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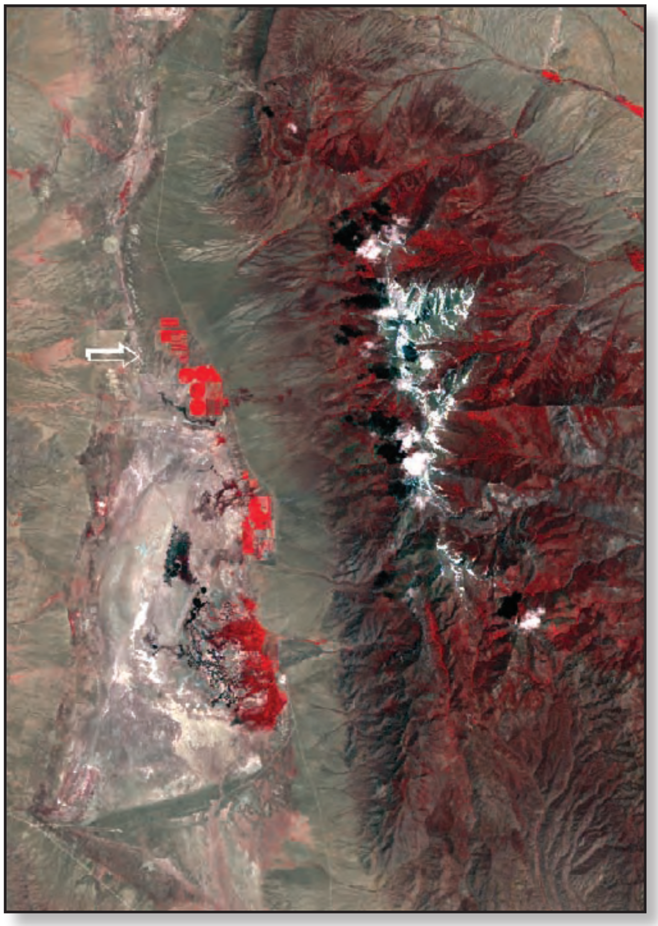
Mapping Evapotranspiration Units in the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah



Scientific Investigations Report 2007–5087

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

Cover: Photograph and infrared image of Snake Range and Spring Valley, White Pine County, Nevada.

Left: Photograph of Snake Range and Spring Valley looking east toward Wheeler Peak from the Spring Valley north of Minerva, Nevada. Shrubland of greasewood and sage is shown in the foreground and a farm and irrigated cropland at the base of Wheeler Peak. Photograph was taken by Ryan Powell, Desert Research Institute, August 22, 2006.

Right: Color infrared composite Landsat image showing the Snake Range with a snow covered Wheeler Peak on the right and Spring Valley on the left, July 12, 2005. The arrow on the Landsat image gives the location and direction at which the photograph was taken.

Mapping Evapotranspiration Units in the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah

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Foreword

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

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

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

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Conversion Factors and Datums

Conversion Factors

Multiply	By	To obtain
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
foot (ft)	0.3048	meter (m)
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)

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

$$°C=(°F-32)/1.8.$$

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

$$°F=(1.8\times°C)+32.$$

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

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

Mapping Evapotranspiration Units in the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah

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Abstract

Accurate estimates of ground-water discharge are crucial in the development of a water budget for the Basin and Range carbonate-rock aquifer system study area. One common method used throughout the southwestern United States is to estimate ground-water discharge from evapotranspiration (ET). ET is a process by which water from the Earth's surface is transferred to the atmosphere. The volume of water lost to the atmosphere by ET can be computed as the product of the ET rate and the acreage of vegetation, open water, and moist soil through which ET occurs. The procedure used in the study groups areas of similar vegetation, water, and soil conditions into different ET units, assigns an average annual ET rate to each unit, and computes annual ET from each ET unit within the outer extent of potential areas of ground-water discharge. Data sets and the procedures used to delineate the ET-unit map used to estimate ground-water discharge from the study area and a qualitative assessment of the accuracy of the map are described in this report.

Introduction

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

The carbonate-rock aquifer extends beneath numerous surface-water drainage basins, or hydrographic areas[1]. Past studies have combined hydrographic areas to delineate basin-fill or regional ground-water flow systems, based primarily on the direction of interconnected ground-water flow in the

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

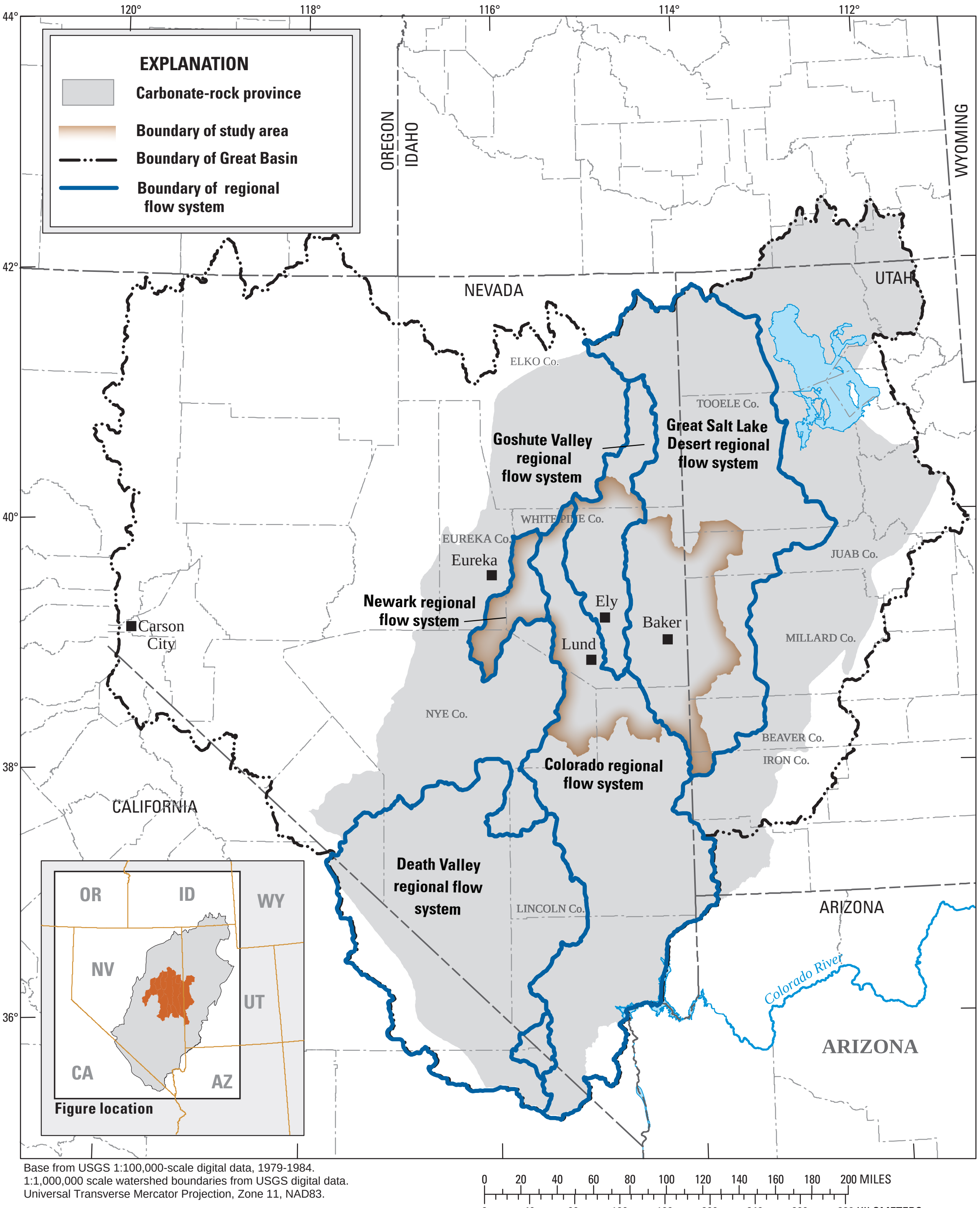


Figure 1. Carbonate-rock province, the Basin and Range carbonate-rock aquifer system study area, and associated regional ground-water flow systems, Nevada and Utah.

