GROUND-WATER HYDROLOGY AND SIMULATED EFFECTS OF DEVELOPMENT IN THE MILFORD AREA, AN ARID BASIN IN SOUTHWESTERN UTAH

REGIONAL AQUIFER-SYSTEM ANALYSIS

U.S. Department of the Interior
U.S. Geological Survey

PROFESSIONAL PAPER 1409–G

AVAILABILITY OF BOOKS AND MAPS OF THE U.S. GEOLOGICAL SURVEY

Instructions on ordering publications of the U.S. Geological Survey, along with prices of the last offerings, are given in the current-year issues of the monthly catalog "New Publications of the U.S. Geological Survey." Prices of available U.S. Geological Survey publications released prior to the current year are listed in the most recent annual "Price and Availability List." Publications that may be listed in various U.S. Geological Survey catalogs (**see back inside cover**) but not listed in the most recent annual "Price and Availability List" may be no longer available.

Order U.S. Geological Survey publications **by mail** or **over the counter** from the offices given below.

BY MAIL

Books

Professional Papers, Bulletins, Water-Supply Papers, Techniques of Water-Resources Investigations, Circulars, publications of general interest (such as leaflets, pamphlets, booklets), single copies of Preliminary Determination of Epicenters, and some miscellaneous reports, including some of the foregoing series that have gone out of print at the Superintendent of Documents, are obtainable by mail from

U.S. Geological Survey, Information Services
Box 25286, Federal Center, Denver, CO 80225

Subscriptions to Preliminary Determination of Epicenters can be obtained ONLY from the

Superintendent of Documents
Government Printing Office
Washington, DC 20402

(Check or money order must be payable to Superintendent of Documents.)

Maps

For maps, address mail orders to

U.S. Geological Survey, Information Services
Box 25286, Federal Center, Denver, CO 80225

OVER THE COUNTER

Books and Maps

Books and maps of the U.S. Geological Survey are available over the counter at the following U.S. Geological Survey Earth Science Information Centers (ESIC's), all of which are authorized agents of the Superintendent of Documents:

- **ANCHORAGE, Alaska**—Rm. 101, 4230 University Dr.
- **LAKEWOOD, Colorado**—Federal Center, Bldg. 810
- **MENLO PARK, California**—Bldg. 3, Rm. 3128, 345 Middlefield Rd.
- **RESTON, Virginia**—USGS National Center, Rm. 1C402, 12201 Sunrise Valley Dr.
- **SALT LAKE CITY, Utah**—2222 West 2300 South
- **SPOKANE, Washington**—U.S. Post Office Bldg., Rm. 135, West 904 Riverside Ave.
- **WASHINGTON, D.C.**—Main Interior Bldg., Rm. 2650, 18th and C Sts., NW.

Maps Only

Maps may be purchased over the counter at the following U.S. Geological Survey office:

- **ROLLA, Missouri**—1400 Independence Rd.

Ground-Water Hydrology and Simulated Effects of Development in the Milford Area, an Arid Basin in Southwestern Utah

By JAMES L. MASON

REGIONAL AQUIFER-SYSTEM ANALYSIS—
GREAT BASIN—NEVADA AND UTAH

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1409-G

1998

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, *Secretary*

U.S. GEOLOGICAL SURVEY

Thomas J. Casadevall, *Acting Director*

The use of firm, trade, and brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Government.

Library of Congress Cataloging-in-Publication Data

Mason, James L.
Ground-water hydrology and simulated effects of development in the Milford area, an arid basin in southwestern Utah / by J.L. Mason.
p. cm. -- (Regional aquifer-system analysis--Great Basin, Nevada and Utah) (U.S. Geological Survey professional paper ; 1409-G)
Includes bibliographical references
Supt. of Docs. no.: I 19. 16: 1409-G
1. Ground-water flow--Utah--Milford Region. I. Title. II. Series. III. Series: Regional aquifer-system analysis--Great Basin, Nevada-Utah.
GB1197.7.M374 1996
551.49'09792'4--dc21 97-13890
CIP
ISBN 0-607-86818-X

For sale by U.S. Geological Survey, Branch of Information Services
Box 25286, Federal Center
Denver, CO 80225

FOREWORD

THE REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM

The RASA Program represents a systematic effort to study a number of the Nation's most important aquifer systems, which, in aggregate, underlie much of the country and which represent an important component of the Nation's total water supply. In general, the boundaries of these studies are identified by the hydrologic extent of each system and, accordingly, transcend the political subdivisions to which investigations have often arbitrarily been limited in the past. The broad objective for each study is to assemble geologic, hydrologic, and geochemical information, to analyze and develop an understanding of the system, and to develop predictive capabilities that will contribute to the effective management of the system. The use of computer simulation is an important element of the RASA studies to develop an understanding of the natural, undisturbed hydrologic system and the changes brought about in it by human activities and to provide a means of predicting the regional effects of future pumping or other stresses.

The final interpretive results of the RASA Program are presented in a series of U.S. Geological Survey Professional Papers that describe the geology, hydrology, and geochemistry of each regional aquifer system. Each study within the RASA Program is assigned a single Professional Paper number beginning with Professional Paper 1400.

Thomas J. Casadevall

Thomas J. Casadevall
Acting Director

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply inch-pound units	By	To obtain metric units
acre	0.4047	square hectometer
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per square mile (acre-ft/mi^2)	476.1	cubic meter per square kilometer
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per mile (ft/mi)	0.1894	meter per kilometer
foot per second (ft/s)	0.3048	meter per second
foot squared per day (ft^2/d)	0.0929	meter squared per day
foot squared per second (ft^2/s)	0.0929	meter squared per second
gallon per minute (gal/min)	0.0631	liter per second
inch (in.)	25.4	millimeter
inch per year (inch/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
square foot (ft^2)	0.0929	square meter
square mile (mi^2)	2.59	square kilometer

In the first part of the text, all units involving time are given in the commonly used form; however, in the latter part of the text where model simulations are discussed, all units involving time are given in seconds—the time unit used for all simulations. The commonly used units involving time are shown in parentheses.

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

GROUND-WATER HYDROLOGY AND SIMULATED EFFECTS OF DEVELOPMENT IN THE MILFORD AREA, AN ARID BASIN IN SOUTHWESTERN UTAH

BY JAMES L. MASON

ABSTRACT

A three-dimensional, finite-difference model was constructed to simulate ground-water flow in the Milford area. The purpose of the study was to evaluate present knowledge and concepts of the ground-water system, to analyze the ability of the model to represent past and current (1984) conditions, and to estimate the effects of various ground-water development alternatives. The alternative patterns of ground-water development might prove effective in capturing natural discharge from the basin-fill aquifer while limiting water-level declines.

Water levels measured during this study indicate that ground water in the Milford area flows in a northwesterly direction through consolidated rocks in the northern San Francisco Mountains toward Sevier Lake. The revised potentiometric surface shows a large area for probable basin outflow, indicating that more water leaves the Milford area than the 8 acre-feet per year estimated previously.

Simulations made to calibrate the model were able to approximate steady-state conditions for 1927, before ground-water development began, and transient conditions for 1950-82, during which ground-water withdrawal increased. Basin recharge from the consolidated rocks and basin outflow were calculated during the calibration process. Transient simulations using constant and variable recharge from surface water were made to test effects of large flows in the Beaver River.

Simulations were made to project water-level declines over a 37-year period (1983-2020) using the present pumping distribution. Ground-water withdrawals were simulated at 1, 1.5, and 2 times the 1979-82 average rate.

The concepts of "sustained" yield, ground-water mining, and the capture of natural discharge were tested using several hypothetical pumping distributions over a 600-year simulation period. Simulations using concentrated pumping centers were the least efficient at capturing natural discharge and produced the largest water-level declines. Simulations using strategically placed ground-water withdrawals in the discharge area were the most efficient at eliminating natural discharge with small water-level declines.

