200)
290
83-688

GROUND-WATER HYDROLOGY AND PROJECTED EFFECTS OF GROUND-WATER WITHDRAWALS IN THE SEVIER DESERT, UTAH

USGS LIBRARY-RESTON
3 1818 00070037 5

U.S. GEOLOGICAL SURVEY

Open-File Report 83-688

U. S. GEOLOGICAL SURVEY
RESTON, VA.
NOV 07 1983
LIBRARY

Prepared in cooperation with the
UTAH DEPARTMENT OF NATURAL RESOURCES,
DIVISION OF WATER RIGHTS

Dept.
Seal

Open-file report
(Geological Survey
(U.S.))

347779

GROUND-WATER HYDROLOGY AND PROJECTED

EFFECTS OF GROUND-WATER WITHDRAWALS

IN THE SEVIER DESERT, UTAH

By Walter F. Holmes

U.S. GEOLOGICAL SURVEY

Open-File Report 83-688

Prepared in cooperation with the

UTAH DEPARTMENT OF NATURAL RESOURCES,

DIVISION OF WATER RIGHTS

Dept.

Seal

Salt Lake City, Utah

1983

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
1016 Administration Building
1745 West 1700 South
Salt Lake City, Utah 84104

Copies of this report can be purchased from:

Open-File Services Section
Western Distribution Branch
Box 25425, Federal Center
Denver, Colorado 80225
[Telephone: (303) 234-5888]

CONTENTS

	Page
Abstract	9
Introduction	10
Purpose, scope, and methods of investigation	10
Previous studies and acknowledgments	10
Well- and spring-numbering system	11
Description of the study area	13
Physiography	13
Geology	13
Climate	13
Vegetation	15
Surface water	15
Ground-water hydrology	17
Consolidated rocks	17
Unconsolidated basin fill	18
Recharge	21
Seepage from streams	21
Seepage from canals	22
Seepage from reservoirs	23
Seepage from unconsumed irrigation water	23
Subsurface inflow from consolidated rocks along the mountain fronts	23
Precipitation on basalt outcrops	23
Subsurface inflow from adjoining areas	24
Movement	24
Discharge	24
Clear Lake Springs	25
Seepage to the Sevier River	25
Evapotranspiration	25
Subsurface outflow to adjoining areas	26
Wells	26
Hydraulic properties	28
Storage	30
Water quality	30
Changes in ground-water conditions, 1963-81	31
Ground-water withdrawals	31
Water levels	31
Water quality	34
Digital-computer modeling	37
General description of model	37
Projected effects of future ground-water withdrawals	39
Ground-water withdrawals equal to the 1977-79 average rate	40

CONTENTS--Continued

Page

Digital-computer modeling--Continued
Projected effects of future ground-water withdrawals--Continued
Ground-water withdrawals one-half the 1977-79 average rate 40
Ground-water withdrawals double the 1977-79 average rate 44
Changes in locations of ground-water withdrawals related to the Intermountain Power Project 44
Summary and conclusions 50
References cited 51

ILLUSTRATIONS

[Plate is in pocket]

Plate 1. Map of the Sevier Desert, Utah, showing the potentiometric surface of the shallow artesian aquifer and water levels in the deep artesian aquifer, March 1981.

Figure 1. Diagram showing well- and spring-numbering system used in Utah 12

2. Map of Utah showing location of the study area 14

3. Graph showing cumulative departure from average annual precipitation at Oak City, 1935-81 16

4. Generalized geologic section near Lynndyl, Utah, showing lithology and divisions of the ground-water reservoir 19

5. Idealized east-west cross section of the Sevier Desert showing the elements of the ground-water system 20

6. Graph showing ground-water withdrawals from the Sevier Desert, 1951-81 27

7-9. Maps showing:

7. Arsenic concentrations in water in the artesian aquifers, 1979-81 32

8. Areas of significant water-level change in the shallow artesian aquifer, March 1963 to March 1981 33

9. Water-level changes in wells in the deep artesian aquifer, March 1963 to March 1981 35

Page

Figure 10. Graphs showing specific conductance of water from selected wells completed in the shallow artesian aquifer, 1958-80 36

11-18. Maps showing:

11. Projected water-level declines in the deep artesian aquifer for the period 1981-2000, assuming ground-water withdrawals equal to the 1977-79 average rate 41

12. Projected water-level declines in the shallow artesian aquifer for the period 1981-2000, assuming ground-water withdrawals equal to the 1977-79 average rate 42

13. Projected water-level changes in the deep artesian aquifer for the period 1981-2000, assuming ground-water withdrawals one-half the 1977-79 average rate 43

14. Projected water-level changes in the shallow artesian aquifer for the perid 1981-2000, assuming ground-water withdrawals one-half the 1977-79 average rate 45

15. Projected water-level declines in the deep artesian aquifer for the period 1981-2000, assuming ground-water withdrawals double the 1977-79 average rate 46

16. Projected water-level declines in the shallow artesian aquifer for the period 1981-2000, assuming ground-water withdrawals double the 1977-79 average rate 47

17. Projected water-level changes in the deep artesian aquifer resulting from changes in the location of ground-water withdrawals related to the Intermountain Power Project for the period 1981-2000 48

18. Projected water-level changes in the shallow artesian aquifer resulting from changes in the location of ground-water withdrawals related to the Intermountain Power Project for the period 1981-2000 49

TABLES

Page

Table 1. Hydraulic coefficients of artesian aquifers in the Sevier Desert 29

2. Steady-state (1952) and transient-state (1980-81) ground-water budgets for the Sevier Desert, computed by the digital model, in acre-feet per year 38

CONVERSION FACTORS AND RELATED INFORMATION

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

Multiply	By	To obtain
acre	0.4047	square hectometer (hm^2)
	0.004047	square kilometer (km^2)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	1233	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per day per foot ($ft^3/d)/ft$	0.0929	cubic meter per day per meter ($m^3/d)/m$
foot (ft)	0.3048	meter (m)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
inch (in.)	25.40	millimeter (mm)
	2.540	centimeter (cm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

Chemical concentrations are given only in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (ug/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of 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 mg/L, the numerical value is about the same as for concentrations in parts per million.

<u>National Geodetic Vertical Datum of 1929 (NGVD of 1929)</u>: A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, called NGVD of 1929, is referred to as sea level in this report.

GROUND-WATER HYDROLOGY AND PROJECTED EFFECTS OF GROUND-WATER WITHDRAWALS IN THE SEVIER DESERT, UTAH

By Walter F. Holmes

ABSTRACT

The principal ground-water reservoir in the Sevier Desert is the unconsolidated basin fill. The fill has been divided generally into aquifers and confining beds, although there are no clearcut boundaries between these units--the primary aquifers are the shallow and deep artesian aquifers. Recharge to the ground-water reservoir is by infiltration of precipitation; seepage from streams, canals, reservoirs, and unconsumed irrigation water; and subsurface inflow from consolidated rocks in mountain areas and from adjoining areas. Discharge is by wells, springs, seepage to the Sevier River, evapotranspiration, and subsurface outflow to adjoining areas.

Changes in ground-water withdrawals, water levels, and quality of water occurred in the artesian aquifers of the Sevier Desert, Utah, during 1963-81. Ground-water withdrawals increased from an average of 9,500 acre-feet (11.7 cubic hectometers) per year between 1951 and 1963 to an average of 27,500 acre-feet (33.9 cubic hectometers) per year between 1964 and 1981. Most of the increased withdrawal was from the deep artesian aquifer.

Water levels declined as much as 19 feet (5.8 meters) in the deep artesian aquifer and as much as 13 feet (4.0) meters in the shallow artesian aquifer between 1963 and 1981. The declines probably are due to increased ground-water withdrawals for irrigation and municipal use.

Concentrations of dissolved constituents in water in the shallow artesian aquifer are increasing in an area near Leamington and Lynndyl. This change probably is the result of more mineralized water entering the shallow artesian aquifer from the overlying water-table aquifer.

Water-level changes resulting from changes in recharge to and discharge from the aquifers were simulated using a digital-computer model of the aquifer system. Ground-water withdrawals for 20 years (1981-2000) were simulated at one-half, one, and two times the 1977-79 average rate. Water-level declines of more than 80 feet (24 meters) were projected in the deep artesian aquifer with withdrawals twice the 1977-79 average, declines of more than 40 feet (12 meters) if withdrawals were equal to the 1977-79 average, and declines of more than 15 feet (4.6 meters) if withdrawals were one-half the 1977-79 average. Computed water-level declines after 20 years in the shallow artesian aquifer were more than 50 feet (15 meters) at two times the 1977-79 average rate, more than 15 feet (4.6 meters) at the 1977-79 average, and less than 4 feet (1.2 meters) at one-half the 1977-79 average.

Changes in locations of ground-water withdrawals related to the Intermountain Power Project would cause water-level declines in the deep artesian aquifer of more than 15 feet (4.6 meters), but only small changes in

water levels in the shallow artesian aquifer after 20 years. These changes are in addition to changes computed for 20 years of withdrawals at the pre-project 1977-79 withdrawal rate.

INTRODUCTION

Purpose, Scope, and Methods

The U.S. Geological Survey evaluated the ground-water reservoir of the Sevier Desert, Utah, during 1979-82, in cooperation with the Utah Department of Natural Resources, Division of Water Rights. The objectives of the study were to add to the understanding of the area's ground-water hydrology, to determine changes in ground-water conditions since the 1961-64 study by Mower and Feltis (1968), and to project the effects on water levels in the artesian aquifers of potential future ground-water withdrawals.

Information collected and methods used to collect it during the study included discharge from wells and springs, water levels in wells, drillers' and geophysical logs of wells, water samples which were analyzed chemically, seepage losses from or gains to canals and streams from measurements of surface-water flow, hydraulic properties of aquifers from aquifer tests, and changes in areas of phreatophyte growth. A digital-computer model of the ground-water system was constructed on the basis of this and other information.

Previous Studies and Acknowledgments

Previous studies of the ground-water hydrology of the Sevier Desert or some aspect of it include those by Meinzer (1911), Nelson (1952), Nelson and Thomas (1953), Mower (1961, 1963, and 1967), Mower and Feltis (1968), Handy and others (1969), Hamer and Pitzer (1978), and Holmes and Wilberg (1982). Previously published compilations of basic data for the Sevier Desert include those by Mower and Feltis (1964) and Enright and Holmes (1982). Other data on changes in water levels and ground-water withdrawals in Utah are in a series of annual ground-water reports prepared by the U.S. Geological Survey, the most recent being that by Appel and others (1983). Many of the conclusions in this report are based on the results of the digital-computer model used in this study, but the details of its design, construction, and calibration are given by Holmes (1983). The U.S. Department of Agriculture (1969) published a water budget for the Sevier River basin. Information on seepage losses from or gains to canals and streams in the area were collected by Herbert and others (1982).

This study could not have been completed without the cooperation of local well owners, and personnel of irrigation companies, municipalities, industrial water users, utility companies, and the Utah Division of Water Rights. The access to wells and data granted by these people is appreciated.

Well- and Spring-Numbering System

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well or spring, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake base line and meridian, and these quadrants are designated by 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 (4 hm^2);[1] the letters a, b, c, and d indicates, 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 (4-hm^2) tract; the letter "S" preceding the serial number denotes a spring. If a well or spring cannot be located within a 10-acre (4-hm^2) tract, one or two location letters are used and the serial number is omitted. Thus (C-12-6)15bac-1 designates the first well constructed or visited in the SW¼NW¼NW¼ sec. 15, T. 12 S., R. 6 W., and (C-20-7)3d-S designates a spring known only to be in the SE¼ sec. 3, T. 20 S., R. 7 W. The numbering system is illustrated in figure 1.

----

[1]Although the basic land unit, the section, is theoretically 1 square mile (1.6 km^2), many sections are irregular. Such sections are subdivided into 10-acre (4-hm^2) tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

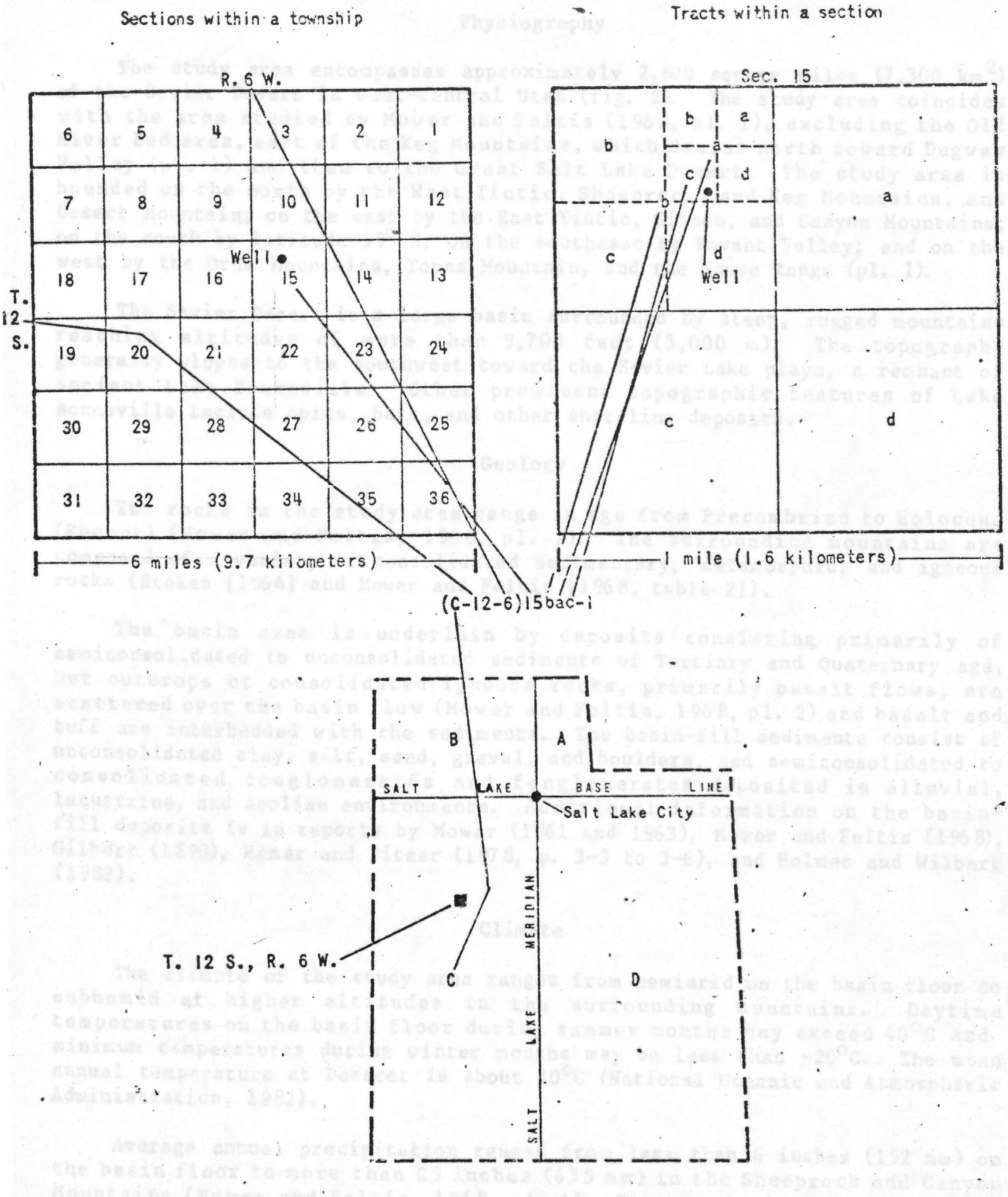

Figure 1.—Well- and spring-numbering system used in Utah.

Description of the Study Area

Physiography

The study area encompasses approximately 2,800 square miles (7,300 km^2) of the Sevier Desert in west-central Utah (fig. 2). The study area coincides with the area studied by Mower and Feltis (1968, pl. 1), excluding the Old River Bed area, east of the Keg Mountains, which drains north toward Dugway Valley (pl. 1) and then to the Great Salt Lake Desert. The study area is bounded on the north by the West Tintic, Sheeprock, and Keg Mountains, and Desert Mountain; on the east by the East Tintic, Gilson, and Canyon Mountains; on the south by latitude 39° N; on the southeast by Pavant Valley; and on the west by the Drum Mountains, Topaz Mountain, and the House Range (pl. 1).

The Sevier Desert is a large basin surrounded by steep, rugged mountains reaching altitudes of more than 9,700 feet (3,000 m). The topography generally slopes to the southwest toward the Sevier Lake playa, a remnant of ancient Lake Bonneville. Other prominent topographic features of Lake Bonneville include spits, bars, and other shoreline deposits.

Geology

The rocks in the study area range in age from Precambrian to Holocene (Recent) (Mower and Feltis, 1968, pl. 2). The surrounding mountains are composed of a variety of consolidated sedimentary, metamorphic, and igneous rocks (Stokes [1964] and Mower and Feltis [1968, table 2]).

The basin area is underlain by deposits consisting primarily of semiconsolidated to unconsolidated sediments of Tertiary and Quaternary age, but outcrops of consolidated igneous rocks, primarily basalt flows, are scattered over the basin flow (Mower and Feltis, 1968, pl. 2) and basalt and tuff are interbedded with the sediments. The basin-fill sediments consist of unconsolidated clay, silt, sand, gravel, and boulders, and semiconsolidated to consolidated conglomerates and fanglomerates deposited in alluvial, lacustrine, and aeolian environments. Additional information on the basin-fill deposits is in reports by Mower (1961 and 1963), Mower and Feltis (1968), Gilbert (1890), Hamer and Pitzer (1978, p. 3-3 to 3-6), and Holmes and Wilberg (1982).

