Ground-Water Resources of Northern Big Smoky Valley, Lander and Nye Counties, Central Nevada

By ELINOR H. HANDMAN and KATHRYN C. KILROY

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CONVERSION FACTORS, VERTICAL DATUM, EQUIVALENTS, AND ABBREVIATIONS

Multiply	By	To obtain
acre	0.4047	square hectometer
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per acre (acre-ft/acre)	0.003048	cubic hectometer per square hectometer
acre-foot per year per acre (acre-ft/yr/acre)	0.003048	cubic hectometer per year per square hectometer
acre-foot per year (acre-ft/yr)	0.001153	cubic hectometer per year
acre-foot per year per mile (acre-ft/yr/mi)	0.001233	cubic hectometer per year per kilometer
cubic foot (ft^3)	0.02832	cubic meter
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 year (ft/yr)	0.3048	meter per year
gallon per day (gal/d)	0.003785	cubic meter per day
gallon per minute (gal/min)	0.06308	liter per second
inch (in.)	25.40	millimeter
inch per month (in/mo)	25.40	millimeter per month
mile (mi)	1.609	kilometer
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer

Temperature: Degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the formula °F = [1.8(°C)]+32. Degrees Fahrenheit can be converted to degrees Celsius by using the formula °C = 0.556(°F-32).

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

Equivalents:

cubic foot per second (ft^3/s)	448.83	gallon per minute
cubic foot per second (ft^3/s)	724.5	acre-foot per year
foot per day (ft/d)	7.48	gallon per day per square foot

Abbreviated units:

µS/cm microsiemens per centimeter at 25° Celsius
mg/L milligram per liter
MW megawatt

Ground-Water Resources of Northern Big Smoky Valley, Lander and Nye Counties, Central Nevada

By Elinor H. Handman *and* Kathryn C. Kilroy

Abstract

Use of ground water from an extensive basin-fill aquifer in northern Big Smoky Valley has been increasing. The water is used for mining, irrigation, stock watering, and domestic supply. An estimated 5 million acre-feet of water is stored in the upper 100 feet of the aquifer; however, only a small part is replenished annually. To determine the sources, movement, available amounts, and use of the water, and potential effects of future development, the U.S. Geological Survey, in cooperation with Nye County, evaluated the ground-water resources. Results of the study indicate that, as of 1985, an estimated 6,600 acre-feet was used each year and more would be needed as usage increased.

During an average year, about 740,000 acre-feet of water falls on the drainage area as snow and rain. Of this quantity, about 90 percent evaporates directly or is transpired by vegetation on the land surface, and about 10 percent infiltrates through rocks, soils, and streambed materials to the water table. Some of the infiltrated water discharges by springflow, which evaporates, runs off, or is transpired. Most of the infiltrated water eventually discharges by evapotranspiration. Despite pumping, water levels generally did not decline during 1965-85 because precipitation was 16 percent greater than the long-term (1890-1985) average and, consequently, recharge to the aquifer also was greater.

A numerical ground-water flow model was used to refine the conceptual flow model and water budget of northern Big Smoky Valley and to evaluate the potential for future development in the basin. The model simulated the ground-water flow system and ground-water budget under natural conditions (no pumping) and under conditions of development equivalent to the 1985 rate and distribution of pumping and to twice the 1985 rate. The model results indicate that, on the basis of 1985 conditions, a maximum decline in the water table of about 40 feet can be expected in the southern part of the basin when equilibrium is reached. To evaluate hydrologic effects of future development, additional (hypothetical) wells were simulated. Model results indicate that, if additional wells were located to capture water that otherwise would be transpired by phreatophytes, and if pumpage and consumptive use were doubled, a new equilibrium could be established. Water levels in the vicinity of the wells could be 44 feet lower than in the unstressed system. Thus, the long-term hydrologic effects of increased development could be minimal.

INTRODUCTION

Northern Big Smoky Valley is similar to other Great Basin valleys in its geologic history, physiography, and land and water use. It is not extensively developed, however, and has not had the declining water levels or changes in water quality that are associated with development in some of the other basins in the Great Basin region. Effective decisions about allocation of ground water for future development will require an understanding of the total amount of water available and its source, distribution, and use.

In northern Big Smoky Valley, the use of ground water for mining and irrigation has fluctuated from 1970 to 1985, but in general has increased—a trend that is likely to continue. The largest population center, Round Mountain, is estimated to have grown from about 200 people in 1970 to about 500 in 1985 as a consequence of increased mining. Residential development also increased in the areas around Kingston Canyon, Gilman Springs, and Carvers, and applications for several Desert Land Entries, in addition to the 21 existing in 1985, are under consideration.

Judicious allocation of ground water to meet increased demands for mining, irrigation, stock, and domestic use requires an awareness of the potential effects of water withdrawals on the hydrologic system, as well as the social, economic, and political consequences of development. Previous studies by Meinzer (1917) and Rush and Schroer (1970) described the geology and water resources of Big Smoky Valley and estimated the quantity and flow of water in the area. Since the 1970 report was published, several new wells have been drilled and geophysical surveys made that provide additional information about the hydrologic system. Also, new techniques have been developed for ground-water assessment, including analysis of Landsat satellite imagery and use of computer models to simulate ground-water flow. The new information and techniques were used to evaluate the ground-water budgets published in earlier reports.

Purpose and Scope of the Report

This report presents the results of a quantitative assessment by the U.S. Geological Survey, in cooperation with Nye County, of ground-water resources in northern Big Smoky Valley during 1983-85. The assessment was based on interpretation of previously published information and new data.

The report describes the sources and amounts of ground water available in northern Big Smoky Valley; the quantity, movement, and quality of water; ground-water use and consumption; and the potential hydrologic effects of future development. The first sections describe the geologic and geographic setting and discuss elements of the hydrologic system and how they function in the area. Subsequent sections contain interpretations of hydrologic data, a detailed discussion of the mathematical model, the results of model simulations, and a guide to sources of information related to ground water. A glossary defines technical terms. The location, water-level data, and other information on wells and test holes that were used in this study are listed in table 13 (back of report).

State and County officials, planners, developers, and water users in general can use the report as (1) an aid in understanding the ground-water system in northern Big Smoky Valley and similar areas, and (2) a source of information for decisions about water development and use.

Methods

To evaluate the ground-water flow system in northern Big Smoky Valley, information was collected from well-drillers' reports, remote-sensing data, land-surface and borehole-geophysical surveys, and results of test drilling by the U.S. Geological Survey. In addition, precipitation and temperature records for Austin from 1877 to 1985, miscellaneous stream and well data from 1914 to 1985, and geophysical data were compiled.

Water levels in wells and streamflow were measured, test wells were drilled, and vegetation surveys were completed during 1984-85. The information provided data and calibration values for a mathematical model that was used to simulate steady-state conditions in the principal aquifer of northern Big Smoky Valley and to estimate effects of future development.

Acknowledgments

The U.S. Geological Survey, in cooperation with Nye County, collected and analyzed the data on which this report is based. Additional information and assistance was provided by other Federal and State agencies. The U.S. Forest Service provided logistic support; the Bureau of Land Management permitted test-well installation on public land; and the Nevada Division of Water Resources provided records of wells and water rights.

Staff of the Smoky Valley Mining Company assisted in periodic water-level measurements and seismic surveys. Private citizens, ranchers, and mining-company officials allowed access to their property for water-level measurements, test borings, and geophysical surveys. Their assistance is sincerely appreciated.

LOCATION AND PHYSIOGRAPHIC FEATURES

Northern Big Smoky Valley, in Lander and Nye Counties, is a north-northeast-trending, elongated basin in central Nevada and is part of the Great Basin region (fig. 1). It was delineated as Hydrographic Area 137B[1] and officially designated "Big Smoky Valley, Northern Part." For this report, it is referred to as northern Big Smoky Valley. The development of topographic features, drainage patterns, and ground-water flow systems is controlled by the major stratigraphic and structural features of the bedrock. Basin-and-range faults, the principal structural features, provide conduits for ground-water flow in some places but may obstruct flow in others.

The basin extends about 70 mi from its northern end, near Austin, to its southern boundary, near Round Mountain, and encompasses more than 1,300 mi^2 (fig. 2). The valley floor is surrounded by mountains, except in the south where it is separated from Tonopah Flat (hydrographic area 137A, fig. 1) by a low ridge. Several intermittent and a few perennial streams flow from the Toiyabe Range in the west and the Toquima Range in the east toward the center of the basin where water accumulates on large playas during periods of rapid snowmelt. Alluvial fans composed of materials eroded from adjacent mountains form sloping areas between the steep mountain fronts and the flat, central valley.

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[1]Formal Hydrographic Areas in Nevada were delineated systematically by the U.S. Geological Survey and Nevada Division of Water Resources in the late 1960's for scientific and administrative purposes (Rush, 1968; Cardinalli and others, 1968). The official Hydrographic Area names, numbers, and geographic boundaries continue to be used in Geological Survey scientific reports and Division of Water Resources administrative activities.

GEOHYDROLOGIC FRAMEWORK

The principal geologic units in northern Big Smoky Valley are consolidated rocks (bedrock) and unconsolidated basin-fill deposits. They differ in origin and water-yielding characteristics and are the framework for storage and movement of ground water. Bedrock units (volcanic, sedimentary, and granitic rocks) underlie the basin-fill deposits and are exposed in mountains to the west, north, and east. Part of the sedimentary bedrock is carbonate rock. The location and extent of principal bedrock outcrops are shown in figure 3. Basin fill (playa, channel, and alluvial-fan deposits), which consists of as much as 5,000 ft of unconsolidated gravel, sand, silt, and clay lenses, overlies bedrock in the center of the basin. Although no basinwide or areally extensive confining units are known in the system, numerous thin confining units and interbedded fine-grained deposits of limited areal extent are in the basin. The location and extent of principal basin-fill deposits at land surface are shown in figure 4. The relation between bedrock and basin-fill deposits is shown in cross section in figure 5.

Consolidated rocks and unconsolidated basin-fill deposits have openings that can store and transmit water; openings include voids between mineral grains (primary porosity) and faults, fractures, and solution cavities (secondary porosity). Primary porosity is most prevalent in the unconsolidated deposits; secondary porosity is more prevalent in bedrock units. The hydrologic properties of the different geologic materials are presented in table 1 and the distribution of materials is shown in figures 3 and 4. In general, more water is stored in and transmitted through unconsolidated basin-fill deposits than bedrock. More water is transmitted through coarse-grained gravels and sands than fine-grained silts and clays, and through well-rounded and well-sorted deposits than angular and poorly sorted deposits, because the openings between coarse and round grains are larger. Basin-fill deposits are the most important aquifers in northern Big Smoky Valley and are the principal subject of this report.

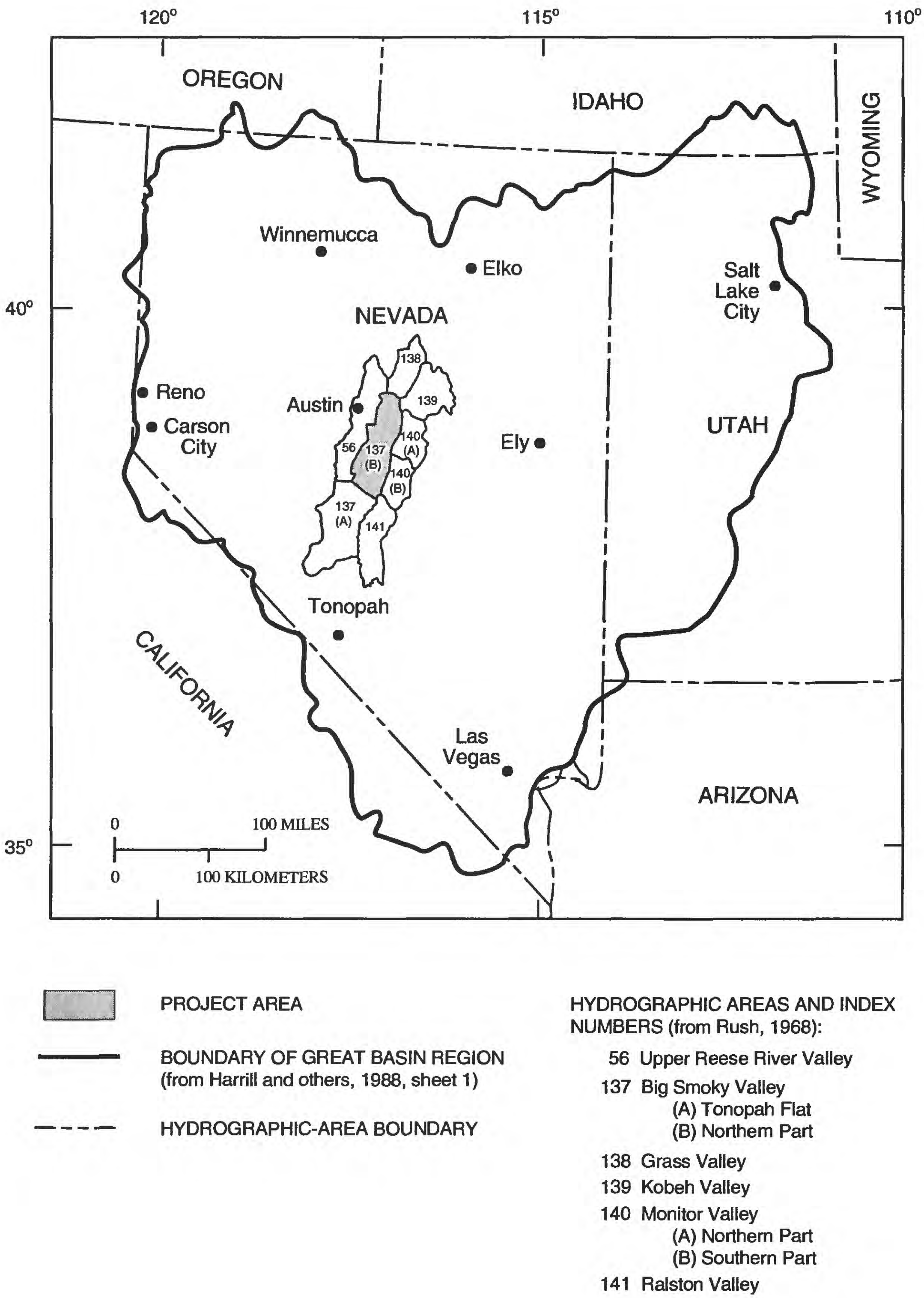


Figure 1. Great Basin physiographic region, and northern Big Smoky Valley and surrounding valleys in Nevada.

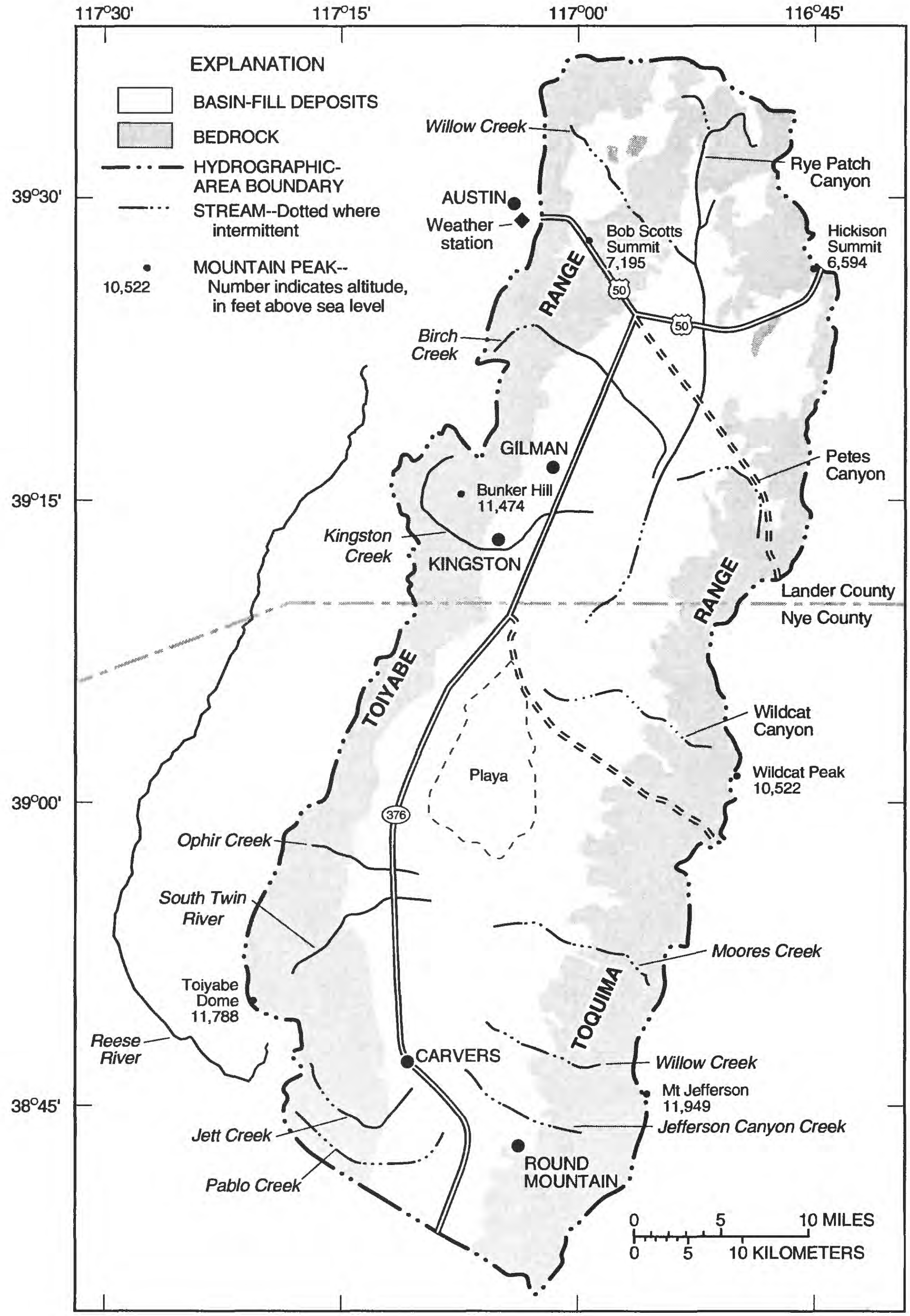


Figure 2. Major streams, mountain peaks, and playa in northern Big Smoky Valley, Nevada.

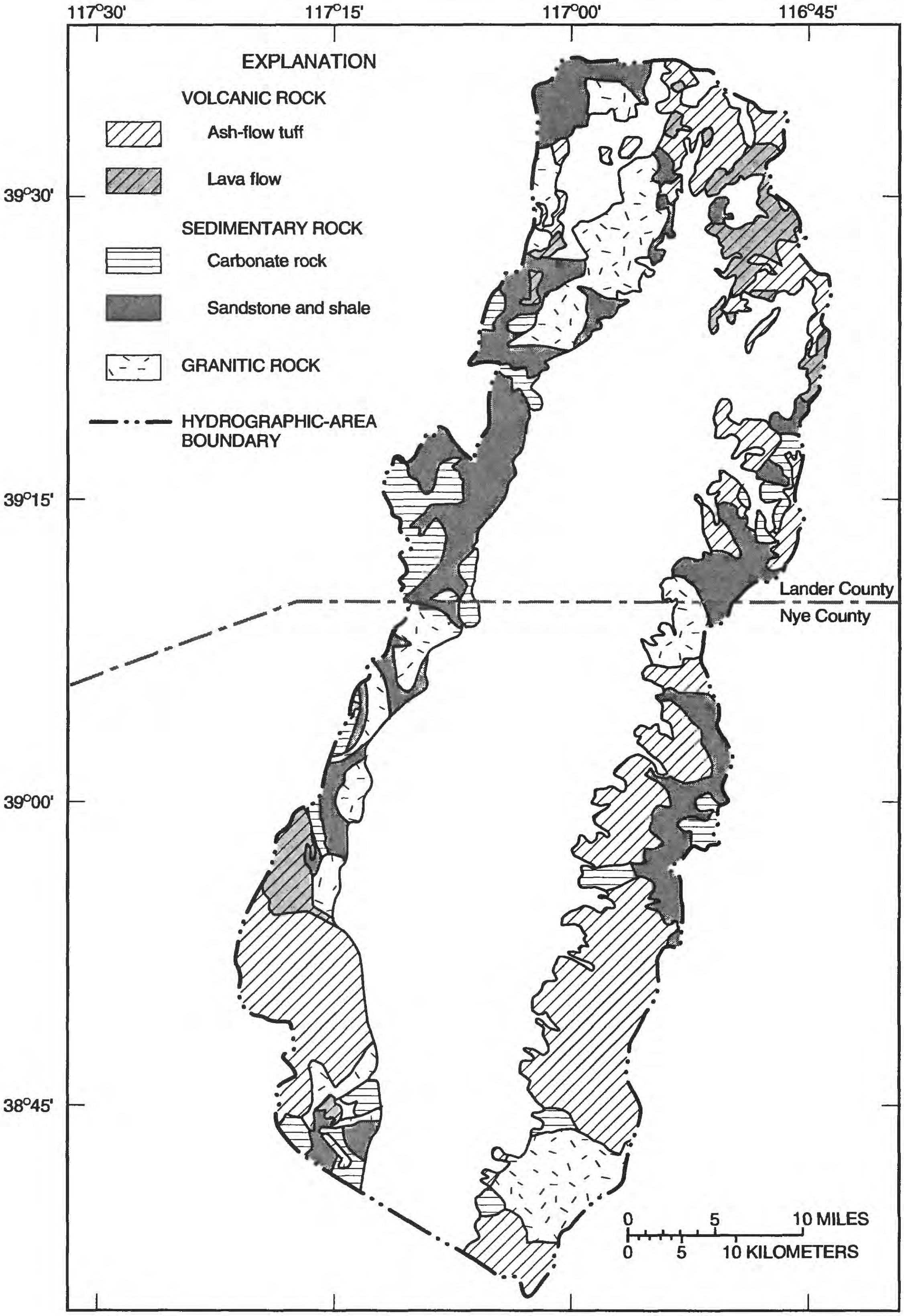


Figure 3. Distribution of bedrock units, northern Big Smoky Valley, Nevada. (Modified from Kleinhampl and Ziony [1984], Nye County, and Stewart and McKee [1977], Lander County.)

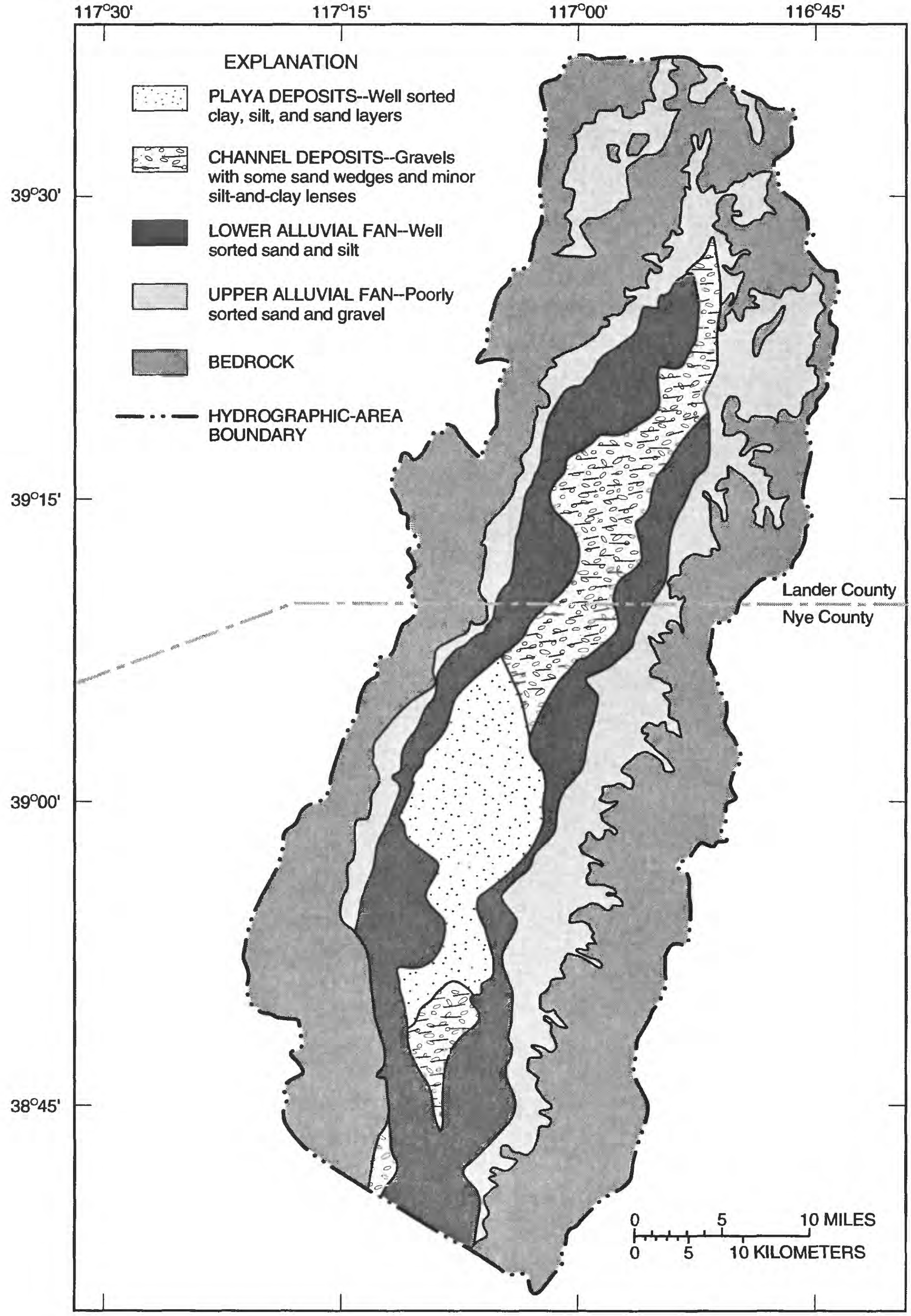


Figure 4. Distribution and types of basin-fill deposits, northern Big Smoky Valley, Nevada. Alluvial-fan deposits in northwestern part of basin are thin and were not included in the ground-water flow model.

Table 1. Hydrologic characteristics of consolidated rocks and unconsolidated basin-fill deposits, northern Big Smoky Valley, Nevada

Type of rock or deposit	Hydrologic features [1]	Probable water yields [2]
	Consolidated rocks [3]	
	Volcanic	
Ash-flow tuff	Interlayered with flows	Very small to small.
Lava flow	Interflow zones	Very small to small.
	Sedimentary	
Carbonate rock	Fractures, solution cavities	Small to large.
Sandstone and shale	Fractures	Very small.
	Granitic	
Granitic rock	Massive, little storage	Very small.
	Unconsolidated basin-fill deposits [4]	
Playa	Fine-grained; layered	Very small.
Channel	Coarse-grained; massive or layered	Small to very large.
Alluvial fan, lower	Medium-grained; well sorted; layered	Moderate to very large.
Alluvial fan, upper	Poorly sorted; deep water table	Moderate to large.

[1] Typical features that may affect the storage and transmission of water.

[2] Relative yields that can be expected from properly developed individual wells, generalized on the basis of several hydrogeologic factors. Well yields can be affected by local variations in aquifer materials, by mutual interference among closely spaced wells, and by boundary conditions. Very small to small yields (less than 10 gallons per minute) are generally adequate for domestic and stock use; moderate yields (10-500 gallons per minute) are adequate for some irrigation uses; large yields (500-1,000 gallons per minute) and very large yields (greater than 1,000 gallons per minute) are required for many irrigation and mining uses.

[3] Distribution of consolidated rocks (bedrock) in northern Big Smoky Valley is shown in figure 3.

[4] Distribution of basin-fill deposits is shown in figure 4.

QUALITY OF WATER

The quality of water in most parts of northern Big Smoky Valley, as determined in previous studies, is suitable for irrigation, mining, stock watering, and domestic uses. Rush and Schroer (1970, table 32) reported analyses of water from 9 streams, 14 wells, and 10 springs, and Trexler and others (1980, table C1) reported analyses of water from 5 streams, 3 wells, and 7 hot springs. Water-quality data also are available for South Twin River. The streamflow-gaging station South Twin River near Round Mountain (USGS station 10249300) is a hydrologic benchmark station for which monthly or quarterly water-quality records have been kept since 1965. Results of the water-quality analyses for this station are in U.S. Geological Survey Water-Data Reports for Nevada (published annually). No new ground-water samples were analyzed for this study because the changes in land and water use from 1970 to 1985 were local and not likely to have affected water quality in most of the basin.

Results of the previous studies indicate that, in general, dissolved-solids concentrations in ground water increase with depth because the deeper water has been in contact with soluble minerals of the aquifer for a longer time. In the central parts of topographically closed basins such as northern Big Smoky Valley, however, deep water moves upward under artesian pressure into shallower aquifers and continues to dissolve minerals along its flow path. Concentrations of dissolved solids are increased further by evapotranspiration near the surface. Dissolved-solids concentrations of ground water in these discharge areas (playas) are greatest at land surface and decrease with depth.

One indication of dissolved-solids concentration is specific conductance, the ability of water to conduct an electric current. Specific conductance is affected by the dissolved-mineral (ion) concentration in water—the less mineralized the water, the lower the conductance. Specific conductance of most of the ground-water samples (from wells and springs) in the basin ranged from 100 to 940 µS/cm. The dissolved-solids concentration in most natural waters ranges from 0.55 to 0.65 times the specific conductance (Hem, 1985, p. 67). Thus, assuming that the dissolved-solids concentration is equal to 0.65 times the specific conductance in the basin, the range of dissolved-solids concentrations is about 65 to 610 mg/L. Dissolved solids and sodium concentrations were generally in the acceptable range for irrigation, stock, and domestic use; exceptions were water from hot springs and from shallow wells on the edge of the playa. Hot water derived from a heat source at depth drives water and volatile gases from the source and dissolves minerals much more readily than cold water. Mineralization increases as water moves from the source to the playa (discharge area).

Specific-conductance measurements reported by Rush and Schroer (1970) in water from 13 wells are summarized in table 2. These limited data and evidence from other domestic and irrigation wells indicate that water of the best quality for most purposes is found outside the playa areas at depths of 200-400 ft.

Table 2. Summary of specific-conductance measurements of water from 13 wells, northern Big Smoky Valley, Nevada

[Specific-conductance values in microsiemens per centimeter at 25 degrees Celsius; data from Rush and Schroer, 1970. Symbols: <, less than; >, greater than]

Number of wells sampled	Depth of wells (feet below land surface)	Specific conductance			
		Minimum	Maximum	Mean	Median
6	< 200	370	15,000	4,401	1,165
5	200-400	140	460	244	200
2	> 400	216	420	318	318

LAND AND WATER USE

Most of the land in northern Big Smoky Valley is undeveloped public land. The Toiyabe and Toquima ranges are national forests administered by the U.S. Forest Service, which protects watersheds (drainage basins) as one of its management functions. Public land in the valley area is administered by the Bureau of Land Management, which processes and records all transactions involving public lands. Most of the area is sparsely vegetated rangeland used for livestock grazing.

Public land may be transferred to private citizens in Nevada through the Desert Land Entry Act. The agricultural potential of Desert Land Entries is discussed by Nelson (1979a, 1979b). In northern Big Smoky Valley, 21 Desert Land Entries (12 in Nye County and 9 in Lander County) have been permitted and 23 applications are under consideration, according to data on file at the Bureau of Land Management, Reno, Nev.

Most private land is on the west side of the valley, where streams and springs supply water for ranches and farms. Wells provide supplemental water supplies. The status of ground-water rights in 1985 is summarized in table 3, and information on individual wells used in this study is in table 13, at the back of this report. Annual ground-water use for irrigation, stock watering, mining, and domestic supply in 1985 is estimated at 6,600 acre-ft, much less than allocated amounts for irrigation, stock, and mining summarized in table 3.

Table 3. Summary of 1985 ground-water rights, northern Big Smoky Valley, Nevada

[Compiled from water-rights data on file with Nevada Department of Conservation and Natural Resources; acre-ft/yr, acre-feet per year; --, not applicable]

Primary water use	Water-rights status [1]	Number of wells	Irrigated acres	Annual duty or amount allocated [2] (acre-ft/yr)
Irrigation	Certificate.........	16	1,701	6,720
	Permit..............	45	16,479	57,351
	Application	38	16,507	66,143
Stock	Certificate.........	20	--	142
	Permit..............	5	--	17
	Application	1	--	72
Mining........	Certificate.........	2	--	49
	Permit..............	25	--	40,605

[1] Certificate: Evidence of appropriation; issued by State Engineer to permit holder upon completing proof of beneficial use.

Permit: Approved application; holder required to make reports and prove beneficial use of water.

Application: Application to State Engineer for permit to appropriate water.

[2] Amount of water necessary to provide for use.

During 1985, 36 wells were inventoried by the Nevada Division of Water Resources for a crop-and-water survey; 23 of the wells (11 pumping and 12 flowing artesian) were used to irrigate 1,474 acres, and 6 were used for stock watering. Locations of fields irrigated by ground water are shown in figure 15. About 90 percent of the irrigated acreage in the basin is used to grow alfalfa, 8 percent is used for hay, and 2 percent for grain (Thomas K. Gallagher, Nevada Division of Water Resources, written commun., 1985).

Use of ground water for mining fluctuates with changes in the industry. Rush and Schroer (1970) reported that mining and milling activities were minimal from 1940 to 1970. Those activities have since increased. Ground-water rights for mining are summarized in table 3. Gold mining was active at Round Mountain, Northumberland Canyon, and Kingston Canyon during the course of this study (1983-85). An estimated 1,780 acre-ft of ground water was used for gold mining and processing and related operations at Round Mountain during 1985 (Donald L. Simpson, Smoky Valley Mining Company, written commun., 1986).

The community of Round Mountain, about 500 people in 1985, is served by public-water supplies from surface-water and ground-water sources. Individual domestic wells and springs served an additional population of about 700 throughout the basin—200 people in Lander County and 500 people in Nye County. At least three-fourths of the population use water from wells. Rural domestic use of ground water in the United States is estimated at about 80 gal/d per person (Solley and others, 1983, p. 12). On the basis of this estimate, total withdrawal from public and domestic wells probably is less than 150 acre-ft/year.

Use of thermal water in northern Big Smoky Valley is negligible in terms of the total water budget. Thermal water at Spencer Hot Springs and Darroughs Hot Springs is used for bathing and swimming. The thermal areas at McLeod (Smoky Valley) Ranch and Darroughs Hot Springs have been explored for their energy potential, and in 1985 the McLeod Ranch area was the site of a pilot geothermal-energy project. The pilot project, cancelled before completion, proposed a power plant that was expected to supply 10 MW of power, enough to provide electricity for about 6,000 homes. Information on the characteristics and distribution of thermal waters in the basin is available in reports by Garside and Shilling (1979) and Trexler and others (1980, 1983).

Northern Big Smoky Valley was designated a critical ground-water area in 1983. New permits for ground-water development are issued only for preferred uses or with limitations specified by the Nevada State Engineer.

OVERVIEW OF WATER BUDGET

Water in northern Big Smoky Valley is derived almost entirely from precipitation within its drainage area. Part of the precipitation is temporarily stored within the valley, but eventually it discharges by evaporation, transpiration, and withdrawal from wells. No streams flow out of the area and ground-water outflow is approximately equal to total inflow.

The amount of water in storage only partly defines how much ground water is available for use. A large volume may be stored but, as withdrawals increase, water levels may decline. As a result, pumping costs may increase, well yields may decrease, and water quality may deteriorate. A more useful measure of the water supply is the amount that is reliably and economically available for use on a long-term basis. Amounts of water available for additional development can be determined by comparing present water use with the renewable supply of water. A water budget is useful for making these comparisons and determinations.

The components of the hydrologic cycle in a drainage area can be described by a water budget that balances recharge, discharge, and change in storage. The components are related by the following equation:

$$\text{Recharge} = \text{Discharge} + \text{Change in Storage.} \tag{1}$$

In the natural (no development) water budget for northern Big Smoky Valley, recharge consists of precipitation over the entire drainage area and regional inflow, discharge is by evapotranspiration and subsurface outflow, and storage is water that accumulates in aquifers and in lakes and ponds within the basin. If recharge is greater than discharge, water is added to storage; if recharge is less than discharge, water is removed from storage and water levels decline.

The quantity of water in each component of the budget varies with time, but over the long term, the budget balances. An increase in recharge as precipitation or regional inflow to an area will be balanced by an increase in discharge as evapotranspiration or subsurface outflow, by rising water levels reflecting an increase in storage, or by both of these adjustments. An equation for the water budget for the natural system is:

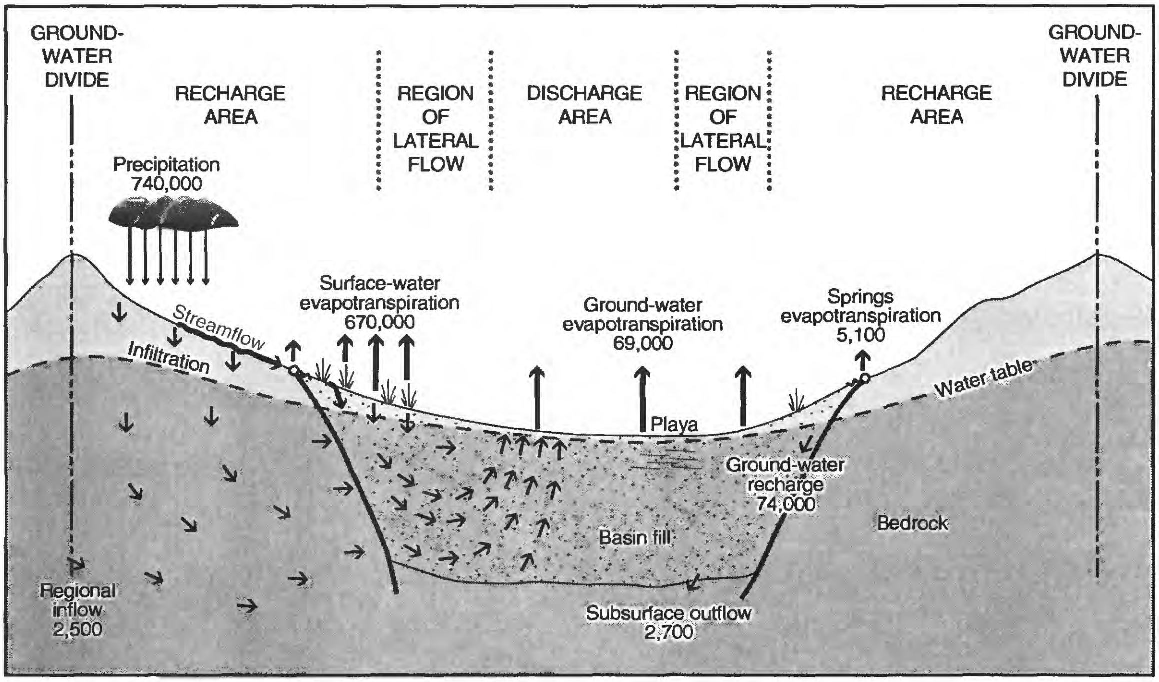
$$\begin{aligned}&\text{Precipitation} + \text{Regional Inflow}\\ &\quad = \text{Evapotranspiration} + \text{Subsurface Outflow}\\ &\qquad + \text{Change in Storage.}\end{aligned} \tag{2}$$

In a natural system at equilibrium, recharge equals discharge and the quantity in storage does not change. When the system is developed (pumped), ground-water withdrawals will increase the discharge component, and water levels will decline, decreasing water in storage. Evapotranspiration and subsurface outflow may decrease and recharge may increase until a new equilibrium is reached. An equation for the water budget for the developed system is:

$$\begin{aligned}&\text{Precipitation} + \text{Regional Inflow}\\ &\quad = \text{Evapotranspiration}\\ &\qquad + \text{Subsurface Outflow}\\ &\qquad + \text{Ground-Water Withdrawals}\\ &\qquad + \text{Change in Storage.}\end{aligned} \tag{3}$$

The hydrologic cycle and water budget for an average year in northern Big Smoky Valley for natural and developed conditions are illustrated in figure 5. In this report, the ground-water components of the hydrologic cycle are emphasized.

