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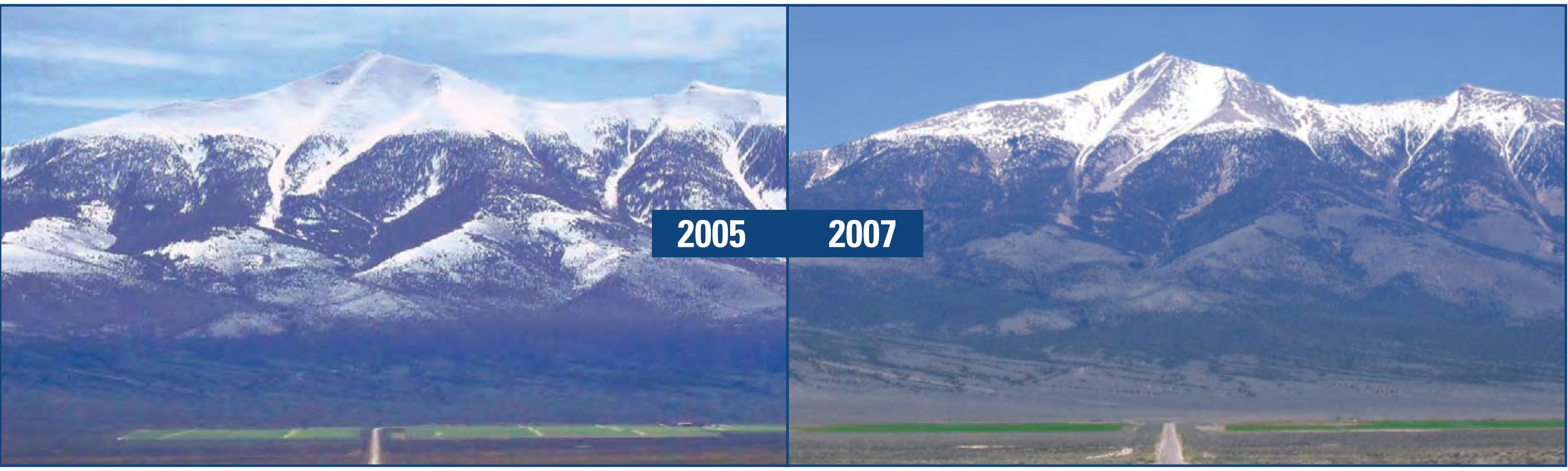

Scientific Investigations Report 2007-5099

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

Cover: Photograph of west side of the 13,065-foot-high Wheeler Peak in southern Snake Range, Great Basin National Park, Nevada. (Photograph taken by Michael Moreo, U.S. Geological Survey, May 17, 2005.

Application of the Basin Characterization Model to Estimate In-Place Recharge and Runoff Potential in the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah

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Foreword

Water demands from the lower Colorado River system are increasing with the rapidly growing population of the southwestern United States. To decrease dependence on this over-allocated surface-water resource and to help provide for the projected increase in population and associated water supply in the Las Vegas area, water purveyors in southern Nevada have proposed to utilize the ground-water resources of rural basins in eastern and central Nevada. Municipal, land management, and regulatory agencies have expressed concerns about potential impacts from increased ground-water pumping on local and regional water quantity and quality, with particular concern on water-rights issues and on the future availability of water to support natural spring flow and native vegetation. Before concerns on potential impacts of pumping can be addressed, municipal and regulatory agencies have recognized the need for additional information and improved understanding of geologic features and hydrologic processes that control the rate and direction of ground-water flow in eastern and central Nevada.

In response to concerns about water availability and limited geohydrologic information, Federal legislation (Section 131 of the Lincoln County Conservation, Recreation, and Development Act of 2004; PL 108-424) was enacted in December 2004 that directs the Secretary of the Interior, through the U.S. Geological Survey (USGS), the Desert Research Institute (DRI), and a designee from the State of Utah, to complete a water-resources study of the basin-fill and carbonate-rock aquifers in White Pine County, Nevada, and smaller areas of adjacent counties in Nevada and Utah. The primary objectives of the Basin and Range carbonate-rock aquifer system (BARCAS) study are to evaluate: (1) the extent, thickness, and hydrologic properties of aquifers, (2) the volume and quality of water stored in aquifers, (3) subsurface geologic structures controlling ground-water flow, (4) ground-water flow direction and gradients, and (5) the distribution and rates of recharge and ground-water discharge. Geologic, hydrologic, and supplemental geochemical information will be integrated to determine basin and regional ground-water budgets.

Results of the study will be summarized in a USGS Scientific Investigations Report (SIR), to be prepared in cooperation with DRI and the State of Utah, and submitted to Congress by December 2007. The BARCAS study SIR is supported by USGS and DRI reports that document, in greater detail than the summary SIR, important components of this study. These reports are varied in scope and include documentation of basic data, such as spring location and irrigated acreage, and interpretive studies of ground-water flow, geochemistry, recharge, evapotranspiration, and geology.

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Conversion Factors and Datums

Conversion Factors

Multiply	By	To obtain
acre	0.004047	square kilometer (km^2)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
foot (ft)	0.3048	meter (m)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
inch per year (in/yr)	2.54	centimeter per year (cm/yr)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8.$$

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Altitude, as used in this report, refers to distance above the vertical datum.

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Application of the Basin Characterization Model to Estimate In-Place Recharge and Runoff Potential in the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah

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Abstract

A regional-scale water-balance model was used to estimate recharge and runoff potential and support U.S. Geological Survey efforts to develop a better understanding of water availability for the Basin and Range carbonate-rock aquifer system (BARCAS) study in White Pine County, Nevada, and adjacent areas in Nevada and Utah. The water-balance model, or Basin Characterization Model (BCM), was used to estimate regional ground-water recharge for the 13 hydrographic areas in the study area. The BCM calculates recharge by using a distributed-parameter, water-balance method and monthly climatic boundary conditions. The BCM requires geographic information system coverages of soil, geology, and topographic information with monthly time-varying climatic conditions of air temperature and precipitation. Potential evapotranspiration, snow accumulation, and snowmelt are distributed spatially with process models. When combined with surface properties of soil-water storage and saturated hydraulic conductivity of bedrock and alluvium, the potential water available for in-place recharge and runoff is calculated using monthly time steps using a grid scale of 82.3 feet (270 meters). The BCM was used with monthly climatic inputs from 1970 to 2004, and results were averaged to provide an estimate of the average annual recharge for the BARCAS study area. The model estimates 526,000 acre-feet of potential in-place recharge and approximately 398,000 acre-feet of potential runoff. Assuming 15 percent of the runoff becomes recharge, the model estimates average annual ground-water recharge for the BARCAS area of about 586,000 acre-feet. When precipitation is extrapolated to the long-term climatic record (1895–2006), average annual recharge is estimated to be 530,000 acre-feet, or about 9 percent less than the recharge estimated for 1970–2004.

Introduction

The Basin and Range carbonate-rock aquifer system (BARCAS) study area encompasses about 13,500 mi^2 and covers about 80 percent of White Pine County, and parts of Elko, Eureka, Nye, and Lincoln Counties in Nevada, as well as parts of Tooele, Millard, Beaver, Juab, and Iron Counties in Utah (fig. 1). White Pine County is within the carbonate-rock province, a relatively large area extending from western Utah to eastern California where ground-water flow is predominantly or strongly influenced by carbonate-rock aquifers. Much of the carbonate-rock aquifer is fractured and, where continuous, forms a regional ground-water flow system that receives recharge from high-altitude areas where fractured carbonate rocks are exposed. Most areas in White Pine County, Nevada, are within four regional ground-water flow systems (fig. 2)—the larger Colorado and Great Salt Lake Desert flow systems, and the smaller Goshute Valley and Newark Valley flow systems (Harrill and others, 1988). Water moving through the carbonate-rock aquifer provides some recharge to overlying basin-fill aquifers, sustains many of the large, perennial low-altitude springs, and hydraulically connects similar carbonate-rock aquifers in adjacent basins. The regional carbonate-rock aquifer typically is overlain by a basin-fill aquifer in the intermountain basins. The basin-fill aquifer is composed of gravel, sand, silt, and clay and often reaches thicknesses of several thousand feet (Harrill and Prudic, 1998). The gravel and sand deposits typically yield water readily to wells and this aquifer is the primary water supply in the area for agricultural, domestic, or municipal use.

