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# Water Budgets for Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas, Middle Humboldt River Basin, North-Central Nevada—Methods for Estimation and Results

Water-Resources Investigations Report 99–4272

Prepared in cooperation with the
NEVADA DIVISION OF WATER RESOURCES

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By David L. Berger

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U.S. GEOLOGICAL SURVEY

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Carson City, Nevada
2000

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
CHARLES G. GROAT, Director



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For additional information contact:

District Chief
U.S. Geological Survey
333 West Nye Lane, Room 203
Carson City, NV 89706–0866

email: GS-W-NVpublic-info@usgs.gov

http://nevada.usgs.gov

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# CONTENTS



## FIGURES

## TABLES



## CONVERSION FACTORS and VERTICAL DATUM

| Multiply | By | To obtain |
|---|---|---|
| acre | 4,047 | square meter |
| acre-foot (acre-ft) | 0.001233 | cubic hectometer |
| acre-foot per year (acre-ft/yr) | 0.001233 | cubic hectometer per year |
| cubic foot per day ($ft^3/d$) | 0.02832 | cubic meter per day |
| foot (ft) | 0.3048 | meter |
| foot per day (ft/d) | 0.3048 | meter per day |
| foot per foot (ft/ft) | 1 | meter per meter |
| foot per year (ft/yr) | 0.3048 | meter per year |
| inch (in or in.) | 25.4 | millimeter |
| inch per year (in/yr) | 25.4 | millimeter per year |
| mile (mi) | 1.609 | kilometer |
| square foot ($ft^2$) | 0.09290 | square meter |
| square mile ($mi^2$) | 2.590 | square kilometer |

**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.

# Water Budgets for Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas, Middle Humboldt River Basin, North-Central Nevada—Methods for Estimation and Results

*By* David L. Berger


## Abstract

Water budgets were developed for three hydrographic areas in the middle Humboldt River Basin of north-central Nevada. The water budgets include estimates of average annual precipitation, runoff, water yield, ground-water recharge, and evapotranspiration determined from recently developed or revised methods. These water budgets are compared to water budgets developed more than 30 years ago.

The distribution of precipitation was obtained from a statistical–topographic model, a precipitation–elevation regressions on independent slopes model, or PRISM, that simulates average annual precipitation at regional scales. Estimates of runoff and water yield were derived by simple regression analysis. Ground-water recharge was estimated by using a revision of the Maxey–Eakin method and by mass-balance calculations. Available climatic data, collected at remote automatic weather stations, were used in the Penman–Monteith equation to estimate evapotranspiration. Estimates of ground-water discharge based on distribution of phreatophyte vegetation were developed from micrometeorological methods and regionalized by using satellite imagery.

The three hydrographic areas—Pine Valley, Carico Lake Valley, and Upper Reese River Valley—were subdivided into mountain blocks, piedmont slopes, and valley lowlands on the basis of the distribution of these landforms within the basin and the patterns of ground-water flow in the underlying hydrogeologic units. Water budgets were determined for each of the three types of landform and were combined to estimate the water budget for each hydrographic area. The water budgets represent average annual conditions for the 1961–90 reference period.

Compared to estimates from the Hardman precipitation map, PRISM-simulated precipitation is about 5 percent greater in Pine Valley, nearly 50 percent greater in Carico Lake Valley, and about 14 percent greater in Upper Reese River Valley. Because nearly half the simulated precipitation is in piedmont-slope areas, they may be areas of significant ground-water recharge.

About 95 percent of the precipitation that falls in the three hydrographic areas is lost to evapotranspiration. About 4 percent of the total precipitation falls on the valley lowlands and is lost to evapotranspiration. Evapotranspiration rates commonly applied in the earlier studies are about 2 feet per year less than rates more recently derived from micrometeorological measurements. Ground-water discharge in vegetated flood plains represents a large component of the total ground-water outflow from each hydrographic area.

New estimates of the percentage of total precipitation that becomes ground water, 8 to 14 percent, are greater than previous estimates, 2 to 7 percent. Recharge from infiltration of runoff is one of the largest contributors to the ground-water reservoirs. Development of water budgets for individual landforms and associated aquifers provides insight to the locations of source areas and processes of ground-water recharge. However, additional detailed investigation is needed to fully understand and quantify the recharge process within the middle Humboldt River Basin.

## INTRODUCTION

A water budget quantitatively describes the dynamic interrelations among the inflow and outflow components of a hydrologic system and is a prerequisite to making an effective water-resources assessment.

### Background

A hydrologic system is a "complex of related parts—physical, conceptual, or both—forming an orderly working body of hydrologic units" (Wilson and Moore, 1998, p. 104), including the interaction of hydrologic processes. The hydrologic systems described in this study include the movement and occurrence of all water from the time it enters the system as precipitation to the time it leaves the system as evapotranspiration, as surface water, or as subsurface outflow. Determining the amount of water that moves through a hydrologic system requires a detailed evaluation of a water budget.

Water budgets are based on the law of mass conservation, whereby inflow to the system equals outflow from the system plus any changes in storage within the system. Under natural conditions, long-term average inflow equals long-term average outflow. Hence the hydrologic system appears to be in a state of equilibrium and the net change in storage negligible. This equation of hydrologic equilibrium, which is fundamental in developing a steady-state water budget, is time dependent and requires that components of inflow and outflow be determined over the same period of time. In basins where human activity has done little to modify a hydrologic system, precipitation, evaporation, transpiration, and the movement of surface and ground water are the principal components that make up a water budget.

Precipitation, evaporation, and runoff can be measured directly; however, these measurements represent only point data and generally are too sparse for regional analyses. To evaluate the water resources of a basin, point data need to be regionalized to the scale of a basin. The increased availability of satellite imagery and other remote-sensing data, along with geographic-information-system technology, have provided new information and tools for regionalizing point measurements. Such data and tools were used in the development of methods for estimating water budgets in this report.

The Humboldt River Basin (fig. 1), in north-central Nevada, is the only major river basin that is entirely within the State. The drainage area of the basin includes about 15 percent of the total area of the State. Precipitation supplies all the water that flows into the basin. Consequently, the variability in climate has a significant impact on the hydrology of the area. In addition, increased development, which has been superimposed on natural climatic fluctuations, affects the water resources of the basin. Traditional water users in the Humboldt River Basin rely heavily on surface water and to a lesser extent on ground water. Surface and ground water are diverted or pumped from aquifers in the basin for a variety of applications including agricultural, public water supply, and mining.

Small annual precipitation on valley floors creates large irrigation requirements for agriculture, one of the largest water applications in the basin. Population increases have led to demands for more public water supplies. In recent years, increased mining activities have placed additional demands on the water resources of the basin. Large volumes of ground water currently are being pumped for pit dewatering at some mine sites in the Humboldt River Basin.

Recent uncertainties about regional and long-term effects of dewatering for open-pit mining operations on the hydrology of the Humboldt River Basin have raised concerns by State and local governments. The U.S. Geological Survey (USGS), in cooperation with the Nevada Division of Water Resources, has undertaken a water-resources assessment of the Humboldt River Basin to address these concerns.

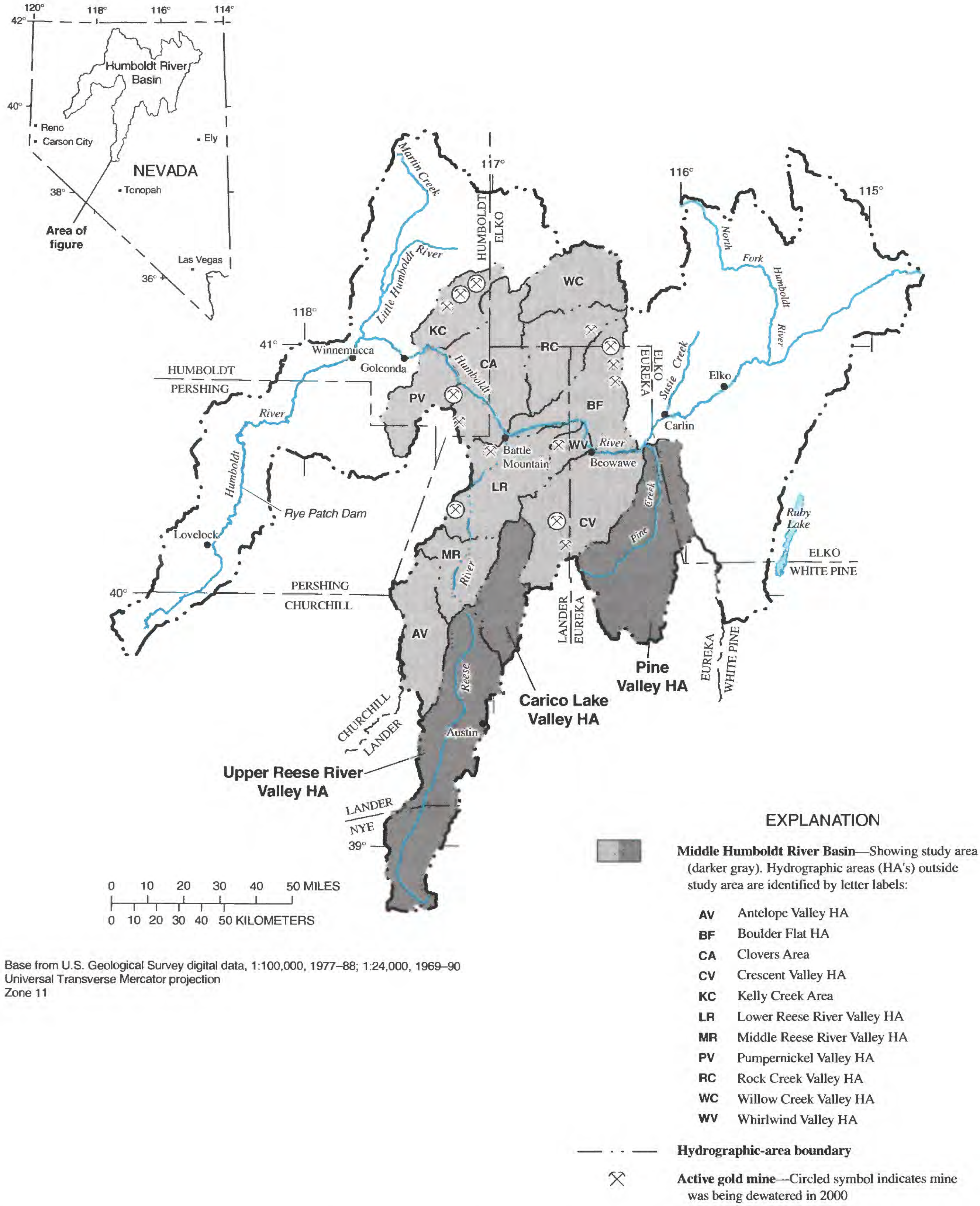


**Figure 1.** Locations of middle Humboldt River Basin and of Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas, north-central Nevada.

The Humboldt River Basin Assessment was designed to evaluate the water resources of the basin. The main objectives of the overall study are to (1) provide a scientific appraisal of surface-water and ground-water resources in the Humboldt River Basin, (2) determine the interactions between surface water and ground water among contributing areas and the main stem of the Humboldt River, and (3) determine the effects of all major water uses in the basin on the quantity, quality, and beneficial use of the basin's water resources.

For this assessment, the Humboldt River Basin (fig. 1) was divided into upper, middle, and lower basins, the boundaries of which are similar to those used by Eakin and Lamke (1966) in their hydrologic reconnaissance study. The focus of this current investigation is on the middle Humboldt River Basin, which has the greatest current and proposed changes in traditional water uses including increases in mining activity. In general, the middle Humboldt River Basin is defined by the hydrographic areas tributary to the Humboldt River from about 10 miles downstream from Carlin to about 5 miles upstream from Golconda.

The main tasks in the assessment of the middle Humboldt River Basin are (1) to obtain hydrologic data for the basin and to tabulate the data in data bases maintained by the USGS, (2) to define the hydrogeologic framework in terms of aquifers that store and transmit ground water and confining units that impede ground-water movement, (3) to describe ground-water conditions, with an emphasis on shallow ground water in basin fill, and (4) to develop and revise methods for estimating water budgets.

## Purpose and Scope

This report presents the results of an investigation to develop a systematic approach for estimating water budgets for individual hydrographic areas[1] or basins within the middle Humboldt River Basin (the fourth assessment task, as listed above). A conceptualized hydrologic flow system, typical for areas in the Humboldt River Basin, is described in terms of inflow and outflow components, the interrelations between those components, and the processes of water movement through the hydrogeologic units of the flow system.

The investigation began in October 1995 with the analysis of three hydrographic areas in the middle Humboldt River Basin: Pine Valley, Carico Lake Valley, and Upper Reese River Valley. These three areas are used to demonstrate the methods for estimating components of a water budget. Selection of these areas was based in part on the availability of hydrologic data from previous investigations.

Data requirements and procedures for development of the methods are described, and the results of applying the methods in the three selected basins are discussed. Budget estimates derived from this study are compared with those developed in earlier studies. The comparisons include ground-water budgets for each basin and, where possible, individual budget components.

## Approach of Investigation

The general approach of this investigation was to subdivide a hydrographic area into three principal physiographic units or landforms—mountain blocks, piedmont slopes, and valley lowlands; this approach is similar to that taken by earlier investigators (Bredehoeft, 1963; Eakin and others, 1965; Eakin and Lamke, 1966). The configuration of ground-water flow associated with each landform is controlled by characteristics of the hydrogeologic units that make up the underlying aquifers. For each landform the budget components were identified and then estimated. The movement of water in hydrogeologic units underlying each landform was taken into account, and the principal water-budget components were analyzed independently. Budget components estimated for each landform then were combined to develop a water budget for the entire hydrographic area.

Some budget components were estimated by newly developed methods or by methods revised from those originally developed more than 50 years ago by USGS scientists. Other components were estimated as

[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 (Cardinalli and others, 1968; Rush, 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.

residuals from mass-balance calculations. Some budget components are presented as a range based on two sets of data collected at different times. The range in values illustrates the uncertainty in estimating water-budget components, some of which may be due to climatic variability.

Management of data and processing procedures used to regionalize point measurements was facilitated by geographic information systems (GIS). The GIS was designed for the assembly, storage, and analysis of spatial-data sets. Spatial relations among several data sets are numerous and very complex. Only some of the relations could be defined in the GIS; other relations were calculated. The spatial-data sets developed and used in this investigation include land-surface altitude, determined from 1-degree digital elevation models (U.S. Geological Survey, 1987), which have an accuracy of about 300 ft; land-use and land-cover digital data (classified at minimum resolutions of 10 acres for open-water bodies and 40 acres for rangeland) derived from 1:250,000-scale high-altitude photography collected in 1980 and 1983 (U.S. Geological Survey, 1986); Landsat Thematic Mapper (TM) satellite data, collected in June 1989 and June 1995, at a resolution of about 320 $ft^2$; hydrographic-area and watershed boundaries digitized from 1:24,000-scale topographic maps having a minimum accuracy of about 43 ft; distribution of geologic units, modified from Plume and Carlton (1988), at 1:1,000,000 scale (accuracy unknown); and the distribution of average annual precipitation for Nevada, developed from Daly and others' (1994) precipitation–elevation regressions on independent slopes model (PRISM), resampled to about a 62-acre area.

## Location and General Features of Study Area

The middle Humboldt River Basin covers an area of nearly 7,470 $mi^2$ in north-central Nevada (fig. 1). As is typical of the Basin and Range Province, the area is characterized by northward-trending mountain ranges separated by broad alluvial valleys. Altitudes within the basin range from about 4,350 ft, where the Humboldt River leaves the basin near Golconda, to almost 11,800 ft, in the Toiyabe Range south of Austin (figs. 1 and 9). The basin is sparsely populated and includes parts of Pershing, Humboldt, Lander, Eureka, Nye, and Elko Counties.

The geologic history of north-central Nevada is complex and is the major control on water movement through the hydrologic systems within the area. Consolidated bedrock ranging in age from Precambrian to late Tertiary composes the mountainous regions. The intervening valleys are filled with unconsolidated deposits of Tertiary and Quaternary age that commonly are several thousand feet thick. The hydrogeologic framework of the Humboldt River Basin was summarized by Plume and Carlton (1988), Plume (1996), and Plume and Ponce (1999).

The climate of the study area is arid in the valleys to subhumid in the mountains and is characterized by hot summers and cold winters. Average annual precipitation over a 30-year reference period (1961–90) is commonly less than 10 in. on the valley floors and as much as 30 in. at the higher altitudes in the mountains (Owenby and Ezell, 1992). Because of the large range in annual precipitation between valley floors and surrounding mountains, the vegetation in north-central Nevada is very diverse.

Fourteen hydrographic areas make up the middle Humboldt River Basin (fig. 1). For this investigation, Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas were selected for developing and refining methods of estimating water budgets. The boundaries of the three selected basins, initially delineated as hydrographic areas by Rush (1968) and Cardinalli and others (1968), were refined further during this investigation by using topographic-drainage boundaries interpreted from 1:24,000-scale maps. The three basins are in the southern part of the middle Humboldt River Basin, south of the Humboldt River. These generally northward-trending and hydrologically and topographically open basins have both surface and subsurface drainage. Mountain-block areas represent more than 40 percent of the total drainage area in each basin. Irrigation for agriculture is the principal use of water in the three basins, and, as of 2000, no mines in the basins were being dewatered.

The Pine Valley Hydrographic Area covers about 1,010 $mi^2$ in the southeastern part of the middle Humboldt River Basin (fig. 1). Pine Valley is about 55 mi long and as much as 20 mi wide. Pine Creek drains the valley and flows northward directly to the Humboldt River. During the period 1947–58, estimates of discharge were made from a continuous-stage-recording gage on Pine Creek, near where it leaves Pine Valley at the north end of the hydrographic area.

The Carico Lake Valley Hydrographic Area has a drainage area of about 380 $mi^2$ (fig. 1). Carico Lake Valley is about 43 mi long and as much as 15 mi wide. Surface water in Carico Lake Valley drains into Crescent Valley Hydrographic Area to the northeast through a narrow pass that cuts bedrock. During years of above-average precipitation and runoff, a shallow lake develops on the small playa in the northern part of the valley lowlands.

The Upper Reese River Valley Hydrographic Area covers nearly 1,140 $mi^2$ in the southern part of the middle Humboldt River Basin. The northeast boundary of Upper Reese River Valley Hydrographic Area is coincident with the southwest boundary of Carico Lake Valley Hydrographic Area (fig. 1). Upper Reese River Valley is more than 85 mi long and is about 18 mi across at the widest part. The Reese River flows northward along the axis of the valley and then through a narrow bedrock canyon to Middle Reese River Valley Hydrographic Area (fig. 1). During years having above-normal precipitation, the Reese River discharges to the Humboldt River near Battle Mountain. Flow of the Reese River was recorded continuously during 1964–68 at a gaging station at the north boundary of the hydrographic area.