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

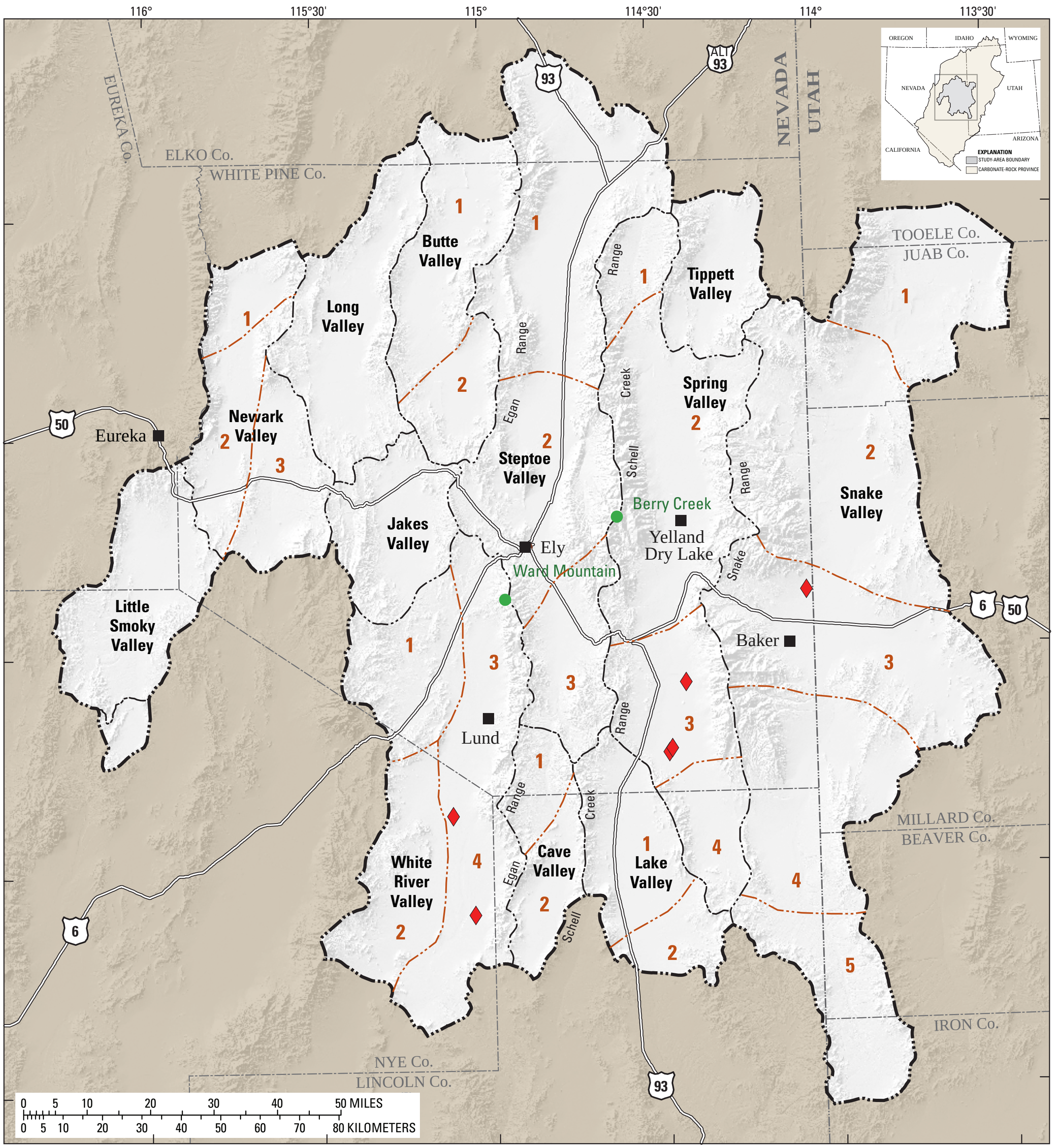
Estimates of ground-water discharge are crucial in developing water budgets that accurately represent the components of the region's ground-water flow system. Although early reconnaissance studies provide general estimates of regional ground-water discharge from many of the major hydrographic areas of the BARCAS study area, the methodologies and techniques applied often differed among the investigations. Developing a defensible water budget for the study area requires that a thorough and more consistent approach be used to estimate ground-water discharge from the region's major discharge areas.

Ground-water discharge in the semi-arid southwestern U.S. often is estimated by partitioning total evapotranspiration into ground- and surface-water components (Laczniak and others, 1999). Evapotranspiration is a process by which water from the Earth's surface is transferred to the atmosphere. Water loss to the atmosphere occurs both as evaporation from open water and soil and as transpiration by plants. Together these two processes are referred to as evapotranspiration or ET, and are the primary mechanisms removing ground water from the soil and shallow water table. As more water is removed by ET, the water table declines, soils dry, and the vigor of the local vegetation decreases. Conversely, as less water is removed, the water table rises, soils moisten, and the vigor of the local vegetation increases. Changes in ET, the depth to the water table, and the extent and vigor of vegetation all are indicators of changes in ground-water availability.

The annual volume of water lost to the atmosphere by ET can be computed as the product of the mean annual rate of ET and the acreage of vegetation, open water, and moist soil contributing to ET. With this volumetric calculation, mean annual ET can be computed for areas of likely ground-water discharge. The specific procedure groups areas of similar vegetation and soil conditions into unique ET units, assigns an average annual ET rate to each unit, and computes annual ET from each ET unit within potential areas of ground-water discharge. Mean annual ET estimates for each ET unit are computed by multiplying the unit's acreage by an appropriate ET rate for the unit's vegetation, water, and soil conditions. During the study, six ET stations were established in Spring, Snake, and White River Valleys (fig. 2). Each of these stations was operated for a period of about 1 year (Moreo and others, 2007). Data collected at these six stations were used to help identify ET units and refine estimates of the annual ET rate for the different vegetation, soil, and moisture conditions observed throughout the study area.

Purpose and Scope

The purpose of this report is to describe the method used to identify and delineate ET units in the study area and to document and release the ET unit and the potential areas of ground-water discharge data sets developed for this study. Data can be accessed at http://water.usgs.gov/lookup/getspatial?sir2007-5087_etunit and http://water.usgs.gov/lookup/getspatial?sir2007-5087_potgwdischarge. The data sets and procedures used to delineate ET units and their spatial distribution also are described in this report. The ET-unit map described and documented in this report was used specifically to calculate annual ET from potential areas of ground-water discharge. ET calculated from the ET-unit map was then partitioned into surface-water and ground-water components to estimate ground-water discharge from hydrographic areas and hydrographic-area subbasins in the study area and reported in the BARCAS summary report (Welch and Bright, 2007).



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

EXPLANATION

- Boundary of study area
- Boundary of hydrographic area
- 4 Boundary of subbasin and No.
- ET station
- SNOTEL site

Figure 2. Hydrographic areas and subbasins and location of precipitation and evapotranspiration (ET) sites in the Basin and Range carbonate-rock aquifer system study area, Nevada and Utah.

Evapotranspiration-Unit Map

Past studies have used Landsat imagery to identify and delineate evapotranspiration units in areas of ground-water discharge throughout arid and semi-arid regions of the Great Basin (Laczniak and others, 1999; Laczniak and others, 2001; Reiner and others, 2002). ET units are defined as areas of similar vegetation type and density and similar soil characteristics where ground water potentially is being lost to the atmosphere by evaporation or through plant transpiration (Laczniak and others, 1999, 2001, 2006). In general, the more dense and healthy the vegetation and the wetter the soil, the greater is the ET. The characteristics of each ET unit differ throughout the study area and range from areas of no vegetation, such as open water, dry playa, and moist bare soil; to areas of denser vegetation dominated by phreatophytic shrubs, grasses, rushes, and reeds.

Another approach used in the Great Basin region to identify and delineate ET units from Landsat imagery is described in Nichols (2001). In this approach, the change in vegetation and soil conditions are assumed to correlate directly with the Modified Soil Adjusted Vegetation Index (MSAVI) calculated from Landsat data. Nichols has applied this approach to many hydrologic areas in the study area.

A Multi-Resolution Land Characteristics consortium was formed in 1999 to purchase three dates of Landsat satellite imagery for the entire United States and to coordinate the production of a comprehensive National Land Cover Database (NLCD) (Homer and others, 2004) for the Nation. The development of the methodology used to spatially discriminate land covers was carefully planned to offer users a full range of flexible applications. The NLCD was considered for this study but was not yet available for the Great Basin.

Southwest Regional Gap Analysis Program (SWReGAP) recently completed land cover maps for five southwestern States (Kepner and others, 2005) that includes Nevada and Utah. SWReGAP is a multi-institutional cooperative effort coordinated by the Gap Analysis Program. The NLCD for the Great Basin combined mapping efforts within the U.S. Geological Survey (USGS) by synergistic mapping with the Gap Analysis Program. Provisional SWReGAP data sets were made available in October 2005 and were used to aid in the mapping of ET units in the study area.

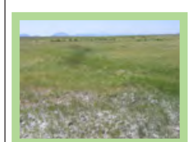
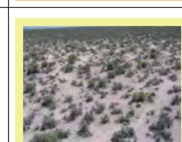
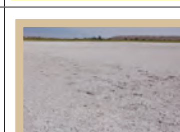
ET units were delineated in potential areas of ground-water discharge by using selected SWReGAP land classes, identification of irrigated croplands for multiple Landsat dates, and MSAVI and Tasseled Cap results from recent Landsat satellite data. Ten ET units were identified as being representative of the different vegetation and soil conditions in the area from which ground water is lost to the atmosphere through ET and are described in table 1. Units delineated were inclusive of irrigated crops and phreatophytic vegetation. Three distinct shrubland ET units were delineated because of the dominance of this vegetation type throughout the study area. ET calculated from the ET-unit map was then partitioned into surface-water and ground-water components to estimate ground-water discharge from hydrographic areas and hydrographic-area subbasins and reported in the BARCAS summary report (Welch and Bright, 2007).