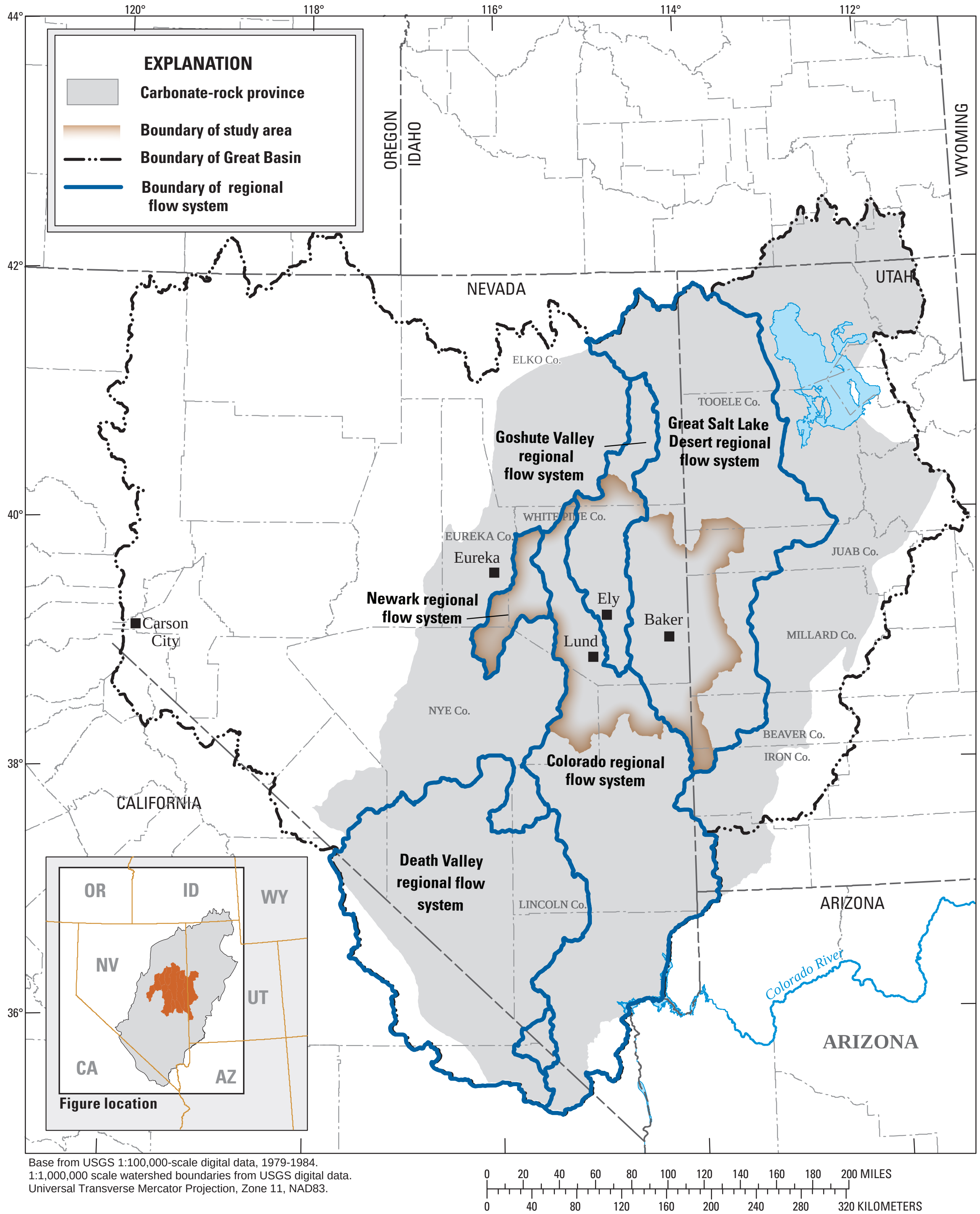
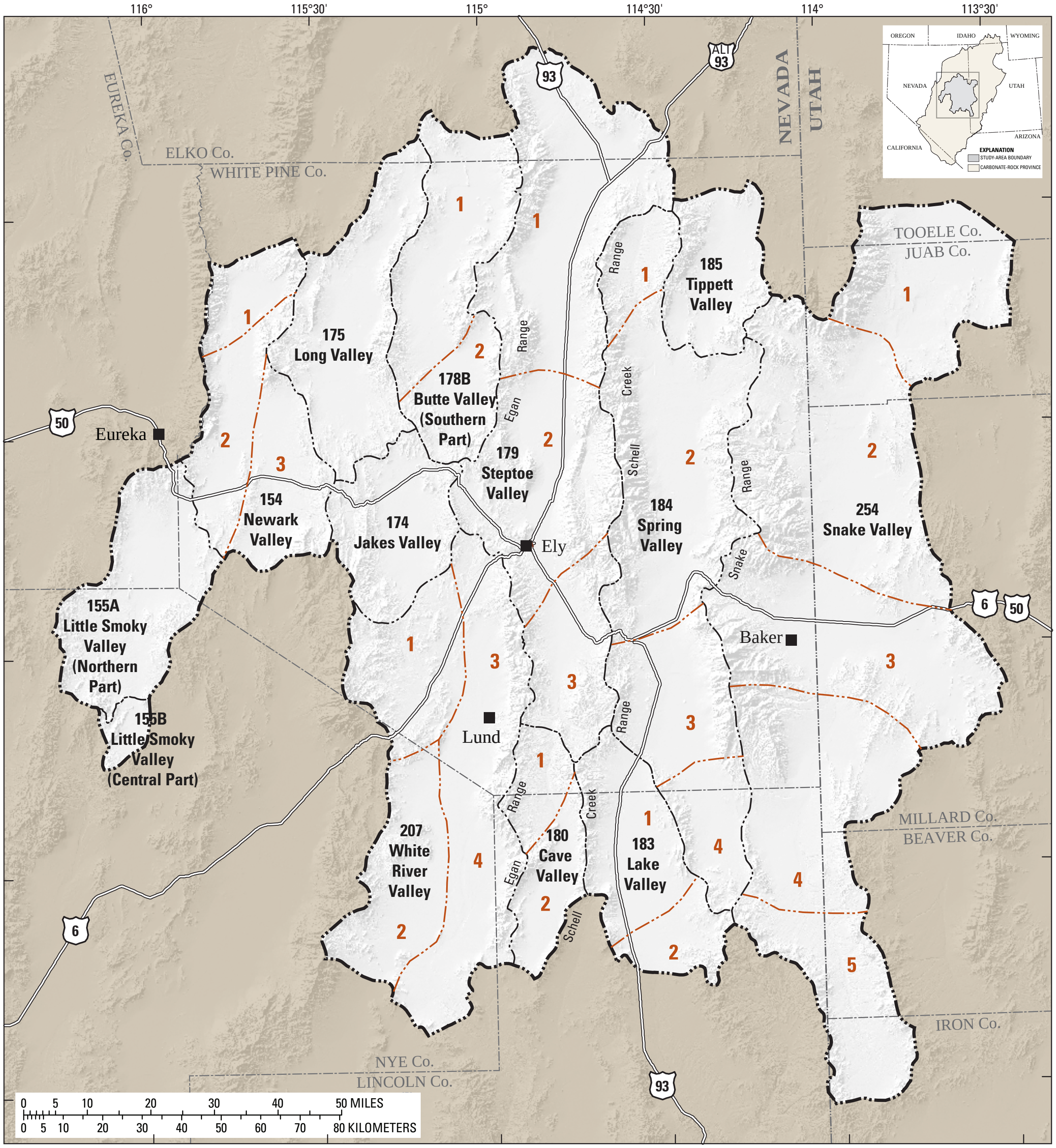


Figure 1. Carbonate-rock province, Basin and Range carbonate-rock aquifer system study area, and associated regional ground-water flow systems, Nevada and Utah.



Base from U.S. Geological Survey digital data 1:100,000, 1978–89.
Universal Transverse Mercator Projection, Zone 11, NAD 83.
Shaded relief base from 1:250,000-scale Digital Elevation Model;
sun illumination from northwest at 30 degrees above horizon.

EXPLANATION

Boundary of study area

174 Jakes Valley — Boundary of hydrographic area and name and number

4 — Boundary of subbasin and No.

Figure 2. Hydrographic areas and subbasins in the Basin and Range carbonate-rock aquifer system study area, Nevada and Utah.

The carbonate-rock aquifer extends beneath numerous surface-water drainage basins, or hydrographic areas[1]. Past studies have combined hydrographic areas to delineate basin-fill or regional ground-water flow systems, based primarily on the direction of interconnected ground-water flow in the underlying carbonate-rock aquifer and the location of terminal discharge areas (Harrill and Prudic, 1998). Although the boundary lines between hydrographic areas generally coincide with actual topographic basin divides, some boundaries are arbitrary or represent hydrologic divisions that have no topographic basis. Hydrographic areas were further divided into sub-basins that are separated by areas where pre-Cenozoic rocks are at or near the land surface (Welch and Bright, 2007). Hydrographic area names in this report generally refer to formal hydrographic areas of Harrill and others (1988) with two exceptions: (1) ‘Little Smoky Valley’ refers to hydrographic areas 155A and 155B, which are the northern and central parts of Harrill and others (1988) description of Little Smoky Valley, respectively, and (2) ‘Butte Valley’ refers only to hydrographic area 178B, which is the southern part of Harrill and others (1988) description of Butte Valley. For most figures and tables in this report, water-budget components were estimated for the northern and central parts of Little Smoky Valley, but were combined and reported as one value.