### Previous Investigations

In 1959, the Nevada State Legislature authorized the Humboldt River Research Project (Statutes, Chapter 97, 1959). The purposes of the project, in part, were to identify hydrologic data and information available for the Humboldt River Basin, quantitatively describe the hydrologic processes in the basin, and develop techniques needed to evaluate the water resources of the Humboldt River Basin. The research project used information from the period 1912–63 for analyzing the hydrologic conditions within the Humboldt River Basin. The project was a Federal–State interagency investigation that resulted in a wide variety of publications including a reconnaissance-level evaluation of the Humboldt River Basin (Eakin and Lamke, 1966), a detailed study of evapotranspiration by woody phreatophytes (Robinson, 1970), a summary of the specific-yield and particle-size relations of Quaternary alluvium (Cohen, 1963), and a geologic investigation of the shallow valley fill in the Winnemucca area (Hawley and Wilson, 1965).

Additionally, the USGS began a cooperative study with the Nevada Division of Water Resources in 1960 to provide preliminary appraisals of Nevada's water resources. These appraisals were published as a series of reconnaissance reports authorized by the Nevada State Legislature (Statutes, Chapter 181, 1960). As a result of the enacted legislation, brief water-resources appraisals for Pine Valley (Eakin, 1961), Carico Lake Valley (Everett and Rush, 1966), and Upper Reese River Valley (Eakin and others, 1965) were published in that series. These reports provide general information on the climate, physiography and surface-water drainage, and geology of the three hydrographic areas. The reports also describe the general hydrologic characteristics of the basin-fill aquifer systems in terms of estimates of annual ground-water recharge and discharge, perennial yield, and storage; include an inventory of wells in the area; and present chemical analyses of ground-water samples from selected wells.

## CONCEPTUALIZATION OF HYDROLOGIC SYSTEM

A basin in the study area can be conceptualized to consist of three landforms. The landforms are interconnected in terms of water movement but differ in their relative positions in a basin and in the characteristics of ground-water flow in the underlying hydrogeologic units. The following sections describe the delineation of a hydrographic area and identify the water-budget components associated with each landform. Although landforms are topographic or surficial features, they can be used to subdivide a typical basin because they generally correspond to different patterns of ground-water flow. Ground-water-flow systems in Nevada were discussed in detail by Mifflin (1968), Eakin and others (1976), and Harrill and Prudic (1998).

### Delineation of Landforms

Mountain blocks, piedmont slopes, and valley lowlands are three easily identifiable landforms in arid and semiarid basins (Peterson, 1981, p. 4), which are typical of the study area. Landforms and bedrock permeability affect the general patterns of ground-water flow, shown schematically in figure 2, which depicts flow perpendicular to the long axes of typical basins.

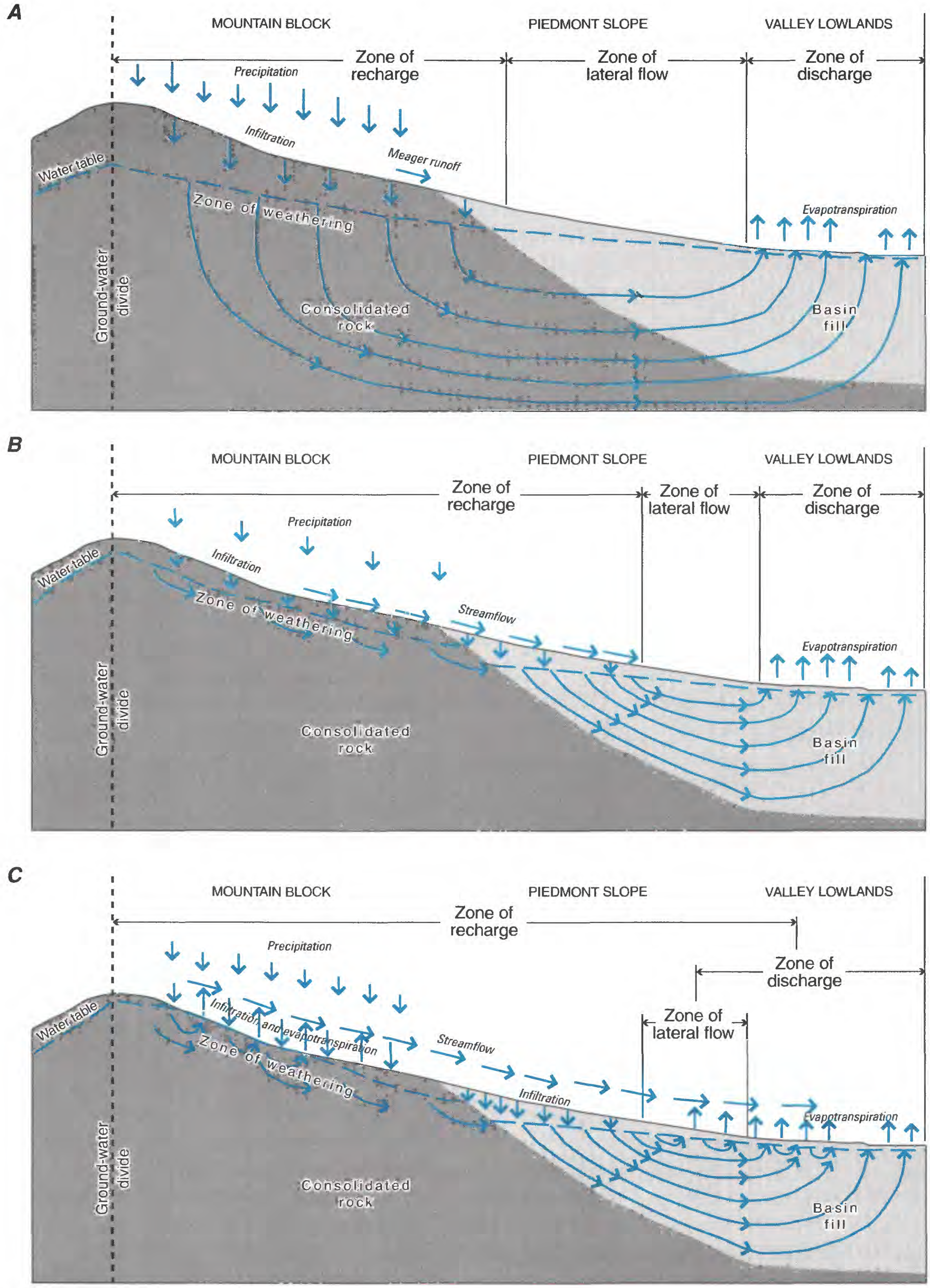


**Figure 2.** Typical basins, showing landforms and general patterns of ground-water movement, middle Humboldt River Basin, north-central Nevada. *A,* Arid basin having permeable bedrock. *B,* Arid basin having poorly permeable bedrock. *C,* Semiarid basin having poorly permeable bedrock.

In the study area, ground water also moves parallel to the long axis and commonly supports subsurface outflow. In general, mountain-block areas can be represented as the zone of recharge, piedmont slopes as the zone of lateral flow, and valley lowlands as the zone of ground-water discharge (Mifflin, 1968, p. 12). For most basins in the study area, the zone of recharge extends to the upper parts of the piedmont slopes (fig. 2*B*), where runoff is concentrated and sediment permeability tends to be more favorable for infiltration. In basins where ground-water flow is part of a regional flow system and where depth to ground water is too great to sustain phreatophyte vegetation or large amounts of ground-water discharge by direct evaporation, valley lowlands may not correspond to the zone of ground-water discharge.

Hydrogeologic units in mountain-block areas consist of bedrock aquifers that transmit water and confining units that impede water movement. These hydrogeologic units also underlie the basin-fill sediments on piedmont slopes and in valley lowlands. The relations of ground-water flow shown in figure 2 commonly are not all found in the same hydrologic system. Patterns and characteristics of ground-water flow are controlled by the permeability of the hydrogeologic units and the aridity of the area. Because rock types have a wide range of permeabilities, various patterns of ground-water flow through bedrock are to be expected. Ground water originating in a mountain block of permeable bedrock follows deep flow paths (fig. 2*A*), whereas water originating in poorly permeable bedrock follows shallow flow paths through zones of weathered and fractured rock (figs. 2*B* and *C*).

### Mountain Block

Mountain blocks, which surround a basin, are the dominant feature of the landscape and commonly extend several thousand feet above adjacent valley floors. For this investigation, mountain-block areas were delineated by the topographic divide along the mountain crest and by the contact between bedrock of the mountain block and the alluvial sediments of the upper piedmont slopes. Mountain blocks commonly are believed to form ground-water divides because of their low permeability (Bredehoeft, 1963, p. 11). However, localized faulting or fracturing and weathering may produce secondary permeability in the bedrock aquifers. A substantial amount of ground water may move through these fractured zones or be stored, where saturated, even though their primary permeability is low. In the Humboldt River Basin, mountain blocks receive a large part of the precipitation that falls in a basin and are the principal source areas of inflow.

### Piedmont Slope

Representing about 50 percent of the total basin area, piedmont slopes typically form the largest part in the three basins. They are composed of several topographic parts, including dissected pediments and alluvial fans (Peterson, 1981, p. 8). Piedmont slopes form the transition between the mountain block and the nearly level land of the valley lowlands. Surface gradients of piedmont slopes generally range from about 8 to 15 percent near the mountain front to about 1 percent where the slopes meet the lowlands (Peterson, 1981, p. 8). The compositions of the geologic materials that comprise the piedmont slope and the underlying basin fill generally are controlled by the depositional environment and the type of bedrock in the adjacent mountain block. Textures of the sediments on the piedmont-slope surfaces typically grade from coarse grained near the mountain front to finer grained downslope toward the valley lowlands. Because of the coarse grain size of the upslope sediments, runoff that issues from the mountain block commonly infiltrates before reaching the valley lowlands. Consequently piedmont slopes are favorable areas for ground-water recharge. Basin-fill aquifers, which make up the principal hydrogeologic units beneath piedmont slopes, consist of unconsolidated to semiconsolidated deposits of poorly sorted gravel, sand, and silt.

### Valley Lowland

Areas of the valley lowland include barren playas that are ephemerally flooded, vegetated flood plains, and alluvial flats. In most basins, the valley lowland is in the axial part of the basin and typically contains the principal tributary of the drainage basin. In general, population and agricultural development are concentrated in the valley lowland, where depth to ground water is commonly shallow. Because of the shallow water table in these areas, ground-water discharge by bare-soil evaporation and phreatophytic transpiration is the dominant hydrologic process. For this investigation, the valley lowlands were delineated by the zone of active ground-water discharge, which includes areas of phreatophyte vegetation and bare soil. Unconsolidated basin-fill deposits, which typically are several thousand feet thick, form the principal hydrogeologic unit beneath the valley lowland. In topographically closed basins, the basin-fill deposits underlying the valley lowland commonly are fine grained, whereas in basins with surface-water outflow, the deposits tend to be more coarse grained. The basin-fill aquifers beneath piedmont-slope and valley-lowland areas are the principal aquifers developed in most basins of the middle Humboldt River Basin.

### Identification of Water-Budget Components

Water-budget components are influenced or controlled by the climate, geomorphology, and geology. The most significant components in the middle Humboldt River Basin are precipitation, water yield, runoff, ground-water recharge and subsurface flow, and evapotranspiration (ET).

Precipitation, in the form of either rain or snow, is the principal source of inflow. Because precipitation generally increases with increasing altitude, the potential for ground-water recharge and runoff is greatest in mountain-block areas and upper parts of piedmont slopes. Because piedmont slopes make up such a large part of a basin area, much of the annual precipitation falls in this part of a basin. Most of the precipitation occurs from December to May as snow in the mountain-block areas.

Runoff is defined as that part of the precipitation that eventually appears in streams (Langbein and Iseri, 1960, p. 17) and that can be divided, with respect to the water source, into direct runoff or baseflow runoff (Wilson and Moore, 1998, p. 172). In the middle Humboldt River Basin, a large part of the runoff is produced by melting snow originating in the mountain blocks (Eakin and Lamke, 1966, p. 32). Runoff generated on piedmont-slope and valley-lowland areas, in part, is a function of the intensity, duration, and distribution of the precipitation; permeability of the surface sediments; temperature; and vegetation type. The water yield from mountain-block areas consists of runoff generated in the watersheds and of ground water that flows from the bedrock aquifer along the mountain front.

In the study area, ground-water recharge takes place by direct infiltration of precipitation in excess of ET and soil-moisture requirements and by indirect infiltration from channelized or nonchannelized runoff or ponded water. Although, in terms of total ground-water recharge, indirect processes of recharge tend to be seasonal, they are significant to the overall water budget in a basin. In areas of permeable bedrock (fig. 2*A*), ground water flows from bedrock aquifers to the basin-fill aquifers underlying the valley along deep ground-water flow paths. In areas of less permeable bedrock (figs. 2 *B* and *C*), water percolates through the thin soil zone or weathered bedrock and moves down-gradient as shallow ground water. In semiarid basins (fig. 2*C*), ground water may discharge as spring flow along the mountain front or seep into stream channels and contribute to baseflow near the upper parts of the piedmont slopes, where it is available to flood-plain vegetation. Ground-water recharge from precipitation on valley lowlands generally is assumed to be negligible but may result from intense storms in areas where the water table is shallow (Olmsted, 1985, p. 15). In the subsurface, ground water moves laterally between aquifers and, in some places, across hydrographic-area boundaries.

Under natural conditions in the middle Humboldt River Basin, ET is the dominant outflow component. Much of the precipitation that falls in the mountain-block and piedmont-slope areas either is consumed by direct evaporation and sublimation or is transpired by vegetation before it is available to the ground-water reservoir. Results of investigations at a commercial waste-burial facility in the Amargosa Desert in southern Nevada suggest that ground water may be discharged by nonisothermal vapor flux through the unsaturated zone in areas where the depth to water is several hundred feet (Fischer, 1992; Prudic, 1996). Although such discharge has not been determined for the middle Humboldt River Basin, it may have significant implications for the overall water budget. In the valley lowlands, annual ET typically exceeds annual precipitation because direct evaporation of ground water takes place in areas of shallow ground water.

## Development of Water Budget

Under natural conditions and during a relatively constant climatic regime, a hydrologic system can be assumed to be in a state of approximate dynamic equilibrium (Theis, 1940, p. 277), where inflow equals outflow. This type of inflow–outflow or steady-state analysis, which was applied in this investigation, assumes that the hydrologic system rapidly responds to stresses and that effects are distributed equally throughout the hydrographic area. Development of a water budget using a lumped-parameter approach of this type does not take into account the areal or seasonal variations of precipitation, evapotranspiration, or temperature. However, this approach does address the interrelations between ground-water flow and other components of a water budget. The general interrelations of budget components for each landform (table 1) and the hydrologic characteristics of a simplified flow system are illustrated schematically in figure 3.

For this investigation, the water budgets were considered on an average annual basis. Therefore, estimates of precipitation, runoff, water yield, ground-water recharge, and ET represent average quantities for a 12-month period. The water year, which begins on October 1 and ends on September 30 of the following calendar year, is used to represent an average year. The 30-year period 1961–90 is used as the reference period for analyses in this investigation.

Generally, unconsolidated deposits that make up basin-fill aquifers have large quantities of ground water in storage. Ground water also can be stored in fractures and in zones of weathering within the bedrock aquifers and in the consolidated rock beneath basin fill in the valley. Because for this investigation the hydrologic systems were assumed to be in approximate equilibrium, the long-term average annual net change in ground-water storage is negligible. However, stresses that disrupt this hydrologic equilibrium would cause ground-water-level fluctuations and corresponding changes in ground-water storage.

The general equilibrium relation for a steady-state water budget equates inflow to outflow. This general assumption was used to develop water budgets that describe relations between the inflow and outflow components for each landform and associated hydrogeologic units. The equations of equilibrium for average annual water budgets and a typical basin in the middle Humboldt River Basin are presented in table 1.