INTRODUCTION

The Great Basin Regional Aquifer-System Analysis (RASA) Program, which began in 1980, is the tenth in a series of 25 studies that represents a systematic effort to study regional-aquifer systems throughout the United States. The general objectives for all RASA studies are to describe the present ground-water system and the original ground-water system as it existed prior to development, analyze the changes to the system, synthesize results of this and earlier studies, and provide capabilities through which effects of future ground-water development can be estimated. Specific objectives of the Great Basin RASA (Harrill and others, 1983, p. 2) are as follows:

1. To develop a data base with sufficient data to support computer ground-water flow modeling of basins throughout the region.
2. To delineate and quantitatively describe ground-water basins that are hydraulically connected to form a flow system.
3. To develop a better understanding of recharge and discharge processes.
4. To develop computer ground-water flow models of basins or flow systems considered to be representative of the region.
5. To evaluate relative hydrologic effects of hypothetical development alternatives on the basins or flow systems for which ground-water flow models were constructed.

6. To design and document generalized ground-water flow models that can be readily applied to similar systems throughout the region.

The Great Basin RASA study area encompasses a series of north-trending mountain ranges separated by alluvial basins. Both the mountain ranges and the basins tend to be 5 to 15 mi wide. Most mountain ranges rise from 1,000 to 5,000 ft above the adjoining basins and can extend for as much as 50 mi.

The Great Basin contains a regional aquifer in which most individual basins are linked hydrologically. Some basins form multibasin ground-water flow systems by the movement of water through permeable sedimentary deposits or consolidated rock, whereas, some basins are linked by rivers or surface-water drainages. The remaining basins function as hydrologically isolated basins. All of these basins occupy structural depressions that have been filled with alluvial deposits derived from the adjacent mountain ranges or lacustrine deposits derived from Quaternary lakes. The water supply is derived from precipitation on the adjacent mountains. Annual recharge to the ground-water systems is usually small in relation to the large volumes of water stored (Harrill and others, 1983, p. 3).

Computer simulation of the ground-water system in the Milford area in southwestern Utah (fig. 1) was one of nine modeling efforts included in the Great Basin RASA Program. Like the other modeling efforts, information obtained from the model of the Milford area might be applicable to other parts of the Great Basin. The Milford area was selected for study because of extensive surface-water irrigation, substantial ground-water withdrawals and water-level declines since 1950, and subsurface inflow to and outflow from the basin.

PURPOSE AND SCOPE

The purpose of this report is to describe the ground-water hydrology of the Milford area, to document the development of the computer ground-water flow model, and to present the results of model simulations. The ground-water system prior to and changes since ground-water development began is described.

For the purposes of this report, the term "Milford area" is the entire study area, including the basin in the center and the surrounding mountain ranges. The term "basin" refers to the structural depression that contains unconsolidated basin-fill deposits and the associated ground-water system.

A three-dimensional, finite-difference model was constructed to simulate ground-water flow in the Milford area. The model was constructed using data obtained mostly during the 1970's; aquifer-test and ground-water-withdrawal data were reevaluated and some new interpretations were made. Additional data on ground-water levels and withdrawals were collected during 1981-83. Three observation wells were drilled in the northwestern part of the Milford area to define more clearly that part of the ground-water system.

The model, which was calibrated to known steady-state and transient conditions, was used for simulations to estimate future water-level declines using present, and multiples of present, ground-water withdrawals. Hypothetical ground-water-withdrawal alternatives were simulated similar to other basin studies as part of the Great Basin RASA Program.

PREVIOUS STUDIES

White (1932) estimated evapotranspiration in the Milford area on the basis of pan-evaporation data and diurnal water-level fluctuations in the vicinity of various types of vegetation. His report includes extensive water-level data that had not been published previously. Nelson (1950, 1954) and Nelson and Thomas (1952) described the ground-water system and the extent of ground-water development in the Milford area. Their reports include ground-water-withdrawal data for individual wells during 1931-53. Criddle (1958) studied consumptive use and irrigation requirements in the area. He estimated consumptive use for each crop type and total consumptive use for the area. Sandberg (1962, 1966) provided additional information on the ground-water hydrology of the area, including well information, well logs, water-level measurements, and chemical analyses of ground water. Mower and Cordova (1974) conducted a comprehensive study of the water resources of the Milford area, with emphasis on the ground-water system.

Numerous geophysical and geochemical studies that defined the Roosevelt Hot Springs Known Geothermal Resource Area (KGRA), located along the eastern margin of the Milford area at the base of the Mineral Mountains, were conducted by the University of Utah with funding from the U.S. Department of Energy. Brumbaugh and Cook (1977), Crebs and Cook (1976), and Thangsuphanich (1976) defined the alluvium-consolidated rock interface along the west margin of the Mineral Mountains by using gravity and ground-magnetic surveys. These geophysical surveys partly defined the depth of the basin fill and defined the interface between the alluvium and the consolidated rock along the Mineral Mountains. Gertson and Smith (1979) reported on an east-west seismic-refraction profile across the basin north of Milford. Smith (1980) studied the potential for water recharging the

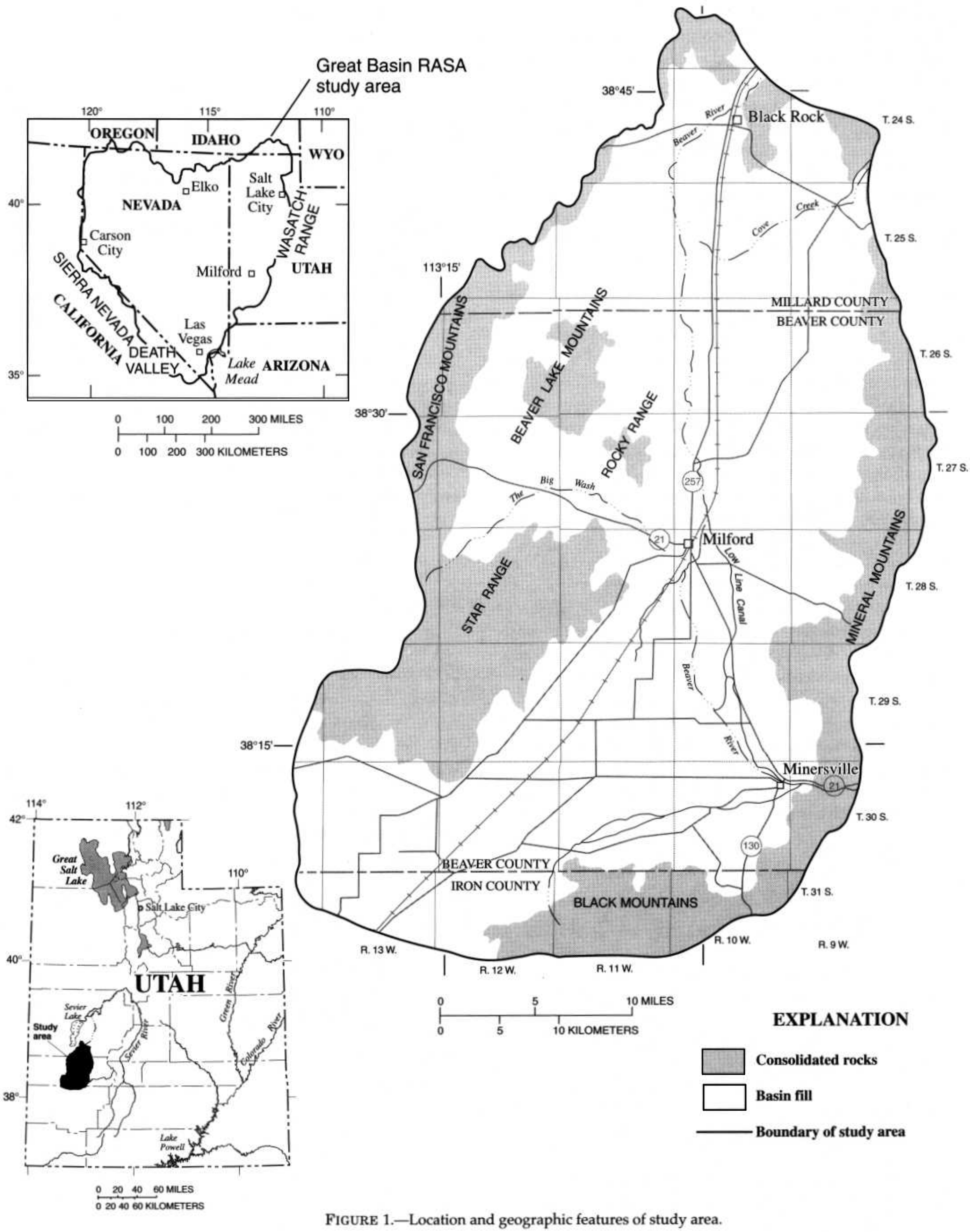

FIGURE 1.—Location and geographic features of study area.