Estimates of recharge are required to develop an understanding of the hydrologic system and potential water availability for the BARCAS study area in east-central Nevada and west-central Utah. Runoff, infiltration, and regional ground-water recharge were estimated with a water-balance model, the Basin Characterization Model (BCM) (Flint and others, 2004), that simulates climatic processes and uses hydraulic properties of soils and rocks. Flint and others (2004) applied this model to provide preliminary estimates of recharge for the Great Basin, which are inclusive of the BARCAS study area. The report by Flint and others (2007) provides details of the conceptual model of deterministic water-balance processes and geographic information system (GIS) databases of the soil, vegetation, and geologic information used in the model.

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

This report describes the results of a study to estimate the spatial distribution and mean-annual rate of recharge for 13 hydrographic areas in the BARCAS study area (fig. 2). The report also documents refinements made to the BCM, presents general results, and provides digital data generated by the model in a useable format for other BARCAS study components, cooperating agencies, and stakeholders. BCM refinements include an improved snow accumulation and snowmelt model, and updated maps of precipitation and air temperature data (Daly and others, 2004).

Dominant Recharge Mechanisms at the Basin Scale

Recharge to a basin occurs through a number of processes, including mountain-block, diffuse, mountain-front, and stream-channel recharge. Mountain-block recharge occurs directly into the underlying bedrock without runoff and is widely distributed in higher altitude, mountainous terrain with permeable bedrock. Diffuse recharge is widely distributed in alluvial valleys and typically is considered a separate process from stream-channel recharge (Stephens, 1995). Mountain-block and diffuse recharge occur by direct infiltration of rainfall and snowmelt, and in this report are referred to as in-place recharge. In-place recharge also occurs by the local-scale lateral redistribution of rainfall and snowmelt following runoff and subsequent overland flow that does not reach the more prominent stream channels. Excess water that does not recharge in-place is referred to as runoff in this report. Runoff can become mountain-front recharge along the boundary between mountain blocks and alluvial valleys, or beneath ephemeral streams as they transition from an upland area with thin soils to an alluvial valley or basin with thick soils. Stream-channel recharge occurs in areas where surface-water flow is diverted into ephemeral or perennial streams on the valley floor. Playa-lake recharge is the result of infiltrating runoff that collects in playas (Stephens, 1995). No attempt is made in this study to route runoff, but only to estimate the amount and source of runoff that may be available for recharge downslope.

Methods Used for Recharge Estimates in the Study Area

Flint and others (2002) and Scanlon and others (2002) provide thorough reviews of the methods used to estimate recharge in the Desert Southwest. The more commonly used methods include Darcian calculations, calculations of flux made on the basis of repeated measurements of water-content profiles, the deviation of a measured temperature profile from a heat-conduction-only profile, chloride-mass balance, atmospheric radionuclides, empirical transfer methods using precipitation, and watershed modeling. Of these methods, only empirical transfer methods and watershed modeling using deterministic models provide spatially distributed estimates.

Maxey and Eakin (1949) developed an empirical transfer method that has been used extensively to estimate recharge to ground-water basins in Nevada. Ground-water discharge was assumed equal to recharge, quantified for 13 hydrographic areas, and extrapolated with the Hardman (1936) precipitation map. Annual precipitation volumes between the 8, 12, 15, 20, and greater than 20 in/yr contour intervals were the independent variables and 0, 3, 7, 15, and 25 percent were the respective coefficients (Nichols, 2000, p. C21). Maxey and Eakin (1949) extrapolated recharge estimates between basins but did not address where recharge occurs within a hydrographic area. Annual recharge estimates with the Maxey-Eakin method ranged from 4,000 to 103,000 acre-ft for the 12 hydrographic areas in the study area (table 1).

Table 1. Comparison of estimated average annual precipitation, runoff, and recharge for 1970–2004 and 1895–2006, and recharge estimate by Maxey-Eakin method, Basin and Range carbonate-rock aquifer system, Nevada and Utah.

[All values multiplied by 1,000 and rounded to nearest acre-foot. **Precipitation:** Values based on Parameter-Elevation regressions on Independent Slopes Model (PRISM; Daly and others, 1994). **Runoff and Recharge:** Values for 1970–2004 estimated from Basin Characterization Model (BCM); values for 1895–2006 estimated from threshold limited power function. Recharge runoff, equals 15 percent of estimated total runoff. Total recharge, equals in-place recharge plus runoff recharge. **Abbreviations**: ft, feet]

Hydrographic area	Precipitation (acre-ft)		Runoff (acre-ft)		Recharge, in acre-feet						
					Maxey-Eakin	BCM 1970–2004			Power function 1895–2006		
	1970–2004	1895–2006	BCM 1970–2004	Power function 1895–2006		In-place	Runoff recharge	Total	In-place	Runoff recharge	Total
Butte Valley	490	470	14	13	[1]15	37	2	39	33	2	35
Cave Valley	267	245	7	6	[2]14	13	1	14	10	1	11
Jakes Valley	266	261	6	6	[3]17	16	1	17	15	1	16
Lake Valley	406	380	22	19	[4]13	12	4	16	10	3	13
Little Smoky Valley	304	268	3	1	[5]4	6	0	6	4	0	4
Long Valley	441	407	11	8	[6]10	29	2	31	24	1	25
Newark Valley	496	458	15	11	[7]18	24	2	26	19	2	21
Snake Valley	2,266	2,160	126	115	[8]103	104	19	123	94	17	111
Spring Valley	1,161	1,131	95	91	[9]75	83	14	97	79	14	93
Steptoe Valley	1,330	1,303	72	70	[10]85	149	11	160	144	10	154
Tippett Valley	212	209	6	6	[11]7	12	1	13	11	1	12
White River Valley	985	893	21	16	[3]38	41	3	44	33	2	35
Total	8,624	8,185	398	362	399	526	60	586	476	54	530

[1] Glancy, 1968
[2] Eakin, 1962
[3] Eakin, 1966
[4] Rush and Eakin, 1963
[5] Rush and Everett, 1966
[6] Eakin, 1961
[7] Eakin, 1960
[8] Hood and Rush, 1965
[9] Rush and Kasmi, 1965
[10] Eakin and others, 1967
[11] Harrill, 1971

Estimates of Regional Ground-Water Recharge Based on the Basin Characterization Model

The basin characterization model (BCM) is a distributed-parameter, water-balance accounting model that is run on a monthly time step and can be used to estimate potential recharge (Flint and others, 2004). The model identifies locations and climatic conditions that allow for excess water, and quantifies the amount of water available either as in-place recharge or as runoff on a monthly basis. The BCM does not distinguish between mountain-front and stream-channel recharge—referred to in this report as runoff—nor does it explicitly quantify the percentage of runoff that becomes recharge. Because the model does not partition runoff, the BCM calculates potential in-place recharge and potential runoff, and generates distributions of both components. BCM has been used to estimate regional ground-water recharge as the sum of the potential in-place recharge and some percentage of the potential runoff. Moreover, the BCM can be applied to compare these processes (for example, in-place dominated versus runoff-dominated terrains) and the potential for recharge under current climate, and past wetter and drier climates. The BCM model was used to delineate processes that control recharge in the BARCAS area and to develop first-order estimates of regional ground-water recharge.

The BCM employs a deterministic water-balance approach that includes the distribution of precipitation, snow accumulation and melt, and the estimation of potential evapotranspiration, along with soil-water storage and saturated hydraulic conductivity of bedrock. The saturated hydraulic conductivity of alluvium also is used wherever soil thickness is greater than 20 ft (6 m). The BCM was used with available GIS data resampled for a resolution of 82.3 ft (270 m): digital elevation model, geology, soils, vegetation, precipitation, and air temperature maps, along with GIS data that were developed for this study (slope, aspect, and potential evapotranspiration). The geology in the BARCAS study area (fig. 3) and the associated saturated hydraulic-conductivity value assigned to the geologic units are dominant factors controlling ground-water recharge in this area.

Precipitation distributions are based on the Parameter-Elevation Regressions on Independent Slopes Model (PRISM; Daly and others, 1994). This model uses measured precipitation data and spatially distributes precipitation by using regressions to account for orographic effects. PRISM maps are available at 1.8-mi (4-km) resolution. Although there are apparent errors in the PRISM maps (Jeton and others, 2005), the PRISM maps were resampled and rescaled at a resolution of 82.3 ft (270 m) for this study to determine the monthly and annual precipitation distributions in the study area over a 30-year period (1970–2004) (fig. 4).

The BCM incorporates spatially distributed parameters (monthly precipitation, monthly minimum and maximum air temperature, monthly potential evapotranspiration, soil-water storage capacity, and saturated hydraulic conductivity of bedrock and alluvium) to determine where excess water is available in a basin and whether the excess water is stored in the soil or infiltrates downward into underlying bedrock. Excess water is partitioned by the BCM model as either potential in-place recharge or potential runoff, depending on the saturated hydraulic conductivity of bedrock and alluvium. Potential in-place recharge is the maximum volume of water for a given time frame that can recharge directly into bedrock or deep alluvium (greater than 20 ft (6 m)). Potential runoff is the maximum volume of water for a given time frame that runs off the mountain front or becomes streamflow. Total potential recharge, or ground-water recharge, is the summation of in-place recharge and some percentage of runoff.

