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Prepared by
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EXECUTIVE SUMMARY

An uncertainty analysis to support the Basin and Range Carbonate Aquifer System (BARCAS) study as an integral part of the water budget analysis for the project area was conducted. The main mission of the BARCAS study was to assess the water resources of the alluvial and carbonate aquifers in White Pine County, Nevada and surrounding areas in Nevada and Utah. This report documents an uncertainty analysis of mean annual ground-water discharge estimates. The objective was to quantify the uncertainty associated with estimates of annual ground-water discharge from 12 valleys (30 subbasins in total) under investigation. Monte Carlo simulations were conducted of 10,000 realizations with input parameters taken from randomly generated values for each individual subbasin based on the estimated statistics and assumed probability distributions of the precipitation rates, ET rates for each ET unit, and acreage associated with each ET unit. Input data for this analysis were obtained from the U.S. Geological Survey staff involved in the BARCAS study. The results of the Monte Carlo analysis show that the coefficient of variation (CV) of total ground-water discharge given the assumptions employed in the uncertainty analysis had a moderate value of 0.24, which indicated the uncertainty of total ground-water discharge estimates was not high given the assumptions employed in the uncertainty analysis. However, for some subbasins in the BARCAS study area, the uncertainty of ground-water discharge values might be quite large. Typically, however, subbasins with high uncertainty of ground-water discharge estimates contribute only a small portion of the total ground-water discharge and therefore a high uncertainty in these valleys did not necessarily translate into high uncertainty of ground-water discharge estimates for the entire BARCAS study area.

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INTRODUCTION

Federal legislation (Section 131 of the Lincoln County Conservation, Recreation, and Development Act of 2004) was enacted in December 2004 that directs the Secretary of the Interior, through the U.S. Geological Survey, the Desert Research Institute, and a designee from the State of Utah, to conduct a water resources study of the alluvial and carbonate aquifers in White Pine County Nevada and surrounding areas in Nevada and Utah. The main objectives of the project, termed the Basin and Range Carbonate Aquifer System (BARCAS) study, were to evaluate the following hydrogeologic characteristics: (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 discharge. Hydrogeologic data have been synthesized and evaluated to produce a conceptual understanding of the ground-water flow system in the BARCAS study area. The BARCAS study was completed in cooperation with the Bureau of Land Management. Welch and Bright (2007) provided a complete description of the BARCAS study.

Principal water budget components were estimated for the entire BARCAS study area. These include recharge, discharge, and inter-basin flow within and out of the study area. Of particular focus in this report is the amount of water lost from the study area through evapotranspiration (ET). Evapotranspiration is the process that transfers water from land surface and soil root zone to the atmosphere; it is the sum of evaporation from open water plus soil and transpiration by plants. Together these two processes are the primary mechanisms that remove water from the soil and the shallow water table, especially in the presence of phreatophytic vegetation that survives, in part, on the uptake of ground water. The mean annual ET from each Nevada Administrative ground-water basin (also called a hydrographic area or basin) was estimated for the BARCAS study using several techniques, including compiling values from the existing literature, conducting field-based measurements and analyzing satellite images.

Estimates of mean annual ground-water discharge obtained from the BARCAS study were based solely on estimates of mean annual ET developed during the study (*i.e.*, no other ground-water sinks existed in the study area). This was based on the assumption that all spring and seep flows discharged within the study area were recycled back into the shallow water table, later to be evaporated or transpired by the local phreatophytic vegetation. Estimates of natural ground-water discharge presented by Welch and Bright (2007) represent natural conditions and account only for ground water lost to the atmosphere.

Note that the estimates for ET rates, hydrographic area and the precipitation data and the associated statistics were obtained from the USGS. Given the large size of the study area (a total of more than 1.1 million acres in 12 valleys), and the dearth of previous studies of the valleys, ground-water discharge through ET was estimated using a rather sparse dataset. As a result, the ET rate and acreage uncertainty have significant influence on the ground-water discharge estimates carried out for the BARCAS study. This report documents an uncertainty analysis of mean annual ground-water discharge estimates. The uncertainty analysis was carried out as an integral part of the BARCAS water budget analysis. The objective of this analysis is to quantify the uncertainty associated with estimates of annual ground-water discharge from the study area addressed in the summary report (Welch and Bright, 2007).

Because discharge estimates are expected to be used in water budget analysis for the study area, it is beneficial to quantify the uncertainty associated with these estimates. The results of this analysis can be used to better understand the uncertainty associated with each valley in the area.

GROUND-WATER DISCHARGE ESTIMATES FOR THE BARCAS STUDY AREA

The volume of water lost to the atmosphere through ET can be computed as the product of the ET rate and the acreage of combined vegetation, open water, and moist soil that contribute to ET. Using this volumetric calculation, mean annual ET was computed for discharge areas within each hydrographic area in the BARCAS study area. Figure 1 shows 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 (from Smith *et al*., 2007).

The rate at which water is transferred from land and plant surfaces to the atmosphere defines the ET rate and is driven by radiative energy originating from the sun and other ecosystem parameters (soil moisture availability, leaf area, etc.). Evapotranspiration rates vary with vegetation type and density, soil type and moisture, and local micrometeorological factors. Evapotranspiration rates reported in the more recent literature were used to develop a range of mean annual ET for each ET unit inclusive of the variations associated with the different vegetation and soil-moisture conditions making up the ET units delineated for the study area (Welch and Bright, 2007). Annual ET ranges for selected ET units were augmented using field data collected at six eddy correlation sites deployed from September 1, 2005 to August 31, 2006. These sites were operated solely for this study by the USGS (Moreo *et al*, 2007).

The landscape was characterized by grouping areas of similar vegetation and soil conditions into unique and discrete thematic classes termed ‘ET units’. Each ET unit was assigned its own rate of ET based on the physical and biological properties of the specifically categorized vegetation and soil. Certain valleys were further subdivided into subbasins where each unit's ET rate in the subbasin was determined by linearly scaling the ET rate range computed for the unit. Scaling within the range was done using the average modified soil adjusted vegetation index (MSAVI) value of the unit computed over the subbasin from the Landsat Thematic Mapper (TM) imagery. The scaling procedure assigned the highest mean MSAVI value computed for any subbasin to the high value of the range and the lowest MSAVI value to the lowest value of the range. In other words, ET rates within the same classification for different subbasins within the same valley can have different values depending on the scaling (quantified by a scalar value). Please refer to Moreo *et al*. (2007) for more details about ET rate measurements and quantifications.