Potential Areas of Ground-Water Discharge

Studies to measure or estimate the amount of ground water used by phreatophytes in the Great Basin region began in 1910 with a study of ET by saltgrass *(Discichlis spicata)* (Lee, 1912). Over the following years, investigators began studying other phreatophytic vegetation of the Great Basin including greasewood *(Sarcobatus vermiculatus)*, rabbittbrush *(Chrysothamnus nauseous)*, and other less common shrubs (White, 1932). The methodologies developed during these studies provided the framework for a series of reconnaissance studies within Nevada that began in 1945 and continued into the 1970s. The reconnaissance studies were part of a cooperative program between the State of Nevada and the USGS to determine the quantity, quality, and distribution of the water resources in the State. The reconnaissance studies nearly always mapped the distribution of phreatophytes and their densities by using standard field techniques as part of an effort to estimate ET. Initially, the phreatophyte extents were mapped from 1:250,000-scale maps, and later from 1:62,500-scale maps (Patrick A. Glancy, U.S. Geological Survey, oral commun., 2006).

Harrill and others (1988) compiled maps of areas where shallow ground water is consumed by ET for the Great Basin part of Nevada. These maps have been used extensively to define the general extent of ground-water discharge areas and were used by these investigators in an effort to delineate major ground-water flow systems in the Great Basin region of Nevada, Utah, and adjacent States. The delineated areas where shallow ground water is consumed by ET that were evaluated by Harrill and others (1988) in the study area were mapped primarily by using the early reconnaissance studies. Discharge area boundaries were scaled photographically to a 1:750,000-scale map (James R. Harrill, U.S. Geological Survey, oral commun., 2006) and recently have been digitized and stored in a geographic information system (GIS) as part of this study.

Table 1. Evapotranspiration (ET) units identified, delineated, and mapped for different vegetation and soil conditions in potential areas of ground-water discharge in the Basin and Range carbonate-rock aquifer system study area, Nevada and Utah, September 2005–August 2006.

ET-unit name	ET-unit description	Photograph
Xerophytic	Area of no substantial ground-water evaporation. Area dominated by bare dry soil and/or sparse, non-phreatophytic vegetation.	
Open Water	Area of open water including reservoirs, ponds. and spring pools.	
Marshland	Area dominated by dense wetland vegetation, primarily tall reeds and rushes, and some grasses. Vegetation cover typically is greater than 50 percent. Open water is present but typically less than 25 percent. Perennially flooded. Water at or very near surface. Depth to water typically is less than 1 foot.	
Meadowland	Area dominated by short, dense perennial grasses, primarily marsh and meadow grasses. Unit includes occasional desert shrubs and trees, primarily Rocky Mountain junipers and cottonwoods. Vegetation cover typically is greater than 50 percent. Soil typically is moist except in later summer and autumn. Depth to water table typically is less than 5 feet.	
Grassland	Area dominated by short, sparse, perennial grasses, including salt grass, and sod and pasture grasses, typically a mix of vegetation types. Unit includes sparse desert shrubs and occasional trees, primarily Rocky Mountain junipers or cottonwoods. Vegetation cover is between 10 and 100 percent. Soil typically is damp to dry. Depth to water table typically is less than 8 feet.	
Moist Bare Soil	Area dominated by moist playa. Near surface soil is damp throughout much of the year. Water table is near or below land surface. Depth to water typically is less than 10 feet.	
Dense Desert Shrubland	Area dominated by sparse desert shrubs, including greasewood, rabbitbrush, shadscale, big sagebrush, and saltbush. Shrubs typically are mixed. Vegetation cover typically is greater than 25 percent. Depth to water can range from about 3 to 50 feet.	
Moderately Dense Desert Shrubland	Area dominated by sparse desert shrubs, including greasewood, rabbitbrush, shadscale, big sagebrush, and saltbush. Shrubs typically are mixed. Vegetation cover typically ranges from 10 to 30 percent. Depth to water can range from about 3 to 50 feet.	
Sparse Desert Shrubland	Area dominated by sparse desert shrubs, including greasewood, rabbitbrush, shadscale, big sagebrush, and saltbush. Shrubs typically are mixed. Vegetation cover typically ranges from 5 to 15 percent. Depth to water can range from about 3 to 50 feet.	
Dry Playa	Area dominated by dry playa. Soil typically dry year round. Water table below land surface. Depth to water typically is greater than 10 feet. This unit may not contribute to ground-water discharge.	
Recently Irrigated Cropland—Historically Mixed Phreatophyte	Area dominated by irrigated cropland. Soil moisture varies with irrigation practice. Water table is below land surface. Depth to water table typically is greater than 5 feet. Prior to irrigation, the unit likely was dominated by sparse desert shrubs to grassland.	

Nichols (2001) mapped areas of ground-water discharge based on the outer boundary of phreatophytes. Nichols mapped these boundaries by using basic reconnaissance-type field methods. His mapping generally was done in early to mid-summer when contrast in the color of greasewood and other rangeland vegetation is high. Control points along roads or trails typically were established by using Global Positioning System (GPS) equipment. Satellite data, aerial photography, and elevation models were used along with these established control points to map the complete phreatophyte boundary at a scale of 1:24,000. This general mapping technique also was used by Laczniak and others (2001) in developing ground-water discharge estimates for the Death Valley regional ground-water flow system. Digital maps delineating the outer boundary of phreatophyte areas throughout central Nevada developed by Nichols (2001) are available in Smith and others (1999) and were acquired for this study.

The Southern Nevada Water Authority (SNWA) mapped areas of ground-water discharge in selected hydrographic areas of eastern Nevada in 2004 (Michael Wallen, Southern Nevada Water Authority, oral commun., 2006). Boundaries previously mapped by Nichols (2001) and aerial photography and other available GIS data were used to guide field and mapping efforts. These boundaries were acquired by the USGS for use in this study.

The boundaries established by Harrill and others (1988), Nichols (2001), and the SNWA all were used to guide field activities and mapping efforts directed at delineating potential areas of ground-water discharge in the study area. The boundaries mapped by these previous investigations were integrated and compared. Identified discrepancies were resolved by field verification efforts conducted in mid-July 2005. The final boundary identifies the outer extent where shallow ground water may be consumed by ET. The area within this boundary is referred to as a potential area of ground-water discharge and the area outside the boundary is assumed to be an area of no ground-water discharge. The potential area of ground-water discharge within a hydrographic area can be a single area delineated by one continuous boundary or can be multiple areas. The size and number of these areas within a hydrographic area is independent of valley size.

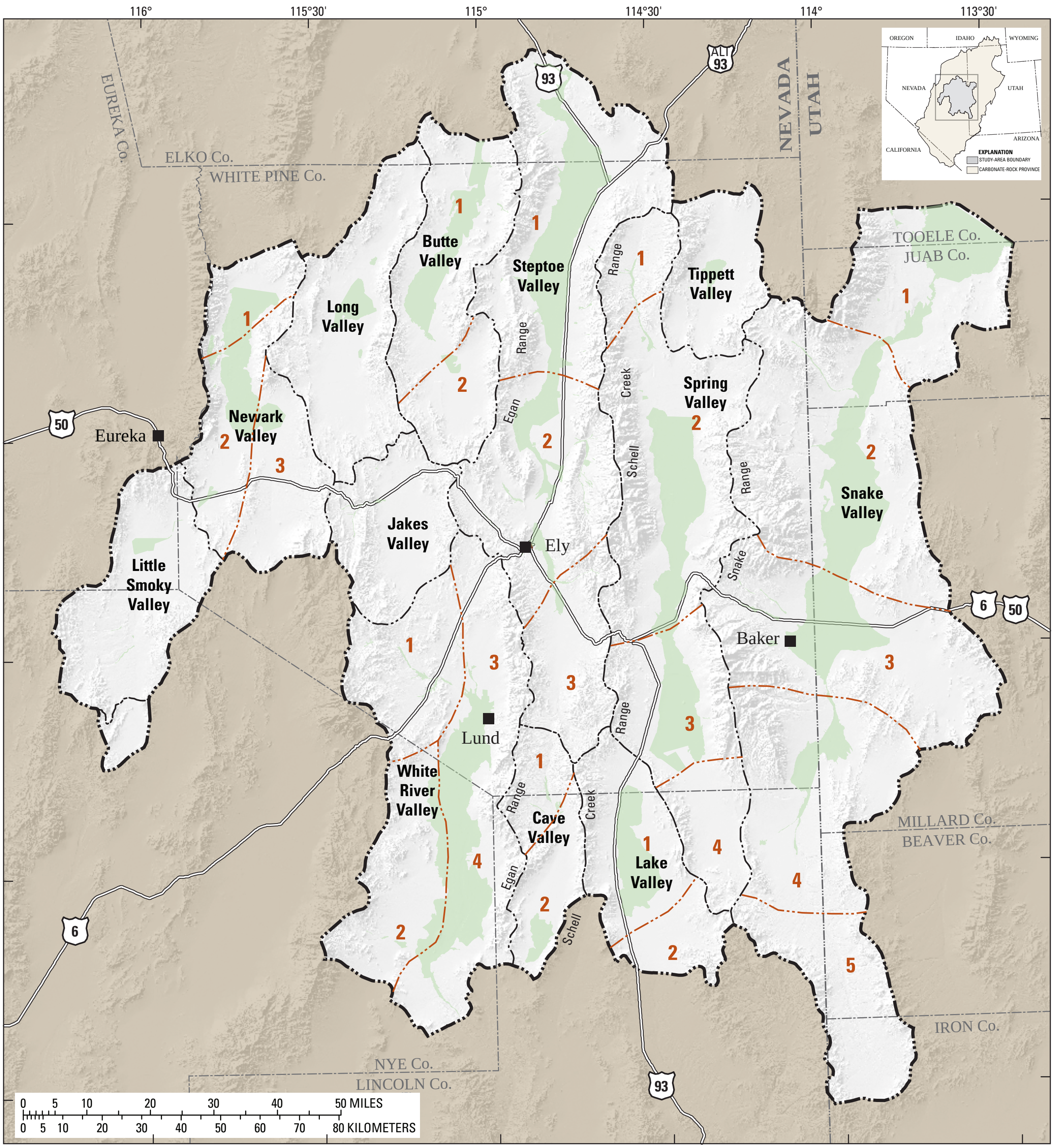
Many of the valleys in the study area are large and often difficult to visit because accessible roads and trails are lacking. A helicopter survey was used to map phreatophyte boundaries in selected valleys during a 2-day period in June 2005. The helicopter was equipped with GPS equipment to record flight-path coordinates. The helicopter flew at an altitude of about 100 ft above land surface and at a speed of about 80 mi/h. Mapping of phreatophytes such as greasewood at this time of year from the air is straightforward, considering the greenness of greasewood compared to the many nonphreatophytic species present in the area. A video clip (clip 1) of a flight through Snake Valley illustrates the contrast and visibility of greasewood in a discharge area typical of the study area. The video clip begins with the helicopter flying northward with the greasewood shrubs on the right and the rangeland grasses on the left. Near the end of the clip the helicopter follows the greasewood boundary by making a left turn. The potential areas of ground-water discharge used to calculate ET in the study were developed by combining and integrating phreatophyte boundaries delineated in previous studies, numerous field mapping efforts, and the phreatophyte extents mapped by the helicopter survey. Potential areas of ground-water discharge as mapped for the study are shown in figure 3. Specific data sources used to delineate the potential areas of ground-water discharge within each hydrographic area are reported in table 2.