Tushar Mountains, east of the Milford area, to flow at depth beneath the Mineral Mountains and to discharge in the Milford area. Smith used a vertical, two-dimensional, finite-element model to determine conditions necessary for the hypothesized flow regime, and concluded that flow beneath the Mineral Mountains was not likely. Rohrs and Bowman (1980) and Bowman and Rohrs (1981) studied the stable isotopes of spring and thermal waters from the Roosevelt Hot Springs. They concluded that the thermal waters had a meteoric origin and probably were from the higher altitudes of the Mineral Mountains.

WELL-NUMBERING SYSTEM USED IN UTAH

The system of numbering wells in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well, describes its position. The State is divided into four quadrants by the Salt Lake Base Line and the Salt Lake Meridian, and these quadrants are designated by A, B, C, and D, indicating respectively, the northeast, northwest, southwest, and southeast quadrants. 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; the letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the section subdivisions is the serial number of the well within the smallest (10-acre) subdivision. Thus, (C-29-11)27dad-1 designates the first well constructed or visited in the SE1/4NE1/4SE1/4 sec. 27, T. 29 S., R. 11 W. The numbering system is shown in figure 2.

DESCRIPTION OF STUDY AREA

PHYSIOGRAPHY

The Milford area, which lies within the Basin and Range physiographic province (Fenneman, 1931), covers 1,160 mi^2 in parts of Millard, Beaver, and Iron Counties, Utah (fig. 1). The center of the Milford area is a north-trending basin, which is bounded by the Mineral Mountains to the east, the Black Mountains to the south, and the San Francisco Mountains to the west. The Beaver Lake Mountains, Rocky Range, and Star Range are small mountain ranges on the west side of the basin. The basin is mostly between altitudes of 4,850 and 5,500 ft above sea level. Most of the mountainous areas are between 5,500 and 9,000 ft; the highest peak (9,660 ft) is in the San Francisco Mountains.

The Milford area is topographically open to the southwest, where no topographic features separate the Milford area from the adjacent Beryl-Enterprise area. Similarly, the north end of the Milford area is topographically open near Black Rock where it joins the Sevier Desert.

The basin is drained by the Beaver River and numerous ephemeral tributaries, which are a part of the Sevier River drainage that terminates in Sevier Lake. The Beaver River channel is normally dry within a short distance downstream from Minersville because of diversions for irrigation. The Beaver River flows westward into the Milford area from Beaver Valley through a narrow gap between the Mineral Mountains and the Black Mountains. The river channel extends north and exits the basin where it is constricted by a basalt flow. Cove Creek, an ephemeral stream, flows into the northeast part of the area through a gap that separates the north end of the Mineral Mountains from the same basalt flow. The Big Wash, an ephemeral stream, drains the area east of the San Francisco Mountains between the Beaver Lake Mountains and the Star Range.

GEOLOGY

The present physiography of the Milford area is the result of several phases of geologic evolution. Thick sequences of marine, miogeosynclinal strata were deposited from late Precambrian through Devonian time (Hintze, 1973, p. 8). Additional deposits accumulated from Mississippian through Early Triassic time but were generally thinner and representative of a near-shore depositional environment (Hintze, 1973, p. 9). During Late Triassic to early Cenozoic time, this part of western Utah was a rugged highland caused by thrust faulting and folding of the Sevier Orogeny (Hintze, 1973, p. 9). During the Oligocene, volcanic activity deposited extensive layers of ignimbrites, lava flows, and volcanic breccias in western Utah (Hintze, 1973, p. 9). From Miocene to Holocene time, the Oligocene volcanic rocks and the earlier miogeosynclinal strata were subjected to block-faulting and crustal extension, which resulted in north-trending, alternating mountain ranges and basins. Erosional debris partially filled the basins prior to and during the deposition of Lake Bonneville lacustrine sediments (Hintze, 1973, p. 9).

Consolidated rocks in the mountains surrounding the basin vary in age and lithology from Precambrian metasediments to Quaternary basalt and rhyolites. The Mineral Mountains on the east are an uplifted horst, most of which is a granitic pluton. The pluton has been K-Ar (potassium-argon) dated between 9.4 and 14.0 m.y. (mil-

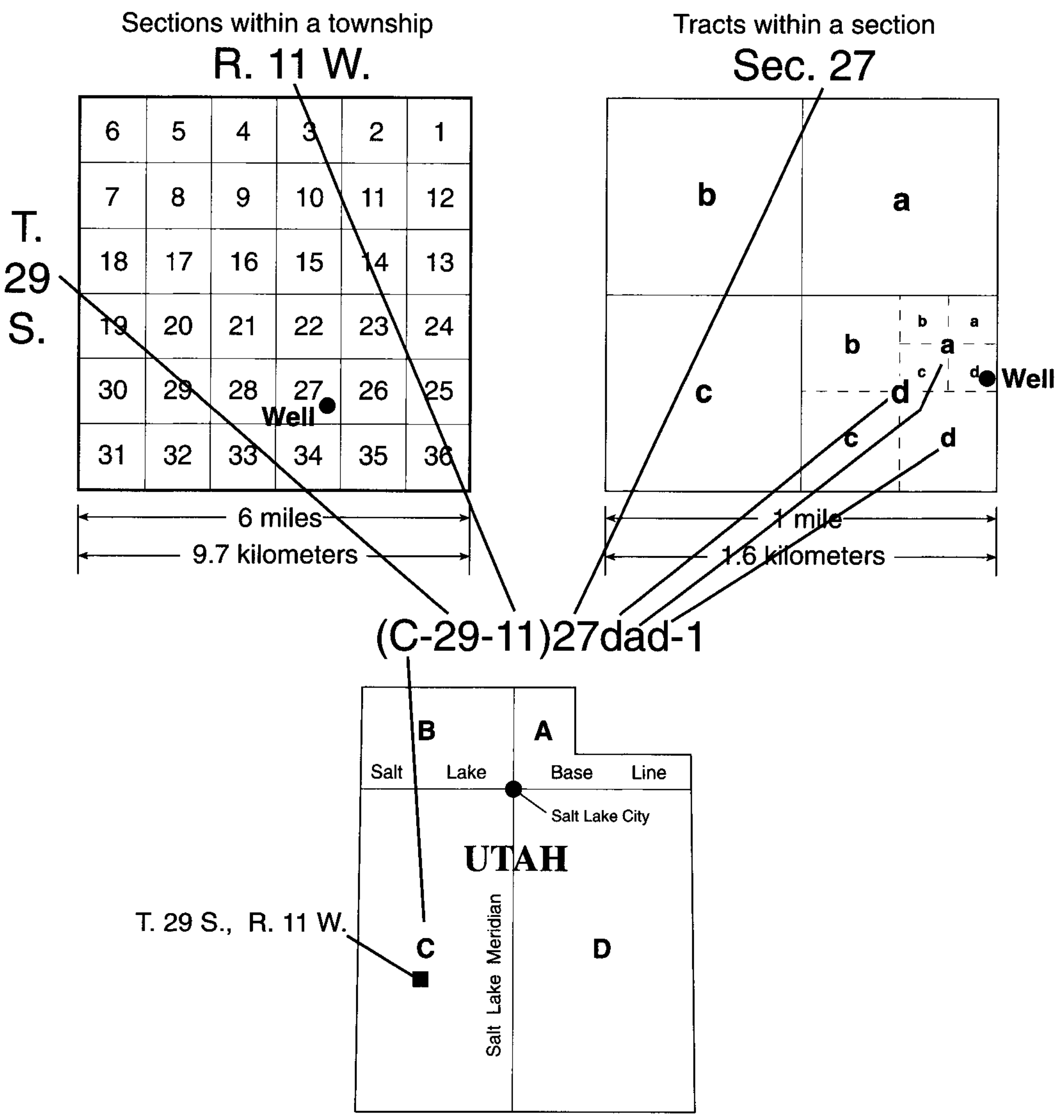

FIGURE 2.—Well-numbering system used in Utah.

lion years) (Armstrong, 1970, p. 217; Ward and others, 1978, p. 1520) and has intruded gneisses of probable Precambrian age, which are exposed along the western margin of the pluton. Repeated igneous activity from middle Tertiary to Quaternary time is evident. Middle Tertiary lavas are exposed on the south flank of the Mineral Mountains. This volcanic activity was followed by the emplacement of rhyolite on the north and west flanks of the Mineral Mountains that postdates the pluton. The youngest rhyolites have been K-Ar dated between 0.8 and 0.5 m.y. (Ward and others, 1978, p. 1520) and are distributed along the western flank. Paleozoic and Mesozoic sedimentary rocks crop out on the north and south ends of the Mineral Mountains.