Sources other than ground water, such as direct precipitation and surface-water runoff, may also contribute to ET in discharge areas. Therefore, to accurately quantify ground-water discharge, surface-water contributions from local precipitation and runoff must be removed from estimates of ET. For this study, ground-water discharge was estimated on the assumption that the contribution to the mean annual ET rate by surface water inflow to the valley floor is negligible. This assumption was supported in part by infrequent flows to the valley floor. Moreover, it also was assumed that the precipitation component supporting

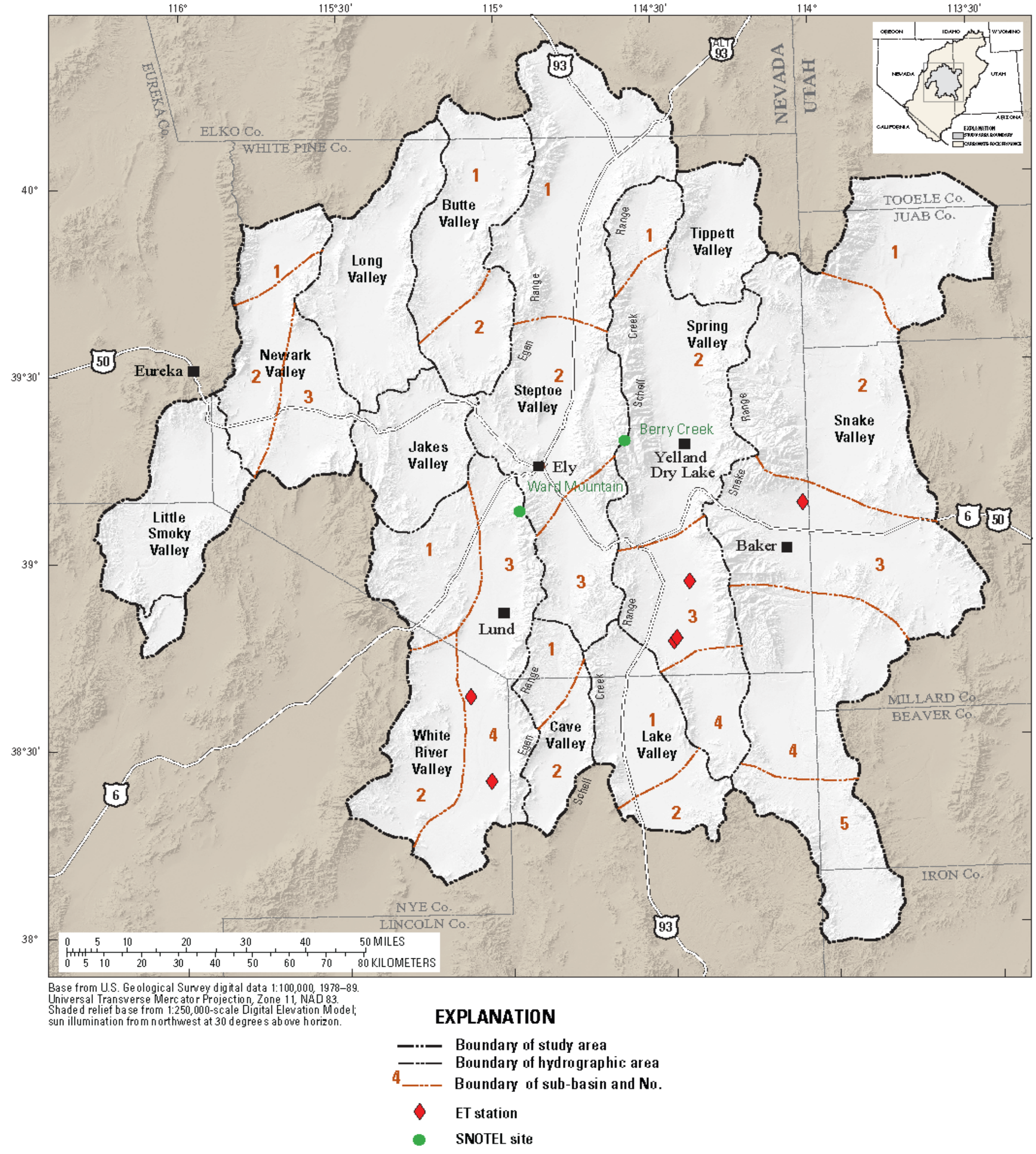

Figure 1. Hydrographic areas and subbasins and location of precipitation and evapotranspiration (ET) sites in the Basin and Range carbonate-rock aquifer system study area, Nevada and Utah (from Smith *et al*., 2007).

ET was about equal to the direct precipitation falling on the discharge area. Although these assumptions were imperfect, they were considered reasonable for these semiarid valleys of the BARCAS study area. Estimates of mean annual ground-water discharge from hydrographic areas in the BARCAS study area were computed by adjusting the calculated total ET rate to remove the local precipitation component. This adjusted ET rate is referred to as the ground-water discharge rate (i.e., ground-water discharge = total ET - local precipitation). In the case where total ET rate was smaller than the local precipitation rate for a certain ET unit, the ground-water discharge rate was set to zero, indicating that the total ET for the ET unit was completely supported by local precipitation and no ground-water was discharged over that area. The estimate of mean annual ground-water discharge for a subbasin was calculated by summing the product of the ground-water discharge computed for each ET unit existing within that subbasin times the area of the respective ET unit:

$$\textit{Groundwater discharge} = \sum_{i=1}^{n} (\textit{area of ET unit})_i \text{ x } (\textit{Groundwater discharge area})_{\mathrm{i}}$$

where *i* is a counter and *n* is the number of ET units (10 in this study). By using the methodology described above, total ground-water loss by processes other than interbasin ground-water flow out of the study area was estimated to be about 440,000 acre-feet per year, most of which is caused by ET (Welch and Bright, 2007).

Annual ET was computed across each ET unit within the subbasin. The precipitation rates and their variabilities were also reported at the subbasin level. Therefore, the uncertainty analysis was carried out at subbasin level. The mean annual ET from each hydrographic area and from each subbasin is estimated by summing annual ET computed for each of the ET units present. Mean annual ET estimates for each ET unit were computed by multiplying the acreage of the unit by an appropriate ET rate for the unit's vegetation and soil conditions. The associated acreage of each ET unit was calculated based on mapping conducted using satellite imagery. Details of the mean annual ET estimations were discussed in Welch and Bright (2007) and Moreo *et al*. (2007).

A total of 10 distinct ET units were mapped from the TM imagery in the BARCAS study area by Smith *et al*. (2007) and Moreo *et al*. (2007). Table 1 lists the 10 ET units and a brief unit description for the BARCAS study area. These 10 ET units were chosen to represent the different vegetation and soil conditions common to areas where ground water is assumed to be lost to the atmosphere through evapotranspiration. The characteristics of each ET unit differed, ranging from areas of no vegetation, such as open water, dry playa, and moist bare soil, to areas of denser vegetation of10 dominated by phreatophytic shrubs, grasses, rushes, and reeds.