**Table 1.** Equations of hydrologic equilibrium for average annual water budgets for landforms and typical basin in middle Humboldt River Basin, north-central Nevada

[Water-budget components (inflow equals outflow; see fig. 3 for hydrologic relations): **Esw**, evaporation from open-water bodies; **ETgw**, evapotranspiration of ground water by phreatophyte vegetation and through areas of bare soil in valley lowland; **ETmb**, evapotranspiration and sublimation of precipitation and soil moisture and from riparian areas in mountain block; **ETps**, evapotranspiration and sublimation of precipitation and soil moisture from piedmont slope; **ETrps**, evapotranspiration from vegetated flood plains of piedmont slope; **ETvl**, evapotranspiration of precipitation and soil moisture from valley lowland; **Pmb**, precipitation on mountain block; **Pps**, precipitation on piedmont slope; **Pvl**, precipitation on valley lowland; **ROmb**, runoff from mountain block; **ROps**, runoff from piedmont slope; **ROvl**, runoff from valley lowland; **SFin**, subsurface flow from adjacent hydrographic areas; **SFmb**, subsurface flow from bedrock aquifer in mountain block; **SFout**, subsurface flow to adjacent hydrographic areas; **SFps**, subsurface flow from basin-fill aquifer beneath piedmont slope; **SFtot**, total outflow as subsurface flow at hydrographic-area boundary; **SFvl**, subsurface flow from basin-fill aquifer beneath valley lowland; **SWin**, surface-water flow from adjacent hydrographic areas; **SWtot**, total outflow as surface water at hydrographic-area boundary (may include ground-water discharge as baseflow)]

| | Average annual water-budget components | | |
|---|---|---|---|
| | Inflow | = | Outflow |
| Landforms: | | | |
| Mountain block | Pmb + SFin | = | ROmb + SFmb + SFout + ETmb |
| Piedmont slope | Pps + ROmb + SWin + SFmb + SFin | = | ROps + SFps + SFout + ETps + ETrps |
| Valley lowland | Pvl + ROps + SWin + SFps + SFin | = | ROvl + SFvl + ETvl + ETgw + Esw |
| Hydrographic area....... | Pmb + Pps + Pvl + SWin + SFin | = | SWtot + SFtot + ETmb + ETps + ETrps + ETvl + ETgw + Esw |

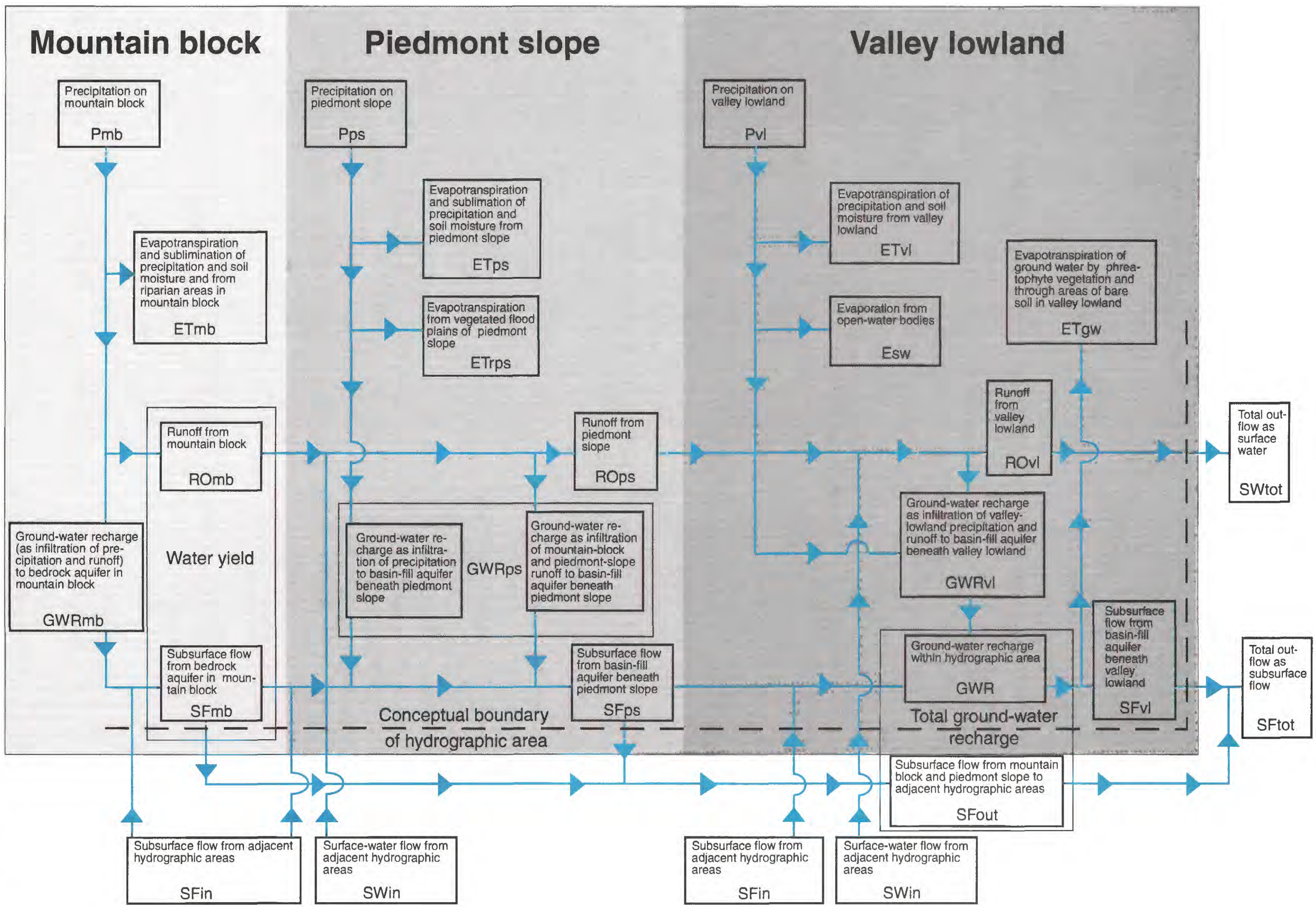


**Figure 3.** Interrelations among water-budget components and landforms for simplified hydrologic flow system, middle Humboldt River Basin, north-central Nevada. Modified from Eakin and Lamke (1966, p. 14).

The budgets for each landform and underlying hydrogeologic units are described in terms of inflows balanced by outflows, where an outflow from one landform commonly represents an inflow to another landform.

In mountain-block areas, precipitation and inflow from adjacent areas are balanced by runoff, subsurface flow from the bedrock aquifer, sublimation and ET of precipitation and soil moisture, and ET from riparian areas. Runoff and subsurface flow that remain within the hydrographic area make up part of the inflow to the piedmont-slope area (fig. 3).

In piedmont-slope areas, precipitation, the water yield from the mountain block, and inflow from adjacent areas are balanced by runoff to the valley lowlands, subsurface flow to the basin-fill aquifer beneath the valley lowlands or to adjacent areas, ET of precipitation and soil moisture, and ET from vegetated flood plains. Subsurface flow leaving the basin-fill aquifer beneath the piedmont-slope area is made up of subsurface flow from the bedrock aquifer and the part of the runoff from the mountain-block and piedmont-slope areas that infiltrates to the ground-water reservoir. In addition, some precipitation on piedmont slopes may directly infiltrate to the ground-water reservoir.

In valley-lowland areas, total annual ET was assumed to be equal to the sum of evaporation from surface water, ET of precipitation, and ET of ground water. This sum is typically greater than the volume of precipitation that falls on the valley lowlands. To develop a water budget for valley-lowland areas, ET of precipitation (ETvl, fig. 3) was assumed to be equal to the average annual precipitation in the valley lowlands. Consequently, net inflow consists of the combined runoff from mountain-block and piedmont-slope areas, subsurface flow from basin-fill aquifers beneath the piedmont slope, and any additional water from adjacent basins. The inflow is balanced by surface-water and subsurface outflow at the hydrographic-area boundary, by evaporation from open-water bodies and from shallow ground water through bare soil, and by transpiration of ground water by phreatophyte vegetation. Evaporation of shallow ground water and soil moisture through areas of bare soil and transpiration of ground water by phreatophyte vegetation were estimated as one outflow component and combined in one budget term (ETgw, fig. 3).

## METHODS FOR ESTIMATING WATER-BUDGET COMPONENTS

The annual quantity of water associated with some of the discussed water-budget components can be estimated or measured directly, but the resulting point data generally are too sparse for regional analysis. The following sections describe the management and processing procedures used to regionalize point data.

By definition, a method is a regular and systematic way of accomplishing a given task, and the assumption is that the set of procedures can be applied elsewhere and produce similar results. Thus, the methods applied to one basin should be applicable to other basins in the middle Humboldt River Basin without significant modification. Nonetheless, the procedures discussed herein are subject to refinement as more information about the identified water-budget components becomes available. In addition, the use of these methods is limited by the uncertainties inherent in the measured or estimated values of the budget components and in the techniques used to areally distribute those values. The conceptualized hydrologic flow system used in this investigation (fig. 3) is a simplification of a real system and is limited by those components that remain poorly understood. Although the water budgets derived by these methods are subject to uncertainty, the overall estimates are believed to represent the proportional distribution of those components within each landform over an average year based on the 30-year reference period 1961–90.

### Precipitation Distribution

A statistical–topographic model was developed by Daly and others (1994) for simulating average annual precipitation at a regional scale over mountainous terrain. The model, called a precipitation–elevation regressions on independent slopes model, or PRISM, was used to simulate precipitation for a map showing the distribution of average annual precipitation for Nevada (G.H. Taylor, Oregon Climate Service, Oregon State University, written commun., 1997). The simulated precipitation distribution shown on that map was derived from weather-station data throughout Nevada.

The map represents average annual precipitation over the 30-year reference period 1961–90 and was used to estimate average annual precipitation in the Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas.

Specifically, the simulated-precipitation map (G.H. Taylor, Oregon Climate Service, Oregon State University, written commun., 1997) consists of digital vector lines of contoured precipitation at 2-in/yr intervals. As part of the present study, a surface was fitted to the original precipitation contours and resampled to a 1,640-ft by 1,640-ft cell size. Areas then were determined from the gridded data set at 1-in/yr precipitation intervals. Methods for estimating average annual runoff, water yield, and ground-water recharge were developed, in part, as functions of the distribution and quantity of annual precipitation simulated by PRISM and were regionalized by using GIS techniques. A summary of the area and distribution of average annual precipitation for each landform in the three hydrographic areas is presented in table 2.

## Runoff and Water Yield

The relation between runoff and water yield was used to develop estimates of subsurface flow from mountain-block areas. The difference between runoff and water yield was assumed equal to subsurface flow. Methods for estimating annual runoff and water yield in western Nevada (Maurer and Berger, 1997) were modified to include areas in north-central Nevada and were applied to the basins selected for this study.

**Table 2.** Area of landforms and distribution of simulated average annual precipitation on landforms in Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas, middle Humboldt River Basin, north-central Nevada

[PRISM, precipitation–elevation regressions on independent slopes model (Daly and others, 1994). <, less than]

| Landform | Area[1] (acres) | PRISM-simulated average annual precipitation[2] by precipitation zone (acre-feet per year) | | | | |
|---|---|---|---|---|---|---|
| | | Zone of at least 8 but <12 inches | Zone of at least 12 but <16 inches | Zone of at least 16 but <20 inches | Zone of at least 20 but <34 inches | Total |
| **Pine Valley Hydrographic Area** | | | | | | |
| Mountain block | 261,800 | 10,600 | 177,600 | 117,200 | 21,000 | 326,000 |
| Piedmont slope | 350,100 | 174,700 | 151,400 | 7,700 | 0 | 334,000 |
| Valley lowland | 32,800 | 26,300 | 1,500 | 0 | 0 | 28,000 |
| Total | 645,000 | 212,000 | 330,000 | 125,000 | 21,000 | 688,000 |
| **Carico Lake Valley Hydrographic Area** | | | | | | |
| Mountain block | 111,400 | 20,200 | 77,300 | 22,100 | 3,400 | 123,000 |
| Piedmont slope | 120,400 | 82,300 | 25,300 | 0 | 0 | 108,000 |
| Valley lowland | 9,700 | 8,100 | 0 | 0 | 0 | 8,000 |
| Total | 242,000 | 111,000 | 103,000 | 22,000 | 3,000 | 239,000 |
| **Upper Reese River Valley Hydrographic Area** | | | | | | |
| Mountain block | 339,200 | 32,600 | 200,600 | 135,400 | 45,300 | 414,000 |
| Piedmont slope | 352,100 | 78,800 | 269,600 | 6,100 | 0 | 354,000 |
| Valley lowland | 36,000 | 5,500 | 29,500 | 0 | 0 | 35,000 |
| Total | 727,000 | 117,000 | 500,000 | 142,000 | 45,000 | 803,000 |

[1] Rounded to nearest 100 acres for each landform; totals rounded to nearest 1,000 acres.

[2] PRISM simulation based on 1961–90 data. Rounded to nearest 100 acre-feet per year for each landform; totals rounded to nearest 1,000 acre-feet per year. Zones based on Nichols (2000); PRISM simulated no annual precipitation of less than 8 inches or greater than 30 inches.

Data from nine gaged and two ungaged watersheds (fig. 4) were used to characterize the relations among average annual runoff, water yield, and precipitation (table 3). The watersheds were selected because the estimates of annual streamflow were based on measurements made near the contact between the bedrock of the mountain block and sediments of the upper piedmont slope and because upstream diversions or regulations of streamflow were minimal. For consistency, average annual-runoff values for the six watersheds in north-central Nevada were adjusted to represent a common 31-year time period (1966–96) on the basis of available records from the South Twin River gaging station. For Ash Canyon Creek, Kings Canyon Creek, and Vicee Canyon creek, annual runoff was adjusted to the long-term average for West Fork Carson River at Woodfords, Calif. Average annual runoff for Centennial Park and Goni watersheds were estimated using a method developed by Moore (1968, p. 33). (Goni is a name in local use only for an area in the Virginia Range, northeast of Carson City and northwest of Centennial Park.)

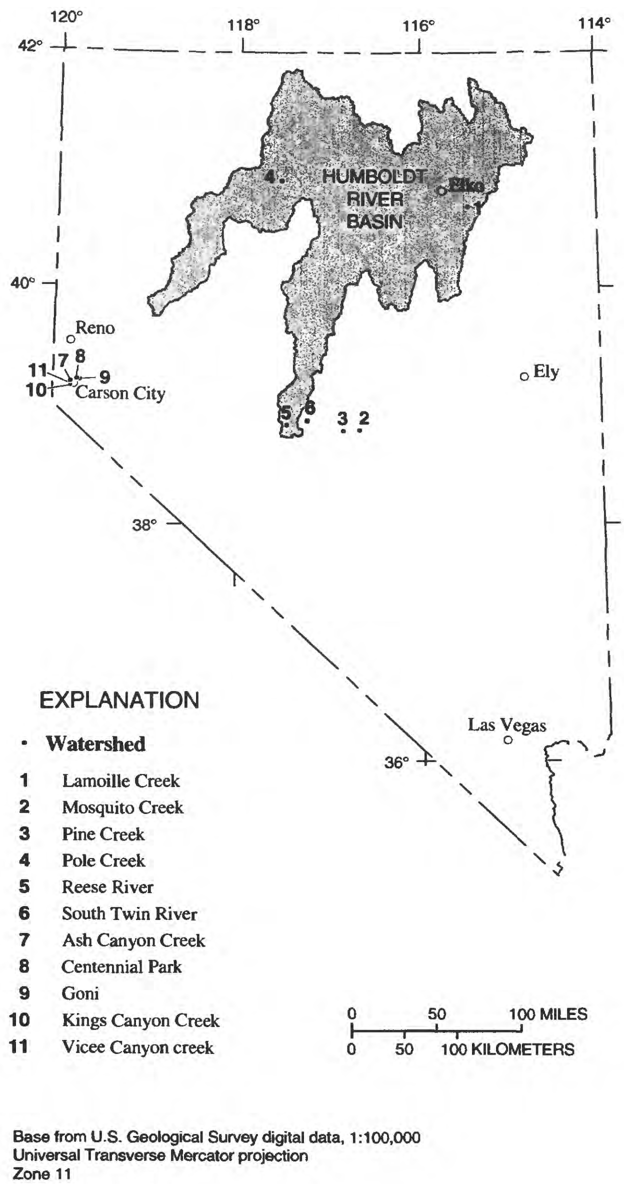


**Figure 4.** Locations of selected watersheds used in deriving relations among average annual precipitation, runoff, and water yield (see table 3). Centennial Park and Goni (name in local use only for area in Virginia Range) are ungaged watersheds; other nine are gaged.

Estimates of average annual water yield and runoff for watersheds in western Nevada (table 3) were made by Maurer and Berger (1997, p. 32). Because selected watersheds in north-central Nevada are thought to be underlain by relatively impermeable rock, average annual runoff was assumed to represent the total water yield from these watersheds.

Annual volumes of PRISM-simulated precipitation and estimates of average annual runoff and water yield were divided by the area of each watershed to account for differences in area. The resulting annual rates produce exponential relations (fig. 5). Simple least-squares regression analyses of average annual runoff and water yield (as the dependent variables) and average annual precipitation (as the independent variable) were done. The regression equation used to describe the relation between average annual runoff and precipitation can be written as

$$\mathrm{ROmb} = 0.0000228\, P_m^{\,3.96} \qquad (1)$$

where ROmb is estimated average annual runoff in mountain block, in inches per year; and

$P_m$ is average annual precipitation in mountain block, in inches per year.

(Eq. 1 applies only to watersheds where average annual precipitation is less than 30 inches; see fig. 5.)

The coefficient of determination for equation 1 ($r^2 = 0.887$) suggests that about 89 percent of the variance in annual runoff from the selected watersheds can be explained by the regression relation. In addition, the significance of probability ($p = 0.0001$) indicates a statistically significant relation between the average annual precipitation simulated by PRISM and the adjusted average annual runoff.

**Table 3.** Simulated average annual precipitation and estimated average annual runoff and water yield for selected watersheds used in developing relations among average annual precipitation in a watershed, runoff, and water yield, north-central and western Nevada

[Site number: Used to identify locations in fig. 4. PRISM, precipitation–elevation regressions on independent slopes model (Daly and others, 1994). —, not used in regression analysis]

| Site number | Watershed | Drainage area[1] (acres) | Predominant rock types exposed in watershed | PRISM-simulated average annual precipitation[2] (inches per year) | Average annual runoff[3] (inches per year) | Average annual water yield (inches per year) |
|---|---|---|---|---|---|---|
| | | | **North-central Nevada** | | | |
| 1 | Lamoille Creek | 15,940 | Granitic | 31.40 | 21.53 | [4]21.53 |
| 2 | Mosquito Creek | 9,600 | Volcanic | 17.34 | 2.21 | — |
| 3 | Pine Creek | 7,750 | Volcanic | 21.88 | 5.88 | [4]5.88 |
| 4 | Pole Creek | 6,610 | Volcanic and clastic | 16.36 | — | 6.12 |
| 5 | Reese River | 34,460 | Volcanic | 17.20 | 3.46 | [4]3.46 |
| 6 | South Twin River | 12,370 | Volcanic | 19.32 | 4.66 | [4]4.66 |
| | | | **Western Nevada[5]** | | | |
| 7 | Ash Canyon Creek | 3,380 | Metamorphic | 28.30 | 9.23 | 10.47 |
| 8 | Centennial Park | 390 | Volcanic | 12.00 | .31 | 1.23 |
| 9 | Goni[6] | 3,050 | Volcanic | 13.93 | .63 | — |
| 10 | Kings Canyon Creek | 3,260 | Metamorphic | 21.94 | 4.42 | 9.75 |
| 11 | Vicee Canyon creek | 1,260 | Granitic | 21.24 | 1.90 | — |

[1] Digitized from U.S. Geological Survey, 1:24,000, Carvers, Carvers NW, Danville, Mosquito Creek, Mount Jefferson, and Pine Creek Ranch, 1982; South Toiyabe Peak, 1979; Arc Dome, Bakeoven Creek, Farrington Canyon, Toms Canyon, 1980; Dianas Punch Bowl, Petes Summit, The Monitor, and Wildcat Peak, 1989; Lamoille, Ruby Dome, and Ruby Valley School, 1990; Verdi Peak, 1991; Marlette Lake, 1992; and Carson City and New Empire, 1994. Rounded to nearest 10 acres.

[2] Based on 1961–90 data.

[3] North-central Nevada: Values adjusted to 31-year record (1966–96) at South Twin River station by using regression relation. Western Nevada: For Ash Canyon Creek, Kings Canyon Creek, and Vicee Canyon Creek, values adjusted to long-term mean flow of West Fork Carson River at Woodfords, Calif. (periods of record: 1900–07, 1910–11, and 1938–95). For Centennial Park and Goni, values estimated by Moore's (1968, p. 11) method.