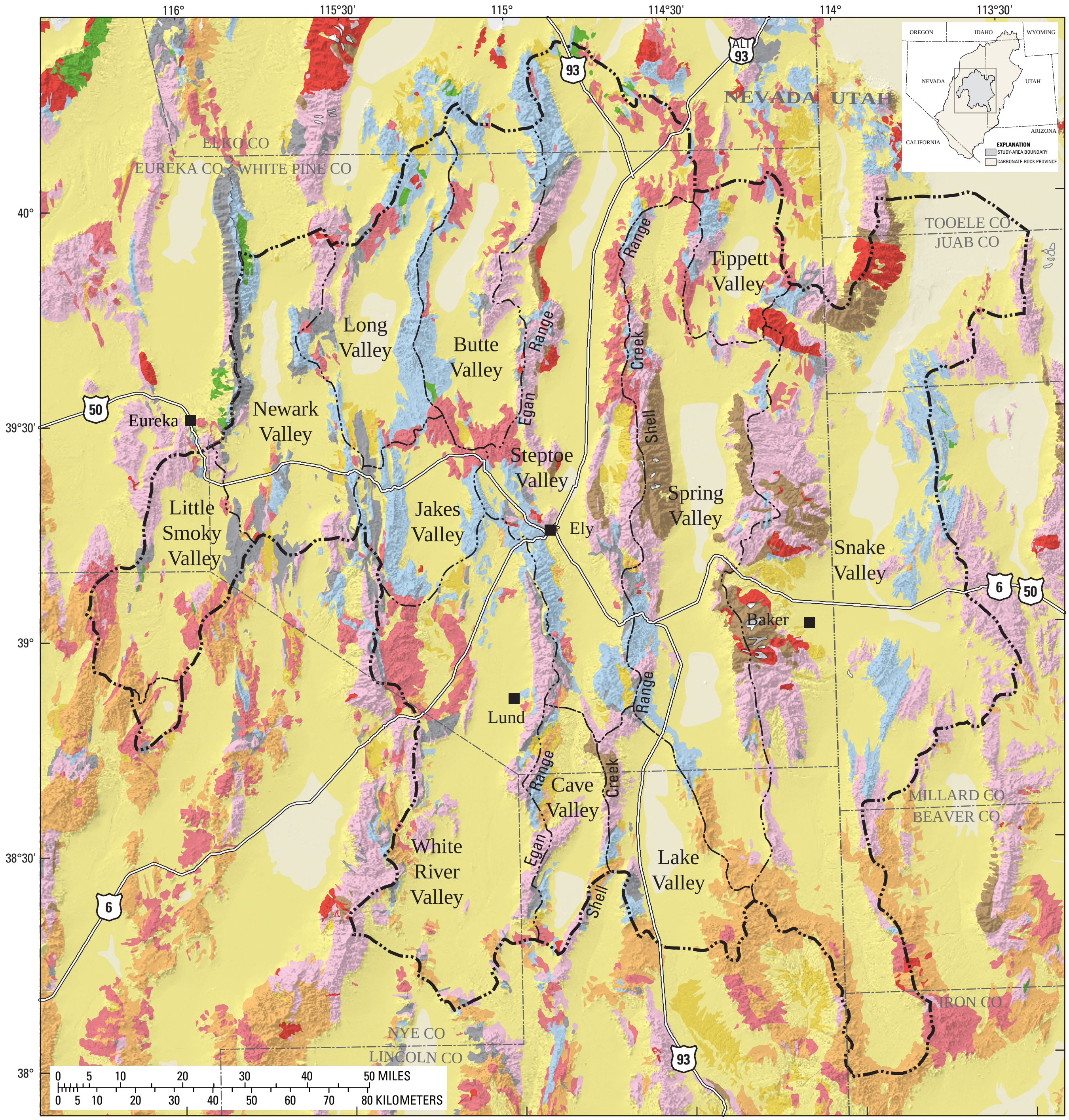
EXPLANATION FOR FIGURE 3

Hydrogeologic unit

- FYSU–Fine-grained younger sedimentary rock unit (primarily lacustrine and playa deposits)
- CYSU–Coarse-grained younger sedimentary rock unit (alluvial and fluvial deposits)
- OSU–Older sedimentary rock unit (consolidated Cenozoic rocks)
- VFU–Volcanic flow unit (basalt, andesite, dacite and rhyolite lava flows)
- VTU–Volcanic tuff unit (ash-flow tuffs)
- MSU–Mesozoic sedimentary rock unit
- UCU–Upper carbonate rock unit (Mississippian to Permian carbonate rocks)
- USCU–Upper siliciclastic rock unit (Mississippian siliciclastic rocks)
- LCU–Lower carbonate rock unit (Cambrian to Devonian predominantly carbonate rocks)
- LSCU–Lower siliciclastic rock unit (Early Cambrian and older siliciclastic rocks)
- IU–Intrusive unit

Boundary of study area

Boundary of hydrographic area



Base from U.S. Geological Survey digital data 1:100,000, 1978–89.
Universal Transverse Mercator Projection, Zone 11, NAD 83.
Shaded relief base from 1:250,000-scale Digital Elevation Model;
sun illumination from northwest at 30 degrees above horizon.

Figure 3. Generalized geology of the Basin and Range carbonate-rock aquifer system study area used in the Basin Characterization Model, Nevada and Utah.

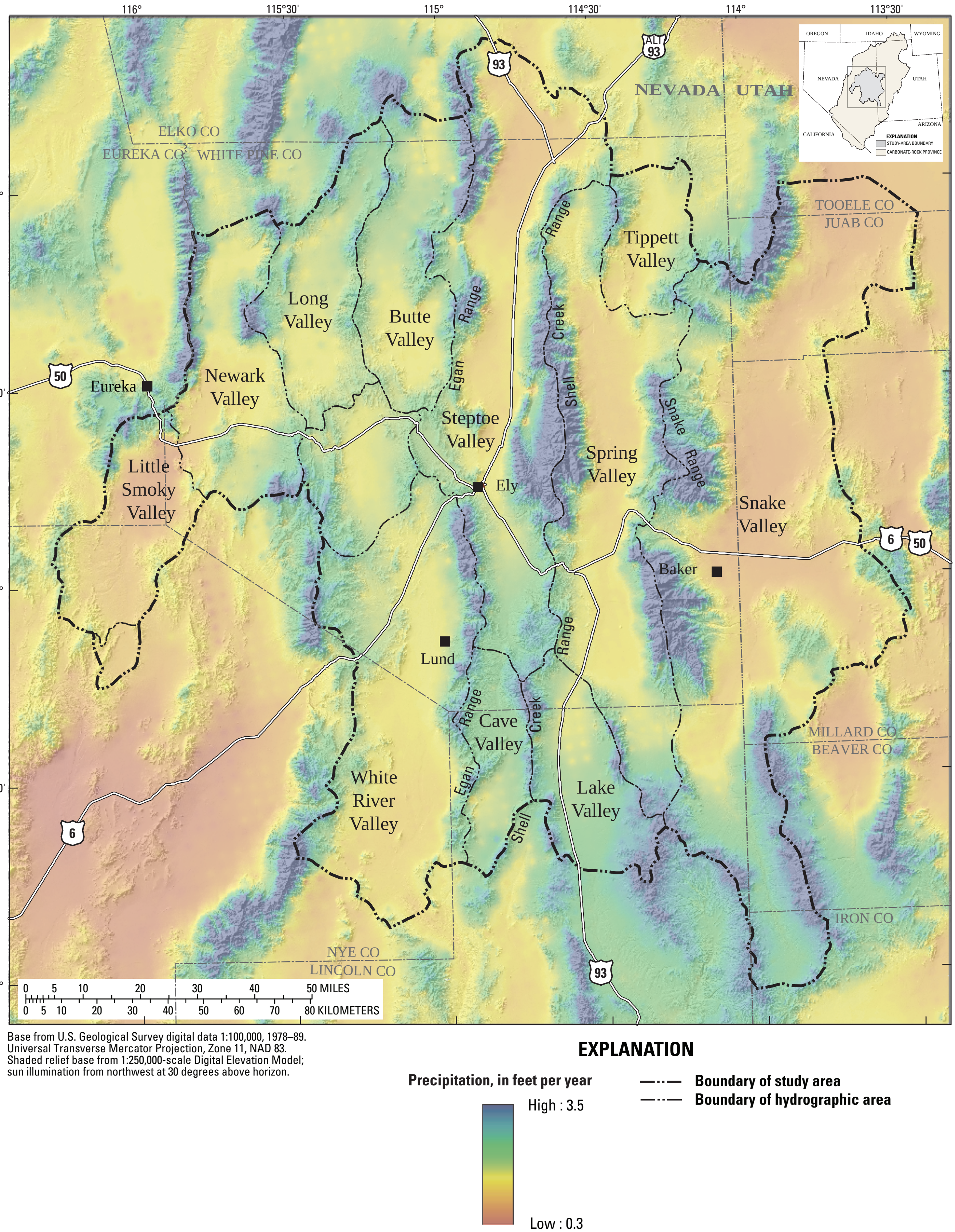


Figure 4. Average annual precipitation for the Basin and Range carbonate-rock aquifer system study area and vicinity from resampled average monthly PRISM data, Nevada and Utah, 1970–2004.