Table 1. Evapotranspiration (ET) units identified, delineated, and mapped in discharge areas of theBARCAS study area (Welch and Bright, 2007).

ET-unit name	ET-unit description
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 ft.
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 fall. Depth to water table typically is less than 5 ft.
Grassland	Area dominated by short, sparse, perennial grasses, including salt grass, and sod and pasture grasses. Unit of10 mixed including 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 ft.
Dense Desert Shrubland	Area dominated by sparse desert shrubs, including greasewood, rabbittbrush, shadscale, big sagebrush, and saltbush. Shrubs typically are mixed. Vegetation cover typically is greater than 25 percent. Depth to water can vary from about 3 ft to about 50 ft.
Moderately Dense Desert Shrubland	Area dominated by sparse desert shrubs, including greasewood, rabbittbrush, shadscale, big sagebrush, and saltbush. Shrubs typically are mixed. Vegetation cover typically ranges from 10 to 30 percent. Depth to water can vary from about 3 ft to about 50 ft
Sparse Desert Shrubland	Area dominated by sparse desert shrubs, including greasewood, rabbittbrush, shadscale, big sagebrush, and saltbush. Shrubs typically are mixed. Vegetation cover typically ranges from 5 to 15 percent. Depth to water can vary from about 3 ft to about 50 ft.
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 ft.
Open Water	Area of open water including reservoirs, ponds, and spring pools.
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 ft. This unit may not contribute to ground-water discharge.
Irrigated Cropland	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 ft. Prior to irrigation, the unit likely was dominated by sparse to moderately dense phreatophytes.

METHOD OF UNCERTAINTY ANALYSIS OF GROUND-WATER DISCHARGE ESTIMATES

As can be seen from the methodology described earlier to estimate ground-water discharge in the BARCAS study, the three physical quantities involved in the estimation process (input parameters) were 1) ET rates for all 10 ET units, 2) the acreage associated with each ET unit, 3) and the local precipitation rates. Because of a rather sparse dataset used in estimating ET rates of all ET units, the ET rates so derived were subject to significant uncertainty and were of10 given as ranges. The acreage of each ET unit was estimated based on mapping conducted using satellite imagery and was also subject to uncertainty. The precipitation data was estimated from precipitation measurements made at a few selected sites (Moreo *et al*., 2007) and a map of mean annual precipitation generated from model simulations of monthly precipitation distributions used to estimate average annual recharge for the BARCAS area over the period 1970–2004 (Flint and Flint, 2007). Therefore, the precipitation estimate was also subjected to uncertainty. As a result, estimates of ground-water discharge for the BARCAS study were subject to uncertainty. The results of this analysis can be used to better understand the magnitude of uncertainty (quantified as variability of ground-water discharge estimates) associated with each discharge unit and each subbasin within the BARCAS study area and the sensitivity of ground-water discharge estimates to the input parameters, so that future data collection can be targeted to reduce uncertainty and increase the confidence level of ground-water discharge estimates.

To quantify the level of uncertainty associated with ground-water discharge estimates, Monte Carlo simulations were conducted that directly incorporate the parameter-level uncertainty by representing the values as statistical distributions of the three input parameters for estimating ground-water discharges. Simulations included 10,000 realizations using input parameters taken from randomly generated values based on the estimated statistics and assumed probability distributions of the ET rates, the precipitation rates, and the areas associated with the ET units. Monte Carlo simulations have a broad range of applications in linear and nonlinear problems and thus have been used extensively for the uncertainty analysis in various fields.

The main purpose of Monte Carlo simulations was to investigate how the uncertainty in the input parameters propagates into the output quantities of interests. The general procedure of Monte Carlo simulation is as follows:

1. Generate numerous equally likely random fields for model input parameters according to the parameter probabilistic distributions;
2. Conduct numerical simulations (called realizations) to calculate the quantities of interest for each random parameter set; and
3. Calculate the statistics (e.g., mean, variance, coefficient of variation, skewness etc.) of the quantities of interest to yield the optimum prediction and associated predictive uncertainty.

In the uncertainty analysis, the input parameters required for the Monte Carlo simulations included estimates of (1) annual precipitation rate for each subbasin, (2) acreage of the ET unit, and (3) ET rate for each ET unit found within the subbasin. Each input parameter was assumed to be characterized by a normal distribution (Laczniak *et al*., 2001). The mean value of each parameter was the value used in estimating mean ground-water ET discharge described earlier. The mean ET rate was estimated by the USGS either through remote sensing analysis, values from the literature, or existing USGS data (Welch and Bright, 2007). The scatter around the mean was described by the coefficient of variation (CV), which is defined as the standard deviation divided by the mean. The CV used in this study for the acreage of each ET unit was assumed to be 10 percent. A CV value of 10 percent was based on similar studies (Laczniak *et al*., 1999; 2001; Reiner *et al*., 2002). The CV value for each

ET rate was determined from ranges given by the USGS. CV values for the ET rate were calculated based on the assumption that ranges represent ±2 standard deviations of a normally distributed variable (i.e., 95 percent of the measurements were assumed to be contained in this range) (Laczniak *et al*., 2001). The precipitation data was estimated from precipitation measurements made at a few selected sites (Moreo *et al*., 2007; Welch and Bright, 2007) and a map of mean annual precipitation generated from model simulations of monthly precipitation distributions used to estimate average annual recharge for the BARCAS area over the period 1970–2004 (Flint and Flint, 2007). The CV values for the precipitation rates were calculated from the given data for each subbasin. By running Monte Carlo simulations for the BARCAS study, the statistics of ground-water discharge estimates can be calculated, including the mean prediction and the associated uncertainty quantified by CV values.

COMPUTATIONAL PROCEDURE OF MONTE CARLO SIMULATIONS

The general procedure used to quantify the uncertainty in estimates of ground-water discharge consisted of six steps.

1. Establish the mean and standard deviation of each parameter (i.e., precipitation rate, acreage of ET unit, and respective ET rate) for each subbasin, based on the methodology described in the previous section.
2. Randomly select a value from the normal distribution of each input parameter. For each subbasin, a total of 21 random parameters are used as input to calculate ground-water ET (i.e., 10 ET rates for each of the 10 ET units, 10 acreage values associated with each of the 10 ET units found within each basin and 1 precipitation value for each subbasin). The random fields of parameters can be generated many different ways. In this study, the random parameters were generated using the spectral method proposed by Robin *et al*. (1993).
3. Calculate ground-water discharge of each ET unit by (a) subtracting the precipitation rate for each subbasin from the randomly selected ET rate (i.e., calculate the ground-water discharge rate), and then (b) multiplying the calculated ground-water discharge rate by its corresponding acreage for that ET unit if the ground-water discharge rate is greater than zero.
4. Sum the ground-water discharges for all ET units within a subbasin. This represents the total ground-water discharge of the subbasin for this realization.
5. Repeat the procedure for all 30 discharge subbasins in the 12 valleys.
6. Sum all subbasin ground-water discharges to calculate the total ground-water discharge for the BARCAS project area. This value represents the total ground-water discharge for this Monte Carlo realization.