A



B

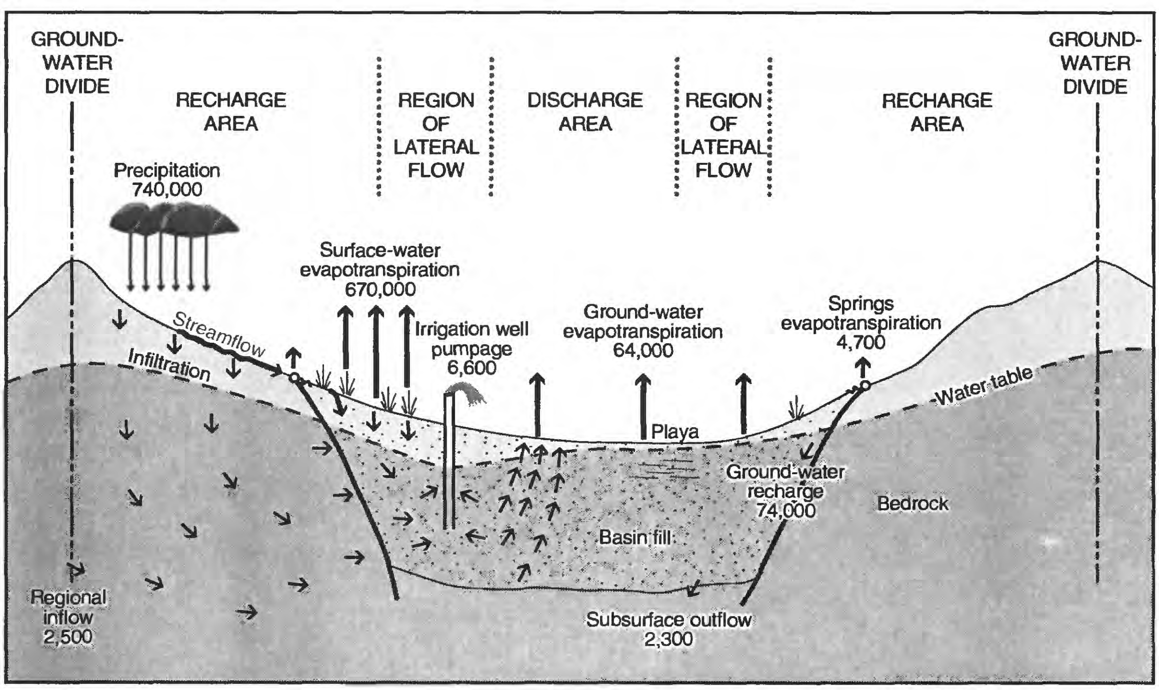


Figure 5. Major elements of hydrologic cycle and average annual water budget, northern Big Smoky Valley, Nevada, under (*A*) natural and (*B*) pumping conditions. Values in acre-feet of water per year. Evapotranspiration based on model simulations. Arrows (shown only on left side of figure) indicate general direction of water movement.

GROUND-WATER BUDGET

Components of the ground-water budget are ground-water recharge, ground-water discharge, and ground-water storage. They are discussed in detail and quantified for northern Big Smoky Valley in the following sections of the report.

Ground-Water Recharge

Sources of ground-water recharge in the basin are (1) direct infiltration of precipitation into the basin-fill aquifer and some subsurface inflow from adjacent bedrock within the basin; (2) infiltration of water from streams, ponds, and irrigation ditches; (3) seepage of irrigation return flows and wastewater disposal; and (4) regional inflow from other basins. In Big Smoky Valley, surface-water infiltration supplies most of the ground-water recharge.

Precipitation

Northern Big Smoky Valley is typical of Great Basin valleys in that little precipitation falls directly on the basin fill. Most precipitation accumulates as snow on the bedrock uplands, melts during the spring, and seeps into the basin-fill aquifer from streams or through bedrock as subsurface inflow.

Mean annual precipitation is much greater in the mountains than on the valley floor, ranging from more than 20 in. at altitudes higher than 9,000 ft above sea level to less than 8 in. at altitudes below 6,000 ft (Price and others, 1974, sheet 1). Most of the high-altitude areas are in the southern and western parts of the basin (fig. 2), hence more precipitation falls, more snow accumulates, and more water runs off these areas. Total precipitation over northern Big Smoky Valley in an average year is estimated at 740,000 acre-ft. Estimates of recharge made for this study, however, indicate that only about 10 percent of this is available to recharge ground water in the natural (undeveloped) system. The remainder evaporates or is transpired by vegetation before it can infiltrate to the water table.

National Oceanographic and Atmospheric Administration records from Austin, Nev., the nearest climatological station for which long-term records are available, show that mean annual precipitation for the 98 years of available data between 1878 and 1985 was 12.7 in. and that the rate varied seasonally, from a mean of about 1.5 in/mo during late winter and early spring (March, April, and May) to about 0.5 in/mo during summer (July, August, and September), as shown in figure 6 (National Climatic Center, 1879-1986; data for some early years are incomplete). Precipitation records from sites at different altitudes indicate that seasonal variations are greatest in the mountains; less precipitation reaches the valley floor and precipitation on the valley floor is more evenly distributed throughout the year (Rush and Schroer, 1968, p. 26-28).

Total annual precipitation at Austin (altitude, 6,605 ft above sea level) ranged from 5.9 in. in 1959 to 22.4 in. in 1983. Cumulative departure from mean annual precipitation, shown in figure 7, indicates the cyclical nature of wet periods (positive slope—during the 1970's, for example) and dry periods (negative slope—during the 1950's, for example). Precipitation during 1965-85 averaged 15.0 in., 18 percent greater than the long-term average, and precipitation during 1981-85 averaged 16.9 in., 33 percent greater than the long-term average. Streamflow and recharge were correspondingly greater than average during this period.

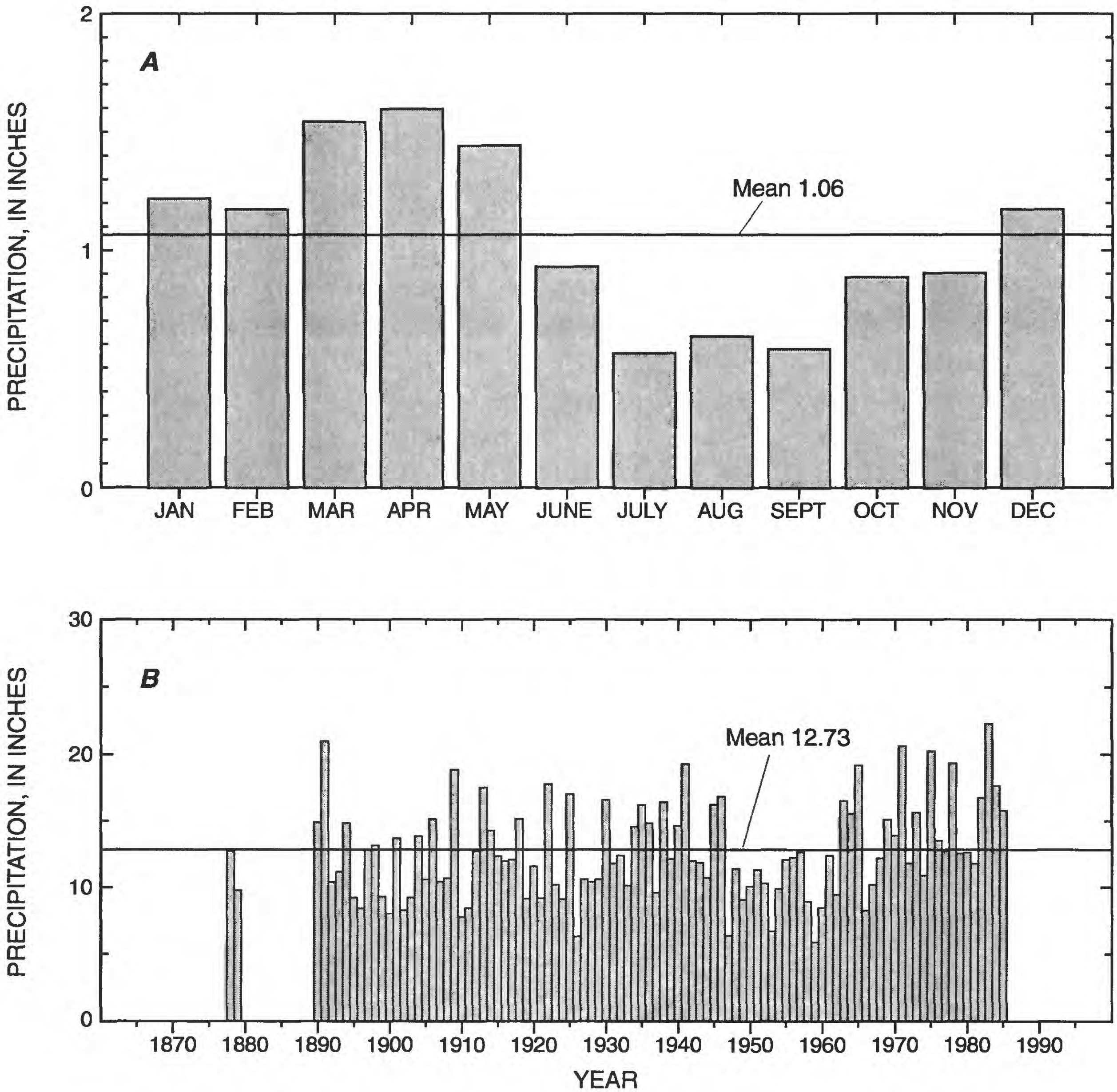


Figure 6. Mean monthly (*A*) and annual mean (*B*) precipitation at Austin, Nevada, water years 1878-1985. Space indicates missing or incomplete annual data, 1880 to 1889.

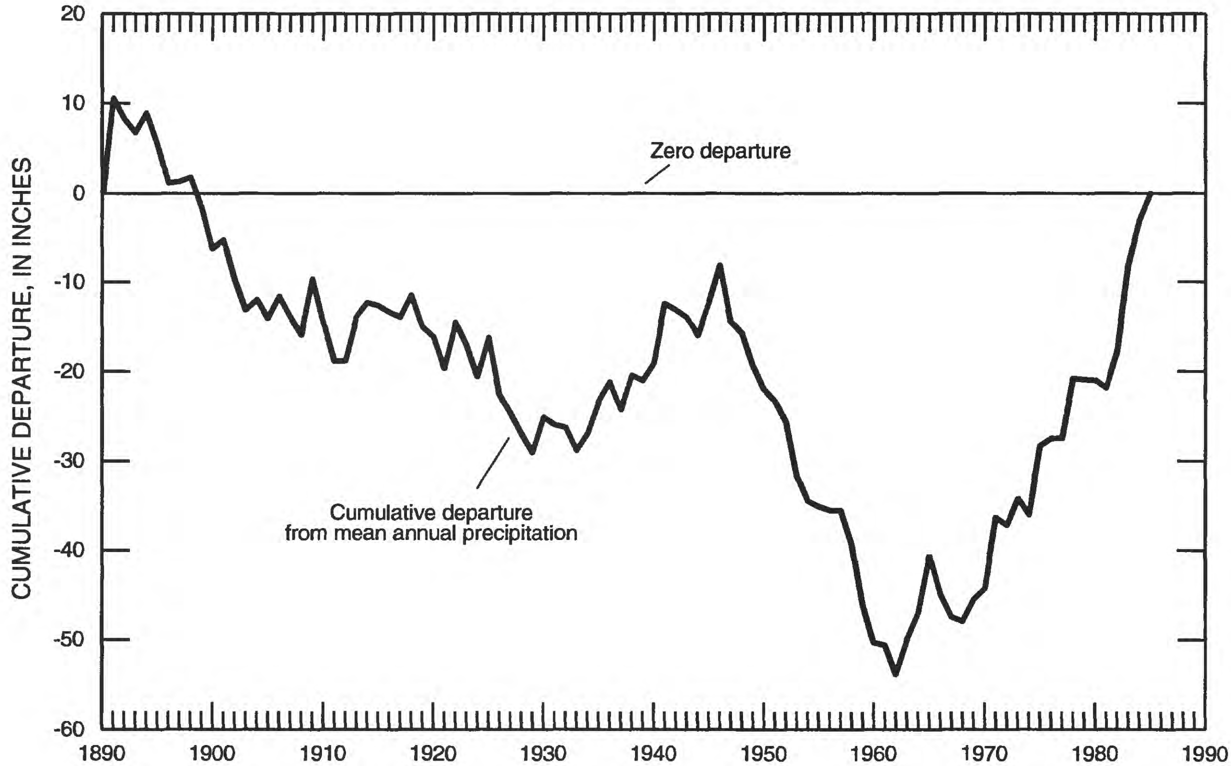


Figure 7. Cumulative departure from mean annual precipitation at Austin, Nevada, 1890-1985.

Surface Water

Infiltration of streamflow from about 50 streams is a major source of recharge to aquifers in northern Big Smoky Valley. As shown in figure 8, the streams originate and terminate within the basin, and most have their headwaters in the Toiyabe Range on the west. The flow in each stream depends primarily on the amount of precipitation in its drainage area. Most of the streams are perennial in the mountains on the west and intermittent in the mountains on the east and in the valley; almost all the streamflow seeps into the basin fill directly through stream-bottom sediments and unlined ditches before it reaches the valley floor. Some surface water diverted for irrigation also infiltrates to ground water. Streamflow, therefore, can be used as an estimate of potential ground-water recharge. Furthermore, if a relation between precipitation and streamflow can be shown, precipitation could be used to estimate streamflow, and thus potential recharge, in areas where streamflow data are sparse or unavailable.

The relation between annual precipitation at Austin and annual mean streamflow measured at streamflow-gaging stations on South Twin River near Round Mountain (USGS station 10249300), Kingston Creek below Cougar Canyon near Austin (USGS station 10249280), and Reese River near Ione (USGS station 10325500) is shown in figures 9 and 10. Reese River, located just outside the basin to the west, is included for comparison because it has a longer history of continuous flow measurements. The discharge of Kingston Creek and South Twin River is compared with the discharge of Reese River (fig. 11). These streams are used to demonstrate the relation between precipitation and streamflow for an extended period. South Twin River streamflow correlates better than Kingston Creek streamflow with Reese River streamflow (figs. 10 and 11) because South Twin and Reese Rivers have their headwaters in the same mountains and their basins have similar characteristics. Kingston Creek annual streamflow correlates better than South Twin and Reese River annual streamflow with Austin precipitation (figs. 9 and 10), probably because the Kingston Creek drainage area is nearer to the Austin weather station where precipitation was measured.

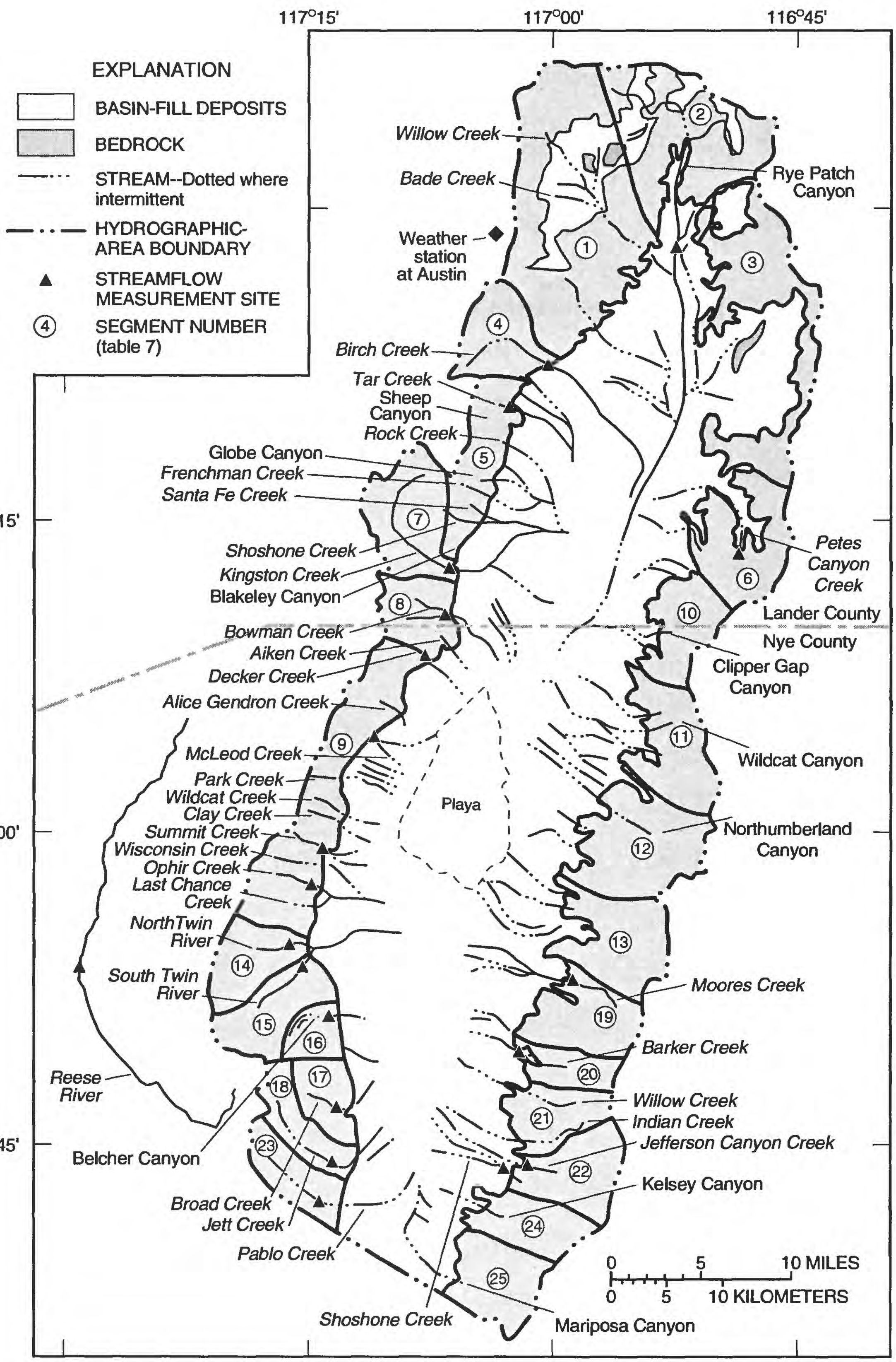


Figure 8. Streams, streamflow-measurement sites, and basin segments, northern Big Smoky Valley, Nevada.

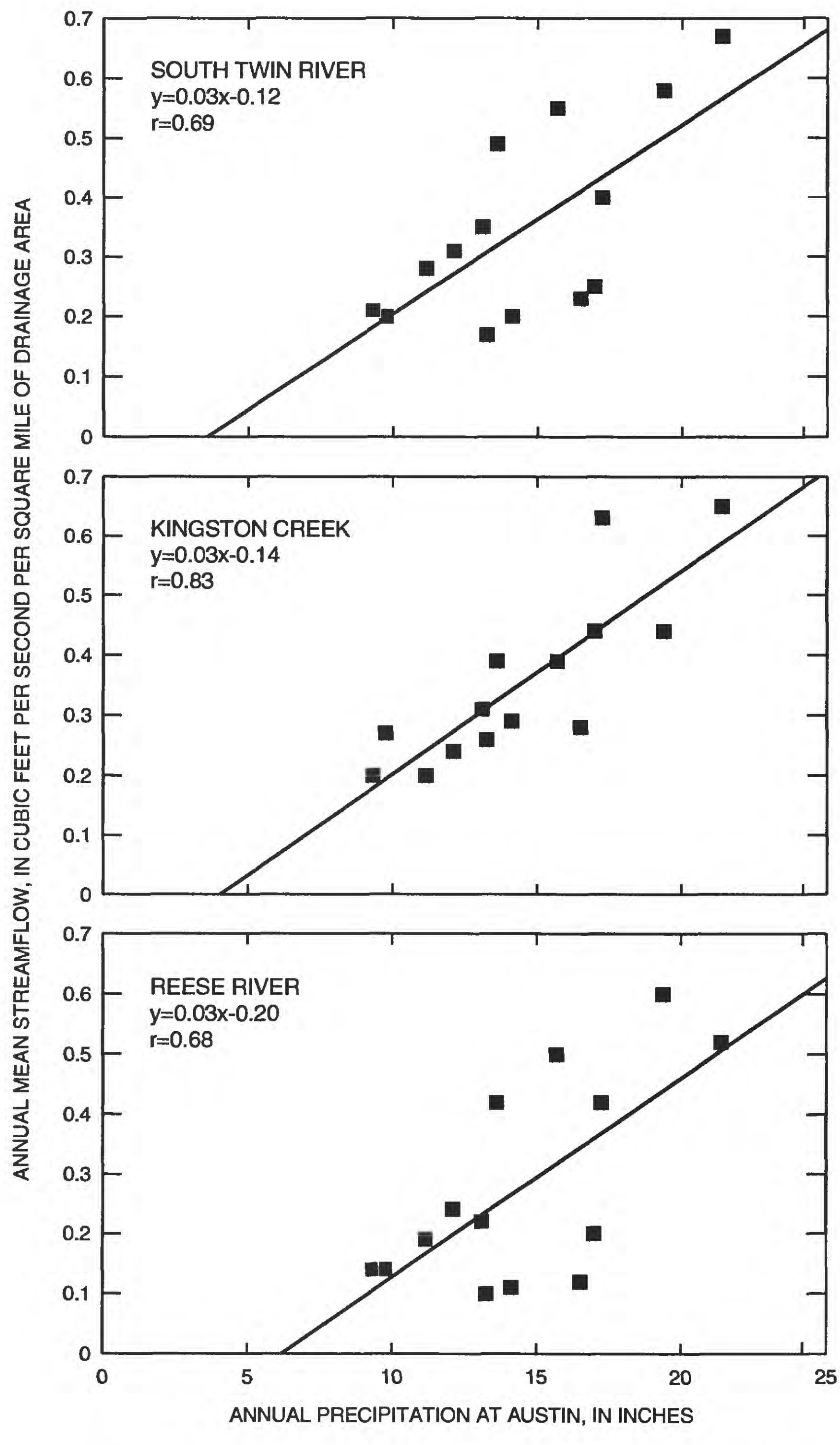


Figure 9. Relations between annual precipitation at Austin and annual mean streamflow of South Twin River near Round Mountain (station 10249300), Kingston Creek below Cougar Canyon near Austin (station 10249280), and Reese River near Ione (station 10325500), water years 1967-80. For each graph, equation of regression line and correlation coefficient (r) are indicated.

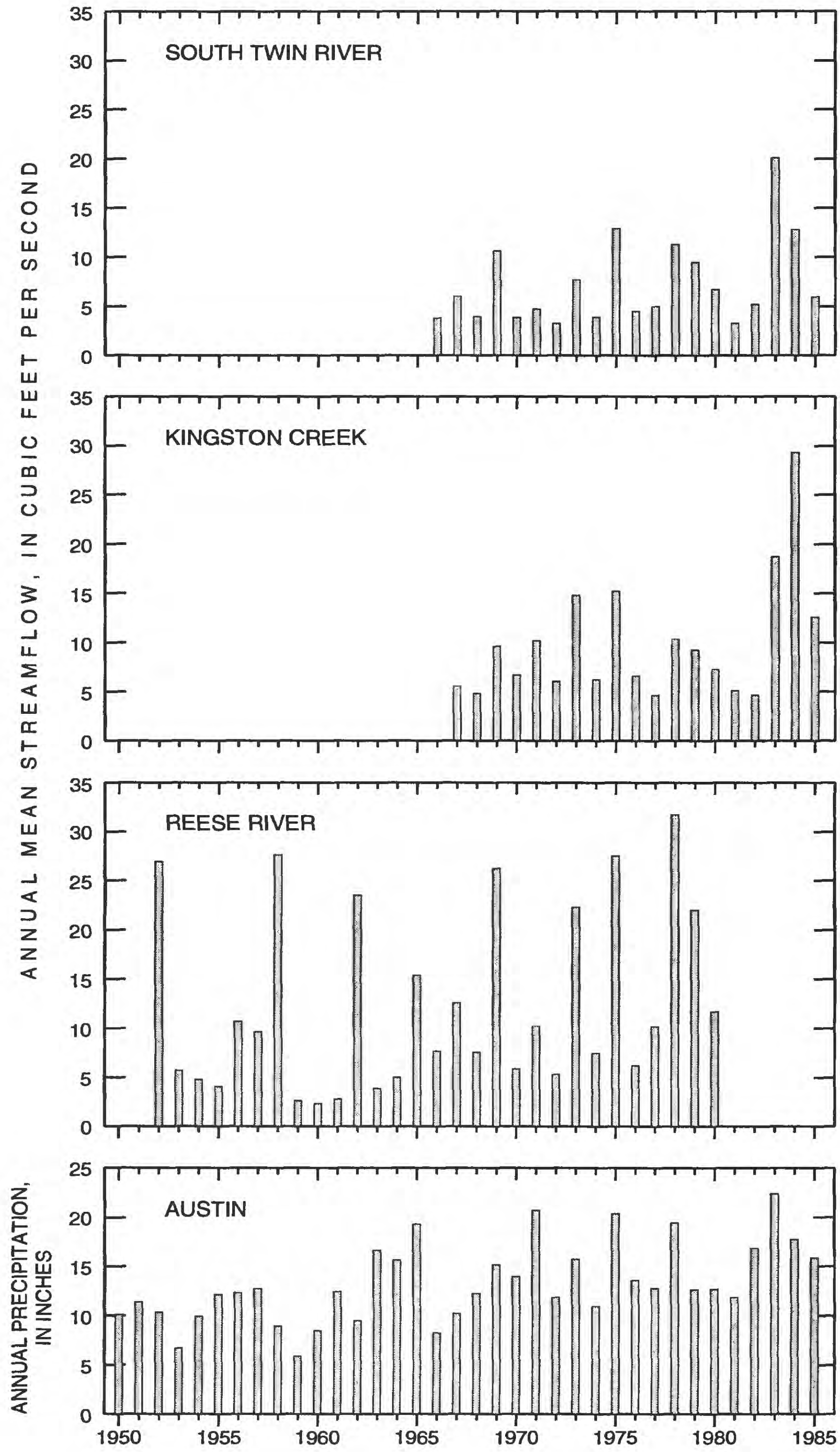


Figure 10. Annual mean streamflow at South Twin River near Round Mountain (station 1024930), 1967-85, Kingston Creek below Cougar Canyon near Austin (station 10249280), 1968-85, and Reese River near Ione (station 10325500), 1952-80, and annual precipitation at Austin, 1950-85. Streamflow-measurement sites are shown in figure 8.

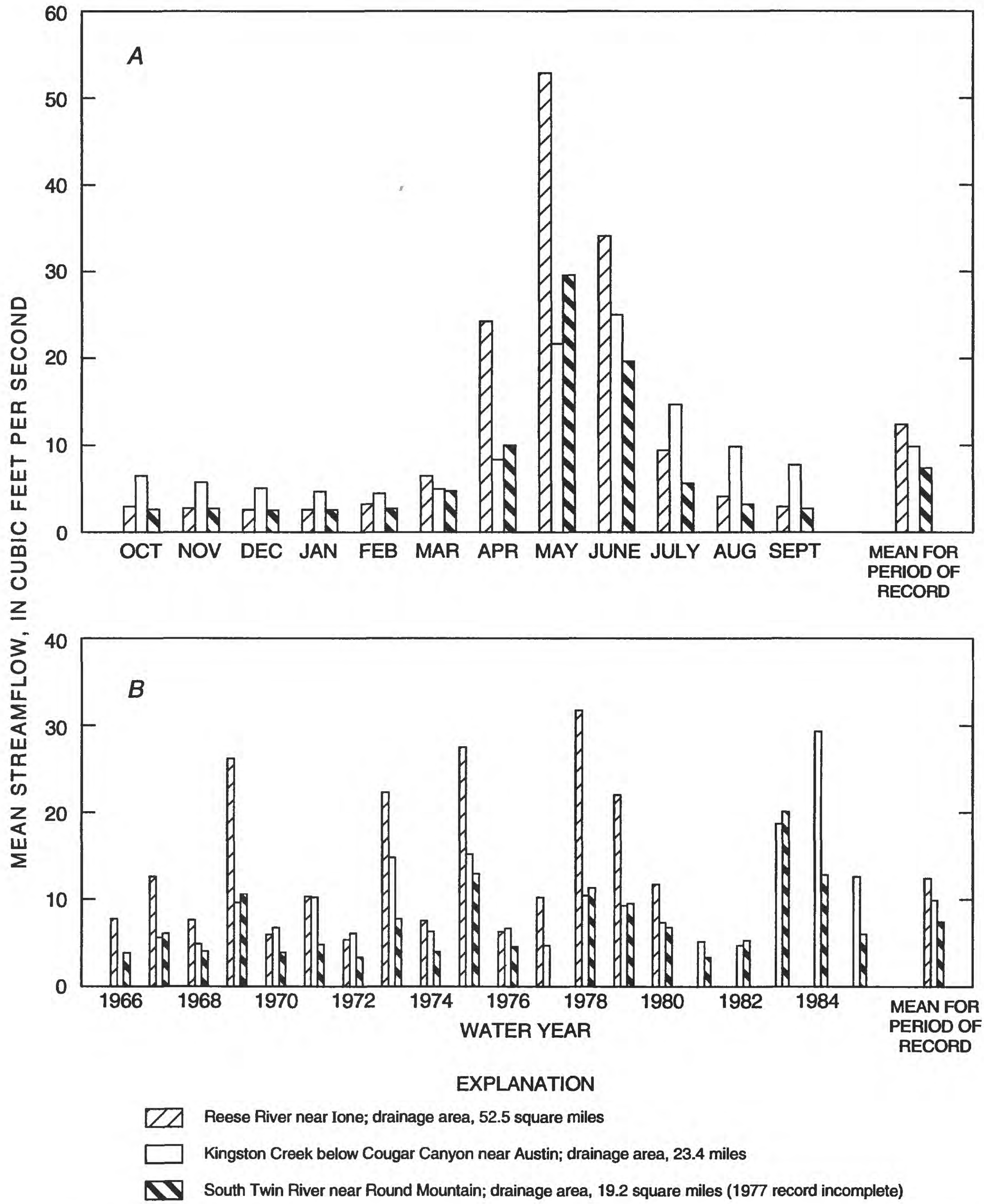


Figure 11. Monthly mean streamflow of (*A*) Reese River (1951-81), Kingston Creek (1967-85), and South Twin River (1966-85), central Nevada, and annual mean streamflow (*B*), 1966-85.

The quantity of streamflow that becomes ground-water recharge was estimated from 30 sets of seepage measurements along six streams in Big Smoky Valley during 1968. Although the measurements are not sufficient to accurately quantify recharge, they indicate that an average of less than 1,500 acre-ft could infiltrate from each perennial stream annually (Rush and Schroer, 1970, p. 30), and a smaller quantity would infiltrate from each intermittent stream. In many places, seepage is restricted by lined ditches and pipelines that carry water to fields for irrigation. Nevertheless, some of the excess irrigation water eventually infiltrates.

To estimate potential ground-water recharge in the basin, the upland area (altitude, above 6,000 ft) was conceptually divided into 25 segments, each of which includes a stream or group of streams (fig. 8). For each segment, three estimates of ground-water recharge were made: potential recharge was estimated by the method of Maxey and Eakin (1949), mean runoff was estimated by the method of Moore (1968), and mean annual streamflow of selected streams was calculated by a method modified from that of Riggs (1969). These methods all exclude the part of precipitation that directly infiltrates bedrock or evaporates before it reaches streams; all assume that streamflow generally infiltrates before reaching the valley floor, evapotranspiration of ground water is insignificant in uplands because of the great depth to the water table in these areas, and evaporation from the stream is insignificant. The Maxey-Eakin and Moore methods utilize the relation between precipitation and runoff. Potential recharge and mean runoff are considered to be about the same in the upland area because the basin is closed and has relatively impermeable bedrock and, for the same reason, both are considered to be approximately equal to mean streamflow.

The three methods were compared in three areas for which long-term continuous records of streamflow are available—the South Twin River, Kingston Creek, and Reese River Basins. Results of estimates, shown in table 4, are within 20 percent of long-term (34 years) mean annual flow adjusted from continuous-measurement records, indicating that reasonable estimates of recharge can made by these methods in areas that have few or no streamflow measurements. Riggs' method is the most accurate because it uses actual streamflow measurements, but it can be applied only where streamflow measurements are available. Maxey and Eakin's method gave more consistent results than Moore's in comparison with measured streamflow for the three test areas.

Table 4. Mean annual streamflow, runoff, and potential recharge of South Twin River, Kingston Creek, and Reese River, Nevada, 1952-85

[Except where indicated, values in cubic feet per second; mi^2, square miles]

Streamflow gaging station (figure 8)	Drainage area (mi^2)	Period of record	Number of years of record	Measured flow [1]	Adjusted flow [2]	Estimated runoff [3]	Estimated potential recharge [4]	Calculated flow [5]
South Twin River [6]	19.2	1966-85	20	7.3	6.5	7.8	6.1	7.2
Kingston Creek [7]	23.4	1967-85	19	9.9	8.6	6.8	8.0	9.2
Reese River [8]	52.5	1952-80	29	12.4	13.9	12.7	13.8	--

[1] For period of record.
[2] Measured flow at gaging station adjusted to long term (1952-1985; 34 years).
[3] Runoff for drainage area upstream from gaging station, calculated by method of Moore (1968).
[4] Recharge for drainage area upstream from gaging station, calculated by method of Maxey and Eakin (1949).
[5] Long-term mean flow calculated by method of Riggs (1969) from selected measurements (correlated with measured flow at Reese River near Ione, U.S. Geological Survey streamflow gaging station 10325500).
[6] South Twin River near Round Mountain (U.S. Geological Survey streamflow gaging station 10249300).
[7] Kingston Creek below Cougar Canyon near Austin (U.S. Geological Survey streamflow gaging station 10249280).
[8] Reese River near Ione (U.S. Geological Survey streamflow gaging station 10325500).

Riggs' method for estimating monthly and annual mean streamflow from ungaged basins uses single measurements made on the 15th day of each month for a 1-year period. Each value is correlated with the monthly mean streamflow from a continuous gaging station on a nearby stream to develop an estimated monthly mean. The annual mean streamflow is computed from the estimated monthly means and is then correlated with the mean annual streamflow from the long-term continuous gaging station. The method was modified for this study because flow was measured only seven times in 18 ungaged streams and estimated for 7 other streams in the basin during the 1968 water year. Each measurement was assumed to represent a 1- to 4-month period of relatively stable streamflow and was correlated with monthly mean flow of either South Twin River or Kingston Creek, depending on seasonal distribution of flow. The 19 streams where peak runoff occurred early in the spring were compared with South Twin River; the 4 streams where peak runoff occurred later in the spring were compared with Kingston Creek, which also peaks late. Results are shown in table 5.

To test the applicability of the modified Riggs' method, the method was used to calculate 1968 monthly mean, 1968 annual mean, and mean annual streamflows of South Twin River and Kingston Creek by correlation with streamflow of the Reese River. The results were compared with mean streamflows from continuous measurements. First, single measurements from the 15th day of each month during the 1968 water year were used (standard method), then seven measurements corresponding to the dates of miscellaneous measurements for the 18 ungaged streams were used (modified method). Results are summarized in table 6.

Table 5. Mean annual streamflow of 25 selected streams, northern Big Smoky Valley, Nevada

[Abbreviations: acre-ft, acre feet; ft³/s, cubic feet per second; mi², square miles]

Streamflow measurement site [1] (figure 8)	Drainage area [2] (mi^2)	Mean annual streamflow [3]		Method of calculation [4]
		ft^3/s	acre-ft	
Moores Creek	8.5	1.0	720	K
Barker Creek	7.5	1.8	1,300	S
Jefferson Canyon Creek	20.6	1.5	1,100	S
Shoshone Creek	6.1	.3	220	S
Pablo Canyon Creek	10.7	3.6	2,600	ES
Jett Creek	7.3	2.5	1,800	S
Broad Creek	6.1	1.6	1,200	S
Belcher Creek	5.1	1.6	1,200	S
South Twin River	19.2	7.3	5,300	A
North Twin River	15.2	4.8	3,500	S
Last Chance Creek	3.8	1.2	870	ES
Ophir Creek	3.9	1.5	1,100	S
Summit Creek	2.9	.9	650	S
Mcleod Creek	2.9	1.4	1,000	S
Decker Creek	2.4	1.3	940	S
Aiken Creek	1.8	1.2	870	ES
Bowman Creek	7.0	2.5	1,800	K
Kingston Creek	23.4	9.9	7,200	B
Blakely Canyon Creek	1.0	.2	140	EK
Globe Creek	2.0	.7	510	ES
Sheep Canyon Creek	2.8	.6	430	S
Tar Creek	2.2	.3	220	S
Birch Creek	17.5	2.2	1,600	K
Bade Creek	2.6	.4	290	ES
Willow Creek	8.8	5.7	4,100	ES
Total	191.3	56.0	40,660	

[1] Clockwise around basin, starting from the east. Streams that drain less than 3 mi² above the mouth of the canyon are intermittent most years; streams that drain more than 10 mi² are perennial; intermediate streams are generally perennial at the mouth of the canyon, but may be intermittent downstream.