In the north end of the San Francisco Mountains, Precambrian and Cambrian metasediments overlie Cambrian quartzites as a result of the Frisco Thrust (Lemmon and Morris, 1983). In the San Francisco Mountains and northern Beaver Lake Mountains, Precambrian and Cambrian metasediments overlie Ordovician through Mississippian limestone, dolomite, and quartzite due to the Beaver Lake Thrust (Lemmon and Morris, 1983). The southern San Francisco Mountains and Star Range are composed primarily of Tertiary latitic ignimbrites and late Tertiary basalt and andesite flows with a few exposures of upper Paleozoic carbonate rocks and Mesozoic sandstone (Hintze, 1980).

The Black Mountains are composed primarily of late Tertiary volcanic rocks with small, intermittent outcrops of basalt. Numerous faults are also present (Hintze, 1980).

Condie and Barsky (1972, p. 337) indicated the Black Rock basalts predated Lake Bonneville. The basalts overlie white tuffaceous clay, silt, and marl of early Pleistocene age. The contact is exposed along cliff faces east of Black Rock in the north end of the study area.

On the basis of gravity data, Carter and Cook (1978, p. 89) suggested that the basin-fill thickness is 1.5 km (about 4,900 ft). In a later study, Gertson and Smith (1979, p. 83) estimated the basin-fill thickness to be 1.8 km (about 5,900 ft).

On the basis of a seismic refraction profile, Gertson and Smith (1979, p. 57) defined two layers within the basin-fill deposits. The lower layer ranges in thickness from 0 km at the margin of the basin to about 1.2 km (3,900 ft) in the center of the basin (Gertson and Smith, 1979, p. 89). The composition of the lower layer is unknown because no well has penetrated this layer; however, Gertson and Smith (1979, p. 58) reported that seismic velocity values recorded for the lower layer were similar to those that Arnow and Mattick (1968, p. B80) assigned to Tertiary sediments. These higher velocity values generally are related to greater cementation and compaction and lower porosity values.

The upper layer of the basin fill ranges in thickness from 0.1 to 0.6 km (about 300 to 2,000 ft)(Gertson and Smith, 1979, p. 89). The upper layer of the basin fill consists of lacustrine deposits of fine-grained clay, silt, and marl along the axis of the basin that are interlayered and intertongued with deltaic and alluvial deposits of clay, silt, sand, and gravel. On the basis of scant well-log data, the lacustrine deposits are more prevalent in the northern one-half of the basin. Along the margins of the basin near the mountain fronts alluvial fans are present. Well-log data from the eastern margin of the basin indicate deposits of mixed clay and sand; whereas well-log data from the western margin of the basin indicate alternating layers of clay and unsorted sand and gravel. Shoreline deposits of sand and gravel reworked from the alluvial fans are present to an altitude of 5,120 ft (Dennis, 1942, p. 124).

The basement rocks below the basin fill are assumed to be Precambrian gneisses. Gertson and Smith (1979, p. 60) reported that seismic velocity values are similar to those recorded for a sonic log in a test well drilled into Precambrian gneisses on the western edge of the Mineral Mountains.

CLIMATE

The climate of the study area varies from semiarid on the basin floor to subhumid at higher altitudes in the surrounding mountains. The mean annual temperature at Milford is 49.3°F; summer highs sometimes exceed 100°F, and winter lows are sometimes less than -10°F (Mower and Cordova, 1974, p. 9). Average growing season is 126 days, usually from mid-May to late September (Criddle, 1958, p. 4). Average annual precipitation at Milford was 8.79 inches for 1932-83 (Avery and others, 1984, p. 62). The 1931-60 normal annual precipitation was 26 in. in the Mineral Mountains and as much as 16 in. in the San Francisco Mountains (U.S. Weather Bureau, 1963). Mower and Cordova (1974, p. 9) reported that average pan evaporation for April-October during 1953-71 was 78 inches/yr. They attributed the high rate of evaporation to frequent wind.

VEGETATION

In the higher altitudes of the surrounding mountains, the predominant vegetation is juniper (*Juniperus* sp.) and pinyon pine (*Pinus edulis*); however, in the Mineral Mountains, scrub oak (*Quercus gambelii* Nutt.) is more prevalent. Along the margins of the basin, the predominant vegetation is sagebrush (*Artemisia tridentata*), with some rabbitbrush (*Chrysothamnus nauseosus*) and shadscale (*Atriplex confertfolia*); all are low to the ground.

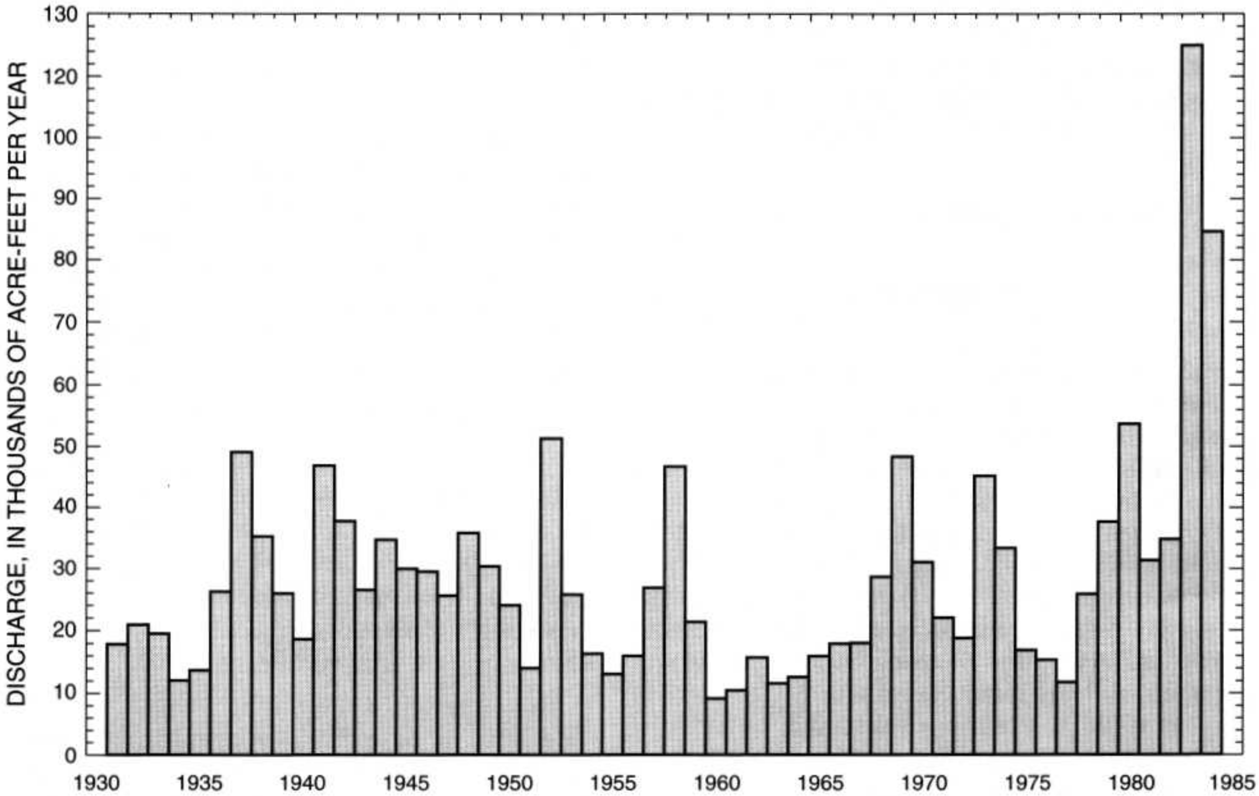

FIGURE 3.—Annual discharge of the Beaver River at Rocky Ford Dam, 1931-84.