After repeating steps 1 to 6 for all 10,000 Monte Carlo realizations, one can compute the probability distribution and the statistics of ground-water discharge for each subbasin as well as that of the entire BARCAS study area from the 10,000 ground-water discharge values calculated. The calculated basic statistics include the mean ground-water ET for each subbasin and the entire study, plus the uncertainty in the estimate, as represented by the distribution and the corresponding CV value.

Note that not all ET units were represented in each subbasin (i.e., acreage was zero in these cases), which was simply a function of the landscape composition. Nonetheless, the generality of the procedure was maintained by following the same procedure described above. Also a test is usually performed to determine the number of realizations required to produce stable statistics of the output ground-water discharge estimates when the output statistics do not change with the increase of the number of Monte Carlo realizations. Since computational demand was not an issue for simple calculations that related input and output variables performed in this study, a large number of 10,000 realizations was used to ensure stable and reliable output ground-water discharge statistics.

RESULTS AND DISCUSSION

Table 2 lists the mean ET rates (ft/year) of 10 ET units for all the subbasins with ground-water discharge areas used in the calculations. Note that Lake Valley – Subbasin 2, Little Smoky Valley – Subbasin 2, Snake Valley – Subbasin 5, and Spring Valley – Subbasin 4 had no ground-water discharge areas and therefore have zero ground-water discharge (thus those subbasins were not listed in the table). The mean ET rates varied from less than 1 ft/year for dry playa to more than 5 ft/year for open water area. Table 3 gives CV values of ET rates for each of the 10 ET units for all subbasins with ground-water discharge areas used in the calculations. It can be seen from Table 3 that CV values ranged from 1 percent for open water to more than 20 percent shrubland in some subbasins. Table 4 shows the mean acreage of the 10 ET units for all the subbasins with ground-water discharge areas. Three shrubland categories accounted for more than 80 percent of the total ground-water discharge area. Among them, moderately dense desert shrubland had about 45 percent of total area and was by far the largest ET unit in the BARCAS study area. Also note that the four largest valleys that contributed to the ground-water discharge (Snake, White River, Spring, and Steptoe) accounted for 78 percent of the total ground-water discharge area. As indicated earlier, the CV values for acreage in all ET units in all subbasins were assumed to be 10 percent and therefore were not shown again. Table 5 shows the mean and CV of precipitation for all subbasins with ground-water discharge areas. The mean precipitation amount varied from 0.55 feet in Little Smoky Valley - Subbasin 1 to more than a foot in Cave Valley. The CV values of precipitation rates ranged from about 1 percent to 18 percent. In summary, the CV values were not very large for all the input parameters for the uncertainty analysis. They were typically from 1 percent to about 20 percent for ET rates and precipitation rates, while the CV for acreage of all ET units was always assumed to be always 10 percent.

Table 6 shows ground-water discharge results for all individual subbasins as well as total ground-water discharge for the BARCAS study area. For comparison, the deterministic estimation results of ground-water discharge are also listed in the table. The deterministic ground-water discharge was determined by using mean input parameter values (*i.e.*, ET rate, acreage and precipitation rate) for each subbasin, which was the same approach used to estimate the ground-water discharge portion of the water budget for the BARCAS study (Welch and Bright, 2007).

Table 2. Mean ET rate in feet per year of the 10 ET units for all the subbasins with ground-water discharge areas (Welch and Bright, 2007).

Subbasin Name	Marsh-land	Meadow-land	Grassland	Dense Desert Shrubland	Moderately Dense Desert Shrubland	Sparse Desert Shrubland	Moist Bare Soil	Open Water	Dry Playa	Irrigated Cropland
Butte Valley - Subbasin 1	4.11	2.56	2.06	1.21	1.10	0.98	2.00	5.10	0.75	1.40
Butte Valley - Subbasin 2	4.10	2.75	2.15	1.11	1.00	0.98	2.00	5.10	0.75	1.40
Cave Valley - Subbasin 1	4.11	2.53	2.15	1.37	1.30	0.98	2.00	5.10	0.75	1.40
Cave Valley - Subbasin 2	4.10	2.75	1.97	1.11	1.00	0.98	2.00	5.10	0.75	1.40
Jakes Valley	4.06	2.41	2.06	1.37	1.30	0.98	2.00	5.10	0.75	1.40
Lake Valley - Subbasin 1	4.11	2.59	2.15	1.21	1.00	0.98	2.00	5.10	1.00	1.40
Little Smoky Valley - Subbasin 1	4.02	2.47	2.06	1.37	1.00	0.74	2.00	5.10	0.75	1.40
Long Valley	4.01	2.47	1.97	1.11	1.00	0.98	2.00	5.10	0.75	1.40
Newark Valley - Subbasin 1	4.08	2.62	2.15	1.27	1.20	0.86	2.00	5.10	1.00	1.40
Newark Valley - Subbasin 2	4.10	2.35	2.15	1.11	1.00	0.98	2.00	5.10	1.00	1.40
Newark Valley - Subbasin 3	4.06	2.41	2.15	1.37	1.30	0.74	2.00	5.10	1.00	1.40
Snake Valley - Subbasin 1	4.07	2.56	2.15	1.27	1.00	0.74	2.00	5.10	0.63	1.40
Snake Valley - Subbasin 2	4.10	2.26	2.15	1.21	1.10	0.86	2.00	5.10	0.63	1.40
Snake Valley - Subbasin 3	4.13	2.59	2.15	1.27	1.00	0.86	2.00	5.10	0.63	1.40
Snake Valley - Subbasin 4	4.12	2.71	2.15	1.21	1.10	0.98	2.00	5.10	0.63	1.40
Spring Valley - Subbasin 1	4.12	2.76	2.15	1.32	1.20	0.98	2.00	5.10	0.81	1.40
Spring Valley - Subbasin 2	4.11	2.62	2.15	1.27	1.00	0.86	2.00	5.10	0.81	1.40
Spring Valley - Subbasin 3	4.11	2.71	2.15	1.21	1.10	0.98	2.00	5.10	0.81	1.40
Steptoe Valley - Subbasin 1	4.11	2.53	2.06	1.21	1.10	0.86	2.00	5.10	0.81	1.40
Steptoe Valley - Subbasin 2	4.05	2.59	2.15	1.32	1.20	0.86	2.00	5.10	0.81	1.40
Steptoe Valley - Subbasin 3	4.03	2.65	2.24	1.27	1.20	0.98	2.00	5.10	0.81	1.40
Tippett Valley	4.10	2.35	2.06	1.21	1.00	0.98	2.00	5.10	0.81	1.40
White River Valley -Subbasin 1	4.12	2.62	2.15	1.32	1.20	0.98	2.00	5.10	0.88	1.40
White River Valley -Subbasin 2	4.12	2.62	2.15	1.21	1.00	0.98	2.00	5.10	0.88	1.40
White River Valley -Subbasin 3	4.03	2.50	2.06	1.21	1.10	0.98	2.00	5.10	0.88	1.40
White River Valley -Subbasin 4	4.03	2.50	2.06	1.21	1.10	0.98	2.00	5.10	0.88	1.40

Note: Lake Valley – Subbasin 2, Little Smoky Valley – Subbasin 2, Snake Valley – Subbasin 5, and Spring Valley – Subbasin 4 have no discharge areas and therefore have zero ground-water discharge.