[2] Drainage area above site of streamflow measurement.

[3] Values are rounded.

[4] K, calculated from miscellaneous measurements, correlated with streamflow at Kingston Creek below Cougar Canyon near Austin (U.S. Geological Survey streamflow gaging station 10249280); S, calculated from miscellaneous measurements, correlated with streamflow at South Twin River near Round Mountain (U.S. Geological Survey streamflow gaging station 10249300); ES, estimated, compare with streamflow at South Twin River near Round Mountain (U.S. Geological Survey streamflow gaging station 10249300); A, based on continuous measurements, 1967-85; B, based on continuous measurements, 1966-85; EK, estimated, compare with streamflow at Kingston Creek below Cougar Canyon near Austin (U.S. Geological Survey streamflow gaging station 10249280).

Table 6. Mean streamflow estimated from miscellaneous streamflow measurements by Riggs' standard and modified methods, northern Big Smoky Valley, Nevada

[Streamflow values in cubic feet per second]

Streamflow gaging station (figure 8)	Measured streamflow		Standard method [1]				Modified method [2]			
			Calculated streamflow		Percent difference [3]		Calculated streamflow		Percent difference [3]	
	1968 mean	Mean annual [4]	1968 mean	Mean annual [5]	1968 mean	Mean annual [5]	1968 mean	Mean annual [5]	1968 mean	Mean annual [5]
South Twin River [6]	4.0	7.3	3.9	7.2	-2	-1	3.9	7.2	-2	-1
Kingston Creek [7]	4.8	9.9	5.4	9.8	+12	-1	5.0	9.2	+4	-2

[1] Streamflow on 15th day of each month during 1968 water year represents mean streamflow for that month; the values are related to monthly mean streamflows of Reese River near Ione (U.S. Geological Survey streamflow gaging station 10325500) for the 1968 water year to develop estimated monthly means. Annual mean streamflow computed from estimated monthly means. Mean annual streamflow estimated from computed annual mean by correlation with mean annual streamflow of Reese River near Ione (U.S. Geological Survey streamflow gaging station 10325500). Method described by Riggs (1969).

[2] Streamflow from seven miscellaneous measurements during 1968 water year represent unequal periods of 1 to 4 months each, related to monthly mean flows of Reese River near Ione (U.S. Geological Survey streamflow gaging station 10325500) for 1968 water year. Method modified from Riggs (1969).

[3] Difference between calculated and measured streamflow as percent of measured flow.

[4] Mean annual streamflow based on continuous measurements for period of record (1967-85 for South Twin River near Round Mountain (U.S. Geological Survey streamflow gaging station 10249300) and 1966-85 for Kingston Creek below Cougar Canyon near Austin (U.S. Geological Survey streamflow gaging station 10249280).

[5] Mean annual streamflow correlated with Reese River near Ione (U.S. Geological Survey streamflow gaging station 10325500), 1952-85.

[6] South Twin River near Round Mountain (U.S. Geological Survey streamflow gaging station 10249300).

[7] Kingston Creek below Cougar Canyon near Austin (U.S. Geological Survey streamflow gaging station 10249280).

Reese and South Twin Rivers have similar streamflow characteristics because both streams originate on Toiyabe Dome and traverse similar geologic terrain. Kingston Creek is different because its streamflow characteristics are affected by secondary porosity of carbonate rocks in the drainage area and by faulting related to the Roberts Mountain Thrust. Secondary porosity and faults increase temporary storage, resulting in a delayed seasonal peak and higher base flows. The differences in flow characteristics are shown in figure 12, which compares hydrographs for Kingston Creek and South Twin River for water year 1980, a typical year in terms of amount and seasonal distribution of precipitation. Kingston Creek has a greater mean streamflow than South Twin River mainly because it drains a larger area. Its mean annual streamflow per square mile of drainage area is slightly larger (0.42 ft^3) than that of South Twin (0.38 ft^3) because more of its drainage area is above 9,000 ft, where more snow accumulates. Since 1970, flow of Kingston Creek has been affected by storage in Groves Reservoir, about 4 mi upstream from the gaging station. However, the reservoir capacity is only 190 acre-ft, and a comparison with hydrographs from years prior to construction shows that its effects are negligible. Kingston Creek also may drain a larger area than encompassed by its topographically defined divide, but available data are insufficient to verify this possibility.

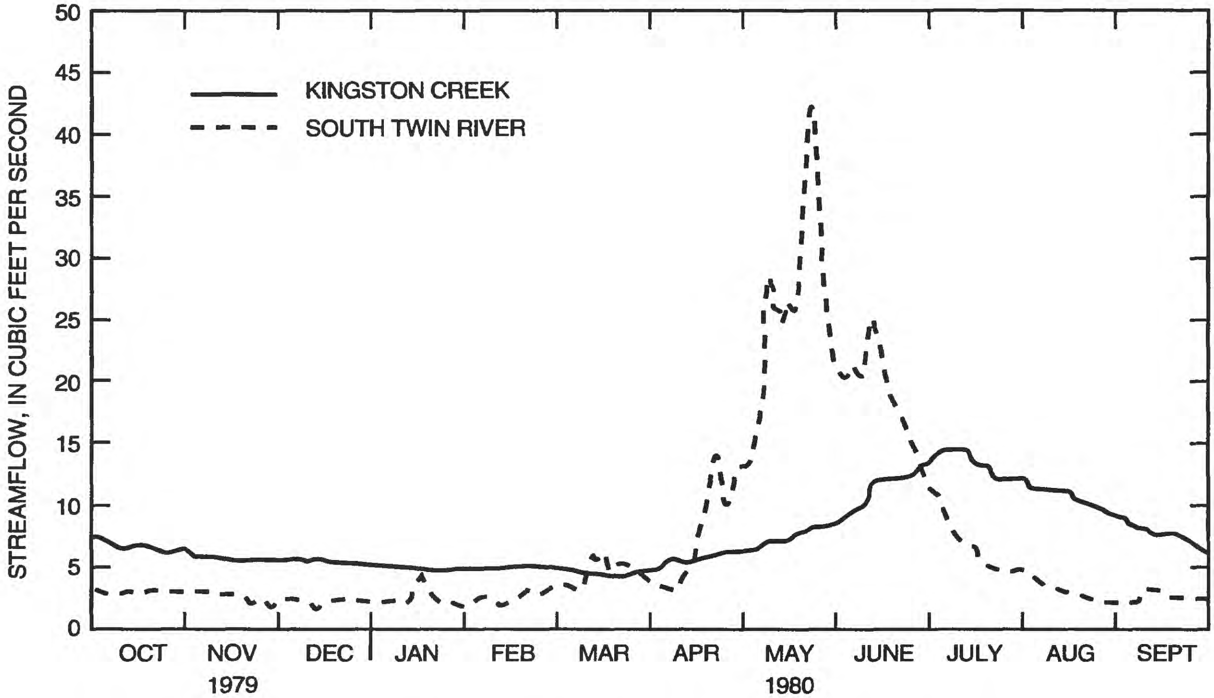


Figure 12. Daily streamflow for Kingston Creek (station 10249280) and South Twin River (station 10249300), northern Big Smoky Valley, Nevada, water year 1980.

Potential recharge estimated by the method of Maxey and Eakin (1949) for the 25 upland-area segments shown in figure 8 are shown in table 7. The total mean annual recharge estimated by this method is about 72,300 acre-ft for the basin. Total estimated streamflow from the 25 streams listed in table 5 accounts for only about 56 percent of the potential recharge from all upland areas. This is partly because the total drainage area of the 25 measured streams, 191.3 mi^2, amounts to only about one-fourth of the total upland area. The remaining (potential estimated) recharge infiltrates from smaller intermittent streams and directly from melting snow in the intervening uplands. For some segments (1, 7, 15, and 23), mean annual streamflow from measurements is slightly higher than recharge estimated by the Maxey and Eakin method (compare tables 5 and 7). The estimate of recharge based on measured streamflow is used for these segments because it is considered more accurate. This brings the total mean annual recharge from direct infiltration of precipitation and surface-water sources, as estimated from precipitation, topography, altitude, streamflow, and seepage relationships, to about 74,000 acre-ft. Most of the total recharge, about 37 percent, occurs in the southwest part of the basin; 29 percent occurs in the northwest; 26 percent in the southeast; and only 8 percent in the northeast.

Table 7. Estimates of potential mean annual recharge from upland areas, northern Big Smoky Valley, Nevada

[Abbreviations: acre-ft, acre feet; ft^3/s, cubic feet per second; mi^2, square miles]

Segment number (figure 8)	Segment area (mi^2)	Estimated recharge [1]		Streams or channels in segment [2]
		ft^3/s	acre-ft	
1	92.7	4.6	3,300	Willow Creek, Bade Creek, three unnamed channels.
2	61.6	2.4	1,700	Rye Patch Canyon.
3	60.6	1.8	1,300	Five unnamed channels.
4	20.8	2.7	2,000	Birch Creek.
5	38.1	6.0	4,440	Spanish, Lynch, Tar, Rock, Crooked, Frenchman, Santa Fe, Shoshone, and lower Kingston Creeks; and Blakely, Globe, and Sheep Canyons.
6	27.9	1.4	1,000	Petes Canyon Creek.
7	23.4	8.0	5,800	Kingston Creek.
8	15.5	3.0	2,200	Carsley, Clear, Aiken, and Bowman Creeks.
9	67.5	11.7	8,500	Decker, Alice Gendron, Decker Bob, McLeod, Park, Wildcat, Clay, Summit, Wisconsin, Ophir, Last Chance, and Hercules Creeks.
10	25.9	1.8	1,300	Clipper Gap Canyon, five unnamed channels.
11	32.4	3.2	2,300	Wildcat Canyon, four unnamed channels.
12	41.4	3.1	2,200	Northumberland Canyon, six unnamed channels.
13	43.6	2.9	2,100	Eight unnamed channels.
14	16.8	5.1	3,700	North Twin River.
15	19.2	6.1	4,400	South Twin River.
16	16.5	3.8	2,800	Belcher Canyon, Cove Creek, eight unnamed channels.
17	14.4	2.9	2,100	Devils Creek, Broad Creek, four unnamed channels.
18	12.6	3.0	2,200	Jett Creek.
19	28.1	4.1	3,000	Moores Creek, Anderson Creek, seven unnamed channels.
20	24.1	3.9	2,800	Barker Creek, four unnamed channels.
21	18.8	2.5	1,800	Willow Creek, Indian Creek.
22	29.8	8.4	6,100	Shoshone Creek, Jefferson Canyon Creek, three unnamed channels.
23	15.4	2.5	1,800	Pablo Creek.
24	20.8	2.2	1,600	Kelsey Canyon.
25	26.5	2.6	1,900	Mariposa Canyon, three unnamed channels.
Total, rounded	794.4	99.7	72,300	

[1] Estimated by method of Maxey and Eakin (1949), rounded.

[2] Most named streams are shown in figure 8; unnamed channels are primarily intermittent and ephemeral streams.

Irrigation and Other Return Flows

About 6,600 acre-ft of ground water was withdrawn from wells in northern Big Smoky Valley during 1985 for mining, irrigation, stock watering, public supply, and private domestic use. Most ground water withdrawn each year is consumed, but some seeps back into the ground. About 15 to 25 percent is assumed to return to the ground-water system by infiltration of irrigation return flows and seepage from disposal systems. Part of this is water in excess of crop needs that is applied to fields for leaching accumulated salts from soils. Rush and Schroer (1970, p. 45-46) estimate that a reasonable leaching requirement for fields of alfalfa and other salt-tolerant crops in the area is 50 acre-ft per 1,000 acre-ft of applied water. Additional water percolates to the water table from ditches, from field applications in excess of crop and leaching requirements, and from mining operations.

Domestic use accounts for less than 2 percent of ground-water withdrawal in the basin, for a total of less than 150 acre-ft annually; therefore, domestic return flows are negligible. Annual return flow from all ground-water uses is estimated to be 1,100 acre-ft.

Subsurface Inflow

One source of ground-water recharge is precipitation and snowmelt that seeps into fractured bedrock in the mountains and flows into the basin-fill aquifer in the subsurface. This water can come from within or from outside a topographic basin. Fiero (1968, p. 50-51) and Rush and Schroer (1970, p. 69) suggest the possibility of leakage of water from Monitor Valley into northern Big Smoky Valley. Water levels in the floor of Monitor Valley are higher than those in Big Smoky Valley (Bedinger and others, 1984a, sheet 1), but that is insufficient evidence to confirm that a hydrologic connection exists between the basins. Results of the present study show that enough precipitation falls within the drainage area of northern Big Smoky Valley to maintain measured water levels in the vicinity of the proposed connection without requiring interbasin flow. However, the presence of thermal water at Spencer Hot Springs, McLeod (Smoky Valley) Ranch, Darroughs Hot Springs, and elsewhere in the basin indicates deep circulation.

Some of the thermal water may be derived from a regional flow system through faults and other openings in bedrock. Northern Big Smoky Valley is on the western edge of a geologic region in which carbonate (limestone and dolomite) rocks predominate. Large quantities of water may be transmitted through secondary porosity (fractures and solution cavities) in these carbonate rocks. Volcanic rocks in the basin may also store and transmit water. Carbonate rocks in the Toquima Range are more likely conduits for regional recharge; interlayered ash-flow tuffs and tuff-sediment units probably are less transmissive. The area is further characterized by faulting, which may impede flow in places and facilitate it in others. According to Trexler and others (1980; 1983), faults control the location of geothermal-resource areas and hot springs in Big Smoky Valley. Hot springs may originate where north- to northeast-striking basin-and-range normal faults intersect older west- to northwest-striking strike-slip faults. The areal distribution of carbonate rocks is shown in figure 3 and major faults and hot springs are shown in figure 13. Comparison of streamflow in sub-basins that include carbonate rocks and those that do not (fig. 12) indicates that some water is held in temporary storage in carbonate bedrock; most of the water in storage, however, probably originates as local precipitation. Recharge from regional inflow probably is only a minor contribution to total recharge of the system because most bedrock surrounding the valley is less permeable at depth; for this study, a total of 2,500 acre-ft/yr was assumed. Research on use of temperature data, chemical analyses, and stable isotopes to evaluate flow paths and sources of recharge (Mifflin, 1968; Trexler and others, 1980; Claassen and others, 1986) may provide methods to verify and quantify interbasin flow in future studies.

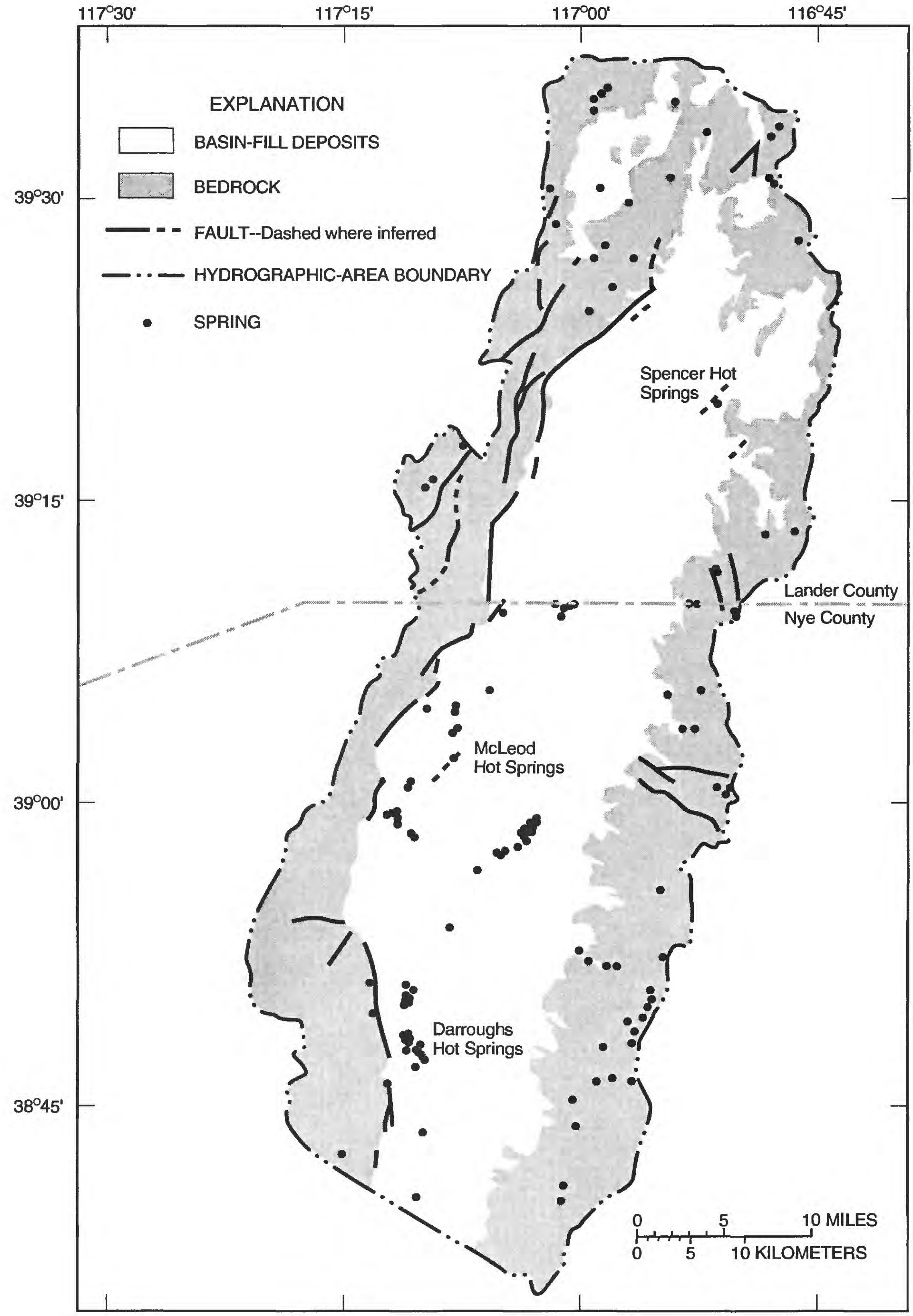


Figure 13. Major faults and springs, northern Big Smoky Valley, Nevada. (Fault locations modified from Kleinhampl and Ziony [1984], Nye County, and Stewart and McKee [1977], Lander County.)

Ground-Water Discharge

Under natural conditions, ground water discharges from the basin by evaporation from soils, transpiration by plants where the water table is close to land surface and subsurface outflow. Ground water that is discharged by springs either is consumed by evapotranspiration or infiltrates back into the ground. (Springs are shown in fig. 13.) No surface water flows out of the basin. About 75-85 percent of the water pumped from wells and applied to cultivated fields is evapotranspired. In northern Big Smoky Valley, the major means of ground-water discharge is evapotranspiration by natural vegetation.

Evapotranspiration

Most precipitation evaporates from the land surface (from open water or bare soil) or is transpired from soil moisture by shallow-rooted plants; about 90 percent of the precipitation in the basin discharges by evapotranspiration before it infiltrates to the water table. Where the water table is shallow, ground water either evaporates directly or is transpired by phreatophytes. The surface textures of bare playas are an indication of depth to ground water and potential for direct evaporation of ground water. A "puffy" surface in the playa west of Tonopah was correlated with shallow ground water and moist sediments. The "puffy" surface is caused by direct evaporation of ground water (Walker, 1966, p. 38-44; Walker and Motts, 1970, p. 148). Much of the playa in northern Big Smoky Valley has a puffy or transitional surface texture, similar to the textures described by Walker and Walker and Motts, which indicates that some ground water evaporates directly from the valley.

Evapotranspiration rates are related to daily and seasonal cycles; the rates respond to changes in air temperature and solar radiation, and—to a lesser extent—to wind speed and soil moisture. Evapotranspiration rates are greatest during the growing season, May through September, when temperatures are highest and periods of daylight are longest. Temperature variations for Austin are shown in figure 14. Average monthly temperature during the growing season for 47 years of available data for the period 1920-1985 at Austin ranged from 51.7°F in May to 70.4°F in July (National Climatic Center, 1921-1986).

The maximum depth of phreatophyte roots and rates of water consumption differ with species. Phreatophyte roots have been observed at 15 to 20 ft below land surface and, in some circumstances, may reach much deeper. Roots of big greasewood may extend 60 ft to ground water (Robinson, 1958, table 1). The amount of ground water transpired by phreatophytes depends on the depth to the water table, varieties and proportions of plants, and abundance of foliage.

Phreatophytes are prevalent around the playas in Big Smoky Valley. The most shallow-rooted and salt-tolerant plants are closest to the playas; more deeply rooted plants are farther away. Greasewood is the most extensive, followed by rabbitbrush and various phreatophytic grasses. Buffaloberry and pickleweed are common in some areas and small stands of cottonwood, willow, and wildrose grow in mountain canyons and near springs. The distribution of predominant phreatophytes, as determined by field mapping and vegetation transects made during 1984-85 and by interpretation of Landsat satellite data for May 30, 1979, and August 22, 1980, is shown in figure 15.

Patterns of land cover in different areas are related to moisture-retention capacities of soils and to sources of moisture—either precipitation or ground water (Miller and others, 1982). Therefore, where moisture contribution from precipitation is known, distribution and density of phreatophyte types can be used as an indication of rates of ground-water discharge. For this study, phreatophytes were mapped by both field observations and analysis of digital images of data from the Landsat satellite to (1) detect long-term changes in vegetation patterns, (2) determine the effects of above-average precipitation during 1983-84, (3) evaluate Landsat mapping techniques by comparison with maps produced by using field observations, and (4) estimate total evapotranspiration rates for comparison with previous estimates. The results of mapping are shown in figure 15.

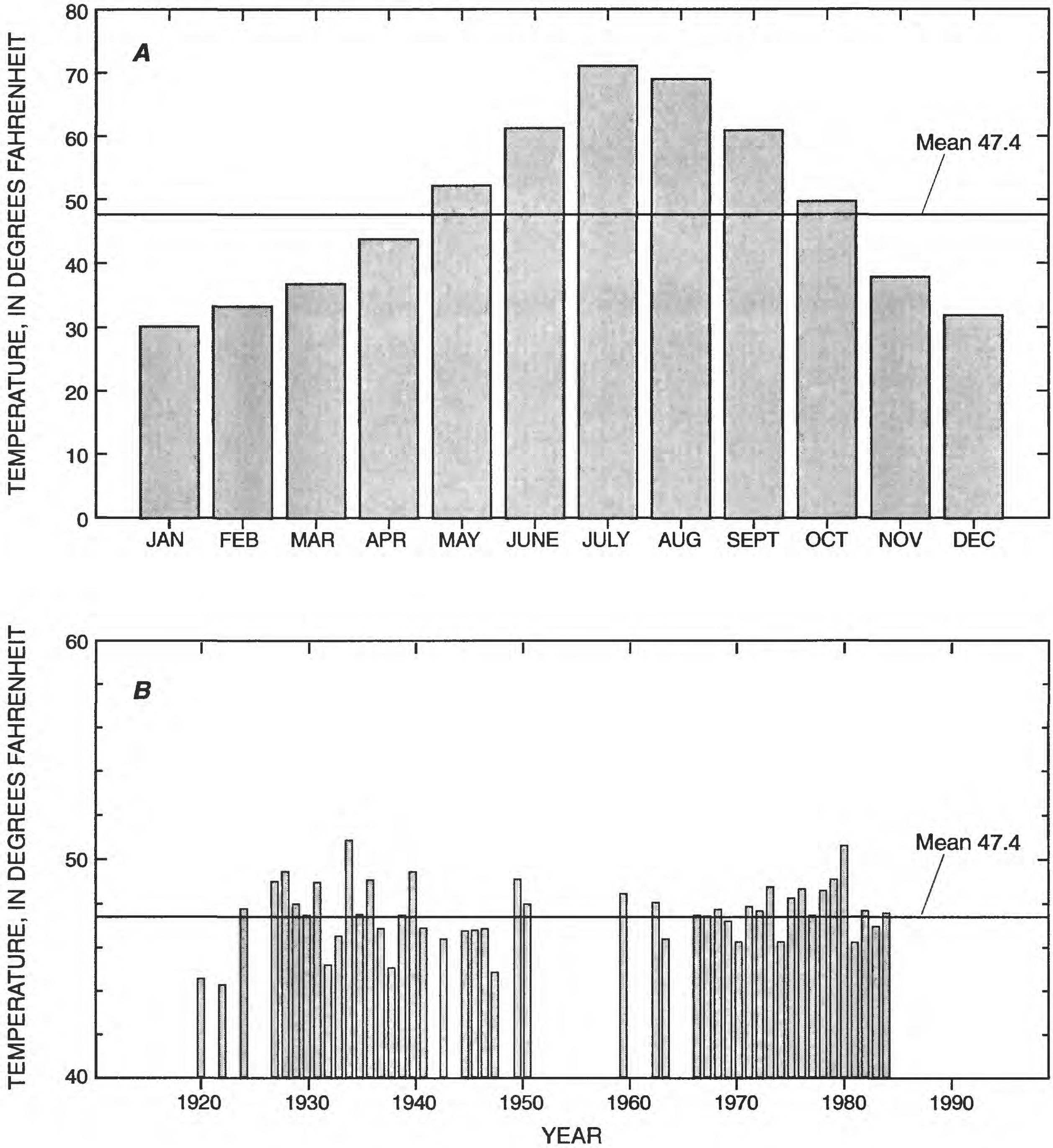


Figure 14. Monthly (*A*) and annual (*B*) mean temperatures at Austin, Nevada, 1920-85. (Space indicates missing or incomplete annual data.)

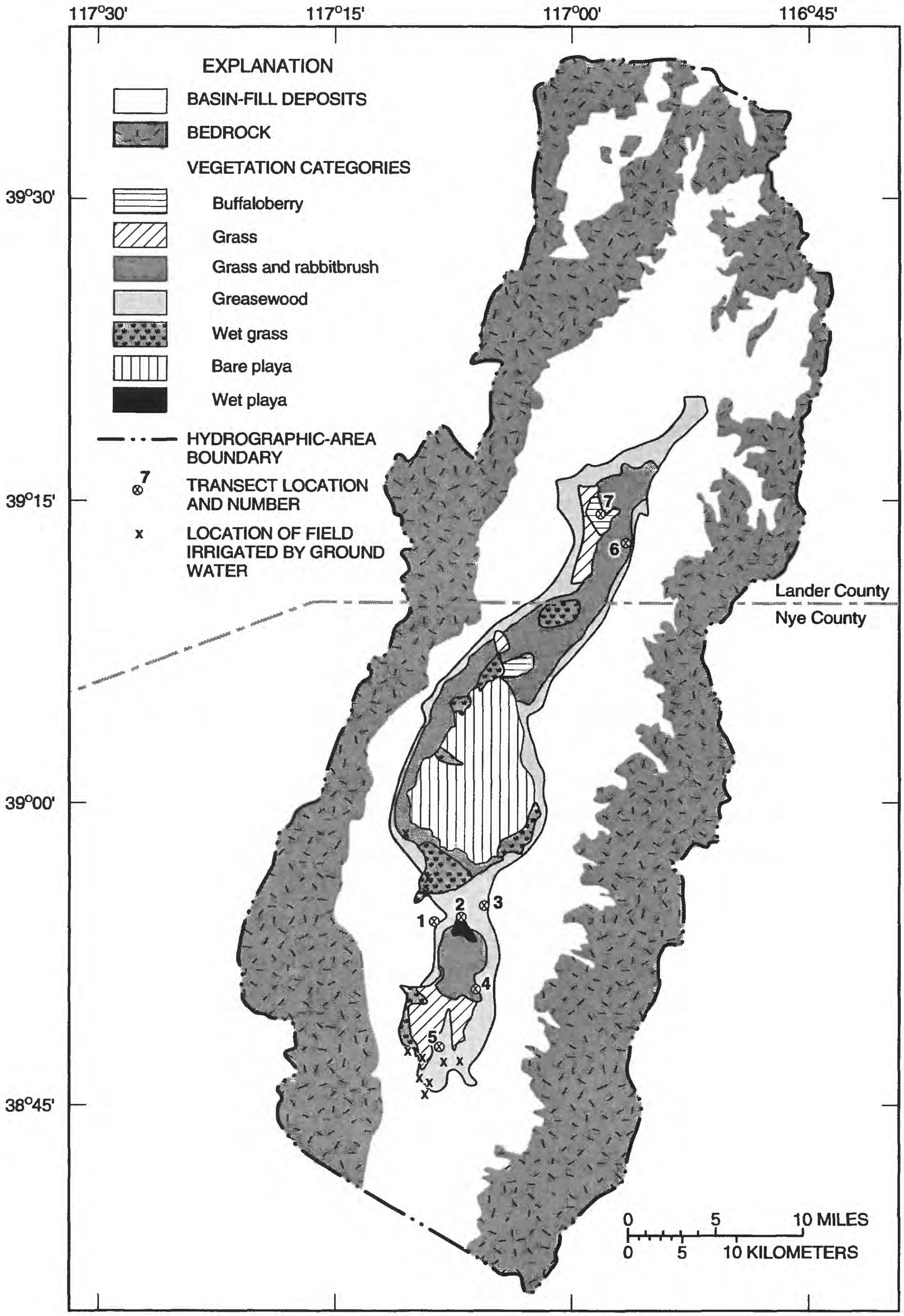


Figure 15. Distribution of vegetation, northern Big Smoky Valley, Nevada.

Long-term changes in vegetation were determined by comparing maps prepared by Meinzer (1917, pl. 2), Rush and Schroer (1970, pl. 1), U.S. Geological Survey (1984a; 1984b), and the more detailed phreatophyte survey produced in 1984 for this study (fig. 15). Comparisons show that areas of irrigated land and grass meadows have changed very little during the past 70 years because their existence and location depend primarily on the long-term availability of water from perennial streams and springs. Areas of bare playa are stable because the alkaline playa soil is unsuitable for vegetation. Other areas are suitable for cultivation, but only where adequate ground-water supplies can be developed or surface water piped in. Ground-water development for irrigation has been minor and is primarily in the south part of the basin.

Phreatophytes respond slowly to climatic change; response to annual variations in precipitation and temperature is minor. The observed effects of above-average precipitation during this study were (1) standing water on parts of the playa and (2) more lush vegetation throughout the basin. Individual shrubs were more vigorous, but they were probably not more numerous than in drier years. The overall distribution of phreatophytes did not appear to have been affected.

As part of the study of northern Big Smoky Valley, multispectral (4 bands) Landsat data from May 30, 1979, and August 22, 1980, were analyzed. Direct comparison of spectral characteristics of the two data sets was not possible by methods available at the time of the study because the data formats were incompatible. The digital data from May 1979 were processed using ELAS (Earth Resources Laboratory Applications Software), and both the 1979 and 1980 data sets were interactively analyzed using RIPS (Remote Information Processing System). Land cover was interpreted by visual inspection of photographs produced from the processed data. Edge- and feature-enhanced images and data-classification and grouping techniques were useful for verifying field maps of phreatophyte assemblages, especially in areas that were inaccessible by vehicles. The images could not be used for independent mapping of phreatophyte zones, however, nor could they be used for direct mapping of evapotranspiration rates.

Estimates of evapotranspiration rates in different areas were based on the maps of phreatophyte distribution. Foliage density, as well as phreatophyte assemblages, were taken into account. Vegetation surveys were made along seven transects during 1984-85 to determine foliage densities using methods described by Horton and others (1964, p. 7). The transects were 200- to 600-ft lines along which vegetation characteristics were observed. Phreatophyte areas and transect locations are shown in figure 15 and vegetation types and densities are summarized in table 8. Evapotranspiration rates for phreatophyte species are those determined by Robinson (1970) for an area near Winnemucca, Nev., and also applied in Smith Creek Valley, an area located closer to Big Smoky Valley (Hines, 1992). The rate of ground-water evapotranspiration for each transect is calculated as the sum of the mean density of each phreatophyte type multiplied by its evapotranspiration rate. Mean density is the average crown height multiplied by the percent cover in the transect.

Annual evapotranspiration rates and totals for evapotranspiration categories in the basin are in table 9. The annual evaporation rate used for bare soil of the playa, 0.1 acre-ft/acre (based on results cited in table 9, footnote 2), may be underestimated. The puffy surface texture of much of the playa indicates the presence of moist sediments just below the surface. The moisture is drawn from the water table by capillary processes. Annual evaporation rates from the playa, calculated as Darcian flow velocities (based on estimated average mean hydraulic conductivity of playa deposits and estimated hydraulic gradient beneath the playa), range from 0.1 to 0.5 and average 0.2 acre-ft/acre. This average estimate agrees with average annual evaporation rates simulated for the playa (0.2 acre-ft/acre) by the ground-water model developed for the study area (see discussion of "Discharge Estimates" under "Hydrologic Variables" in this report).

Total evapotranspiration from ground water is estimated at 67,300 acre-ft/yr (table 9). The estimate is based on field surveys of the distribution and abundance of vegetation types, evapotranspiration rates for four species of phreatophytes (Robinson, 1970), evaporation rates for bare soil estimated from hydrologic properties of playa deposits, and rates for open water (Farnsworth and others, 1982; Houghton and others, 1975). Hines (1992) used similar methods to quantify ground-water evapotranspiration in Smith Creek Valley, Nev. The total mean annual evapotranspiration estimated for this study is within 5 percent of the rate (64,000 acre-ft) reported for northern Big Smoky Valley by Rush and Schroer in 1970.

Table 8. Vegetation characteristics and densities along transects, northern Big Smoky Valley, Nevada

[Terminology and methods from Horton and others (1964). Abbreviations: ft, foot; ft^3, cubic foot; acre-ft/acre/yr, acre-feet per acre per year]

Type of vegetation	Transect number (figure 15)						
	1	2	3	4	5	6	7
	Length of transect, in feet						
	200	300	300	300	210	600	300
Greasewood (phreatophyte)							
Percent cover [1]	10.4	7.1	10.4	11.6	40.4	5.8	11.6
Percent of total vegetation [2]	51.7	100	83.3	61.2	95.1	48.4	29.5
Mean crown height [3] (ft)	2.08	2.46	2.20	2.30	2.83	2.39	3.31
Volume [4] (ft^3)	.22	.18	.23	.27	1.15	.14	.38
Sagebrush							
Percent cover	6.5	0	0	0	2.1	0	0
Percent of total vegetation	32.4	0	0	0	4.9	0	0
Mean crown height (ft)	1.98	--	--	--	1.27	--	--
Volume (ft^3)	.13	--	--	--	.03	--	--
Hopsage and shadscale							
Percent cover	3.2	0	2.1	7.4	0	0	0
Percent of total vegetation	16.0	0	16.7	38.8	0	0	0
Mean crown height (ft)	.97	--	1.16	1.06	--	--	--
Volume (ft^3)	.03	--	.02	.08	--	--	--
Rabbitbrush (phreatophyte)							
Percent cover	0	0	0	0	0	3.2	8.2
Percent of total vegetation	0	0	0	0	0	26.6	20.9
Mean crown height (ft)	--	--	--	--	--	2.07	3.02
Volume (ft^3)	--	--	--	--	--	.07	.25
Grasses (phreatophyte)							
Percent cover	0	0	0	0	0	3.0	11.3
Percent of total vegetation	0	0	0	0	0	25.0	29.0
Mean crown height (ft)	--	--	--	--	--	1.34	3.82
Volume (ft^3)	--	--	--	--	--	.04	.43
Buffaloberry (phreatophyte)							
Percent cover	0	0	0	0	0	0	8.1
Percent of total vegetation	0	0	0	0	0	0	20.7
Mean crown height (ft)	--	--	--	--	--	--	5.86
Volume (ft^3)	--	--	--	--	--	--	.47
Total vegetation cover (percent of area)	20.1	7.1	12.5	19.0	42.5	12.0	39.1
Phreatophyte cover (percent of area)	10.4	7.1	10.4	11.6	40.4	12.0	39.2
Apparent crown height [5] (range, in ft)	2.5-3.3	.3	2.5-3.1	2.3-3.0	3.4-3.8	2.6-3.2	4.8-8.2
Phreatophyte volume (ft^3)	.22	.18	.23	.27	1.15	.25	1.53
Evapotranspiration rate [6] (acre-ft/acre/yr)	.15	.13	.16	.19	.80	.16	.80

[1] Part of the land surface covered or shaded by green canopy (crown) of plants.

[2] Percent of total vegetation along transect.

[3] Weighted average computed from individual height and intercept measurements. Equals sum of products of height and intercept for each plant divided by sum of the intercepts. (Intercept is maximum distance plant is crossed by a tape held horizontally along transect.)

[4] Cubic feet of foliage per square foot of land surface (volume of foliage per unit area along transect).

[5] Range in height of tallest 15 percent of phreatophyte plants in transect.

[6] Calculated as acre-feet per year per acre. Assumes 0.60 acre-foot of ground water per acre-foot of foliage for greasewood, 1.14 for rabbitbrush, and 0.62 for buffaloberry. Rates are from Robinson's experiments (1970, p. 27-31) for greasewood, rabbitbrush, and willow, respectively. (Of Robinson's plants, willow is assumed to be closest to buffaloberry in ground-water use.) Excludes ground-water evapotranspiration from grass; therefore, rate computed for transect 7 is underestimated.

Table 9. Estimated mean annual evapotranspiration of ground water, northern Big Smoky Valley, Nevada

Category [1]	Annual evapotranspiration rate [2] (acre-feet per acre) Mean	Range	Area (acres)	Estimated depth to water (feet below land surface)	Estimated mean annual evapotranspiration (acre-feet)
Playa (bare soil)	0.1	0.01-0.6	31,000	1-12	3,100
Greasewood.	.3	.1-1.0	36,700	10-50	11,000
Rabbitbrush and grass. .	.4	.3-1.1	36,100	5-15	14,400
Grass	.5	.3-1.0	8,700	1-12	4,400
Buffaloberry	1.5	1.0-3.2	3,200	1-12	4,800
Wet grass (meadow) . . .	2.0	.5-2.0	13,400	0-5	26,800
Wet playa (open water) .	3.5	--	800	0	2,800
Total	[3].5		129,900		67,300

[1] Predominant vegetation based on volume of foliage. For detailed description of evapotranspiration assemblages and distribution, see figure 15.

[2] Estimates compiled from Rush and Schroer (1970), Robinson (1958, 1970), and vegetation transects completed for this study.

[3] Weighted mean annual rate for areas of ground-water evapotranspiration.

Springs

Small springs are common in northern Big Smoky Valley at the edge of the playa, particularly on the west side, and near the mountain front. Some of the larger springs on the valley floor discharge hot water and may be related to regional faulting and the regional flow system. Locations of springs and major faults are shown in figure 13. Spring locations were identified on topographic maps and checked in the field.