Along the axis of the basin where the water table is shallow and the land is not irrigated, stands of greasewood (*Sarcobatus vermiculatus*), rabbitbrush, saltgrass (*Distichlis stricta*), and pickleweed (*Allenrolfea occidentalis*) are the principal phreatophytes; of these, greasewood is the most common. Willow (*Salix* sp.) and saltcedar (*Tamarix gallica*), which are phreatophytes, grow along the Beaver River channel and major canals. Mower and Feltis (1968, p. 14) reported that saltcedar was introduced into the Sevier Desert to the north prior to 1950, and saltcedar probably was introduced into the Milford area about the same time.

Cottonwood (*Populus* sp.) and willow grow in upland areas near springs. Cottonwood and other trees grow in the center of the valley where they were planted for shade and windbreaks.

SURFACE WATER

The Beaver River was a perennial stream through the Milford area until 1914, when Rocky Ford Dam was constructed to impound water 5 mi east of Minersville, outside the study area. Flow in the Beaver River channel below the reservoir now is small; practically all the water is diverted for irrigation. Only in wet years is the discharge from the reservoir great enough to cause extensive flow in the channel. In winter months, 5 ft^3/s or less flows in the channel (Nelson, 1950, p. 185).

Annual discharge of the Beaver River at Rocky Ford Dam (fig. 3) averaged 26,100 acre-ft/yr from 1931 to 1982 (Appel and others, 1983, p. 77). During 1931-82, the minimum annual discharge, 9,150 acre-ft, occurred in 1960 (Mower and Cordova, 1974, p. 11). Annual discharges of 125,000 acre-ft in 1983 and 94,800 acre-ft in 1984, far larger than the maximum during 1931-82, were reported by Avery and others (1984, p. 60) and Seiler and others (1985, p. 61).

All other streams are ephemeral and ungaged. Only rarely (such as during intense rainfall) does any appreciable flow reach the lower part of the basin. Using the channel-geometry method of Moore (1968, p. 29-39), Mower and Cordova (1974, p. 11) estimated mean annual runoff from 13 ephemeral streams to be 7,100 acre-ft. These 13 streams drain 160 mi^2, producing an average yield of about 45 acre-ft/mi^2. By applying this yield to the entire 540 mi^2 of mountainous area, Mower and Cordova (1974, p. 11) estimated mean annual runoff to be about 24,000 acre-ft.

Practically all flow entering the area in the Beaver River channel is diverted near Minersville. The water enters either the Utopia Ditch and Minersville Canal for irrigation in the area near Minersville, or into the Low Line Canal that carries water north toward Milford.

GROUND-WATER HYDROLOGY

CONSOLIDATED ROCKS

The consolidated rocks in the Milford area can be divided into three hydrogeologic units. Precambrian gneiss and Tertiary and Quaternary granite and basalt are grouped into one unit because of their assumed overall low permeability and porosity. Although the hydrologic properties of basalt can be markedly different than gneiss and granite, there is no information in the Milford area to differentiate between these rock types. These consolidated rocks might contain water in widely spaced joints; and if the joints are large and well connected, the granite and basalt can accept large quantities of water. The consolidated rocks could contribute a substantial quantity of water to the unconsolidated basin fill by subsurface flow. Wells intersecting systems of open joints could produce moderate quantities of water.

The second unit includes Tertiary fine-grained extrusive rocks other than basalts, such as latitic ignimbrites and andesite flows. These rocks contain small quantities of water in poorly developed and poorly connected joints. This unit probably does not accept an appreciable quantity of water for recharge and would not yield water readily to wells.

The third unit includes Precambrian through Cretaceous carbonate rocks, sandstones, and metasedimentary rocks that have hydrologic properties similar to the Tertiary and Quaternary granite and basalt. These rocks could have joints and fractures that contain water but the carbonate rocks have the additional potential for storing and transmitting large quantities of water due to enlargement of the fractures through dissolution. The sandstones could have some primary permeability related to intergranular porosity, but it probably would be subordinate to secondary permeability from fracturing and jointing.

UNCONSOLIDATED BASIN FILL

DESCRIPTION

The ground-water system of the Milford area is made up of unconsolidated basin fill. The ground-water system is unconfined along the margins of the basin, but becomes confined in the center of the southern one-half of the basin. The upper 200 to 300 ft of the saturated basin fill in this area is under both unconfined and semiconfined conditions. The lateral extent of the confined aquifer is assumed to coincide with the main area of ground-water development. The confined aquifer might extend further to the southwest and toward the mountains, but this is unknown because of a lack of well data outside the developed area. The depth to the bottom of the main confining bed ranges from 200 to 300 ft as shown by Mower and Cordova (1974, pl. 2A and 2B). Because of the lack of data, a lower limit for the confined or principal basin-fill aquifer cannot be determined except by geophysical methods, which suggest a total thickness of 2,000 ft.

In the center of the northern one-half of the basin, water from the basin fill discharges in this area where the hydraulic head is near the land surface. Data are insufficient, however, to determine whether the ground-water system in the northern one-half of the basin is truly confined with a confining layer at depth, or whether the upward hydraulic gradient is associated only with upward movement of ground water to a discharge area at land surface.

Along the center of the southern one-half of the basin, the basin fill is composed of alternating clay, sand, and gravel. The basin fill along the eastern margin of the basin, for the most part, is composed of unsorted clay and sand with intermixed gravel in the alluvial fans. In some areas along the western margin of the basin, sequences of alternating clay, sand, and gravel are present, but no data are available to determine if any of the clay layers act as confining beds. Along the center of the northern one-half of the basin, the basin fill is generally composed of unsorted clay and sand.

MOVEMENT

The general direction of ground-water movement is from south to north with a strong east to west component, as shown in figure 4. Subsurface flow enters the ground-water system from the Beryl-Enterprise area to the southwest and from the southeast under the Beaver River channel and through its associated alluvial fan. Along the eastern margin of the basin, the hydraulic gradient indicates flow toward the axis of the basin.