Delineation of Evapotranspiration Units

An ET-unit map was created by using data from SWReGAP ecological systems, interpreted Landsat data from multiple dates, and Landsat MSAVI and Tasseled Cap products. An explanation of the data used, the processing techniques, and a field accuracy assessment are described in the following section.

Southwest Regional Gap Analysis Program

The SWReGAP identifies 125 land-cover classes referred to as ecological systems. An ecological system is a mid-scale classification unit defined by NatureServe http://www.natureserve.org/publications/usEcologicalsystems.jsp. Ecological systems represent recurring groups of biological communities that exist in similar physical environments. Selected classes of the SWReGAP that conform with characteristics of defined ET units were used in developing ET-unit distributions. The ET units defined by SWReGAP classes are marshlands, dry playa, and open water bodies. The mapping of these SWReGAP classes relied on multiple date imagery over a season and is consistent with the NLCD. Other ecological systems also were evaluated as to whether they adequately represented the extent of other ET units. Other evaluated systems included mixed salt desert scrub, greasewood flat, and big sagebrush shrubland. Field observations indicated that these ecological systems did not correlate well with ET units and tended to map an area larger than the outer extent of potential areas of ground-water discharge.



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

EXPLANATION

Potential areas of ground-water discharge

Boundary of study area

Boundary of hydrographic area

4 Boundary of subbasin and No.

Figure 3. Potential areas of ground-water discharge in the Basin and Range carbonate-rock aquifer system study area, Nevada and Utah.

Table 2. Potential areas of ground-water discharge mapped by hydrographic area in the Basin and Range carbonate-aquifer system study area, Nevada and Utah.

[**Helicopter:** Aerial mapping done during 2005 study using helicopter. **Southern Nevada Water Authority (SNWA)**: Field verified column indicates that hydrographic area was visited and that the boundary was checked by field personnel in 2005 (Michael Wallen, unpub. data, 2005)]

Hydrographic area	Method or Report				Field verified
	Heli-copter	SNWA	Nichols (2001)	Harrill and others (2005)	
Butte Valley		×	×	×	×
Cave Valley	×	×			
Jakes Valley		×	×		×
Lake Valley	×			×	×
Little Smoky Valley			×	×	×
Long Valley		×	×	×	×
Newark Valley			×	×	×
Snake Valley	×	×		×	
Spring Valley		×	×	×	×
Steptoe Valley		×	×	×	
Tippett Valley			×		
White River Valley	×	×		×	×

Landsat Thematic Mapper Imagery

Landsat Thematic Mapper imagery was used to delineate ET units in the study area. Landsat satellites orbit the Earth such that they acquire data over the same area at the same time every 16 days. These Earth-orbiting satellites are equipped with sensors to detect and acquire solar-reflected and earth-emitted radiation. Spectral reflectance, as acquired by Landsat sensors, represents an average value over a pixel (picture element) that measures about 100 ft by 100 ft. These pixel dimensions define the spatial resolution of the imagery.

Landsat data are available as scenes that image an area measuring about 115 mi by 115 mi. Each scene is defined by a path and row number. Multi-scene units are defined as consecutive scenes (rows) within a single path acquired and archived on the same date. Two multi-scene units were acquired to delineate ET units in the study area: (1) entity-id lt5039032000019419 inclusive of scenes acquired July 12, 2005, along path 39 at rows 32, 33 and 34; and (2) entity-id lt5040032000018400 inclusive of scenes acquired July 3, 2005, along path 40 at rows 32, 33, and 34. These scenes were selected because they met the criteria required to best delineate ET units. Scenes were contemporary with other ongoing field and data-collection activities being conducted as part of the study. Experience based on recently completed ET studies indicates that the optimum acquisition dates for delineating ET units in the study area fall between late June and early July—June 21 being the day with the longest daylight hours (a period of peak solar radiation), and early July, the approximate period when transpiration by phreatophytes is near its peak. Another factor considered in image selection is the potential influence of any recent precipitation. Snowpack telemetry (SNOTEL) sites operated by the Natural Resources Conservation Service were reviewed at Ward Mountain, located south of Ely and Berry Creek, just east of Ely (fig. 2). On the basis of data collected from these telemetry sites, no significant precipitation had occurred since June 21, and therefore, vegetative conditions captured in these images are assumed not to be influenced by local precipitation.

All acquired imagery was georeferenced to allow geospatial evaluations and direct comparison with other spatially referenced datasets. Georeferencing assigns map coordinates to an image by using known ground control points and the corresponding image row and column. A mathematical transformation equation is determined to relate the image to map coordinates (Lillesand and Kiefer, 1987). Previously georeferenced Landsat imagery by the USGS that was acquired in 2000 was used in the georeferencing process. Corrections to georeference the 2005 images were applied by using a first-order polynomial equation. Each 2005 multi-scene image used between 30 and 35 control points. The root mean square error or positional accuracy for each multi-path image was about 100 ft.

Image standardization is the process of normalizing imaged spectral data for differences in sun illumination geometry, atmospheric effects, and instrument calibration. Standardization is required to accurately compare pixel spectral reflectance between images of different dates. Pixel values in each image were standardized by using software developed and distributed by the Remote Sensing and GIS Laboratory of Utah State University http://www.gis.usu.edu/docs/projects/swgap/ImageStandardization.htm. For atmospheric corrections, the technique COST without Tau was used. The interested reader is directed to Huang and others (2007*)* for more detail on the normalization procedure.

Recently Irrigated Cropland

Recently irrigated cropland was delineated for the study area by Welborn and Moreo (2007). These investigators digitized cropland areas by using Landsat imagery from 2000, 2002, and 2005. Digitized field delineations were stored as polygons in an ArcGIS geodatabase and attributed with information including water source, method of application, and crop type. Each digitized field was field checked and verified during the summer of 2005.

Modified Soil Adjusted Vegetation Index and Tasseled Cap Transformation

ET units not mapped by SWReGAP were delineated by using the Modified Soil Adjusted Vegetation Index (MSAVI) (Qi and others, 1994) and a Tasseled Cap transformation (Huang and others, 2002) from normalized Landsat data. A vegetation index is a number that is generated by the combination of remote sensing bands and has some relation to the amount of vegetation in a given pixel. The MSAVI is an index which removes soil influences from the vegetation index at sparse plant cover. Because sparsely vegetated conditions are most important in the Great Basin, the MSAVI is considered an appropriate index from which to map changes in plant cover. The Tasseled Cap transformation is being used to develop land-cover classes for the NLCD. The Tasseled Cap transformation compresses all the satellite spectral bands into a few bands associated with physical scene characteristics of brightness, greenness, and wetness. Brightness is a weighted sum of all Landsat reflectance bands, which is a response to changes in total reflectance, driven primarily by soil reflectance changes. Greenness contrasts the sum of the visible and near-infrared bands and has been shown to correlated to percentage canopy coverage. Wetness contrasts the sum of the visible and near-infrared bands against the sum of the longer wavelength bands (Crist and Cicone, 1984).