[4] Annual water yield was assumed to be equal to annual runoff in this watershed.

[5] Modified from Maurer and Berger (1997).

[6] Name in local use only.

The equation that best approximates the relation between average annual water yield and precipitation (for $P_m$<30 in. only, as for eq. 1) can be written as

$$W = 0.00273\, P_m^{2.56} \qquad (2)$$

where $W$ is average annual water yield in mountain block, in inches per year; and

$P_m$ is average annual precipitation in mountain block, in inches per year.

About 86 percent of the variance in average annual water yield can be accounted for by the regression equation (2), as suggested by an $r^2$ value of 0.863. The small $p$-value, 0.0008, indicates a strong predictive relation between average annual water yield and precipitation. Estimates of average annual runoff and water yield for mountain-block areas of Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas are presented in table 4.

The portion of precipitation that falls on piedmont slopes and becomes runoff is largely unknown. Runoff generated in piedmont-slope areas from short periods of high-intensity storms or low-altitude snowmelt is very erratic in occurrence and probably accounts for less than 10 percent of the total runoff but could be greater. Contributions to runoff from low-altitude snowmelt have been observed in streamflow data collected by Plume (1995, p. 33–36) in the upper Humboldt River Basin. He suggested that low-altitude snowmelt in the spring of 1989 may have produced recharge in the lowlands along Susie Creek near Carlin (fig. 1) sufficient to maintain relatively high baseflow several months later. About 7 percent of the average annual runoff in the middle Humboldt River

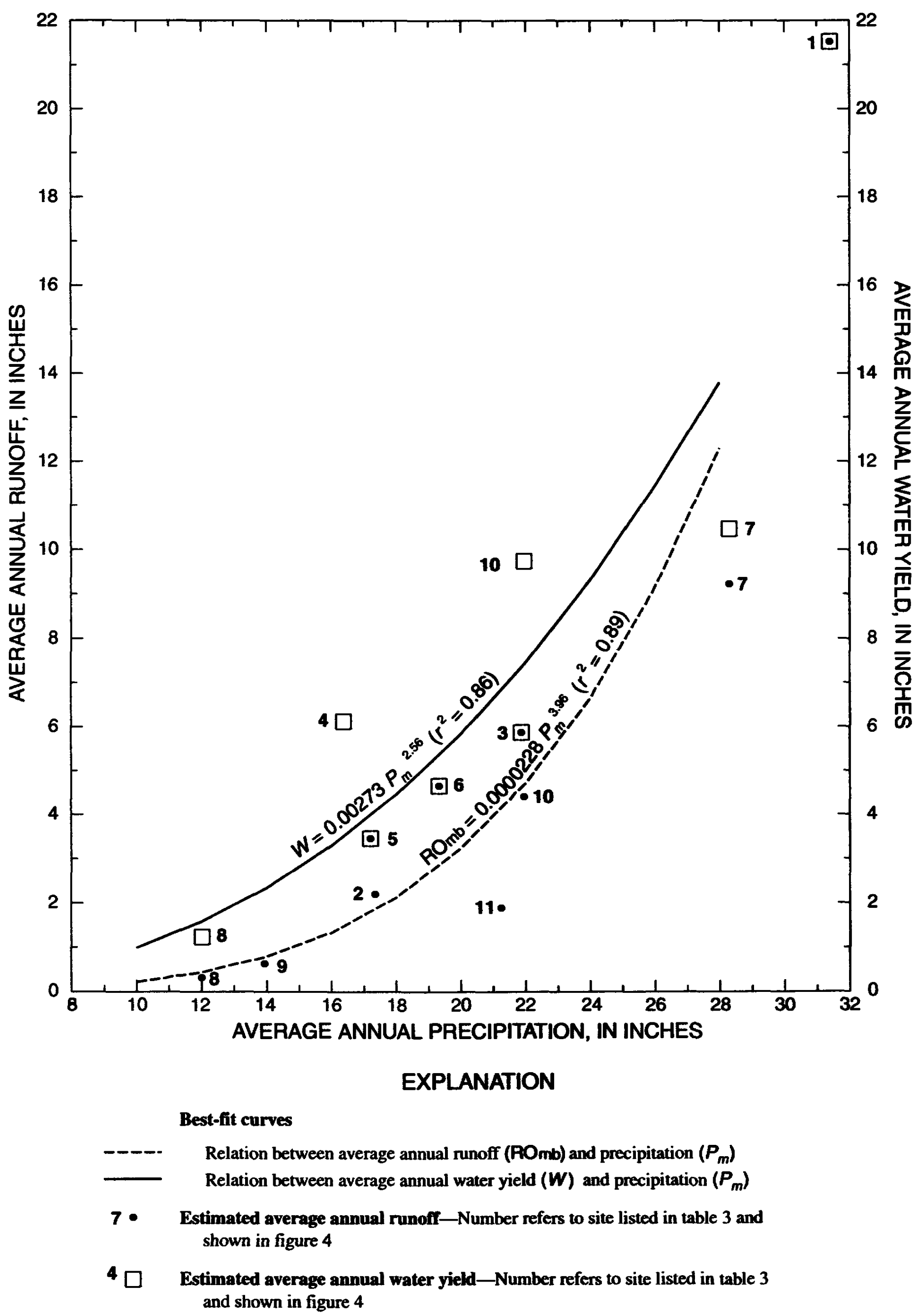


**Figure 5.** Relations among average annual runoff, water yield, and annual precipitation for selected watersheds in north-central and western Nevada. Data modified from Maurer and Berger (1997, p. 32).

Basin may originate in piedmont-slope areas, according to data presented by Eakin and Lamke (1966, p. 32). In some watersheds of Nevada, runoff is thought to occur only in the mountain block (Scott, 1971). To develop a generalized water budget, average annual runoff originating from precipitation in piedmont-slope areas was estimated to range from 0 to 10 percent of the total runoff generated in the hydrographic area (table 5). Runoff generated in valley-lowland areas was assumed to be negligible; consequently, total surface-water outflow at the hydrographic-area boundary equaled the net sum of runoff generated in the mountain block and on the piedmont slopes and the volume contributed by ground-water discharge.

**Table 4.** Simulated average annual precipitation and estimated average annual runoff, water yield, evapotranspiration, and subsurface flow in mountain-block areas in Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas, middle Humboldt River Basin, north-central Nevada

[PRISM, precipitation–elevation regressions on independent slopes model (Daly and others, 1994)]

| Hydrographic area | Average annual precipitation[1] | | Average annual runoff[2] (acre-feet per year) | Average annual water yield[3] (acre-feet per year) | Average annual evapotranspiration[4] (acre-feet per year) | Average annual subsurface flow[5] (acre-feet per year) |
|---|---|---|---|---|---|---|
| | Rate (inches per year) | Volume (acre-feet per year) | | | | |
| Pine Valley | 14.94 | 326,400 | 22,300 | 60,600 | 265,800 | 38,300 |
| Carico Lake Valley | 13.25 | 123,000 | 5,900 | 18,900 | 104,100 | 13,000 |
| Upper Reese River Valley | 14.65 | 413,900 | 26,600 | 74,400 | 339,500 | 47,800 |

[1] PRISM simulation based on 1961–90 data; rate rounded to nearest 0.01 inch per year, and volume, to nearest 100 acre-feet per year.

[2] **ROmb**, estimated from equation 1 (see text); rounded to nearest 100 acre-feet.

[3] Estimated from equation 2 (see text); rounded to nearest 100 acre-feet.

[4] **ETmb**, estimated as difference between average annual precipitation in mountain-block areas and average annual water yield; includes sublimated precipitation and soil moisture; rounded to nearest 100 acre-feet.

[5] From bedrock aquifers in mountain-block areas to basin fill underlying piedmont-slope areas and to adjacent hydrographic areas. **SFmb**, estimated as difference between average annual water yield and average annual runoff; rounded to nearest 100 acre-feet.

## Ground-Water Recharge and Subsurface Flow

Two approaches are taken for estimating ground-water recharge. The first approach is based on an empirical relation between precipitation and ground-water recharge. This recharge method estimates average annual ground-water recharge, as a bulk volume, on the basis of recent estimates of ground-water discharge by ET and subsurface outflow (Nichols, 2000). The second approach, based on mass-balance calculations among several budget components, provides an indication of the quantity of ground-water recharge contributed by individual processes within a landform. The estimates of ground-water recharge are used to evaluate the ground-water budget and individual budget components, particularly subsurface flow between aquifers underlying adjacent landforms.

### Revision of Maxey–Eakin Method

From 1947 to 1951, a method for estimating ground-water recharge was developed (Maxey and Eakin, 1949; Eakin and others, 1951) and applied in most of the water-resources reconnaissance studies throughout Nevada (see section “Previous Investigations”). The method, now called the Maxey–Eakin method (Watson and others, 1976, p. 336), estimates average annual recharge as a specific percentage of the annual precipitation in designated precipitation zones. The original percentages were derived from empirical studies of 13 basins in east-central Nevada, by applying trial-and-error methods until the estimates of recharge equaled the estimates of natural ground-water discharge by ET (Maxey and Eakin, 1949, p. 40–41). Ground-water ET rates used in the development of the Maxey–Eakin method were obtained from ET-tank studies by Lee (1912) in Owens Valley, Calif., and White (1932) in the Escalante Desert, Utah. More-recent ET studies using micrometeorological methods, along with the availability of digital precipitation data, provide the basis for revising the Maxey–Eakin method.

Estimates of ground-water ET in valley-lowland areas were made in 16 basins in eastern Nevada as part of an evaluation of regional ground-water flow systems by Nichols (2000). His methods are described briefly in the section “Discharge by Evapotranspiration.” All but one of the 16 basins were used to revise the Maxey–Eakin recharge method. They were selected because all or most of the ground-water discharge was by ET or because independent estimates of ground-water outflow were available. The basins were assumed to be in hydrologic equilibrium, where ground-water inflow equals ground-water outflow.

**Table 5.** Estimated average annual runoff, evapotranspiration, and subsurface flow from piedmont-slope areas in Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas, middle Humboldt River Basin, north-central Nevada

[All values rounded to nearest 100 acre-feet per year. Bold symbols (in footnotes) correspond to those used in table 1 and fig. 3. PRISM, precipitation–elevation regressions on independent slopes model (Daly and others, 1994); RAWS, remote automatic weather station; TM, Thematic Mapper]

| Hydrographic area | Average annual runoff[1] (acre-feet per year) | Average annual evapotranspiration[2] (acre-feet per year) | Average annual evapotranspiration from vegetated flood plains[3] (acre-feet per year) | Average annual subsurface flow[4] (acre-feet per year) |
|---|---|---|---|---|
| Pine Valley | 0–2,500 | 306,300–333,800 | 3,200–4,100 | 52,500–79,300 |
| Carico Lake Valley | 0–700 | 105,400–107,600 | 1,100–1,200 | 21,700–23,400 |
| Upper Reese River Valley | 0–3,000 | 308,100–354,500 | 10,900–11,700 | 71,400–110,000 |

[1] **ROps**, estimated assuming runoff generated in piedmont-slope areas represents 0 to 10 percent of total annual runoff generated in hydrographic area.

[2] **ETps**, evapotranspiration of precipitation and soil moisture estimated as ranging from 10.5 inches per year, which is average rate derived by applying Penman–Monteith equation (Monteith, 1965) to 1987–95 RAWS data, to total precipitation on piedmont slope as simulated by PRISM.

[3] **ETrps**, estimated from Landsat TM data (Nichols, 2000).

[4] From basin-fill aquifer beneath piedmont slope to basin fill in valley lowland (**SFps**), estimated as sum of (1) subsurface flow from bedrock aquifer in mountain block that remains in hydrographic area (**SFmb**), (2) difference between sum of mountain-block runoff (**ROmb**) plus piedmont-slope runoff (**ROps**) and surface-water outflow at hydrographic-area boundary (**SWtot**), (3) difference between precipitation on piedmont slope (**Pps**) and sum of average annual runoff (**ROps**) and average annual evapotranspiration, including that from vegetated flood plains (**ETps** and **ETrps**), and (4) subsurface inflow from adjacent hydrographic areas (**SFin**).

For each basin, PRISM-simulated average annual precipitation values were distributed into four precipitation zones: at least 8 but less than 12 in, at least 12 but less than 16 in, at least 16 but less than 20 in, and at least 20 but less than 34 in. Multiple-regression analysis was used to develop recharge coefficients to describe the relation between precipitation (as independent variable) and ground-water recharge (as dependent variable) in each zone. The regression equation that best approximates this relation (Nichols, 2000) can be written as

$$R_{gw} = 0.008(P_a) + 0.130(P_b) + 0.144(P_c) + 0.158(P_d), \quad (3)$$

where $R_{gw}$ is average annual ground-water recharge based on estimates of ground-water discharge, in acre-feet per year;

$P_a$ is average annual volume of precipitation in hydrographic area in zone of at least 8 but less than 12 in, in acre-feet per year;

$P_b$ is average annual volume of precipitation in hydrographic area in zone of at least 12 but less than 16 in, in acre-feet per year;

$P_c$ is average annual volume of precipitation in hydrographic area in zone of at least 16 but less than 20 in, in acre-feet per year; and

$P_d$ is average annual volume of precipitation in hydrographic area in zone of at least 20 but less than 34 in, in acre-feet per year.

Similar to the original Maxey–Eakin method, this revised relation (eq. 3) assumes ground-water recharge is negligible if annual precipitation is less than 8 in. The recharge coefficients derived by Nichols (2000) for estimating average annual ground-water recharge are applicable only to the distribution of precipitation simulated by PRISM and acquired from G.H. Taylor (Oregon Climate Service, Oregon State University, written commun., 1997).

### Mass-Balance Approach

A mass-balance calculation for estimating ground-water recharge yields a budget showing the sources from which ground water is derived. Total ground-water inflow to a basin consists of the sum of recharge derived within each landform and net inflow from adjacent areas that ultimately reaches the saturated basin fill.

Ground-water recharge to bedrock aquifers in the mountain block is from direct infiltration of precipitation or indirect infiltration of runoff. For this investigation, ground-water recharge in mountain-block areas is determined as the residual between estimates of runoff (eq. 1) and water yield (eq. 2).

Beneath piedmont-slope areas, ground-water inflow to the basin-fill aquifer consists of (1) subsurface flow from the mountain block (determined as the residual between estimates of runoff and water yield), (2) the quantity of runoff that originates in the mountain block and combines with runoff from the piedmont slope and subsequently infiltrates, (3) a portion of the precipitation that falls on the piedmont slope and infiltrates, and (4) subsurface inflow or surface-water inflow that subsequently infiltrates from adjacent hydrographic areas.

Ground-water recharge from infiltration of runoff is estimated as the difference between the sum of mountain-block plus piedmont-slope runoff and the total volume of runoff that makes up the quantity of surface water leaving the basin at the hydrographic-area boundary (SWtot, fig. 3). This calculation does not account for losses from ET and direct evaporation along stream channels and therefore represents a maximum quantity of ground-water recharge. Runoff generated on valley-lowland areas is assumed to be minor because of the small amount of precipitation that falls on those areas. The portion of precipitation that recharges the basin-fill aquifer beneath piedmont slopes is estimated as the difference between precipitation and the sum of runoff plus all ET losses from piedmont slopes. This calculation also represents a maximum quantity of ground-water recharge.

Ground water beneath the valley lowlands consists of subsurface flow from the basin-fill aquifers underlying the piedmont slopes, subsurface inflow and infiltration of surface water from adjacent areas, and ground-water recharge that takes place on the valley lowlands from infiltration of precipitation and runoff, which are assumed to be a minor amount.

Although the quantity of subsurface flow that moves across hydrographic-area boundaries is generally unknown, it could represent a significant component of the water budget. Determination of interbasin flow is at best difficult and should not be attempted without supporting hydrogeologic data. Results from a study by Plume and Ponce (1999) provided most of the information needed for estimating subsurface flow by using Darcy's law. As modified from Heath (1989, p. 12), Darcy's law can be expressed as

$$Q = 0.0084\,K\,A(dh/dl), \qquad (4)$$

where $Q$ is quantity of subsurface flow, in acre-feet per year;
$K$ is hydraulic conductivity, in feet per day;
$A$ is saturated cross-sectional area through which flow occurs, perpendicular to the direction of flow, in square feet;
$dh/dl$ is hydraulic gradient, in feet per feet; and
0.0084 is factor to convert cubic feet per day into acre-feet per year.

A value of 10 ft/d was used to represent an average hydraulic-conductivity value for basin-fill sediments (Plume and Ponce, 1999). Cross-sectional areas of basin fill beneath hydrographic-area boundaries were estimated on the basis of interpretation of gravity data (D.A. Ponce, U.S. Geological Survey, written commun., 1997). Water-level data collected in the spring of 1996 (Plume and Ponce, 1999) were used to estimate hydraulic gradients.

## Discharge by Evapotranspiration

Currently, no data to determine directly the loss of water by ET and sublimation are available for mountain-block areas of the Humboldt River Basin. For this investigation, ET was estimated as the difference between average annual precipitation that falls in mountain-block areas and the estimated average annual water yield (eq. 2).

Average annual ET in piedmont-slope areas was derived by applying the Penman–Monteith equation (Monteith, 1965) to available climatic data collected at remote automatic weather stations (RAWS). RAWS data used in the analyses were collected at 14 sites in and near the Humboldt River Basin; the sites are away from urban influences and generally are in the lower parts of piedmont-slope areas, at altitudes from 4,550 to 6,800 ft. The period of record for the RAWS data is 1990–95; several stations have records that were continuous since 1987. The Penman–Monteith equation uses energy balances and transport resistances related to plant canopy to estimate actual ET rates. Measurements of net radiation and aerodynamic and canopy resistances are not made at RAWS, but because they are required to solve the Penman–Monteith equation, several assumptions had to be made for these variables.

Net radiation was estimated from calculations of solar radiation above each RAWS and correlated to a derived relation between solar and measured net radiation (based on 1990 data) in Toano Draw, about 70 mi northeast of Elko (M.J. Johnson, U.S. Geological Survey, written commun., 1997). The derived relation is assumed to be similar to that for the middle Humboldt River Basin for similar periods of record, although it does not take into account variability in local climate conditions.

Values for aerodynamic and canopy-resistance terms were estimated, in part, on the basis of previous work in eastern Washington (S.A. Tomlinson, U.S. Geological Survey, written commun., 1993; Tomlinson, 1997) and northeastern Nevada (M.J. Johnson, U.S. Geological Survey, written commun., 1997). Reasonable heights of rangeland vegetation were used to estimate a range of aerodynamic-resistance terms for use in the Penman–Monteith equation. Values of canopy resistance for the RAWS are unknown and are estimated from other studies (S.A. Tomlinson, U.S. Geological Survey, written commun., 1993; Tomlinson, 1997; M.J. Johnson, U.S. Geological Survey, written commun., 1997).