Climate

The climate of the study area ranges from semiarid on the basin floor to subhumid at higher altitudes in the surrounding mountains. Daytime temperatures on the basin floor during summer months may exceed 40°C and minimum temperatures during winter months may be less than -20°C. The mean annual temperature at Deseret is about 10°C (National Oceanic and Atmospheric Administration, 1982).

Average annual precipitation ranges from less than 6 inches (152 mm) on the basin floor to more than 25 inches (635 mm) in the Sheeprock and Canyon Mountains (Mower and Feltis, 1968, pl. 4). The cumulative departure from

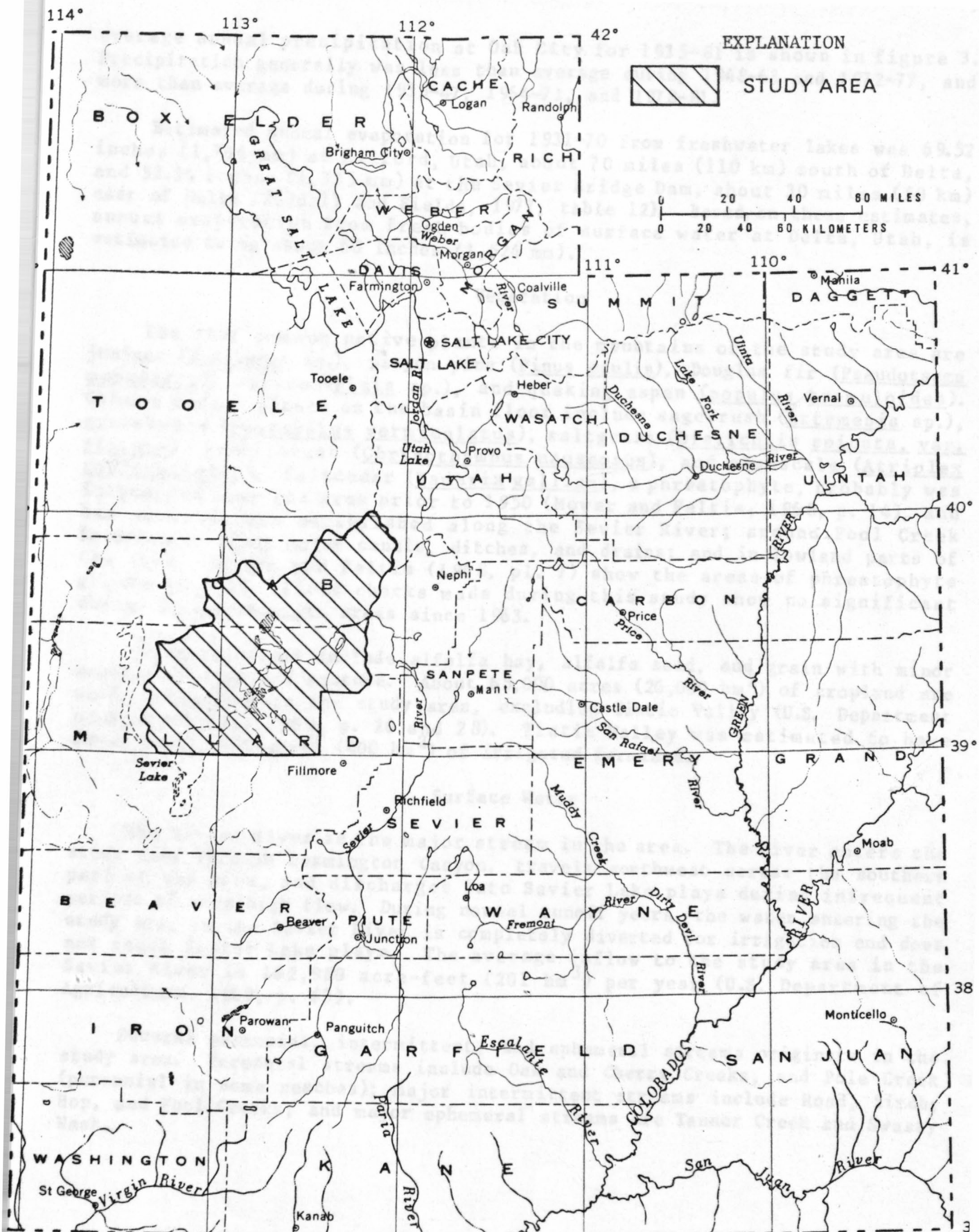

Figure 2.—Location of the study area.

average annual precipitation at Oak City for 1935-81 is shown in figure 3. Precipitation generally was less than average during 1948-63 and 1972-77, and more than average during 1935-47, 1964-71, and 1978-81.

Estimated annual evaporation for 1931-70 from freshwater lakes was 69.52 inches (1,766 mm) at Milford, Utah, about 70 miles (110 km) south of Delta, and 52.54 inches (1,335 mm) at the Sevier Bridge Dam, about 30 miles (50 km) east of Delta (Waddell and Fields, 1977, table 12). Based on these estimates, annual evaporation from fresh bodies of surface water at Delta, Utah, is estimated to be about 60 inches (1,524 mm).

Vegetation

The most common native plants in the mountains of the study area are juniper (*Juniperus* sp.), pinyon pine (*Pinus edulis*), Douglas fir (*Pseudotsuga menziesii*), spruce (*Picia* sp.), and quaking aspen (*populus tremuloides*). Common native plants on the basin floor include sagebrush (*Artemesia* sp.), greasewood (*Sarcobatus vermiculatus*), saltgrass (*Distichlis spicata, var. stricta*), rabbitbrush (*Chrysothamnus nauseosus*), and shadscale (*Atriplex confertifolia*). Saltcedar (*Tamarix gallica*), a phreatophyte, probably was introduced into the area prior to 1950 (Mower and Feltis, 1968, p. 14), and has since become established along the Sevier River; around Fool Creek Reservoirs; along major canals, ditches, and drains; and in lowland parts of the area. Mower and Feltis (1968, pl. 7) show the areas of phreatophyte growth in 1963. Field checks made during this study show no significant change in phreatophyte areas since 1963.

Irrigated crops include alfalfa hay, alfalfa seed, and grain with minor amounts of corn and pasture. About 65,000 acres (26,000 hm^2) of cropland are under irrigation in the study area, excluding Tintic Valley (U.S. Department of Agriculture, 1969, p. 26 and 28). Tintic Valley was estimated to have fewer than 1,000 acres (400 hm^2) of irrigated farmland.

Surface Water

The Sevier River is the major stream in the area. The river enters the study area through Leamington Canyon, travels southwest across the southern part of the area, and discharges into Sevier Lake playa during infrequent periods of very high flow. During normal runoff years, the water entering the study area in the Sevier River is completely diverted for irrigation and does not reach Sevier Lake playa. The average inflow to the study area in the Sevier River is 162,980 acre-feet (201 hm^3) per year (U.S. Department of Agriculture, 1969, p. 63).

Several perennial, intermittent, and ephemeral streams originate in the study area. Perennial streams include Oak and Cherry Creeks, and Pole Creek (perennial in some reaches); major intermittent streams include Road, Birch, Hop, and Fool Creeks; and major ephemeral streams are Tanner Creek and Swasey Wash.

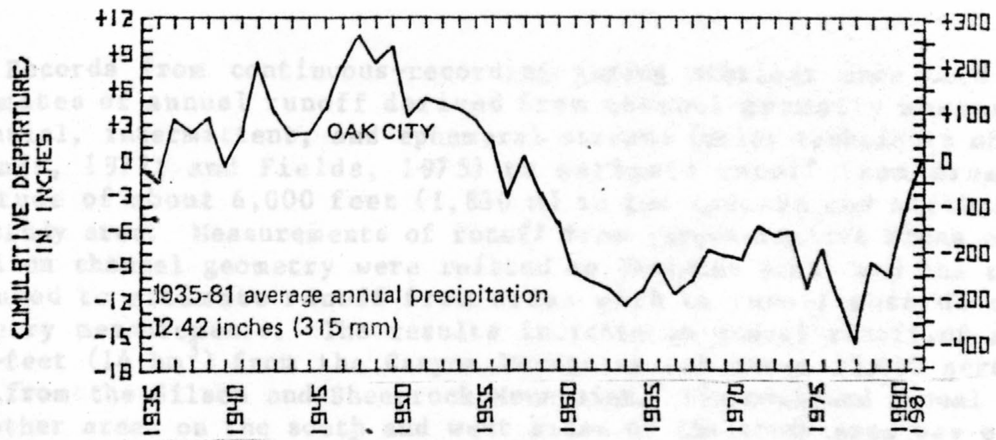

Figure 3.—Cumulative departure from average annual precipitation at Oak City, 1935-81.

Records from continuous-recording gaging stations were used along with estimates of annual runoff derived from channel-geometry measurements for perennial, intermittent, and ephemeral streams (using techniques of Hedman and Kastner, 1977; and Fields, 1975) to estimate runoff from areas above an altitude of about 6,000 feet (1,830 m) in the eastern and northern parts of the study area. Measurements of runoff from representative areas or estimates based on channel geometry were related to drainage area, and the relationship was used to estimate runoff from areas with no runoff records or channel-geometry measurements. The results indicate an annual runoff of about 11,000 acre-feet (14 hm^3) from the Canyon Mountains and about 15,600 acre-feet (19.2 hm^3) from the Gilson and Sheeprock Mountains. The combined annual runoff from all other areas on the south and west sides of the study area was estimated to be 8,000 acre-feet (9.9 hm^3) per year.

GROUND-WATER HYDROLOGY

Ground water in the Sevier Desert is present in both consolidated rocks and unconsolidated basin fill. The principal ground-water reservoir in the Sevier Desert is the unconsolidated basin fill, but consolidated rocks in the mountains and in some local areas on the basin floor are important sources of water.

Consolidated Rocks

Consolidated rocks yield water to springs in the mountains and to a few wells along the margins of the basin. The largest known yield from consolidated rocks is at Clear Lake Springs, (C-20-7)3d-S, where the average annual discharge during 1960-64 was 14,900 acre-feet (18.4 hm^3). The springs discharge from basalt of the Pavant Flow of late Pliocene or early Pleistocene age (Mower, 1967, p. E9). Other large springs discharging from consolidated rocks are Baker Hot Springs, (C-14-8)10dca-S1, with a discharge of about 2,000 acre-feet (2.5 hm^3) per year from volcanic rocks; and Indian Springs, (C-12-5)16aca-S1, which discharges about 800 acre-feet (1.0 hm^3) per year from the Salt Lake(?) Formation of Pliocene(?) age (Enright and Holmes, 1982, table 2).

Wells completed in consolidated rocks have variable yields. Conglomerates of Tertiary age yield water to wells near Oak City, and the Salt Lake(?) Formation of Pliocene(?) age yields water to a well in Tintic Valley (Mower and Feltis, 1968, table 2). A deep oil-test hole in sec. 23, T. 15 S., R. 7 W. flowed 800 to 1,200 gallons per minute (50 to 76 L/s) of water from Tertiary sediments and volcanics at a depth of about 10,000 feet (3,000 m) (Hamer and Pitzer, 1978, fig. 6). Wells south of the study area near Flowell in Pavant Valley (27 mi or 43 km south of Delta) obtain large yields from fractured basalt aquifers (Mower, 1965, table 8 and p. 40), and might yield substantial amounts of water to wells in the Sevier Desert, although more test drilling will be necessary to verify this possibility. In general, consolidated rocks consisting of conglomerate of Tertiary age yield water to wells on the basin floor, and Pre-Cenozoic sedimentary and metamorphic rocks yield water to springs in the mountains.

Unconsolidated Basin Fill

The principal aquifers of the Sevier Desert are within the unconsolidated basin fill, although in the extreme southeastern part of the area, basalt may yield large quantities of water to wells as it does in the adjacent Pavant Valley (Mower, 1965, table 8). The unconsolidated basin fill, as identified in drillers' logs of wells (C-15-5)33dcb-1 and (C-16-5)9aaa-1 (Enright and Holmes, 1982, tables 1 and 5), is at least 1,300 feet (396 m) thick and may be as thick as 2,140 feet (652 m) (Mower and Feltis, 1968, p. 15).

The basin fill generally consists of alluvial-fan and aeolian deposits along the edges of the basin and fluvial deposits of the Sevier River interbedded with lacustrine deposits of Lake Bonneville and probably older lakes in the center of the basin. The fluvial deposits become finer grained from the eastern side of the basin toward the west and southwest, until southwest of Delta, the fluvial deposits cannot be distinguished from the fine-grained lacustrine deposits. In general, the fluvial deposits consist of sand and gravel, and the lacustrine deposits consist of clay, silt, sand, and gravel.

Mower and Feltis (1968, p. 23) divided the ground-water reservoir in most of the Sevier Desert into upper and lower artesian aquifers, a lower-permeability zone (or confining bed) between them, and a water-table aquifer, except along the western, eastern, and northeastern margins of the basin fill where there is only a single aquifer under water-table conditions. In this report, the upper and lower artesian aquifers are termed the shallow and deep artesian aquifers, following the usage of Mower (1961 and 1963) and Holmes and Wilberg (1982), and the basalt aquifer in the extreme southeastern part of the study area is included in the water-table aquifer. A generalized geologic section near Lynndyl, Utah (fig. 4) shows lithology and divisions of the ground-water reservoir; and an idealized cross section east-west across the Sevier Desert (fig. 5) shows the various elements of the ground-water system.

At most locations, there are no clearcut boundaries between the aquifers and confining beds. The estimated thickness of the water-table aquifer in the center of the basin is 50 feet (15.2 m); but the water-table aquifer near the mountain fronts, where it includes beds that are laterally equivalent to those of the artesian aquifers, may be several hundred feet thick. The water-table aquifer in the center of the basin consists of predominantly fine-grained sediments.

The shallow and deep artesian aquifers are easily identified near Lynndyl, but as the unconsolidated deposits become coarser grained toward the Canyon Mountains on the east, or become finer grained toward the center of the basin near Delta, the separation of the aquifers becomes difficult (fig. 4, and Mower and Feltis, 1968, pl. 3). The thickness of the confining layer between the shallow and deep artesian aquifers ranges from about 400 to 500 feet (120-150 m) near Lynndyl to about 100 to 175 feet (30-53 m) near Sugarville (Mower and Feltis, 1968, p. 30). The layer consists of beds of clay and silt with some sand and gravel. West of Sugarville, the sediments of the confining bed may become more coarse grained, and the aquifers and

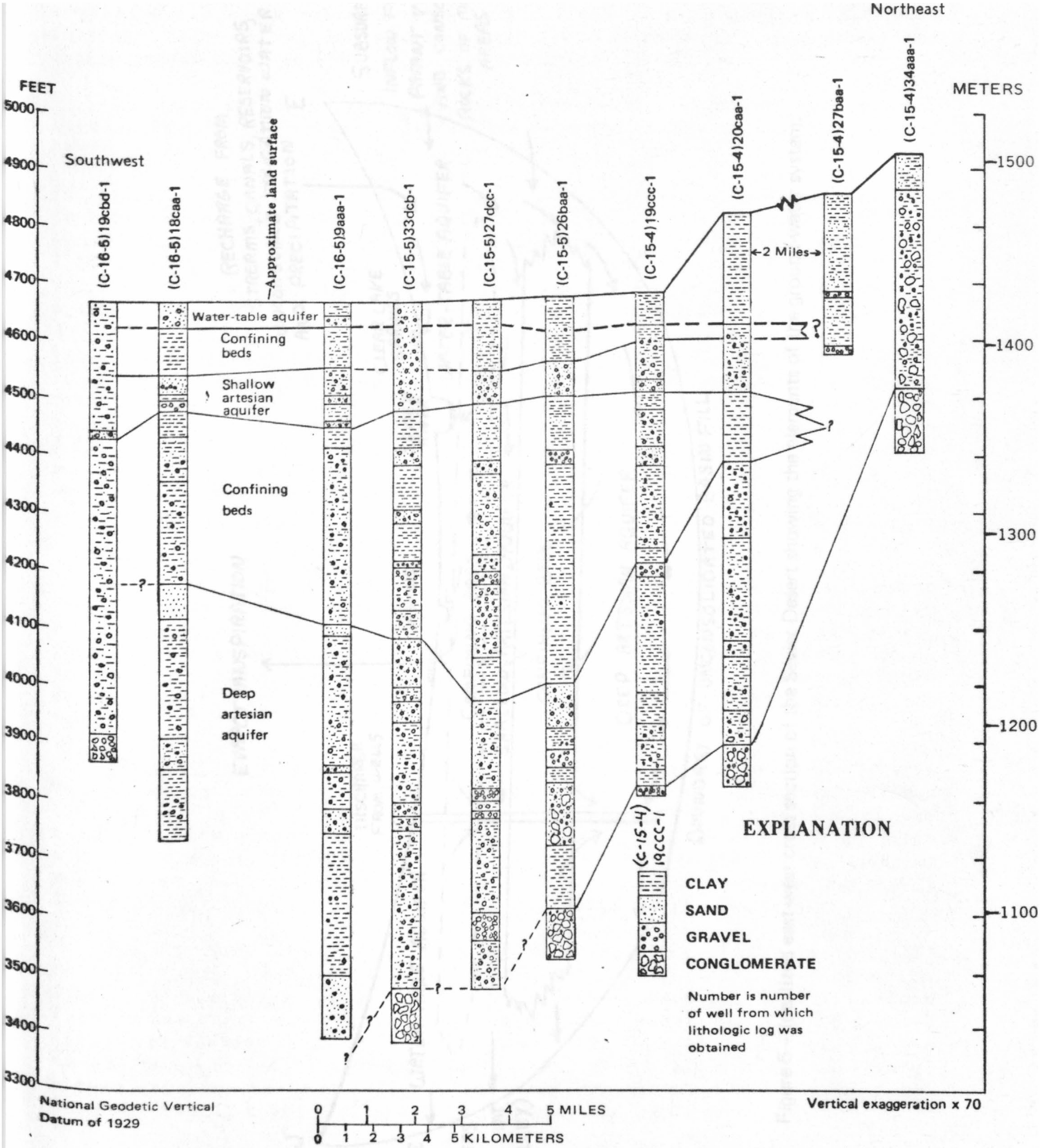

Figure 4.—Generalized geologic section near Lynndyl, Utah, showing lithology and divisions of the ground-water reservoir (modified from Holmes and Wilberg, 1982).