Table 3. CV values of ET rate in feet per year of the 10 ET units for all the subbasins with ground-water discharge areas.

Subbasin Name	Marsh-land	Meadow-land	Grassland	Dense Desert Shrubland	Moderately Dense Desert Shrubland	Sparse Desert Shrubland	Moist Bare Soil	Open Water	Dry Playa	Irrigated Cropland
Butte Valley - Subbasin 1	0.012	0.107	0.133	0.165	0.182	0.153	0.075	0.010	0.167	0.071
Butte Valley - Subbasin 2	0.012	0.100	0.128	0.180	0.200	0.153	0.075	0.010	0.167	0.071
Cave Valley - Subbasin 1	0.012	0.109	0.128	0.146	0.154	0.153	0.075	0.010	0.167	0.071
Cave Valley - Subbasin 2	0.012	0.100	0.140	0.180	0.200	0.153	0.075	0.010	0.167	0.071
Jakes Valley	0.012	0.114	0.133	0.146	0.154	0.153	0.075	0.010	0.167	0.071
Lake Valley - Subbasin 1	0.012	0.106	0.128	0.165	0.200	0.153	0.075	0.010	0.125	0.071
Little Smoky Valley -Subbasin 1	0.012	0.111	0.133	0.146	0.200	0.203	0.075	0.010	0.167	0.071
Long Valley	0.012	0.111	0.140	0.180	0.200	0.153	0.075	0.010	0.167	0.071
Newark Valley - Subbasin 1	0.012	0.105	0.128	0.157	0.167	0.174	0.075	0.010	0.125	0.071
Newark Valley - Subbasin 2	0.012	0.117	0.128	0.180	0.200	0.153	0.075	0.010	0.125	0.071
Newark Valley - Subbasin 3	0.012	0.114	0.128	0.146	0.154	0.203	0.075	0.010	0.125	0.071
Snake Valley - Subbasin 1	0.012	0.107	0.128	0.157	0.200	0.203	0.075	0.010	0.198	0.071
Snake Valley - Subbasin 2	0.012	0.122	0.128	0.165	0.182	0.174	0.075	0.010	0.198	0.071
Snake Valley - Subbasin 3	0.012	0.106	0.128	0.157	0.200	0.174	0.075	0.010	0.198	0.071
Snake Valley - Subbasin 4	0.012	0.101	0.128	0.165	0.182	0.153	0.075	0.010	0.198	0.071
Spring Valley - Subbasin 1	0.012	0.100	0.128	0.152	0.167	0.153	0.075	0.010	0.154	0.071
Spring Valley - Subbasin 2	0.012	0.105	0.128	0.157	0.200	0.174	0.075	0.010	0.154	0.071
Spring Valley - Subbasin 3	0.012	0.101	0.128	0.165	0.182	0.153	0.075	0.010	0.154	0.071
Steptoe Valley - Subbasin 1	0.012	0.109	0.133	0.165	0.182	0.174	0.075	0.010	0.154	0.071
Steptoe Valley - Subbasin 2	0.012	0.106	0.128	0.152	0.167	0.174	0.075	0.010	0.154	0.071
Steptoe Valley - Subbasin 3	0.012	0.104	0.123	0.157	0.167	0.153	0.075	0.010	0.154	0.071
Tippett Valley	0.012	0.117	0.133	0.165	0.200	0.153	0.075	0.010	0.154	0.071
White River Valley -Subbasin 1	0.012	0.105	0.128	0.152	0.167	0.153	0.075	0.010	0.142	0.071
White River Valley -Subbasin 2	0.012	0.105	0.128	0.165	0.200	0.153	0.075	0.010	0.142	0.071
White River Valley -Subbasin 3	0.012	0.110	0.133	0.165	0.182	0.153	0.075	0.010	0.142	0.071
White River Valley -Subbasin 4	0.012	0.110	0.133	0.165	0.182	0.153	0.075	0.010	0.142	0.071

Note: Lake Valley – Subbasin 2, Little Smoky Valley – Subbasin 2, Snake Valley – Subbasin 5, and Spring Valley – Subbasin 4 have no discharge areas and therefore have zero ground-water discharge.

Table 4. Mean acreage in acres of the 10 ET units for all the subbasins with ground-water discharge areas.

Subbasin Name	Marsh-land	Meadow-land	Grassland	Dense Desert Shrubland	Moderately Dense Desert Shrubland	Sparse Desert Shrubland	Moist Bare Soil	Open Water	Dry Playa	Irrigated Crop-land
Butte Valley - Subbasin 1	64	478	615	5,827	50,897	7,891	0	4	0	202
Butte Valley - Subbasin 2	0	0	0	79	3,244	371	0	0	0	0
Cave Valley - Subbasin 1	81	503	280	842	354	6	0	0	0	0
Cave Valley - Subbasin 2	0	0	2	534	7,005	3,546	0	0	194	0
Jakes Valley	25	91	146	540	203	6	0	26	0	187
Lake Valley - Subbasin 1	630	1,143	822	4,077	32,384	16,296	0	26	94	0
Little Smoky Valley -Subbasin 1	62	355	379	1,191	1,678	2,108	0	0	5	216
Long Valley	2	3	4	1,219	12,155	4,901	0	0	0	0
Newark Valley - Subbasin 1	996	2,247	1,397	6,228	11,110	2,556	1	1	1,111	208
Newark Valley - Subbasin 2	192	639	661	3,620	14,284	6,035	0	1	10,625	285
Newark Valley - Subbasin 3	0	1	0	172	7,526	2,830	0	0	24	0
Snake Valley - Subbasin 1	334	693	347	2,527	6,854	17,772	0	0	56,499	1,785
Snake Valley - Subbasin 2	541	1,746	1,463	7,988	34,568	66,023	578	115	5,553	1,138
Snake Valley - Subbasin 3	432	1,696	799	3,638	26,758	46,090	0	100	1,081	5,136
Snake Valley - Subbasin 4	535	1,816	834	7,368	17,297	3,254	0	212	0	1,873
Spring Valley - Subbasin 1	119	303	154	747	377	61	0	0	0	0
Spring Valley - Subbasin 2	1,259	3,223	2,386	13,055	43,870	23,563	2,810	6	15,509	2,867
Spring Valley - Subbasin 3	699	1,639	1,007	9,301	39,639	12,083	9	0	520	2,492
Steptoe Valley - Subbasin 1	790	2,251	2,442	16,691	69,506	26,861	237	5	2,464	2,766
Steptoe Valley - Subbasin 2	2,993	5,171	3,813	13,197	15,992	3,158	21	147	0	2,354
Steptoe Valley - Subbasin 3	152	498	254	1,427	985	76	0	287	0	0
Tippett Valley	0	21	51	1,013	4,569	1,623	0	0	497	0
White River Valley -Subbasin 1	142	340	188	737	748	134	0	0	0	841
White River Valley -Subbasin 2	48	293	253	2,419	15,552	9,881	0	0	19	490
White River Valley -Subbasin 3	104	1,114	1,083	4,733	4,953	541	0	0	9	4,965
White River Valley -Subbasin 4	2,877	2,182	2,413	16,450	68,298	34,353	14	685	941	295