Annual ET, determined from the application of the Penman–Monteith equation to the RAWS data, averages about 10.5 in/yr and ranges from 9 to 12 in/yr. The high end of the range is similar to results obtained by Plume (1995, p. 55). Average annual precipitation at the RAWS over the period of record 1987–95 is generally below the average annual precipitation during the 30-year reference period 1961–90. Average annual potential ET estimated by Shevenell (1996, p. 29), for areas of piedmont slopes ranged from about 12 in/yr to nearly 48 in/yr. Whether the rates obtained from the Penman–Monteith equation result from below-average precipitation or are a function of the assumptions used in the analyses is uncertain. Regardless, this approach and the use of available RAWS data provide an objective method for estimating average annual ET in these areas of a basin. To develop a water budget, the average ET rate of 10.5 in/yr was used as a minimum ET rate and the annual quantity of precipitation that falls on piedmont-slope areas was used as a maximum rate.

In valley-lowland areas, total ET is assumed equal to the sum of average annual precipitation that falls within the area plus the consumptive use of ground water by phreatophyte vegetation. A method for estimating ground-water ET at regional scales was developed recently by Nichols (2000) and was applied to the valley lowlands of the study area to estimate average annual ground-water ET.

The method developed by Nichols (2000) resulted from the difficulty of and need for transferring site-specific ET values, estimated by micrometeorological methods, to remote rangeland areas. The approach taken to accomplish this task involved two steps. First, energy budgets of ground-water ET from native rangelands and bare soils were determined at a number of sites in Nevada and California (Duell, 1990; Nichols, 1994; Nichols and others, 1997) and were used to develop a functional relation between plant cover and ground-water ET. Not only was a strong correlation found between plant cover and ground-water ET, but plant cover was shown to be a major factor in determining the rate of ground-water ET (Nichols, 2000). Plant cover is a function of plant density and the total green-leaf area of plants, which can be determined from remotely sensed data. Therefore the second step in this approach was to use remote-sensing data to estimate plant cover and hence regional ground-water ET.

Different vegetation indices have been developed from remotely sensed data, particularly Landsat TM satellite data, to enhance vegetation signals and to describe vegetation quantitatively. A modified soil-adjusted vegetation index (MSAVI), proposed by Qi and others (1994), was used to describe plant cover in areas of sparse vegetation. MSAVI values were derived from the Landsat TM data and converted to plant-cover values, at a cell resolution of about 90 by 90 ft, by using relations described by Nichols (2000). Plant-cover values then were assigned to zones corresponding to bare soil or to percentages of plant cover (less than 10, at least 10 but less than 20, at least 20 but less than 35, at least 35 but less than 50, and at least 50). For the valley-lowland areas, these plant-cover zones were color coded and plotted on 1:24,000-scale maps. These maps were used to guide the field mapping of phreatophyte vegetation during the summer of 1997 and to verify the boundaries between phreatophytes and other rangeland vegetation. An average rate of ground-water ET then was calculated for cells in each zone as a function of a weighted-mean plant cover and summarized to determine annual ground-water ET from the valley-lowland areas (table 6).

Each plant-cover value and the corresponding rate of ground-water ET represents an area of about 8,100 $ft^2$, which is the resolution of the MSAVI data. The Landsat TM data used to derive the MSAVI values were collected in June 1989 and June 1995. The average annual ET determined for the valley lowlands in each basin was less in 1989 than in 1995. Although the total area of phreatophyte vegetation was essentially the same for the two periods, the greater ET in 1995 was due to an increase in plant cover in the at-least-

**Table 6.** Average annual evapotranspiration rates from areas of bare soil or phreatophyte vegetation, evaporation rates from open water, and annual volume of ground-water evapotranspiration from valley lowlands, 1989 and 1995, in Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas, middle Humboldt River Basin, north-central Nevada

[ET, evapotranspiration; MSAVI, modified soil-adjusted vegetation index; TM, Thematic Mapper]

| Zone | Area[1] (acres) | | Average annual evapotranspiration[2] Rate (feet per year) | | Average annual evapotranspiration[2] Volume (acre-feet per year) | |
|---|---|---|---|---|---|---|
| | 1989 | 1995 | 1989 | 1995 | 1989 | 1995 |
| **Pine Valley Hydrographic Area** | | | | | | |
| Bare soil | 170 | 70 | 0.15 | 0.15 | 30 | 10 |
| Plant cover[3]: | | | | | | |
| Less than 10 percent | 15,360 | 5,500 | .50 | .62 | 7,710 | 3,380 |
| At least 10 but less than 20 percent | 9,450 | 17,530 | 1.35 | 1.36 | 12,720 | 23,810 |
| At least 20 but less than 35 percent | 3,610 | 5,190 | 2.17 | 2.17 | 7,820 | 11,280 |
| At least 35 but less than 50 percent | 1,990 | 3,130 | 2.55 | 2.55 | 5,080 | 7,980 |
| At least 50 percent | 2,320 | 1,470 | 2.64 | 2.64 | 6,120 | 3,870 |
| Estimated total annual ground-water ET[4] | | | | | 39,500 | 50,300 |
| Open-water bodies | 16 | 15 | 4.2 | 4.2 | 70 | 60 |
| **Carico Lake Valley Hydrographic Area** | | | | | | |
| Bare soil | 520 | 160 | 0.15 | 0.15 | 80 | 20 |
| Plant cover[3]: | | | | | | |
| Less than 10 percent | 7,870 | 4,680 | .31 | .57 | 2,460 | 2,660 |
| At least 10 but less than 20 percent | 820 | 4,120 | 1.27 | 1.25 | 1,040 | 5,150 |
| At least 20 but less than 35 percent | 260 | 430 | 2.19 | 2.14 | 570 | 920 |
| At least 35 but less than 50 percent | 190 | 140 | 2.54 | 2.55 | 480 | 360 |
| At least 50 percent | 80 | 190 | 2.64 | 2.64 | 210 | 500 |
| Estimated total annual ground-water ET[4] | | | | | 4,800 | 9,600 |
| Open-water bodies | 0 | 9 | 4.2 | 4.2 | 0 | 40 |
| **Upper Reese River Valley Hydrographic Area** | | | | | | |
| Bare soil | 220 | 710 | 0.15 | 0.15 | 30 | 110 |
| Plant cover[3]: | | | | | | |
| Less than 10 percent | 14,890 | 9,900 | .45 | .47 | 6,630 | 4,670 |
| At least 10 but less than 20 percent | 10,420 | 16,390 | 1.40 | 1.36 | 14,600 | 22,340 |
| At least 20 but less than 35 percent | 6,420 | 5,870 | 2.18 | 2.17 | 13,980 | 12,760 |
| At least 35 but less than 50 percent | 2,510 | 1,600 | 2.54 | 2.53 | 6,380 | 4,050 |
| At least 50 percent | 830 | 690 | 2.64 | 2.64 | 2,190 | 1,820 |
| Estimated total annual ground-water ET[4] | | | | | 43,800 | 45,800 |
| Open-water bodies | 4 | 150 | 4.2 | 4.2 | 20 | 630 |

[1] Derived from MSAVI from 1989 and 1995 Landsat TM images and from field measurements. Bare-soil and plant-cover values rounded to nearest 10 acres.
[2] Includes both ground-water ET (Nichols, 2000) and surface-water evaporation. For each zone, rate rounded to nearest 0.01 foot, and annual volume to nearest 10 acre-feet.
[3] Values are weighted means.
[4] **ETgw** (table 1 and fig. 3). Rounded to nearest 100 acre-feet.

10-but-less-than-20-percent zone and a corresponding decrease in plant cover in the less-than-10-percent zone (fig. 6). This change in the plant-cover distribution probably was a function of precipitation. Annual precipitation in the study area during 1989 was less than 90 percent of the average during the reference period 1961–90, but in 1995 it was more than 120 percent of the average.

ET from vegetated flood plains in piedmont-slope areas (table 5) also was estimated from plant-cover values derived from Landsat-TM-based MSAVI data. The methods using MSAVI data may not be entirely appropriate for estimating ET in these areas because of the smaller area covered by vegetation as compared to the areal extent of phreatophyte vegetation in the valley lowlands. However, the method does provide a lower ET limit for vegetated flood plains (Nichols, 2000). The consumptive use of water in vegetated flood plains in the piedmont-slope areas is assumed to represent ground-water discharge.

Evaporation from open-water bodies such as shallow lakes, including ephemeral lakes in playas, was estimated on the basis of pan-evaporation measurements made at Beowawe and Rye Patch Dam in the Humboldt River Basin and at Ruby Lake in northeastern Nevada (fig. 1). Average annual pan-evaporation measurements from these three sites ranged from 3.9 to 4.6 ft (Shevenell, 1996, p. 5). A rate of 4.2 ft/yr was used for average annual evaporation from open-water bodies in the water budget for the valley lowlands. Areas of open-water bodies in the study area were determined from Landsat TM data collected in June 1989 and June 1995. Total surface area of open water in the selected basins in 1989 was about 150 acres (about 89 percent) less than the total area in 1995 (table 6).

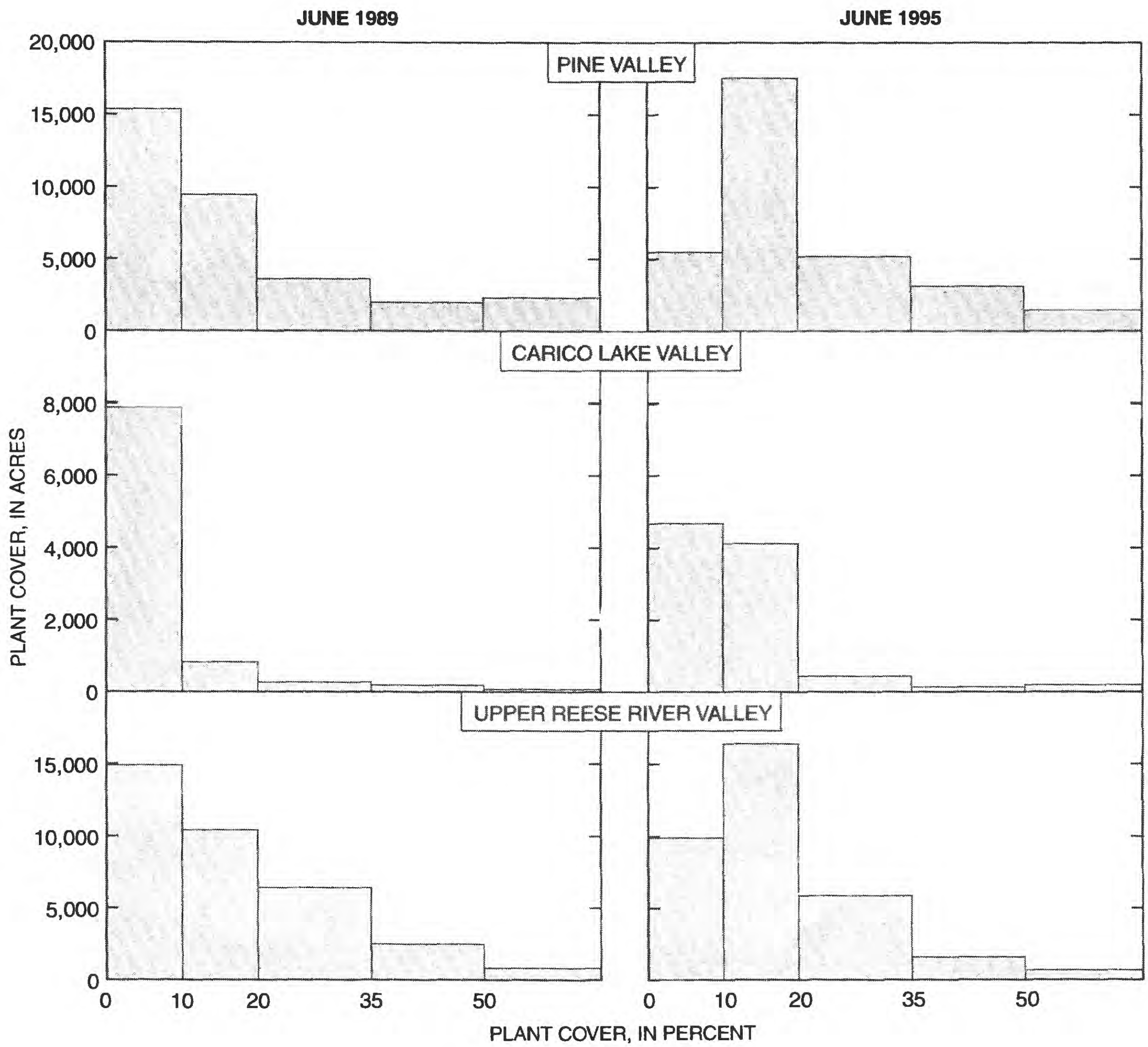


**Figure 6.** Distribution of plant cover in Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas, middle Humboldt River Basin, north-central Nevada. Derived from Landsat Thematic Mapper data for June 1989 and June 1995.

## WATER-BUDGET ESTIMATES

The preceding methods applied to Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas resulted in water budgets representing average annual conditions over the reference period 1961–90. Several ground-water components, derived in part from the water budgets, are compared to similar components estimated by previous investigators. Comparison between the distribution of precipitation used in previous investigations (Hardman and Mason, 1949) and PRISM-simulated precipitation is presented in table 7.

### Pine Valley Hydrographic Area

For average conditions, annual inflow to Pine Valley (fig. 7) is derived entirely from precipitation within the hydrographic area (table 8). Nearly equal amounts of annual precipitation are simulated by PRISM (table 2) for areas of the mountain block (326,400 acre-ft/yr, or 47 percent of the total) and piedmont slope (333,800 acre-ft/yr, or 49 percent of the total). Annual precipitation simulated for valley-lowland areas (27,800 acre-ft/yr) represents only about 4 percent of the total. Estimates of annual precipitation based on the Hardman precipitation map (Hardman and Mason, 1949; Eakin, 1961, p. 20; Eakin and Lamke, 1966, p. 58) indicate that about 61 percent of the annual precipitation occurs in the mountain block and only about 39 percent occurs in the piedmont-slope and valley-lowland areas (table 7). Although only 34,000 acre-ft/yr more precipitation is simulated by PRISM than estimated from the Hardman map, the relative distribution between the two precipitation maps is significantly different.

Outflow from Pine Valley is dominated by ET, which makes up about 97 percent of the annual total (table 8). Other outflow components include surface-water outflow by Pine Creek at the north boundary of the hydrographic area and subsurface outflow to adjacent hydrographic areas. On the basis of 12 years of continuous streamflow data (1947–58), adjusted to the long-term record (1922–95) of Martin Creek in the northwestern part of the Humboldt River Basin (fig. 1), an estimated 8,100 acre-ft of surface water discharges from Pine Valley to the Humboldt River annually. Hydrograph-separation analysis (Eakin, 1961, p. 10; Rorabaugh, 1964) suggests that about 5,000 acre-ft of the annual surface-water outflow is contributed by ground water (table 9).

Estimates of subsurface outflow from Pine Valley were made indirectly by previous investigators. Eakin (1961, p. 24), using a form of Darcy's law, estimated that less than 300 acre-ft/yr of ground water leaves Pine Valley beneath the north boundary of the hydrographic area. The estimate was made for young basin-fill sediments. Additional ground water may flow through older basin fill and fractured volcanic rocks along the north boundary. Interbasin flow from Garden Valley (fig. 7), a subbasin in the southeastern part of Pine Valley, eastward to Diamond Valley (outside the Humboldt River Basin) was indicated by Eakin (1962, p. 21)

**Table 7.** Comparison of Hardman and PRISM-simulated average annual precipitation for Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas, middle Humboldt River Basin, north-central Nevada

[PRISM, precipitation–elevation regressions on independent slopes model (Daly and others, 1994)]

| Hydrographic area | Average annual precipitation (acre-feet per year) | | | | | |
|---|---|---|---|---|---|---|
| | Mountain block | | Piedmont slope and valley lowland, combined[3] | | Hydrographic-area totals[4] | |
| | Hardman[1] | PRISM[2] | Hardman[1] | PRISM[2] | Hardman | PRISM |
| Pine Valley | 399,000 | 326,400 | 255,000 | 361,600 | 654,000 | 688,000 |
| Carico Lake Valley | [5]87,000 | 123,000 | [5]74,000 | 115,700 | 161,000 | 239,000 |
| Upper Reese River Valley | 374,000 | 413,900 | 328,000 | 389,500 | 702,000 | 803,000 |

[1] Hardman and Mason (1949), Eakin (1961), Eakin and Lamke (1966), Everett and Rush (1966). Values rounded to nearest 1,000 acre-feet per year.

[2] Simulated on basis of 1961–90 data (see table 2). Values rounded to nearest 100 acre-feet per year.

[3] Combined for comparison with results from previous investigations.

[4] Rounded to nearest 1,000 acre-feet per year.

[5] Assumes boundary of mountain block and piedmont slope can be represented by 6,000-foot altitude contour.