The MSAVI was used to map phreatophytic shrubs and grasses in the potential areas of ground-water discharge. Vegetation indices have been used often to quantify the abundance and vigor of vegetation imaged by multispectral sensors (U.S. Geological Survey EROS Data Center, 2006). The use of vegetation indices to map vegetation cover is based on the assumption that the greener and denser the vegetation, the greater the vegetation index. Nichols (2001) takes advantage of this relation and uses the MSAVI to quantify the amount of ground water lost to the atmosphere by ET. In applying this approach, Nichols assumes that ground-water ET is a function of ET, and that ET is a function of plant cover. Nichols (2001, p. B8) uses MSAVI to develop ranges in plant cover and describes the type or types of vegetation occurring in each defined plant-cover range. In general, shrubs dominate where plant cover is less than 35 percent and grasses dominate where plant cover is greater than 35 percent. Xerophyte conditions, areas where phreatophytes are absent and bare soil dominates, exist where plant cover is less than about 7 percent. These general relations between percentage of cover and plant type also were observed in the study area during field visits. ET units were defined by using breaks in MSAVI values to correlate with boundaries between xerophyte areas (no substantial ground-water discharge) and phreatophyte areas dominated by sparse desert shrubland, moderately dense desert shrubland, dense desert shrubland, grassland, or meadowland.

MSAVI values are dimensionless and range from -1.0 to 1.0. For this study, values from 0 to 1 were scaled from 0 to 200. Values less than 0 were set to 0. Values 0 to 14 were identified as xerophyte, 15 to 20 are sparse desert shrubland, 21 to 28 are moderately dense desert shrubland, 29 to 43 are dense desert shrubland, 44 to 55 are grassland, and 56 to 92 are meadowland. The MSAVI values from 93 to 200 usually occurred where ET units were assigned to recently irrigated cropland or marshland. If not, they were assigned to meadowland.

The Tasseled Cap brightness, greenness, and wetness bands were used to map areas of moist bare soil. An unsupervised classification based on these three bands was applied to the data set. Unsupervised classification clusters pixels in a data set according to statistics only, without any user-defined training classes. The user then identifies clusters that relate to what is being mapped. Yelland Dry Lake in northern Spring Valley and an area around Twin Springs in northern Snake Valley (fig. 2) were used to identify the moist bare soil. These areas of moist bare soil are intended to represent locations where moisture is present throughout much of the year and where the depth to ground water is shallow.

The Tasseled Cap band of greenness also was considered in mapping shrubs and grasses. The SNWA established shrub transects in different hydrographic areas of the study area. These shrub transects defined the occurrence of shrubs over a 328-foot linear length of vegetation. Forty-five of these were used to define the percentage of plant cover. Values of the Tasseled Cap greenness and MSAVI at each transect were compared to the percentage of plant cover. The MSAVI showed a slightly higher correlation than the Tasseled Cap (fig. 4). The correlation of the MSAVI and the Tasseled Cap greenness with the percent plant cover is similar, but the MSAVI correlates better with the lower percentage of plant cover. The MSAVI was chosen to map the ET units representing shrubs and grasses.

Assembly and Distribution of Evapotranspiration Units

A map presenting the spatial distribution of ET units was developed by using units defined by the MSAVI and Tasseled Cap analysis, the delineation of recently irrigated cropland, and the data of SWReGAP products. A single ET-unit map was created from ET units developed by each of these different data sets by layering the data according to priorities. The initial ET-unit map was assembled by first using the MSAVI data set. The moist bare soil ET unit, derived by the Tasseled Cap procedure, replaced the MSAVI data wherever moist bare soil occurred. The ET units of marshland, open water, and dry playa, derived from the SWReGAP data, replaced the previous

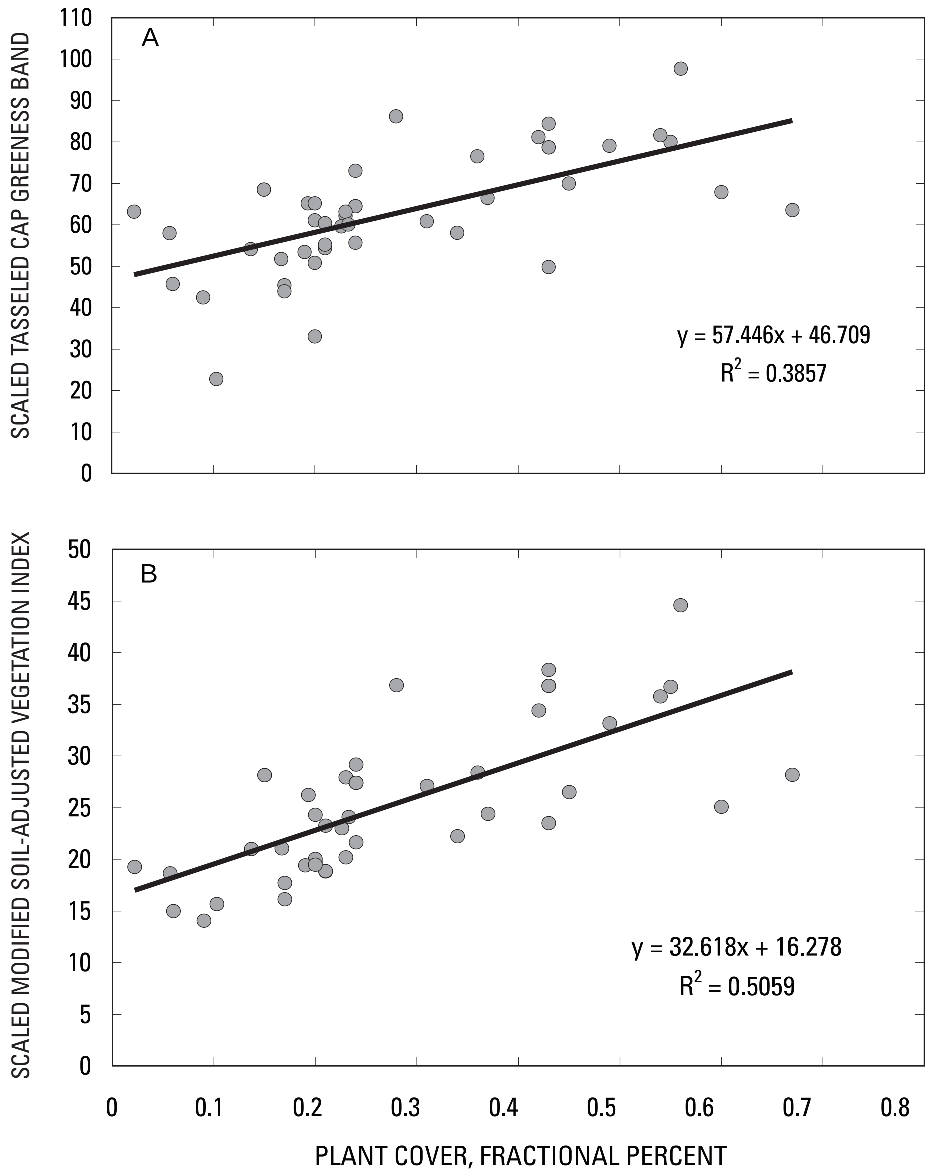


Figure 4. Percentage of plant cover determined from transects compared to scaled values of (A) Tasseled Cap *g*reenness band and (B) modified soil *a*djusted vegetation index.

MSAVI and Tasseled Cap data wherever those ET units occurred. Finally, the recently irrigated cropland, derived from photo interpretation of the three Landsat data sets, replaced ET units from the other data sets wherever recently irrigated cropland occurred. The ET units and the source of their information are summarized in table 3.

Table 3. Evapotranspiration (ET) units and the source used to develop the ET-unit map.

ET unit	Source
Open water, marshland, dry playa	SWReGAP
Recently irrigated cropland	Landsat 2000, 2002, 2005
All shrubland, grassland, and meadowland	MSAVI from 2005
Moist bare soil	Tasseled Cap from 2005
Xerophyte	MSAVI from 2005

A filtering technique was applied to all ET units except those representing recently irrigated cropland and those developed from SWReGAP. The filtering technique added and removed pixels on the basis of a minimum mapping unit. The size of the minimum mapping unit depends on the scale and resolution of the spectral data set being used to delineate land cover (Anderson and others, 1976) and on the intended use of the map product. The processing of SWReGAP by the Gap Analysis Program included a minimum mapping unit filter that was set to 1.1 acres as described in the SWReGAP for Nevada, Utah, New Mexico, Colorado, and Arizona Project Status (U.S. Environmental Protection Agency, 2007). The procedure is described in section, "Mapping Methods and Accuracy" of the Southeast Idaho Mapping Zone Documentation (U.S. Geological Survey, 2007a). This same procedure and criteria were used to filter the ET units defined by the MSAVI and Tasseled Cap. The minimum mapping unit was set at four adjacent pixels which measure about 35,000 ft^2 or 0.8 acre in the source imagery. An area of this size provides sufficient resolution within the fetch areas of ET stations established as part of the study (Moreo and others, 2007). The ET units as mapped within the delineated potential areas of ground-water discharge by using the filtering technique and the methods and priorities previously discussed are shown in figure 5.