Note: Lake Valley – Subbasin 2, Little Smoky Valley – Subbasin 2, Snake Valley – Subbasin 5, and Spring Valley – Subbasin 4 have no discharge areas and therefore have zero ground-water discharge.

Table 5. Mean and CV of precipitations in ft/year for all the subbasins with ground-water discharge areas (Welch and Bright, 2007).

Subbasin Name	Mean Precip (ft)	CV	Subbasin Name	Mean Precip (ft)	CV
Butte Valley - Subbasin 1	0.95	0.049	Snake Valley - Subbasin 3	0.56	0.088
Butte Valley - Subbasin 2	0.85	0.068	Snake Valley - Subbasin 4	0.68	0.049
Cave Valley - Subbasin 1	1.11	0.014	Spring Valley - Subbasin 1	0.81	0.018
Cave Valley - Subbasin 2	1.08	0.093	Spring Valley - Subbasin 2	0.69	0.051
Jakes Valley	0.96	0.100	Spring Valley - Subbasin 3	0.79	0.025
Lake Valley - Subbasin 1	0.99	0.067	Steptoe Valley - Subbasin 1	0.67	0.111
Little Smoky Valley - Subbasin 1	0.52	0.097	Steptoe Valley - Subbasin 2	0.77	0.140
Long Valley	0.94	0.022	Steptoe Valley - Subbasin 3	0.94	0.099
Newark Valley - Subbasin 1	0.91	0.138	Tippett Valley	0.80	0.021
Newark Valley - Subbasin 2	0.86	0.184	White River Valley -Subbasin 1	0.94	0.063
Newark Valley - Subbasin 3	0.78	0.021	White River Valley -Subbasin 2	0.75	0.044
Snake Valley - Subbasin 1	0.55	0.045	White River Valley -Subbasin 3	0.86	0.017
Snake Valley - Subbasin 2	0.55	0.061	White River Valley -Subbasin 4	0.77	0.062

Note: Lake Valley – Subbasin 2, Little Smoky Valley – Subbasin 2, Snake Valley – Subbasin 5, and Spring Valley – Subbasin 4 have no discharge areas and therefore have zero ground-water discharge.

Table 6. Summary statistics for subbasin ground-water discharge and total ground-water discharge.

Subbasin Name	Deterministic (acre-feet)	Mean (acre-feet)	CV
Butte Valley – Subbasin 1	11,319	12,575	0.689
Butte Valley – Subbasin 2	558	628	0.890
Cave Valley – Subbasin 1	1,534	1,541	0.173
Cave Valley – Subbasin 2	17	510	1.505
Jakes Valley	858	853	0.107
Lake Valley – Subbasin 1	6,135	9,403	0.472
Little Smoky Valley – Subbasin 1	3,955	3,917	0.139
Long Valley	1,234	1,976	0.884
Newark Valley – Subbasin 1	14,345	14,664	0.216
Newark Valley – Subbasin 2	7,699	8,891	0.516
Newark Valley – Subbasin 3	4,015	3,987	0.410
Snake Valley – Subbasin 1	17,361	18,182	0.351
Snake Valley – Subbasin 2	54,836	53,818	0.231
Snake Valley – Subbasin 3	39,038	38,074.	0.247
Snake Valley – Subbasin 4	21,049	20,768	0.199
Spring Valley – Subbasin 1	1,733	1,724	0.137
Spring Valley – Subbasin 2	46,991	46,772	0.218
Spring Valley – Subbasin 3	26,889	26,472	0.317
Steptoe Valley – Subbasin 1	56,945	56,161	0.291
Steptoe Valley – Subbasin 2	40,983	40,961	0.137
Steptoe Valley – Subbasin 3	3,569	3,569	0.104
Tippett Valley	1,742	1,772	0.481
White River Valley – Subbasin 1	2,114	2,121	0.127
White River Valley – Subbasin 2	8,677	8,595	0.379
White River Valley – Subbasin 3	9,124	9,096	0.175
White River Valley – Subbasin 4	56,786	56,000	0.268
Total Ground-water ET	439,509	443,032	0.241

Note: Lake Valley – Subbasin 2, Little Smoky Valley – Subbasin 2, Snake Valley – Subbasin 5, and Spring Valley – Subbasin 4 have no discharge areas and therefore have zero ground-water discharge.

The results show that the mean total ground-water discharge from the Monte Carlo simulations (443,032 acre-feet) and the total ground-water discharge calculated based on the mean values of each parameter within each individual subbasin (439,508 acre-feet) were very close. In fact, the difference between the two estimates was less than one percent. The Monte Carlo simulations indicated a relatively moderate CV value of 0.241. For some subbasins, however, the uncertainty could be quite large. Although the mean total ground-water discharge from the Monte Carlo simulations and the total ground-water discharge calculated based on the mean values of input parameters within each individual subbasin were within 1 percent of each other, the difference between these two results for some individual subbasins can be quite large. Specifically, the percentage difference between the deterministically calculated total ground-water discharge and the mean total ground-water discharge range from a mere 0.02 percent for the Steptoe Valley – Subbasin 3 to a very large 2,975 percent for Cave Valley - Subbasin 2. The subbasins with over 10 percent difference include Butte Valley - Subbasin 1 (11.1%), Butte Valley - Subbasin 2 (12.6%), Cave Valley - Subbasin 2 (2975%), Lake Valley - Subbasin 1 (53.3%), Long Valley (60.1%), Newark Valley - Subbasin 2 (15.5%). One common feature for those subbasins with large percent difference was that they also had high uncertainties with large CV values resulting from Monte Carlo simulations.