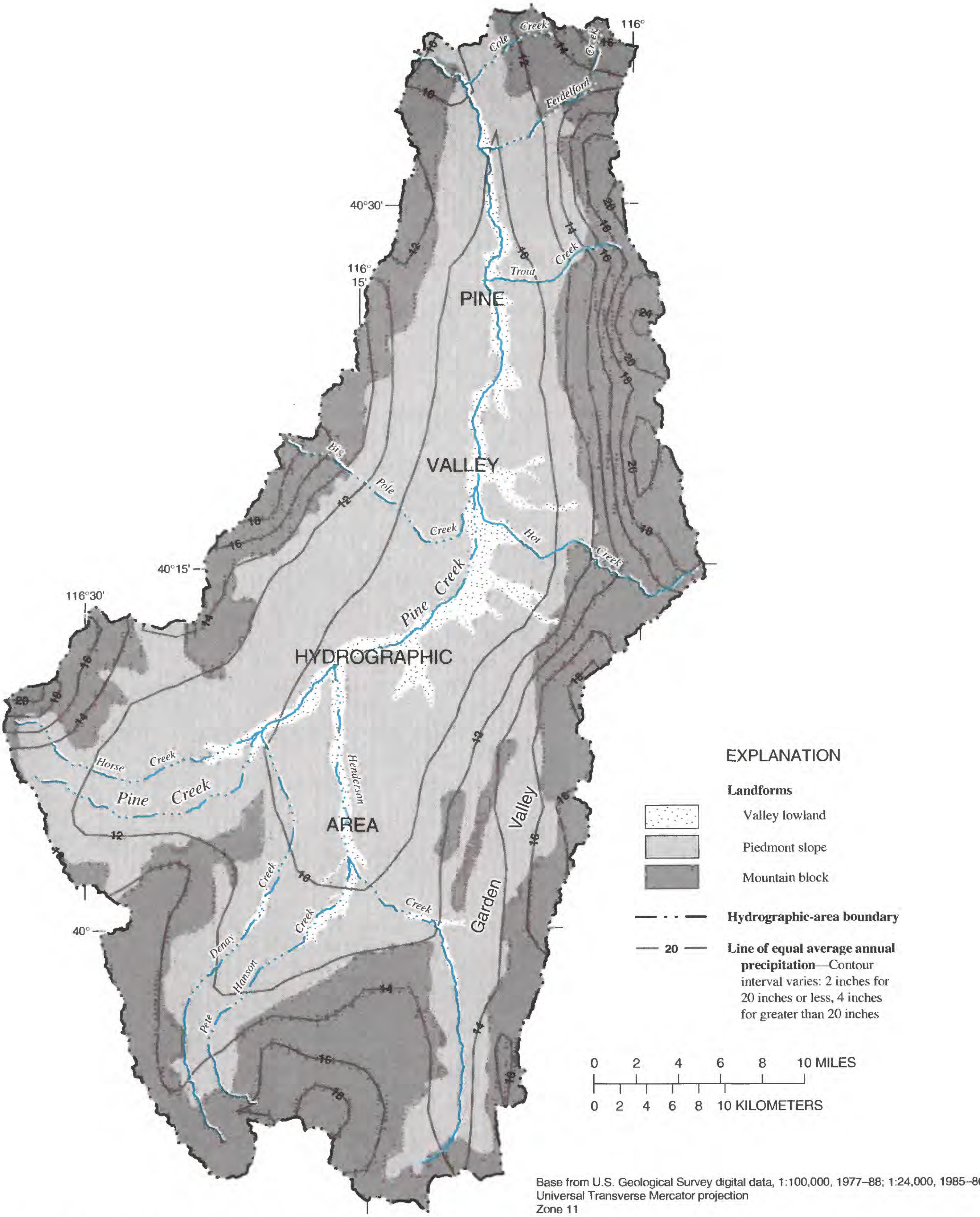


**Figure 7.** Distribution of precipitation and landforms in Pine Valley Hydrographic Area, middle Humboldt River Basin, north-central Nevada, 1961–90. Average annual-precipitation data derived from precipitation–elevation regressions on independent slopes model, or PRISM (Daly and others, 1994).

**Table 8.** Average annual water budgets for Pine Valley Hydrographic Area, middle Humboldt River Basin, north-central Nevada

[Bold symbols in parentheses correspond to those used in table 1 and fig. 3. Values for separate flow components rounded to nearest 100 acre-feet per year; totals rounded to nearest 1,000 acre-feet per year. ET, evapotranspiration. —, no data or not applicable]

| Water-budget components | Inflow (acre-feet per year) | Outflow (acre-feet per year) |
|---|---|---|
| **Mountain-block water budget** | | |
| Inflow: | | |
| Precipitation on mountain block (**Pmb**)[1] | 326,400 | — |
| Subsurface flow from adjacent hydrographic areas to bedrock aquifer (**SFin**) | — | — |
| Outflow: | | |
| Runoff from mountain block to piedmont slope (**ROmb**)[2] | — | 22,300 |
| Subsurface flow from bedrock aquifer in mountain block to basin-fill aquifer beneath piedmont slope (**SFmb**)[2] | — | 38,300 |
| Subsurface flow from mountain block to adjacent hydrographic areas (**SFout**) | — | — |
| ET and sublimation of precipitation and soil moisture and ET from riparian vegetation (**ETmb**)[2] | — | 265,800 |
| Total | 326,000 | 326,000 |
| **Piedmont-slope water budget** | | |
| Inflow: | | |
| Precipitation on piedmont slope (**Pps**)[1] | 333,800 | — |
| Runoff from mountain block to piedmont slope (**ROmb**)[2] | 22,300 | — |
| Surface-water flow from adjacent hydrographic areas (**SWin**) | 0 | — |
| Subsurface flow from bedrock aquifer in mountain block to basin-fill aquifer beneath piedmont slope (**SFmb**)[2] | 38,300 | — |
| Subsurface flow from adjacent hydrographic areas (**SFin**) | — | — |
| Outflow: | | |
| Runoff generated on piedmont slope (**ROps**)[3] | — | 0–2,500 |
| Subsurface flow from basin-fill aquifer beneath piedmont slope to basin-fill aquifer beneath valley lowland (**SFps**)[3] | — | 52,500–79,300 |
| Subsurface flow from basin-fill aquifer beneath piedmont slope to adjacent hydrographic areas (**SFout**) | — | — |
| ET and sublimation of precipitation and soil moisture (**ETps**)[3] | — | 306,300–333,800 |
| ET from vegetated flood plains (**ETrps**)[3] | — | 3,200–4,100 |
| Total | 394,000 | 362,000–420,000 |
| **Valley-lowland water budget** | | |
| Inflow: | | |
| Precipitation on valley lowland (**Pvl**)[1] | 27,800 | — |
| Runoff from piedmont slope to valley lowland (**ROps**)[3] | 0–2,500 | — |
| Surface-water flow from adjacent hydrographic areas (**SWin**) | 0 | — |
| Subsurface flow from basin-fill aquifer beneath piedmont slope to basin-fill aquifer beneath valley lowland (**SFps**)[3] | 52,500–79,300 | — |
| Subsurface flow from adjacent hydrographic areas (**SFin**) | — | — |
| Outflow: | | |
| Runoff generated on valley lowland (**ROvl**) | — | 0 |
| Subsurface flow from basin-fill aquifer beneath valley lowland to adjacent hydrographic areas (**SFvl**) | — | [4]300 |
| ET of precipitation and soil moisture (**ETvl**) | — | 27,800 |
| ET of ground water from valley lowland (**ETgw**)[5] | — | 39,500–50,300 |
| Evaporation from open-water bodies (**Esw**) | — | 60–70 |
| Total | 80,000–110,000 | 68,000–78,000 |
| **Pine Valley Hydrographic Area water budget** | | |
| Inflow: | | |
| Precipitation in Pine Valley Hydrographic Area (**Pmb, Pps, Pvl**) | 688,000 | — |
| Surface-water flow from adjacent hydrographic areas (**SWin**) | 0 | — |
| Subsurface flow from adjacent hydrographic areas (**SFin**) | 0 | — |
| Outflow: | | |
| Surface-water flow from Pine Valley Hydrographic Area at hydrographic-area boundary (**SWtot**) | — | [6]8,100 |
| Subsurface flow from Pine Valley Hydrographic Area at hydrographic-area boundary (**SFtot**) | — | [7]9,300 |
| ET and sublimation from Pine Valley Hydrographic Area (**ETmb, ETps, ETrps, ETvl, ETgw, Esw**) | — | 642,700–681,900 |
| Total | 688,000 | 660,000–699,000 |

[1] See table 2.

[2] See table 4.

[3] See table 5.

[4] Eakin (1961, p. 24).

[5] See table 6.

[6] Derived from continuous-stage-recording gage on Pine Creek (1947–58) and adjusted to long-term record at Martin Creek (1922–95).

[7] Combined values: 9,000 acre-feet per year estimated by Harrill (1968, p. 26) to exit from Garden Valley, subbasin in southeastern part of Pine Valley Hydrographic Area, and additional 300 acre-feet per year estimated by Eakin (1961, p. 24) to exit Pine Valley beneath north hydrographic-area boundary. Because assignment to landform is uncertain, this subsurface flow is accounted for only in overall hydrographic-area budget.

and subsequently estimated by Harrill (1968, p. 26) to be about 9,000 acre-ft/yr. Because it is uncertain to which landform this estimate corresponds, it is accounted for only in the overall hydrographic-area budget for Pine Valley and in the ground-water budget (tables 7 and 9).

The average annual inflow to the ground-water system in Pine Valley, estimated from a mass-balance calculation, ranges from 52,000 to 79,000 acre-ft (table 9). The recharge estimate derived by the revised Maxey–Eakin method (eq. 3) falls well within this range. A previous estimate of ground-water recharge to Pine Valley by Eakin (1961, p. 20) may be as much as 33,000 acre-ft/yr less than estimated by the two recharge methods.

Ground-water recharge from precipitation that falls on piedmont-slope areas of Pine Valley may be as much as 24,300 acre-ft/yr (table 9). This indicates that part of the annual precipitation on piedmont-slope areas may infiltrate directly to the ground-water reservoir or may recharge the reservoir after an intermediate step as runoff. The water-balance calculation suggests that large alluvial areas designated as piedmont slopes in Pine Valley may contribute more to the ground-water reservoir than previously thought.

The estimated range in ground-water ET, derived from micrometeorological methods using two MSAVI data sets, is more than twice Eakin's (1961, p. 22) estimate. Although the total area of phreatophyte vegetation mapped from remote-sensing data is similar to the area that Eakin mapped, ET rates derived by Nichols' (2000) methods are as much as 2.0 ft/yr greater for native vegetation than those derived from Eakin's (1961, p. 22) data.

## Carico Lake Valley Hydrographic Area

Most of the annual inflow to the Carico Lake Valley Hydrographic Area (fig. 8) is from precipitation (table 10). PRISM simulates about 50 percent more annual precipitation than estimated from the Hardman precipitation map (table 7), derived from data presented by Everett and Rush (1966, p. 14). More than half of the difference occurs in the combined areas of the piedmont slope and valley lowlands.

Additional inflow, as subsurface flow from Upper Reese River Valley Hydrographic Area, was estimated on the basis of 1996 field data and the application of Darcy's law (eq. 4). The low topographic divide that makes up the hydrographic-area boundary between Carico Lake Valley and Upper Reese River Valley Hydrographic Areas is underlain by nearly 2,000 ft of alluvial deposits and Tertiary volcanic rocks (D.A. Ponce, U.S. Geological Survey, written commun., 1997). Ground-water levels in the northern part of Upper Reese River Valley are generally 50 ft higher than levels in the southwestern part of Carico Lake Valley. Water-level data indicate a hydraulic gradient of about 10.6 ft/mi across the boundary. The calculation of ground-water flow using Darcy's law assumes a uniform hydraulic gradient over the cross-sectional area. About 3,000 acre-ft/yr of subsurface flow was estimated to enter Carico Lake Valley on the basis of the preceding hydrogeologic conditions. Whether this estimate represents an average annual value in part depends on how closely the hydraulic gradient between the two areas reflects an average annual gradient and how close the assumed hydraulic conductivity of 10 ft/d is to the average value for the saturated hydrogeologic units beneath the boundary.

The overall water budget for Carico Lake Valley Hydrographic Area is affected by an imbalance in the water budget for the valley-lowlands area, where annual inflow is almost twice the annual outflow (table 10). The imbalance may be due, in part, to an overestimation of the subsurface-flow component from mountain-block areas. Nearly 70 percent of the ground-water flow that ultimately reaches the aquifer underlying the valley lowlands was assumed to be recharged in the mountain blocks within the hydrographic area (table 11). Although not estimated in this study, subsurface flow to adjacent hydrographic areas may account for some of the imbalance in the valley-lowlands water budget. Everett and Rush (1966, p. 17) estimated that less than 300 acre-ft/yr leaves Carico Lake Valley as subsurface flow to Crescent Valley Hydrographic Area (table 10, fig. 1). Additional analysis is needed to better quantify this subsurface-flow component.

**Table 9.** Average annual ground-water budget for Pine Valley Hydrographic Area, middle Humboldt River Basin, north-central Nevada

[Values for separate flow components and subtotals rounded to nearest 100 acre-feet per year; totals rounded to nearest 1,000 acre-feet per year. Bold symbols (in footnotes) correspond to those used in table 1 and fig. 3. —, no data or not applicable]

| Ground-water-budget component | Estimated flow (acre-feet per year) | | |
|---|---|---|---|
| | By mass-balance calculation, this investigation | By revised recharge method, this investigation | By other methods, previous investigations |
| **Inflow** | | | |
| Ground-water recharge: | | | |
| To mountain block | [1]38,300 | — | [2]14,000 |
| To piedmont slope, from runoff | [3]14,200–16,700 | — | — |
| To piedmont slope, from precipitation | [4]0–24,300 | — | — |
| To valley lowland | Negligible | — | — |
| Subtotal ground-water recharge | 52,500–79,300 | [5]65,900 | [6]46,000 |
| Subsurface inflow from adjacent hydrographic areas | 0 | — | [2]0 |
| Total inflow | 52,000–79,000 | 66,000 | 46,000 |
| **Outflow** | | | |
| Ground-water evapotranspiration in valley lowland | [7]39,500–50,300 | — | [8]19,100 |
| Ground-water discharge from vegetated flood plains | [9]3,200–4,100 | — | — |
| Ground-water discharge to Pine Creek in valley lowland | [10]5,000 | — | [11]5,000 |
| Subsurface outflow to adjacent hydrographic areas | [12]9,300 | — | [12]9,300 |
| Total outflow | 57,000–69,000 | — | 33,000 |

[1] See table 4.
[2] Eakin and Lamke (1966, p. 58).
[3] Estimated as difference between sum of mountain-block runoff (**ROmb**; table 4) plus piedmont-slope runoff (**ROps**; table 5) and total surface-water outflow at hydrographic-area boundary (**SWtot**; table 8).
[4] Estimated as difference between piedmont-slope precipitation (**Pps**; table 2) and sum of piedmont-slope runoff (**ROps**; table 5) plus evapotranspiration components (**ETps** and **ETrps**; table 5).
[5] Estimated from equation 3 (see text).
[6] Eakin (1961, p. 20).
[7] See table 6.
[8] Derived from Eakin (1961, p. 22); Eakin applied correction of 2,000 acre-feet per year for below-average conditions.
[9] See table 5.
[10] Estimated by hydrograph-separation analysis (Rorabaugh, 1964) and from Eakin (1961, p. 10).
[11] Derived from Eakin (1961, p. 22).
[12] Mostly outflow to Diamond Valley Hydrographic Area (outside Humboldt River Basin), 9,000 acre-feet per year estimated by Harrill (1968, p. 26); value also includes 300 acre-feet per year outflow to Humboldt River, estimated by Eakin (1961, p. 24).

Ground-water inflow to Carico Lake Valley Hydrographic Area is calculated to be almost five times that estimated earlier by Everett and Rush (1966, p. 14). The lower end of the range of ground-water recharge, derived from the mass-balance calculation, is only about 800 acre-ft/yr greater than the estimate derived by the revised Maxey–Eakin method (table 11). The revised method is based on the volume of precipitation that falls within the hydrographic area and does not account for ground water that originates outside the area. Consequently, the estimated 3,000 acre-ft/yr of ground-water inflow from Upper Reese River Valley would be in addition to the estimate of ground-water recharge derived by the revised method. However, both methods for estimating ground-water recharge result in an imbalance of 12,000 to 16,000 acre-ft/yr between ground-water inflow and outflow, which may suggest additional subsurface outflow.

Although the area of ground-water discharge mapped by Everett and Rush (1966, p. 16) is nearly

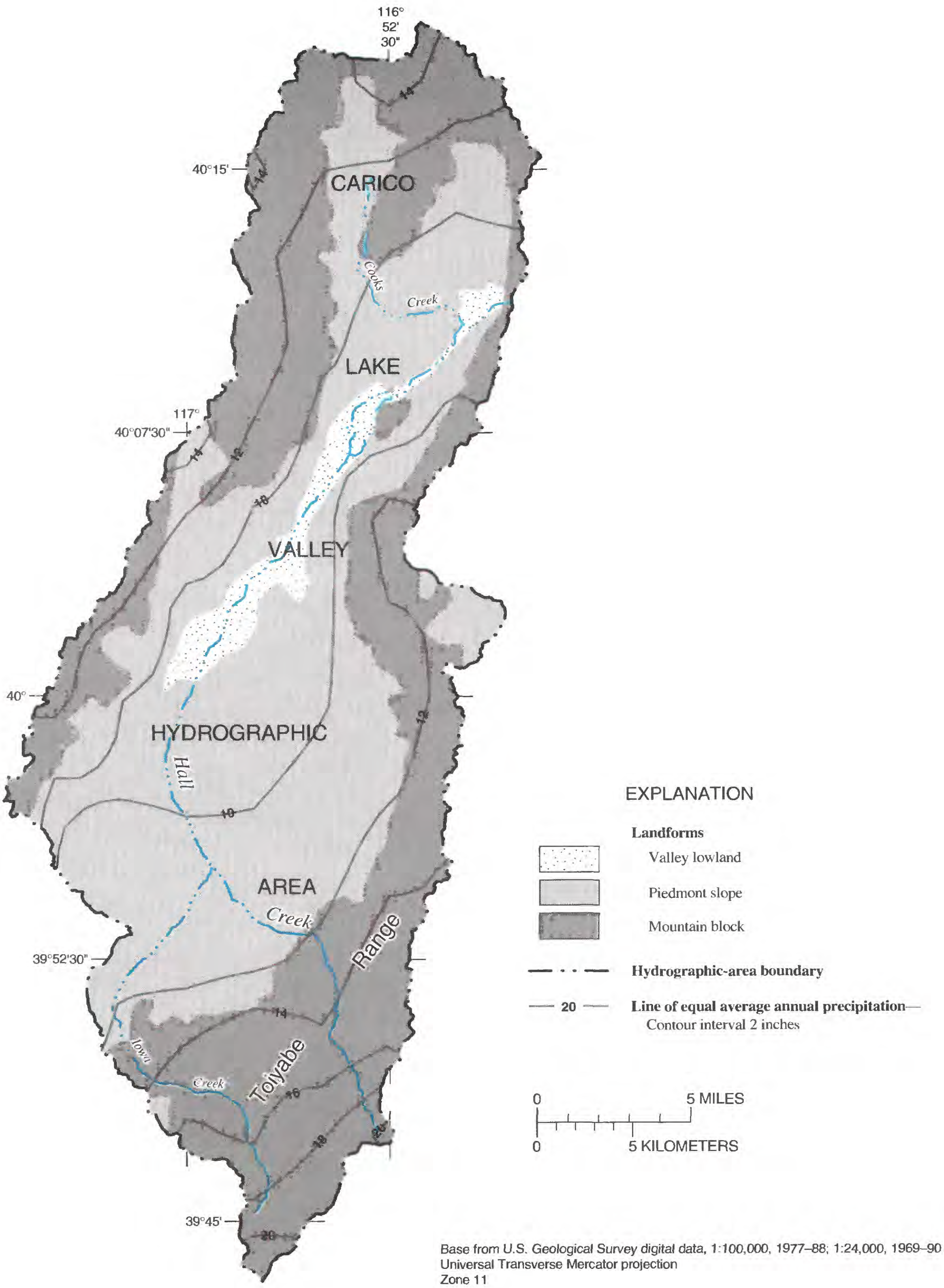


**Figure 8.** Distribution of precipitation and landforms in Carico Lake Valley Hydrographic Area, middle Humboldt River Basin, north-central Nevada, 1961–90.