The shrubland units are the most prominent ET unit in the study area (fig. 6). The three shrubland ET units account for about 83 percent of the acreage delineated as potentially contributing to ground-water discharge. The more-densely vegetated meadowland and marshland ET units typically occur near springs and along major spring-drainage channels near the center of the valley floor, whereas the less-densely vegetated ET units typically occur along the outer edges of discharge areas (fig. 5). The more-densely vegetated ET units of marshland, meadow, and grassland account for only about 6 percent of the total delineated acreage, whereas, the least-vegetated units (dry playa, moist bare soil, sparse desert shrubland, moderately dense desert shrubland, and dense desert shrubland) account for about 91 percent. About 1,700 mi^2 are covered with phreatophytes or moist bare soil in the study area and potentially discharge ground water. The delineated acreage of each ET unit is shown by major hydrographic area in table 4.

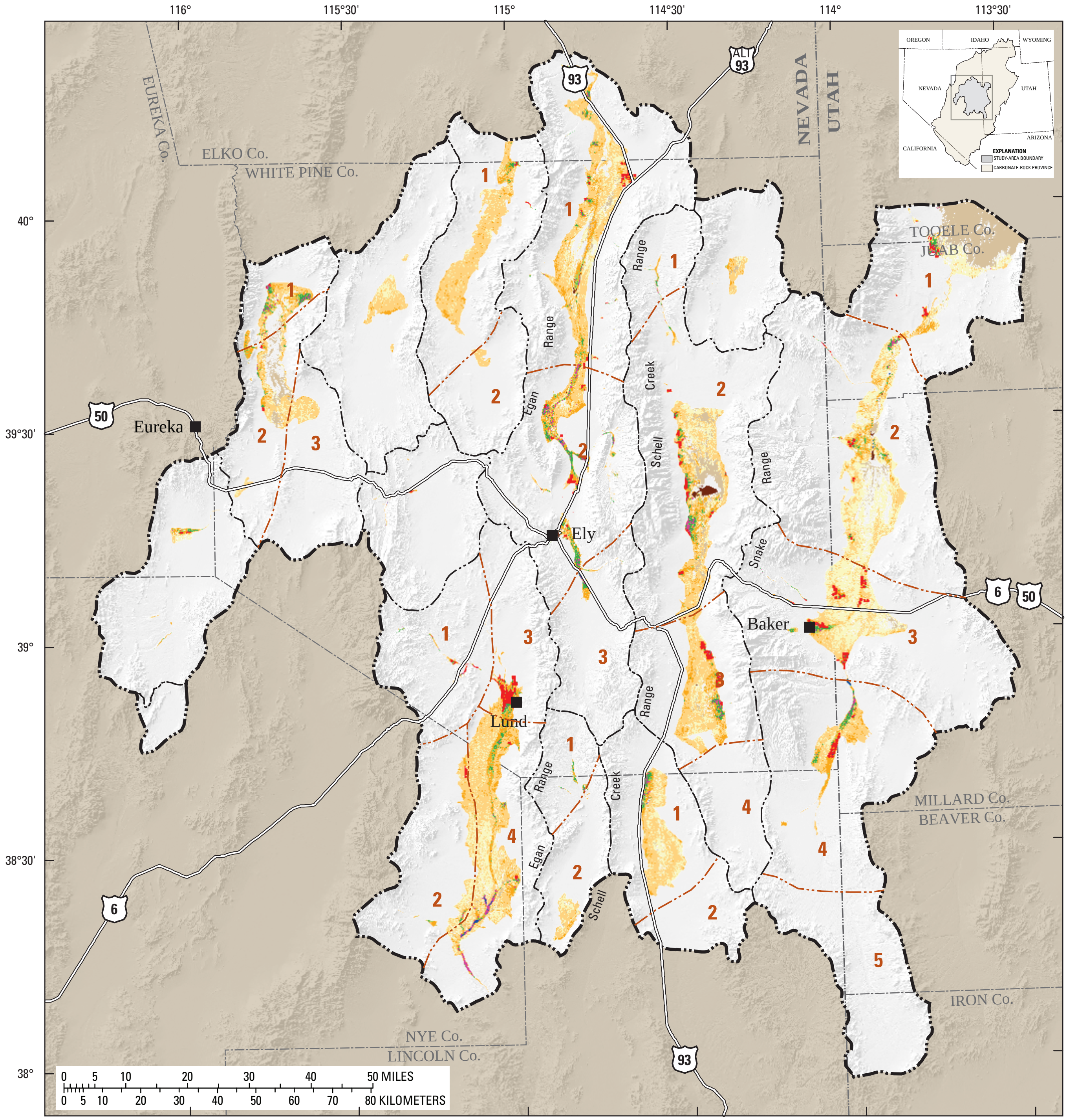
ET-unit acreage also is provided in table 4 by subbasin. Subbasins are internal divisions within a hydrographic area. Major hydrographic areas in the study area were subdivided into these smaller internal units to help spatially resolve and refine the current understanding of interbasin flow. Subbasins are delineated such that their boundaries represent potential hydrologic divides within the larger hydrographic area and are based primarily on geophysical interpretations of gravity data and assumed properties of known subsurface rock (Sweetkind and others, 2007). Subbasin boundaries commonly were delineated to coincide with interpreted intrabasin shallow bedrock. As presented in table 4, the subbasins within a hydrographic area are not named but identified numerically (fig. 2). The first subbasin in a hydrographic area is the northernmost area. If a hydrographic area is not divided into subbasins, it is identified as subbasin 1.

Evapotranspiration-Unit Field Accuracy

An assessment of the mapped accuracy of the ET units provides information to potential users about the maps reliability and usefulness as related to some intended purpose. Some needs require high-accuracy maps, whereas others may require much less spatial accuracy. Map quality and accuracy typically are assessed by using a probability based sampling design and relatively large number of samples per class or map unit. This type of assessment often is referred to as a map accuracy assessment. The quality of a map's assessed accuracy depends on the quality of the information used to ground truth or verify the map data. For the intended purpose of this map product, field-based ground-truth observations were considered sufficient to assess accuracy. A discussion of map accuracy, methods, and protocol can be found at U.S. Geological Survey (2007b).

Many different sources can introduce bias into an accuracy assessment. For example, bias can be introduced by sampling only along roads that provide easy access. The accuracy of a mapped ET unit can be affected by the nature of its boundary. For example, transitional boundaries are more difficult to locate, whereas boundaries defined by an abrupt change from one unit to the next are more easily detected. Because the ET-unit map has sharp and distinguished boundaries to delineate between different ET units, whereas in nature, different ET units transition spatially, an ET-unit map does not reflect this transitional nature. The ET-unit map rather provides estimates of acreages associated with generalized vegetation and/or soil-moisture conditions from which to make estimates of evapotranspiration.

Field assessment of the accuracy of the shrubland, grassland, meadowland and xerophyte ET units in Snake and Spring Valleys was done during August and September of 2006. In Snake Valley 28 field sites were visited and in Spring Valley 38 were visited. The guidelines used to direct field activities closely followed those described by the SWReGAP in the "Field Methodologies and Training Manual for Nevada Field Crews" document (U.S. Environmental Protection Agency, 2003).



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

EXPLANATION

ET units

- Open water
- Irrigated cropland
- Marshland
- Meadowland
- Grassland
- Dense desert shrubland
- Moderately dense desert shrubland
- Sparse desert shrubland
- Moist bare soil
- Dry playa

Boundary of study area

Boundary of hydrographic area

4 **Boundary of subbasin and No.**

Figure 5. Spatial distribution of evapotranspiration (ET) units in the Basin and Range carbonate-rock aquifer system study area, Nevada and Utah.

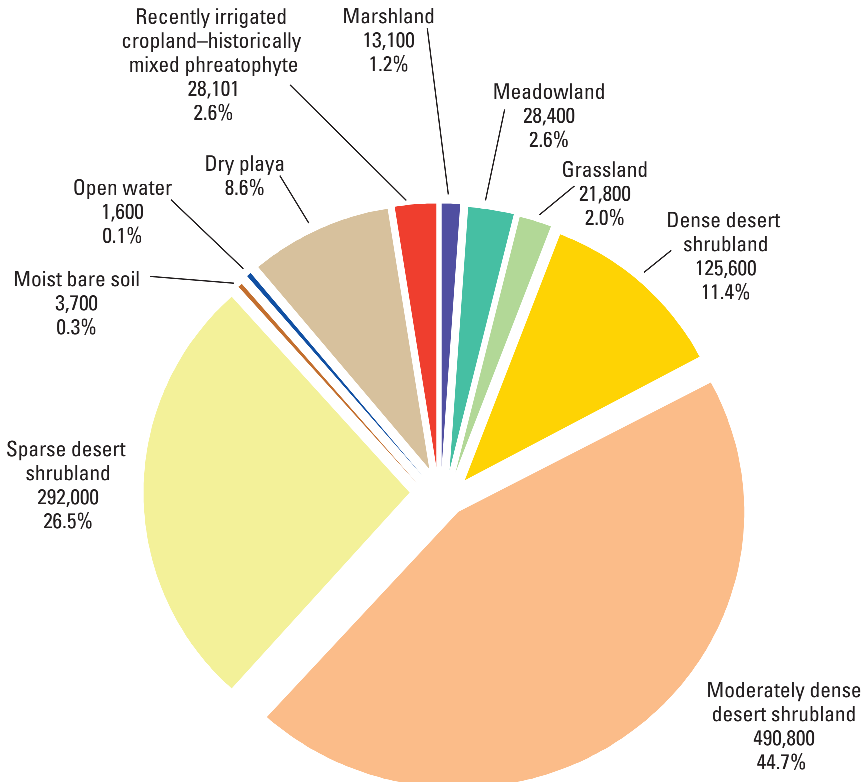


Figure 6. Evapotranspiration (ET)-unit acreage and percentage in the Basin and Range carbonate-rock aquifer system study area, Nevada and Utah.