Total springflow is estimated on the basis of field observations to be about 5,000 acre-ft/yr; however, some springflow near the mountain front probably discharges from a perched water table. Part of the flow from springs is used for irrigation and stock watering, but most of it either seeps back into the ground or is evapotranspired by native vegetation. Therefore, ground-water discharge by springs is accounted for in the water budget primarily by evapotranspiration.

Subsurface Outflow

Ground-water levels in Monitor Valley to the north and east and Reese River Valley to the west are higher than those in Big Smoky Valley (Bedinger and others, 1984a, sheet 1). Therefore, if any interbasin flow exists with respect to these valleys, the gradient probably would be inward from the west, north, and east toward the center of Big Smoky Valley.

No evidence of subsurface outflow to the surrounding valleys has been reported in previous studies. However, water levels in the Tonopah Flat area to the south are lower than in the basin, and the regional gradient in bedrock is also toward the south. Basin-fill deposits are continuous across the topographic divide between northern Big Smoky Valley and the Tonopah Flat area, and some water may flow southward from the south end of the basin into the Tonopah Flat area. Results of the model developed for this study indicate that some subsurface outflow occurs toward the south.

Withdrawals

Water from pumped and flowing wells in northern Big Smoky Valley is used for irrigation, mining, stock watering, public supply, and private domestic use. For well locations and other information about individual wells, see table 13 at the back of this report. The status of water-rights allocations for major uses is summarized in table 3. During 1985, irrigation and mining use constituted 98 percent of the total ground water used. For this study, estimates of rates and locations of ground-water withdrawals were based on the 1985 annual crop and water survey conducted by the Nevada Division of Water Resources, State records of well permits and water allocations, mining company records of pumping, reports by water users, and estimates of irrigated acreage from field surveys and analysis of Landsat images. The amount of ground water used on some fields is difficult to determine because the fields are irrigated by both surface and ground water.

Total ground water withdrawn during 1985 is estimated to be about 6,600 acre-ft. Withdrawals may have been relatively low during the study (1983-1986) because precipitation and surface-water runoff were greater than normal. Estimated withdrawals for 1985 were about 4,200 acre-ft more than the amount estimated by Bedinger and others (1984b, sheet 2) for 1975, and about 4,500 acre-ft more than the estimate by Rush and Shroer (1970, p. 44) for 1968. The increase was primarily a result of the large increase in water used for mining. In addition, cropland irrigated with ground water increased from 960 acres in 1968 to 1,474 acres in 1985. Locations of fields irrigated with ground water are shown in figure 15. Most ground-water withdrawals, especially from high-yield irrigation wells, are in the southern part of the basin. The increased use of water resulting from expanded mining and agricultural activities and a larger population may be partially offset by more efficient irrigation methods.

Ground-Water Storage

Water is stored both on the land surface and underground. At the surface, it is stored in lakes, ponds, and stream channels and also as soil moisture, snow, and ice cover. Underground, it is stored in aquifers. Surface storage is relatively temporary, whereas ground water may remain in storage for years or centuries.

Basin-fill deposits and, to a lesser extent, bedrock store ground water in northern Big Smoky Valley. According to Rush and Schroer (1970, p. 16-17), 5 million acre-ft is stored in the upper 100 ft of saturated alluvium. The water moves from areas of recharge in and near the mountains to areas of discharge near the center of the basin, as shown in figure 5. Ground-water movement depends on permeability and hydraulic gradient and is highly variable. On average, the velocity of water through coarse sand is about 1 ft/d, but through clay is as slow as 0.02 ft/yr (Heath, 1983, p. 25). The distance from the bedrock contact on the margin of northern Big Smoky Valley to the center of the valley is about 5 mi. If the velocity is 0.5 ft/d, assuming a direct flowpath, a particle of water moving through basin-fill deposits would take about 145 yr to travel the 5 mi.

Changes in storage result in fluctuations of water levels. These storage changes are a result of increases or decreases in recharge, consumption, or both. When water is withdrawn from the basin-fill aquifer by wells, water levels decline in the vicinity of the wells and water is removed from storage. Changes in water levels in individual wells with time are shown in figure 16. The water level in a well at site 8 (J-K Ranch) in the southern part of the basin was lower in 1985 than it was during the 1950's and 60's. In other areas, for example in wells at sites 4 (Triple T Ranch) and 6 (R O Ranch), water levels rose. During 1965-85, water levels probably declined in the southern part of the basin (where development is greatest), but may have risen in less developed areas, because recharge during this period was 16 percent greater than the long-term (1878-1985) average.

The amount of water that can be withdrawn from storage and the rate of withdrawal depend on the quantity of water in storage, availability of recharge to replenish the supply, and the hydraulic properties of the aquifer materials through which the water flows. Not all of the water stored in aquifers of northern Big Smoky Valley is readily available for use. In mountainous and upland areas near the margins of the basin, the depth to water is too great for economical pumping; in many areas, yields are too small for irrigation; and in the playa area, water quality is unacceptable for many uses.

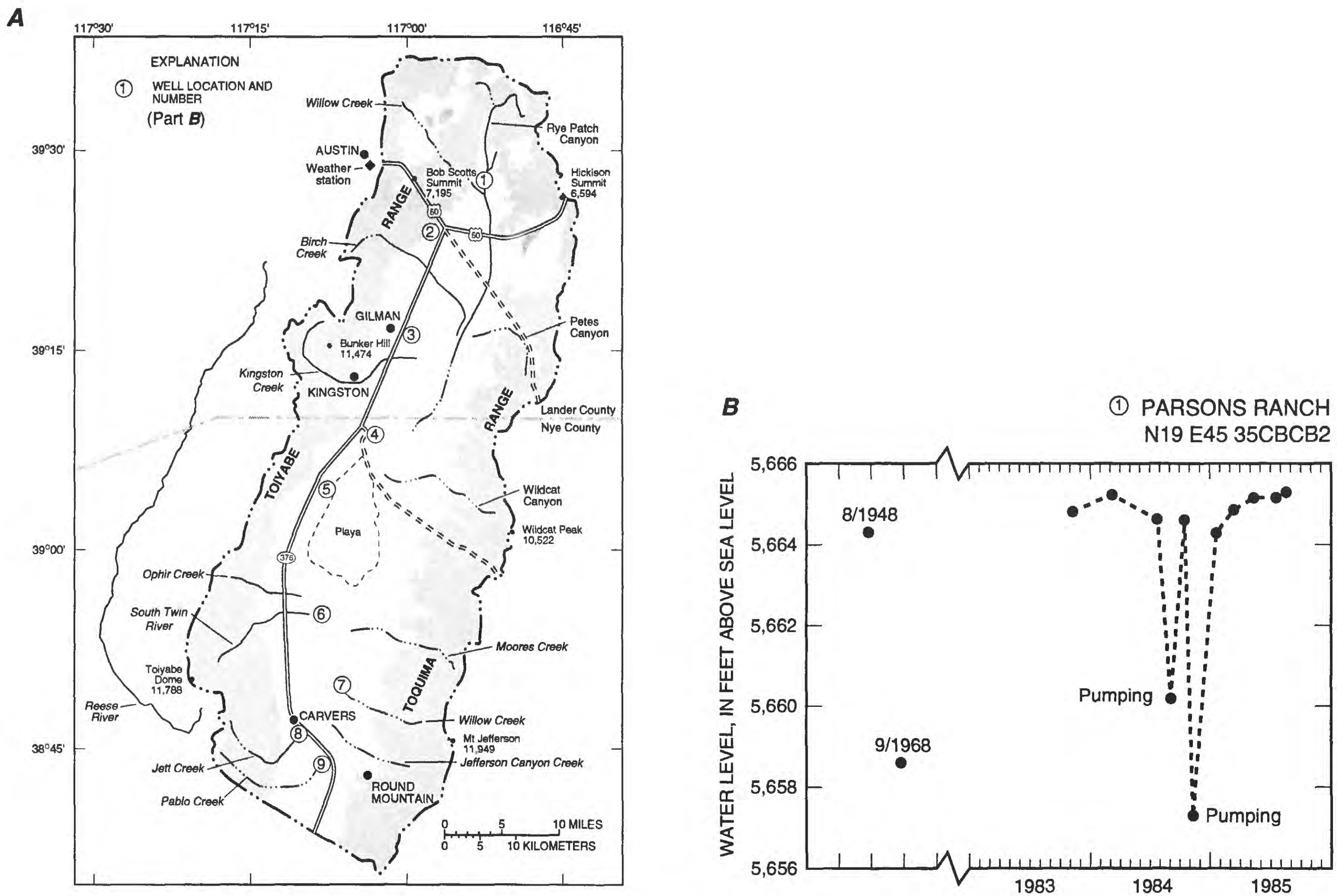
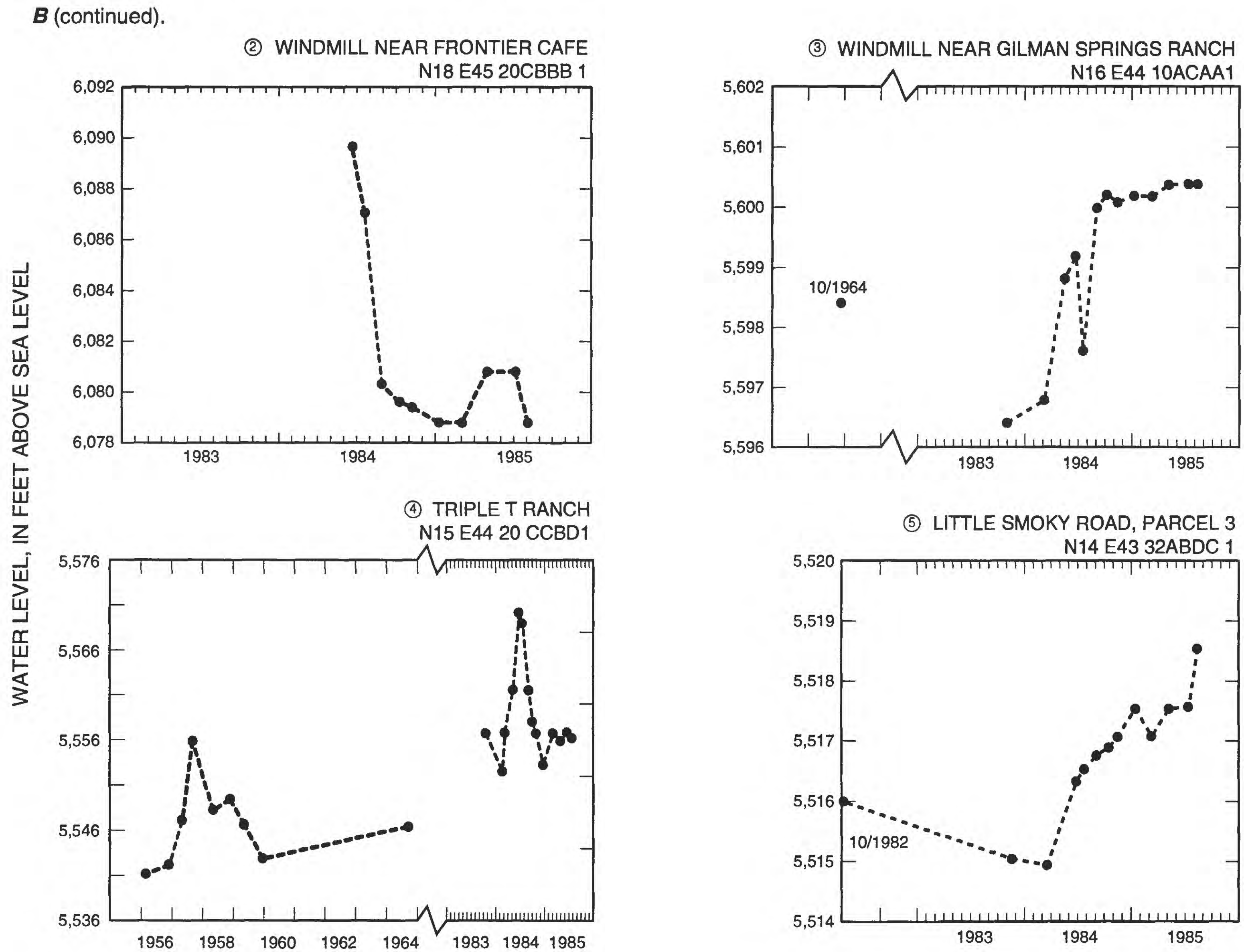


Figure 16. Water-level changes at selected wells, northern Big Smoky Valley, Nevada. (*A*) Location of wells; (*B*) hydrographs of wells. For additional information on wells, see table 13.



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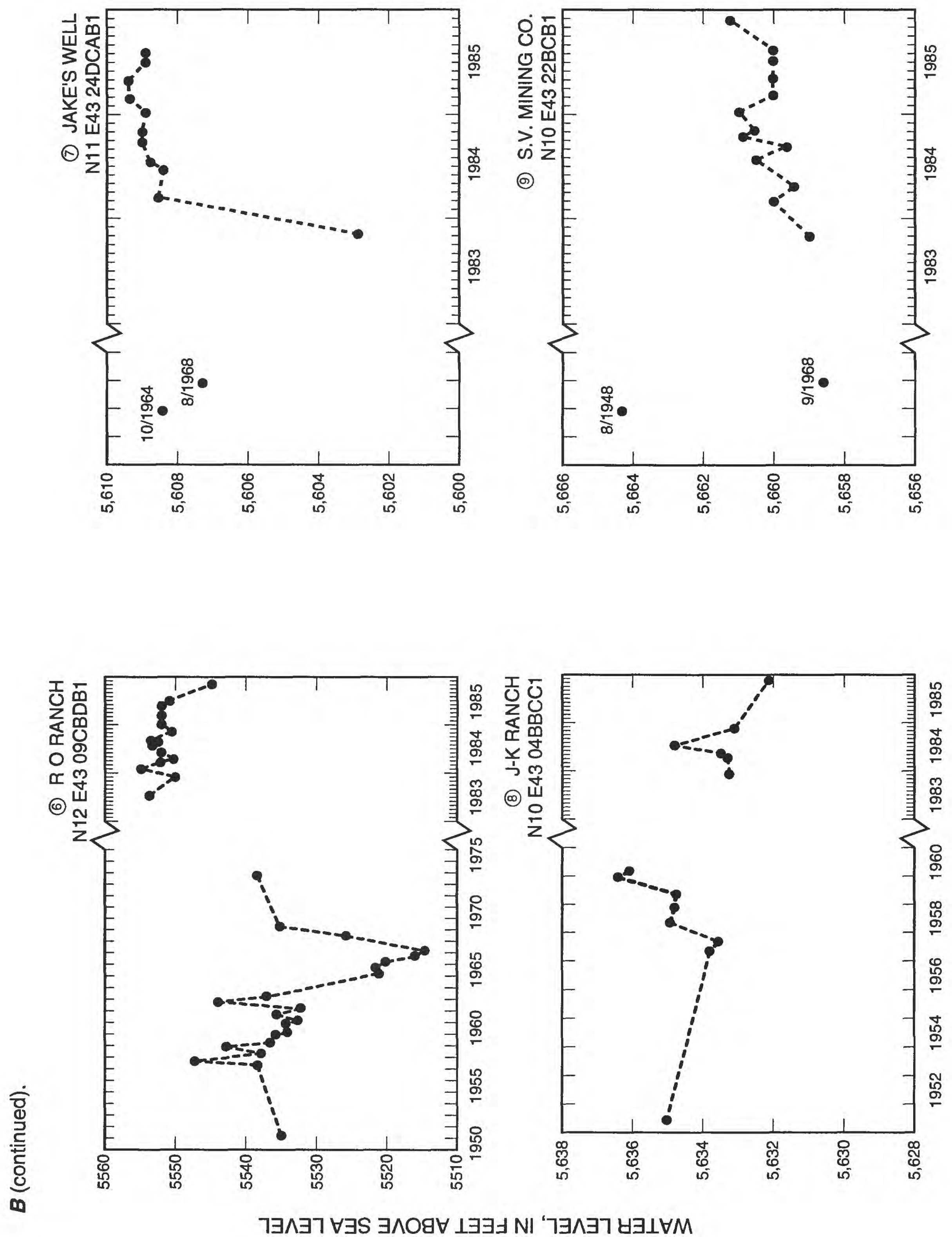


Figure 16. Continued.

DISTRIBUTION AND MOVEMENT OF GROUND WATER

Runoff from precipitation in the mountains infiltrates primarily at the margin of the basin-fill aquifer and along stream channels. The recharged ground water moves slowly downgradient toward the playas, where most of the discharge takes place. The amount of water stored in and moving through the aquifer depends on the hydraulic properties of the aquifer materials. In northern Big Smoky Valley, basin-fill deposits are layered; coarse-grained gravel and sand layers predominate near the mountains and fine-grained silt and clay layers are more common at the center (fig. 4).

Although the general direction of ground-water flow is horizontal from the margins to the center of the basin, vertical components of flow are also important. At the mountain front, water moves downward as well as horizontally, whereas in the central part of the basin upward flow predominates. General directions of ground-water flow are shown in figure 5. Where coarse and fine deposits are interlayered, as is typical throughout the basin, the fine-grained layers impede vertical flow. Water downgradient from recharge areas may be under pressure beneath the fine-grained confining layers; therefore, wells that are completed in coarser grained sediments underlying the fine-grained layers may flow. These conditions are prevalent near the playas, where several wells flow.

Ground water moving through basin fill ultimately discharges from the basin, primarily by evapotranspiration. At the southern end of the basin, water is withdrawn from wells and a small amount discharges by subsurface outflow to Tonopah Flat.

SIMULATION OF GROUND-WATER FLOW

The ground-water budget developed for northern Big Smoky Valley was evaluated by using a three-dimensional mathematical model to simulate ground-water flow. The model mathematically describes the ground-water system and is used to help understand the system, to evaluate the effects of current stresses (ground-water withdrawals), and to predict the effects of future stresses.

Steady-state and transient models were developed for this study. The steady-state model simulates equilibrium conditions: the amount of recharge to the system is in balance with the amount of discharge, and storage does not change with time. The transient model simulates the effects of withdrawals and provides estimates of changes in storage.

Model Design and Construction

A three-dimensional, finite-difference model that solves the equations of ground-water flow by the "Strongly Implicit Procedure" was used for this study. McDonald and Harbaugh (1988) describe the procedure and the physical and mathematical concepts on which the model is based, and list the associated computer programs. For the transient model, a 20-yr period was simulated in ten 2-yr stress periods with four time steps per period; the acceleration parameter for successive time steps was 1.0 (equal-duration steps). The equations were considered solved when calculated heads in all model cells changed less than 0.01 ft between successive iterations within a time step, which resulted in mass-balance errors less than 0.05 percent for all simulations.

Extent and Thickness of Modeled Area

The lateral extent of the modeled area roughly coincides with the extent of basin-fill deposits and with the topographic divide between northern Big Smoky Valley and Tonopah Flat to the south (fig. 17). The basin-fill deposits contact bedrock along the mountain fronts at an altitude of 6,200 to 6,400 ft. The thickness of the modeled area is the difference between the altitude of the land surface and the altitude at the contact between basin-fill deposits and bedrock beneath the valley. Some areas near the northern, eastern, and western edges of the basin, where the basin-fill deposits are thin, were excluded from the model because the fill in those areas is unsaturated. The modeled area extends to about 1 mi south of the southern topographic divide for two reasons: (1) to allow for uncertainty in the position of the ground-water divide and (2) to determine the effects on the flow system and the water budget of withdrawals from irrigation wells just south of the topographic divide.

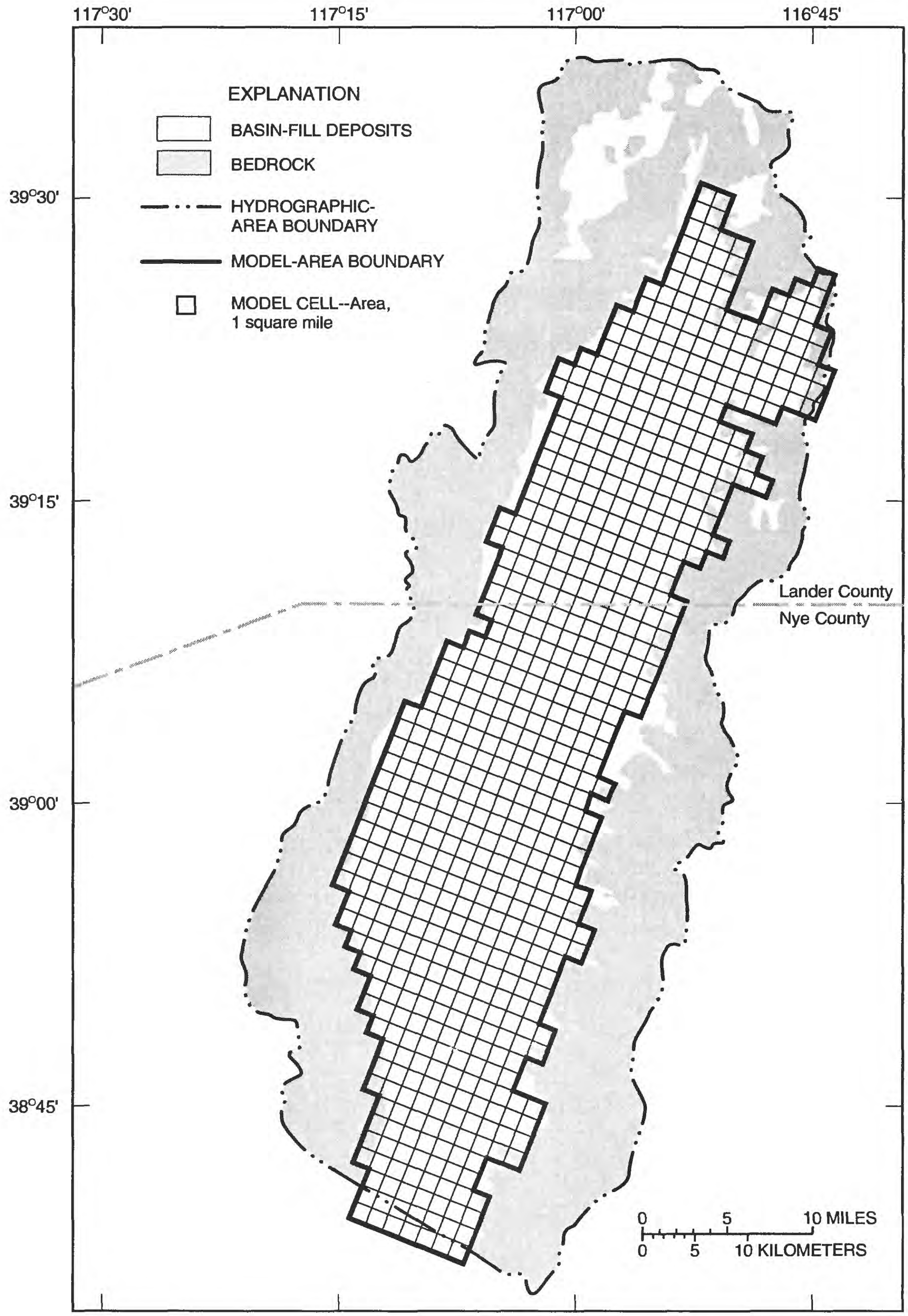


Figure 17. Extent of modeled area, northern Big Smoky Valley, Nevada.

Information about the thickness of fill and the configuration of the underlying bedrock surface was used to define the dimensions of the aquifer. This information was not available from direct measurements because the few wells that were drilled through the basin fill into bedrock are all near the margins of the fill. Geophysical methods, however, also provide information about the subsurface. Gravity measurements were interpreted to determine distribution and thickness of materials of different density (basin fill and bedrock), and seismic methods were used to determine depth to the water table and depth to bedrock.

Maps by Erwin and Bittleston (1977) and Healy and others (1981) were used for gravity measurements for the area. Additionally, more recent data available from Saltus (1988a; 1988b) were used. The maximum thickness of the basin fill was estimated from gravity data to be about 5,000 ft using the method described by Schaefer and Maurer (1981). Thickness of basin-fill deposits based on gravity measurements is shown in figure 18.

A seismic-refraction survey was made at the south end of the basin, east of Jett Creek Canyon, during 1984 to verify the interpretation of gravity measurements. Results of the seismic survey were inconclusive. Basin-fill materials at that location are coarse grained and the deposits are thick; either the seismic signals did not penetrate to the bedrock surface or the refracted signals were not detectable at land surface.

Basin-fill thicknesses calculated from gravity data for this report are in general agreement with estimates made by Rush and Schroer (1970), but are less than those made by Erwin (1982, p. 3) and Bedsun (1980, p. BSV3). Interpretations of thickness differ because additional gravity data were available for this study and because different methods of calculating thickness from gravity measurements and different assumptions about rock densities may have been used in previous investigations. A greater thickness provides more storage, but does not have much effect on the yields of wells in the upper layers or on the overall ground-water budget.

Model Grid System

The principal ground-water aquifer consists of layers of unconsolidated gravels, sands, silts, and clays that are as much as 5,000 ft thick in the center of the basin. The silt and clay lenses are local confining units that restrict vertical flow. They differ in number, thickness, depth, and continuity throughout the basin and could not be mapped where subsurface data are lacking. For modeling purposes, therefore, coarse- and fine-grained units were combined and their effects were considered collectively.

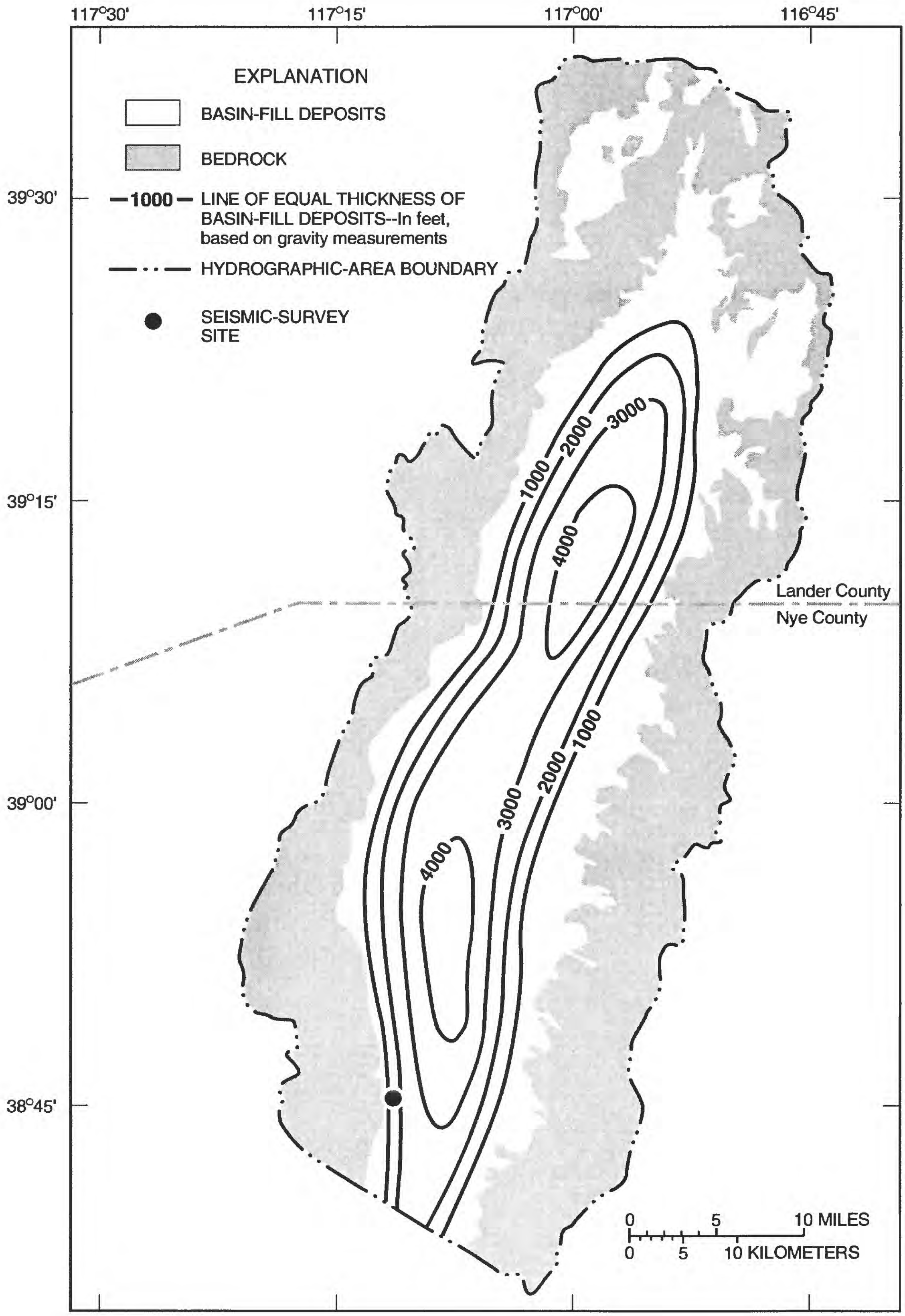


Figure 18. Generalized thickness of basin-fill deposits based on geophysical surveys, northern Big Smoky Valley, Nevada.

The aquifer was approximated by three layers, as shown in figure 19. The effects of numerous thin confining units and interbedded fine-grained deposits of limited lateral extent were simulated by a vertical leakance factor between the layers. Figure 20 shows how aquifer layers and confining beds are represented in the model.

The aquifer system was conceptually divided into a grid of rectangular blocks, 16 columns by 61 rows by 3 layers. Horizontal grid spacing is constant at 1 mi by 1 mi, whereas the thickness of the layers is variable. The 1-mi grid was chosen to accommodate the large extent of the area and uneven distribution of data. The grid is oriented north-northeast so that its axes are aligned approximately parallel to the principal axis of the basin and the average direction of streamflow. The total number of cells in the three-layer system is 2,928, of which 1,578 cells are active. The grid system and cell types for each of the three layers are shown in figure 21.

Layer 1, the uppermost layer, represents an unconfined (water-table) aquifer (fig. 19). It consists of all the saturated material below the water table and above an altitude of 5,320 ft. Its minimum thickness is 100 ft in the center of the basin, but it is considerably thicker toward the edges, where the water-table altitude may be as much as 500 ft higher. Layer 1 contains most of the wells in the basin and some shallow springs.

Layer 2, the middle layer, is modeled as a confined aquifer. Its base is at 4,430 ft, which is 1,000 ft below minimum land-surface altitude, and its maximum thickness is 890 ft. Some deep wells and most of the cold-water springs derive water from layer 2 along preferential pathways related to faults.

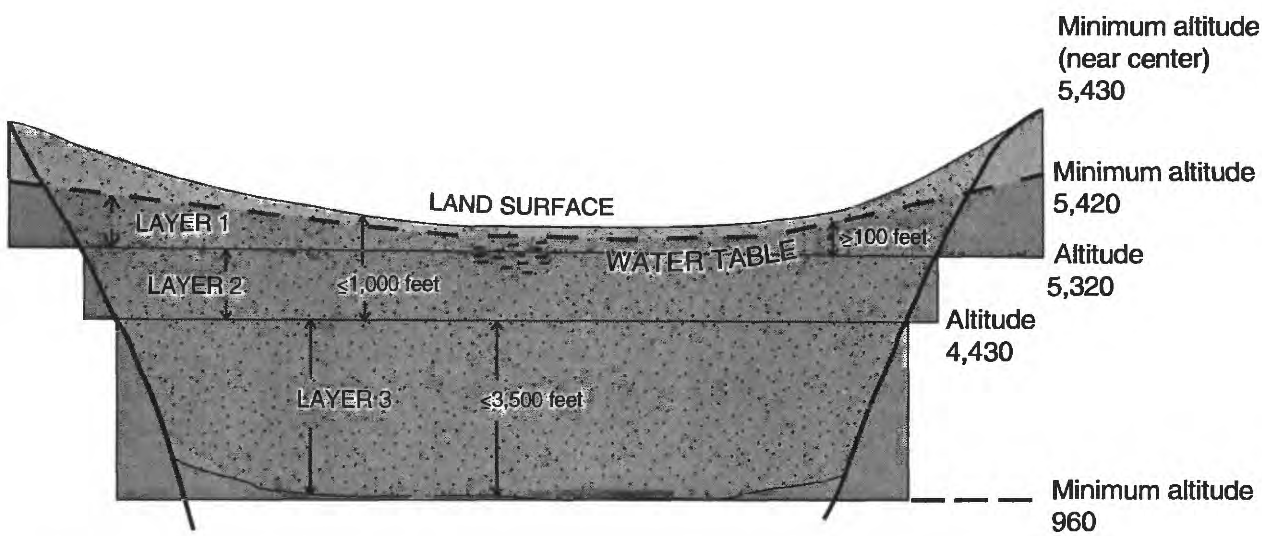
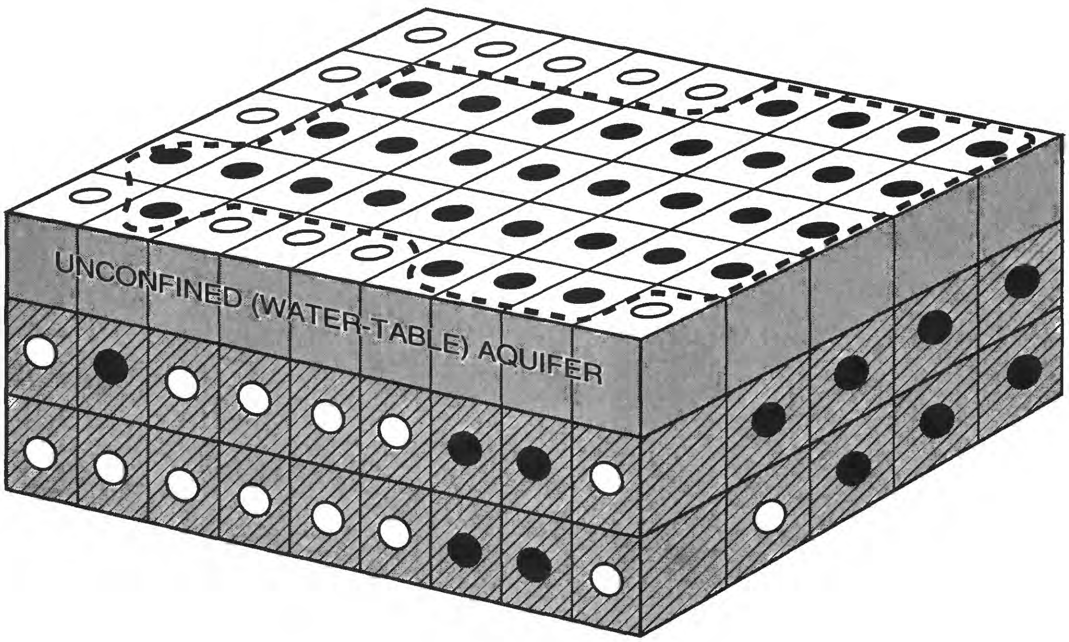


Figure 19. Schematic cross-section of three-layer conceptual model of northern Big Smoky Valley, Nevada. Altitude in feet above sea level.

Layer 3, the bottom layer, also is modeled as confined. It extends downward from the bottom of layer 2 to the bedrock surface and ranges in thickness from 0 ft at the edge to a maximum thickness of about 3,500 ft in the center of the basin. No wells tap layer 3, but some of the hot springs may originate at this depth. Little direct information is available about the properties of materials in layer 3, but the hydraulic conductivity of materials from similar alluvial valleys is reported to decrease with depth (Durbin and others, 1978, p. 76-78). The same relation is assumed here. Layer 3 is important because it contains large volumes of water in storage.



EXPLANATION

UNCONFINED MODEL LAYER

CONFINED MODEL LAYER

AQUIFER BOUNDARY

ACTIVE NODE

INACTIVE NODE

Figure 20. Configuration of three-layer model that represents part of a hypothetical aquifer system. Water levels are calculated for every active node (cell center) in each aquifer layer, but not for confining layers. Vertical flow through several discontinuous confining layers is simulated in the model by a leakance factor.