The high uncertainty for these subbasins mainly stemmed from the way the estimate accounts for the portion of the total ET supported by precipitation. For example, if the annual ET rate for an ET unit was smaller than the annual precipitation rate in a particular realization, then the annual ground-water discharge was set to equal zero (*i.e.*, all ET for this ET unit was entirely supported by precipitation). For this reason, some subbasins with annual ET rates close to the precipitation rate had larger CVs, and therefore, larger uncertainties. Moreover, the probability density functions were positively skewed because the otherwise negative values of ground-water discharge were replaced with zero values. For the same reason, subbasins with high ground-water discharge CV values typically had mean ET rates very close to the mean precipitation rates. For those subbasins, there was a very high probability of sampling a precipitation rate larger than the ET rate because they had very similar mean values. As a result, many realizations occurred with calculated zero ground-water discharge rates for those subbasins and therefore ground-water discharge distributions were typically clustered near zero, but greater than zero. This was the result of the analytical method and should also explain why high ground-water discharge CV subbasins typically had higher mean ground-water discharge than was deterministically calculated. Given that the input parameter CV values ranged from 1 percent to about 20 percent, the calculated CV of ground-water discharge was at 24.1 percent which was larger than any input parameter CV values. While their overall contributions to the total ground-water discharge were not significant, the high uncertainties of the subbasins discussed above increased the uncertainty of total ground-water discharge slightly.

Figure 2 shows the probability density functions generated from 10,000 realizations of simulated annual ground-water discharge from the two subbasins in Butte Valley. The ground-water discharge predictions in both subbasins were quite uncertain (CV = 0.689 for subbasin 1 and CV = 0.890 for subbasin 2) compared to the input parameter CVs which were significantly smaller, and the ground-water discharge distributions were positively skewed with a high probability of close to zero ground-water discharge values. These results likely occurred because of the relatively small difference between the annual ET rates in the

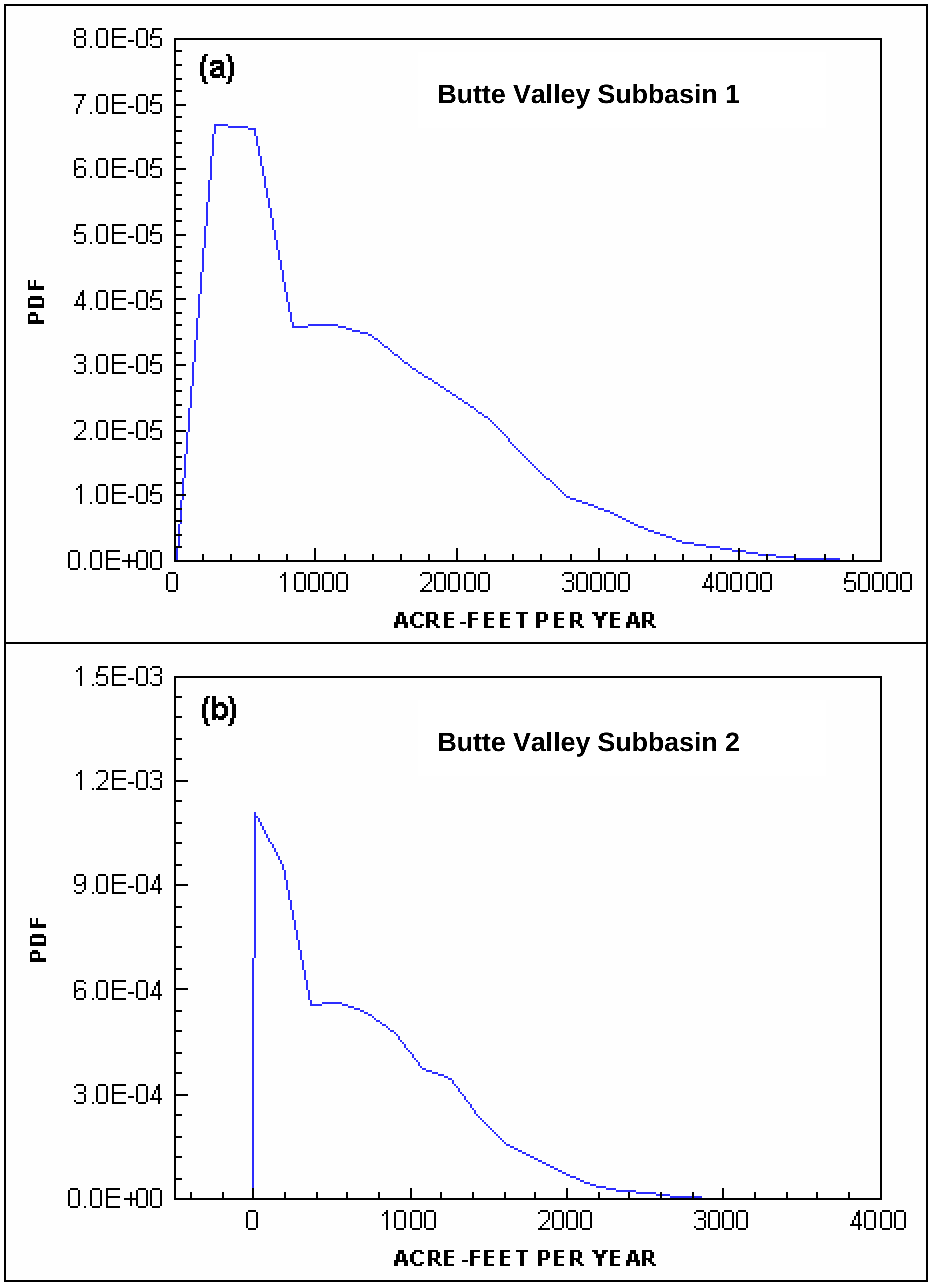

Figure 2. Probability density function generated from 10,000 realizations of simulated annual ground-water discharge from Butte Valley, (a) subbasin 1, (b) subbasin 2.

subbasins and their corresponding annual precipitation. For the two ET units with the largest acreage in subbasin 1 (moderately dense desert shrubland and sparse desert shrubland), the differences between mean ET and precipitation rates were only 0.152 ft (1.1 ft mean annual ET rate versus 0.948 ft mean annual precipitation) and 0.032 ft (0.980 ft mean annual ET rate versus 0.948 ft mean annual precipitation), respectively, as shown in Table 2 and Table 5. For the two ET units with the largest acreage in subbasin 2 (moderately dense desert shrubland and sparse desert shrubland), the differences between the ET and precipitation rates were 0.151 ft (1.0 ft mean annual ET rate versus 0.849 ft mean annual precipitation rate) and 0.131 ft (0.980

ft mean annual ET rate versus 0.849 ft mean annual precipitation rate), respectively. In addition to the small difference between mean annual ET rates and mean annual precipitation rates, the two largest ET units in both subbasins of Butte Valley (i.e., moderately dense desert shrubland and sparse desert shrubland) also had the most uncertain ET rate estimates (signified by larger CVs of ET rates) of all the ET units (see Table 3). This would also contribute to the higher CVs of estimated ground-water discharge for the valley.