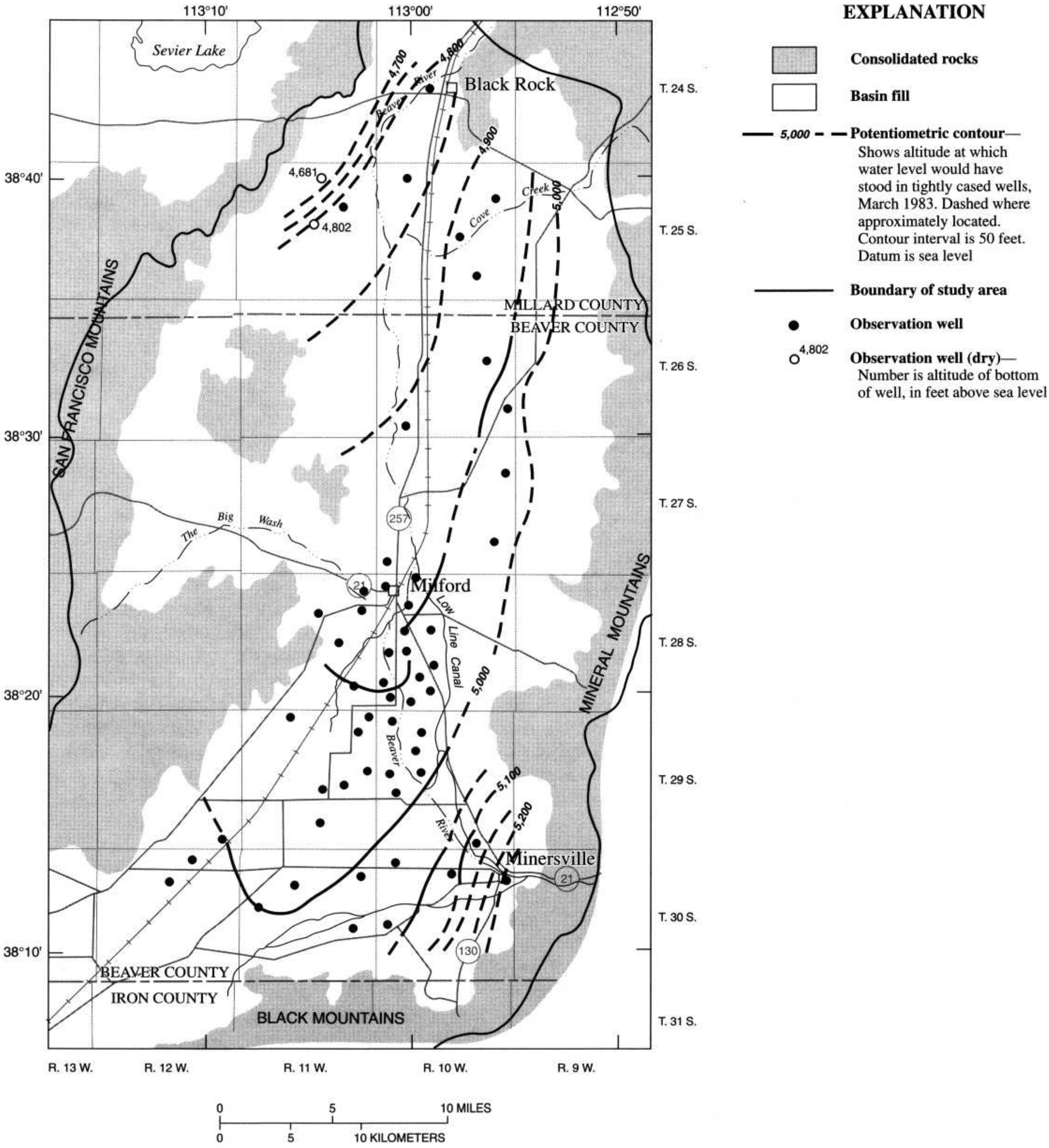

FIGURE 4.—Potentiometric surface of the principal aquifer, Milford area, 1983.

Along the southwestern margin of the basin, limited water-level data indicate that the ground-water flow direction is basically to the north, paralleling the Star Range, with little movement to the east of these uplands. This suggests limited inflow from the consolidated rocks. Based on information from three test holes drilled during this project, the ground-water gradient in the northwest part of the basin indicates movement through the consolidated rocks in the north end of the San Francisco Mountains toward Sevier Lake.

RECHARGE

Subsurface inflow from consolidated rocks along the mountain fronts was estimated by Mower and Cordova (1974, p. 22) to be 16,000 acre-ft/yr. This estimate was derived by subtracting all known and estimated sources of recharge from the estimated total ground-water discharge under steady-state conditions, assuming that recharge equals discharge. They also assumed that subsurface inflow from consolidated rocks was distributed along the surrounding mountains. On the basis of the revised direction of ground-water flow (fig. 4) as compared to the direction of ground-water flow shown in Mower and Cordova (1974, pl. 4), the major source of subsurface inflow from consolidated rocks is from the Mineral Mountains. By using the approach of Maxey and Eakin (1949, p. 40), which consists of assuming that a percentage of precipitation over upland areas seeps into consolidated rocks, subsurface inflow from the Mineral Mountains was estimated to be more than 15,000 acre-ft/yr. This is almost equal to the recharge estimated for the whole area by Mower and Cordova. On the basis of ground-water flow direction, the mountains to the south and west do not contribute an appreciable quantity of subsurface inflow from consolidated rocks.

In the extreme northern part of the basin, east of Black Rock, an unknown but large quantity of subsurface inflow enters the unconsolidated basin-fill aquifer from basalt that overlies clastic deposits of early Pleistocene age. Mower and Cordova (1974, p. 62) estimated the discharge from one spring orifice to be from 500 to 1,000 gal/min.

Subsurface inflow from tributary basins was estimated by Mower and Cordova (1974, p. 16) to be 1,700 acre-ft/yr by using Darcy's Law. The contribution was estimated to be 1,000 acre-ft/yr from the Beryl-Enterprise area and 700 acre-ft/yr from Beaver Valley. Later, during calibration of a ground-water flow model for the Beryl-Enterprise area, Mower (1982, p. 47), estimated the outflow from that area toward Milford to be 2,100 acre-ft/yr. This study did not attempt to collect new field data to verify these estimates.

Through canal-loss measurements, Mower and Cordova (1974, p. 18) estimated that 34 percent of the water diverted from the Beaver River infiltrates to the ground-water system. They reported that approximately 4 percent probably is consumed by vegetation, leaving 30 percent to recharge the ground-water system. Also, they reported that the long-term average annual recharge from losses along the 23 mi of canals in the Milford area was 8,300 acre-ft/yr.

Seepage from irrigated lands contributes a substantial amount of water to the ground-water system. Willardson and Bishop (1967, p. 35) reported water-application efficiencies of 60 to 80 percent (losses between 40 and 20 percent) with furrow or flooding methods. Losses may decrease with more efficient irrigation practices. Assuming an average seepage loss of 30 percent of the water applied to irrigated lands (ground water and surface water), Mower and Cordova (1974, p. 15) estimated that 22,700 acre-ft/yr infiltrates to the ground-water system, based on irrigation practices for 1970-71. They also estimated that infiltration from precipitation on irrigated lands was 2,000 acre-ft/yr, and infiltration from lawns and gardens was 100 acre-ft/yr.

Mower and Cordova (1974, p. 18) assumed that 30 percent of the annual runoff in ephemeral stream channels infiltrates to the ground-water system. Using the 24,000 acre-ft/yr estimate for ephemeral streamflow reported in the surface-water section of this report, this yields 7,200 acre-ft/yr. This includes underflow along The Big Wash, which was estimated to be 2,200 acre-ft/yr. With the revised flow system, which is in contrast to the flow system shown in Mower and Cordova (1974, pl. 4), only recharge from the Mineral Mountains affects the entire ground-water system. The Mineral Mountains cover an area of 125 mi^2, about 25 percent of the mountainous area. Using the assumptions of Mower and Cordova (1974, p. 18), 25 percent of 24,000 acre-ft, or 6,000 acre-ft, would run off the Mineral Mountains and would be available for recharge. Thirty percent of that figure gives 1,800 acre-ft of recharge to the ground-water system from these mountains. Minimum flow in the Beaver River channel is about 5 ft^3/s during the winter (Nelson, 1950, p. 185), which is about 1,800 acre-ft/yr, assuming a 6-month low-flow period. All of this flow is assumed to recharge the ground-water system.

Water-level fluctuations in wells within the area of ground-water withdrawal are a response to the long-term trends of precipitation, recharge from the Beaver River and the associated surface-water irrigation system, and ground-water withdrawals. Water levels within this area declined steadily from 1950 to 1968. Since 1968, water levels generally have declined at a slower rate with some rises that probably are related to high flows in the Beaver River. Similar trends can be seen by comparing the percentage of rise or decline of flow in the Beaver River from one year to the next to the percentage of wells that shows a rise during the following spring, especially for years with a substantial increase of flow in the Beaver River (fig. 5). Water-level rises in wells near the Beaver River channel or near large canals could be the result of an increase in the infiltration of surface-water in combination with a decrease in ground-water withdrawals because of the availability of surface water.