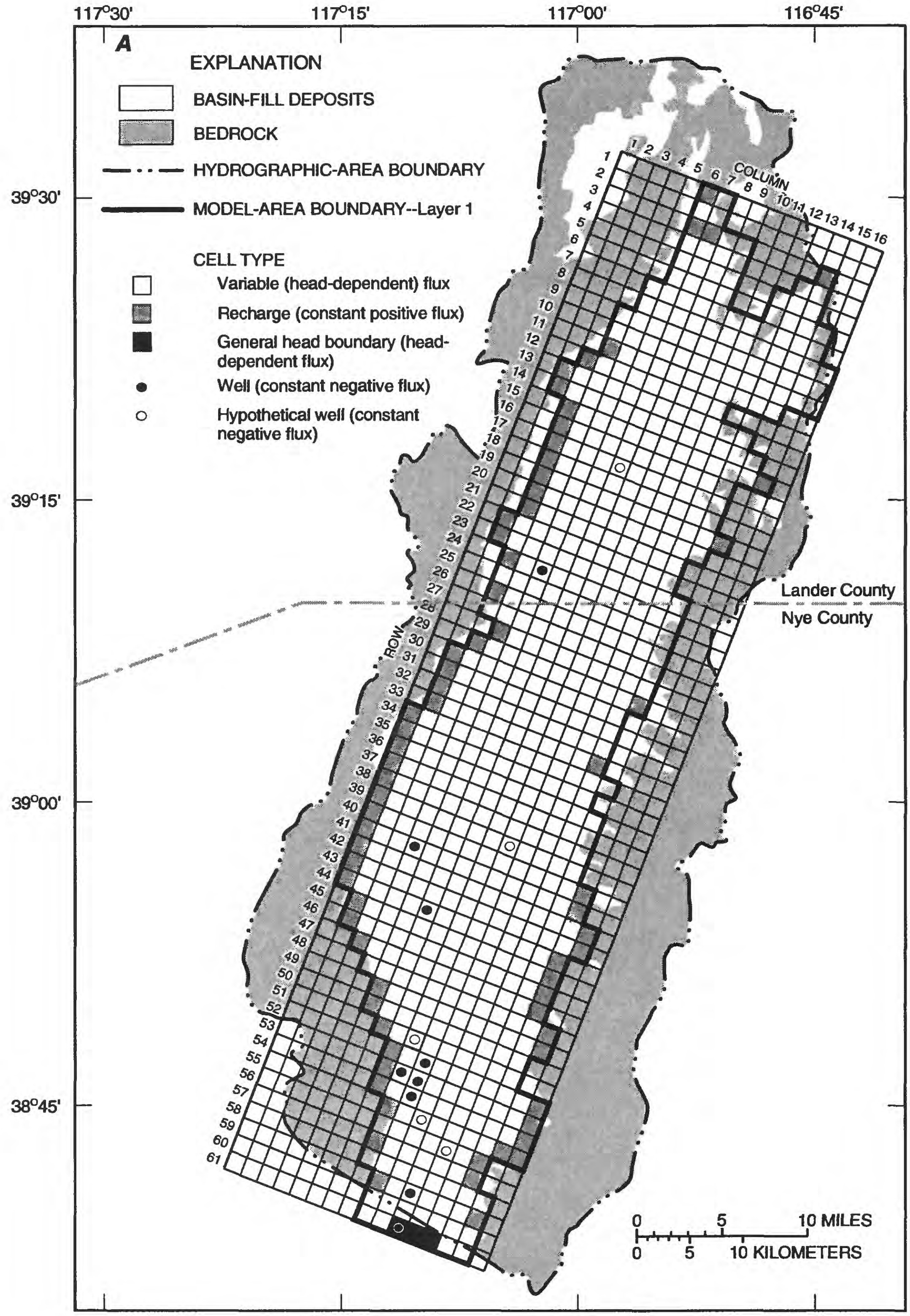
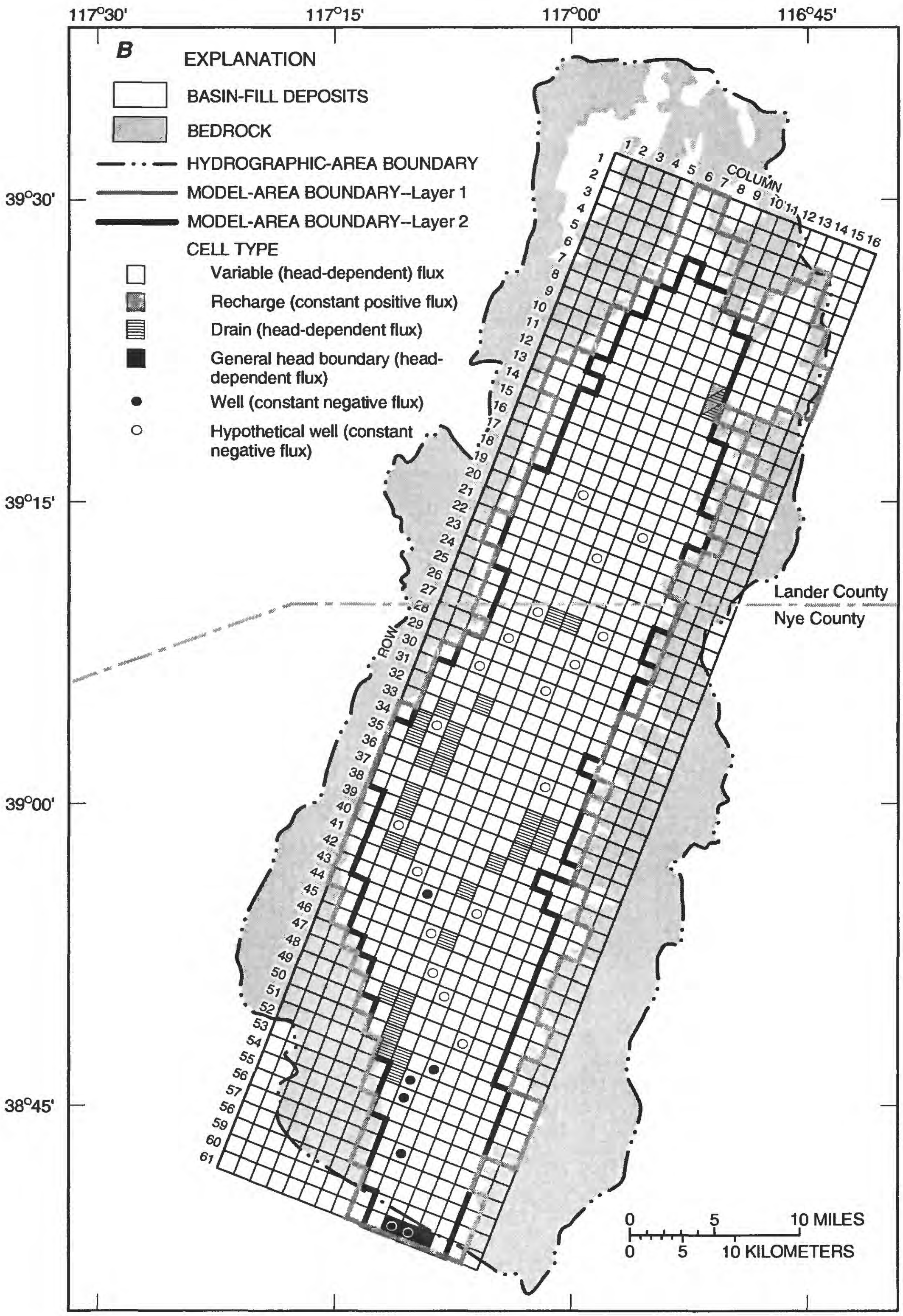


Figure 21. Grid system and cell types for (*A*) layer 1, (*B*) layer 2, and (*C*) layer 3 in ground-water flow model, northern Big Smoky Valley, Nevada.



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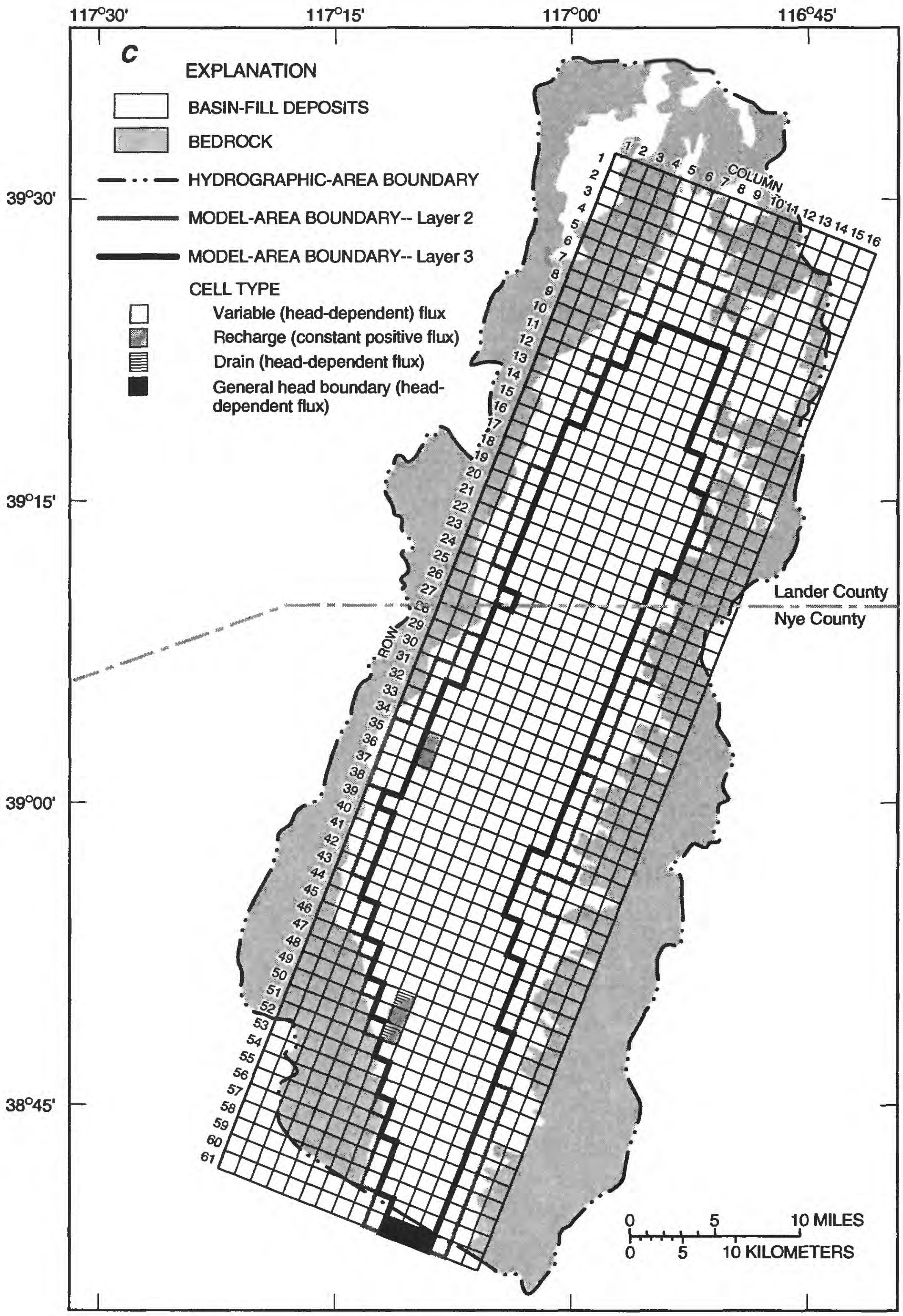


Figure 21. Continued.

Boundary Conditions

The model uses three types of boundaries—no flow, head-dependent flux, and specified flux. A no-flow boundary surrounds most of the active part of the model (fig. 21). It corresponds with the bedrock contact and extends beneath all three layers at the base of the aquifer. Upward leakage from the bedrock is assumed to be negligible except along faults in areas of hot springs.

Most of the upper surface of the model is represented by a head-dependent flux boundary. Discharge from this boundary is by evapotranspiration and depends on the water level in the aquifer.

Specified-flux nodes represent areas of recharge to or discharge from the basin. Seepage from streams, subsurface lateral inflow, and wells are simulated by specified-flux nodes. A specified (constant) flux in cells in the bottom layer simulates recharge from hot springs by upward leakage from bedrock into basin-fill deposits along fracture zones, and in layers 1 and 2 to simulate seepage from streams and discharge by wells.

Springs can be simulated by specified flux or by head-dependent boundary conditions. For this study, springs are represented by drains in layers 2 and 3. The rate of flow depends on a conductance between the drain and the aquifer and on the head difference between the drain and the aquifer. Water discharges into the drain only when the head in the aquifer at the drain cell is greater than the altitude of the drain.

The southern border was initially simulated by a no-flow boundary on the assumption that a ground-water divide coincides with the low topographic divide that separates northern Big Smoky Valley from Tonopah Flat. To test the possibility that some water may flow out of the modeled area into Tonopah Flat, a head-dependent boundary was assigned to three cells in each layer near the center of the southern boundary of the model. With the head-dependent boundary, the ground-water divide shifts northward from the topographic divide and subsurface outflow occurs to the south. Water levels simulated by this alternative are more consistent with observed levels, implying that outflow to Tonopah Flat does occur.

Aquifer Properties

Characteristics of basin-fill deposits that affect ground-water storage and movement are required components of the model. They include estimates of average hydraulic conductivity or transmissivity for each node, vertical hydraulic conductivity and thickness of confining units, and, for transient models, storage coefficients.

Horizontal Hydraulic Conductivity and Transmissivity

Arrays of hydraulic-conductivity values for layer 1 and transmissivity values for layers 2 and 3 were specified as input to the model. Transmissivities were calculated by multiplying the hydraulic conductivity assigned to each cell by the average saturated thickness represented by the cell. The transmissivity of layer 1 varies with the water level; transmissivities of layers 2 and 3 are constant.

The hydraulic conductivity of basin-fill materials is a function of their provenance and depositional environment. It is consequently related to geomorphic features of the basin (especially slope), which correlate with land-surface altitudes in northern Big Smoky Valley. Conceptual cross-sectional diagrams of the basin are shown in figure 5; typical landforms and subsurface sediments based on geophysical and lithologic logs of wells are shown in figure 4. Each type of basin-fill deposit (playa, braided channel, and alluvial fan) has its own characteristics. Playas are relatively low-altitude, low-slope features dominated by fine-grained lake sediments (layered sands, silts, and clays). Fine-grained units impede vertical movement of water through the system and, on a basinwide scale, the impediment to vertical flow can be described as a systemwide vertical-to-horizontal anisotropy in hydraulic conductivity. Channel deposits consist primarily of gravels, some sand wedges, and only minor lenses of silt and clay; channel deposits are coarser at higher altitudes where slopes are steepest. Alluvial fans include well sorted, braided-fan deposits and poorly sorted, mass-flow deposits that decrease in thickness and particle size with decreasing slope down the fan.

Layer 1.—The average hydraulic conductivity of the upper part of the aquifer was determined for 64 well sites for which reliable drillers' logs, geologists' logs, geophysical profiles, or well-test data were available. First, specific-capacity data from 26 wells were used to estimate horizontal hydraulic conductivity by the Theis (1963) method. Then a coarseness factor, based on descriptions of materials from those wells and 36 additional wells, was calculated by the method described by Plume (1989); descriptions were inferred from geophysical logs where available. Second, hydraulic conductivities calculated from specific capacity were correlated with coarseness factors for 24 wells. Correlation was poor because (1) descriptions of materials by different drillers were inconsistent, (2) estimating coarseness from descriptions introduced errors, and (3) factors such as grain shape and packing, as well as size, affect hydraulic conductivity but were not taken into consideration. Of the two methods, the Theis method is considered more accurate because it is based on actual performance of aquifer materials during pumping. Finally, calculated hydraulic-conductivity values were related to types of deposits, which in northern Big Smoky Valley are found at different land-surface altitudes. The relation between hydraulic-conductivity values estimated from specific-capacity data for 26 wells and land-surface altitude at the well sites is shown in figure 22. Correlation (r = 0.75) is good, an indication that reasonable estimates of hydraulic conductivities in northern Big Smoky Valley can be derived by using this relation. To compute an estimated hydraulic conductivity (x) at a specific altitude (y) using the equation in figure 22, a bias correction factor (bcf; Helsel and Hirsch, 1992) of 1.43 is applied as follows:

$$\text{est}(x) = 10^{(-26.8 + 0.0049y)}\,\text{bcf}. \qquad (4)$$

Initial estimates of hydraulic conductivity used in the model ranged from 1.3 ft/d on the playa to 100 ft/d (left axis in figure 22) at higher altitudes on the alluvial fan; the estimates were made using the equation in figure 22. No specific-capacity data were available for wells at sites above an altitude of 5,900 ft, but—because alluvial-fan sediments at higher altitudes are poorly sorted—100 ft/d was taken as a maximum and assigned to all cells that represent land surface above 5,900 ft. During calibration of the model, hydraulic conductivities assigned to model cells were adjusted to a range of 1.6-22 ft/d (right axis scale in fig. 22). The resulting distribution of hydraulic conductivities is shown in figure 23.

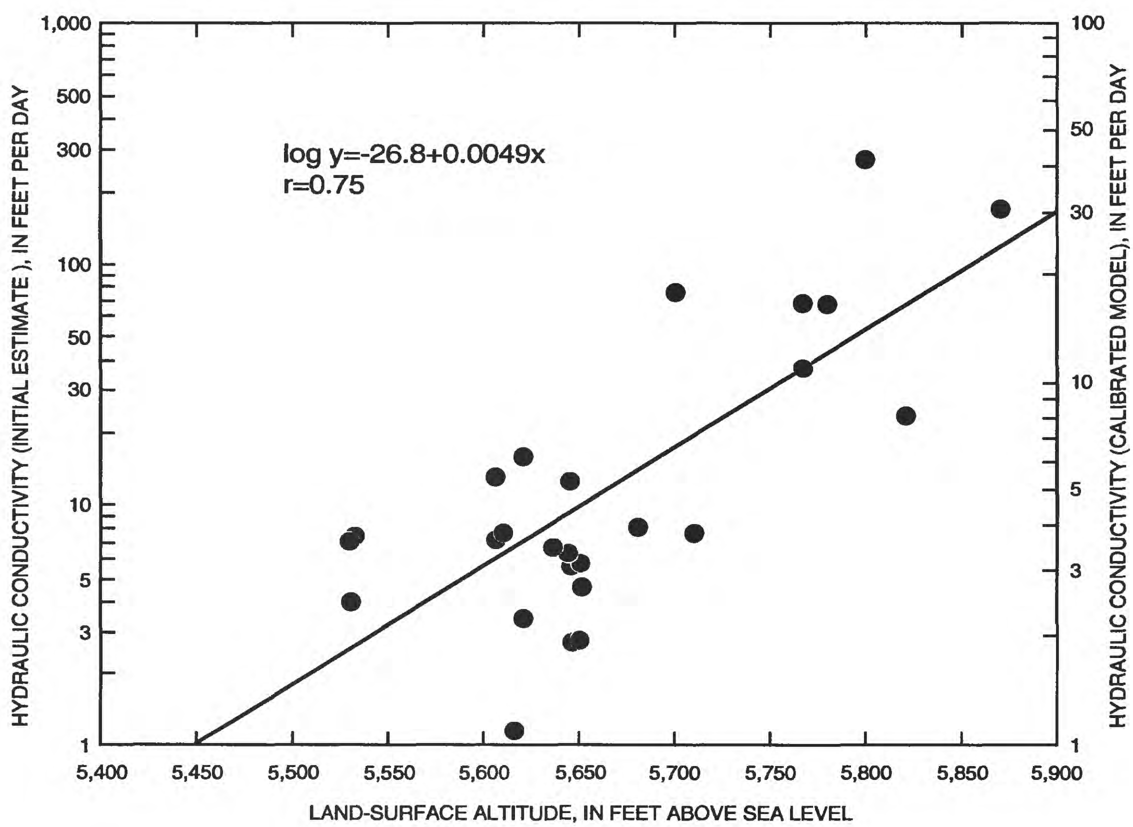


Figure 22. Relation between hydraulic conductivity and land-surface altitude, northern Big Smoky Valley, Nevada.

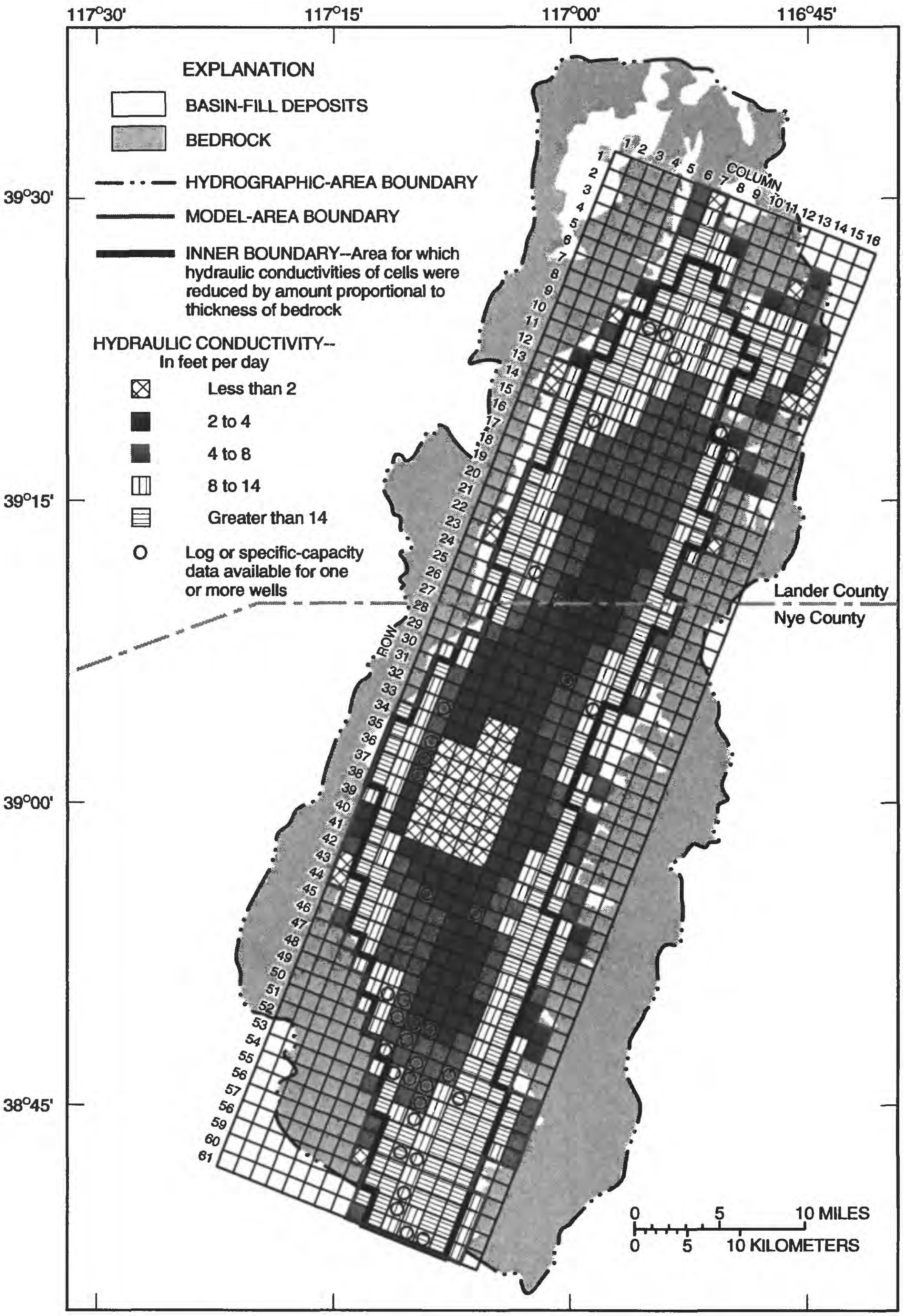


Figure 23. Horizontal hydraulic conductivity of layer 1, ground-water flow model of northern Big Smoky Valley, Nevada.

After adjustment of the range of hydraulic conductivities, a correction was made to compensate for a decreasing thickness of basin-fill deposits where they contact bedrock at the mountain front. Layer 1 has a flat bottom (fig. 19) that is below the base of the basin-fill deposits in some border cells. The thickness of these specific cells includes a vertical section of bedrock for which hydraulic conductivity is assumed to be negligible. The saturated thickness calculated by the model for these cells is greater than the actual saturated thickness of the basin-fill deposits. To compensate, the hydraulic conductivity for each of the cells was reduced by an amount proportional to the percent of bedrock in the vertical section of the cell. Affected border cells are indicated in figure 23.

Layers 2 and 3.—The hydraulic conductivity of coarse-grained materials tends to decrease with depth as a result of compaction, decomposition, and cementation (precipitation of dissolved minerals from circulating ground water). Using data from deep test holes in sediments of Salinas Valley, Calif., Durbin and others (1978, p. 77) plotted the relation between hydraulic conductivity and depth below the water table. Their graph shows a 25-percent decrease in hydraulic conductivity for each 500-ft increment of depth. Applying this relation to the model for Big Smoky Valley, the initial hydraulic conductivity of each layer-2 cell was estimated as 75 percent of the hydraulic conductivity of the overlying layer-1 cell, on the basis of an average depth of 500 ft from the water table to the middle of layer 2. Similarly, initial hydraulic conductivity for each layer-3 cell was estimated as 25 percent of that of the corresponding layer-1 cell, on the basis of an average depth of 2,500 ft from the water table to the middle of layer 3. Initial transmissivities used in the model for layer-2 and layer-3 cells were then calculated by multiplying the hydraulic conductivity of each cell by its saturated thickness.

Vertical Hydraulic Conductivity and Leakance

Vertical hydraulic conductivity was estimated for basin-fill material and a leakance factor was calculated to simulate vertical flow through confining units. Vertical hydraulic conductivity was initially estimated as 1 percent of the horizontal hydraulic conductivity for each cell in each layer. The leakance factor is based on the vertical hydraulic conductivity and saturated thickness of cells in adjacent layers. Leakance (Lv) between layer-1 and layer-2 cells (adapted from equation 51 of McDonald and Harbaugh [1988, p. 5-13]) is calculated as:

$$Lv = \frac{Kv1 \times Kv2}{(Kv1 \times Th2) + (Kv2 \times Th1)}, \quad (5)$$

where $Kv1$ is the vertical hydraulic conductivity of the layer-1 cell,

$Kv2$ is the vertical hydraulic conductivity of the layer-2 cell beneath it,

$Th1$ is one-half the initial saturated thickness of the layer-1 cell, and

$Th2$ is one-half the thickness of the layer-2 cell.

The leakance factor simulating vertical flow between layer 2 and layer 3 is calculated similarly using vertical hydraulic conductivity and thickness of corresponding layer-2 and layer-3 cells. Values of leakance factors are shown in figure 24.

Storage Coefficient

The steady-state model simulates the system at equilibrium: recharge is equal to discharge, and storage does not change. The transient model simulates changes in water levels and changes in storage. Because the transient model involves changes in storage, it requires storage coefficients. In an unconfined aquifer, layer 1 in the model, the storage coefficient is equivalent to the specific yield of the aquifer materials. An average specific yield of 0.15 was computed from well logs by Rush and Schroer (1970, p. 15). It was decreased by one-third as an estimate for the finer grained playa deposits on the basis of values for different materials reported by Johnson (1967, p. 70). Thus, an initial storage coefficient of 0.15 was assigned to most layer-1 cells, 0.10 to cells in the playa areas, and 0.12 to a single row of transition cells surrounding the playa.

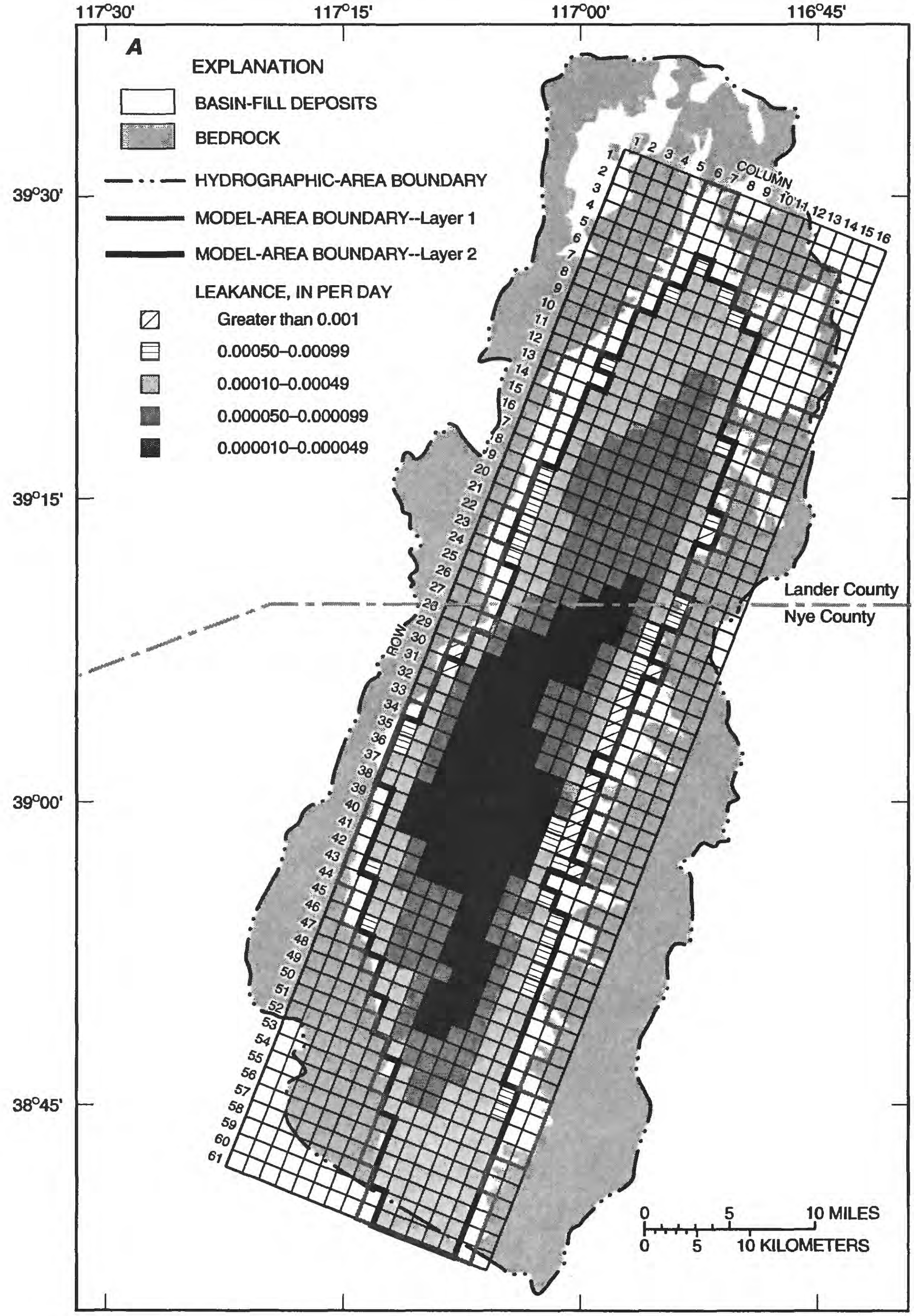


Figure 24. Leakance (*A*) between layers 1 and 2 and (*B*) between layers 2 and 3 of ground-water flow model, northern Big Smoky Valley, Nevada.

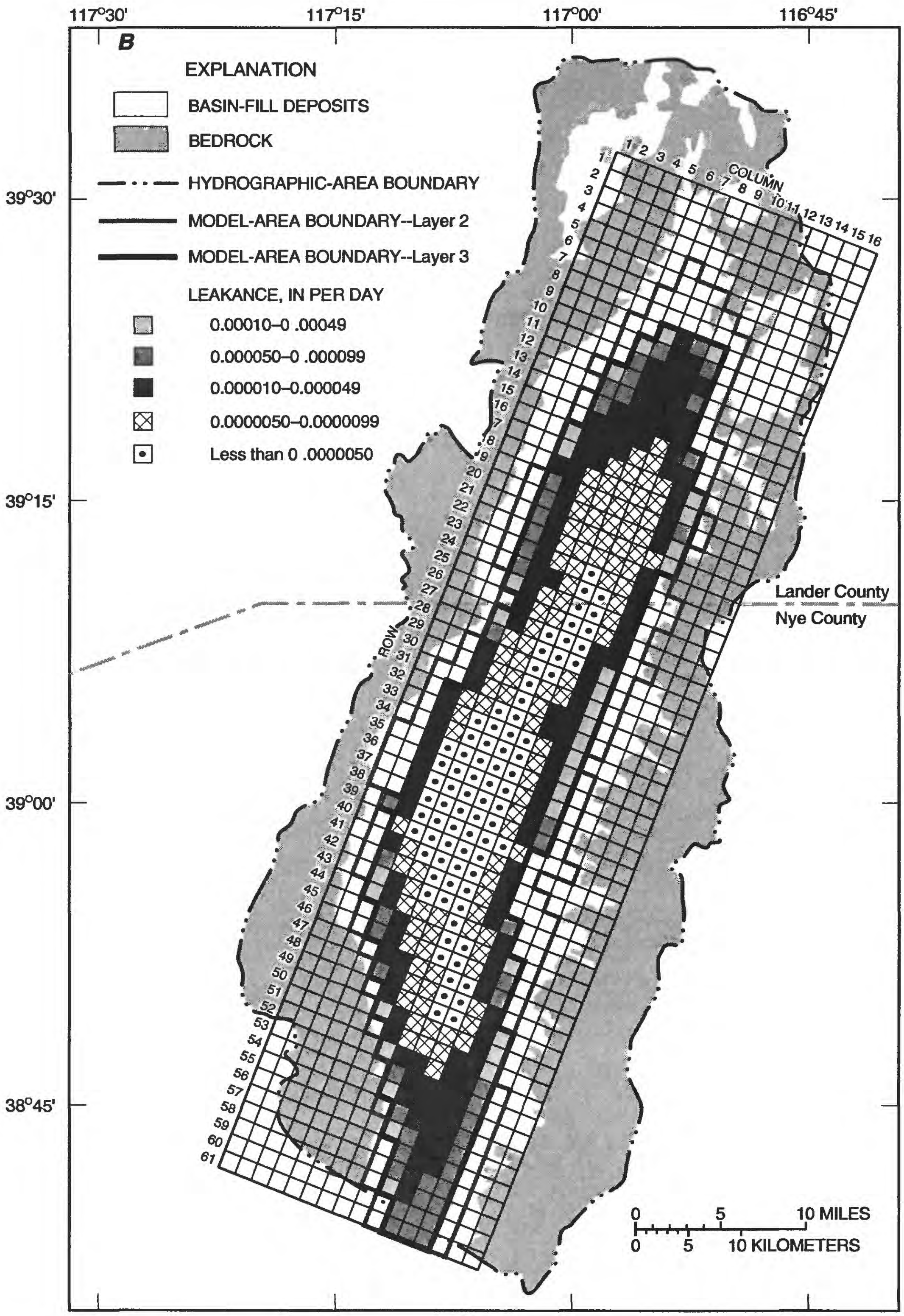


Figure 24. Continued.

Storage coefficients for confined aquifers, layers 2 and 3 in the model, are directly proportional to their saturated thickness. Initial storage coefficients for layer-2 and layer-3 cells were estimated as 0.000001 per foot multiplied by the thickness of basin-fill deposits in the cell, on the basis of the relation given by Lohman (1972, p. 53). Layer 2 has a flat top at an altitude of 5,320 ft and a flat bottom at 4,430 ft, a difference of 890 ft. Initial storage coefficients for most layer-2 cells were therefore estimated as 0.00089. Near the edge of the modeled area, where the saturated thickness is thinner, storage coefficients are smaller. Initial storage coefficients for layer-3 cells range from a maximum of 0.0035 at the deepest part of the basin to 0.00003 in some border cells.

Hydrologic Variables

In addition to the definition of the model configuration, boundary conditions, and hydraulic properties of aquifers and confining units, other factors were considered. Initial values of the altitude of the water table in layer 1, the potentiometric surface in layers 2 and 3, the rates and distribution of recharge, and the locations and rates of discharge of wells also were developed for the model. Measured or observed values were used where possible; estimates were made where measurements were unavailable, sparse, or otherwise inadequate. The model computes discharge rates for evapotranspiration, springs, and subsurface outflow.

Initial Water Levels

Measured water levels were used to estimate initial heads for each node in the model. Initial heads do not affect the results of steady-state models, but are required for solution of the flow equations. One or more water-level measurements were available for each of 165 wells in northern Big Smoky Valley. The data were collected sporadically over a long period (1913-85) during varying climatic conditions. Meinzer (1917, p. 100) reported water levels for 16 wells and test borings that were measured during 1913; Rush and Schroer (1970) reported levels for 74 wells; several drillers' reports on file with the Nevada Department of Conservation and Natural Resources report water levels; and since 1983, annual surveys of water use, including water levels, have been reported by the same Department. In addition, 279 water-level measurements were made at 96 wells during the course of this study, and 47 levels were reported by drillers and owners. Maximum levels were considered most representative of the natural (predevelopment) system because they were less affected by pumping. Well locations and maximum measured water levels are shown in figures 27 and 28 and listed in table 13.

Initial heads for layer 1 were based on the highest measured water levels in 113 wells that tap the water-table aquifer above an altitude of 5,320 ft (the bottom of layer 1). Data were plotted and contoured and a water level was assigned to each cell. Similarly, initial heads for layer-2 cells were based on the highest measured water levels in 24 wells completed totally or partly at depths corresponding to layer 2. Altitudes of 27 springs provided additional control for layer-2 heads. Initial heads in layer-3 cells were set at the same altitude as heads in overlying layer-2 cells because no measurements were available for that depth (below 4,430 ft).

The resulting potentiometric surfaces are only approximations because (1) measurements were made in different seasons and in different years, (2) wells are clustered in some areas and sparse in others, (3) the water level at each node is an average for all wells within the cell or an interpolation between measured water levels for cells with no water-level measurement, (4) the screened or open interval is different in each measured well, and (5) the land-surface altitude at many sites was interpolated from contours on topographic maps and some of them are accurate only to within 20 ft.

Ground-water levels generally fluctuate more in upland or recharge areas than in discharge areas. Using the highest measured water level could result in water-level gradients between recharge and discharge areas that are greater than average. Using average values for recharge could result in estimates of hydraulic conductivity that are lower than actual values in order to simulate the steeper gradient.

Recharge Estimates

Recharge values from surface-water sources within the basin and from subsurface inflow of water from a regional flow system were entered in the model. Rates and distribution are discussed in the following sections.

Surface Water

Recharge from infiltration of precipitation in basin segments was assigned to border cells in layer 1 of the model (fig. 25). In segments of the basin from which mean streamflow (either measured or estimated) equals or exceeds the potential recharge shown in table 7, that streamflow was assigned as recharge to the border cell of the model representing where the stream enters the basin fill. Where streamflow is less than the estimated potential recharge from an area, the difference (excess recharge) was apportioned equally among the border cells for that segment. The difference represents precipitation that directly infiltrates in bedrock areas, moves downgradient, and recharges basin-fill deposits in the shallow subsurface. This recharge does not include water that surfaces as springflow from a perched water table, unless the springflow runs off and reinfiltrates as ground-water recharge. Recharge from surface water was about 74,000 acre-ft/yr.

Although recharge was assigned only to border cells, seepage from streams extends from the mountain front to the valley floor. Rush and Schroer (1970, p. 30) estimated average seepage rates at about 720 acre-ft/yr/mi of stream, on the basis of 30 tests on six streams. Some streams are diverted to irrigated areas by pipelines and lined ditches, so that less water infiltrates near the mountain front and more infiltrates downslope. Simulating recharge only along the edge of the model instead of along stream channels could result in a greater proportion of flow simulated near the mountains. To accommodate this greater flow at the bedrock boundary, model hydraulic conductivities would need to be higher than they would be if recharge were distributed along the channels. These higher conductivities, however, might compensate for lower conductivities resulting from the use of average high water levels. The error introduced by simulating all recharge at border cells rather than distributing it downslope, therefore, is considered negligible; total recharge to the basin is accounted for and overall budget calculations are not affected.

Regional Inflow

Water that infiltrates bedrock may circulate deeply before entering the basin-fill deposits from beneath, especially in areas of carbonate solution channels and fractured volcanic bedrock. This water contributes to the flow of hot springs in the Darroughs, McLeod (Smoky Valley) Ranch, and Spencer areas. The model does not simulate such inflow directly; intrabasin inflow at depth is included in recharge from surface water. Subsurface inflow of geothermal water from outside the basin (interbasin flow), however, was considered separately as underflow and applied at bottom-layer cells.

To simulate the possible effects of interbasin inflow in geothermal areas, recharge was added to seven cells in the bottom layer of the model in the Darroughs, McLeod (Smoky Valley) Ranch, and Spencer Hot Spring areas. For locations of these cells, see figure 21, layers 2 and 3. The annual discharge from hot springs and the amounts and rates of recharge from outside the basin cannot be estimated from available information. Recharge from interbasin flow in geothermal areas was assumed to be 360 acre-ft/yr per cell on the basis of observed springflow and associated vegetation, a total of 2,500 acre-ft/yr for the basin. This increases mean annual recharge to the basin by 3 percent.