The model also quantifies the rate of infiltration as mean monthly net infiltration. Potential evapotranspiration, soil-water storage capacity, and saturated hydraulic conductivity of bedrock and alluvium are the primary factors influencing the occurrence and magnitude of net infiltration into underlying soil or rock horizons. Net infiltration occurs when the available water derived from precipitation, snowmelt, or run-on (water coming from upstream sources) exceeds the storage capacity of the soil (or rock). Potential evapotranspiration decreases soil-water content, thus increasing the availability for soil-water storage between monthly precipitation, snowmelt, and run-on events. Potential evapotranspiration is controlled by the relative proportion of bare soil and vegetated surfaces, and other topographic (slope, aspect, and latitude), atmospheric, and soil components that influence the amount of energy available for evapotranspiration.

In upland areas, the water-entry potential of the fractured network must be exceeded before significant infiltration into the underlying bedrock can occur. In these areas, soil thickness is the dominant factor affecting soil-storage capacity and where thin soils overlie bedrock, the soil-water content can rapidly approach saturation. If the saturated hydraulic conductivity of bedrock is low within upland areas, infiltration is relatively slow and evapotranspiration can remove a substantial amount of water from storage between precipitation, snowmelt, and run-on events. In upland areas of high saturated hydraulic conductivity, infiltration is relatively fast and less time is available for evapotranspiration to remove stored soil water. In upland areas with thick soils, a greater volume of water is needed to exceed the storage capacity of the root zone, or the saturated hydraulic conductivity of bedrock and alluvium must be sufficiently high to quickly drain the root zone.

The effects of potential evapotranspiration are similar in alluvial fans and basins. In areas with thick soils and deeper root zones, infiltration may occur slowly and stored soil water can efficiently be removed by evapotranspiration between precipitation events (decreasing recharge) if the soil field capacity is high and the saturated hydraulic conductivity is low (finer-grained soils). Infiltration may occur more rapidly and stored soil water will be removed by evapotranspiration between precipitation events less efficiently (increasing recharge) if the soil field capacity is low and the saturated hydraulic conductivity is high (coarser-grained soils). In locations with deep soils where the water penetrates to below 20 ft (6 m), the saturated hydraulic conductivity of the underlying alluvium controls the infiltration rate.

The mechanisms controlling net infiltration dictate where and how recharge occurs in a given basin. Analyses of basins using the BCM water-balance method can help determine when, where, and how the water-balance terms, the material properties, and the physical mechanisms are integrated to generate net infiltration and ultimately regional ground-water recharge. Knowledge of where recharge occurs is critical when attempting to quantify recharge by means of field measurements. For example, measuring streamflow losses or calculating a Darcy flux from data obtained under a stream channel would not provide much relevant information when attempting to estimate recharge in a basin dominated by in-place recharge processes. Probable locations of potential in-place recharge and potential runoff can be identified because the BCM-determined distribution of net infiltration depends primarily on the integration of spatial and temporal data for precipitation, soil-water storage, saturated hydraulic conductivity of bedrock and alluvium, and evapotranspiration.

Basin-Scale Model Application—Generation of Input Parameters

The BCM code is written in FORTRAN-90 and calculates potential in-place recharge and potential runoff using ASCII files developed from ARC-GIS grids of the distributed climatic and surface parameters. One parameter, potential evapotranspiration, is calculated by using a pre-processing code that runs on a daily time step, with results averaged and developed into monthly grids. The BCM integrates results using a series of water-balance equations developed to calculate the area and the amount of potential recharge for each basin. Model grid cells are analyzed for each month to determine where excess water is available for potential recharge. Available water (AW), in inches per month, is defined as:

$$AW = P + S_m - PET - S_a + S_s , \tag{1}$$

where

P is precipitation,

S_m is snowmelt,

PET is potential evapotranspiration,

S_m is snow accumulation and snowpack carried over from the previous month, and

S_s is stored soil water carried over from the previous month.

The BCM allows snowpack and soil moisture to be carried over from month to month—an extremely important process in the BARCAS area where temperatures are low enough to form ice or maintain snowpack. For example, because snow may accumulate and persist for several months in the winter before melting in the spring, large volumes of water may be made available for potential recharge in a single monthly model time step.

Potential runoff is calculated as the available water minus the total storage capacity of the soil, which is soil porosity multiplied by soil thickness. Potential in-place recharge is calculated as the available water remaining after runoff minus the field capacity of the soil, which is the water content at which infiltration becomes negligible. Maximum in-place recharge equals the hydraulic conductivity of the bedrock and occurs when total storage capacity of the soil is reached. Any water remaining after the monthly time step is carried over into the next month in the S_s term.

Temporally Invariable Inputs

Estimates of the storage capacity of a soil (porosity multiplied by thickness) for the BCM are based on soil texture data from the State Soil Geographic Database (STATSGO; http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/), a state-compiled geospatial database of soil properties that maintains unit consistencies across state boundaries (U.S. Dept. of Agriculture, National Resource Conservation Service, 1994). Soil thickness ranged from 0 to more than 20 ft (6 m) for Quaternary alluvial deposits (Hevesi and others, 2003). A soil thickness in excess of 20 ft (6 m) was truncated because water infiltrating greater than 20 ft (6 m) was assumed to recharge the saturated ground-water system. For areas where quaternary alluvial deposits were not present, soil thickness ranged between 0 and 7 ft (2 m), and was estimated using a STATSGO distribution.

The spatial distribution of saturated hydraulic conductivity in bedrock and alluvium was determined by using bedrock geologic maps (Nevada: Stewart and others (2003); Utah: Utah Geological Survey, 2007). On the basis of estimates from literature, aquifer-test results, and surface-based infiltration experiments, saturated hydraulic-conductivity values ranged from 0.0003 to 608 ft/yr (0.00009 and 185 m/yr) (table 2). Alluvial deposits of Quaternary age typically have the highest saturated hydraulic-conductivity value in the study area. Carbonate rocks have the highest saturated hydraulic-conductivity values for bedrock units, and outcropping granitic and metamorphic rocks have the lowest values for bedrock units. The hydraulic properties of macropores and fractures are incorporated in the bulk estimates of hydraulic conductivity; however, hydraulic-conductivity estimates of bedrock are uncertain because of the unknown hydrologic properties and spatial distributions of fractures, faults, and fault gouge.

Table 2. Range of saturated hydraulic conductivities for generalized bedrock and alluvium.

Bedrock or surficial unit	Saturated hydraulic conductivity (feet per year)	
	Low	High
Alluvium	152	548
Eolian	608	608
Granites/intrusive rocks	.0003	3
Lacustrine	.03	.03
Limestone	30	61
Metamorphic rocks	.0003	.3
Playas	.003	.003
Sandstone/sedimentary rocks	30	58
Volcanic rocks	.003	30

Temporally Variable Inputs

Climate was simulated by using spatially distributed, monthly estimates of precipitation, minimum air temperature, and maximum air temperature. PRISM precipitation and temperature model results are available as monthly averages from 1895 to 2006 for a 1.8-mi (4-km) grid (Daly and others, 2004). The 1.8-mi grids were interpolated to 82.3-ft (270-m) grids for 1970–2004 by using spatial gradient and inverse distance squared weighting (Nalder and Wein, 1998), based on the equation:

$$Z = \left[\sum_{i=1}^{N} \frac{Z_i + (X - X_i)\times C_x + (Y - Y_i)\times C_y + (E - E_i)\times C_e}{d_i^2} \right] / \left[\sum_{i=1}^{N} \frac{1}{d_i^2} \right], \quad (2)$$

where:

Z is estimated climatic variable, at a specific location defined by easting (X) and northing (Y) coordinates, and elevation (Z) respectively;

Z_i is climate variable at PRISM grid cell i;

X_i, Y_i, E_i are easting and northing coordinates and elevation of PRISM grid cell i;

N is number of PRISM grid cells;

d_i is distance from the site to PRISM grid cell i; and

C_x, C_y, C_e are regression coefficients for easting, northing, and elevation that are solved for each interpolated cell.

A search radius of 4.5 mi (10,000 m) was used to limit the influence of distant data. Approximately 25 PRISM grid cells were used to estimate temperature and precipitation for each cell, with the closest cell having the most influence.

Potential evapotranspiration was estimated with latitude, topographic shading, and air temperature (Flint and Childs, 1987). Net radiation and soil heat flux (Shuttleworth, 1993) were intermediate results used to calculate potential evapotranspiration from the Priestley–Taylor (1972) equation (1972). Potential evapotranspiration distribution and rates (fig. 5) were corrected for vegetated and bare soil areas (National Gap Analysis Program, 2007).