The characterization of shrub-dominated environments requires an estimate of the approximate area of vegetation cover. Making this estimate whether by observation or by measurement can be difficult where plant vigor, dimensions, and spacing vary. To help guide this effort, field personnel viewed charts which have been used to estimate the percentage composition of rocks and sediments (Compton, 1962, p. 332-333). With these charts, the black specs were considered to be shrubs in order to estimate the percentage of plant cover within the circle. Estimates of plant cover based on these charts are expected to be accurate to within about 5 percent.

A single evaluation of how well the field crew estimated vegetation cover by using the geology field charts was done near the Snake Valley ET Station. An estimate of the percentage of vegetation cover was made by performing an unsupervised classification (as explained in the "Modified Soil Adjusted Vegetation Index and Tasseled Cap Transformation" section of this report) from a photograph taken with a hand-held digital camera during the helicopter survey. The photographic image covered an area of about 50 by 40 ft with a spatial resolution of approximately 0.3 in. and is shown in figure 7*A*. An unsupervised classification of this photograph produced 32 different clusters. These clusters were combined into green plant leaf, leafless wood, soil, and shadow groups. This was done by identifying those clusters that were green colors on the photograph which represented green vegetation, for example. This also was done for the various soil colors, dark shadows, and leafless wood. The resulting percentage of each group was 13.1 for green plant leaf, 4.8 for leafless wood, 60.2 for soil, and 21.9 for shadows (fig. 7*B*). Some shadowed area is likely to include active greasewood. Non-green leafed wood is not considered shrub cover in that it does not contribute to ET and is not characterized as vegetation by vegetation indexes computed from remotely sensed spectral data. Assuming that about one tenth of the shadowed area is active vegetation, shrub cover for this area is estimated at about 15 percent. This estimate was consistent with the 10- to 20-percent moderately dense desert shrubland estimated by field observation at this site using the geology field charts to estimate percentage of vegetation cover (Moreo and others, 2007, table 3, p. 13).

Map accuracy can be expressed as overall accuracy, producer accuracy, and user accuracy. To determine map accuracies for this study, the ET unit identified from the field observations was compared to the ET unit of the map. Overall accuracy is the most general measure and is calculated as the number of correct observations divided by the total number of observations. This does not mean that every ET unit was successfully classified at that accuracy. The producer's accuracy relates to the probability that a field visited ET unit will be correctly mapped on the ET-unit map and measures the errors of omission. In contrast, the user's accuracy indicates the probability that a sample from the ET-unit map actually matches what is found at the field visited sites and measures the error of commission (U.S. Geological Survey, 2007b).

Table 4. Evapotranspiration (ET)-unit acreage delineated by hydrographic area and subbasin in Basin and Range carbonate-rock aquifer system study area, Nevada and Utah.

[**Hydrographic area subbasin:** SB is subbasin. Number is subbasin number. **Active ET-unit** total does not include xerophytic acreage. –, not applicable]

Hydro-graphic-area sub-basin	ET-unit acreage, in acres											
	Xero-phytic	Marsh-land	Meadow-land	Grass-land	Dense desert shrubland	Moderately dense desert shrubland	Sparse desert shrubland	Moist bare soil	Open water	Dry playa	Irrigated cropland	Active ET-unit total
Butte Valley												
1	141	64	478	615	5,827	50,897	7,891	0	4	0	202	65,977
2	8	0	0	0	79	3,244	371	0	0	0	0	3,694
Total	149	64	478	615	5,906	54,141	8,262	0	4	0	202	69,671
Cave Valley												
1	2	81	503	280	842	354	6	0	0	0	0	2,066
2	141	0	0	2	534	7,005	3,546	0	0	194	0	11,282
Total	143	81	503	283	1,376	7,359	3,552	0	0	194	0	13,348
Jakes Valley												
–	27	25	91	146	540	203	6	0	26	0	187	1,224
Lake Valley												
1	962	630	1,143	822	4,077	32,384	16,296	0	26	94	0	55,472
2	0	0	0	0	0	0	0	0	0	0	0	0
Total	962	630	1,143	822	4,077	32,384	16,296	0	26	94	0	55,472
Little Smoky Valley												
Northern part	409	62	355	379	1,191	1,678	2,108	0	0	5	216	5,994
Central part	0	0	0	0	0	0	0	0	0	0	0	0
Total	409	62	355	379	1,191	1,678	2,108	0	0	5	216	5,994
Long Valley												
–	78	2	3	4	1,219	12,155	4,901	0	0	0	0	18,283
Newark Valley												
1	5,218	996	2,247	1,397	6,228	11,110	2,556	1	1	1,111	208	25,856
2	8,606	192	639	661	3,620	14,284	6,035	0	1	10,625	285	36,341
3	110	0	1	0	172	7,526	2,830	0	0	24	0	10,553
Total	13,933	1,188	2,887	2,058	10,020	32,920	11,421	1	2	11,760	493	72,750
Snake Valley												
1	8,603	334	693	347	2,527	6,854	17,772	0	0	56,499	1,785	86,810
2	16,034	541	1,746	1,463	7,988	34,568	66,023	578	115	5,553	1,138	119,711
3	3,896	432	1,696	799	3,638	26,758	46,090	0	100	1,081	5,136	85,729
4	92	535	1,816	834	7,368	17,297	3,254	0	212	0	1,873	33,189
5	0	0	0	0	0	0	0	0	0	0	0	0
Total	28,625	1,842	5,951	3,443	21,520	85,476	133,139	578	427	63,133	9,932	325,440
Spring Valley												
1	1	119	303	154	747	377	61	0	0	0	0	1,761
2	5,761	1,259	3,223	2,386	13,055	43,870	23,563	2,810	6	15,509	2,867	108,549
3	1,239	699	1,639	1,007	9,301	39,639	12,083	9	0	520	2,492	67,389
4	0	0	0	0	0	0	0	0	0	0	0	0
Total	7,001	2,076	5,165	3,547	23,104	83,886	35,707	2,819	6	16,029	5,359	177,698
Steptoe Valley												
1	8,762	790	2,251	2,442	16,691	69,506	26,861	237	5	2,464	2,766	124,013
2	968	2,993	5,171	3,813	13,197	15,992	3,158	21	147	0	2,354	46,848
3	17	152	498	254	1,427	985	76	0	287	0	0	3,679
Total	9,746	3,936	7,920	6,509	31,315	86,483	30,096	258	440	2,464	5,120	174,540
Tippet Valley												
–	42	0	21	51	1,013	4,569	1,623	0	0	497	0	7,775
White River Valley												
1	46	142	340	188	737	748	134	0	0	0	841	3,131
2	239	48	293	253	2,419	15,552	9,881	0	0	19	490	28,954
3	27	104	1,114	1,083	4,733	4,953	541	0	0	9	4,965	17,503
4	2,006	2,877	2,182	2,413	16,450	68,298	34,353	14	685	941	295	128,508
Total	2,318	3,172	3,929	3,936	24,340	89,551	44,909	14	685	970	6,591	178,096
Basin and Range carbonate-aquifer system study area												
Total		13,079	28,444	21,793	125,620	490,805	292,020	3,670	1,616	95,145	28,101	1,100,292