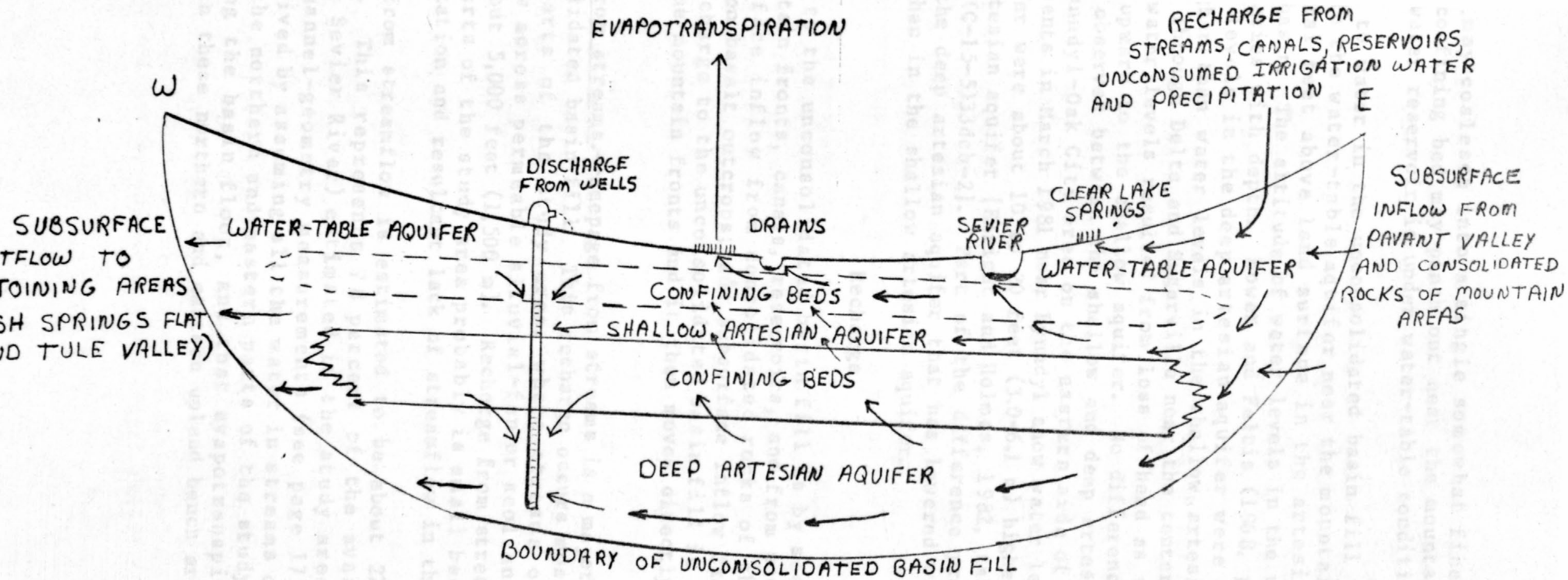

Figure 5.—Idealized east-west cross section of the Sevier Desert showing the elements of the ground-water system.

confining bed may coalesce into a single somewhat fine-grained, artesian aquifer. The confining bed may pinch out near the mountain fronts where the entire ground-water reservoir is under water-table conditions.

The depth to water in the unconsolidated basin fill ranges from several hundred feet in the water-table aquifer near the mountains surrounding the basin to several feet above land surface in the artesian aquifers in the center of the basin. The altitude of water levels in the unconsolidated basin fill locally varies with depth. Mower and Feltis (1968, p. 30) reported that in 1964 water levels in the deep artesian aquifer were about 20 to 30 feet (6.1-9.1 m) higher than water levels in the shallow artesian aquifer along a line extending through Delta and Sugarville near the center of the basin. The difference in water levels resulted from loss of head as water from the deep aquifer moved upward to the shallow aquifer. No differences in water levels, however, were observed between the shallow and deep artesian aquifers in the Leamington-Lynndyl-Oak City area on the eastern side of the basin. Water-level measurements in March 1981 near Lynndyl show water levels in the shallow artesian aquifer were about 10 to 20 feet (3.0-6.1 m) higher than water levels in the deep artesian aquifer [Enright and Holmes, 1982, table 1, wells (C-15-5)33dcb-1 and (C-15-5)33dcb-2]. Part of the difference probably is caused by pumping from the deep artesian aquifer that has lowered water levels in that aquifer more than in the shallow artesian aquifer.

Recharge

Recharge to the unconsolidated basin fill is by seepage from streams along the mountain fronts, canals, reservoirs, and from unconsumed irrigation water; subsurface inflow from consolidated rocks of the mountain areas; precipitation on basalt outcrops; and subsurface inflow from adjoining areas. Most of the recharge to the unconsolidated basin fill is to the water-table aquifer near the mountain fronts and it then moves directly into the artesian aquifers.

Seepage from streams.--Seepage from streams is a major source of recharge to the unconsolidated basin fill. This recharge occurs mostly in the northern and eastern parts of the study area, where streams originating in the mountains flow across permeable alluvial-fan or aeolian deposits above an altitude of about 5,000 feet (1,500 m). Recharge from streams in the southern and western parts of the study area probably is small because of the small annual precipitation and resultant lack of streamflow in these areas.

Recharge from streamflow is estimated to be about 27,000 acre-feet (33 hm^3) per year. This represents 78 percent of the available streamflow (excluding the Sevier River) estimated in the study area from streamflow records and channel-geometry measurements (see page 17). The 78 percent figure was derived by assuming all the water in streams originating in the mountains in the northern and eastern parts of the study area infiltrates before reaching the basin floor, and that evapotranspiration losses are insignificant in these northern and eastern upland bench areas.

Mower and Feltis (1968, p. 25-26) reported that the Sevier River is a major source of recharge to the Sevier Desert. More detailed recent studies by Herbert and others (1982, p. 4-5) show that the Sevier River in 1980 had a net gain of about 9 cubic feet per second (0.25 m^3/s) in a section of the river near Leamington, although the upper part of the reach studied in Leamington Canyon did have a loss of 4 cubic feet per second (0.11 m^3/s). During periods of large ground-water withdrawals and resulting water-level declines, some water from the Sevier River probably infiltrates the upper part of the ground-water reservoir.

Seepage from canals.--Recharge from canal seepage was estimated using the results of seepage and infiltration studies. The U.S. Bureau of Reclamation (Palmer B. DeLong, written commun., December 8, 1970, and February 24, 1971) conducted a seepage and infiltration study on the Central Utah Canal between a point 100 feet (30 m) downstream from the feeder canal turnout for Fool Creek Reservoir No. 1 to a point 200 feet (61 m) south of State Highway 26. Only 18.5 miles (29.8 km) of the 28.4 miles (45.7 km) of the canal that are within the study area (pl. 1) were included in Delong's study. The U.S. Geological Survey (Herbert and others, 1982) conducted seepage studies in 1980 on the Leamington and McIntyre Canals, and on a section of the Central Utah Canal. The section of the Central Utah Canal was not previously studied by the Bureau of Reclamation and includes that part of the canal between the diversion on the Sevier River and the feeder canal turnout for Fool Creek Reservoir No. 1.

Results of the seepage and infiltration studies indicate an average annual loss of about 12,000 acre-feet (14.8 hm^3) from the Central Utah and McIntyre Canals. This figure consists of about 10,500 acre-feet (12.9 hm^3) per year determined from the data of Palmer B. Delong (U.S. Bureau of Reclamation, written commun., December 8, 1980, and February 24, 1971) and about 1,500 acre-feet (1.8 hm^3) per year based on the study of Herbert and others, 1982 [5 percent of annual diversion of 30,000 acre-feet (37 hm^3)]. The largest losses occur near Oak City where infiltration rates of about 47 feet (14.3 m) per day when the canal was empty and 7 feet (2.1 m) per day when the canal was full were measured by the U.S. Bureau of Reclamation using a pipe driven about 8 to 12 inches (203-305 mm) into the sand and gravel underlying the Central Utah Canal. The infiltration rate measured at this site was more than 10 times greater than rates measured at four other sites along the canal.

Seepage from canals in the irrigated areas around Delta probably is small. Fine-grained deposits at or near the land surface and an extensive program of canal lining that began in the 1960's probably limit recharge from canal seepage in this area to a small amount. The small amount of recharge that does occur probably moves to drains in the immediate vicinity of the canals.

Some recharge by seepage from canals that collect the discharge from drains may occur northwest of Delta, where the water levels in the upper part of the unconsolidated basin fill may be lower than the bottom of the canals. Canal discharge in this area was measured and estimated on July 30, 1981, to be about 6 cubic feet per second (0.17 m^3/s) (Roger Walker, Sevier River Water

Commissioner, written commun., August 2, 1981). For the purpose of this report, it was estimated that 15 percent or about 700 acre-feet (0.86 hm^3) per year of the flow in the canals recharges the unconsolidated basin fill northwest of Delta.

Seepage from reservoirs.--Reservoir seepage recharges the unconsolidated basin fill at Fool Creek Reservoirs Nos. 1 and 2, about 4 miles (6.4 km) south of Lynndyl (pl. 1). Seepage from the two reservoirs was estimated by the U.S. Department of Agriculture (1969, p. 63) to be about 2,800 acre-feet (3.5 hm^3) per year. Delta and Gunnison Bend Reservoirs along the Sevier River in the study area are underlain by fine-grained sediment and any seepage from them probably returns to the river within a short distance and does not contribute significant amounts of recharge.

Seepage from unconsumed irrigation water.--Most of the seepage from unconsumed irrigation water occurs along the mountain front between Leamington and Oak City, where infiltration rates in the sand and gravel deposits probably are large. Mower and Feltis (1968, p. 27-28) estimated seepage losses in this area to be greater than 25 percent of the water diverted for irrigation. Assuming a 30-percent seepage loss, and an estimated average annual application of about 12,000 acre-feet (14.8 hm^3) of water from the Central Utah Canal (Roger Walker, verbal commun., Jan. 19, 1982), 5,500 acre-feet (6.8 hm^3) from Oak Creek (estimated from U.S. Geological Survey gaging-station records), 9,600 acre-feet (11.8 hm^3) from the McIntyre and Leamington Canals (estimated from data from the seepage studies by Herbert and others, 1982), and 2,400 acre-feet (3.0 hm^3) from ground-water withdrawals, the estimated recharge from unconsumed irrigation water is about 9,000 acre-feet (11 hm^3) per year.

In the irrigated farmland around Delta, where fine-grained deposits are at or near the surface, the seepage losses from unconsumed irrigation water probably are small. The unconsumed irrigation water that does infiltrate to the water table probably moves short distances and discharges to a complex system of drains, and some of this water is rediverted for irrigation on lower lying lands. Most of the drain water, however, eventually ponds in large unvegetated areas and evaporates.

If water levels were to decline by an estimated 10 feet (3.0 m) in the irrigated areas near Delta, an estimated 10,000 acre-feet (12.3 hm^3) per year of water might not be discharged by drains and would add to the total recharge.

Subsurface inflow from consolidated rocks along the mountain fronts.--Mower and Feltis (1968, p. 28) suggested that subsurface inflow to the unconsolidated basin fill in the Sevier Desert from consolidated rocks in the mountains may be an important source of recharge. Data collected during this study were insufficient to calculate the amount of recharge from this source.

Precipitation on basalt outcrops.--Recharge by precipitation on the aquifer outcrop probably is limited mainly to areas where highly fractured basalt is covered by thin deposits of soil or sand. Mower (1967, p. E27) estimated that about 1 inch (25.4 mm) of precipitation on the basalt flow near Pavant Butte recharges the aquifer. Using this estimate, recharge from precipitation on about 80,000 acres (32,000 hm^2) of basalt in the study area (Mower and Feltis, 1968, pl. 2) is about 7,000 acre-feet (8.6 hm^3) per year. This assumes that all the basalt is permeable and water in it is in hydraulic connection with the rest of the ground-water system.

Recharge from precipitation in the remainder of the Sevier Desert is small. Mower and Feltis (1968, p. 24-25) estimated that from 1949-64 recharge from precipitation totaled 17,000 acre-feet (21 hm^3) or 1,100 acre-feet (1.4 hm^3) per year and occurred only in the winter and spring of 1951-52 and 1961-62 when the December 1 to March 31 precipitation exceeded 6 inches (152 mm). During years of normal precipitation, recharge from precipitation, with the exception of that on basalt outcrops, is small.

Subsurface inflow from adjoining areas.--Subsurface inflow from adjoining areas is an important source of recharge along the southern and southeastern borders of the Sevier Desert. Mower (1965, p. 54) estimated the total subsurface flow from Pavant Valley to the Sevier Desert in 1959 to be 14,000 acre-feet (17.3 hm^3). Later studies by Mower (1967, p. E27) indicate the earlier estimate of subsurface outflow from the four southern ground-water districts of Pavant Valley was low by about 30 percent. Assuming the two northern ground-water districts were underestimated by the same percentage, the total flow from Pavant Valley to the Sevier Desert during 1959 would be about 18,000 acre-feet (22.2 hm^3). Mower and Feltis (1968, p. 28) estimated subsurface flow from the Beaver River valley (including inflow from the Milford area) to be 1,000 acre-feet (1.2 hm^3) per year.

Movement

Ground water in the unconsolidated basin fill in the Sevier Desert generally moves from recharge areas near the mountains on the northeast and east toward discharge areas in the western part of the study area. Near the mouth of Leamington Canyon, ground water moves toward and discharges to the Sevier River, and in the southeastern part of the study area, ground water generally moves west or northwest from Pavant Valley toward Clear Lake Springs (Mower, 1967, p. E15). Plate 1 shows the potentiometric surface of the shallow artesian aquifer in March 1981, and the altitude of the potentiometric surface in the deep artesian aquifer at wells where water levels could be measured. Small anomalies in the potentiometric surface near Delta are caused by withdrawals of water for irrigation or municipal use. Data were not available to construct a map showing the altitude of the potentiometric surface in the water-table aquifer.

Discharge

Discharge from the unconsolidated basin fill in the Sevier Desert is from Clear Lake Springs, seepage to the Sevier River, evapotranspiration, subsurface flow to adjoining areas, and wells.

Clear Lake Springs.--Most of the ground water entering the Sevier Desert from Pavant Valley discharges at Clear Lake Springs (Mower, 1967, p. E15). Mower (1967, p. E9) reported an average discharge at Clear Lake Springs of 14,900 acre-feet (18.4 hm^3) per year during 1960-64. Measurements of discharge during 1969-81 by the Utah Division of Wildlife Resources (Carl Lind, written commun., Aug. 19, 1982) show a variation in annual discharge from a maximum of about 19,000 acre-feet (23 hm^3) in 1974 to a minimum of about 13,000 acre-feet (16 hm^3) in 1978, and an average of about 16,000 acre-feet (20 hm^3) per year.

Seepage to the Sevier River.--Known discharge from the unconsolidated basin fill to the Sevier River occurs primarily near and up to about 5 miles (8 km) below the mouth of Leamington Canyon where water levels in the unconsolidated basin fill locally are higher than the altitude of the Sevier River. Seepage studies during 1980 showed a net gain of about 9 cubic feet per second (6,500 acre-ft/yr or 0.25 m^3s) (Herbert and others, 1982, p. 4-5). In the reach of the river from about 5 to about 9 miles (8 to about 14 km) below the mouth of Leamington Canyon no gains to or losses from the river were observed (Herbert and others, 1982, p. 5). The seepage studies in 1980 were conducted at the end of the irrigation season when discharge to the river derived from seepage from canals, reservoirs, and unconsumed irrigation water would be greater than at other times of the year. Therefore the 6,500 acre-foot per year (80 hm^3) figure may be more than the actual average seepage to the river in this area.

Downstream from the reach of the river studied by Herbert and others (1982), little is known about seepage to the Sevier River. Southwest of Delta the river flows through an area of ground-water discharge by evapotranspiration where the water table is at shallow depths. In this area the river may also receive seepage locally from the ground-water reservoir.

Evapotranspiration.--Discharge by evapotranspiration was estimated by Mower and Feltis (1968, p. 52) to be between 135,000 and 175,000 acre-feet (166 and 216 hm^3) per year. The estimate by Mower and Feltis includes 3,000 to 8,000 acre-feet (3.7 to 9.9 hm^3) per year of evapotranspiration in the Old River Bed, which is not part of the area of this report. The average evapotranspiration rate derived from the data of Mower and Feltis (1968, table 7) was between 0.30 and 0.39 foot (0.09 and 0.12 m) per year.