Snow accumulation and sublimation were computed by using an adaptation of the operational National Weather Service energy and mass-balance model (the Snow-17 model; Anderson (1976); Shamir and Georgakakos, 2005). This model calculates the potential for snowmelt as a function of air temperature and an empirical melt factor that varies with day of year (Lundquist and Flint, 2006). Snow depth is calculated for areas where precipitation occurs and air temperature is less than or equal to +1.5°F. Sublimation of snow is calculated as a percentage of potential evapotranspiration. Snow accumulation and melt were calibrated to snow cover extent that was present within 4 days of the last day of a month as mapped by Moderate Resolution Imaging Spectroradiometer (MODIS) remote-sensing data (U.S. Geological Survey, 2007). The temperature threshold at which accumulation and melt occurs was adjusted to calibrate the snow model (Lundquist and Flint, 2006).

Model Results

Annual recharge averaged 586,000 acre-ft for 1970–2004, or about 7 percent of the 8,624,000 acre-ft of precipitation that fell during this period in the BARCAS area. About 526,000 acre-ft of in-place recharge was estimated with the greatest rates occurring in mountains adjacent to Snake, Spring, and Steptoe Valleys (fig. 6). About 398,000 acre-ft of potential runoff was estimated for the BARCAS area, of which 15 percent (about 60,000 acre-ft) was assumed to become recharge. Although the percentage of potential runoff that becomes recharge can vary significantly (Flint and others, 2004), an assumed value of 15 percent is considered reasonable for central Nevada. Previous investigations have used a lower value of 10 percent for Death Valley regional flow system in southern Nevada, up to values as high as 90 percent for the Humboldt regional flow system in northern Nevada. Much of recharge from runoff occurred in the Schell Creek Range separating Steptoe and Spring Valleys, and the southern Spring Range separating Snake and Spring Valleys (fig. 7).

BCM-derived recharge estimates are 60 percent greater than previous Maxey-Eakin method for the BARCAS area (table 1). Differences between BCM and Maxey-Eakin estimates for individual basins ranged from less than1,000 acre-ft/yr for Jakes and Cave Valleys to 75,000 acre-ft/yr for Steptoe Valley. Percent differences between BCM and Maxey-Eakin derived recharge were consistently greater for basins in which limestone with high saturated hydraulic conductivities were prevalent in the adjacent mountain ranges (see fig. 8 and table 1).

The uncertainty of BCM-derived ground-water recharge estimates is dependent, in part, on the uncertainty of input parameters or assumptions made on hydrologic processes. The greatest source of parameter uncertainty likely is the saturated hydraulic conductivity of bedrock because this parameter significantly affects the partitioning of water between in-place recharge and runoff. Also, the uncertainty of recharge estimates assuming a value of 15-percent recharge from runoff may be reasonable for in-place recharge-dominated basins, but the uncertainty may be significant for runoff-dominated basins (table 1). For example, the range of ground-water recharge exceeds 80 percent of the best estimate in Lake, Snake, and Spring Valleys where runoff exceeds in-place recharge.

BCM rechare estimates were derived by assuming that net infiltration is equal to in-place recharge and that topographic boundaries coincide with ground-water divides. Actual conditions may differ from these assumptions for some areas but the effect on average annual, regional recharge estimates likely would be minimal. For example, net infiltration can move laterally in the unsaturated zone, but over time most of the water will recharge the saturated ground-water flow system. Moreover, differences between topographic boundaries and ground-water divides may alter recharge estimates in some sub-basins. However, these differences would not substantially affect regional recharge because the primary recharge areas occur along ranges entirely within the study area.

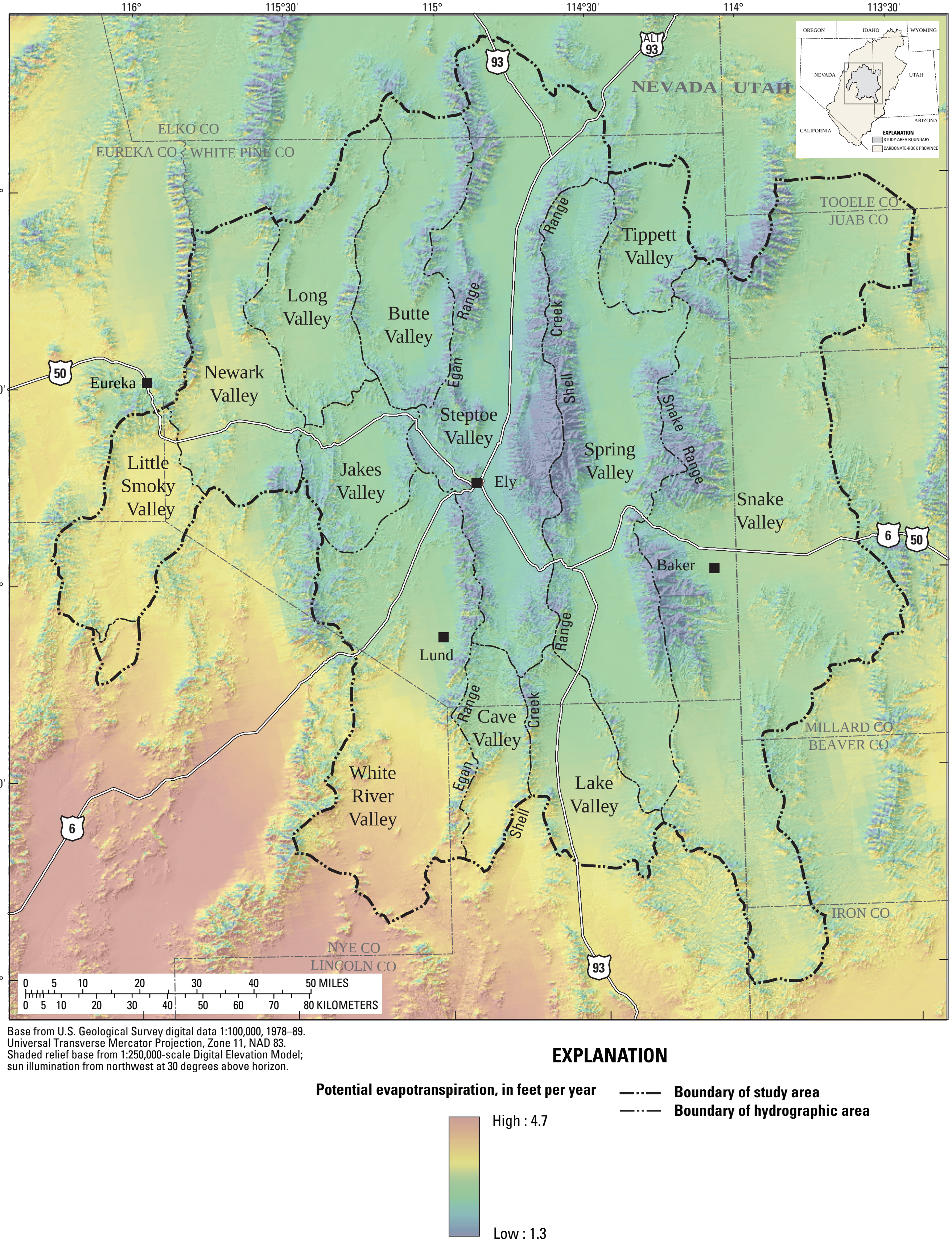
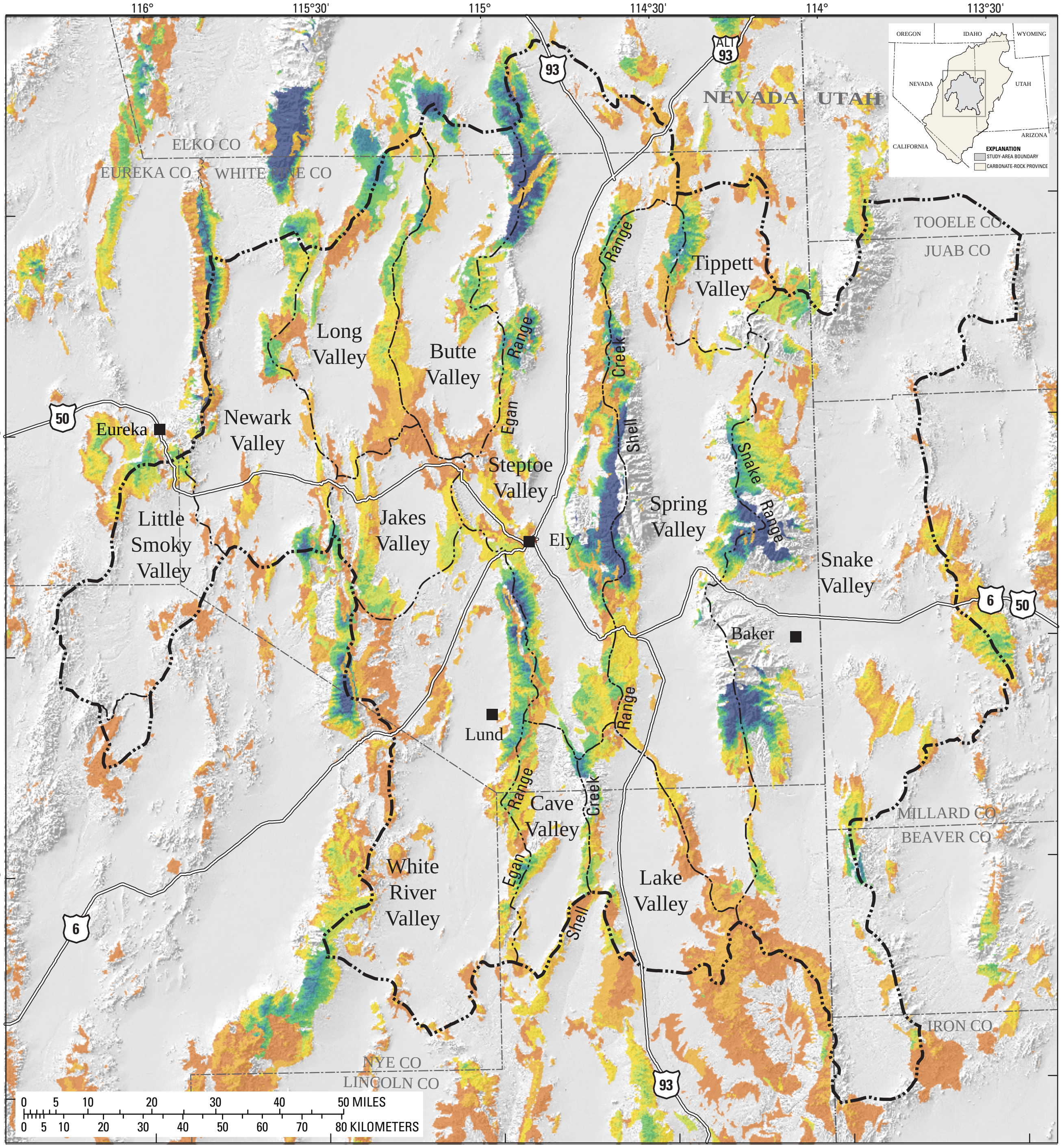