DISCHARGE

Mower and Cordova (1974, p. 32) estimated evapotranspiration to be 24,000 acre-ft in 1971, compared to an estimated 33,000 acre-ft for 1927 that they obtained by adjusting White's 1932 estimate. As reported by Mower and Cordova (1974, table 10), the difference in evapotranspiration is due to declining water levels within the area of ground-water development. The phreatophyte area mapped by Mower and Cordova (1974, pl. 3) was field checked during this study and no substantial differences were found.

Subsurface outflow toward the north to the Sevier Desert was estimated to be 8 acre-ft/yr by Mower and Cordova (1974, p. 33) using Darcy's Law. A low estimate for transmissivity of 75 ft^2/d was used in the calculation; however, based on the new direction of ground-water flow as compared to the direction of ground-water flow shown in Mower and Cordova (1974, pl. 4), the main component of basin outflow is toward the northwest through the consolidated rocks at the north end of the San Francisco Mountains. Model simulations of the Milford area, discussed in a later section of this report, provided an estimate for this outflow.

Since 1931, the U.S. Geological Survey, in cooperation with the State of Utah, has estimated ground-water withdrawals in this area. The estimates were made from periodic discharge and power-consumption measurements and yearly power-consumption records, or from a summation of water from irrigation wells that have water meters. From 1931 through 1949, ground-water withdrawals averaged 16,100 acre-ft/yr, with a maximum of 22,760 acre-ft in 1947, and a minimum of 10,860 acre-ft in 1931. Discharge from wells began to increase markedly in 1949 (fig. 6). From 1950 through 1982, ground-water withdrawals averaged 49,000 acre-ft/yr. Since 1949, the maximum withdrawal was 70,200 acre-ft in 1974, and the minimum withdrawal was 30,900 acre-ft in 1950. Associated with the increase in ground-water withdrawals, water levels began to decline after 1950 as shown by the hydrographs of two observations wells (fig. 7). The large fluctuations in the hydrographs are a result of seasonal variations due to pumping; however, the long-term trend of water-level decline is clearly visible.

HYDRAULIC PROPERTIES

The hydraulic properties of an aquifer describe its ability to transmit and store water. Transmissivity, which depends on the hydraulic conductivity and the saturated thickness of the porous medium, can be determined from aquifer-test data and estimated from specific capacities. Mower and Cordova (1974, p. 13) reported transmissivity values ranging from 1,000 to about 40,000 ft^2/d, based on their analysis of aquifer-test data by the Theis curve-matching procedure (Lohman, 1972, p. 34) and the Cooper and Jacob straight-line solution (Lohman, 1972, p. 19). As part of this study, aquifer-test data collected by Mower and Cordova were analyzed using the Hantush modified method (Lohman, 1972, p. 32). Transmissivity values ranged from about 1,000 to 55,000 ft^2/d with the highest values in the south end of the developed area as indicated by the concentration of observation wells in figure 4.

Mower and Cordova (1974, p. 13) reported specific-yield values from 0.04 for clayey silt to 0.2 for sandy gravel. They determined the values from short-term aquifer tests and the neutron-radiation method described by Keys and MacCary (1971, p. 74-86). They also reported a storage coefficient value of 1.0×10^{-3} for the confined aquifer in the central part of the basin. Storage coefficient values were determined in the present study from aquifer-test data using the Hantush modified method. Values ranged from 0.002 to 6.0×10^{-5}.

STORAGE

Mower and Cordova (1974, p. 24) estimated that 40 million acre-ft of ground water is stored in the ground-water system. They derived this estimate by multiplying the volume of saturated materials, 95 million acre-ft, by an average water content of 40 percent by volume. They also estimated water content for different lithologies from 110 relatively undisturbed soil samples and from neutron moisture-probe measurements. Lithologic logs and the estimated values for water content were used to determine average water content for the entire ground-water system. Their estimated volume of saturated materials, however, was based on a maximum depth of slightly over 500 ft. Drilling since the early 1970's has shown that the depth of saturated materials is greater than 500 ft and that the bottom of the ground-water system has not been reached; therefore, the amount of water in storage probably is greater than the value estimated by Mower and Cordova.

Mower and Cordova (1974, p. 27) reported that less than one-half of the estimated 40 million acre-ft stored in the ground-water system may be recoverable. The amount of recoverable water in storage is determined from the volume of the ground-water system and the spe-

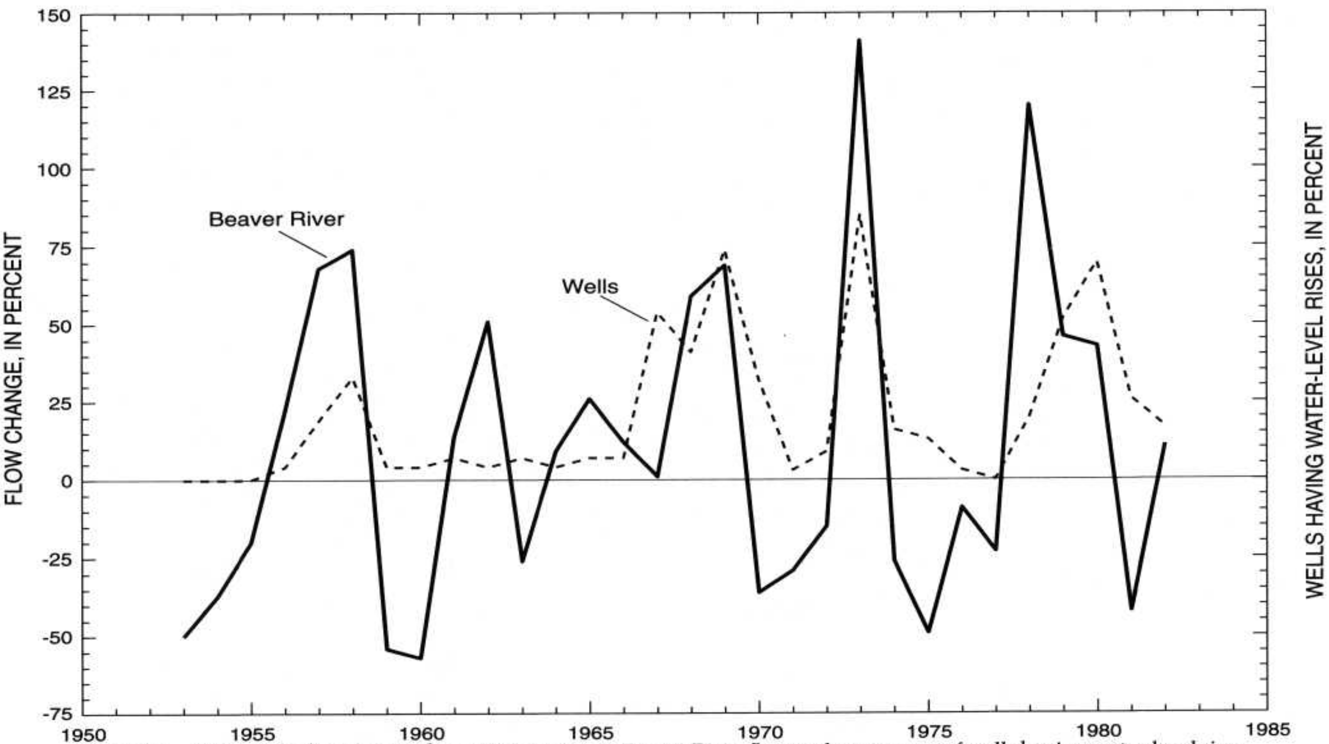

FIGURE 5.—Percentage change from the preceding year in Beaver River flow and percentage of wells having water-level rises the following spring for each year, 1953-82.

