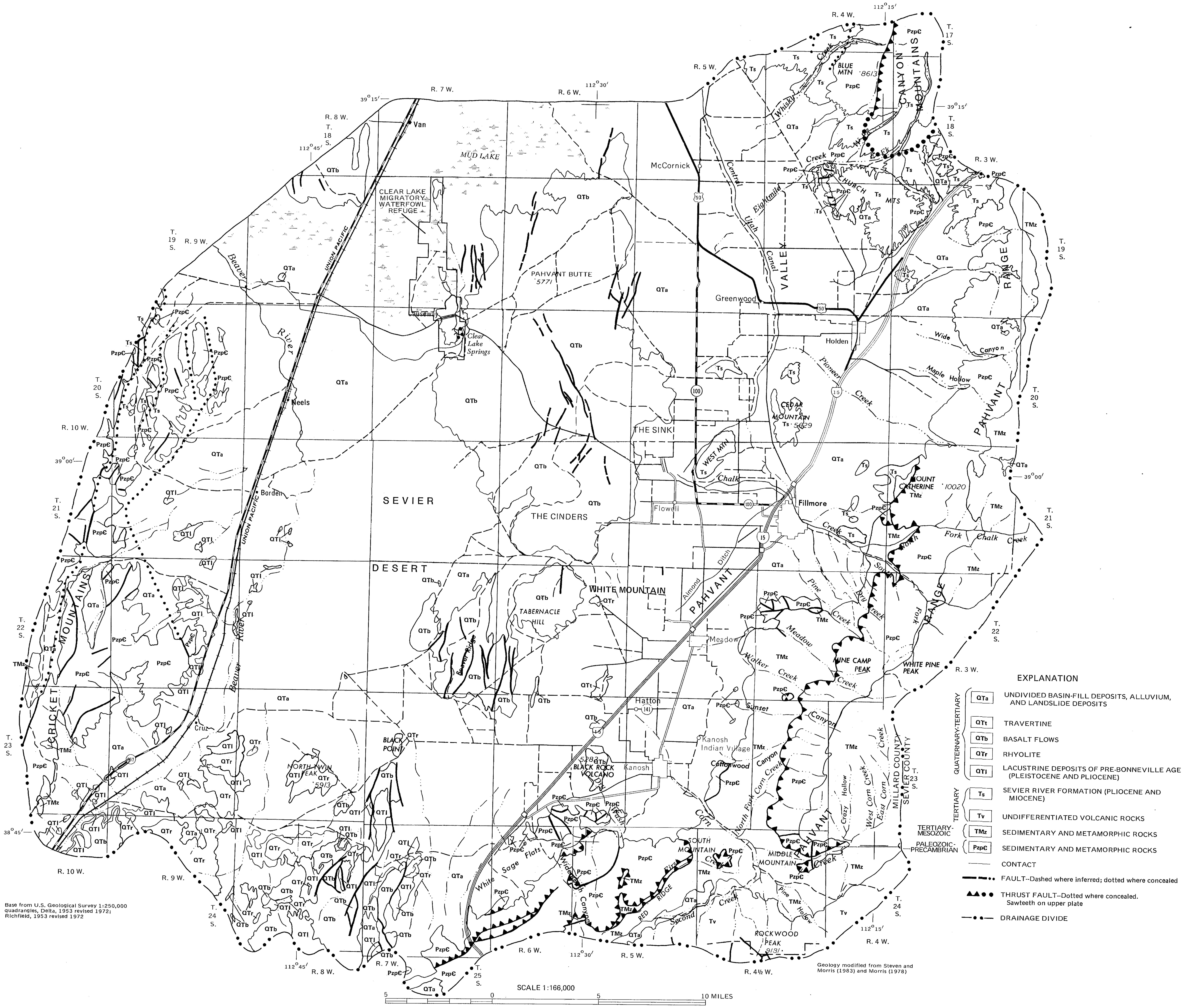
PLATE 1



MAP SHOWING GENERALIZED GEOLOGY OF PAHVANT VALLEY AND ADJACENT AREAS, UTAH

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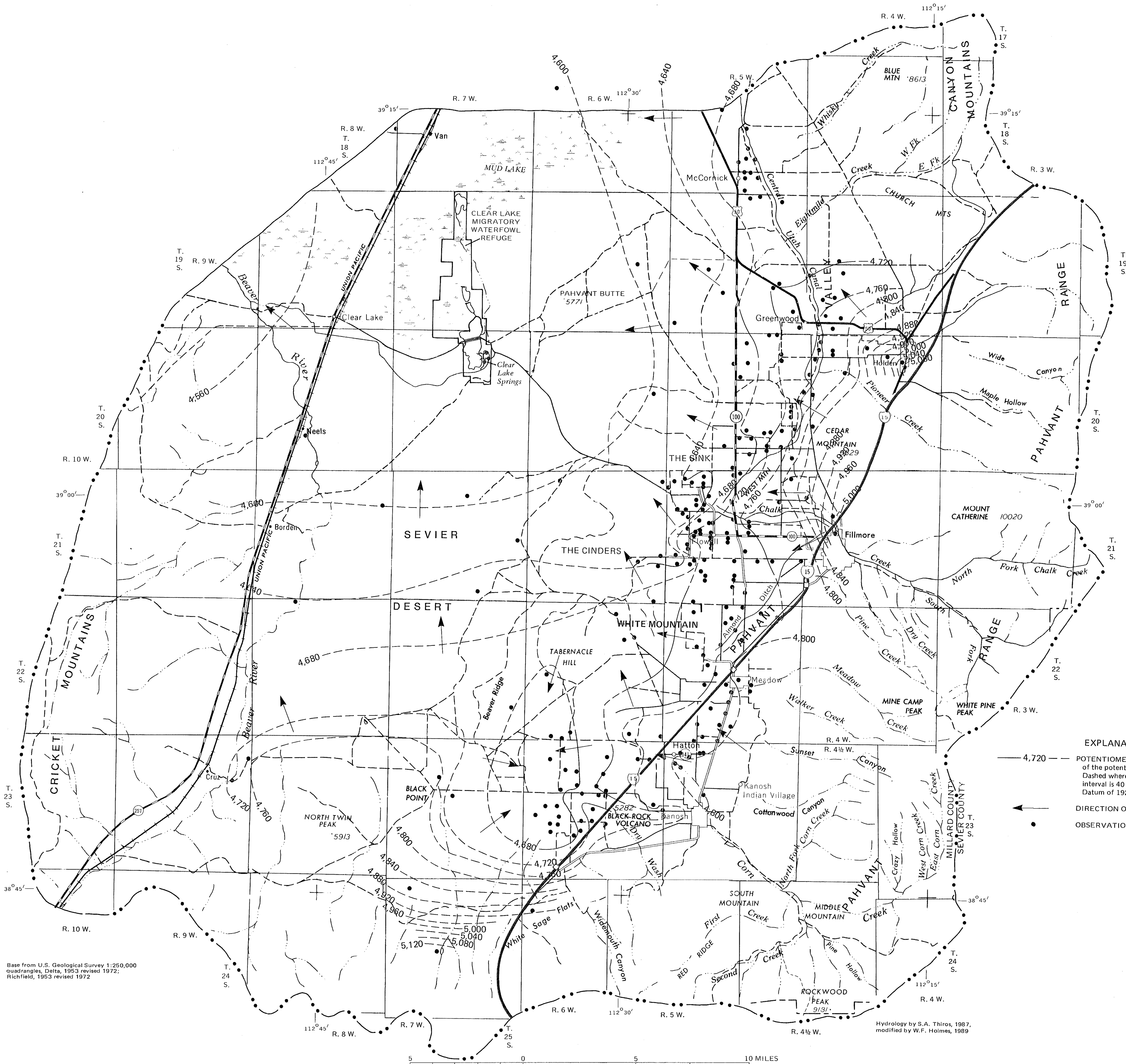

EXPLANATION

4,720 — — POTENTIOMETRIC CONTOUR–Shows altitude of the potentiometric surface, spring 1986. Dashed where approximately located. Contour interval is 40 feet. National Geodetic Vertical Datum of 1929

← DIRECTION OF GROUND-WATER MOVEMENT

• OBSERVATION WELL

Base from U.S. Geological Survey 1:250,000 quadrangles, Delta, 1953 revised 1972; Richfield, 1953 revised 1972