Figure 5. Average annual potential evapotranspiration, Basin and Range carbonate-rock aquifer system study area, Nevada and Utah.



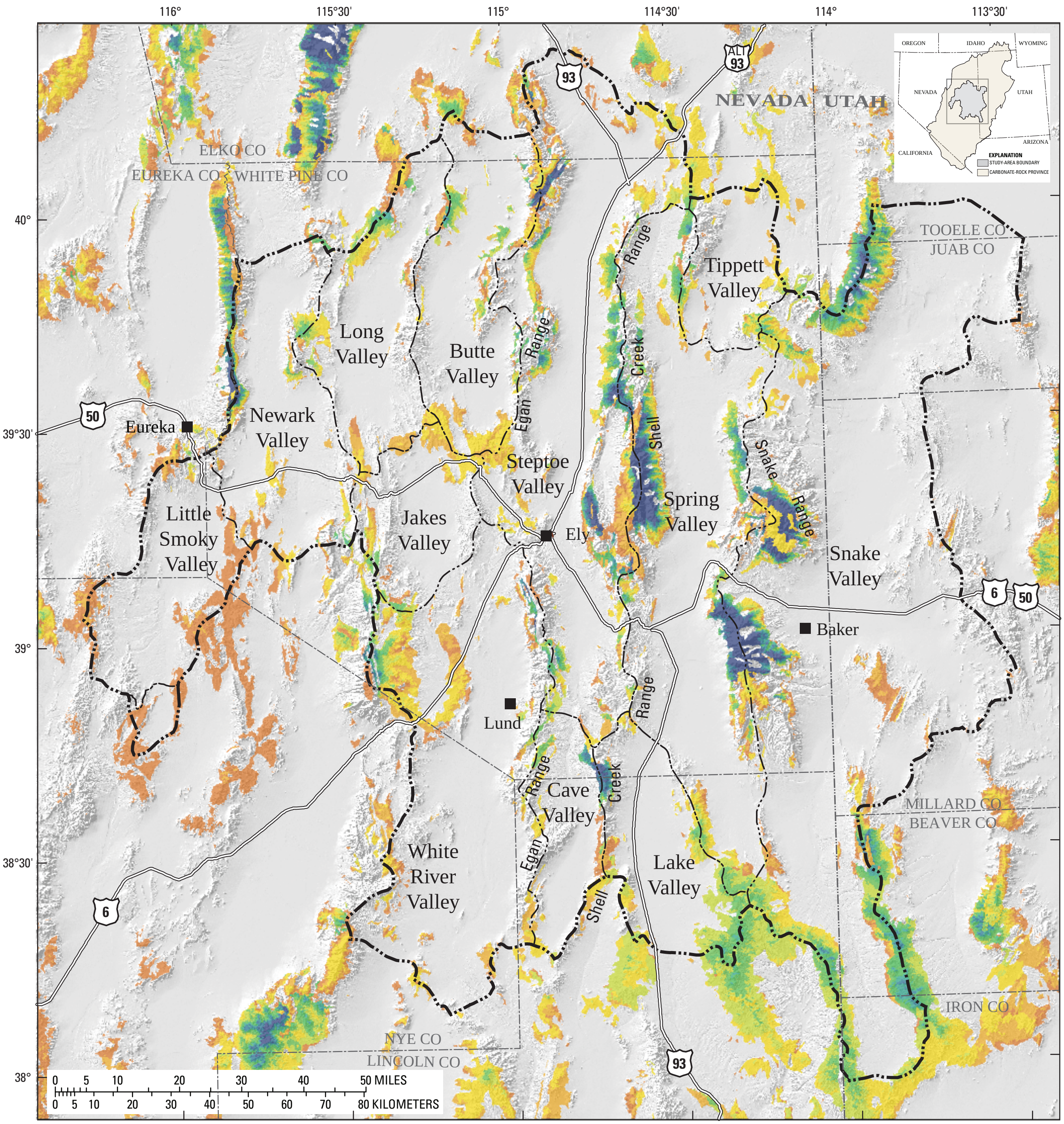
Base from U.S. Geological Survey digital data 1:100,000, 1978–89.
Universal Transverse Mercator Projection, Zone 11, NAD 83.
Shaded relief base from 1:250,000-scale Digital Elevation Model;
sun illumination from northwest at 30 degrees above horizon.

EXPLANATION

Potential in-place recharge, in feet per year

- < 0.02
- 0.02 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.6
- 0.6 - 0.8
- 0.8 - 1
- **Boundary of study area**
- **Boundary of hydrographic area**

Figure 6. Potential in-place recharge enerated using the Basin Characterization Model, Basin and Range carbonate-rock aquifer system study area and vicinity, Nevada and Utah.



Base from U.S. Geological Survey digital data 1:100,000, 1978–89.
Universal Transverse Mercator Projection, Zone 11, NAD 83.
Shaded relief base from 1:250,000-scale Digital Elevation Model;
sun illumination from northwest at 30 degrees above horizon.

EXPLANATION

Potential runoff, in feet per year

- < 0.02
- 0.02 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.6
- 0.6 - 0.8
- 0.8 - 1

Boundary of study area

Boundary of hydrographic area

Figure 7. Potential runoff generated using the Basin Characterization Model, Basin and Range carbonate-rock aquifer system study area and vicinity, Nevada and Utah

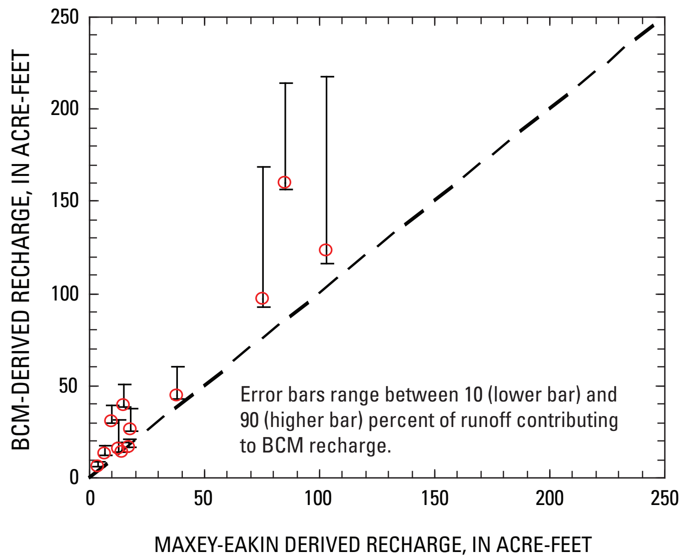


Figure 8. Relation of ground-water recharge estimated by using the Maxey and Eakin method (1949) and the Basin Characterization Model (BCM). Red circles represent total estimated BCM recharge equal to potential in-place recharge plus 15 percent of the potential runoff.

Long-Term Recharge

Recharge during 1895–2006 was estimated and assumed representative of long-term recharge to the BARCAS area (table 1). Long-term recharge estimates were expected to differ from BCM results because annual precipitation for 1895–2006 (8,185,000 acre-ft), was 5 percent less than for 1970–2004, (8,624,000 acre-ft).