Recent studies by Van Hylckama (1974, figs. 34-35) in Arizona indicate that both depth to water and soil-water salinity have substantial effects on evapotranspiration rates of saltcedar, and these effects presumably apply to evapotranspiration rates of other phreatophytes. Mower and Feltis (1968, p. 52-59) did not specifically base their estimates of evapotranspiration rates on depth to water and did not include the effect of water quality in their methods of estimation. Data collected from test holes in the Sevier Desert indicate that water levels in and near some of the phreatophyte areas mapped by Mower and Feltis in the northern and western parts of the study area (1968, pl. 7) exceed 50 feet (15.2 m) [Enright and Holmes, 1982, table 1, wells (C-13-6)20acb-1 and (C-13-6)26bac-1] and that shallow ground water has a specific conductance exceeding 20,000 micromhos per centimeter (or a dissolved-solids content of more that 10,000 mg/L) [Enright and Holmes, 1982, table 5, wells (C-15-7)32dcd-1 and (C-17-9)30aab-1]. Some phreatophytes in these areas may be transpiring soil moisture derived from precipitation that is perched or retained in sandy soils and may not be withdrawing much water from the ground-water system. In addition, evapotranspiration rates may be lower than estimated by Mower and Feltis because of the high salinity of the water.

Recent estimates of evapotranspiration based on streamflow losses in the southeastern Uinta Basin of eastern Utah (Holmes and Kimball, 1983, p. 41) yield a rate of 0.05 foot (0.015 m) per year from greasewood-covered alluvial valleys with vegetation densities (10 percent) and water quality similar to that of the Sevier Desert. Based on this rate, the amount of ground-water discharge by evapotranspiration from 408,000 acres (165,000 hm^2) of phreatophytes (Mower and Feltis, 1968, table 7) may be as small as 20,000 acre-feet (25 hm^3) per year.

<u>Subsurface outflow to adjoining areas</u>.--Discharge by subsurface outflow to adjoining areas probably occurs along the western boundary of the study area. An apparent ground-water gradient toward the west and northwest (pl. 1) indicates ground-water flow in that direction. Holmes (1983, table 1) estimated 8,800 acre-feet (10.9 hm^3) per year of subsurface outflow to adjoining areas west of the Sevier Desert.

The eventual discharge point for the outflow is unknown, but Bolke and Sumsion (1978, p. 13) estimated that about 31,000 acre-feet (38.2 hm^3) per year enters the Fish Springs Flat area, northwest of Sevier Desert, by inflow from adjoining basins; a study by Stephens (1977, p. 21) also indicated subsurface inflow to Tule Valley, west of the Sevier Desert. Both areas may receive subsurface inflow from the Sevier Desert. Gates and Kruer (1981, p. 31-38) summarized the hydrology of west-central Utah and discussed the considerable body of evidence that suggests flow in carbonate rocks between basins northwest and southwest of the Sevier Desert. They mentioned the possibility of subsurface flow from the Sevier Desert to basins to the west, but because they lacked water-level data and because they believed the Sevier Lake playa was the ultimate discharge point for ground water in the Sevier Desert, they concluded the flow was not large.

<u>Wells</u>.--The estimated withdrawal from wells in the study area in 1981 was 18,000 acre-feet (22.2 hm^3) (Enright and Holmes, 1982, table 7). Areas of major ground-water use include Leamington, Lynndyl, Oak City, Delta, and Sugarville. Most of the water withdrawn is for irrigation or municipal use, with smaller quantities for industry, domestic, and stock uses. The 1951-81 ground-water withdrawals in the Sevier Desert are shown in figure 6.

Ground-water withdrawals in a given year are related primarily to the availability of surface water. During water years 1980 and 1981, the supply of surface water from the Sevier River as measured at gaging station 10224000 (Sevier River near Lynndyl, Utah) was about 164,600 acre-feet (203 hm^3) per year, about 21 percent above the 44-year average of 135,000 acre-feet (167 (hm^3). This excess supply of surface water resulted in a reduced withdrawal of ground water in 1980-81--an average of 15,500 acre-feet (19.1 hm^3) per year

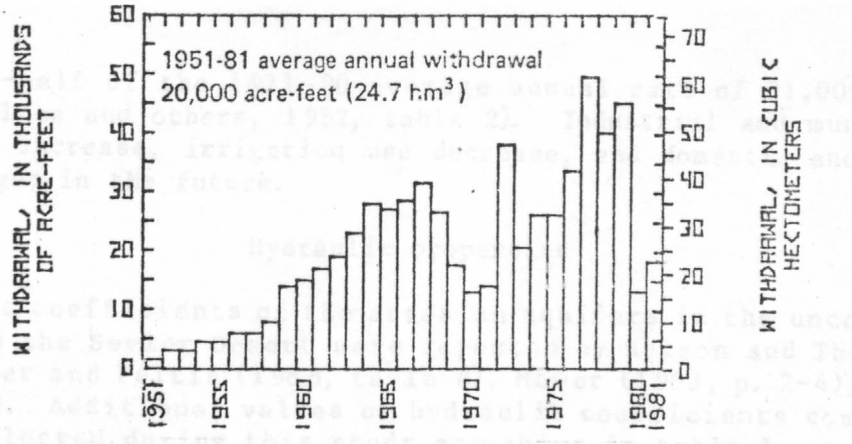

Figure 6.—Ground-water withdrawals from the Sevier Desert, 1951-81.

(fig. 6), one-half of the 1971-80 average annual rate of 31,000 acre-feet (38.2 hm^3) (Holmes and others, 1982, table 2). Industrial and municipal uses probably will increase, irrigation use decrease, and domestic and stock uses remain unchanged in the future.

Hydraulic properties

Hydraulic coefficients of the artesian aquifers in the unconsolidated basin fill in the Sevier Desert were reported by Nelson and Thomas (1953, table 3), Mower and Feltis (1968, table 8), Mower (1963, p. 2-4), and Mower (1961, p. C94). Additional values of hydraulic coefficients computed from test data collected during this study are shown in table 1, some of which differ from previously reported values computed from data collected during past tests at the same wells. The primary reason for these differences is the methods used in the analysis of the test data. During this study the Hantush modified method (Lohman, 1972, p. 32) and the ratio method (Neuman and Witherspoon, 1972) for determining hydraulic coefficients of leaky confined aquifers were used for aquifer tests when enough data were available. These methods generally give lower values of transmissivity and coefficient of storage than the Theis curve-matching procedure (Lohman, 1972, p. 34).

The transmissivity of the shallow artesian aquifer, as estimated from data of aquifer tests, ranges from a high of about 47,000 feet squared per day (4,400 m^2/d) [Mower and Feltis, 1968, table 8, well (C-15-5)2ddc-1] on the east side of the study area near Lynndyl, to a low of about 3,600 feet squared per day (340 m^2/d) in the central part of the area west of Sugarville [Nelson and Thomas, 1953, table 3, well (C-16-8)19ddd-1]. The transmissivity of the deep artesian aquifer ranges from about 27,000 feet squared per day (2,500 m^2/d) near Lynndyl to about 2,000 feet squared per day (190 m^2/d) south of Delta [Mower and Feltis, 1968, table 8, wells (C-16-5)18caa-1 and (C-17-6)28acb-1]. The decrease in transmissivity in both aquifers from east to west probably is related to the deposition of more permeable alluvial gravels and sands in the eastern and central part of the study area compared with the deposition of fine-grained alluvial and lacustrine deposits in its southwestern and western parts (Mower and Feltis, 1968, p. 15). There is no major change in thickness of the aquifers related to this change in transmissivity.

The hydraulic conductivity of the water-table aquifer is estimated to range from about 1,000 feet (460 m) per day in the basalt aquifer in the extreme southeastern part of the study area (Holmes, 1983, p. 8) to about 1 foot (0.3 m) per day in the central part of the basin. The estimates of hydraulic conductivity in the central part of the basin are based on descriptions of material in drillers' logs (Mower, 1978, p. 16, and Enright and Holmes, 1982, table 3). The hydraulic conductivity of the water-table aquifer generally is greater near the mountain fronts and decreases toward the center of the basin.

Holmes and Wilberg (1982, p. 11) determined the vertical hydraulic conductivity of the confining bed between the shallow and deep artesian aquifers near Lynndyl to be 6×10^{-3} foot per day (1.8×10^{-3} m/d). No tests

Table 1.--Hydraulic coefficients of artesian aquifers in the Sevier Desert

Pumped well	Observation well or wells	Aquifer or confining bed tested	Transmissivity (feet squared per day)	Storage coefficient	Vertical hydraulic conductivity of confining beds (feet per day)	Method of analysis or reference
(C-15-4)19ccc-1	(C-15-4)20caa-1 (C-15-5)15dad-1 26baa-1 27dcc-1 33dcb-1 (C-16-5)9aaa-1 18caa-1 19cbd-1	deep artesian aquifer	12,700	6.4×10^{-5}	--	Hantush modified method (Lohman, 1972, p. 32); Ratio method (Neuman and Witherspoon, 1972); Holmes and Wilberg (1982)
	(C-15-4)19ccc-1	do.	12,900	--	--	Straight-line method (Lohman, 1972, p. 23)
	(C-15-5)15dad-2 26baa-2 27dcc-2 33dcb-2	confining bed between deep and shallow artesian aquifer	--	--	6×10^{-3}	Ratio method (Neuman and Witherspoon, 1972); Holmes and Wilberg (1982)
(C-15-4)26dcc-1	(C-15-4)26dcc-1	unknown	23,300	--	--	Straight-line method (Lohman, 1972, p. 23)
	34aaa-1	unknown	24,900	1.2×10^{-3}	--	Hantush modified method (Lohman, 1972, p. 32)
(C-15-5)33dcb-1	(C-15-5)33dcb-1	deep artesian aquifer	11,000	--	--	Do.
(C-15-6)19bcc-1	(C-15-6)18bcc-1 19ccc-1 (C-15-7)13ddd-2	do.	[1]5,400	[1]2×10^{-3}	--	Modified Theis nonequilibrium method (Intermountain Power Project, 1981, p. 15)
(C-16-5)9aaa-1	(C-16-5)9aaa-1	do.	8,500	--	--	Straight-line method (Lohman, 1972, p. 23)
18caa-1	18caa-1	do.	7,200	--	--	Do.
19cbd-1	19cbd-1	do.	4,800	--	--	Do.
(C-17-6)29ccc-1	(C-17-6)29ccc-1	do.	3,900	--	--	Do.

[1]Average of results derived from all observation wells.

were made that yielded a value for the vertical hydraulic conductivity of the material overlying the shallow artesian aquifer.

The storage coefficient of the artesian aquifers estimated from aquifer tests ranges from about 2 x 10^{-2} (Nelson and Thomas, 1953, table 3) to about 6 x 10^{-5} (Holmes and Wilberg, 1982, table 2). The specific yield of the water-table aquifer is estimated to range from about 0.27 near the mountain fronts to about 0.02 in the center of the basin. These values are based on estimates of specific yield from other studies tabulated by Johnson (1967, table 29) and descriptions of material in drillers' logs (Enright and Holmes, 1982, table 3).

Storage

The amount of recoverable water in storage in the unconsolidated basin fill is estimated to be about 200 million acre-feet (250,000 hm^3). The estimate is based on an area of 2,000 square miles (5,180 km^2), an average saturated thickness of 1,000 feet (305 m), and an estimated average specific yield of 0.15. The estimate of saturated thickness is higher than the 775 feet (236 m) reported by Mower and Feltis (1968, p. 36). Drilling since 1963 has indicated that saturated deposits containing fresh water extend to a depth of about 1,300 feet (400 m) near Lynndyl (Holmes and Wilberg, 1982, tables 1 and 5). Thus, an average saturated thickness (including confining beds) of 1,000 feet (305 m) was assumed.

The estimate of water in storage was made assuming that water levels will be drawn down enough so that the artesian aquifers are dewatered, and that a specific yield typical of water-table conditions will govern the amount of water released from storage, rather than an artesian coefficient of storage. Most of this stored ground water is fresh, but some is of poor quality, especially that in the water-table aquifer in the central part of the study area.

WATER QUALITY

The chemical quality of samples of water collected from wells and springs in the Sevier Desert is reported in Enright and Holmes (1982, table 5). Dissolved solids in spring water ranged from 3,710 milligrams per liter at (C-14-8)10dca-S1 to less than 100 milligrams per liter at spring (C-16-3)8abd-S1. In general, the two springs discharging from basalt flows of late Pliocene or early Pleistocene age contained larger concentrations of dissolved solids than springs discharging from other consolidated rocks or unconsolidated basin fill. Data on specific conductance of water from springs (Enright and Holmes, 1982, table 2) indicate that water discharged from alluvium of Quaternary age generally had a lower dissolved-solids concentration than water from consolidated rocks.

Dissolved solids in water from wells ranged from about 200 milligrams per liter for well (C-16-5)19cbd-1 to about 49,000 milligrams per liter for well (C-20-12)1aac-1. The smallest concentrations were in water from wells perforated deeper than 500 feet (152 m) between Lynndyl and Delta. The largest concentrations were in water from wells perforated above 200 feet (61 m) in the southwestern part of the study area, where dissolved-solids concentrations can exceed 10,000 milligrams per liter. These large concentrations probably result from evapotranspiration which has concentrated salts in the water-table aquifer; or in the case of water from well (C-20-12)1aac-1, the large concentration of dissolved solids may reflect the movement of shallow ground water from Sevier Lake playa toward the northwest (pl. 1). The large concentrations of sodium (13,000 mg/L) and chloride (28,000 mg/L) in this sample, which are products of evaporation, seem to support this contention.

Extremely large concentrations of arsenic have been found in water from some wells in the Sevier Desert. The arsenic concentrations in water samples from the artesian aquifers are shown in figure 7. The largest observed concentrations are in the south-central part of the study area and may be related to the volcanic deposits in the Black Rock Desert.

Concentrations of nitrate plus nitrite (reported in mg/L as N) in water from some large-discharge irrigation wells in the Oak City-Fool Creek area range from about 4 to 22 milligrams per liter (Enright and Holmes, 1982, p. 51, 53). These large concentrations may be the result of downward leakage of unconsumed irrigation water contaminated with material dissolved from fertilizer, animal waste, or septic-tank effluent.

CHANGES IN GROUND-WATER CONDITIONS, 1963-81

Changes in ground-water conditions since 1963 include increased ground-water withdrawals, declines in water levels, and deterioration of water quality.

Ground-Water Withdrawals

Ground-water withdrawals during the 18-year period from 1964 to 1981 averaged about 27,500 acre-feet (33.9 hm^3) per year, almost three times the 13-year 1951 to 1963 average of about 9,600 acre-feet (11.8 hm^3) per year (fig. 6). Most of the increased withdrawals were from the deep artesian aquifer for irrigation.

Since 1963, annual withdrawals from wells have been as low as 13,000 to 18,000 acre-feet (16-22 hm^3) during years when surface water for irrigation was plentiful (such as 1970, 1971, and 1980); and as high as 40,000 to 49,500 acre-feet (49-61 hm^3) during years when surface water was in short supply (such as 1977, 1978, and 1979).

Water Levels

Water levels generally have declined in the area since 1963. Areas of significant water-level change in the shallow artesian aquifer during the 18-year period from March 1963 to March 1981 are shown in figure 8. Maximum declines of 10 to 13 feet (3-4 m) occurred over several square miles of the study area about 4 miles (6 km) west of Delta. Water-level changes in the parts of the study area not shown in figure 8 were less than 5 feet (1.5 m).

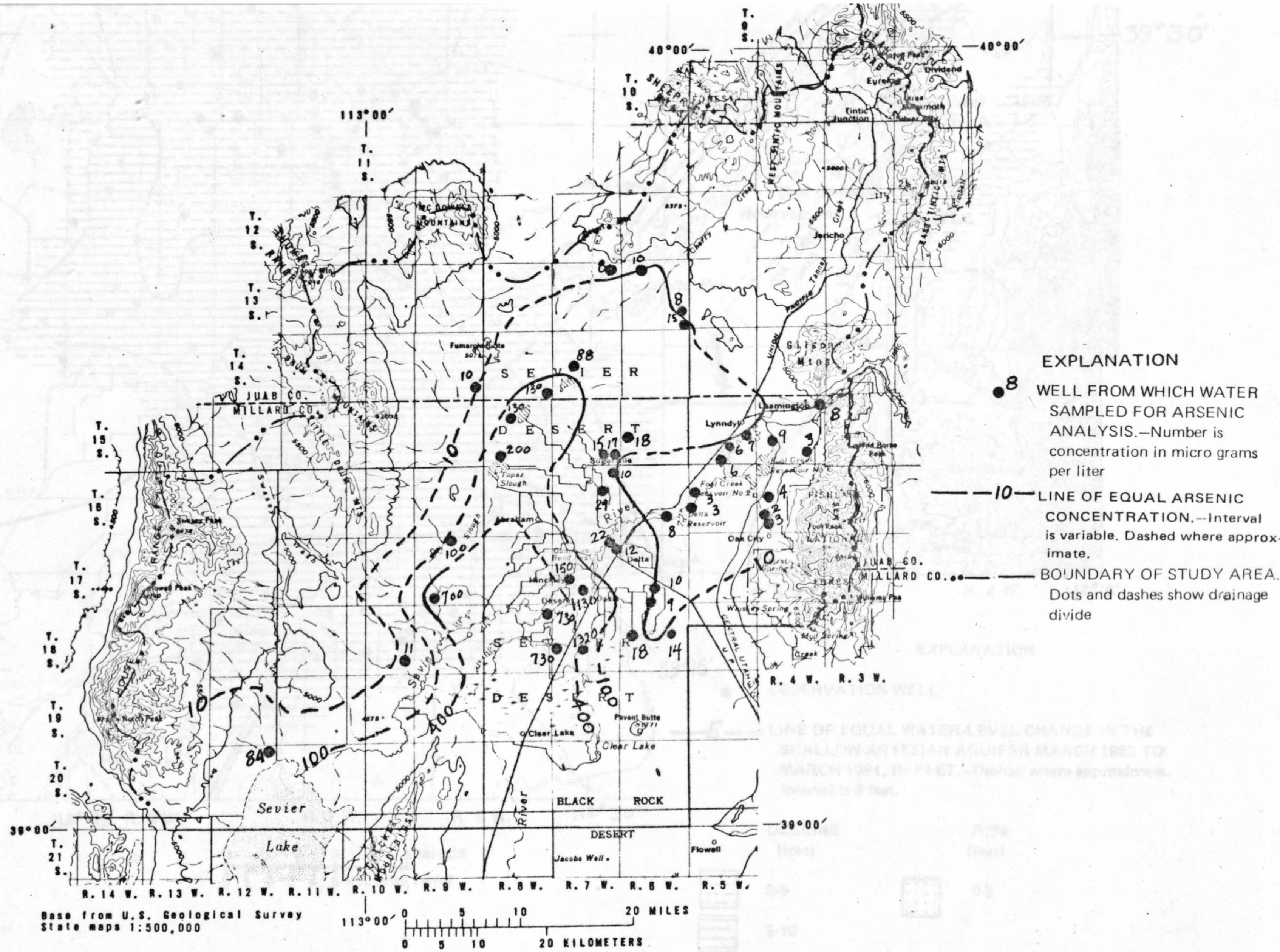

Figure 7.—Arsenic concentrations in water in the artesian aquifers, 1979-81.