**Table 10.** Average annual water budgets for Carico Lake Valley Hydrographic Area, middle Humboldt River Basin, north-central Nevada

[Bold symbols in parentheses correspond to those used in table 1 and fig. 3. Values for separate flow components rounded to nearest 100 acre-feet per year; totals rounded to nearest 1,000 acre-feet per year. ET, evapotranspiration. —, no data or not applicable; <, less than]

| Water-budget components | Inflow (acre-feet per year) | Outflow (acre-feet per year) |
|---|---|---|
| **Mountain-block water budget** | | |
| Inflow: | | |
| Precipitation on mountain block (**Pmb**)[1] | 123,000 | — |
| Subsurface flow from adjacent hydrographic areas to bedrock aquifer (**SFin**) | — | — |
| Outflow: | | |
| Runoff from mountain block to piedmont slope (**ROmb**)[2] | — | 5,900 |
| Subsurface flow from bedrock aquifer in mountain block to basin-fill aquifer beneath piedmont slope (**SFmb**)[2] | — | 13,000 |
| Subsurface flow from mountain block to adjacent hydrographic areas (**SFout**) | — | — |
| ET and sublimation of precipitation and soil moisture and ET from riparian vegetation (**ETmb**)[2] | — | 104,100 |
| Total | 123,000 | 123,000 |
| **Piedmont-slope water budget** | | |
| Inflow: | | |
| Precipitation on piedmont slope (**Pps**)[1] | 107,600 | — |
| Runoff from mountain block to piedmont slope (**ROmb**)[2] | 5,900 | — |
| Surface-water flow from adjacent hydrographic areas (**SWin**) | 0 | — |
| Subsurface flow from bedrock aquifer in mountain block to basin-fill aquifer beneath piedmont slope (**SFmb**)[2] | 13,000 | — |
| Subsurface flow from Upper Reese River Valley Hydrographic Area to basin-fill aquifer beneath piedmont slope (**SFin**) | [3]3,000 | — |
| Outflow: | | |
| Runoff generated on piedmont slope (**ROps**)[4] | — | 0–700 |
| Subsurface flow from basin-fill aquifer beneath piedmont slope to basin-fill aquifer beneath valley lowland (**SFps**)[4] | — | 21,700–23,400 |
| Subsurface flow from basin-fill aquifer beneath piedmont slope to adjacent hydrographic areas (**SFout**) | — | — |
| ET and sublimation of precipitation and soil moisture (**ETps**)[4] | — | 105,400–107,600 |
| ET from vegetated flood plains (**ETrps**)[4] | — | 1,100–1,200 |
| Total | 130,000 | 128,000–133,000 |
| **Valley-lowland water budget** | | |
| Inflow: | | |
| Precipitation on valley lowland (**Pvl**)[1] | 8,100 | — |
| Runoff from piedmont slope to valley lowland (**ROps**)[4] | 0–700 | — |
| Surface-water flow from adjacent hydrographic areas (**SWin**) | 0 | — |
| Subsurface flow from basin-fill aquifer beneath piedmont slope to basin-fill aquifer beneath valley lowland (**SFps**)[4] | 21,700–23,400 | — |
| Subsurface flow from adjacent hydrographic areas (**SFin**) | — | — |
| Outflow: | | |
| Runoff generated on valley lowland (**ROvl**) | — | 0 |
| Subsurface flow from basin-fill aquifer beneath valley lowland to adjacent hydrographic areas (**SFvl**) | — | [6]<300 |
| ET of precipitation and soil moisture (**ETvl**) | — | 8,100 |
| ET of ground water from valley lowland (**ETgw**)[5] | — | 4,800–9,600 |
| Evaporation from open-water bodies (**Esw**) | — | 0 |
| Total | 30,000–32,000 | 13,000–18,000 |
| **Carico Lake Valley Hydrographic Area water budget** | | |
| Inflow: | | |
| Precipitation in Carico Lake Valley Hydrographic Area (**Pmb, Pps, Pvl**) | 239,000 | — |
| Surface-water flow from adjacent hydrographic areas (**SWin**) | 0 | — |
| Subsurface flow from adjacent hydrographic areas (**SFin**) | 3,000 | — |
| Outflow: | | |
| Surface-water flow from Carico Lake Valley Hydrographic Area at hydrographic-area boundary (**SWtot**) | — | [7]200–300 |
| Subsurface flow from Carico Lake Valley Hydrographic Area at hydrographic-area boundary (**SFtot**) | — | [6]<300 |
| ET and sublimation from Carico Lake Valley Hydrographic Area (**ETmb, ETps, ETrps, ETvl, ETgw, Esw**) | — | 223,500–230,600 |
| Total | 242,000 | 224,000–231,000 |

[1] See table 2.

[2] See table 4.

[3] Estimated from equation 4 (see text).

[4] See table 5.

[5] See table 6.

[6] Everett and Rush (1966, p. 17).

[7] Zones (1961, p. 20).

**Table 11.** Average annual ground-water budget for Carico Lake Valley Hydrographic Area, middle Humboldt River Basin, north-central Nevada

[Values for separate flow components and subtotals rounded to nearest 100 acre-feet per year; totals rounded to nearest 1,000 acre-feet per year. Bold symbols (in footnotes) correspond to those used in table 1 and fig. 3. —, no data or not applicable; <, less than]

| Ground-water-budget component | Estimated flow (acre-feet per year) | | |
|---|---|---|---|
| | By mass-balance calculation, this investigation | By revised recharge method, this investigation | By other methods, previous investigations |
| | **Inflow** | | |
| Ground-water recharge: | | | |
| To mountain block | [1]13,000 | — | — |
| To piedmont slope, from runoff | [2]5,700–6,300 | — | — |
| To piedmont slope, from precipitation | [3]0–1,100 | — | — |
| To valley lowland | Negligible | — | — |
| Subtotal ground-water recharge | 18,700–20,400 | [4]17,900 | [5]4,300 |
| Subsurface inflow from adjacent hydrographic areas | [6]3,000 | — | [7]0 |
| Total inflow | 22,000–23,000 | [4]18,000 | 4,000 |
| | **Outflow** | | |
| Ground-water evapotranspiration in valley lowland | [8]4,800–9,600 | — | [9]3,800 |
| Ground-water discharge from vegetated flood plains | [10]1,100–1,200 | — | — |
| Ground-water discharge as surface-water outflow at hydrographic-area boundary. | — | — | [11]<300 |
| Subsurface outflow to adjacent hydrographic areas | [11]<300 | — | [11]300 |
| Total outflow | 6,000–11,000 | — | 4,000 |

[1] See table 4.

[2] Estimated as difference between sum of mountain-block runoff (**ROmb**; table 4) plus piedmont-slope runoff (**ROps**; table 5) and total surface-water outflow at hydrographic-area boundary (**SWtot**; table 10).

[3] Estimated as difference between piedmont-slope precipitation (**Pps**; table 2) and sum of piedmont-slope runoff (**ROps**; table 5) plus evapotranspiration components (**ETps** and **ETrps**; table 5).

[4] Estimated from equation 3 (see text).

[5] Everett and Rush (1966, p. 14).

[6] Estimated from equation 4 (see text).

[7] Everett and Rush (1966, p. 11).

[8] See table 6.

[9] Everett and Rush (1966, p. 16).

[10] See table 5.

[11] Everett and Rush (1966, p. 17).

twice the area derived from Landsat TM data collected in June 1989 and June 1995, their estimate of total ground-water ET is from 1,000 to 5,800 acre-ft/yr less than that estimated during this investigation (table 11). The difference is due, in part, to the higher rates derived from micrometeorological methods. Everett and Rush (1966, p. 16) used an average ET rate of 0.2 ft/yr for an areal density of 15 to 30 percent plant cover. For a plant cover of at least 10 but less than 35 percent, the average ET rate derived by micrometeorological methods is about 1.8 ft/yr (table 6).

## Upper Reese River Valley Hydrographic Area

Inflow to Upper Reese River Valley Hydrographic Area (fig. 9) originates entirely as precipitation within the hydrographic area (table 12). About 100,000 acre-ft/yr more precipitation is simulated by PRISM than determined from the Hardman precipitation map (Hardman and Mason, 1949; Eakin and others, 1965, p. 28; Eakin and Lamke, 1966, p. 58). More than half the difference occurs in the piedmont-slope and valley-lowland areas (table 7).

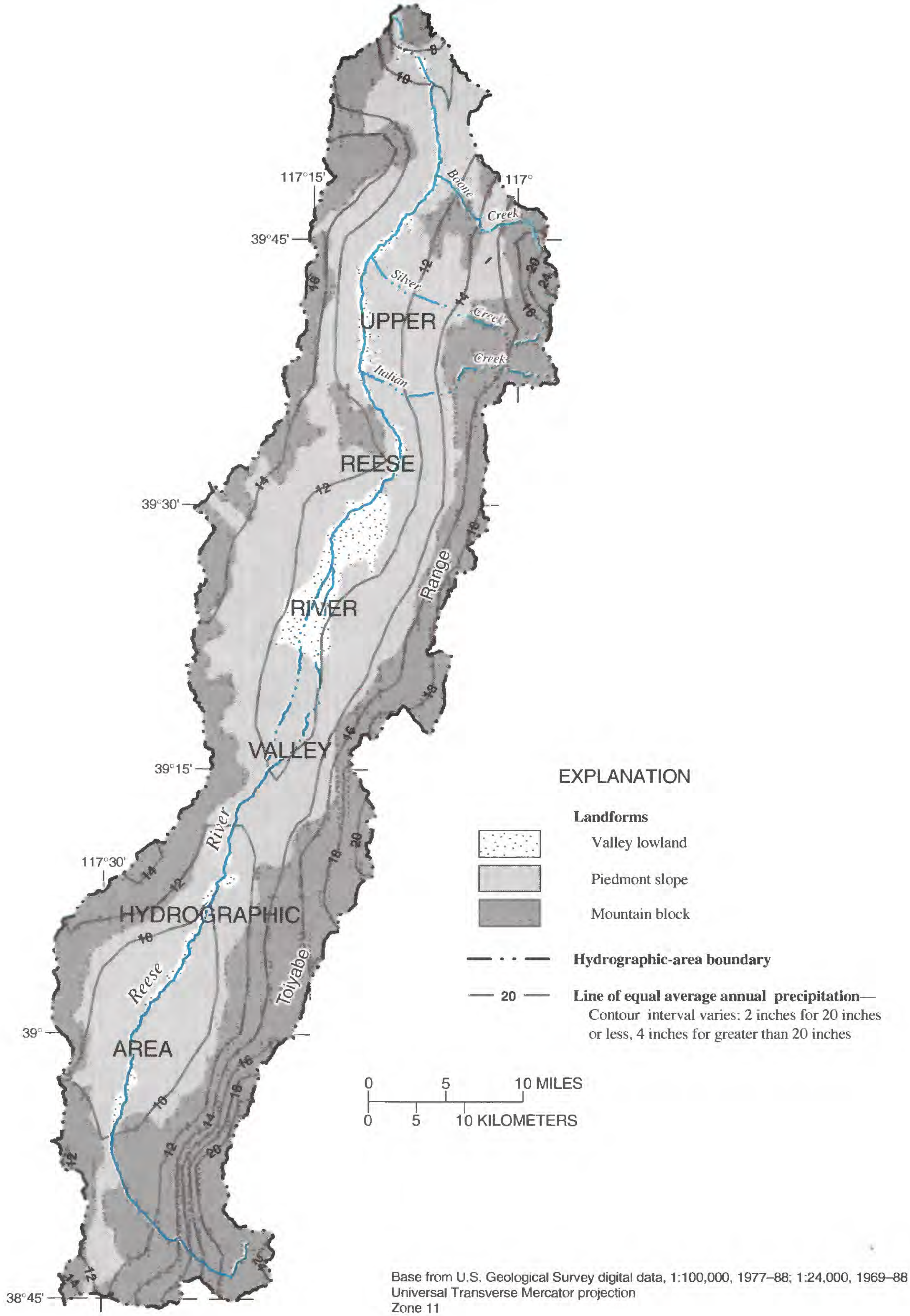


**Figure 9.** Distribution of precipitation and landforms in Upper Reese River Valley Hydrographic Area, middle Humboldt River Basin, north-central Nevada, 1961–90.

**Table 12.** Average annual water budgets for Upper Reese River Valley Hydrographic Area, middle Humboldt River Basin, north-central Nevada

[Bold symbols in parentheses correspond to those used in table 1 and fig. 3. Values for separate flow components rounded to nearest 100 acre-feet per year; totals rounded to nearest 1,000 acre-feet per year. ET, evapotranspiration. —, no data or not applicable]

| Water-budget components | Inflow (acre-feet per year) | Outflow (acre-feet per year) |
|---|---|---|
| **Mountain-block water budget** | | |
| Inflow: | | |
| Precipitation on mountain block (**Pmb**)[1] | 413,900 | — |
| Subsurface flow from adjacent hydrographic areas to bedrock aquifer (**SFin**) | 0 | — |
| Outflow: | | |
| Runoff from mountain block to piedmont slope (**ROmb**)[2] | — | 26,600 |
| Subsurface flow from bedrock aquifer in mountain block to basin-fill aquifer beneath piedmont slope (**SFmb**)[2] | — | 47,800 |
| Subsurface flow from mountain block to adjacent hydrographic areas (**SFout**) | — | — |
| ET and sublimation of precipitation and soil moisture and ET from riparian vegetation (**ETmb**)[2] | — | 339,500 |
| Total | 414,000 | 414,000 |
| **Piedmont-slope water budget** | | |
| Inflow: | | |
| Precipitation on piedmont slope (**Pps**)[1] | 354,500 | — |
| Runoff from mountain block to piedmont slope (**ROmb**)[2] | 26,600 | — |
| Surface-water flow from adjacent hydrographic areas (**SWin**) | 0 | — |
| Subsurface flow from bedrock aquifer in mountain block to basin-fill aquifer beneath piedmont slope (**SFmb**)[2] | 47,800 | — |
| Subsurface flow from adjacent hydrographic areas (**SFin**) | 0 | — |
| Outflow: | | |
| Runoff generated on piedmont slope (**ROps**)[3] | — | 0–3,000 |
| Subsurface flow from basin-fill aquifer beneath piedmont slope to basin-fill aquifer beneath valley lowland (**SFps**)[3] | — | 71,400–110,000 |
| Subsurface flow from basin-fill aquifer beneath piedmont slope to Carico Lake Valley Hydrographic Area (**SFout**) | — | [4]3,000 |
| ET and sublimation of precipitation and soil moisture (**ETps**)[3] | — | 308,100–354,500 |
| ET from vegetated flood plains (**ETrps**)[3] | — | 10,900–11,700 |
| Total | 429,000 | 393,000–482,000 |
| **Valley-lowland water budget** | | |
| Inflow: | | |
| Precipitation on valley lowland (**Pvl**)[1] | 35,000 | — |
| Runoff from piedmont slope to valley lowland (**ROps**)[3] | 0–3,000 | — |
| Surface-water flow from adjacent hydrographic areas (**SWin**) | 0 | — |
| Subsurface flow from basin-fill aquifer beneath piedmont slope to basin-fill aquifer beneath valley lowland (**SFps**)[3] | 71,400–110,000 | — |
| Subsurface flow from adjacent hydrographic areas (**SFin**) | — | — |
| Outflow: | | |
| Runoff generated on valley lowland (**ROvl**) | — | 0 |
| Subsurface flow from basin-fill aquifer beneath valley lowland to Middle Reese River Valley Hydrographic Area (**SFvl**) | — | [5]500 |
| ET of precipitation and soil moisture (**ETvl**) | — | 35,000 |
| ET of ground water from valley lowland (**ETgw**)[6] | — | 43,800–45,800 |
| Evaporation from open-water bodies (**Esw**) | — | 0–600 |
| Total | 106,000–148,000 | 79,000–82,000 |
| **Upper Reese River Valley Hydrographic Area water budget** | | |
| Inflow: | | |
| Precipitation in Upper Reese River Valley Hydrographic Area (**Pmb, Pps, Pvl**) | 803,000 | — |
| Surface-water flow from adjacent hydrographic areas (**SWin**) | 0 | — |
| Subsurface flow from adjacent hydrographic areas (**SFin**) | 0 | — |
| Outflow: | | |
| Surface-water flow from Upper Reese River Valley Hydrographic Area at hydrographic-area boundary (**SWtot**) | — | [5]3,000 |
| Subsurface flow from Upper Reese River Valley Hydrographic Area at hydrographic-area boundary (**SFtot**) | — | [7]3,500 |
| ET and sublimation from Upper Reese River Valley Hydrographic Area (**ETmb, ETps, ETrps, ETvl, ETgw, Esw**) | — | 737,300–787,100 |
| Total | 803,000 | 744,000–794,000 |

[1] See table 2.
[2] See table 4.
[3] See table 5.
[4] Estimated from equation 4 (see text).
[5] Eakin and others (1965, p. 24).
[6] See table 6.
[7] Combined values: 3,000 acre-feet per year to Carico Lake Valley Hydrographic Area, estimated from equation 4 (see text), and less than 500 acre-feet per year to Middle Reese River Valley Hydrographic Area, estimated by Eakin and others (1965).

Nearly all the outflow from the Upper Reese River Valley is by ET (table 12). In addition, Eakin and others (1965, p. 24) estimated that about 3,000 acre-ft/yr leaves the hydrographic area as surface water through a narrow canyon in Reese River Valley. Most of the flow is during short periods of high-intensity rain or during the spring runoff. Hydrograph-separation analysis (Rorabaugh, 1964) on limited streamflow data indicates that about one third of the annual surface-water outflow is contributed by ground water. Other outflow includes about 3,500 acre-ft/yr of subsurface flow to adjacent hydrographic areas. As previously discussed, about 3,000 acre-ft/yr was estimated to leave the hydrographic area as ground-water flow to Carico Lake Valley. Also, nearly 500 acre-ft/yr of ground water was estimated to flow northward beneath the narrow canyon to the Middle Reese River Valley Hydrographic Area (Eakin and others, 1965).