Long-term recharge was estimated by relating annual recharge to annual precipitation for 1895–2006 using a threshold-limited, power function applied to each sub-basin (fig. 9). The regression approach was applied by assuming that antecedent conditions from previous years do not affect annual recharge. This assumption is incorrect for predicting recharge in a particular year but should minimally affect an estimate for a 112-year average. Using this method, long-term recharge for each subbasin equaled the average of annual estimates for 1895–2006 (table 3). The threshold-limited, power functions largely interpolated values because more than 98 percent of the annual precipitation volumes for 1895–2006 were within the range that was observed during the 1970–2004 precipitation period (fig. 9).

Long-term recharge was calculated as the combination of in-place recharge of 476,000 acre-ft and 15 percent of the potential runoff (362,000 acre-ft) for a total of 530,000 acre-ft, which is 9 percent less than the 585,000 acre-ft of recharge estimated during the 1970–2004 period. Estimates of long-term recharge for Jakes and Little Smoky Valleys ranged between 0 and 33 percent less than 1970–2004 (table 1). Estimates of long-term recharge for Snake, Spring, and Steptoe Valleys were 6 percent less than estimates for the 1970–2004 period.

Although recharge estimates presented in this report are an extension of the regional recharge study for the Great Basin by Flint and others (2004), results of these two studies may differ for some areas. Differences in estimated ground-water recharge are the result of different climatic data and an improved snow accumulation and snowmelt model used in the current evaluation.

Table 3. Estimated average annual precipitation, runoff, and recharge for 1895–2006, by subbasin, Basin and Range carbonate-rock aquifer system, Nevada and Utah.

[All values multiplied by 1,000 and rounded to nearest 0.5 acre-ft. **Precipitation:** Values based on Parameter-Elevation Regressions on Independent Slopes Model (PRISM; Daly and others, 1994). **Runoff and Recharge:** Values for 1895–2006 estimated from threshold limited power function. Recharge runoff, equals 15 percent of estimated total runoff. Total recharge, equals in-place recharge plus runoff recharge.**Abbreviations**: ft, feet]

Subbasin	Area (acres)	Precipitation (acre-ft)	Runoff (acre-ft)	Recharge (acre-ft)		
				In-place	Runoff recharge	Total
Butte Valley						
1	317	339	9	29	1	30
2	144	131	4	4	1	5
Cave Valley						
1	93	103	4	5	1	6
2	131	142	2	5	0	5
Jakes Valley						
1	253	261	6	15	1	16
Lake Valley						
1	253	242	8	8	1	9
2	97	138	11	2	2	4
Little Smoky Valley–northern part						
	372	246	1	4	0	4
Little Smoky Valley–central part						
	38	22	0	0	0	0
Long Valley						
1	435	407	8	24	1	25
Newark Valley						
1	106	98	2	7	0	7
2	194	160	7	4	1	5
3	220	200	3	8	0	8
Snake Valley						
1	359	259	13	1	2	3
2	710	567	27	34	4	38
3	558	479	35	23	5	28
4	460	467	7	32	1	33
5	283	387	32	4	5	9
Spring Valley						
1	101	120	6	12	1	13
2	570	618	60	46	9	55
3	253	253	19	18	3	21
4	152	140	6	4	1	5
Steptoe Valley						
1	600	589	29	59	4	63
2	431	463	31	59	5	64
3	220	251	9	26	1	27
Tippett Valley						
1	211	209	6	11	1	12
White River Valley						
1	237	227	10	7	2	9
2	270	216	1	3	0	3
3	199	182	3	16	0	16
4	338	267	2	7	0	7
Total	860 4	8,185	361	476	53	530

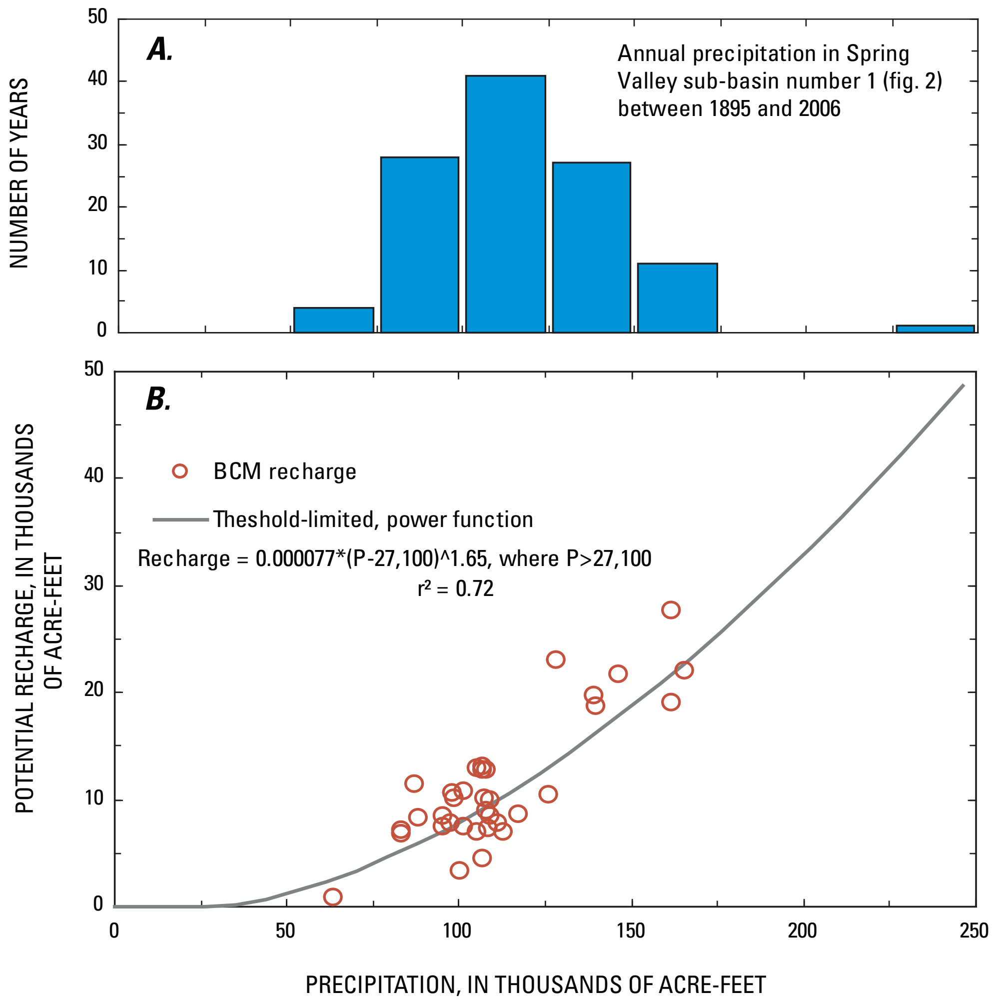


Figure 9. (*A*) annual precipitation frequency during 1895–2006 and (*B*) threshold-limited, power function regression between precipitation and estimated ground-water recharge from the Basin Characterization Model (BCM), 1970–2004, for Spring Valley subbasin number 1, Basin and Range carbonate-rock aquifer system, Nevada and Utah.

Summary

The Basin Characterization Model (BCM) is a monthly, distributed-parameter, water-balance method that was used to support USGS efforts to develop an understanding of water availability in the Basin and Range carbonate-rock aquifer system study in east-central Nevada and west-central Utah. Modified PRISM monthly rainfall and air-temperature maps for 1970–2004 were used to determine average potential recharge and runoff for 13 hydrologic areas (with 30 sub-basins) in the study area. The BCM used GIS coverages of soil, geology, and topographic information and additional process models to develop spatial distributions of potential evapotranspiration (run at a daily time step and developed into grids of mean monthly potential evapotranspiration), snow accumulation, and snowmelt. A simple water-balance equation was used with surface properties of soil-water storage and saturated hydraulic conductivity of bedrock and alluvium to determine the potential water available for runoff and in-place recharge. Results of the BCM indicate that average annual precipitation equaled 8,624,000 acre-ft for 1970–2004, of which 526,000 acre-ft is potential in-place recharge and approximately 398,000 acre-ft is potential runoff. If 15 percent of the runoff becomes recharge, about 586,000 acre-ft of ground-water recharge is estimated for the BARCAS study area (approximately 7 percent of the precipitation).

When extrapolated to the long-term climatic record (1895–2006) using a threshold-limited power function, average annual precipitation equaled 8,185,000 acre-ft, of which 476,000 acre-ft is potential in-place recharge and approximately 362,000 acre-ft is potential runoff. If 15 percent of the runoff becomes recharge then about 530,000 acre-ft of total recharge is estimated for the BARCAS study area (about 6 percent of the precipitation). These values are considered preliminary but provide a reference point and a framework for further analysis.

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Application of the Basin Characterization Model to Estimate In-Place Recharge and Runoff Potential in the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah

SIR 2007–5099