Return Flows

To simulate recharge from irrigation and mining return flow in the model, recharge values were estimated for individual cells based on the following assumptions: (1) all return flows recharge layer 1; (2) irrigation wells are located near points of use (irrigated fields, fig. 15); consequently, return flows recharge ground water at the site of withdrawal (simulated wells, fig. 21A, B); (3) irrigation return flow is 15 percent of withdrawal for irrigation based on average values for the western United States (Lauritzen and Terrill, 1967, p. 1105); (4) mining return flows recharge ground water at Round Mountain; and (5) mining return flow is 20 percent of the pumpage for mining. Annual recharge from return flow is about 1,100 acre-ft, based on 1985 water-use estimates.

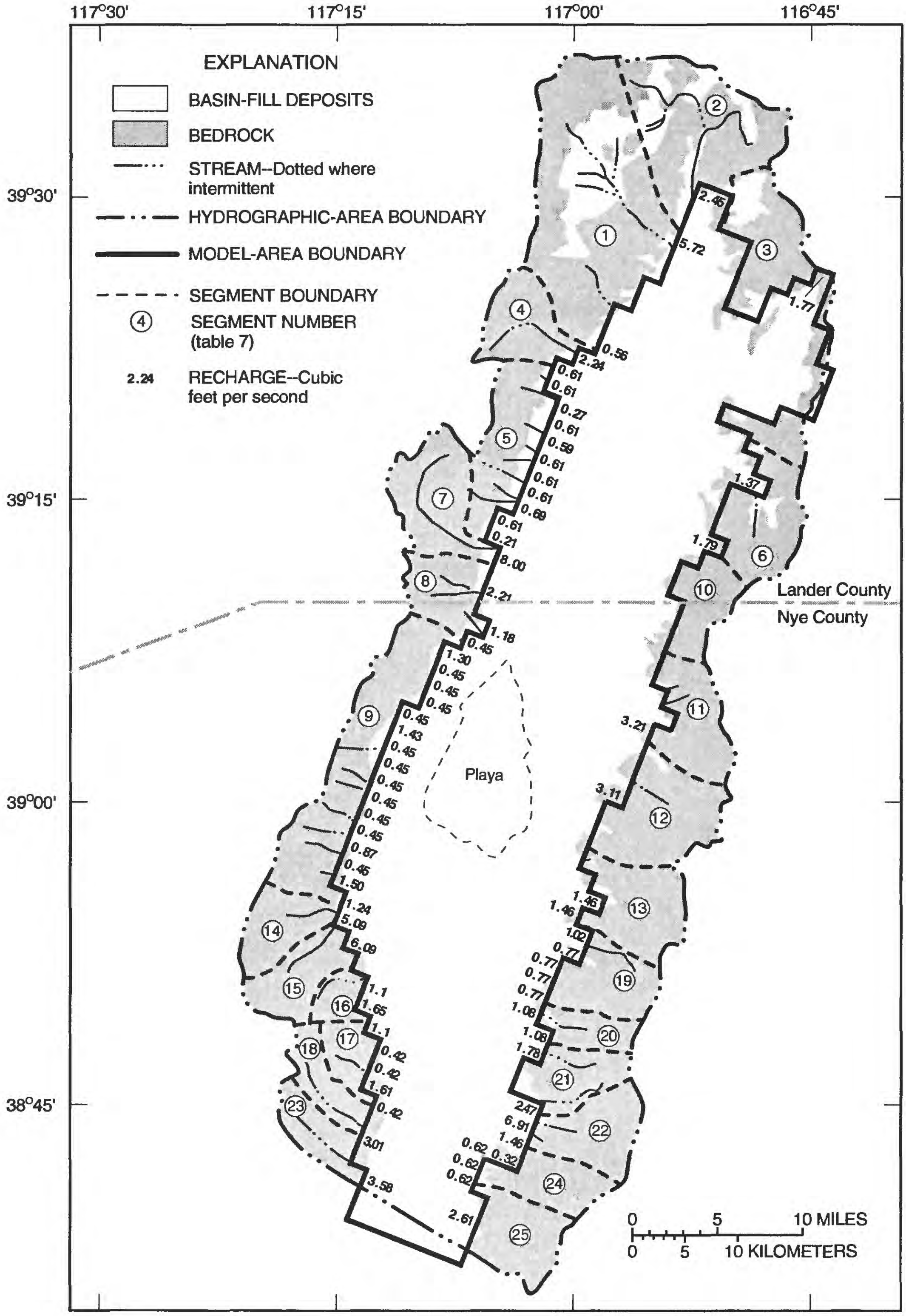


Figure 25. Estimates of recharge from precipitation to layer 1 in the ground-water flow model, northern Big Smoky Valley, Nevada. (Stream names and measurement sites are shown in figure 8.)

Discharge Estimates

The major mechanisms for discharge from the basin are evaporation of water from the land surface and transpiration by plants, considered collectively as evapotranspiration. No surface water flows out of the area, but some ground water probably flows southward into the Tonopah Flat area. In addition, some ground water is discharged by springs and by flowing and pumped wells; most of this is evaporated or transpired. Evapotranspiration, subsurface outflow, and spring discharge were simulated by the model and compared with independent estimates to help calibrate the model. Discharge values for wells were entered in the model as a constant flux from appropriate layer-1 and layer-2 cells.

Evapotranspiration

For the model to calculate evapotranspiration, a maximum evapotranspiration rate and an "extinction depth" were assigned to each cell. The theoretical maximum rate of ground-water evapotranspiration in the study area is 3.9 ft/yr, assuming 4.6 ft of evaporation from open water surface (Houghton and others, 1975, p. 62; Farnsworth and others, 1982, map 3) and subtracting 0.7 ft of precipitation (Houghton and others, 1975, p. 45). Evapotranspiration is a function of depth to water; it is greatest where the water table is closest to land surface and, for the simulations, it is assumed to decrease linearly with depth to water.

Extinction depth is the depth at which the evapotranspiration rate equals zero. Values for initial extinction depths entered in the model ranged from 12 ft in the playa areas (where water evaporates from the water table) to 30 ft on the fans (where phreatophyte roots reach maximum depth).

Discharge values for springs originating in layer 1 of the model were assumed to be included in the total evapotranspiration. This is reasonable because most spring discharge is consumed by evapotranspiration, although a small amount may infiltrate and return to ground water. Springs originating at depth were simulated as drains in layers 2 and 3.

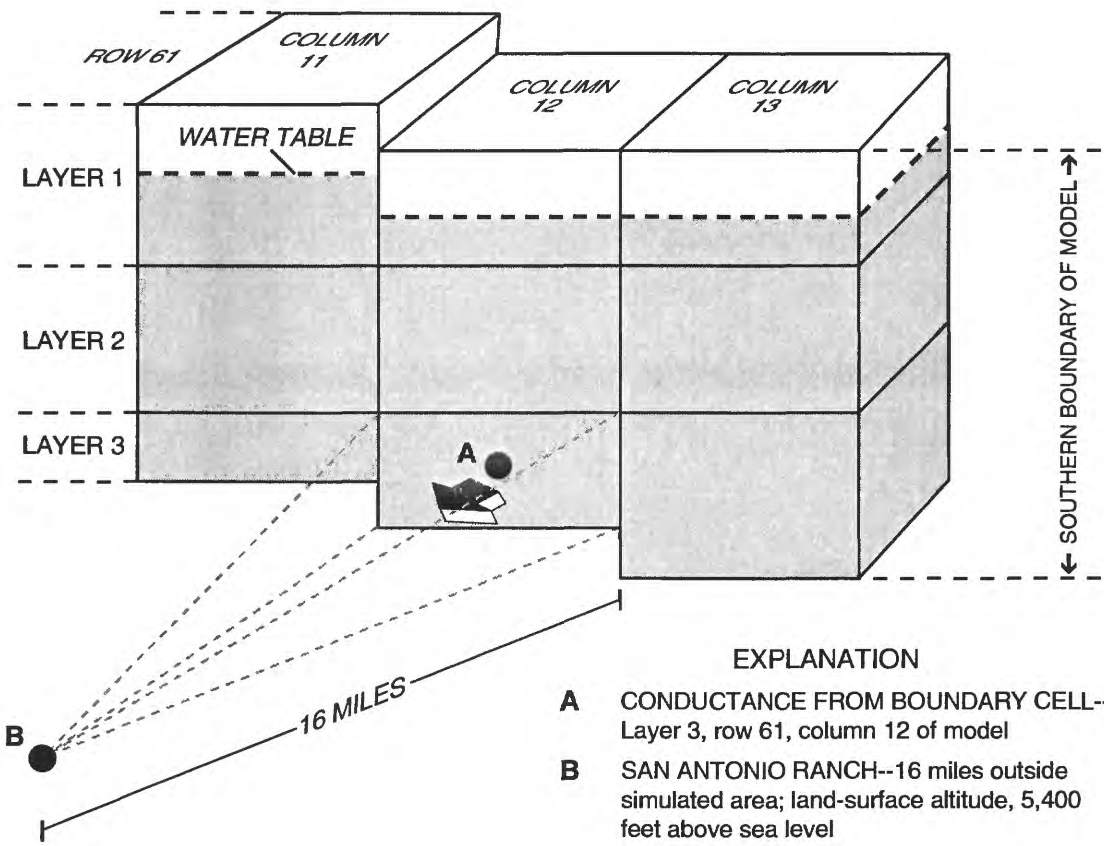
Springs

Springs are simulated in the model by 32 drain cells in layer 2 and 2 drain cells in layer 3, although some springs may originate in shallower sediments. Drains that represent locations of observed springs were assigned to layer-2 cells. The layer-3 drains represent Darroughs Hot Springs and Smoky Valley (McLeod) Ranch, where springflow probably originates at great depth. Spencers Hot Springs was simulated by a layer-2 drain because the model is only two layers thick at that location. A drain was simulated in layer 2 above the two layer-3 drains to represent spring seepage from both layers along preferential flow paths related to faults.

Conductance values for layer-2 drains were calculated by multiplying the vertical leakance factor between layers 1 and 2 of the cell (fig. 24) by 100,000 (ratio of hydraulic conductivity of the drain to confining-bed leakance), by the average spring-discharge area, and by the number of springs in the 1-mi^2 area represented by the drain cell. The ratio of 100,000 was determined by trial-and-error matching of simulated discharge from drains with measured or estimated springflow. The area of spring discharge was estimated as an average of 100 ft^2 for each spring on the basis of field observations. Conductance values for layer-3 drains were calculated in the same way by using confining-bed leakance between layers 2 and 3.

Subsurface Outflow

To determine the effects of outflow to Tonopah Flat, a head-dependent boundary was assigned to three cells in each layer on the south boundary of the model. The estimated water levels of springs and flowing wells at San Antonio Ranch, 16 mi south of the modeled area, were used as controls (fig. 26). The rate of flow out of each head-dependent cell is proportional to the head gradient between that cell and the springs at San Antonio Ranch.



Layer	Row	Column	Control altitude[1]	Horizontal conductance (feet squared per day)
1	61	11	5,390	1,120
1	61	12	5,390	1,120
1	61	13	5,390	1,210
2	61	11	5,405	2,160
2	61	12	5,405	2,160
2	61	13	5,405	2,250
2	61	11	5,410	674
2	61	12	5,410	596
2	61	13	5,410	458

[1] Estimated head in aquifer beneath San Antonio Ranch

Figure 26. Horizontal conductance from southern boundary of ground-water flow model, northern Big Smoky Valley, Nevada.

The following equation was used to simulate flow across the boundary at each cell:

$$Q = KA\,(dh/dx)\;, \qquad (6)$$

where Q is the discharge,

K is the hydraulic conductivity,

A is the cross-sectional area,

dh is the difference in head between the cell and the springs, and

dx is the distance from the cell to the springs.

The hydraulic conductivity of the cell interface, initially estimated to be the same as the horizontal hydraulic conductivity of the cell, was reduced by 50 percent during calibration. The cross-sectional area is the width of the cell (5,280 ft) multiplied by the saturated thickness of the node. The distance between the head-dependent cells and the springs is 16 mi. The head at the node varies and is simulated by the model. The heads at the springs were assigned. The heads at the springs were estimated to be 5,390 ft for layer 1, 5,405 ft for layer 2, and 5,410 ft for layer 3 on the basis of land-surface altitude and an assumed upward movement of water to the springs at San Antonio Ranch.

Withdrawals

To represent ground-water withdrawals from wells, a constant flux was specified for nine cells in layer 1 and seven cells in layer 2 that correspond to locations of irrigation and mining wells that were in use during 1985 (see fig. 27). Estimates of withdrawals from individual cells were based on the following assumptions: (1) total discharge from a cell is the sum of withdrawals by all wells in the area represented by the cell, and it occurs at the center of the cell; (2) wells that are open to the aquifer only above an altitude of 5,320 ft (bottom of layer 1) withdraw water from layer 1; (3) wells that are open to the aquifer completely or partially below an altitude of 5,320 ft withdraw water from layer 2; (4) water is withdrawn at a constant rate (seasonal withdrawals are apportioned evenly throughout the year); and (5) total annual withdrawal from wells is 6,600 acre-ft on the basis of 1985 water-use estimates.

To simulate pumping at twice the 1985 rates of withdrawal, 23 hypothetical wells were added to the model—5 in layer 1 and 18 in layer 2 (fig. 27). Many are in areas where irrigation wells exist but were not pumped during the period of the study. Discharge from each hypothetical well was assumed to be 290 acre-ft/yr. Return flows from the hypothetical wells were simulated as 15 percent of pumpage on the basis of estimated average values for western states (Lauritzen and Terrell, 1967, p. 1105).

Calibration and Results of Model

The model was calibrated using the trial-and-error procedure in which initial values of horizontal and vertical hydraulic conductivity were changed during repeated simulations until simulated water levels generally matched measured water levels. The process was considered complete when (1) the differences between measured heads and heads simulated by the model were within an acceptable range (mean for 56 layer-1 wells, less than 1-ft difference; mean for 44 layer-2 wells, less than 6 ft difference) and (2) simulated discharges by evapotranspiration, springs, and subsurface outflow matched independent estimates and observations. Values of conductivity were kept within reasonable limits on the basis of knowledge of the ground-water flow system being investigated and the characteristics of similar systems.

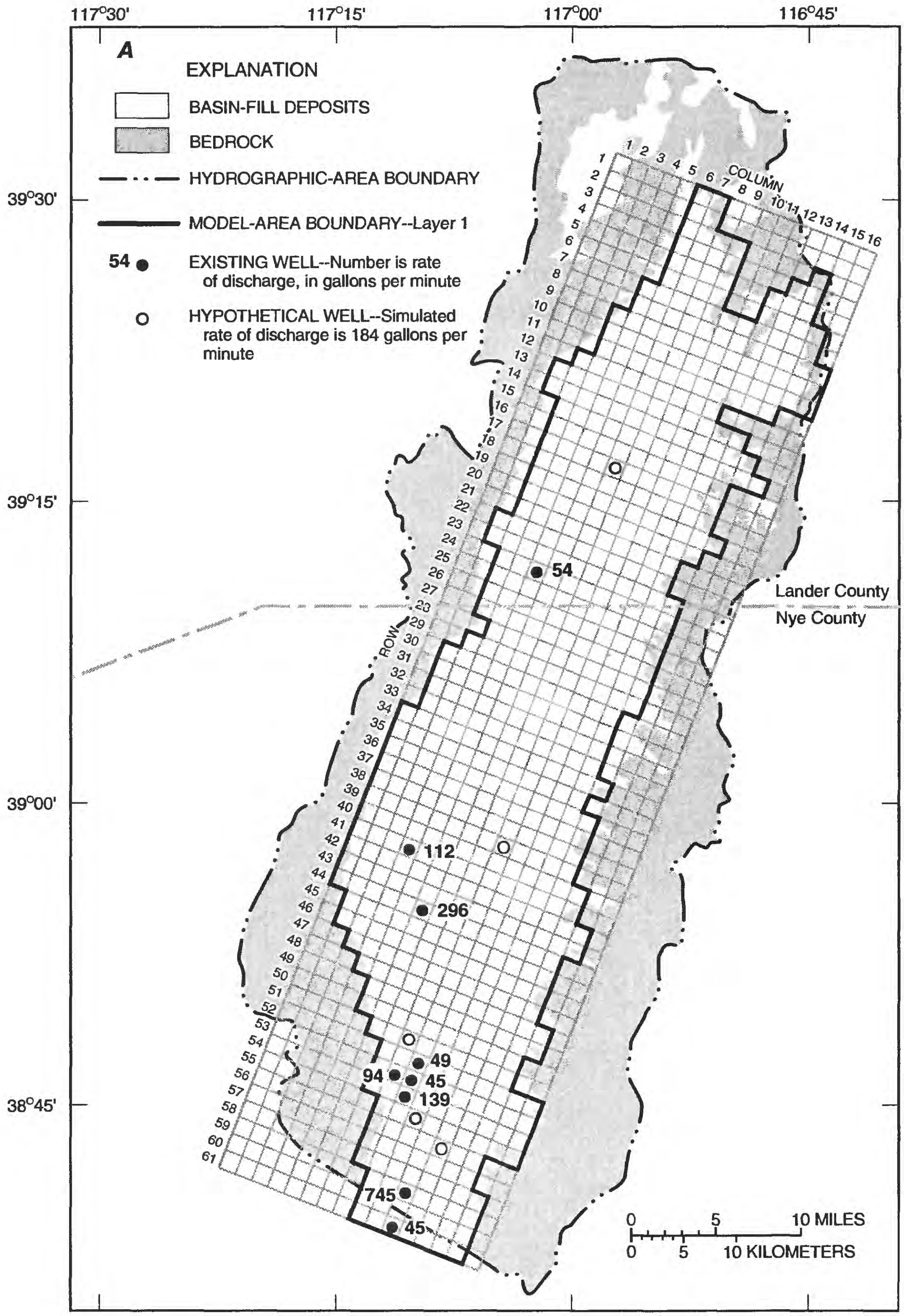


Figure 27. Ground-water withdrawal from cells in (*A*) model-layer 1 and (*B*) model-layer 2, northern Big Smoky Valley, Nevada.

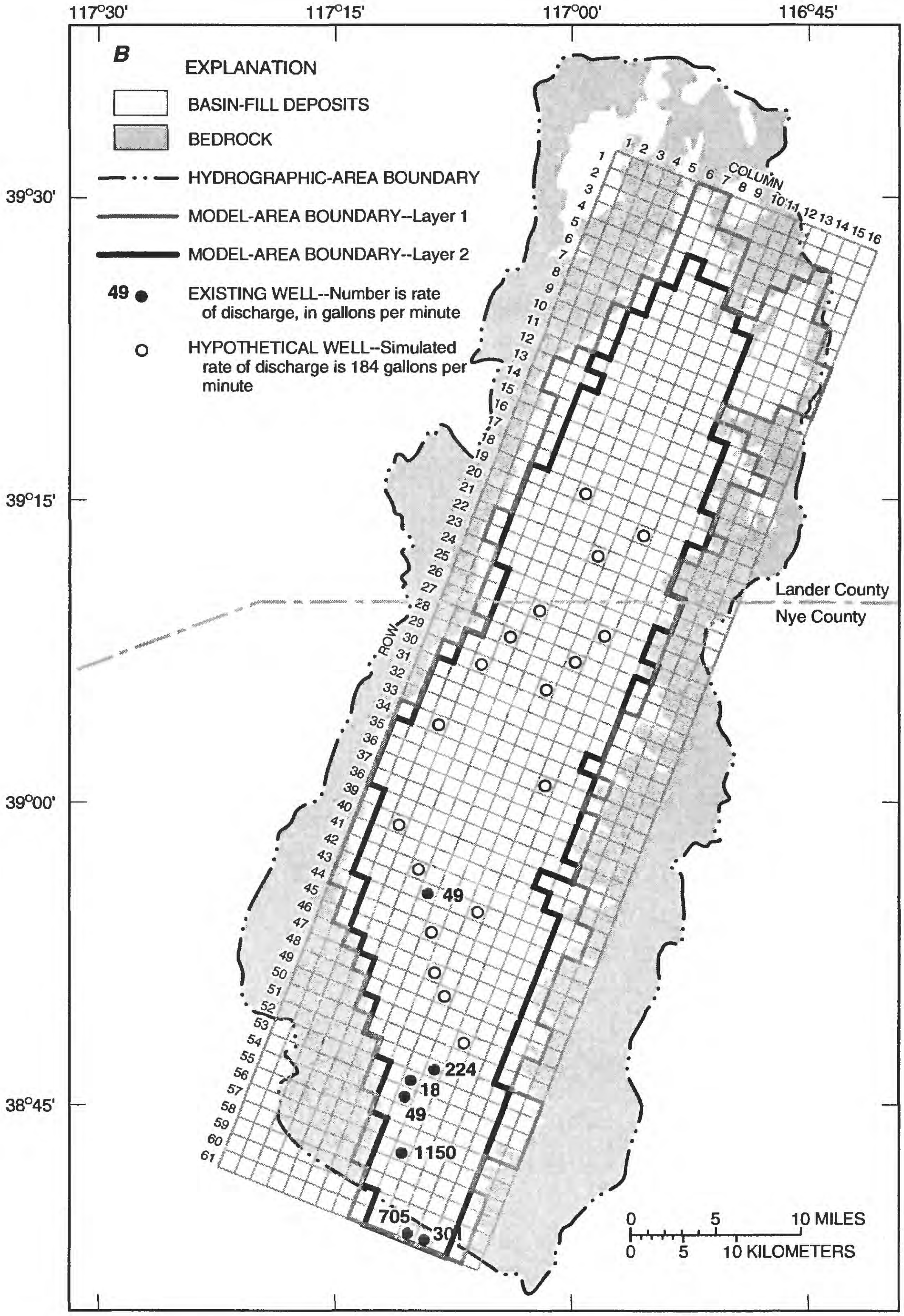


Figure 27. Continued.

During calibration of the northern Big Smoky Valley model, rates and distribution of recharge to the system and discharge by wells were held constant while initial estimates of boundary conditions and hydraulic conductivities were adjusted. Measured water levels and simulated heads for layers 1 and 2 of the calibrated model are shown in figure 28, and simulated evapotranspiration is shown in figure 29.

Only the steady-state model was calibrated; its boundary conditions and aquifer properties were applied to the transient model. The transient model could not be calibrated independently because water-level data were insufficient to match a historical period. Therefore, until water-level data for a longer period are available to refine the transient model, it cannot be considered a predictive tool.

Calibration heads.—During calibration, only cells representing areas with measured water levels from wells or observed levels from springs were matched with heads simulated by the model because of the uncertain accuracy of interpolated values. Calibration was based on 56 cells in layer 1 and 44 cells in layer 2 (fig. 28).

South boundary.—The south boundary of the model area was simulated as a no-flow boundary, a constant-flux boundary, and a head-dependent boundary. The head-dependent boundary provided the best approximation of subsurface outflow from the system because it is responsive to changing conditions. Initial simulations allowed too much outflow and resulted in low water levels in the southern part of the basin. Simulated water levels could be higher if recharge from the mountains south of the boundary was impeding southward flow, recharge north of the boundary was greater than that estimated, or initial estimates of hydraulic conductivity were too high. Because of greater uncertainty about hydraulic-conductivity estimates, these were adjusted during calibration. A 50-percent reduction in the initial hydraulic-conductivity values resulted in an acceptable match between simulated and observed water levels.

Aquifer properties.—Horizontal hydraulic conductivity in layer 1 was adjusted during calibration to better match the potentiometric gradient, as discussed in the section titled "Aquifer Properties" under "Model Design and Construction" and shown in figure 22. Vertical hydraulic conductivity, leakance between layers, and conductance values at drains simulating springs were adjusted separately; no significant improvement resulted from these changes. Specific-yield values for layer 1 and storage coefficients for layers 2 and 3 were assigned for the transient model. Values were not adjusted because changes in head and storage simulated by the transient model were reasonable with respect to the limited historical data.

Regional inflow.—As a result of adding recharge from regional ground-water inflow to three areas of the model, simulated spring discharge and evapotranspiration rates increased and local water levels rose in comparison to rates and levels from simulations that did not include the inflow. Heads near Darroughs Hot Springs increased a maximum of 2 ft in layer 1, 3 ft in layer 2, and 19 ft in layer 3; heads near McLeod Ranch increased a maximum of 3 ft in layer 1, 4 ft in layer 2, and 33 ft in layer 3; heads near Spencer Hot Springs increased a maximum of 3 ft in layer 1 and 6 ft in layer 2 (the model has only 2 layers near Spencer). The median of water levels throughout layers 1 and 2 changed less than 1 ft. More than 90 percent of the regional inflow was discharged by evapotranspiration. The simulated water levels and ground-water budget were consistent with observations (measured water levels), indicating that some inflow from bedrock at these sites is reasonable, but the accuracy of the model is insufficient to show that the source of the water is outside the basin. Regional inflow of 2,500 acre-ft was included in the model calibrations and sensitivity analyses.

Evapotranspiration.—Evapotranspiration simulated by the calibrated model of the natural (unstressed) system is shown in figure 29. Simulated evapotranspiration for equilibrium conditions, without pumping, is about 69,000 acre-ft, and, with pumping, is about 64,000 acre-ft. Estimates from phreatophyte maps are within these simulated values (about 67,000 acre-ft), indicating that the simulated values are reasonable. The distribution of evapotranspiration simulated by the model also coincides reasonably well with the mapped distribution of phreatophytes (compare fig. 29 with fig. 15). Initial extinction depths were retained during calibration because they resulted in acceptable simulation of rates and distribution of evapotranspiration and because changing the extinction depths would change simulated ground-water levels, but would not change the evapotranspiration discharge.

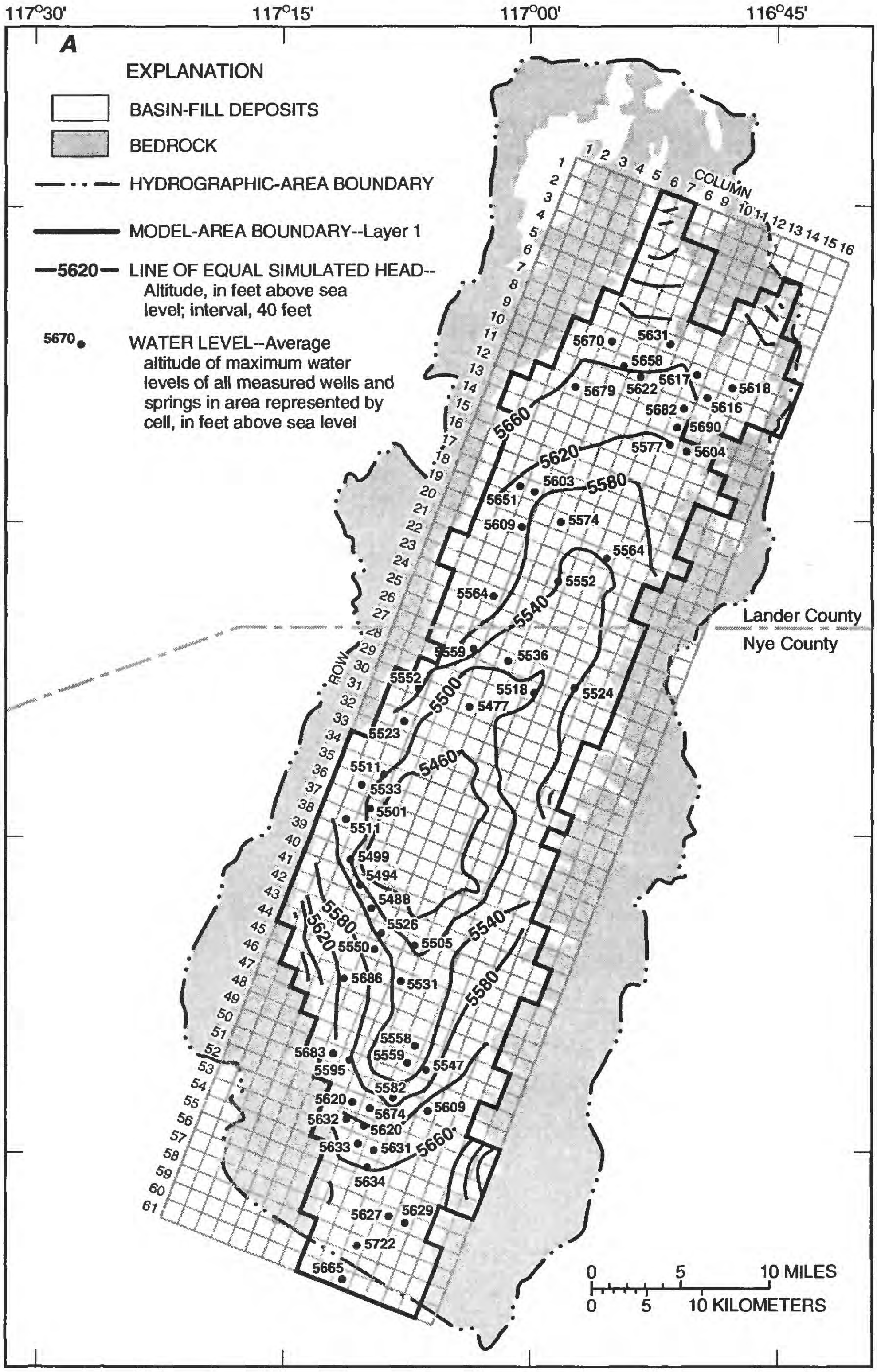


Figure 28. Measured water levels and simulated heads in (*A*) model-layer 1 and (*B*) model-layer 2, northern Big Smoky Valley, Nevada.

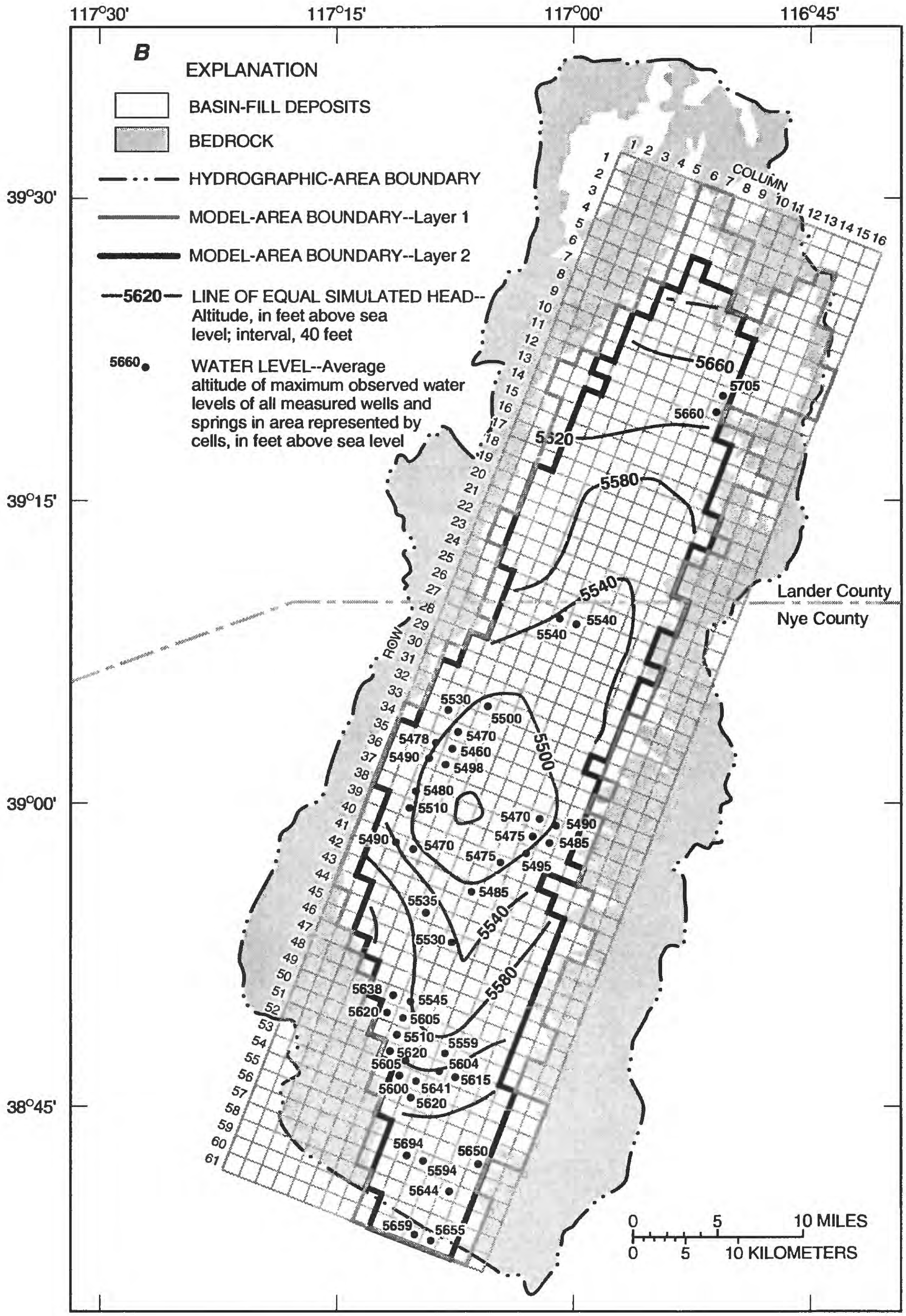


Figure 28. Continued.

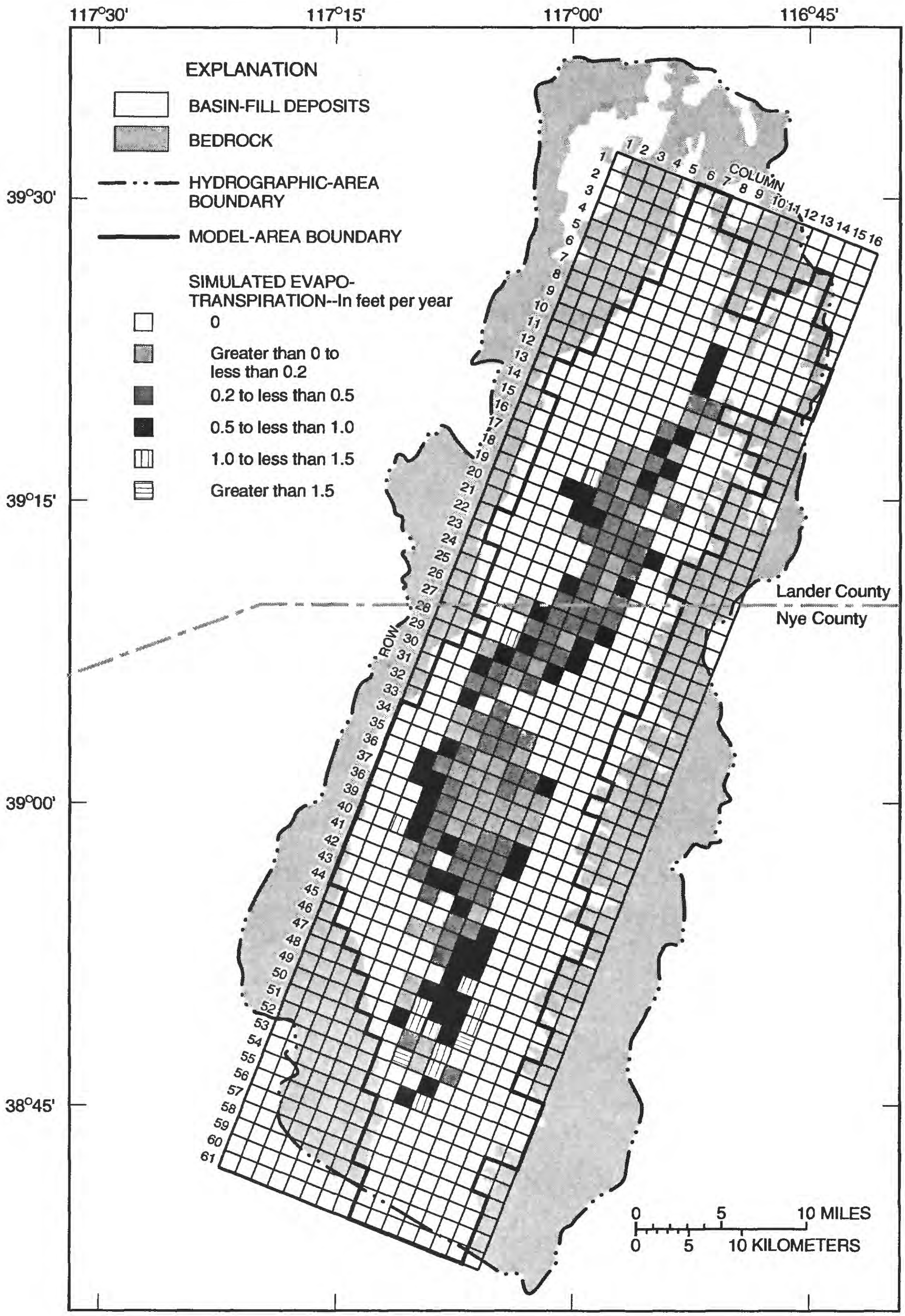


Figure 29. Simulated ground-water evapotranspiration, northern Big Smoky Valley, Nevada.

Springs.—Springflow simulated by the steady-state model without pumping was about 5,100 acre-ft/yr. The springflow was from 19 of the 32 drains assigned to layer 2 and from both drains in layer 3. The nonflowing drains were assumed to represent springs that originate in perched or shallow aquifers and their discharge, therefore, was included in evapotranspiration from layer 1. Discharge from springs calculated by the steady-state model with pumping was about 4,700 acre-ft/yr. This springflow is from 18 drains in layer 2 and 2 drains in layer 3. Total rates of springflow simulated by the model closely agreed with the 5,000 acre-ft/yr estimated from field observations, but may be high because the estimates include discharge by shallow springs.

Subsurface outflow.—Model simulations indicate that 2,700 acre-ft of water discharges from the basin by subsurface outflow under natural equilibrium conditions. Most of the discharge is southward through layer 2. About 2,300 acre-ft of subsurface outflow was simulated for equilibrium conditions with pumping, whereby about 15 percent of the simulated natural outflow was captured by the pumping wells. Simulated outflow shifted the ground-water divide 2 mi northward, lowered water levels as far north as 5 mi from the model boundary, and resulted in an acceptable distribution of heads. Although the assumption of subsurface outflow is reasonable, its inclusion was not necessary in the simulation of measured water levels under equilibrium conditions because the simulated outflow represents less than 4 percent of the estimated total discharge from the basin. The head-dependent boundary that allows outflow, however, provides a better representation of heads and more plausible representation of the aquifer system than a no-flow boundary would provide.