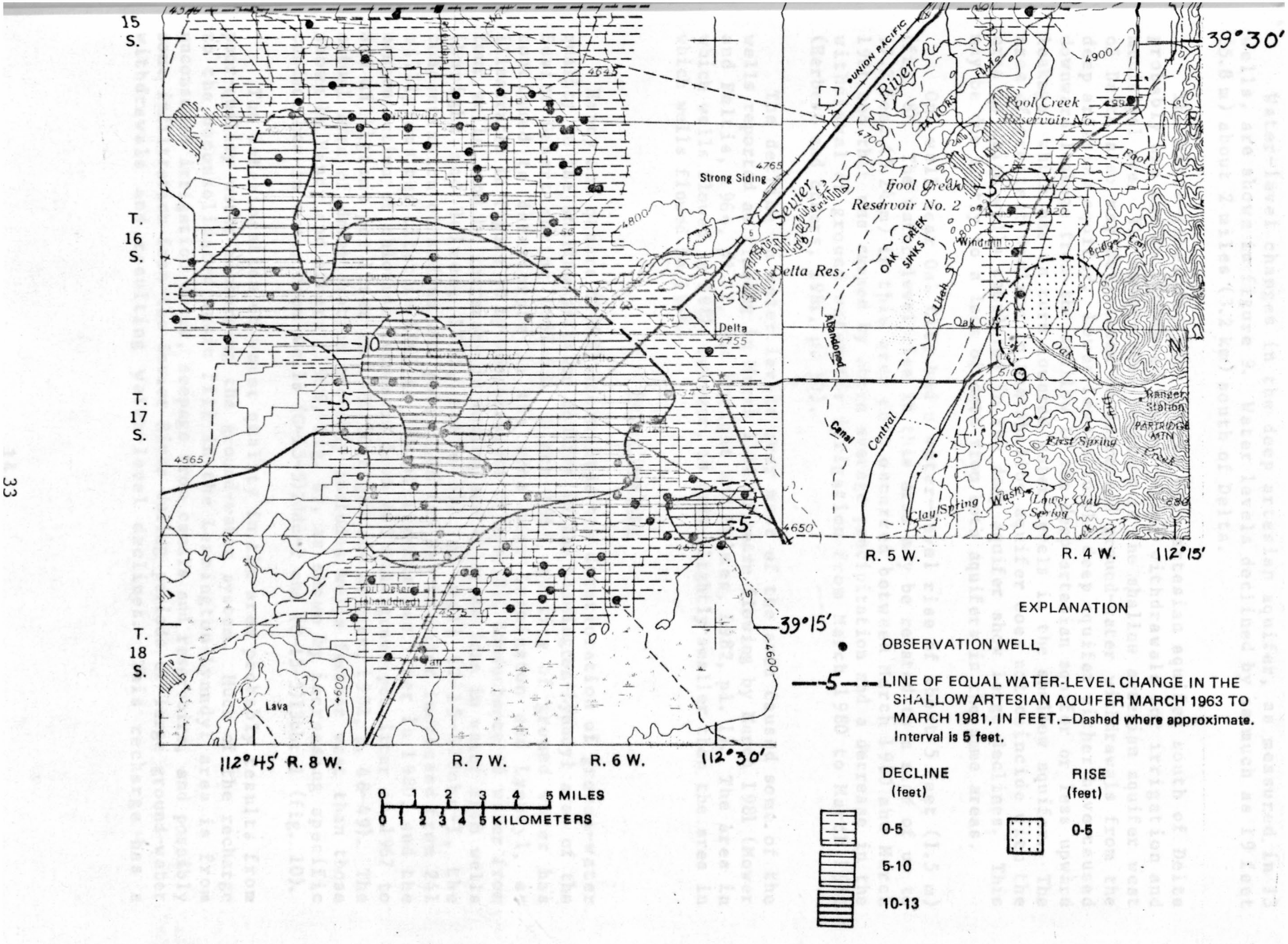

Figure 8.—Areas of significant water-level change in the shallow artesian aquifer, March 1963 to March 1981.

Water-level changes in the deep artesian aquifer, as measured in 13 wells, are shown in figure 9. Water levels declined by as much as 19 feet (5.8 m) about 2 miles (3.2 km) south of Delta.

The water-level declines in the deep artesian aquifer south of Delta probably are due to increased ground-water withdrawals for irrigation and municipal use. The water-level declines in the shallow artesian aquifer west of Delta also may be related to increased ground-water withdrawals from the deep artesian aquifer. Lower levels in the deep aquifer either have caused downward leakage from the shallow to the deep artesian aquifer or less upward leakage, which has in turn lowered water levels in the shallow aquifer. The area of greatest decline in the shallow aquifer does not coincide with the area in which wells completed in the deep aquifer show large declines. This may be due mostly to a lack of data from both aquifers in the same areas.

One well near Oak City had a water-level rise of about 5 feet (1.5 m) (fig. 8). The water-level rise in this area may be related to a rise of up to 17.2 feet (5.24 m) in this area that occurred between March 1980 and March 1981 and that was caused by above average precipitation and a decrease in the withdrawal of ground water for irrigation from March 1980 to March 1981 (Herbert and others, 1981, p. 10).

The decline in water levels over most of the area caused some of the wells reported as flowing in March 1964 to cease flowing by March 1981 (Mower and Feltis, 1964, pl. 1, and Enright and Holmes, 1982, pl. 1). The area in which wells flowed in 1981, however, is only slightly smaller than the area in which wells flowed in 1964.

Water Quality

Handy and others (1969) documented the deterioration of ground-water quality in the shallow artesian aquifer in the Leamington-Lynndyl area of the Sevier Desert during 1958-68. Since 1968, quality of ground water has continued to deteriorate in the area near Leamington and Lynndyl, as illustrated in figure 10 by measurements of specific conductance of water from four wells, and by increases in sodium and chloride ions in water from wells (Enright and Holmes, 1982, table 5). At well (C-15-4)8cba-1, the concentration of sodium and potassium (as Na) in water increased from 241 milligrams per liter in 1967 to 316 milligrams per liter in 1980, and the concentration of chloride increased from 665 milligrams per liter in 1967 to 690 milligrams per liter in 1980 (Enright and Holmes, 1982, p. 48-49). The actual area of deterioration probably includes wells farther west than those shown by Handy and others (1969, fig. 6), as shown by increasing specific conductance in water from wells (C-15-5)2ddc-1 and (C-15-5)13bbc-1 (fig. 10).

The deterioration of water quality in the area probably results from poor-quality water recharging the ground-water system. Much of the recharge to the unconsolidated basin fill in the Leamington-Lynndyl area is from unconsumed irrigation water, seepage from canals and reservoirs, and possibly some infiltration from the Sevier River during periods of large ground-water withdrawals and resulting water-level declines. This recharge has a

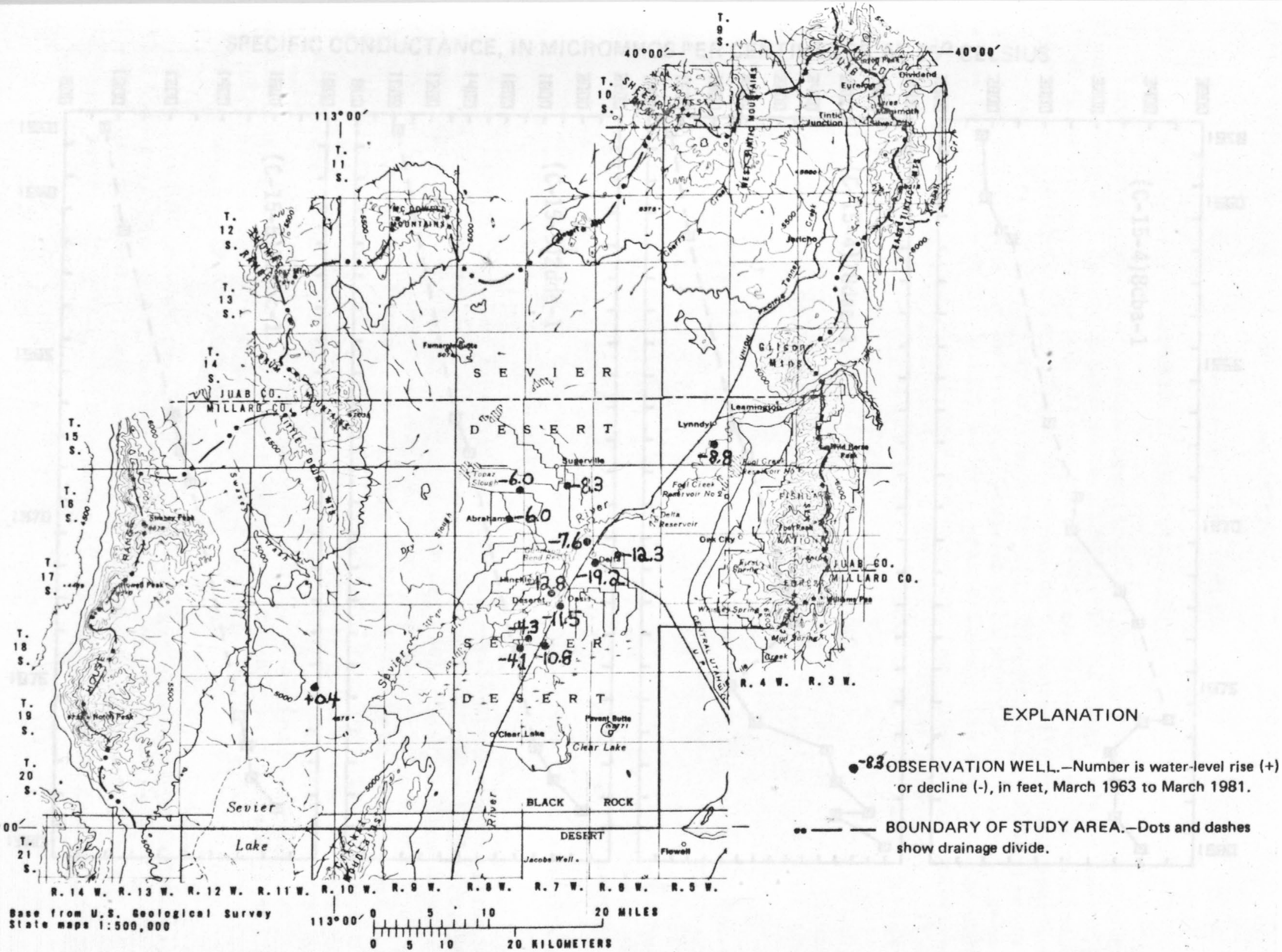

Figure 9.--Water-level changes in wells in the deep artesian aquifer, March 1963 to March 1981.

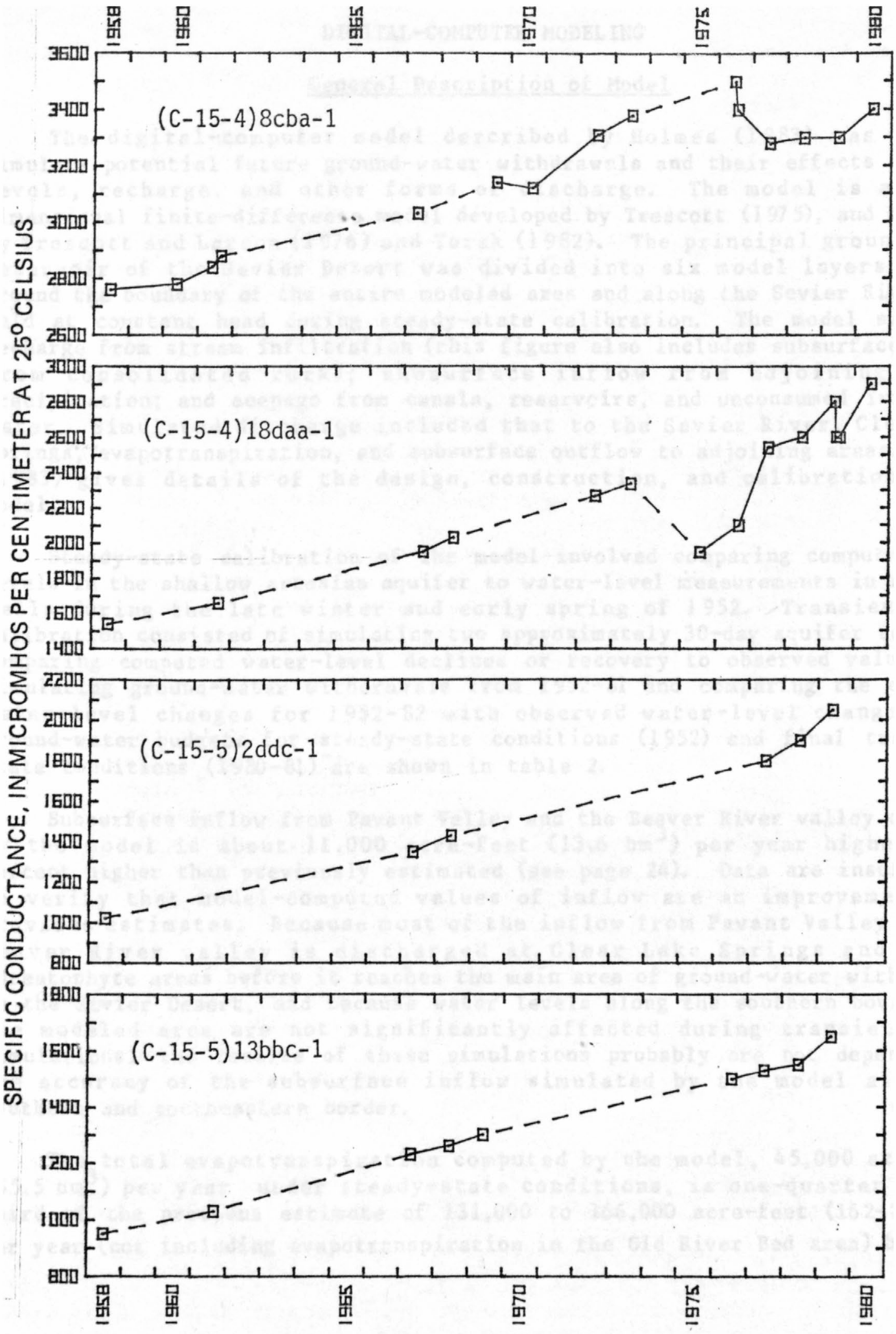

Figure 10.—Specific conductance of water from selected wells completed in the shallow artesian aquifer, 1958-80.

relatively large concentration of dissolved minerals (Handy and others, 1969, p. D-231). Deterioration of water quality probably will continue in the future under present hydrologic conditions.

DIGITAL-COMPUTER MODELING

General Description of Model

The digital-computer model described by Holmes (1983) was used to simulate potential future ground-water withdrawals and their effects on water levels, recharge, and other forms of discharge. The model is a three-dimensional finite-difference model developed by Trescott (1975), and modified by Trescott and Larson (1976) and Torak (1982). The principal ground-water reservoir of the Sevier Desert was divided into six model layers. Nodes around the boundary of the entire modeled area and along the Sevier River were held at constant head during steady-state calibration. The model simulated recharge from stream infiltration (this figure also includes subsurface inflow from consolidated rock); subsurface inflow from adjoining areas; precipitation; and seepage from canals, reservoirs, and unconsumed irrigation water. Simulated discharge included that to the Sevier River, Clear Lake Springs, evapotranspiration, and subsurface outflow to adjoining areas. Holmes (1983) gives details of the design, construction, and calibration of the model.

Steady-state calibration of the model involved comparing computed water levels in the shallow artesian aquifer to water-level measurements in selected wells during the late winter and early spring of 1952. Transient-state calibration consisted of simulating two approximately 30-day aquifer tests and comparing computed water-level declines or recovery to observed values; and simulating ground-water withdrawals from 1952-81 and comparing the computed water-level changes for 1952-82 with observed water-level changes. The ground-water budgets for steady-state conditions (1952) and final transient-state conditions (1980-81) are shown in table 2.