Estimates of ground-water recharge for Upper Reese River Valley derived by the revised Maxey–Eakin method and a mass-balance approach are more than twice Eakin and others' (1965) estimates (table 13). Because of the assumption that nearly all the runoff is available for recharge, infiltrated runoff accounts for about 25 percent of the total ground-water recharge in the revised water budget. This is in good agreement

**Table 13.** Average annual ground-water budget for Upper Reese River Valley Hydrographic Area, middle Humboldt River Basin, north-central Nevada

[Values for separate flow components and subtotals rounded to nearest 100 acre-feet per year; totals rounded to nearest 1,000 acre-feet per year. Bold symbols (in footnotes) correspond to those used in table 1 and fig. 3. —, no data or not applicable; <, less than]

| Ground-water-budget component | Estimated flow (acre-feet per year) | | |
|---|---|---|---|
| | By mass-balance calculation, this investigation | By revised recharge method, this investigation | By other methods, previous investigations |
| **Inflow** | | | |
| Ground-water recharge: | | | |
| To mountain block | [1]47,800 | — | [2]23,000 |
| To piedmont slope, from runoff | [3]23,600–26,600 | — | [4]11,000 |
| To piedmont slope, from precipitation | [5]0–35,500 | — | — |
| To valley lowland | Negligible | — | — |
| Subtotal ground-water recharge | 71,400–110,000 | [6]93,400 | [7]34,000 |
| Subsurface inflow from adjacent hydrographic areas | 0 | — | [2]0 |
| Total inflow | 71,000–110,000 | 93,000 | 34,000 |
| **Outflow** | | | |
| Ground-water evapotranspiration in valley lowland | [8]43,800–45,800 | — | [9]33,000 |
| Ground-water discharge from vegetated flood plains | [10]10,900–11,700 | — | [9]4,000 |
| Ground-water discharge as surface-water outflow at hydrographic-area boundary. | [11]<1,000 | — | — |
| Subsurface outflow to adjacent hydrographic areas | [8]3,500 | — | [9]500 |
| Total outflow | 59,000–62,000 | — | 38,000 |

[1] See table 4.
[2] Eakin and Lamke (1966, p. 58).
[3] Estimated as difference between sum of mountain-block runoff (**ROmb**; table 4) plus piedmont-slope runoff (**ROps**; table 5) and total runoff at hydrographic-area boundary (**SWtot**; table 12).
[4] Eakin and others (1965, p. 25).
[5] Estimated as difference between piedmont-slope precipitation (**Pps**; table 2) and sum of piedmont-slope runoff (**ROps**; table 5) plus evapotranspiration components (**ETps** and **ETrps**; table 5).
[6] Estimated from equation 3 (see text).
[7] Eakin and others (1965, p. 27–28) calculated 58,000 acre-feet per year by Maxey–Eakin method (Watson and others, 1976) but reported it as 37,000 acre-feet per year because of assumed deficiency of precipitation in mountain areas.
[8] Rounded to nearest 1,000 acre-feet per year.
[9] See table 6.
[10] Eakin and others (1965).
[11] See table 5.
[12] Estimated from hydrograph-separation analysis (Rorabaugh, 1964).

with Eakin and others' (1965, p. 23) estimate that about 30 percent of the runoff generated in mountain-block areas within the Upper Reese River Valley becomes ground-water recharge. Additional work is needed to understand and quantify recharge processes that take place on piedmont slopes within the Humboldt River Basin.

Mass-balance calculations of ground-water outflow from Upper Reese River Valley are more than 20,000 acre-ft/yr greater than estimated earlier by Eakin and others (1965) (table 13). Half of this difference between the outflow estimates is a result of the larger estimates of ground-water ET from vegetated flood plains and the estimate of additional subsurface outflow to Carico Lake Valley Hydrographic Area. Application of higher ET rates, derived by micrometeorological methods for phreatophyte vegetation, accounts for the remaining difference in outflow. The revised ground-water budget for the Upper Reese River Valley Hydrographic Area shows an imbalance between inflow and outflow that suggests additional, unaccounted outflow from the hydrographic area. Estimates of ground-water ET from vegetated flood plains, which are considered to be minimum estimates, may account for some of the imbalance. Additional ground water may flow out through the fractured volcanic rock along the north boundary of Upper Reese River Valley.

## Discussion of Water-Budget Estimates

Although the newly estimated water budgets are subject to a number of qualifications, they illustrate the relative distribution and movement of water and are considered to represent average annual conditions for the reference period 1961–90. Previous budget estimates generally represent average conditions for the reference period 1912–63 (Eakin and Lamke, 1966, p. 63).

In Pine Valley, average annual precipitation simulated by PRISM is about 5 percent greater than that estimated from the Hardman precipitation map (Hardman and Mason, 1949); in Upper Reese River Valley, it is about 14 percent greater; and in Carico Lake Valley, nearly 50 percent greater. The Hardman precipitation map, which was developed from weather records and other data collected over a period of several decades (through 1936), was correlated with data on altitude and topography, latitude, and vegetation type. Precipitation measured at Austin, Battle Mountain, Elko, Lovelock, and Winnemucca indicates below-average precipitation from about 1915 to the early 1930's (Hardman and Mason, 1949, p. 13; Eakin and Lamke, 1966, p. 21). The reference period 1961–90 had an almost-equal number of years of below- and above-average precipitation (J.W. James, Nevada State Climatologist, oral commun., 1998).

Of equal importance to the total volume of precipitation is the difference in the relative distribution of the precipitation among the three landforms in a hydrographic area. Nearly half of the annual precipitation occurs on piedmont slopes. Because these are relatively large areas and receive a substantial amount of annual precipitation, they may be more significant contributors to ground water and runoff than previously thought. According to the Hardman precipitation map, more than 50 percent of Carico Lake Valley Hydrographic Area and about 30 percent of Upper Reese River Valley Hydrographic Area receive less than 8 in. of average annual precipitation. PRISM simulated no average annual precipitation of less than 8 in. in the three hydrographic areas.

More than 95 percent of the total precipitation in the three basins is lost to ET. Nearly equal amounts of precipitation in mountain-block and piedmont-slope areas are estimated to be lost to ET. The small amount of precipitation (about 4 percent) that falls on valley lowlands is lost to ET. According to recent work using micrometeorological methods for determining ground-water discharge by ET (Nichols, 2000), annual ET rates from phreatophyte vegetation appear to be significantly greater than previously assumed. In general, the average annual ET rates used for areas having at least 50 percent plant cover in earlier studies ranged from about 0.1 to 0.5 ft/yr, whereas the rates determined from micrometeorological methods range from about 0.5 to more than 2.5 ft/yr. The higher rates are significant in hydrographic areas that currently are undergoing ground-water development based on the concept of perennial yield, or the volume of natural discharge that can be captured (Malmberg, 1967, p. 37). Ground-water ET from vegetated flood plains ranges from about 7 to 20 percent of the estimated total ground-water ET.

On the basis of the revised runoff method (eq. 1) and the water-yield equation (eq. 2), about 11 percent of mountain-block precipitation becomes ground-water recharge. Eakin and Lamke (1966, p. 58) had estimated that contribution to be generally 6 to 8 percent. However, total ground-water inflow, derived from mass-balance calculations, generally is much greater than previously estimated, owing, in part, to the greater precipitation simulated by PRISM. From 7 to 14 percent of the total annual precipitation was estimated to become ground-water recharge on the basis of the new water budgets—compared to earlier estimates of 3 to 7 percent. The earlier estimates of ground-water recharge were based on the original Maxey–Eakin method and resulted in bulk estimates of recharge with no indication of where recharge occurred. Developing water budgets for individual landforms and the associated aquifers and doing mass-balance calculations have provided some insight into the areal distribution and processes of ground-water recharge.

## SUMMARY AND CONCLUSIONS

The middle Humboldt River Basin includes 14 hydrographic areas that cover about 7,470 $mi^2$ in north-central Nevada. Although agricultural irrigation has accounted for much of the water use in the basin, increased mining activities in recent years have placed additional demands on the basin's limited water resources. In 1995, the USGS, in cooperation with the Nevada Division of Water Resources, began a water-resources assessment of the middle Humboldt River Basin to address concerns about regional and long-term effects of dewatering at open-pit mining operations. A systematic approach for estimating water budgets of individual hydrographic areas within the middle Humboldt River Basin was developed as part of this assessment. Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas were selected for demonstrating the methods for estimating components of a water budget.

Each hydrographic area is subdivided on the basis of three easily identifiable landforms—mountain blocks, piedmont slopes, and valley lowlands—and the characteristics of ground-water flow in the underlying hydrogeologic units. Mountain blocks form the main zone of recharge, piedmont slopes the main zone of lateral flow, and the valley lowlands the main zone of ground-water discharge.

The most significant water-budget components identified in the middle Humboldt River Basin are precipitation, runoff, water yield, ground-water recharge and subsurface flow, and ET. Precipitation is the principal source of inflow to the hydrographic areas, and ET is the dominant outflow component. The water yield from mountain blocks consists of runoff generated in the watersheds and subsurface flow from bedrock aquifers. Ground-water recharge occurs by infiltration of precipitation, runoff, nonchannelized flow, or ponded water.

The water budgets were developed assuming approximate equilibrium and no long-term average annual net change in ground-water storage (steady-state conditions). The estimated budget components represent average annual volumes over a 30-year reference period (1961–90). Equations of hydrologic equilibrium were used to describe the water budgets in terms of inflow balanced by outflow. In some instances, outflow from one landform represents inflow to an adjacent landform.

A statistical–topographic model developed by Oregon State University was used to determine the distribution of precipitation. Known as PRISM, the model simulates average annual precipitation at regional scales. The simulated precipitation was derived from weather-station data throughout Nevada and represents the average for the 30-year reference period. Methods were developed for estimating runoff, water yield, and ground-water recharge as functions of the distribution and quantity of average annual precipitation.

Runoff and water yield from mountain-block areas were estimated from regression analyses among average annual streamflow, water yield, and precipitation. The estimated water yield was used in the water budgets to describe the relation between mountain-block runoff and subsurface flow. Runoff originating on piedmont slopes was estimated to range from 0 to 10 percent of the total runoff generated within hydrographic-area boundaries.

Ground-water recharge was estimated by a modified Maxey–Eakin method and by a mass-balance calculation. The ground-water recharge estimates were used to evaluate individual budget components, particularly subsurface flow between aquifers underlying adjacent landforms. The estimates also were used in identifying locations and processes of ground-water recharge in each basin.

Water loss by ET and sublimation in the mountain blocks could only be determined indirectly as the difference between average annual precipitation and average annual water yield. Average annual ET from piedmont slopes was derived, in part, by the Penman–Monteith equation using weather-station data. ET from valley lowlands was estimated from a more recently developed method using micrometeorological techniques and remotely sensed Landsat TM (satellite) data.

Applied to the three selected hydrographic areas, these methods yielded revised water budgets representing average annual conditions over the reference period 1961–90. Previous water budgets for Pine Valley, Carico Lake Valley, and Upper Reese River Valley Hydrographic Areas relied exclusively on the Hardman precipitation map and were assumed generally to represent average conditions for the reference period 1912–63.

Annual inflow to Pine Valley is derived entirely from precipitation within the hydrographic area. Nearly equal amounts of precipitation are simulated to occur on the mountain block and piedmont slope. Outflow from Pine Valley is mostly by ET but also includes some surface-water outflow (about 8,100 acre-ft/yr) and subsurface outflow (about 9,300 acre-ft/yr) to adjacent hydrographic areas. The average annual inflow to the ground-water system, estimated by mass balance, is 52,500 to 79,300 acre-ft, a range that includes the recharge estimate derived from the revised Maxey–Eakin method. The new estimates of recharge may be as much as 30,000 acre-ft/yr greater than previous results.

Annual inflow to Carico Lake Valley Hydrographic Area is mostly from precipitation but also includes some subsurface inflow (about 3,000 acre-ft/yr) from Upper Reese River Valley. Ground-water recharge to Carico Lake Valley estimated by the two methods is almost five times that previously estimated. The water budget for Carico Lake Valley is affected by an imbalance in the water budget for the valley-lowlands area, where annual inflow is almost twice the annual outflow.

Annual inflow to Upper Reese River Valley originates entirely as precipitation within the hydrographic area. More than 100,000 acre-ft/yr more precipitation was simulated by PRISM than determined from the Hardman precipitation map. More than half the difference occurs on the piedmont slopes and in the valley lowlands. Nearly all the outflow from Upper Reese River Valley is by ET. The imbalance in the ground-water budget suggests that outflow may be greater than assumed in the current budget. For instance, ground-water discharge from vegetated flood plains may be higher than estimated, and subsurface outflow through the fractured volcanic rock along the north boundary may be greater than estimated.

The average annual precipitation simulated by PRISM is about 5 percent greater for Pine Valley than that estimated from the Hardman precipitation map, about 14 percent greater for Upper Reese River Valley, and nearly 50 percent greater for Carico Lake Valley. Some of the difference between the estimates may be because the periods of record of the PRISM and Hardman data only overlapped by a few years.

The relative distribution of annual precipitation among the three landforms in a hydrographic area is as significant as the total volume of precipitation. Because nearly half the annual precipitation occurs on piedmont slopes, more ground-water recharge may occur in these areas than previously assumed. The Hardman precipitation map indicates that more than 50 percent of Carico Lake Valley Hydrographic Area and about 30 percent of Upper Reese River Valley Hydrographic Area receive less than 8 in. of annual precipitation. PRISM simulated no areas with precipitation of less than 8 in. in the three hydrographic areas.

Total ground-water inflow and outflow for all three hydrographic areas, derived from mass-balance calculations, are generally greater than estimated by previous investigators. The percentage of total precipitation that becomes ground water was estimated to be about twice previous estimates (7 to 14 percent compared to 3 to 7 percent). Most of the precipitation that falls in the three areas is lost to ET prior to becoming either runoff or ground water. The average annual ET rates derived by micrometeorological methods range from about 0.5 to more than 2.5 ft/yr, which is higher than the rates assumed in earlier studies (0.1–0.5 ft/yr).

## GLOSSARY

Some of the technical terms and acronyms used in this report are defined for the convenience of the reader. Most of the following definitions were modified from (1) Langbein and Iseri (1960), (2) Tomlinson (1994), (3) Horton (1998), and (4) Wilson and Moore (1998).

**Aerodynamic resistance.** Turbulent resistance between average height of canopy and height at which temperature and wind speed were measured (2).

**Aquifer.** Formation, group of formations, or part of formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs (4).

**Average conditions.** Conditions under which numerical value for hydrologic variable, such as precipitation or streamflow, is equal to arithmetic mean for selected time period. Also see definition of "natural conditions."

**Baseflow.** Sustained or fair-weather flow of stream, whether or not affected by works of man. That part of stream discharge that is not attributable to direct runoff from precipitation or melting snow (4).

**Canopy resistance.** Resistance to transport of water and vapor away from soil and canopy (2).

**Coefficient of determination ($r^2$).** Measure of proportion of total variance of dependent variable that is accounted for by independent variables in regression analyses.

**Dewatering (mining).** Removal of ground water in conjunction with mining operations when excavation has penetrated below water table (3).

**Evaporation.** Process by which water passes from liquid state to vapor state (4).

**Evapotranspiration (ET).** Loss of water from land area through transpiration by plants and evaporation from soil and surface-water bodies (4).

**Geographic information system (GIS).** Computer program and associated data bases that organize data in layers which can be integrated, queried, and analyzed (3, 4).

**Ground water.** That part of subsurface water that is in saturated zone (4).

**Ground-water discharge.** Release of water from saturated zone (4).

**Ground-water recharge.** Process of downward movement of water to saturated zone and addition of water to ground-water reservoir (4).

**Ground-water storage.** Quantity of water in saturated zone (4).

**Head.** Height above standard datum (4).

**Hydraulic conductivity.** Volume of water that will move in porous medium in unit time under unit hydraulic gradient through unit area measured at right angles to direction of flow (4).

**Hydraulic gradient.** In aquifer, rate of change of total head per unit of distance of flow at given point and in given direction (4).

**Hydrograph.** Graph showing multiple characteristics of water (such as flow) with respect to time.

**Hydrologic equilibrium.** Expression of law of mass conservation for water budgets. State in which inflow equals outflow, corrected for changes in storage.

**Hydrologic processes.** Physical operation or series of operations that result in movement of water within hydrologic system.

**Hydrologic system.** Complex of related parts—physical, conceptual, or both—forming orderly working body of hydrologic units and interacting hydrologic processes (4).

**Inflow.** Process of flowing in or into; includes all water that enters hydrologic system (4).

**Landsat.** Series of United States satellites that collect multispectral images of Earth's surface in visible, reflected, and thermal-infrared bands (4).

**Natural conditions.** Conditions under which hydrologic processes and variables are not affected by man. For water budgets, such conditions commonly are assumed to represent long-term steady state.

**Net radiation.** Difference between incoming and reflected radiation (2).

**Open-pit mining.** Process of removing mineral deposits that are found sufficiently close to surface that tunnels are unnecessary.

**Outflow.** Process of flowing out; includes all water that leaves hydrologic system (4).

**Overland flow.** That part of surface runoff flowing over land surfaces toward stream channels (4).

**Permeability.** Property or capacity of porous rock, sediment, or soil for transmitting water (4).

**Phreatophyte.** Plant that obtains its water supply from saturated zone (4).

**Residual.** Difference between measured station value and value predicted by regression equation.

**Runoff.** That part of precipitation appearing in surface streams (4).

**Spring.** Place where ground water flows naturally from rock or soil onto land surface or into body of surface water (4).

**Steady state.** State of balance in hydrologic system where little or no change in hydraulic head occurs through time (4).

**Streamflow.** Type of channel flow; applies to that part of surface runoff traveling in stream whether or not it is affected by diversion or regulation (4).

**Surface water.** All waters on surface of Earth (1).

**Transpiration.** Process by which plants give off water vapor through their leaves (4).

**Water budget.** Accounting of inflow to, outflow from, and storage in hydrologic unit such as drainage basin, aquifer, soil zone, lake, or reservoir (4).

**Watershed.** Region drained by, or contributing water to, stream, lake, or other body of water (4).

**Water table.** Upper surface of saturated zone (4).

**Water year.** Period of 12 months from October 1 through September 30; term used by federal agencies in reference to surface-water supply (4).

**Water yield.** Runoff from drainage basin; includes ground-water outflow that appears in stream plus ground-water outflow that bypasses gaging station and leaves basin underground. May be expressed as precipitation minus evapotranspiration (4, 1).

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