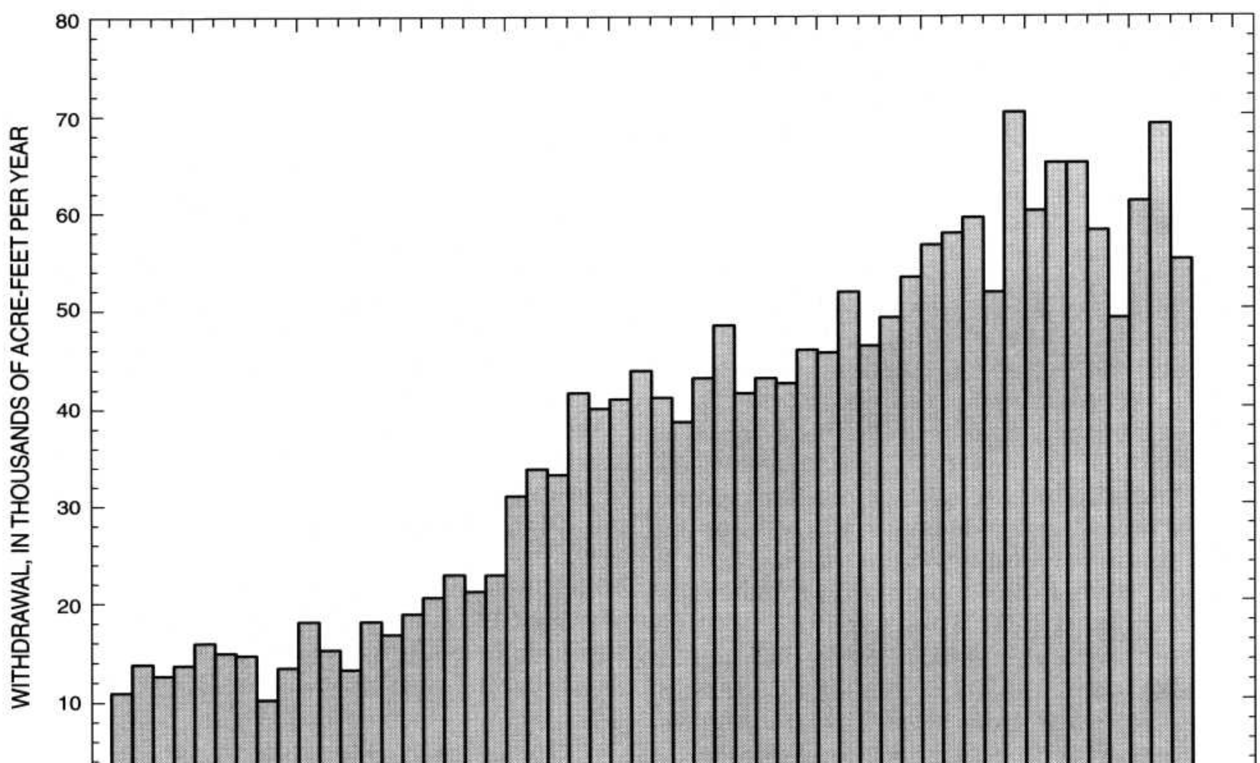

FIGURE 6.—Annual ground-water withdrawals in the Milford area, 1931-82.

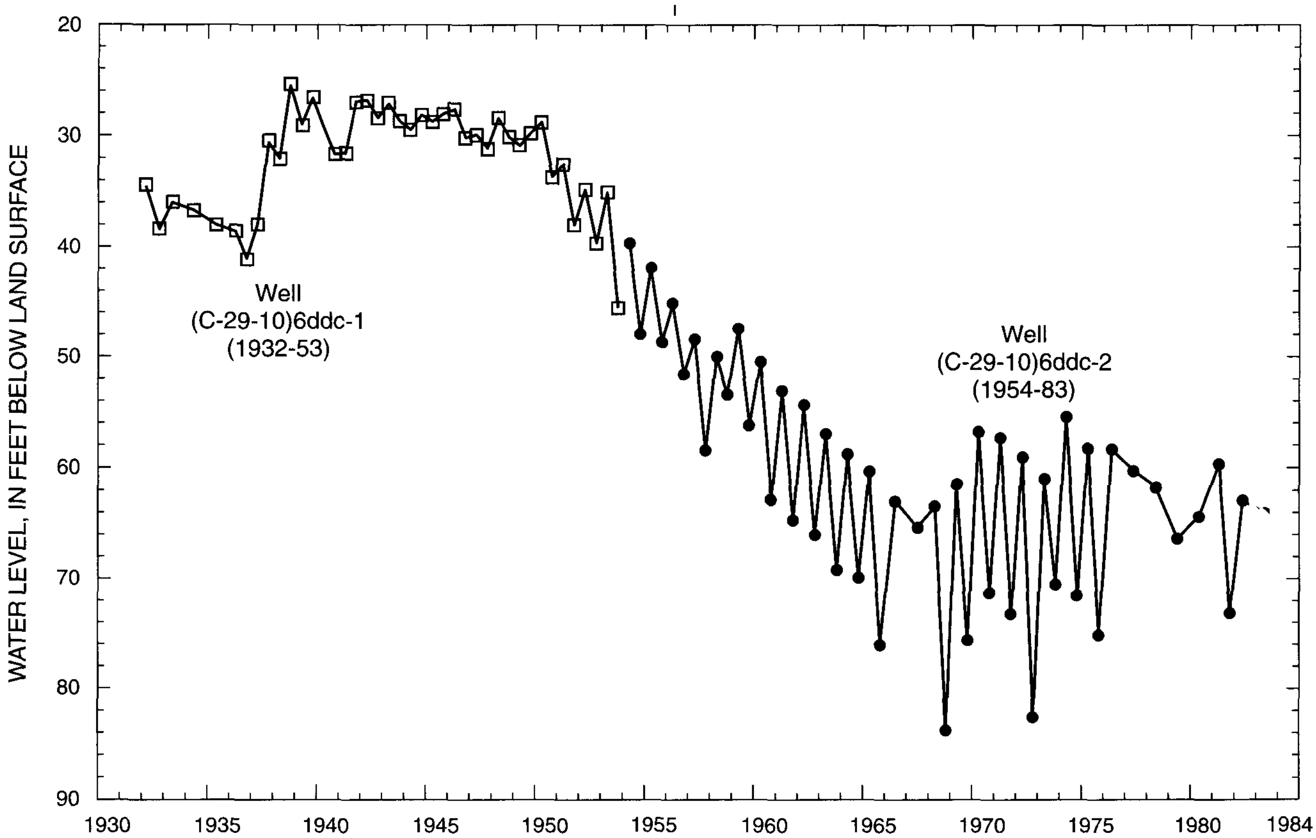

FIGURE 7.—Water levels in two adjacent observation wells in the Milford area, 1932-83.

cific yield, assuming that the water levels will have been lowered so that the confined aquifers have been dewatered; thus, a specific yield representative of water-table conditions will determine the amount of water released from storage. The ground-water system in the Milford area covers approximately 550 mi^2. Assuming an average saturated thickness of 400 ft for the basin fill and a specific yield of 0.15, the amount of recoverable water in storage was estimated to be 21 million acre-ft.

SIMULATION OF GROUND-WATER FLOW

A three-dimensional, finite-difference computer program developed by McDonald and Harbaugh (1988) was used to describe ground-water flow in the basin fill in the Milford area. The finite-difference algorithm used in their computer program can generate only an approximate solution to the partial-differential equation that describes ground-water flow; therefore, the model needs to be considered a tool to help describe the ground-water system. The ground-water model was used to (1) verify or improve estimates of recharge and discharge and the hydraulic properties that describe the basin-fill aquifer; and (2) simulate past and future stresses on the basin-fill aquifer. Both short-term stresses using the present pattern of ground-water withdrawal, and long-term stresses using hypothetical distributions of ground-water withdrawal were simulated. The short-term simulations projected effects of present withdrawals and potential increases in withdrawals. The long-term simulations tested the effects of three kinds of ground-water development: "sustained" yield, ground-water mining, and the capture of natural discharge.

MODEL DESIGN

MODEL GRID AND LAYERS

The three-dimensional, ground-water flow model uses a block-centered or cell-oriented grid system as described by McDonald and Harbaugh (1988, p. 5-1). The grid used for the Milford model consists of 55 rows and 29 columns. Cell spacing ranged from 0.5 to 1.5 mi. The smallest cells, located in the area with numerous wells, cover 0.25 mi^2; largest cells cover 1.5 mi^2. The area of active cells (those actually included in the model calibrations) used in the final model design are shown on plate 1.

The original model design included two layers; an unconfined upper layer and a confined lower layer, except