Subsurface inflow from Pavant Valley and the Beaver River valley computed by the model is about 11,000 acre-feet (13.6 hm^3) per year higher or 60 percent higher than previously estimated (see page 24). Data are insufficient to verify that model-computed values of inflow are an improvement over previous estimates. Because most of the inflow from Pavant Valley and the Beaver River valley is discharged at Clear Lake Springs and nearby phreatophyte areas before it reaches the main area of ground-water withdrawals in the Sevier Desert, and because water levels along the southern boundary of the modeled area are not significantly affected during transient-state simulations, the results of these simulations probably are not dependent on the accuracy of the subsurface inflow simulated by the model along its southern and southeastern border.

The total evapotranspiration computed by the model, 45,000 acre-feet (55.5 hm^3) per year under steady-state conditions, is one-quarter to one-third of the previous estimate of 131,000 to 166,000 acre-feet (162-205 hm^3) per year (not including evapotranspiration in the Old River Bed area) by Mower

Table 2.--Steady-state (1952) and transient-state (1980-81) ground-water budgets for the Sevier Desert, computed by the digital model, in acre-feet per year

Budget element	Steady state (1952)	Transient state (end of 1980-81 pumping period)
Recharge		
Stream infiltration along mountain fronts and subsurface inflow from consolidated rocks of the mountain areas		
Canyon Mountains	9,300	9,300
Sheeprock and Gilson Mountains	17,300	17,300
Subsurface inflow from adjoining areas		
Pavant Valley	26,800	26,800
Beaver River valley (including some from Milford area)	3,400	3,400
Sevier Lake area (including Cricket Mountains)	3,700	3,700
Precipitation on basalt outcrops	7,000	7,000
Seepage from canals, reservoirs, and unconsumed irrigation water		
Central Utah Canal	11,900	11,900
Canals west of Sugarville	700	700
Fool Creek Reservoirs	2,800	2,800
Unconsumed irrigation water on eastern boundary	8,600	8,600
Total (rounded)	92,000	(1) 92,000
Discharge		
Seepage to Sevier River	18,500	3,600
Clear Lake Springs	19,500	19,300
Evapotranspiration	45,000	42,300
Subsurface outflow to adjoining areas on western boundary	8,800	8,800
Wells	0	13,600
Total (rounded)	92,000	(1) 88,000

[1] The difference between recharge and discharge for the transient-state ground-water budget is because part of the recharge (about 4,000 acre-feet per year) is going into ground-water storage because the amount of water pumped from wells decreased between 1977-79 and 1980-81, resulting in rises in water levels.

and Feltis (1968, table 7). Recent studies indicate the previous average rates of evapotranspiration, 0.30 and 0.39 foot (0.09 and 0.12 m) per year, may be too large (see page 25). The model computes evapotranspiration in relation to depth to water, by assuming a rate of about 0.3 foot (0.09 m) per year when the water level is at the land surface (this figure was derived from the model calibration process) and a linear decrease in the evapotranspiration rate until it is zero at a depth to water of 30 feet (9.1 m). The average rate computed by the model is 0.12 foot (0.04 m) per year over the area covered by phreatophytes. It is likely that the total evapotranspiration computed by the model is closer to the true value than the estimate made by Mower and Feltis.

The digital model developed in this study has some limitations. The simplified boundary conditions do not automatically allow changes in inflow to or outflow from the modeled area due to changes in hydraulic gradients; and recharge is constant for all simulations regardless of actual variations in precipitation, streamflow, reservoir stage, and irrigation. In addition, head-dependent discharge from the water-table aquifer to drains in the irrigated areas around Delta was not incorporated into the model because of the lack of data on the water-table aquifer and because of the difficulty of simulating the network of closely-spaced drains using the model grid with its minimum node spacing of 1 mile (1.61 km). If water levels in the water-table aquifer were to decline by 10 feet (3.0 m), an estimated 10,000 acre-feet (12.3 hm^3) per year of water discharged to drains might remain in the water-table aquifer, but this potential "source" of water cannot be accounted for by the model as it is presently designed. Also, discharge by subsurface outflow to adjacent areas is assumed to occur only in the water-table aquifer. Despite these limitations, the model reproduced observed water-level changes between 1952 and 1982 reasonably well (Holmes, 1983, fig. 7), and should make satisfactory projections of the effects of future ground-water withdrawals on ground-water levels.

Projected Effects of Future Ground-Water Withdrawals

The digital-computer model was used to project the effects on water levels of future ground-water withdrawals over a 20-year simulation period with water levels computed by the model for 1981 as a starting point. The 1977-79 average withdrawal rate of 43,400 acre-feet (53.5 hm^3) per year and the 1977-79 well locations were used as a standard for all simulations. About 60 percent of the withdrawals during 1977-79 were from the deep artesian aquifer and about 40 percent were from the shallow artesian aquifer. The following ground-water withdrawal rates were simulated for 20-year periods: (1) ground-water withdrawals approximately equal to the standard (1977-79) average rate--43,400 acre-feet (53.5 hm^3) per year; (2) ground-water withdrawals at approximately one-half the standard--21,700 acre-feet (27 hm^3) per year; (3) ground-water withdrawals at approximately double the standard--86,800 acre-feet (197 hm^3) per year; and (4) ground-water withdrawals at the standard rate with changes in the locations of withdrawals associated with the Intermountain Power Project including reductions in withdrawals from wells for which water rights have been purchased by the Project.

In the first three simulations, water-level-change maps were prepared that represent the difference between the computed water levels at the end of each simulation and the 1981 water levels. In the fourth simulation, withdrawals simulated were equal to the 1977-79 average rate plus 5,400 acre-feet (6.7 hm^3) at the site of the Intermountain Power Project minus withdrawals from wells for which water rights have been purchased by the Project (Jerry Olds, Utah Division of Water Rights, written commun., Aug. 16, 1982). The water-level changes computed for the fourth simulation are only those caused by changes in the locations of withdrawals associated with the Intermountain Power Project, including reductions in withdrawals from wells for which water rights have been purchased by the Project.

Water-level-change maps were not prepared for the water-table aquifer. Water-level and other data for the water-table aquifer were insufficient to design and calibrate the model in terms of this aquifer, and projected levels for the water table may not be reliable. In general, changes in water levels in the water table near the mountain fronts were about the same as changes in water levels in the shallow artesian aquifer, and in the center of the basin changes in water levels in the water table were less than those in the shallow artesian aquifer.

Ground-Water Withdrawals Equal to the 1977-79 Average Rate

Ground-water withdrawals equal to the 1977-79 average rate over a period of 20 years (1981-2000) would cause water-level declines of more than 40 feet (12 m) in the deep artesian aquifer near Lynndyl (fig. 11), and water-level declines of more than 15 feet (4.6 m) in the shallow artesian aquifer near the Fool Creek Reservoirs (fig. 12). The 1977-79 average withdrawal of 43,400 acre-feet (54 hm^3) per year is the highest 3-year average on record (fig. 6), and therefore, this simulation represents the worst possible case based on previous history.

At the end of the 20-year period, the Sevier River will no longer be a line of net discharge, but instead will be recharging the ground-water reservoir at a net rate of about 8,900 acre-feet (11 hm^3) per year. Evapotranspiration also will decrease, due to declining water levels, to about 39,800 acre-feet (49 hm^3) per year.

Ground-Water Withdrawals One-Half the 1977-79 Average Rate

Ground-water withdrawals at one-half the 1977-79 average rate for 20 years (1981-2000) would cause water-level declines of more than 15 feet (4.6 m) near Lynndyl and rises of more than 5 feet (1.5 m) near Delta in the deep artesian aquifer (fig. 13). Near Lynndyl, therefore, water levels will continue to decline even if withdrawals were only one-half the 1977-79 average rate. Near Delta, however, a reduction in withdrawals would allow water levels in the deep artesian aquifer to recover. Ground-water withdrawal at

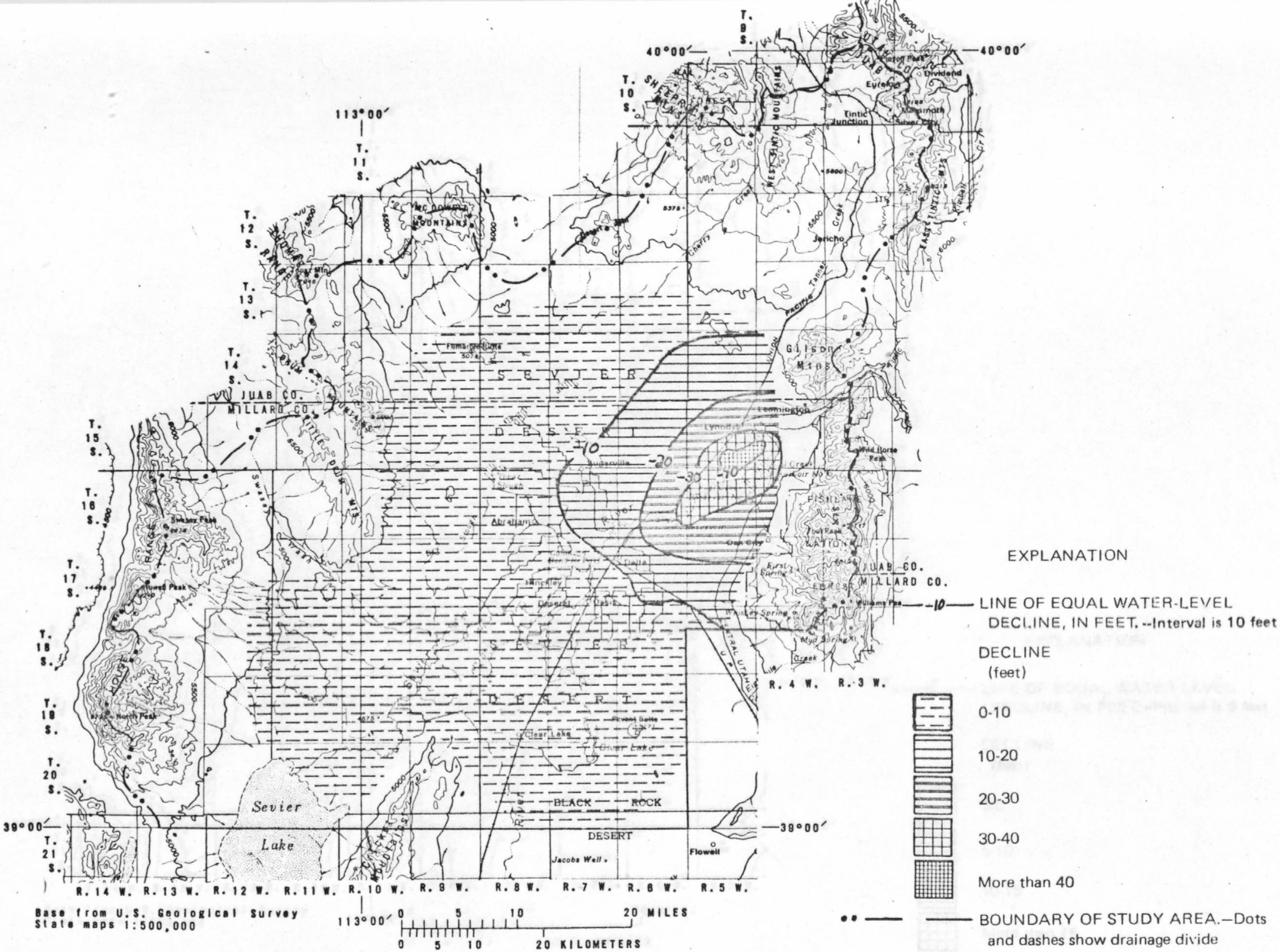

Figure 11.—Projected water-level declines in the deep artesian aquifer for the period 1981-2000, assuming ground-water withdrawals equal to the 1977-79 average rate.

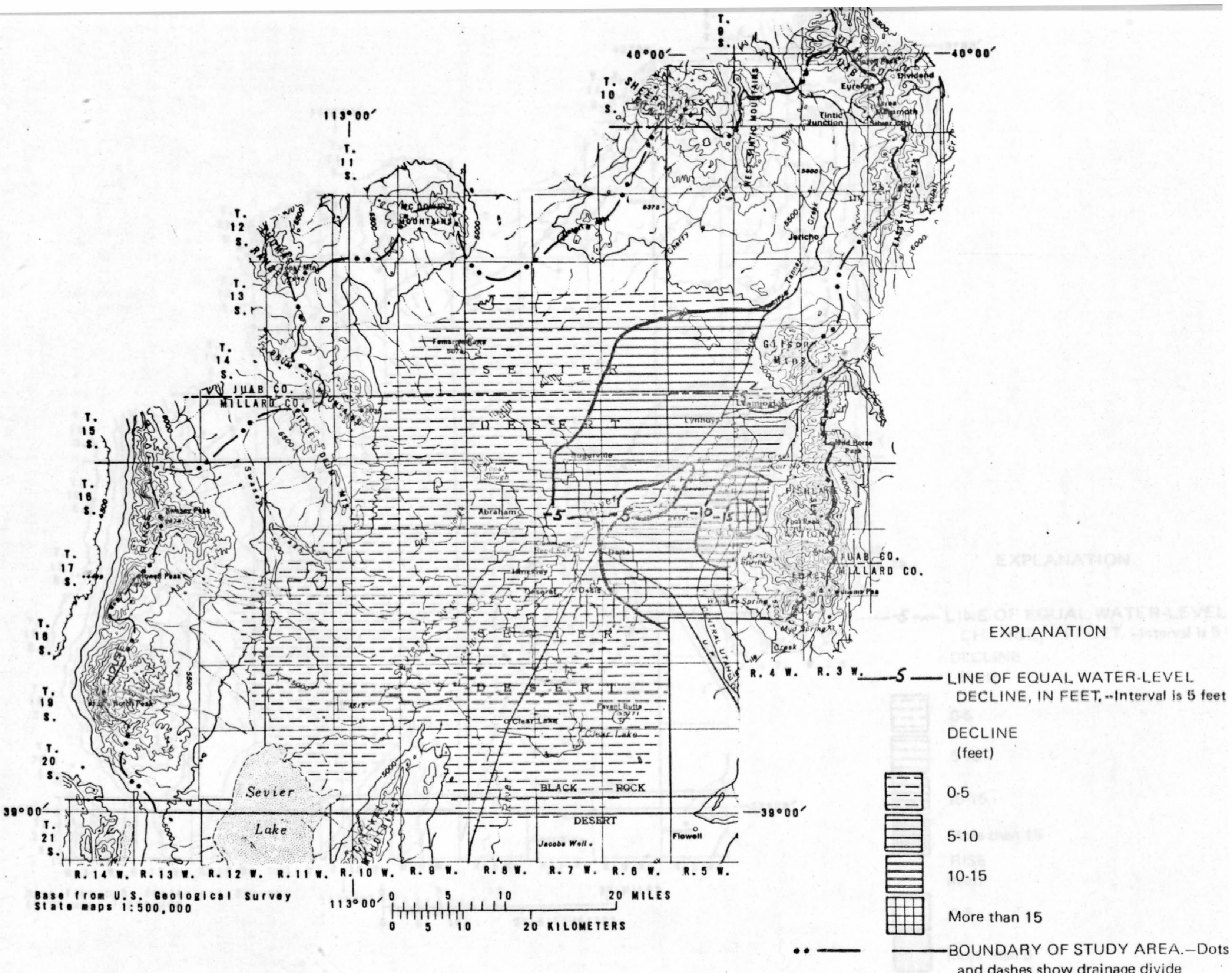

Figure 12.—Projected water-level declines in the shallow artesian aquifer for the period 1981-2000, assuming ground-water withdrawals equal to the 1977-79 average rate.