Sensitivity Analysis

Boundary conditions and aquifer properties were systematically changed to test the sensitivity of the model and to determine the effects of uncertainty in estimated values. A series of simulations was made in which values for boundary conditions or aquifer properties were changed sequentially while the others were held constant. The simulations were made using the steady-state model of the natural (undeveloped) system. Changes in hydraulic heads at layer-1 and layer-2 cells and computed rates of natural discharge from springs, evapotranspiration, and subsurface outflow were evaluated as indicators of sensitivity. Results of the sensitivity analysis (table 10) show that the model is most sensitive to changes in recharge and is least sensitive to changes in either hydraulic conductivity or thickness of layer 3. Combinations of changes, however, such as reductions in both transmissivity and recharge, could compensate for each other. As both factors are uncertain to some degree, sensitivity analysis cannot be used to verify either one.

Transmissivity.—Increases and decreases in transmissivity of each layer affected head and discharge in layer 1 more than in layer 2, and had very little effect on layer 3. Doubling the transmissivity is equivalent to doubling the thickness of the layer while holding hydraulic conductivity constant, or to doubling the hydraulic conductivity while holding the thickness constant. Doubling the transmissivity of layer 3 had no effect on heads in layers 1 and 2 and an insignificant effect on discharge (table 10). The model is most sensitive to errors in estimates of hydraulic conductivity of layer 1. It is relatively insensitive to errors in estimates of thickness of basin-fill deposits.

Vertical leakance.—Increases and decreases in vertical leakance test the sensitivity of the model to errors in estimates of water flow through confining units or in estimated vertical-to-horizontal anisotropy in hydraulic conductivity. Vertical leakance between layers 1 and 2 and layers 2 and 3 were changed simultaneously. Effects on simulated heads were moderate; increased leakance resulted in a median decrease of 4 ft in head in layer-1 cells and 6 ft in layer-2 cells, whereas decreased leakance resulted in a comparable increase in heads. As shown in table 10, the greatest effect of changes in vertical leakance was on springflow, which increased by 29 percent when vertical leakance was reduced by half, and decreased by 24 percent when vertical leakance was doubled. The overall effect is small, however, because springflow accounts for only a small percentage of total discharge.

Table 10. Results of sensitivity analysis of steady-state model for northern Big Smoky Valley, Nevada

	Change (multiplication factor)	Median change in head[1] (feet)		Total discharge[1] (cubic feet per second)						
				Springflow			Evapotranspiration		Subsurface outflow	
		Layer 1	Layer 2	Number[2]	Discharge	Percent change	Discharge	Percent change	Discharge	Percent change
Calibrated model[3]	None	0	0	19	7.0	0	94.9	0	3.7	0
Transmissivity:										
Layer 1	2.0	-10	-8	15	5.6	-21	97.5	+3	3.4	-7
	1.2	-2	_2	18	6.7	-14	95.8	+1	3.6	-1
	.8	+3	+2	19	7.4	+6	94.2	-1	3.7	+1
	.5	+8	+6	19	8.1	+15	93.4	-2	3.8	+4
Layer 2	2.0	-6	-4	18	8.0	+14	95.0	0	3.4	-6
	1.2	-1	-1	19	7.3	+4	95.5	+1	3.6	-1
	.5	+6	+4	18	6.0	-14	95.4	+1	3.8	+4
Layer 3	2.0	0	0	19	7.2	+2	95.4	+1	3.6	-2
	.5	0	0	18	7.0	-1	94.7	0	3.7	+1
Vertical leakance:										
Layers 1-2 and 2-3	2.0	-4	-6	15	5.3	-24	97.6	+3	3.6	-1
	.5	+5	+7	21	9.0	+29	92.1	-3	3.7	+1
Transmissivity and vertical leakance:										
All layers	2.0	-22	-17	14	5.0	-29	98.8	+4	3.1	-15
	.5	+22	+18	24	8.8	+25	92.7	-2	4.1	+11
Recharge:										
All recharge	2.0	+26	+22	25	13.7	+95	192.9	+103	4.5	+22
	1.2	+7	+6	19	8.3	+18	114.3	+20	3.9	+6
	.8	-9	-7	15	5.5	-22	76.1	-20	3.4	-8
	.5	-26	-21	13	3.3	-54	47.4	-48	2.8	-23
Regional inflow[4]	0	0	0	18	6.5	-7	92.4	-2	3.7	0

Table 10. Results of sensitivity analysis of steady-state model for northern Big Smoky Valley, Nevada—Continued

	Change (multiplication factor)	Median change in head[1] (feet)		Total discharge[1] (cubic feet per second)						
				Springflow			Evapotranspiration		Subsurface outflow	
		Layer 1	Layer 2	Number[2]	Discharge	Percent change	Discharge	Percent change	Discharge	Percent change
Evapotranspiration:										
Maximum rate	2.0	-2	-2	19	6.6	-5	96.0	+1	3.7	-1
	.5	+4	+4	20	7.7	+10	93.8	-1	3.7	+2
Extinction depth	2.0	-19	-19	13	4.1	-42	98.6	+4	3.5	-6
	.5	+9	+9	21	8.7	+24	92.6	-2	3.8	+2
Head-dependent boundary:										
Leakance factor	2.0	0	0	19	6.8	-2	92.6	-2	6.6	+79
	.5	0	0	19	7.1	+1	96.3	+2	1.9	-47
Drain (spring) interface:										
Leakance factor	2.0	0	0	18	10.0	+42	92.2	-3	3.7	0
	.5	0	0	19	4.6	-35	97.3	+2	3.7	0

[1] Differences between sensitivity test and calibrated model; plus sign (+) indicates increase, minus sign (-) indicates decrease.
[2] Number of springs (drains) discharging water from layer 2.
[3] Steady-state simulation of the natural (undeveloped) flow system.
[4] Interbasin flow is estimated to be 3.5 cubic feet per second (3 percent of total recharge).

Transmissivity and vertical leakance.—If assumptions about the relations between horizontal and vertical conductivity and between conductivity, leakance, and depth are correct, then any error in estimate of horizontal hydraulic conductivity of layer 1 will result in corresponding errors throughout the system. Therefore, the combined effects of changes in transmissivity of all layers and in vertical leakance between them was analyzed. These changes strongly affected simulated heads. As shown in table 10, median change in head in response to increases and decreases of transmissivity by a factor of 2 was 22 ft in layer 1 and 18 ft in layer 2. Discharges were also affected; in terms of percent change, springflow was affected the most, evapotranspiration the least; in terms of total amounts, evapotranspiration was affected the most.

Recharge.—Initial recharge estimates resulted in realistic simulated rates and distribution of discharge. To determine the sensitivity of the model to errors in recharge estimates, recharge values were increased and decreased by 20 percent and by a factor of 2 (see table 10). The change by a factor of 2 resulted in a median change in head of 26 ft in layer 1 and 22 ft in layer 2. Change in springflow and evapotranspiration was directly proportional to the percent change in total recharge. The sensitivity analysis appears to support the reliability of recharge estimates used in the model calibration, although the effects of greater recharge could have been balanced by higher values for horizontal and vertical conductivity, resulting in the same distribution of simulated water levels.

Evapotranspiration.—The maximum rate and extinction depth of evapotranspiration were increased and decreased separately by a factor of 2. Changing the maximum rate had very little effect on heads or discharge. Change in the extinction depth, however, had a significant effect on heads in both layers and on springflow. Doubling the extinction depth resulted in median declines of 19 ft in layer-1 and layer-2 water levels, an expanded area from which evapotranspiration occurs, and a 42-percent decrease in springflow. Discharge from six drain cells ceased. Decreasing the extinction depth resulted in a 9-ft rise in head in both layers and a 24-percent increase in springflow.

Subsurface outflow.—To test the sensitivity of the model to errors in estimates of flow across the head-dependent southern boundary of the model, conductance values for all three layers along the boundary were increased and decreased by a factor of 2. Although median heads throughout the basin did not change, heads were affected locally at the southern end. Doubling the conductance values resulted in a maximum 29-ft decline in head at the southern boundary, and decreasing the conductance by 50 percent resulted in a maximum 14-ft rise at the boundary, although the median of heads throughout the basin was not affected (because of the great extent of the basin). As shown in table 10, doubling the conductance caused a 79-percent increase in subsurface outflow, whereas decreasing the conductance by 50 percent caused a 47-percent reduction. Effects on evapotranspiration and springflow were insignificant because the outflow is less than 5 percent of the total simulated discharge.

Springs.—The conductance values that simulate flow across the interface between the aquifer and the drains that represent springs in the model was increased and decreased by a factor of 2. These changes had no effect on the median of heads throughout the basin, but in the vicinity of springs, heads declined locally as much as 5 ft in layer 1 and 12 ft in layer 2 when conductance was doubled, and rose by the same amount when conductance was decreased by 50 percent. Increasing the conductance resulted in a 42-percent increase in springflow and a 3-percent decrease in evapotranspiration; decreasing the conductance resulted in a 35-percent decrease in spring flow and a 2-percent increase in evapotranspiration. Subsurface outflow was not affected by these changes.

Ground-Water Budgets from Model Simulations

The model was used to simulate the ground-water budget for northern Big Smoky Valley under natural (undeveloped) and stressed (developed) conditions. The results of the simulations are presented in table 11 in terms of ground-water budgets for (1) natural conditions before development, (2) equilibrium conditions at 1985 withdrawal rates and distribution of ground-water development, (3) nonequilibrium conditions after 20 years of development, and (4) equilibrium conditions with increased development. A discussion of the limitations of the simulations and examples of potential effects of future stress are discussed in subsequent sections of the report.

Table 11. Ground-water budgets from model simulations for northern Big Smoky Valley, Nevada

[Unless otherwise indicated, all values in acre-feet per year, rounded to two significant figures]

Component of the ground-water budget [1]	Model-simulation number and conditions				
	1 Equilibrium; natural system (no withdrawal); average recharge	2 Equilibrium; withdrawal at 1985 rates; average recharge	3a Nonequilibrium; 20 years withdrawal at 1985 rates; average recharge	3b Nonequilibrium; 20 years withdrawal at 1985 rates; 1965-85 recharge	4 Equilibrium; withdrawal at twice 1985 withdrawal rates; average recharge
Recharge					
Precipitation and surface water	74,000	74,000	74,000	[1]86,000	74,000
Irrigation return	0	1,200	1,200	1,200	2,200
Regional inflow	2,500	2,500	2,500	3,100	2,500
Total recharge	77,000	78,000	78,000	90,000	79,000
Discharge					
Pumpage	0	6,600	6,600	6,600	13,000
Evapotranspiration	69,000	64,000	67,000	71,000	59,000
Springflow	5,100	4,700	4,900	5,300	4,400
Subsurface outflow	2,700	2,300	2,500	2,500	2,300
Total discharge	77,000	78,000	81,000	85,000	79,000
Storage					
Net storage change	0	0	-2,600	+4,600	0
Water-level change, in feet					
Average change [2]	--	-3	-1	+1	-4
Maximum decline [3]	--	41	22	17	44

[1] Mean annual recharge for 20-year period; final year (1985) recharge from precipitation was 90,000 acre-feet and total recharge for 1985 was 94,000 acre-feet.
[2] Change relative to natural equilibrium conditions (simulation 1); plus sign (+) indicates rise, minus sign (-) indicates decline.
[3] Maximum simulated declines were in the southern part of the basin.

The first simulation is a steady-state model in which water levels and flow paths approximate natural equilibrium conditions. It represents the system before development (table 11, column 1). Of the water that recharges the basin (about 77,000 acre-ft), about 90 percent is discharged by evapotranspiration, 7 percent by springs, and 3 percent by subsurface outflow to Tonopah Flat. The results of this simulation are shown in figure 28.

The second simulation is a steady-state model that represents the system at equilibrium with 1985 development stresses (table 11, column 2). Equilibrium conditions could be reached if present pumping continued and no additional stresses were applied to the system. In this simulation, about 8 percent of the recharge is withdrawn by wells, 83 percent discharges by evapotranspiration, 6 percent discharges by springs, and 3 percent leaves the basin by subsurface outflow. A maximum decline in the water table of about 40 ft is simulated in the southern part of the basin.

The third simulation consists of transient models that simulate effects of 1985 rates of withdrawal on the natural (undeveloped) system during (a) a 20-year period during which recharge values approximated the long-term average, and (b) a 20-year period, from 1965 to 1985, during which recharge values exceeded the long-term average by 16 percent, to correspond to the greater-than-average precipitation measured at Austin. The 20-year period was selected to simulate the ground-water system as it changed from the natural (unstressed) state to an approximation of present (1985) conditions. Results are shown in table 11, columns 3a and 3b. Both simulations produced systems that have not reached equilibrium. A comparison of the water levels from these two simulations shows the effects of the 1965-85 period of greater-than-average recharge. After 20 years of development under average conditions (column 3a), discharge would exceed recharge by almost 4 percent and the volume of water in storage would decrease. In contrast, for the period of greater-than-average recharge (column 3b), recharge would exceed discharge by almost 6 percent and the volume of water in storage would increase.

The fourth simulation represents a potential equilibrium that might result from increased development of the ground-water system. It simulates withdrawals at twice the 1985 rate (table 11, column 4). Initial conditions were represented by simulation 2, and recharge values equaled the long-term average. Increased withdrawals were from 23 hypothetical wells located to capture water that otherwise would be discharged by evapotranspiration. Hypothetical wells are in areas near the playa, where (1) the water table is shallow, (2) the water quality is acceptable for irrigation and for human consumption, and (3) wells are likely to withdraw water that would otherwise be evapotranspired by phreatophytes. The wells are isolated from other high-yield wells by at least 1 mi. Simulated annual withdrawals were about 300 acre-ft per well, enough to irrigate about 100 acres of alfalfa. The model showed that 94 percent of the increased withdrawals would come from water that would otherwise be discharged by evapotranspiration, 6 percent from springflow, and less than 1 percent from subsurface outflow to Tonopah flat. As a result of the increased withdrawals, evapotranspiration would decrease by 8 percent, springflow by 7 percent, and subsurface outflow by 2 percent, relative to equilibrium conditions resulting from 1985 withdrawal rates. Model results indicate that water-level declines would average about 3 ft, and the maximum decline would be about 4 ft, in comparison with equilibrium conditions resulting from 1985 withdrawal rates (table 11, column 2).

Assumptions and Limitations

All models of ground-water flow are approximations because no set of equations can fully describe all processes that take place in an aquifer and all of its characteristics at all points. Simplifying assumptions must be made in order to model complex hydrogeologic situations. The basic assumption in modeling is that the approximations, simplifications, and estimates are reasonable. The reliability of the results is assessed by how closely the calibrated model approximates actual conditions.

In parts of northern Big Smoky Valley, data are sparse and inadequate to fully define the flow system. For example, conditions in the deep subsurface and underlying bedrock are estimated because data are not available and indirect methods are subject to different interpretations. Furthermore, where data are available, they must be averaged within each cell of the model.

For this study, simplifying assumptions were made about recharge, discharge, and aquifer properties. Nearly all recharge was assumed to infiltrate through the uppermost layer of the model, whereas in the natural system, a significant amount of water may be transmitted to the aquifer through bedrock at all depths. The model also assumed a small rate of subsurface inflow in the vicinity of major hot springs, but the actual rate and distribution of flow is unknown. All withdrawals were assumed to be distributed evenly with time, whereas in reality, only mining water is withdrawn year round; irrigation water is withdrawn only during the growing season—about 140 days per year. Evapotranspiration rates are based on limited experimental data, primarily from areas outside northern Big Smoky Valley. Only the basin-fill aquifer was modeled, although local carbonate and volcanic bedrock units may yield useful quantities of water.

A limitation on the application of models is that solutions of models are not unique; combinations of different values for amounts and distribution of hydrologic variables and hydraulic properties could result in the same distribution of water levels. The results of the steady-state models developed in this study were based on reasonable values and knowledge of the aquifer and they provide a plausible approximation of the ground-water flow system. In contrast, until long-term historical data are available for corroboration, the transient models should be considered examples rather than reliable predictors of aquifer performance and response.

As water use and development increase and more data on recharge, discharge, and changes in storage become available, the model can be further refined. Its accuracy and potential utility as a predictive tool will increase and the hydrologic effects of different patterns of development then can be determined with greater confidence.

Potential Effects of Future Development

Some management strategies consider mean annual recharge as the theoretical upper limit to ground-water development. In northern Big Smoky Valley, only a small part of mean annual recharge, 8 percent, is withdrawn for irrigation, mining, and other human activities. Therefore, increases in ground-water withdrawals are possible. Much of the recharge, but not all, can be used because development by wells requires consideration of water quality, transport, and use, and is unlikely to efficiently capture all the water that would otherwise discharge by natural processes of evaporation and transpiration. Increased withdrawals will result in changes in the water budget and adjustments in the ground-water flow system.

According to results of simulations, a new equilibrium may be established if withdrawals are small. For example, present rates of consumption are likely to result in an average water-level decline of 41 ft in the vicinity (within one-quarter mile) of pumped wells in the southern part of the basin. Depending on distribution of pumped wells in the basin, sustained withdrawals at twice the present rates would probably cause average water levels ultimately to decline an additional 4 ft. As withdrawals increase and water levels decline, rates of evapotranspiration, springflow, and subsurface outflow would also decrease, resulting in a new equilibrium between recharge and discharge.

The maximum rate of withdrawal for which a new equilibrium can be established, and the most preferable locations for individual new wells, were not investigated during this study. Appropriate well locations depend on social, economic, and legal, as well as hydrologic, considerations that were beyond the scope of this study. However, some estimates have been made. An estimated 13,000 acre-ft of ground water could be withdrawn from the Lander County part of the basin and 52,000 acre-ft from the Nye County part by capturing all ground water that is discharged by evapotranspiration, according to Rush and Schroer (1970, p. 64-65). They give examples of well yields, well spacing, and water-level drawdowns needed to lower the water table to at least 50 ft below land surface during the growing season, so that it would be out of reach of phreatophyte roots. Results of the present study indicate that average long- term rates of evapotranspiration may be 5-10 percent higher than those estimated in the 1970 report. If the higher rates are correct, the 1970 estimates can be considered conservative upper limits for development of ground water.

If withdrawals exceed mean annual recharge, and if no new sources of recharge (such as recycled or imported supplies) are introduced, water in storage gradually will be depleted; the system would not reach equilibrium and water levels would continue to decline. Eventually, the costs of pumping would outweigh the benefits. Large withdrawals could be made on a temporary basis for mining or other uses, however, allowing subsequent recovery of water levels.

Where the aquifer is full (water table is at or near land surface), as in the central part of the valley, some water evaporates from the surface during years of above-average precipitation. Surface streams reach the playa, where water ponds and eventually evaporates. Shallow water remains on the playa for many months during wet years, but it is unsatisfactory for use because it is an undependable supply and its quality is poor. Theoretically, storage potential in aquifers could be enhanced by pumping water from areas of high water levels surrounding the playa, thus increasing the potential for recharge. Infiltration rates can be increased by spreading, ponding, or injecting the water. Using withdrawals to create new storage is practical only if the pumped water can be put to sufficiently beneficial use to offset costs of pumping and of increasing recharge. This alternative is practiced to some extent where aquifers are pumped for irrigation late in the growing season and replenished by infiltration of surface water during the following spring.

SUMMARY AND CONCLUSIONS

Mining, irrigation, and domestic use of ground water is increasing in northern Big Smoky Valley. Effective decisions about water allocation to meet increasing demands require an understanding of the sources, amount, distribution, and use of ground water in the basin. To improve this understanding, the U.S. Geological Survey, in cooperation with Nye County, completed a 3-year study; results of the study are described in this report.

The principal source of ground water in northern Big Smoky Valley is an extensive basin-fill aquifer consisting of gravel, sand, silt, and clay layers. Total thickness of this aquifer is as much as 5,000 ft in the center of the basin. An estimated 5 million acre-ft of water is stored in the upper 100 ft of the aquifer, but only a small part is replenished annually.

Of the average 740,000 acre-ft of water that falls on the basin as snow and rain each year, 90 percent evaporates from the surface or is transpired by vegetation; only 10 percent infiltrates to the water table. Most of the water infiltrates from about 50 streams that originate and terminate within the basin. Streams are perennial in the western mountains and intermittent in the rest of the basin. The largest perennial streams, Kingston Creek and South Twin River, have mean annual streamflows of 7,200 and 5,300 ft^3/s, respectively.

Water withdrawn from wells in the basin, except in areas of thermal water and near playas, is generally of acceptable quality for irrigation, stock, and domestic use. The best quality ground water for most purposes is likely to be found away from playas at depths of 200-400 ft.

Most ground water in the basin discharges by evapotranspiration, primarily by natural vegetation. Annual evapotranspiration of ground water, based on phreatophyte distribution estimated primarily from Landsat data, is about 67,000 acre-ft. Total withdrawals during 1985 for irrigation, mining, stock watering, public supply, and private domestic use were about 6,600 acre-ft; 98 percent of the water was used for irrigation and mining. Some ground water discharges by subsurface outflow southward to Tonopah Flat.

Despite pumping, water levels in the basin-fill aquifer did not decline during 1965-85. Water levels rose in most parts of the basin because precipitation during this 20-year period was 16 percent greater than the long-term (1890-1985) average. Streamflow and ground-water recharge, consequently, were also greater than average. Water levels declined in the southern part of the basin, however, as a result of development.

A numerical ground-water flow model was used to refine the conceptual flow model of northern Big Smoky Valley and to evaluate the potential for future development in the basin. The model was used to estimate ground-water budgets for four sets of conditions: (1) natural equilibrium (steady-state conditions) before development, (2) equilibrium based on 1985 rates and distribution of withdrawals, (3) nonequilibrium (transient conditions) after 20 years of development, and (4) equilibrium with increased development. To evaluate hydrologic effects of increased development, additional (hypothetical) wells were simulated. Results indicate that sustained withdrawals at twice the 1985 rate could cause average water levels to decline 4 ft in comparison to water levels resulting from 1985 withdrawal rates; local declines could be as much as 44 ft in the vicinity of pumped wells. The declining water levels would result in decreasing rates of evapotranspiration, springflow, and subsurface outflow to the south. A new equilibrium, however, could be established. If the additional wells were located to capture water that otherwise would be transpired by phreatophytes, the long-term hydrologic effects of increased development could be minimal.

SOURCES OF ADDITIONAL INFORMATION

Several State and Federal agencies are involved in collecting water-resources data in Nevada, assessing water and land use, and planning and management. Mailing addresses and types of information available from some of the principal agencies are in table 12. The National Water Information System (NWIS), administered by the U.S. Geological Survey, is a central computerized source of basic data. NWIS is managed in Nevada by the USGS District Office in Carson City.

Table 12. Selected sources of information about water resources and land use in Nevada

Name, address, and internet address	Type of information available
Nevada State agencies	
Department of Conservation and Natural Resources Division of Water Resources Division of Water Planning Division of Environmental Protection 123 W. Nye Lane Carson City, NV 89710 http://www.state.nv.us/cnr/ndwp	Water-resource plans and assessments; water-right permits (Cartier and others, 1995); licensing water-right surveyors and well drillers; dam safety; geothermal resources; drillers' reports and logs of wells (Bauer and Cartier, 1995); water-quality information and regulations; water availability, water-supply and water-demand reports; protection of beneficial uses, discharge permits, monitoring discharge quality; and forecasts of water supply and demand
University of Nevada:	
Bureau of Mines and Geology Reno, NV 89557 http://www.nbmg.unr.edu	Earthquake-hazard, radon-hazard, and landslide-hazard reports; geologic and mineral-resources maps; flood- and debris-hazard maps; geology, geophysics, geothermal, and commodities reports; rock and mineral collections for research; mining district data bases; unpublished mine-workings data; air photos
Desert Research Institute Water Resource Center Atmospheric Sciences Center Western Regional Climate Center P.O. Box 60220 Reno, NV 89506 http://www.dri.edu	Water resources, water and air quality, basic and applied environmental research

Table 12. Selected sources of information about water resources and land use in Nevada—Continued

Name, address, and Internet address	Type of information available
Federal agencies	
U.S. Department of Agriculture:	
Agricultural Research Service 920 Valley Road Reno, NV 89512 http://www.ars.usda.gov	Water-use technology for agriculture; pasture and range studies
Forest Service Toiyabe National Forest 1200 Franklin Way Reno, NV 89505 http://www.fs.fed.us	Productivity of forests and range lands; protection of tributary waters; maps and air photos; forest regulations
Natural Resources Conservation Service 1201 Terminal Way P.O. Box 4850 Carson City, NV 89710 http://www.ncg.nrcs.usda.gov	Water supply and conservation; soil surveys; snow-course and reservoir-storage data; resource maps (land, water, and soils); air photos
U.S. Department of Commerce:	
National Oceanic and Atmospheric Administration 2601 E. Plumb Lane Reno, NV 89502 http://www.noaa.gov	Weather records and forecasts; weather modification; reports and data
U.S. Department of the Interior:	
Bureau of Land Management 850 Harvard Way P.O. Box 12000 Reno, NV 89520 http://www.blm.gov	Range and livestock management; land use; oil and gas leasing; mining claims; land ownership; survey markers; land-status maps; orthophoto maps; color infrared, color, and black-and-white air photos
U.S. Geological Survey 333 W. Nye Lane Carson City, NV 89706 http://wwwnv.wr.usgs.gov	Water resources; biological resources; mining; geology, hydrology, cartography, geography, and remote sensing; reports, maps, and data; National Water Information System (NWIS)

Table 13. Location, water levels, and other information for wells and test holes, northern Big Smoky Valley, Nevada

U.S. Geological Survey site designation: Each site is identified by the local (Nevada) site-identification system and by latitude and longitude. The local site-identification system is based on an index of hydrographic areas in Nevada (Rush, 1968) and on the rectangular subdivision of the public lands referenced to the Mount Diablo base line and meridian. Each number consists of three units separated by spaces: The first unit is the township, preceded by an N or S to indicate location north or south of the base line. The second unit is the range, preceded by an E to indicate location east of the meridian. The third unit consists of the section number and letters designating the quarter section, quarter-quarter section, and so on (A, B, C, and D indicate the northeast, northwest, southwest, and southeast quarters, respectively), followed by a number indicating the sequence in which the site was recorded. For example, NO9 E43 05DCAC1 is the first well recorded in the southwest quarter (C) of the northeast quarter (A) of the southwest quarter (C) of the southeast quarter (D) of section 5, township 9 north, range 43 east, Mount Diablo base line and meridian.

Owner or name of well: Abbreviations: NV DOT, Nevada Department of Transportation; USBLM, Bureau of Land Management; USGS, U.S. Geological Survey.

Primary water use Abbreviations: H, domestic; I, irrigation; K, mining; N, industrial; P, public supply; S, stock; U, unused; Z, Other.

Water-level depth: F, flowing; P, pumping; O, obstruction in well; >, water level deeper than indicated depth; -, water level above land surface (flowing).

Water-level source of data: Measurement by USGS, unless otherwise indicated; C, measured by Smoky Valley Mining Co.; D, reported by driller; R, reported by owner; Z, measured by Nevada Division of Water Resources.

[Symbol: --, information not available]

U.S. Geological site designation			Owner or name of well	Primary water use	Well depth (feet)	Casing diameter (inches)	Altitude of land surface (feet above sea level)	Water-level measurement		
Local identification	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)						Date	Depth (feet below land surface)	Source of data
N09 E43 05DCAC1	383946	1171016	Rogers, E. (windmill)	U	202	6	5,780	08-18-50	115	D
								08-23-68	122.70	
								05-15-84	131.4(O)	
								11-07-84	130.0(O)	Z
N09 E43 09BBBB1	383938	1170953	McPherson (northwest well)	I	513	16	5,799	10-28-62	140	D
								04-16-68	139.63	
								05-15-84	150.97	
								11-07-84	149.2	Z
								11-20-85	151.1	Z
N09 E43 09DBAA1	383913	1170905	McPherson (southeast well)	I	595	14	5,780	06-01-66	225	D
						12		04-16-68	214.80	
								05-15-84	219.45	
								11-07-84	218.9	Z
								11-20-85	217.3	Z
N10 E43 02BA1	384537	1170713	Fisher, L.	H	170	6	5,710	04-04-84	85	D
								11-20-85	62.3	Z

N10 E43 04BBCC1	384530	1170952	Manley, G. (J-K Ranch)	U	155	14	5,643	06-10-51	8	D
								05-02-57	9.24	
								09-03-57	9.48	
								05-07-58	8.09	
								11-23-58	8.22	
								05-12-59	8.27	
								12-17-59	6.62	
								03-07-60	6.94	Z
								11-16-83	9.7	
								03-13-84	9.71	
								04-19-84	9.50	
								06-19-84	8.20	Z
								11-07-84	9.9	Z
								11-20-85	10.6	
N10 E43 04CA1	384513	1170926	Vinson, F.	H	150	8	5,640	05-04-84	-1	D
N10 E43 04DB1	384514	1170911	Vinson, F.	H	140	6	5,640	03-31-84	4	D
N10 E43 05AAAA2	384543	1170956	Manley, G. (J-K Ranch)	U	200	10	5,630	04-15-68	F	
								11-09-83	F	Z
								11-17-83	F	Z
								11-07-84	F	Z
								11-20-85	F	
N10 E43 05AAAB1	384543	1170959	Manley, G.	S	55	14	5,635	06-21-84	-3.03	
N10 E43 05AADC1	384543	1170953	Manley, G. (J-K Ranch)	U	304	16	5,635	01-09-63	12	D
						14		10-12-64	6	R
								04-15-68	10.15	
N10 E43 09BBBD1	384246	1170944	Sonerholm, P.	H	112	6	5,680	02-10-80	52	D
N10 E43 20AABD1	384304	1171004	S.V. Mining Co. (east pump house)	K	592	16	5,765	11-13-48	105	D
						12		07-24-68	106.80	
								11-17-83	P	Z
								11-03-83	106.34	
								07-18-84	P	C
								11-07-84	P	Z
								11-20-85	P	Z
N10 E43 20AABD2	384304	1171003	S.V. Mining Co. (west pump house)	K	372	16	5,770	07-15-52	98	D
						12		07-24-68	97.97	
								11-17-83	P	Z
								07-18-84	41.5(P)	
								11-07-84	P	Z
								11-20-85	P	Z

Table 13. Location, water levels, and other information for wells and test holes, northern Big Smoky Valley, Nevada—Continued

U.S. Geological site designation			Owner or name of well	Primary water use	Well depth (feet)	Casing diameter (inches)	Altitude of land surface (feet above sea level)	Water-level measurement		
Local identification	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)						Date	Depth (feet below land surface)	Source of data
N10 E43 22BCB 1	384252	1170839	S.V. Mining Co.	U	238	20	5,705	08-06-48	40.75	
								07-09-68	46.43	
								11-03-83	46.00	Z
								11-17-83	47.3	
								02-23-84	45.04	
								04-19-84	45.6	C
								07-18-84	44.55	C
								09-04-84	45.4	C
								10-07-84	44.1	Z
								11-07-84	44.5	
								01-06-85	44.0	C
								03-03-85	45.0	C
								05-02-85	45.0	C
								07-06-85	45.0	C
								08-04-85	45.0	C
								11-20-85	43.8	Z
N10 E43 22CCDA1	384219	1170830	--	U	--	12	5,715	07-09-68	57.53	R
								03-01-82	60	
N10 E43 24AADB1	384257	1170531	S.V. Mining Co.	U	--	--	6,030	03-01-82	380	R
N10 E43 26BBDD1	384205	1170725	S.V. Mining Co.	U	--	--	5,770	03-01-82	141	R
N10 E43 26CCCB1	384129	1173039	S.V. Mining Co.	U	--	--	5,765	03-01-82	121	R
N10 E43 28CCCC1	384124	1170953	Christensen, I. (at pond)	I	485	16	5,779	03-06-63	130	D
								04-16-68	118.94	
								07-08-68	118.82	
								05-18-84	106 (P)	
								11-20-85	131.2	Z
N10 E44 20BBBD1	384302	1170418	--	N	307	20	6,260	--	40	R
N10 E44 23B 1	384253	1170039	Stevens, T.	U	65	6	6,900	08-22-68	23.26	

N11 E43 01C 1	385021	1170610	Exploration	U	16	--	5,570	09-26-13	12	
N11 E43 06DB1	385017	1171116	Berg, Karl	I	372	16	5,625	1965	F	D
N11 E43 07DACA1	384933	1171058	Berg, Roger	U	11	72	5,620	11-09-83	8.37	
								03-13-84	9.39	
								06-20-84	9.33	
N11 E43 07DADB1	384933	1171056	Berg, Roger	U	--	72	5,620	06-20-84	1.0	
N11 E43 07DBAC1	384935	1171111	Berg, Roger	U	--	4	5,680	03-14-84	F	
								06-20-84	>0	
N11 E43 07DDDB1	384918	1171059	Darrough Ranch (hot)	Z	800	12	5,620	1968	F	Z
								11-07-84	F	Z
								11-20-85	F	
N11 E43 08BBAD1	384959	1171037	Berg, Russell	S	38	3	5,580	03-15-84	F	
								06-20-84	-5.83	
N11 E43 08CCCC2	384915	1171047	Darrough Ranch	H	55	6	5,580	10-30-50	F	D
								11-03-83	.01	
								03-14-84	.00	
N11 E43 09CC1	384917	1170931	Penole, F.	H	318	8	5,540	05-25-82	F	D
								11-07-84	F	Z
								11-20-85	F	Z
N11 E43 11ADAB1	384946	1170626	Howd, A. (Barker Ranch)	U	75	12	5,560	1951	18	D
								08-21-68	3.21	
								06-19-84	.16	
N11 E43 11ADAD1	384944	1170624	Howd, A. (Barker Ranch windmill)	U	24	45	5,555	10-10-64	10	R
								07-23-69	2.98	
								06-19-84	3.23	
N11 E43 11ADDA1	384941	1170625	Howd, A. (Barker Ranch)	U	16	8	5,555	10-10-64	10	R
								08-21-68	5.67	
								06-19-84	3.91	
N11 E43 22BACC1	384810	1170822	Carver, R.	S	85	--	5,559	06-19-84	F	Z
								11-07-84	F	Z
								11-20-85	F	
N11 E43 22CDDA1	384733	1170816	S.V. Mining Co. (dug well)	S	12	--	5,582	09-10-13	6.5	R
								1971	F	R

Table 13. Location, water levels, and other information for wells and test holes, northern Big Smoky Valley, Nevada—Continued

U.S. Geological site designation: Local identification	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Owner or name of well	Primary water use	Well depth (feet)	Casing diameter (inches)	Altitude of land surface (feet above sea level)	Water-level measurement: Date	Depth (feet below land surface)	Source of data
N11 E43 24DCAB1	384739	1170543	Jake's well (windmill)	S	96	6	5,687	10-10-64	78.46	
								08-21-68	79.63	
								11-09-83	84.09	
								03-13-84	78.40	
								06-19-84	78.58	
								07-18-84	78.22	C
								10-07-84	78.0	C
								11-07-84	78.0	C
								01-06-85	78.1	C
								03-03-85	77.6	C
								05-02-85	77.6	C
								07-06-85	78.1	C
								08-04-85	78.1	C
N11 E43 27DBBB1	384702	1170804	Carver, R.	I	580	12	5,610	06-19-84	5.65	
N11 E43 27DCCB1	384641	1170805	Carver, R.	I	750	16	5,630	03-27-61	20.75	
								03-30-61	13.00	
								07-09-68	17.13	
								06-19-84	14.78	Z
								11-07-84	12.0	Z
								11-20-85	13.8	
N11 E43 29ADBA1	384715	1170956	Fisher, L. (windmill)	S	38	8	5,580	08-01-84	7.99	
N11 E43 29ADBC1	384712	1170959	Fisher, L.	H	130	8	5,585	06-12-78	13	D
								08-01-84	12.92	
N11 E43 29ADBD1	384712	1170955	Hubred, H.	H	160	6	5,590	03-14-84	9.79	
N11 E43 29BADA1	384721	1171021	Carver, R. (trough)	S	--	4	5,605	06-19-84	F	
N11 E43 29BBDD1	384716	1171038	Carver, R. (pond)	I	170	6	5,625	06-19-84	F	
N11 E43 29BCAD1	384713	1171037	Carver, R. (3 wells)	I	--	6	5,625	06-19-84	F	

N11 E43 29BDBD1	384713	1171032	Carver, R.	I	300	16	5,620	06-21-68	F	
N11 E43 29BDCA1	384704	1171029	Carver, G., and Turk, W.	H	146	8	5,630	04-18-84	-4	
								07-31-84	F	
N11 E43 29CAAB1	384702	1171026	NV DOT	P	180	8	5,630	06-20-84	F	
N11 E43 29CDAD1	384642	1171022	Berg, Karl	I	67	--	5,640	03-14-84	.5	
								06-20-84	P	Z
								11-07-84	F	Z
								11-20-85	F	
N11 E43 29CDDD1	384637	1171020	Berg, Karl	I	372	12	5,640	03-14-84	F	Z
								11-07-84	F	Z
								11-20-85	F	
N11 E43 29DBCB1	384656	1171019	Trailer Park 1	P	173	8	5,625	06-18-72	F	
								06-21-84	P	
N11 E43 29DCAD1	384643	1171004	Berg, Karl	I	206	12	5,610	12-20-82	18	Z
						(well	deepened)	11-16-83	12.1	Z
								03-14-84	11.4	
								06-20-84	11.98	
								11-07-84	F	Z
								11-20-85	F	Z
N11 E43 29DCBA1	384650	1171012	Trailer Park 2	P	230	8	5,615	06-20-84	-36.96	
N11 E43 30AADA1	384722	1171054	Forest Service	H	--	--	5,635	11-03-83	F	
								03-15-84	F	
N11 E43 30AADC1	384718	1171100	Horse Arena	S	155	6	5,660	06-21-84	1.18	
N11 E43 32AABC1	384630	1171001	Fannin, D.	I	125	8	5,615	03-14-84	F	
N11 E43 32DAAC1	384607	1170955	Cecchini, C.	S	126	6	5,620	05-24-84	-1	D
								06-20-84	-7.75	
N11 E43 32DBDD1	384558	1171006	Davis, H.	H	150	6	5,635	05-24-84	-1	D
								06-20-84	-3.33	
N11 E43 32DCAD1	384555	1171006	Berg, Daniel	H	150	6	5,635	05-09-84	-1	D
N11 E43 32DDAA1	384556	1170952	Osterhoudt, D.	H	150	6	5,635	06-09-84	-1	D
								06-20-84	-12.75	
N11 E43 32DDDA1	394548	1170950	Manley, G. (J-K Ranch)	I	60	2	5,625	11-09-83	F	
								03-15-84	F	
N11 E43 33BCCB1	384615	1170946	Stonier, R.	S	111	5	5,610	03-14-84	F	

Table 13. Location, water levels, and other information for wells and test holes, northern Big Smoky Valley, Nevada—Continued