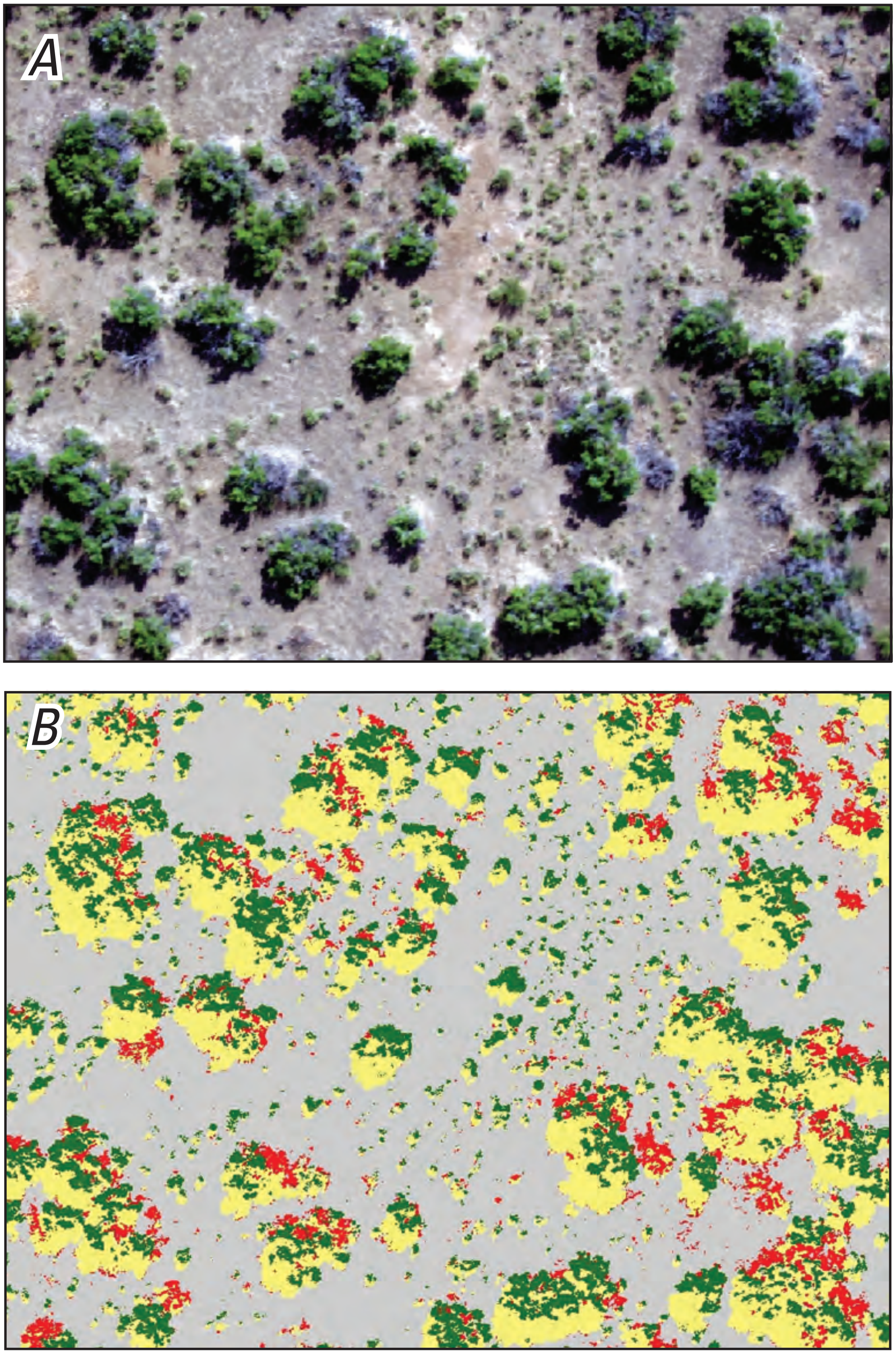


Figure 7. (*A*) natural color and (*B*) color-classified photograph of greasewood near ET station in Snake Valley, Nevada. Photograph taken looking downward from helicopter during aerial survey, June 6, 2005.

Accuracies for the SWReGAP ecological systems were computed qualitatively. A detailed description of these accuracies can be obtained from the SWReGAP ‘PROVISIONAL’ Landcover and Related Datasets document (Southwest Regional Gap Analysis Project, 2007a). Accuracies are presented as summaries that are brief descriptions provided by the teams involved in the mapping process. Summaries are intended to provide an evaluation on how well each class was mapped from the perspective of the land-cover mapping analyst, taking into consideration the number of training and reference samples in the observation sample set for the cover class and the team’s knowledge and familiarity with the mapping area. Two SWReGAP mapping zones, NV-4 and UT-1, are present in the study area. The qualitative summaries describing the accuracy of ecological systems representing open water, marshland, and dry playa ET units mapped in zones NV-4 and UT-1 are briefly summarized in table 5. The overall accuracy of the SWReGAP for all ecosystems in NV-4 and UT-1 is reported to be 53 and 59 percent, respectively (Southwest Regional Gap Analysis Project, 2007b). Table 5 also provides qualitative summaries for the desert shrubland, grassland, and meadowland ET units mapped as part of the study and based on field work described in the previous paragraph.

Table 5. Field accuracy assessment of evapotranspiration (ET)-unit map of Basin and Range carbonate-rock aquifer system study area, Nevada and Utah.

[NA, not applicable]

ET-unit name	Narrative	Accuracy, in percent correct	
		Producer	User
Open water	The number of reference sites is small. The unit generally mapped well.	[1]75/NA	[1]100/NA
Marshland	The number of reference sites is small in Nevada. In Utah, the number of reference sites is significantly larger. Confusion occurs with riparian woodland and shrubland.	[1]18/93	[1]25/100
Meadowland	Meadowland generally mapped well. The primary source of confusion was with grassland.	[2]88	[2]88
Grassland	The number of reference sites was small. The greatest confusion was with meadowland and sparse desert shrubland. Most of the conflicts correlated with the presence of a small annual forb known as *halogeten glomeratus*. Its presence was likely caused by above normal precipitation during the year.	[2]33	[2]33
Moist bare soil	Only Yelland Dry Lake was visited. At the time of the visit, conditions were extremely dry. The playa is known to be persistently moist and the depth to ground water ranges from about 4 to 10 feet (Todd Mihevc, Desert Research Institute, oral commun., 2006).	NA	NA
Dense desert shrubland	The number of reference sites was large. Comparison of mapped and observed conditions indicates that the unit mapped well.	[2]100	[2]53
Moderately dense desert shrubland	The number of reference sites was large. In general, the unit mapped well. Limited confusion occurs with sparse desert shrubland.	[2]69	[2]72
Sparse desert shrubland	The number of reference sites was adequate. Confusion occurs with moderately dense desert shrubland.	[2]67	[2]94
Dry playa	The number of reference sites in Nevada was small. In Utah, the number of reference sites was large. The ET unit was mapped well in Utah. Confusion occurs with salt desert scrub and greasewood flats.	[1]25/73	[1]33/25
Xerophyte	The number of reference sites was small.	[2]50	[2]50
Recently irrigated cropland	All irrigated fields (cropland) were checked and verified in the field. Misidentifications were corrected accordingly and assumed to be 100 percent accurate.	[3]100	[3]100

[1]Source is from SWReGAP, Nevada and Utah. First percent is for Nevada and second percent is for Utah.
[2]Source is from USGS and DRI field visits in Spring and Snake Valleys.
[3]Source is from USGS field visits in all valleys.

The overall accuracy of the ET units delineated from the MSAVI and Tasseled Cap procedures was 72 percent. In general, a number of errors occurred between ET units of one density with an ET unit of the next higher or lower density. For example, an area in the field of sparse desert shrubland was classified as moderately dense desert shrubland. This error can occur because of the difficulty to measure the percentage of vegetation cover. Another example of error is an area that in the field was observed to be sparse desert shrubland was mapped as the ET unit grassland. This probably was the result of an annual plant that was alive during the satellite overpass in the summer, but dormant during the field sampling. A more-accurate map describing the spatial distribution of desert shrub and grass ET units could be developed by using Landsat imagery acquired at different dates within a year and imagery acquired during different years.

Summary

The purpose of this report is to document the ET-unit map used to delineate areas of vegetation, open water, and moist soil that contribute to ET in the study area. This data set is referred as an ET-unit map.

The data sets used to develop the ET-unit map are based on Landsat satellite data. The SWReGAP program developed a five-state land cover map base on ecological systems. The ecological systems describing open water, marshlands, and dry playa were used to delineate those ET units. Landsat data were acquired for the dates of July 3 and 12 of 2005. To delineate ET units of shrubs and grasses, the Landsat data were used to produce the MSAVI, an index that relates to the greenness and density of plant growth. The ET units of meadowland, grassland, dense desert shrubland, moderately dense desert shrubland, and sparse desert shrubland were delineated. The 2005 imagery also was used to produce the Tasseled Cap transformation. The brightness, greenness, and moisture bands were used to identify ET units of moist bare soil. The 2005 imagery, along with Landsat imagery from 2002 and 2000, was used to identify recently irrigated croplands by photo interpretation.

The final ET-unit map was assembled from the SWReGAP, MSAVI, Tasseled Cap datasets, the interpretations from Landsat imagery and field mapping. The recently irrigated cropland was used as is and had the highest priority. The SWReGAP classes also were used as is and had the second highest priority. The moist bare soil derived from the Tasseled Cap transformation was used and had the next priority. Finally, the ET units from the MSAVI were used at the lowest priority. The MSAVI and Tasseled Cap data sets were filtered such that the minimum mapping unit was about 0.8 acre. The SWReGAP data had a minimum mapping unit of 1.1 acre. The boundary of potential areas of ground-water discharge was used as a mask allowing only those areas within the boundary to be used in the final ET-unit map.

Phreatophytic, xerophytic, and recently irrigated cropland in the study area identified from the ET-unit map have been summarized. About 1,675 mi^2 in the study area are covered with phreatophytes or moist bare soil that potentially discharged ground water. This area does not include acreage of recently irrigated croplands. An accuracy assessment of the ET units was conducted by field visits to Snake and Spring Valleys and has been summarized. The accuracy of the shrubland ET units, accounting for about 83 percent of the potential ground-water discharge acreage, indicated that 67 to 100 percent of the field sites visited was mapped correctly. The ET-unit map developed used a consistent approach to delineate ET units throughout the study area. The ET-unit map also included selected classes from a national land cover data set.

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For more information contact:
Director, Nevada Water Science Center
U.S. Geological Survey
2730 N. Deer Run Road
Carson City, Nevada 89701
http://nevada.usgs.gov

USGS

Smith and others

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