Hydrology by S.A. Thiros, 1987, modified by W.F. Holmes, 1989

5 0 5 10 MILES

5 0 5 10 KILOMETERS

MAP SHOWING POTENTIOMETRIC-SURFACE CONTOURS, SPRING 1986, PAHVANT VALLEY AND ADJACENT AREAS, UTAH

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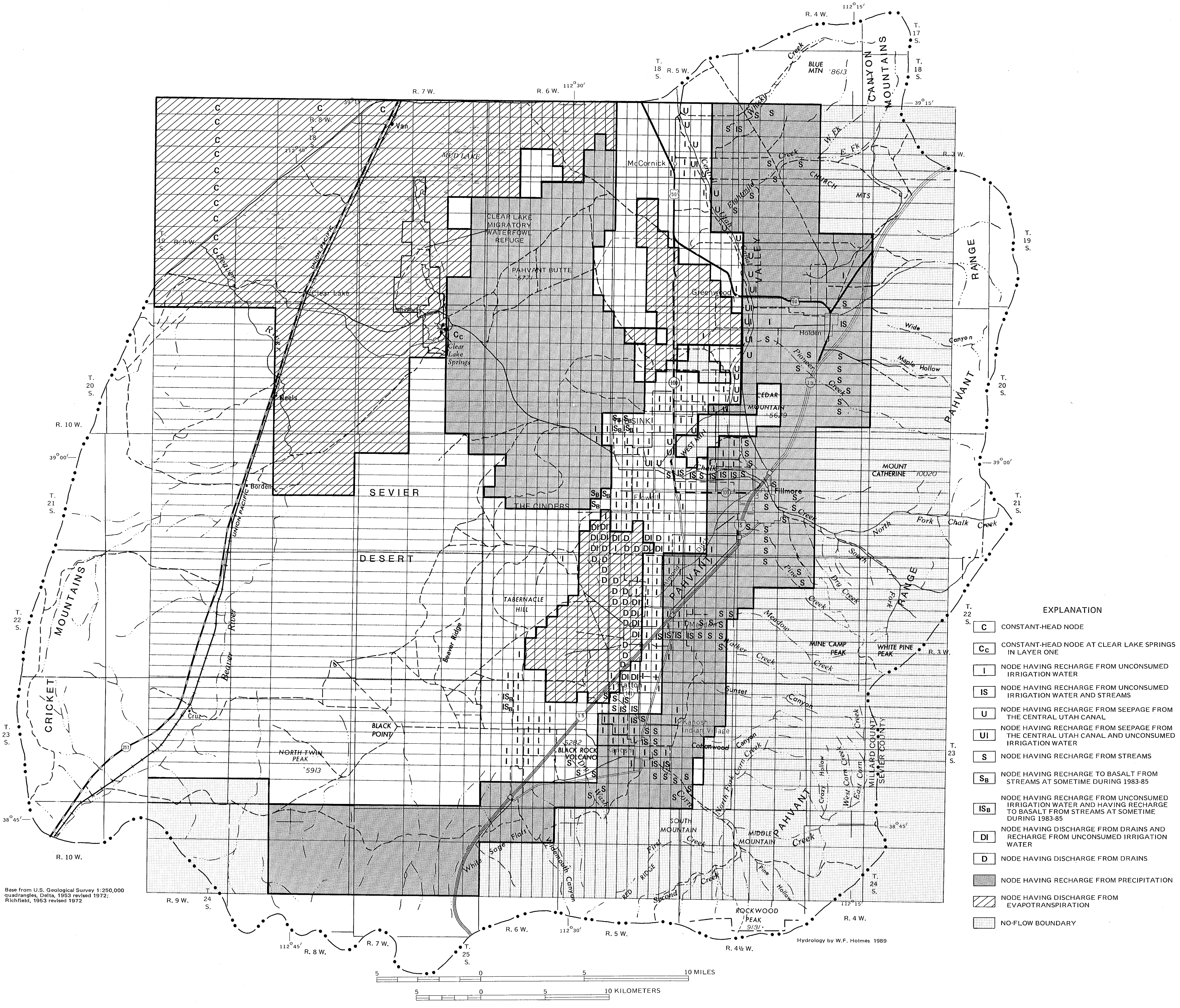
PLATE 4



MAP SHOWING DIGITAL-COMPUTER MODEL GRID AND INFORMATION ON THE UPPERMOST MODEL LAYER, PAHVANT VALLEY AND ADJACENT AREAS, UTAH