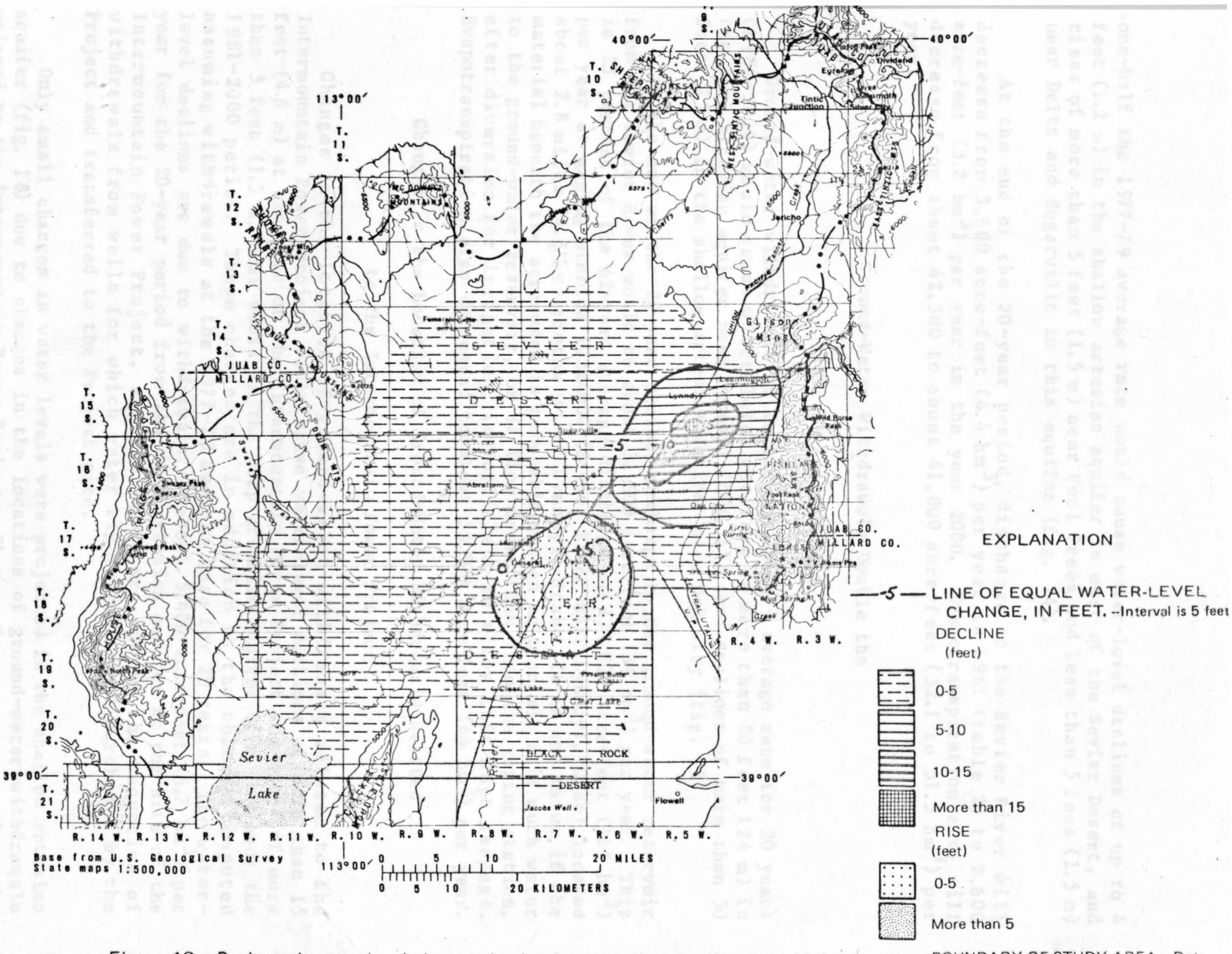

Figure 13.--Projected water-level changes in the deep artesian aquifer for the period 1981-2000, assuming ground-water withdrawals one-half the 1977-79 average rate.

one-half the 1977-79 average rate would cause water-level declines of up to 4 feet (1.2 m) in the shallow artesian aquifer in most of the Sevier Desert, and rises of more than 5 feet (1.5 m) near Fool Creek and less than 5 feet (1.5 m) near Delta and Sugarville in this aquifer (fig. 14).

At the end of the 20-year period, discharge to the Sevier River will decrease from 3,600 acre-feet (4.4 hm^3) per year in 1981 (table 2) to 2,600 acre-feet (3.2 hm^3) per year in the year 2000. Evapotranspiration also will decrease from about 42,300 to about 41,800 acre-feet (52.1 to 51.5 hm^3) per year.

Ground-Water Withdrawals Double the 1977-79 Average Rate

Ground-water withdrawals at double the 1977-79 average rate for 20 years (1981-2000) would cause water-level declines of more than 80 feet (24 m) in the deep artesian aquifer near Lynndyl (fig. 15), and declines of more than 50 feet (15 m) in the shallow artesian aquifer near Oak City (fig. 16).

At the end of the 20-year period, recharge to the ground-water reservoir from the Sevier River would be about 31,900 acre-feet (39 hm^3) per year. This is 23 percent of the 42-year average discharge of 134,000 acre-feet (165 hm^3) per year at gaging station 10224000 (Sevier River near Lynndyl, Utah) located about 2.8 miles (4.5 km) southwest of Lynndyl, Utah. It is not known if the material beneath the streambed is permeable enough to transmit this much water to the ground-water reservoir, or if flow downstream from the gaging station, after diversion for irrigation, is sufficient to allow this much seepage. Evapotranspiration also decreased to about 35,500 acre-feet (44 hm^3) per year.

Changes in the Location of Ground-Water Withdrawals Related to the Intermountain Power Project

Changes in the location of ground-water withdrawals related to the Intermountain Power Project would cause water-level declines of more than 15 feet (4.6 m) at the site of the Intermountain Power Project and rises of more than 5 feet (1.5 m) near Oasis in the deep artesian aquifer (fig. 17) over the 1981-2000 period. These changes are in addition to the changes computed assuming withdrawals at the 1977-79 average rate for 20 years. The water-level declines are due to withdrawals of about 5,400 acre-feet (6.7 hm^3) per year for the 20-year period from the deep artesian aquifer at the site of the Intermountain Power Project, and the rises are due to the reduction of withdrawals from wells for which water rights have been purchased by the Project and transferred to the Project site.

Only small changes in water levels were projected in the shallow artesian aquifer (fig. 18) due to changes in the locations of ground-water withdrawals related to the Intermountain Power Project. Changes in seepage to or from the

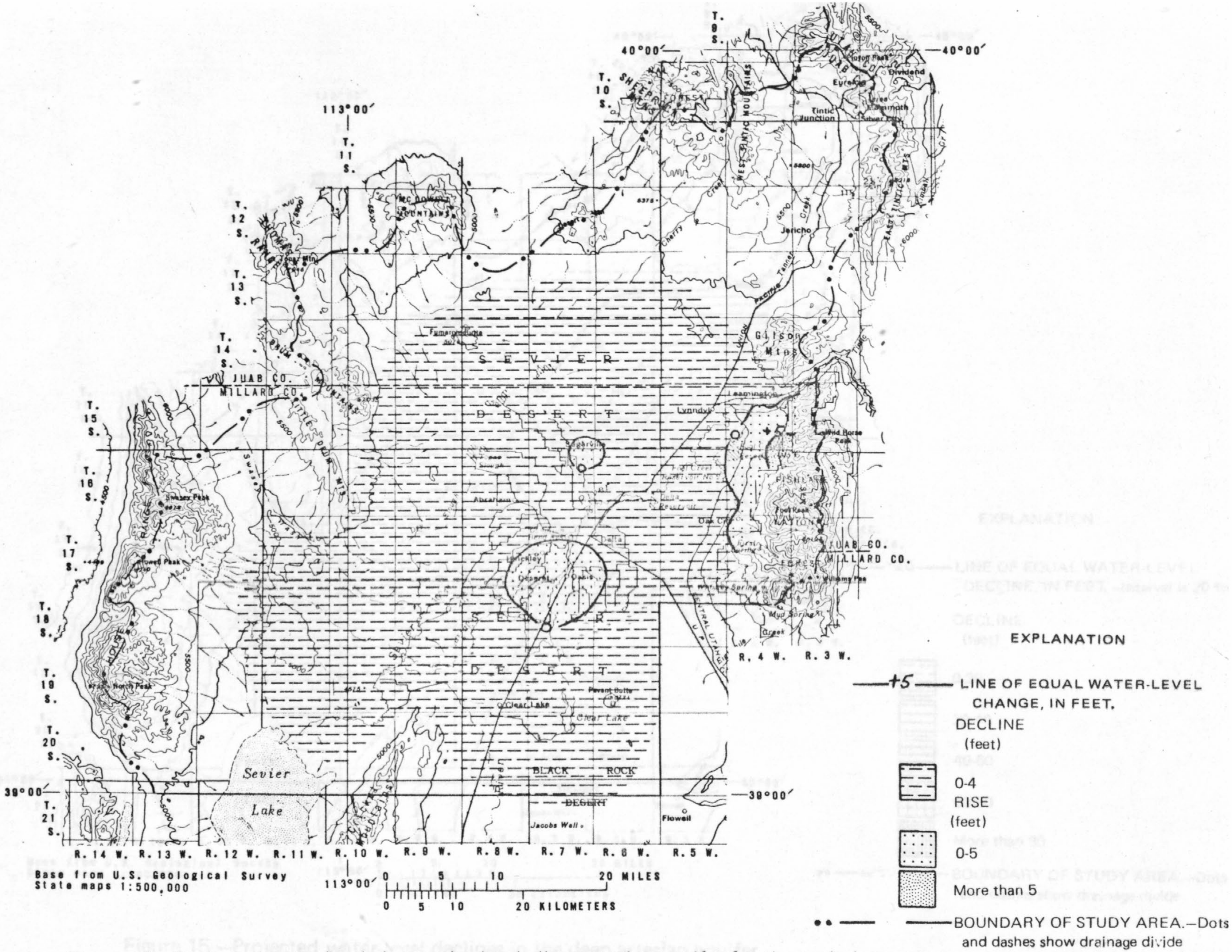

Figure 14.—Projected water-level changes in the shallow artesian aquifer for the period 1981-2000, assuming ground-water withdrawals one-half the 1977-79 average rate.

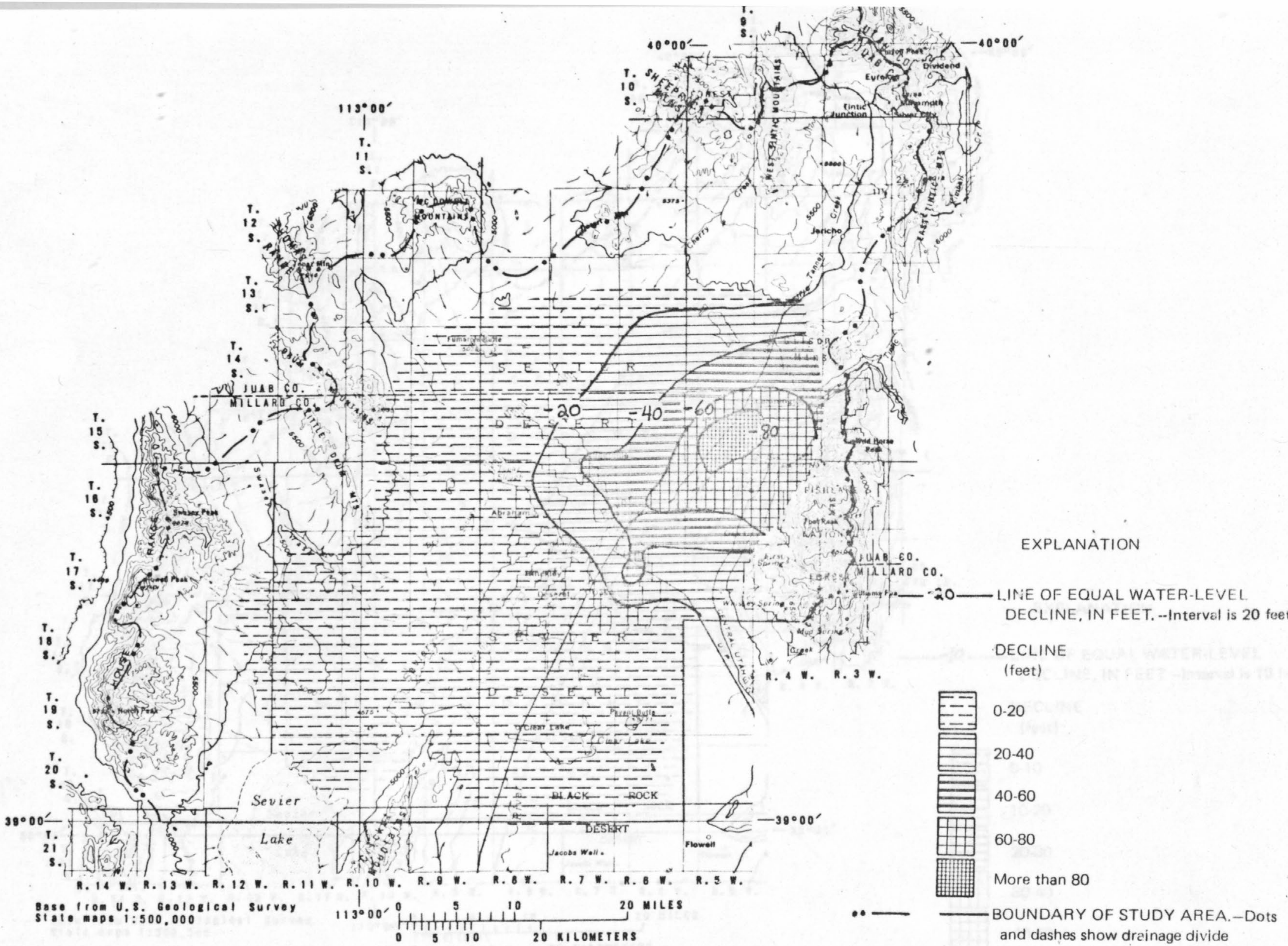

Figure 15.—Projected water-level declines in the deep artesian aquifer for the period 1981-2000, assuming ground-water withdrawals double the 1977-79 average rate.

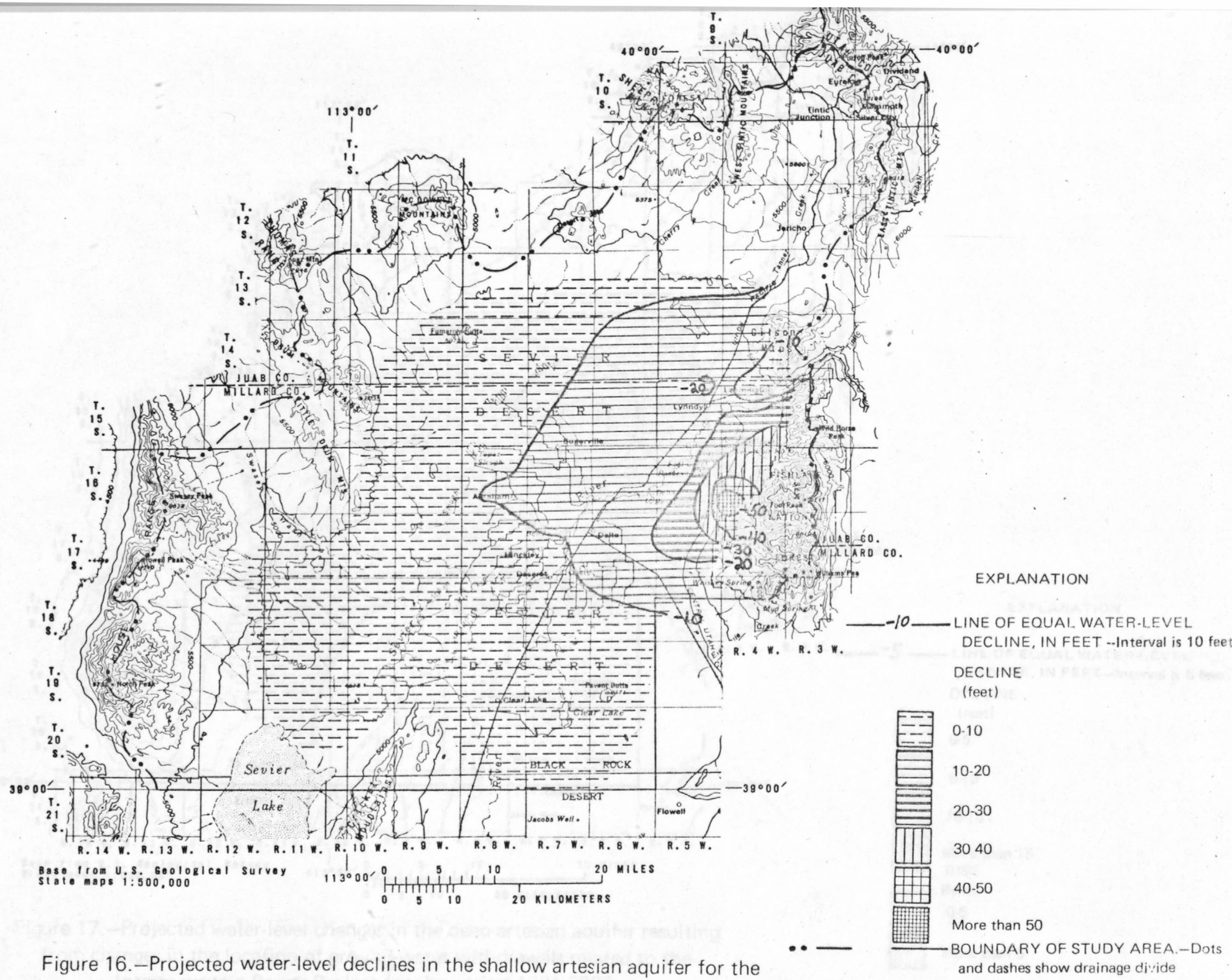

Figure 16.—Projected water-level declines in the shallow artesian aquifer for the period 1981-2000, assuming ground-water withdrawals double the 1977-79 average rate.