U.S. Geological site designation			Owner or name of well	Primary water use	Well depth (feet)	Casing diameter (inches)	Altitude of land surface (feet above sea level)	Water-level measurement		
Local identification	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)						Date	Depth (feet below land surface)	Source of data
N11 E43 33BCCC1	384611	1170947	Stonier, R.	I	295	16	5,615	07-14-65	F	D
						12		11-09-83	F	
N12 E43 04DB1	385539	1170906	Zimmerman, E. (R O Ranch)	I	545	16	5,530	09-05-65	5	D
								04-16-68	2.08	
								11-07-84	F	Z
								11-20-85	F	Z
N12 E43 04DCBD1	385531	1170904	Zimmerman, E. (R O Ranch)	I	408	16	5,530	11-03-83	3.4	Z
								11-16-83	11.3	
								03-14-84	5.78	
								06-20-84	9.53	C
								07-18-84	10.42	
								08-30-84	9.6	C
								10-07-84	9.5	C
								11-07-84	9.4	C
								11-07-84	10.6	Z
								01-06-85	10.9	C
								03-03-85	8.9	C
								05-01-85	7.9	C
								07-06-85	8.9	C
								08-04-85	23.9	C
								11-20-85	11.3	Z
N12 E43 04DCCD1	385525	1170903	Zimmerman, E. (R O Ranch house well)	H	81	6	5,530	11-03-83	4.82	
								03-14-84	4.19	
								05-18-84	2.51	
								06-20-84	4.69	C
								07-18-84	5.33	
								08-30-84	5.3	C
								10-07-84	4.1	C
								11-07-84	11.2(P)	C
								01-06-85	4.8	C

								03-03-85	3.8	C
								05-02-85	1.8	C
								07-06-85	3.8	C
								08-04-85	14.8(P)	C
N12 E43 09BCBC1	385506	1170940	Zimmerman, E. (R O Ranch)	I	286	14	5,565	05-14-51	60	D
								07-10-68	35.59	
								03-14-84	30.4	
								06-20-84	29.9	
								07-18-84	30.45	C
								08-30-84	29.6	C
								10-07-84	29.1	C
								11-07-84	29.5	C
								11-07-84	30.4	Z
								01-06-85	175 (P)	C
								03-03-85	29.0	C
								05-02-85	29.0	C
								07-06-85	30.0	C
								08-09-85	P	C
								11-20-85	31.0	Z
N12 E43 09CBDB1	385452	1170931	Zimmerman, E. (R O Ranch)	U	190	14	5,570	04-03-51	35	D
								05-02-57	31.62	
								09-03-57	22.72	
								05-07-58	32.19	
								11-23-58	27.08	
								04-12-59	33.41	
								12-17-59	34.21	
								03-07-60	35.87	
								12-01-60	35.62	
								03-09-61	37.34	
								09-18-61	34.32	
								03-21-62	37.77	
								10-12-62	26.02	
								03-26-63	32.89	
								03-22-65	48.70	
								09-16-65	48.34	
								03-21-66	49.75	
								09-12-66	54.00	
								03-20-67	55.25	

Table 13. Location, water levels, and other information for wells and test holes, northern Big Smoky Valley, Nevada—Continued

U.S. Geological site designation			Owner or name of well	Primary water use	Well depth (feet)	Casing diameter (inches)	Altitude of land surface (feet above sea level)	Water-level measurement		
Local identification	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)						Date	Depth (feet below land surface)	Source of data
N12 E43 09CBDB1—Continued								06-23-68	44.28	
								04-19-69	34.75	
								10-04-73	31.61	Z
								11-16-83	16.1	
								03-14-84	18.92	
								05-08-84	14.81	
								06-20-84	18.05	C
								07-18-84	19.75	C
								08-30-84	17.8	C
								10-07-84	16.5	Z
								11-07-84	17.5	C
								11-08-84	16.1	
								01-06-85	19.2	C
								03-03-85	17.7	C
								05-02-85	17.7	C
								07-06-85	17.7	C
								08-04-85	19.2	C
								11-20-85	25.0	Z
N12 E43 11CAA 1	385452	1170712	Zimmerman, E. (R O Ranch)	S	73	6	5,505	03-06-51	F	D
								11-07-84	F	Z
								11-20-85	F	Z
N12 E43 19BA1	385336	1171129	USGS-MX (test)	U	200	2	5,745	average	58.9	R
N12 E43 23B 1	385300	1170710	USGS Playa 1	U	4	2	5,520	07-25-68	3.23	
N12 E44 18AD1	385411	1170421	MX Test Well	U	160	2	5,600	--	--	
N13 E43 05CBCD1	390053	1171052	Millett Ranch	U	101	6	5,520	1917	F	R
								11-08-83	F	
N13 E43 06D 1	390033	1171050	Millett Ranch	H	140	6	5,530	1964 --	-15	R
N13 E43 19A 1	385823	1171116	Turk, W.	H	15	4	5,520	09-29-13	9.0	

N13 E43 19ABDD1	385842	1171104	Turk, W.	U	40	4	5,490	05-18-84	1.06	
								06-21-84	1.23	
N13 E43 30AAAD1	385753	1171050	--	I	127	6	5,495	--	F	D
N13 E44 32AAAA1	385702	1170315	Charnock Ranch	U	--	8	5,495	08-20-68	6.78	
N14 E43 02B 1	390556	1170701	Twist (Heffern Ranch)	U	190	8	5,530	1913	F	R
								04-16-68	.10	
N14 E43 03DCCC1	390543	1170757	Guelich, R. (Twist Ranch)	H	--	--	5,560	11-09-83	12.7	
								03-14-84	11.04	
								05-18-84	10.48	
								06-21-84	8.8	
								08-01-84	7.88	
N14 E43 10A 1	390513	1170732	Twist Ranch	H	60	--	5,540	1964	20	R
N14 E43 10ACCD1	390518	1170750	Johnson, Roy	S	100	6	5,510	10-08-64	F	R
								06-21-84	-4.5	
N14 E43 10CABD1	390513	1170812	Johnson, Ted	U	161	6	5,500	06-21-84	-1.3	
N14 E43 16D 1	390351	1170851	Twist Ranch	I	204	12	5,530	1968 -	F	R
N14 E43 28ABCB1	390302	1170902	Guelich, R. (Smoky Valley [McLeod] Ranch)	I	264	12	5,480	11-16-83	10.0	Z
								03-14-84	10.12	
								06-21-84	9.04	
								11-07-84	9.7	Z
								11-20-85	8.6	Z
N14 E43 28ACDC1	390245	1170855	Guelich, R. (Smoky Valley Ranch)	H	180	6	5,500	06-21-84	-10.5	Z
								11-07-84	F	Z
								11-20-85	F	
N14 E43 28DBDD1	390235	1170857	Guelich, R. (pond well)	Z	202	7	5,480	06-21-84	F	
N14 E43 32ABDC1	390204	1171010	Guelich, R. (Little Smoky Road, Parcel 3)	H	118	6	5,520	10-14-82	4	D
								11-08-83	4.92	
								03-14-84	4.99	
								06-21-84	3.60	
								07-18-84	3.4	C
								08-30-84	3.2	C
								10-06-84	3.1	C
								11-07-84	2.9	C
								01-06-85	2.4	C

Table 13. Location, water levels, and other information for wells and test holes, northern Big Smoky Valley, Nevada—Continued

U.S. Geological site designation: Local identification	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Owner or name of well	Primary water use	Well depth (feet)	Casing diameter (inches)	Altitude of land surface (feet above sea level)	Water-level measurement: Date	Depth (feet below land surface)	Source of data
N14 E43 32ABDC1—Continued								03-03-85	2.9	C
								05-02-85	2.4	C
								07-06-85	2.4	C
								08-04-85	1.4	C
N14 E43 32ADCD1	390152	1170958	Guelich, R. (Little Smoky Road, Parcel 1)	H	80.0	6	5,480	10-13-82	6	D
								11-08-83	6.52	
								03-14-84	6.61	
								06-21-84	6.89	
								07-18-84	5.89	C
								08-29-84	5.4	C
								10-06-84	6.9	C
								11-07-84	5.1	C
								01-06-85	5.4	C
								03-03-85	4.9	C
								05-02-85	5.4	C
								07-06-85	5.4	C
								08-04-85	4.9	C
N14 E43 32DBC 1	390140	1171018	Guelich, R. (Little Smoky Road, Parcel 2)	H	100	6	5,520	10-14-82	10	D
								11-08-83	F	
								03-14-84	F	
								06-21-84	-6.42	
N14 E44 36DCBA1	390128	1165856	Cyprus Mines, Well No. 5	Z	422	8	5,980	11-01-83	199	R
								12-02-83	200	R
								01-02-84	226.5	R
								02-01-84	200	R
								03-01-84	214	R
								04-02-84	241	R
								05-01-84	218	R

N14 E44 36DDBB1	390130	1165845	Cyprus Mines, Well 2a	K	700	6	6,020	08-16-82	387	R
								08-25-82	398	R
								08-30-82	396	R
								09-07-82	393	R
								09-13-82	400	R
								09-20-82	398	R
								09-28-82	392	R
								10-11-82	385	R
								10-18-82	383	R
								11-08-82	377	R
								01-11-83	377	R
								02-01-83	373	R
								03-01-83	403	R
								04-05-83	403	R
								05-02-83	395	R
N14 E45 31CACC1	390129	1165809	Cyprus Mines, Well 1a	K	281	6	6,080	08-02-82	253	R
								08-16-82	253	R
								08-25-82	253	R
								08-30-82	246	R
								09-07-82	246	R
								09-13-82	245	R
								09-20-82	245	R
								09-28-82	246	R
								10-11-82	245	R
								10-18-82	245	R
								11-08-82	243	R
								01-11-83	246	R
								02-01-83	244	R
								03-01-83	246	R
								04-05-83	245	R
								05-02-83	254	R
								06-01-83	258	R
								07-01-83	259	R
								08-01-83	260	R
								09-01-83	260	R
								10-04-83	260	R
								11-01-83	260	R
								12-02-83	260	R

Table 13. Location, water levels, and other information for wells and test holes, northern Big Smoky Valley, Nevada—Continued

U.S. Geological site designation			Owner or name of well	Primary water use	Well depth (feet)	Casing diameter (inches)	Altitude of land surface (feet above sea level)	Water-level measurement		
Local identification	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)						Date	Depth (feet below land surface)	Source of data
N14 E45 31CDBB1	390125	1165810	Cyprus Mines, Well 1b	H	531	8	6,080	08-16-82	344	R
						6		08-25-82	344	R
								08-30-82	341	R
								09-07-82	338	R
								09-13-82	331	R
								09-20-82	330	R
								09-28-82	341	R
								10-11-82	340	R
								10-18-82	339	R
								11-08-82	340	R
								01-11-83	338	R
								02-01-83	336	R
								03-01-83	332	R
								04-05-83	334	R
								05-02-83	340	R
								07-01-83	333	R
								08-01-83	338	R
								09-01-83	330	R
								10-04-83	344	R
								11-01-83	341	R
								12-02-83	340	R
								01-02-84	345	R
								02-01-84	343	R
								03-01-84	343.5	R
								04-02-84	344	R
								05-01-84	345	R
N15 E43 35CDBC1	390644	1170710	Guelich, R. (Smoky Joe's)	H	144	6	5,560	11-03-83	20.20	
								03-14-84	20.89	
								05-18-84	17.91	
								06-21-84	16.45	
								08-01-84	17.75	

N15 E44 01AABB1	391153	1165835	Kingston Ranch	S	201	6	5,550	1954	F	R
N15 E44 02C 1	391045	1170014	Vigas, E.	S	22	6	5,580	09-19-13	17.4	
N15 E44 05AAC 1	391148	1170307	Brazos Metals	N	325	6	5,840	06-01-81	260	D
N15 E44 20CCBD1	390839	1170406	Zimmerman, E. (Triple T Ranch)	H	57	6	5,580	03-07-56	39.60	
								12-01-56	38.61	
								05-02-57	33.75	
								09-03-57	24.92	
								05-07-58	32.58	
								11-23-58	31.33	
								05-12-59	34.14	
								12-17-59	37.93	
								09-09-64	34.35	
								11-03-83	23.19	
								02-22-84	27.54	
								03-15-84	23.22	
								05-14-84	18.50	
								06-21-84	9.7	C
								07-18-84	11.22	C
								08-30-84	19.0	C
								10-06-84	22.2	C
								11-07-84	23.4	
								01-06-85	27.0	C
								03-03-85	23.4	C
								05-02-85	24.0	C
								07-06-85	23.4	C
								08-04-85	24.0	C
N15 E44 22BCBC1	390850	1170141	Daniel's (Adobe) Ranch	U	--	24	5,550	07-23-69	14.46	
								03-15-84	>24	
N15 E44 31D 1	390625	1170425	USGS Playa 2	U	6	2	5,480	07-25-68	2.10	
N15 E45 31BCAB1	390707	1165810	Zimmerman, E. (windmill east of Triple T)	S	45	8	5,640	10-08-64	15.55	
								11-10-83	16.91	
								03-15-84	16.62	

Table 13. Location, water levels, and other information for wells and test holes, northern Big Smoky Valley, Nevada—Continued

U.S. Geological site designation: Local identification	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Owner or name of well	Primary water use	Well depth (feet)	Casing diameter (inches)	Altitude of land surface (feet above sea level)	Water-level measurement: Date	Depth (feet below land surface)	Source of data
N16 E44 10ACAA1	391600	1170044	Bell, R. (windmill near Gilman Springs Ranch)	U	30	6	5,620	10-03-64	21.56	
								11-07-83	23.55	
								03-15-84	23.22	
								05-18-84	21.18	
								06-22-84	20.77	
								07-18-84	22.4	C
								08-30-84	20.0	C
								10-06-84	19.8	C
								11-07-84	19.9	C
								01-06-85	19.8	C
								03-03-85	19.8	C
								05-02-85	19.6	C
								07-06-85	19.6	C
								08-04-85	19.6	C
N16 E44 10BBAB1	391612	1170121	Unknown (house vacant in 1984)	U	49	--	5,670	03-15-84	26.0	
								06-22-84	21.11	
N16 E44 13DA1	391446	1165816	Young (windmill)	S	22	7	5,580	06-27-85	1.43	
N16 E44 16DDDA1	391435	1170145	Young Brothers Ranch (open hole)	U	600	--	5,680	11-02-83	64.96	
								03-15-84	64.65	
								06-22-84	62.24	C
								07-18-84	60.51	C
								08-30-84	59.4	C
								10-06-84	56.0	
								11-07-84	56.0	C
								01-06-85	56.0	C
								03-03-85	56.0	C
								05-02-85	56.0	C
								07-06-85	56.0	C
								08-04-85	56.0	C
N16 E44 24BB1	391352	1165911	--	S	15	--	5,580	09-18-13	11.7	

N16 E44 24BD1	391341	1165857	Young Brothers	U	120	6	5,570	1948	F	R
								1964	2	
N16 E45 18DB1	391424	1165738	USBLM, Alkali Flat	S	150	8	5,570	07-20-68	5.87	
N16 E45 28BACA1	391313	1165542	Windmill	U	--	36x72	5,570	08-13-68	4.39	
N17 E44 01DCDD1	392126	1165829	Young, Lavar (Birch Creek Ranch)	H	301	8	5,920	06-15-51	241	D
						6		10-02-64	297.3	
								07-26-68	286.5	
								11-02-83	295.04	
								02-22-84	295.8	
								06-22-84	291.54	C
								07-18-84	284.00	C
								08-30-84	288.20	C
								10-06-84	283.9	C
								11-07-84	282.2	C
						(well no longer in use)		01-06-85	282.0	C
								03-03-85	281.7	C
								05-02-85	257.7	C
								07-06-85	257.7	C
								08-04-85	257.7	C
N17 E45 03BDBC1	392145	1165413	USGS (BSV 3a)	Z	210	4	5,730	09-02-84	73.93	
								10-30-84	103.49	
								12-15-84	103.10	
N17 E45 03BDBC2	392145	1165413	USGS (BSV 3b)	Z	125	2	5,730	09-02-84	93.77	
								10-30-84	104.18	
								12-15-84	103.45	
N17 E45 13DDDD1	391936	1165128	USBLM	U	66	8	5,670	07-17-84	7.2	
N17 E45 25BDAA1	391833	1164708	USGS (BSV 6)	Z	82	4	5,670	1984	82	
N17 E45H11DADA1	391937	1165117	USBLM (Spencer Hot Springs)	U	60	5	5,700	11-09-48	F	D
								11-06-83	F	
								07-16-84	F	
N17 E45H12BCCB1	391949	1165115	Spencer area	U	--	--	5,680	07-17-84	F	
N17 E45H12CDB 1	391931	1165057	5 hot wells	U	--	--	5,740	07-19-84	F	
N17 E45H24CBCA1	391754	1165107	USGS (BSV 5)	Z	240	4	5,780	09-05-84	177.37	
								11-01-84	176.82	

Table 13. Location, water levels, and other information for wells and test holes, northern Big Smoky Valley, Nevada—Continued

U.S. Geological site designation			Owner or name of well	Primary water use	Well depth (feet)	Casing diameter (inches)	Altitude of land surface (feet above sea level)	Water-level measurement		
Local identification	Lati-tude (degrees, minutes, seconds)	Longi-tude (degrees, minutes, seconds)						Date	Depth (feet below land surface)	Source of data
N17 E45H25ADAB1	391721	1165013	USGS (BSV 4)	Z	205	4	5,950	10-30-84	205	
N17 E46 06CD1	392023	1164949	Consol. Uranium	U	--	12	5,747	08-13-68	131.40	
N18 E45 20CADA1	392416	1165636	Kaltenvach (Frontier cafe)	H	200	6	6,080	09-30-64	158.3	
								11-03-83	158.64	
N18 E45 20CBBB1	392423	1175702	Windmill (near Frontier cafe)	S	64	6	6,115	06-22-84	25.37	C
								07-18-84	27.96	C
								08-30-84	34.7	C
								10-06-84	35.4	C
								11-07-84	35.6	
								01-06-85	36.2	C
								03-03-85	36.2	C
								05-02-85	34.2	C
								07-06-85	34.2	C
								08-04-85	36.2	C
N18 E45 20DB1	392414	1165618	--	U	175	6	6,020	08-12-68	175	
N18 E45 25BCDA1	392337	1165218	USBLM (windmill)	U	108	5	5,728	1964	100	R
								11-19-53	96.60	
								09-18-55	99.1	
								10-01-64	100	R
								08-12-68	103.41	
				(windmill	destroyed,	well	plugged)	11-07-83	0	
N18 E45 28CDCD1	392308	1165534	USGS (BSV 2a)	Z	264	4	5,810	09-02-84	175.51	
								10-29-84	175.13	
								12-15-84	174.44	
N18 E45 28CDCD2	392308	1165534	USGS (BSV 2b)	Z	175	2	5,810	09-02-84	127.05	
N18 E45 29ADCA1	392333	1165604	USGS (BSV 1a)	Z	320	4	5,880	09-02-84	241.7	
								10-29-84	250.02	
								12-15-84	249.30	

N18 E45 29ADCA2	392333	1165604	USGS (BSV 1b)	Z	100	2	5,880	09-02-84	75.81	
								10-29-84	94.46	
								12-15-84	95.08	
N18 E45 34CCCC1	392213	1165448	USBLM	U	86	6	5,745	7-17-84	86	0
N18 E45H36DACC1	392122	1165021	USBLM (windmill)	S	92	4	5,699	08-13-68	82.49	R
								09-01-73	92	
						(windmill	destroyed)	11-02-83	84.26	
								03-15-84	85.29	
N18 E46 32DADA1	392122	1164753	USBLM - Pete's well (windmill)	U	166	12	5,771	08-19-68	153.45	
								03-15-84	155.50	
								07-31-84	153.40	
N19 E44 13CD1	393019	1165854	Streshley, M.	H	55	6	6,510	1959	12	D
N19 E45 35CBCB1	392744	1165325	Parsons (Givens Ranch)	I	50	12	5,960	12-06-61	F	
								04-16-68	F	
								11-02-83	F	
								02-22-84	F	Z
								11-07-84	F	Z
								11-20-85	F	
N19 E45 35CBCB2	392742	1165331	Parsons (Givens Ranch)	H	40	6	5,960	04-19-48	20	D
								11-02-83	15.44	
								02-22-84	14.85	
								07-18-84	15.58	C
								08-30-84	21.0	C
								10-06-84	15.6	C
								11-07-84	24.5(P)	C
								01-06-85	16.0	C
								03-03-85	15.3	C
								05-02-85	15.0	C
								07-06-85	15.0	C
								08-04-85	14.8	C
N20 E45 22CADB1	393445	1165416	Lake Ranch	S	--	6	6,625	10-01-64	28.95	

REFERENCES CITED

Bauer, E.M., and Cartier, K.D., 1995, Reference manual for data base on Nevada well logs: U.S. Geological Survey Open-File Report 95-460, 31 p.

Bedinger, M.S., Harrill, J.R., Langer, W.H., Thomas, J.M., and Mulvihill, D.A., 1984a, Maps showing ground-water levels, springs, and depth to ground water, Basin and Range Province, Nevada: U.S. Geological Survey Water-Resources Investigations Report 83-4119-B, 2 sheets, scale 1:500,000.

Bedinger, M.S., Harrill, J.R., and Thomas, J.M., 1984b, Maps showing ground-water units and withdrawal, Basin and Range Province, Nevada: U.S. Geological Survey Water-Resources Investigations Report 83-4119-A, 2 sheets, scale 1:500,000.

Bedsun, D.A., 1980, Geological and hydrological profiles in Missile-X Valleys: New Mexico Engineering Research Institute Report NMERI-DP/EM-26, 9 p.

Cartier, K.D., Bauer, E.M., and Farnham, J.L., 1995, Reference manual for data base on Nevada water-rights permits: U.S. Geological Survey Open-File Report 95-452, 30 p.

Claassen, H.C., Reddy, M.M., and Halm, D.R., 1986, Use of the chloride ion in determining hydrologic-basin water budgets—A 3-year case study in the San Juan Mountains, Colorado, U.S.A.: Journal of Hydrology, v. 85, no. 1, p. 49-71.

Durbin, T.J., Kapple, G.W., and Freckleton, J.R., 1978, Two-dimensional and three-dimensional digital flow models of the Salinas Valley ground-water basin, California: U.S. Geological Survey Water-Resources Investigations Report 78-113, 134 p.

Erwin, J.W., 1982, Discussion of a set of regional gravity data for the Millett 1 by 2 degree sheet, Nevada: Nevada Bureau of Mines and Geology Open-File Report 82-8, 4 p.

Erwin, J.W., and Bittleston, E.W., 1977, Bouguer gravity map of Nevada—Millett sheet: Nevada Bureau of Mines and Geology Map 53, scale 1:250,000.

Farnsworth, R.K., Thompson, E.S., and Peck, E.L., 1982, Evaporation atlas for the contiguous 48 United States: National Oceanic and Atmospheric Administration Technical Report NWS 33, 26 p.

Fiero, G.W., Jr., 1968, Regional groundwater flow systems of central Nevada: University of Nevada, Reno, Desert Research Institute, Center for Water Resources Research, Miscellaneous Report No. 5, 212 p.

Garside, L.J., and Schilling, J.H., 1979, Thermal waters of Nevada: Nevada Bureau of Mines and Geology Bulletin 91, 163 p.

Harrill, J.R., Gates, J.S., and Thomas, J.M., 1988a, Major ground-water flow systems in the Great Basin region of Nevada, Utah, and adjacent states: U.S. Geological Survey Hydrologic Investigations Atlas HA-694-C, 2 sheets.

Healy, D.L., Snyder, D.B., and Wahl, R.R., 1981, Bouguer gravity map of Nevada—Tonopah sheet: Nevada Bureau of Mines and Geology Map 73, scale 1:250,000.

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 84 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: N.Y., Elsevier, p.253-257.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hines, L.B., 1992, Quantification of naturally occurring evapotranspiration from Smith Creek Valley, Nevada—Application of lysimeter and hydraulic conductivity methods to a semiarid basin, *in* Subitzky, Seymour, ed., Selected papers in the hydrologic sciences: U.S. Geological Survey Water-Supply Paper 2340, p. 9-20.

Horton, J.S., Robinson, T.W., and McDonald, H.R., 1964, Guide for surveying phreatophyte vegetation: U.S. Department of Agriculture, Agriculture Handbook 266, 37 p.

Houghton, J.G., Sakamoto, C.M., and Gifford, R.O., 1975, Nevada's weather and climate: Nevada Bureau of Mines and Geology Special Publication 2, 78 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.

Kleinhampl, F.J., and Ziony, J.I., 1984, Geologic map of northern Nye County, Nevada: Nevada Bureau of Mines and Geology Bulletin 99A, pl. A1A.

Lauritzen, C.W., and Terrell, P.W., 1967, Reducing water losses in conveyance and storage, *in* Hagan, R.M., Haise, H.R., and Edminster, T.W., eds., Irrigation of agricultural lands: American Society of Agronomy, Monograph 11, p. 1105-1119.

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

Maxey, G.B., and Eakin, T.E., 1949, Ground water in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada: Nevada State Engineer, Water Resources Bulletin 8, 59 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. Al, 586 p.

Meinzer, O.E., 1917, Geology and water resources of Big Smoky, Clayton, and Alkali Spring Valleys, Nevada: U.S. Geological Survey Water-Supply Paper 423, 161 p.

Mifflin, M.D., 1968, Delineation of ground-water flow systems in Nevada: University of Nevada, Desert Research Institute Technical Report H-W 4, 111 p.

Miller, R.F., Branson, F.A., McQueen, I.S., and Snyder, C.T., 1982, Water relations in soils as related to plant communities in Ruby Valley, Nevada: Journal of Range Management, v. 35, no. 4, p. 462-468.

Moore, D.O., 1968, Estimating mean runoff in ungaged semiarid areas: Nevada Department of Conservation and Natural Resources, Water Resources Bulletin 36, 39 p.

National Climatic Center, 1879-1986, Climatological data, annual summary, Nevada, 1878-1985: Asheville, N.C., U.S. National Oceanic and Atmospheric Administration, no. 13 (published annually).

Nelson, J.E., 1979a, A summary of agricultural potential for desert land entries in Nevada: U.S. Bureau of Land Management, Administrative report, 17 p.

———1979b, Analysis of agricultural potential for desert land entries in Nevada: U.S. Bureau of Land Management, Administrative report, 40 p.

Plume, R.W., 1989, Ground-water conditions in Las Vegas Valley, Clark County, Nevada—Part I. Hydrogeologic framework: U.S. Geological Survey Water-Supply Paper 2320-A, 15 p.

Price, Don, Eakin, T.E., and others, 1974, Water in the Great Basin region—Idaho, Nevada, Utah, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA-487, 3 sheets, scale 1:2,000,000.

Riggs, H.C., 1969, Mean streamflow from discharge measurements: Bulletin of the International Association of Scientific Hydrology, v. 14, no. 4, p. 95-110.

Robinson, T.W., 1958, Phreatophytes: U.S. Geological Survey Water-Supply Paper 1423, 84 p.

———1970, Evapotranspiration by woody phreatophytes in the Humboldt River Valley near Winnemucca, Nevada, *with a section on* Soil-moisture determinations, by A.O. Waananen: U.S. Geological Survey Professional Paper 491-D, 41 p.

Rush, F.E., 1968, Index of hydrographic areas, Nevada: Nevada Division of Water Resources, Information Report 6, 38 p.

Rush, F.E., and Schroer, C.V., 1970, Water resources of Big Smoky Valley, Lander, Nye, and Esmeralda Counties, Nevada: Nevada Division of Water Resources, Bulletin 41, 84 p.

Saltus, R.W., 1988a, Bouguer gravity anomaly map of Nevada: Nevada Bureau of Mines and Geology Map 94a, scale 1:750,000.

———1988b, Gravity data for the state of Nevada on magnetic tape: EROS Data Center, Sioux Falls, SD 57198.

Schaefer, D.H., and Maurer, D.K., 1981, Geophysical reconnaissance of Lemmon Valley, Washoe County, Nevada: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-1123, 29 p.

Solley, W.B., Chase, E.B., and Mann, W.B., IV, 1983, Estimated use of water in the United States in 1980: U.S. Geological Survey Circular 1001, 56 p.

Stewart, J.H., and McKee, E.H., 1977, Geology and mineral deposits of Lander County, Nevada—Part I. Geology: Nevada Bureau of Mines and Geology Bulletin 88, 105 p.

Theis, C.V., 1963, Estimating the transmissibility of a water-table aquifer from the specific capacity of a well, *in* Bentall, Ray, comp., Methods of determining permeability, transmissibility, and drawdown: U.S. Geological Survey Water-Supply Paper 1536-I, p. 332-336.

Trexler, D. T., Flynn, Thomas, Koenig, B.A., and Ghusn, George, Jr., 1983, Geothermal resources of Nevada: National Geophysical Data Center, National Oceanic and Atmospheric Administration map, scale 1:500,000.

Trexler, D.T., Koenig, B.A., Flynn, Thomas, and Bruce, J.L., 1980, Assessment of the geothermal resources of Carson-Eagle Valleys and Big Smoky Valley, Nevada: Nevada Bureau of Mines and Geology Report DOE/NV/10039-2, 162 p. plus appendixes.

U.S. Geological Survey, 1984a, Land use and land cover, 1980—Tonopah, Nevada, *in* Land use series: U.S. Geological Survey Open-File Report 84-016-1, scale 1:250,000.

———1984b, Land use and land cover, 1983—Millett, Nevada, *in* Land use series: U.S. Geological Survey Open-File Report 84-045-1, scale 1:250,000.

Walker, R.F., 1966, Geomorphology of the southern part of Big Smoky Valley, Esmeralda County, Nevada: Amherst, University of Massachusetts, unpublished M.S. thesis, 101 p.

Walker, R.F., and Motts, W.S., 1970, Reconnaissance geology of Big Smoky playa, Nevada—Chapter 4, *in* Motts, W.S., ed., Geology and hydrology of selected playas in western United States: Amherst, University of Massachusetts, Final Scientific Report (Part II), 286 p.

GLOSSARY

The following terms are defined as used in this report. Terms identified by bold type within definitions are also listed and defined in this glossary.

Alluvial fan. A low, fan-shaped deposit of **unconsolidated** gravel, sand, silt, and clay formed by a stream issuing from a mountain front. It slopes gently outward from the mountain front, increasing in width toward the lowland.

Aquifer. Rocks or sedimentary deposits that can yield water of usable quantity to wells and springs. In this report, the term primarily refers to **basin-fill deposits** known or inferred to be capable of yielding moderate to large amounts of water to individual wells.

Artesian. **Ground water** confined under sufficient pressure to rise above the **aquifer** when penetrated by a well.

Basin. A **drainage basin**; referred to as a closed basin if it has no outlet for **surface-water runoff**.

Basin-fill deposits. **Unconsolidated** and partly **consolidated** materials eroded from rock in adjacent mountains; predominantly consist of **sorted** sediment deposited by streams or in lakes; include gravel, sand, silt, and clay. Where coarse grained, form principal **aquifers** of northern Big Smoky Valley.

Bedrock. **Consolidated** (solid) rock that underlies **basin-fill deposits**. It is exposed at land surface in the mountains, but is buried beneath as much as 5,000 feet of **unconsolidated** and partly **consolidated** materials in the center of northern Big Smoky Valley.

Carbonate rock. **Bedrock** composed primarily of calcium and magnesium carbonate minerals—for example, limestone, dolomite, and marble.

Cell. A hypothetical block of **aquifer** used in **model simulations**. In three-dimensional **models**, its location is described in terms of column, row, and layer.

Confining bed, confining layer. A layer of rock or sediment that has very low **hydraulic conductivity**; it hampers the movement of water into, out of, or within an **aquifer**.

Cone of depression. A depression in the **water table** or other **potentiometric surface** produced by the withdrawal of water from an **aquifer**.

Consolidated. Firm and cohesive; cemented.

Darcian flow. Flow of **ground water** through an **aquifer**; controlled by **hydraulic conductivity** of the **aquifer** material and **head** difference. Named for Henry Darcy, a French hydraulic engineer who, in 1856, published his investigations of flow of water through sand beds.

Desert Land Entry. A legal process that transfers State land to private agricultural use. From 1877 to 1976, private citizens acquired 376,388 acres in Nevada through the Desert Land Act.

Digital model (of **ground-water** flow). A set of mathematical equations that represent the flow system, the computer routines required for solving the equations, and the data (specifying properties of the hydrogeologic framework and delineating the problem to be solved).

Discharge (**ground water**). Water that moves from the subsurface to the land surface, to **surface water**, or to the atmosphere.

Discharge (**surface water**). Rate of flow; streamflow.

Dissolved solids. Dissolved mineral constituents derived largely from solution of rocks and soils. Locally include mineral matter leached from mine tailings, agricultural chemicals, and sewage. In northern Big Smoky Valley, dissolved-solids concentrations generally are greater in **ground water** than in **surface water**.

Drainage area, drainage basin. The entire land surface that receives water and contributes it ultimately to a particular stream channel, lake, or playa.

Drawdown. The lowering of the water level in a well as a result of withdrawal; the difference between the static level and the pumping level.

Evapotranspiration. Loss of water to the atmosphere by a combination of direct evaporation from water surfaces and moist soil, and **transpiration** by plants.

Gradient. Rate of change of a variable quantity, such as temperature or pressure, with respect to distance measured in the direction of maximum change.

Granitic rock. Coarse-grained granular **bedrock** formed by crystallization and solidification of magma (molten rock deep in the earth).

Ground water. Generally, all subsurface water, as distinct from **surface water**; specifically, that part of the subsurface water that is in the **saturated zone**.

Head. The height of a column of water above or below a datum plane, such as sea level. In a **ground-water** system, it is a function of altitude and pressure. Informally called "water level."

Hydraulic conductivity. The capacity of a rock or sediment to transmit water. It is expressed as the volume of water that will move in a unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. Ranges from high for fractured rock, gravel, and coarse sand to low for unfractured rock, silt, and clay.

Hydraulic properties (of an **aquifer**). Properties, such as particle size and **aquifer** thickness, that affect the flow of water through saturated rock or sediments. (See also **hydraulic conductivity**).

Infiltration. The movement of water into soil or porous rock.

Intermittent stream. A stream or part of a stream that flows primarily in direct response to precipitation and is dry for part of the year.

Irrigation return flow. That part of irrigation water that is not consumed by **evapotranspiration** and that migrates to an **aquifer** or **surface-water** body.

Leakance. Flow of water through **confining beds**; expressed as the ratio of vertical **hydraulic conductivity** to thickness of the **confining beds**.

Model. See **Digital model, Steady-state model, Transient model.**

Perennial stream. A stream that flows throughout the year.

Phreatophyte. A plant that not only consumes soil moisture, but also draws water from underlying **ground water** in the **saturated zone**. Some may tap **ground water** more than 50 feet below land surface.

Physiographic province. A region of similar geologic history and geographic features that differs from adjacent regions.

Playa. The flat floor of a desert **basin** that has only interior drainage; may be occupied by a shallow lake during or after prolonged heavy rains or snowmelt.

Porosity. The voids or openings in a rock or sedimentary deposit. Porosity may be expressed quantitatively as the ratio of the volume of openings to the total volume of the rock or sediment.

Potentiometric surface. A surface that represents the total **head** in an **aquifer**; that is, it represents the height above or below a datum plane, such as sea level, at which the water level will stand in tightly cased wells that penetrate the **aquifer**. (See also **Water table**.)

Recharge (ground water). Water that enters the **saturated zone**.

Remote sensing. Collection of information by methods that record reflected or radiated electromagnetic energy; includes photography, infrared detection, microwave frequency reception, radar, and other geophysical measurements. Used in hydrogeologic studies to determine structural features of the Earth's surface and distribution of vegetation.

Runoff. That part of precipitation that directly runs off the land surface or is transported by streams. May include **ground-water** discharge to streams.

Satellite imagery. The spectral characteristics of the land surface measured remotely from a satellite; can include ultraviolet to radio-band wavelengths.

Saturated thickness. The thickness of an **aquifer** below the **water table**.

Saturated zone. The subsurface zone in which all interconnected spaces are filled with water under pressure equal to or greater than atmospheric pressure. The **water table** is the upper limit of this zone.

Sedimentary rock. Consolidated rock formed of cemented or indurated sediments (sandstone, siltstone, shale, or conglomerate) or by chemical precipitation (some **carbonate rocks**).

Seepage. Infiltration or percolation of water through surficial materials (sediments or **consolidated** rock).

Simulation. The representation of a system by a device such as a model that imitates the behavior of the system; results in a simplified version of a natural situation.

Sorting (of sediments). Deposition of **unconsolidated** materials according to grain size, based on particle diameter and density.

Specific conductance (of water). A measure of the ability of water to conduct electric current; expressed in microsiemens per centimeter at 25 degrees Celsius. It is related to, and serves as an approximate measure of, the **dissolved-solids** concentration.

Steady-state model (of **ground-water** flow). A **model** that simulates distribution of **head** in an **aquifer** at equilibrium.

Storage. Water naturally or artificially detained in an **aquifer** or **drainage basin**; refers to **ground water** or water impounded on land surface.

Storage coefficient. The volume of water released from storage in a unit volume of an **aquifer** when the **head** is lowered a unit distance.

Surface water. A body of water on land surface; for example, a stream or lake.

Thermal water. Heated, mineralized water that may issue from a spring, geyser, or well. In northern Big Smoky Valley, it is derived from precipitation that moves downward in **bedrock** and is heated by contact with hot rocks at depth.

Transect. A line along which a land survey is made.

Transient model (of **ground-water** flow). A **model** that simulates distribution of **head** in an **aquifer** at successive times under changing conditions.

Transmissivity. The rate at which water is transmitted through a unit width of **aquifer** under a unit hydraulic **gradient**. Equal to the average **hydraulic conductivity** multiplied by the **saturated thickness**.

Transpiration. The process by which water passes through living organisms, primarily plants, and into the atmosphere.

Unconsolidated. Loose, not firmly cemented or interlocked; for example, sand (in contrast to sandstone).

Unsaturated zone. The subsurface zone above the **water table**; important with regard to **evapotranspiration**, **infiltration**, and **recharge** processes.

Volcanic rock. Rock formed by cooling of lava.

Water budget. An accounting of the inflow, outflow, and changes in storage of water in a **drainage basin** or **aquifer**.

Water table. The upper surface of the **saturated zone**. It is the upper surface in an unconfined **aquifer** at which the pressure is atmospheric, and is defined by the levels at which water stands in wells that penetrate just far enough to hold standing water. In wells penetrating to greater depths, the water level will be above or below the water table if an upward or downward component of **ground-water** flow predominates.

Water year. The 12-month period, October 1-September 30, during which a complete hydrologic cycle normally occurs. The water year is designated by the calendar year in which it ends; thus, the year ending September 30, 1985, is called the "1985 water year."