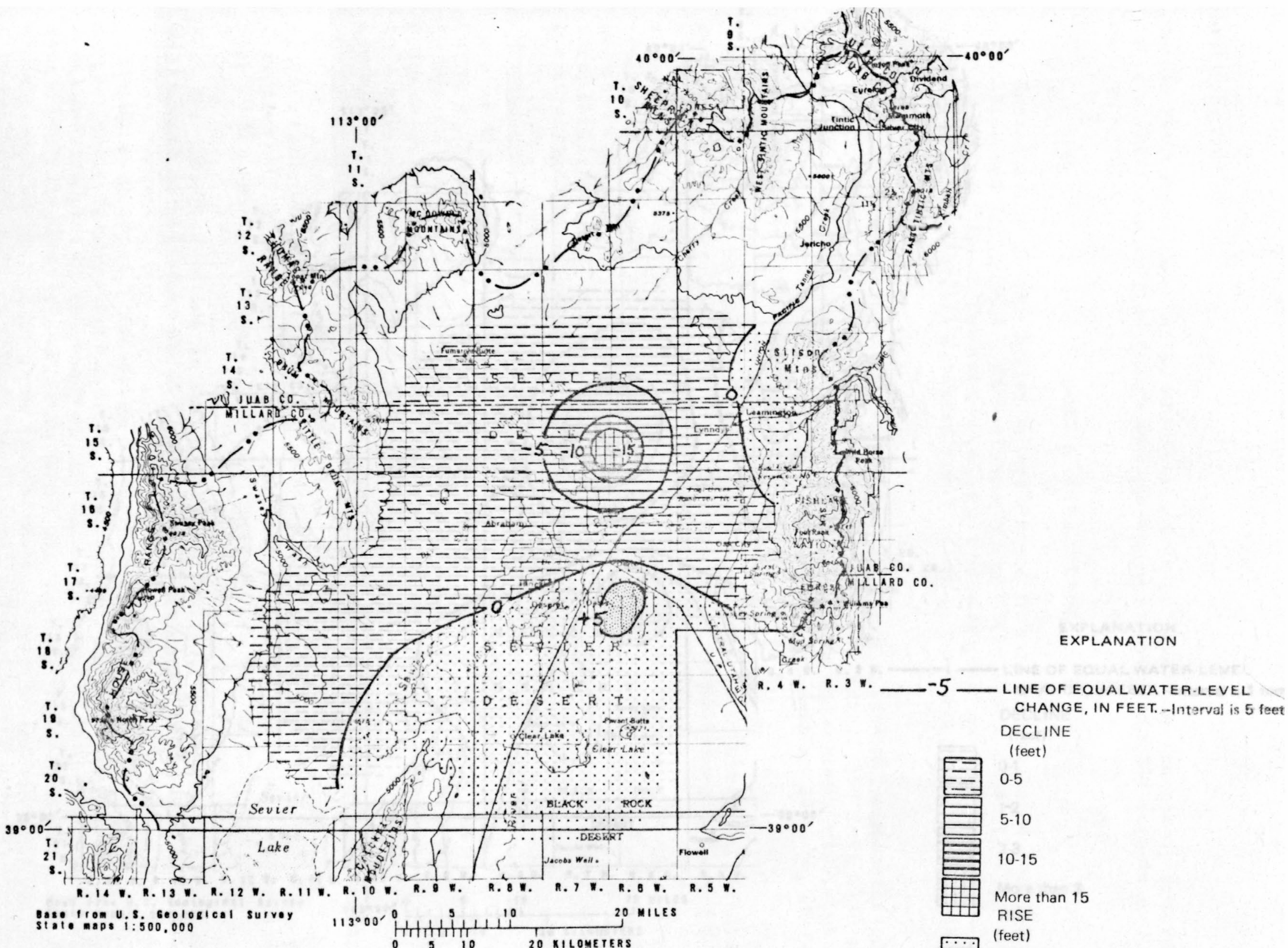

Figure 17.—Projected water-level changes in the deep artesian aquifer resulting from changes in the location of ground-water withdrawals related to the Intermountain Power Project for the period 1981-2000.

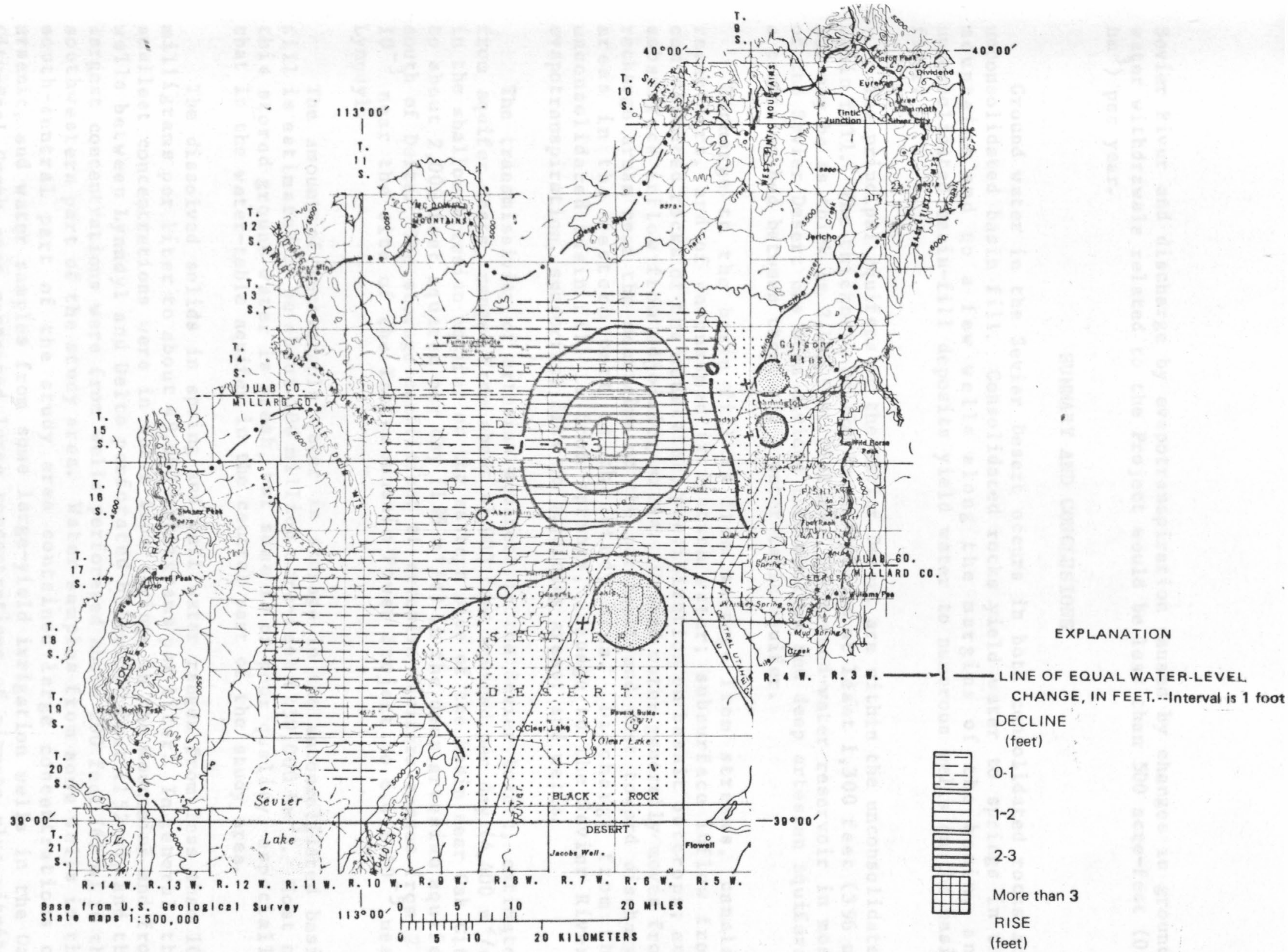

Figure 18.—Projected water-level changes in the shallow artesian aquifer resulting from changes in the location of ground-water withdrawals related to the Intermountain Power Project for the period 1981-2000.

Sevier River and discharge by evapotranspiration caused by changes in ground-water withdrawals related to the Project would be less than 500 acre-feet (0.6 hm^3) per year.

SUMMARY AND CONCLUSIONS

Ground water in the Sevier Desert occurs in both consolidated rocks and unconsolidated basin fill. Consolidated rocks yield water to springs in the mountains and to a few wells along the margins of the basin, and unconsolidated basin-fill deposits yield water to numerous wells on the basin floor.

The principal aquifers of the Sevier Desert are within the unconsolidated basin fill. The thickness of the basin fill is at least 1,300 feet (396 m) and may be as thick as 2,140 feet (652 m). The ground-water reservoir in most of the Sevier Desert has been divided into shallow and deep artesian aquifers, a confining bed between them, and a water-table aquifer.

Recharge to the basin fill is from seepage from streams, canals, reservoirs, and of unconsumed irrigation water; subsurface inflow from consolidated rocks of the mountains; precipitation on basalt outcrops; and subsurface inflow from adjoining areas. Ground water generally moves from recharge areas near the mountains on the northeast and east toward discharge areas in the western part of the study area. Discharge from the unconsolidated basin fill is from springs, seepage to the Sevier River, evapotranspiration, subsurface flow to adjoining areas, and wells.

The transmissivity of artesian aquifers in the Sevier Desert, estimated from aquifer tests, ranges from about 47,000 feet squared per day (4,400 m^2/d) in the shallow artesian aquifer on the eastern side of the basin near Oak City to about 2,000 feet squared per day (186 m^2/d) in the deep artesian aquifer south of Delta. The storage coefficient of artesian aquifers ranges from 2 x 10^{-3} near the site of the Intermountain Power Project to 6.4 x 10^{-5} near Lynndyl.

The amount of recoverable water in storage in the unconsolidated basin fill is estimated to be about 200 million acre-feet (250,000 hm^3). Most of this stored ground water is fresh, but some is of poor quality, especially that in the water-table aquifer in the central part of the study area.

The dissolved solids in spring and well water ranges from less than 100 milligrams per liter to about 49,000 milligrams per liter. In general, the smallest concentrations were in water from springs in the mountains and from wells between Lynndyl and Delta perforated below 500 feet (152 m), and the largest concentrations were from wells perforated above 200 feet (61 m) in the southwestern part of the study area. Water samples from some wells in the south-central part of the study area contained large concentrations of arsenic, and water samples from some large-yield irrigation wells in the Oak City-Fool Creek area contained large concentrations of nitrate plus nitrite.

Ground-water withdrawals have increased from a 1951 to 1963 average of 9,600 acre-feet (11.8 hm^3) per year to an average of 27,500 acre-feet (33.9 hm^3) per year from 1964 to 1981. During 1963-81, water levels declined 19 feet (5.8 m) in the deep artesian aquifer south of Delta and 10 to 13 feet (3.0-4.0) in the shallow artesian aquifer west of Delta, probably because of increased ground-water withdrawals for irrigation and municipal use.

Ground-water quality in the shallow artesian aquifer in the Leamington-Lynndyl area has continued to deteriorate since 1968. The deterioration probably is the result of water of poor quality (unconsumed irrigation water, seepage from canals and reservoirs, and possibly some infiltration from the Sevier River) recharging the unconsolidated basin fill in this area.

A digital-computer model was used to project the effects of future ground-water withdrawals on water levels, recharge, and discharge. The 1977-79 average withdrawal rate of 43,400 acre-feet (53.5 hm^3) over a simulation period of 20 years was used as a standard. Maximum water-level declines of up to 40 feet (12 m) were projected if ground-water withdrawals are equal to the 1977-79 average rate, maximum declines of up to 15 feet (1.5 m) if ground-water withdrawals are one-half the 1977-79 average rate, and maximum declines of up to 80 feet (24 m) if ground-water withdrawals are double the 1977-79 average rate. Projected maximum water-level declines due to changes in the location of ground-water withdrawals related to the Intermountain Power Project are 15 feet (1.5 m).

REFERENCES CITED

Appel, C. L., and others, 1983, Ground-water conditions in Utah, spring of 1983: Utah Division of Water Resources Cooperative Investigations Report 23, 97 p.

Bolke, E. L., and Sumsion, C. T., 1978, Hydrologic reconnaissance of the Fish Springs Flat area, Tooele, Juab, and Millard Counties, Utah: Utah Department of Natural Resources Technical Publication 64, 30 p.

Enright, Michael, and Holmes, W. F., 1982, Selected ground-water data, Sevier Desert, Utah, 1935-82: U.S. Geological Survey Open-File Report 82-910 (duplicated as Utah Hydrologic-Data Report 37), 59 p.

Fields, F. K., 1975, Estimating streamflow characteristics for streams in Utah using selected channel-geometry parameters: U.S. Geological Survey Water-Resources Investigations 34-74.

Gates, J. S., and Kruer, S. A., 1981, Hydrologic reconnaissance of the southern Great Salt Lake Desert and summary of the hydrology of west-central Utah: Utah Department of Natural Resources Technical Publication 71, 55 p.

Gilbert, G. K., 1890, Lake Bonneville: U.S. Geological Survey Monograph 1, 438 p.

Hamer, B. N., and Pitzer, A. G., 1978, Hydrology Report for the Lynndyl Site: Report prepared by the Los Angeles Department of Water and Power for the Intermountain Power Project.

Handy, A. H., Mower, R. W., and Sandberg, G. W., 1969, Changes in chemical quality of ground water in three areas in the Great Basin, Utah, in Geological Survey Research, 1969: U.S. Geological Survey Professional Paper 650-D, p. D228-D234.

Hedman, E. R., and Kastner, W. M., 1977, Streamflow characteristics related to channel geometry in the Missouri River Basin: U.S. Geological Survey Journal of Research, Vol. 5, No. 3, p. 285-300.

Herbert, L. R., and others, 1981, Ground-water conditions in Utah, spring of 1981: Utah Division of Water Resources Cooperative Investigations Report 21, 75 p.

Herbert, L. R., Cruff, R. W., and Holmes, W. F., 1982, Seepage study of the Sevier River and the Central Utah, McIntyre, and Leamington Canals, Juab and Millard Counties, Utah: Utah Department of Natural Resources Technical Publication 74, 43 p.

Holmes, W. F., 1983, Three-dimensional digital-computer model of the principal ground-water reservoir of the Sevier Desert, Utah: U.S. Geological Survey Water-Resources Investigations Report 83-4179, p. 123.

Holmes, W. F., and Kimball, B. A., 1983, Ground-water in the southeastern Uinta Basin, Utah and Colorado: U.S. Geological Survey Open-File Report 83-217 (to be printed as a U.S. Geological Survey Water-Supply Paper).

Holmes, W. F., and Wilberg, D. E., 1982, Results of an aquifer test near Lynndyl, Utah: U.S. Geolological Survey Open-File Report 82-514, 17 p.

Intermountain Power Project, 1981, Well drilling and testing report: City of Los Angeles Department of Water and Power, 29 p.

Johnson, A. I., 1967, Specific yield--compilation of specific yields for various materials: U.S. Geological Survey Water-Supply Paper 1662-D, 74 p.

Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Meinzer, O. E., 1911, Ground water in Juab, Millard, and Iron Counties, Utah: U.S. Geological Survey Water-Supply Paper 277, 162 p.

Mower, R. W., 1961, Relation of the deep and shallow artesian aquifers near Lynndyl, Utah, in Geological Survey Research, 1961: U.S. Geological Survey Professional Paper 424-C, p. C94-C97.

Mower, R. W., 1963, Effects on the shallow artesian aquifer of withdrawing water from the deep artesian aquifer near Sugarville, Millard County, Utah: Utah State Engineer Information Bulletin 10, 9 p.

_____ 1965, Ground-water resources of Pavant Valley, Utah: U.S. Geological Survey Water-Supply Paper 1794, 78 p.

_____ 1967, Causes of fluctuations in the rate of discharge of Clear Lake Springs, Millard County, Utah: U.S. Geological Survey Water-Supply Paper 1839-E, 31 p.

_____ 1978, Hydrology of the Beaver Valley area, Beaver County, Utah, with emphasis on ground water: Utah Department of Natural Resources Technical Publication 63, 90 p.

Mower, R. W., and Feltis, R. D., 1964, Ground-water data, Sevier Desert, Utah: U.S. Geological Survey open-file report (duplicated as Utah Basic-Data Report 9), 34 p.

_____ 1968, Ground-water hydrology of the Sevier Desert, Utah: U.S. Geological Survey Water-Supply Paper 1854, 75 p.

National Oceanic and Atmospheric Administration, Environmental Data and Information Service, 1982, Climatological data, annual summary, Utah, 1981: v. 83, no. 13, 15 p.

Nelson, W. B., 1952, Sevier Desert, Millard County, in Thomas, H. E., Nelson, W. B., Lofgren, B. E., and Butler, R. G., Status of development of selected ground-water basins in Utah: Utah State Engineer Technical Publication 7, p. 63-66.

Nelson, W. B., and Thomas, H. E., 1953, Pumping from wells on the floor of the Sevier Desert, Utah: Transactions, American Geophysical Union, v. 34, no. 1, p. 74-84.

Neuman, S. P., and Witherspoon, P. A., 1972, Field determination of the hydraulic properties of leaky multiple aquifer systems: Water Resources Research, v. 8, no. 5, p. 1284-1298.

Stephens, J. C., 1977, Hydrologic reconnaissance of the Tule Valley drainage basin, Juab and Millard Counties, Utah: Utah Department of Natural Resources Technical Publication 56, 37 p.

Stokes, W. L., [ed.], 1964, Geologic map of Utah: Salt Lake City, University of Utah.

Torak, L. J., 1982, Modifications and corrections to the finite-difference model for simulation of three-dimensional ground-water flow: U.S. Geological Survey Water-Resources Investigations 82-4025, 30 p., plus appendixes.

Trescott, P. C., 1975, Documentation of finite-difference model for simulation of three-dimensional ground-water flow: U.S. Geological Survey Open-File Report 75-438, 32 p., plus appendixes.

Trescott, P. C., and Larson, S. P., 1976, Documentation of finite-difference model for simulation of three-dimensional ground-water flow: U.S. Geological Survey Open-File Report 76-591 (supplement to U.S. Geological Survey Open-File Report 75-438), 21 p.

U.S. Department of Agriculture, 1969, Water budget analysis, Sevier River basin, Utah, Appendix IV: 92 p.

Van Hylckama, T. E. A., 1974, Water use by saltcedar as measured by the water budget method: U.S. Geological Survey Professional Paper 491-E, 30 p.

Waddell, K. M., and Fields, F. K., 1977, Model for evaluating the effects of dikes on the water and salt balance of Great Salt Lake, Utah: Utah Geological and Mineral Survey Water-Resources Bulletin 21, 54 p.