Figure 3 shows probability density functions for the subbasins in Cave Valley. For subbasin 1, the ground-water discharge followed a normal distribution. The two largest ET units in subbasin 1 were the dense desert shrubland and the meadowland (see Table 4), which had significantly higher mean ET rates than mean precipitation rates. In subbasin 1, these two largest ET units both had moderate CVs of annual ET rates (0.146 and 0.109 respectively) and the CV for annual precipitation rate was very small (0.014 for both subbasins), thus explaining the normal distribution of ground-water discharge estimates in subbasin 1. For subbasin 2, the ground-water discharge distribution was positively skewed with a very large uncertainty (CV = 1.505). For the three desert shrubland units with the largest acreage in the subbasin, the differences between the mean annual ET and precipitation rates were all small and other ET units were virtually non-existent in the subbasin (see Table 4). For the largest ET unit in the subbasin (*i.e*., moderately dense desert shrubland), the difference between the mean annual ET rate and the mean annual precipitation rate was only -0.08 ft, and for the other two desert shrubland units, the differences were also very small (-0.1 and 0.02 ft, respectively from Table 2 and Table 5). As a result, the ground-water discharge was small but quite uncertain for this subbasin.

Figure 4 shows a normally distributed probability density function for the estimated ground-water discharge in Jakes Valley. For the ET units with significant acreage (the dense desert shrubland, the moderately dense desert shrubland, and the irrigated cropland) the mean annual ET rates were all significantly higher than the mean annual precipitation rate (see Table 2 and Table 5). Therefore, the ground-water discharge was normally distributed in the valley.

Figure 5 shows probability density functions for Lake Valley. Here, only subbasin 1 contributed to ground-water discharge. There were no mapped ET units in subbasin 2 of Lake Valley. For the two ET units with largest acreage (i.e., moderately dense desert shrubland and sparse desert shrubland), the differences between annual ET and precipitation rates were only 0.008 and -0.012 ft, respectively (see Table 2 and Table 5). These two ET units were by far the largest in the subbasin (see Table 4). As discussed earlier, this would explain a relatively large CV value (CV = 0.472) of ground-water discharge estimates for the subbasin.

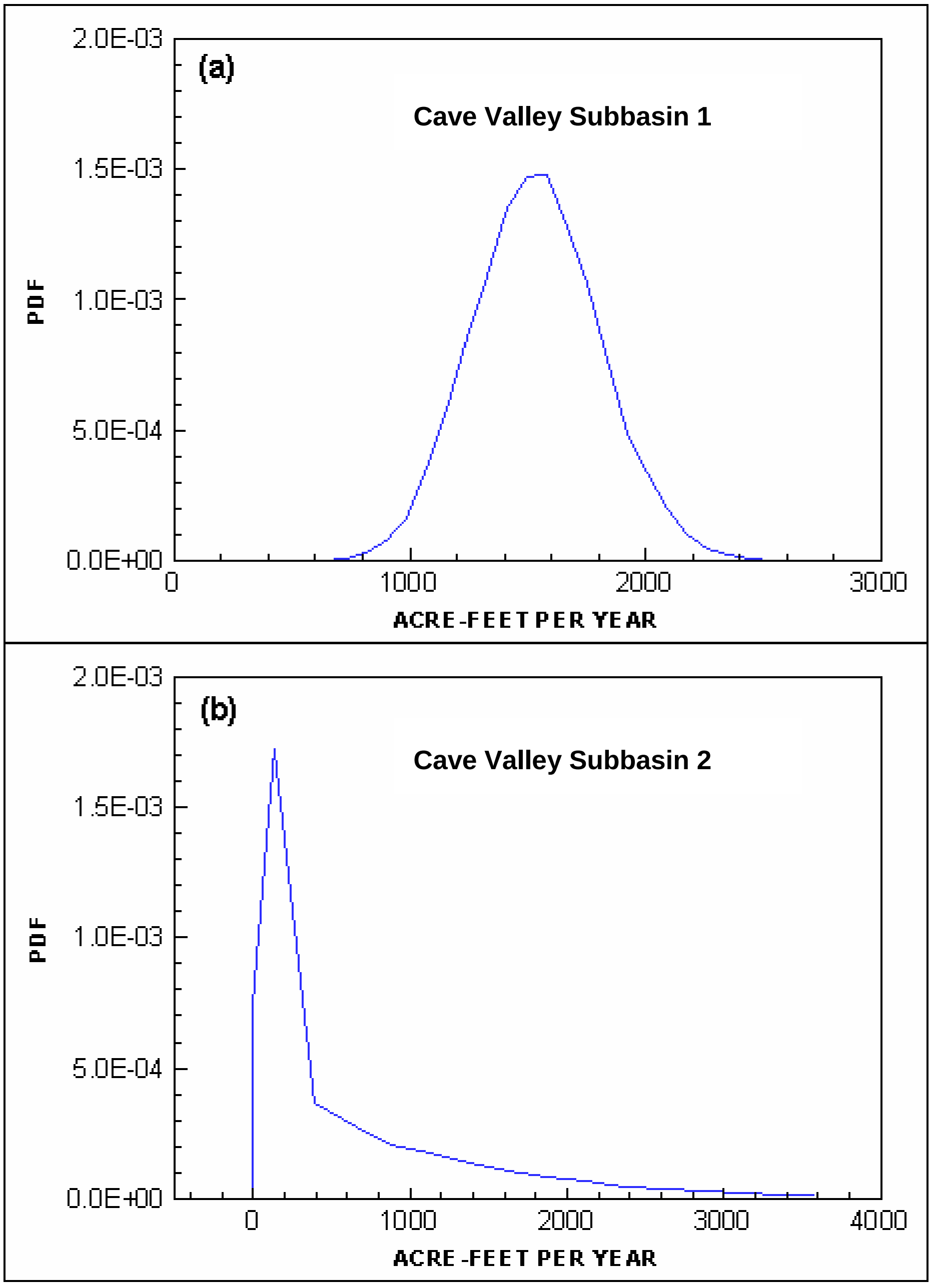

Figure 3. Probability density function generated from 10,000 realizations of simulated annual groundwater discharge from Cave Valley, (a) subbasin 1, (b) subbasin 2.

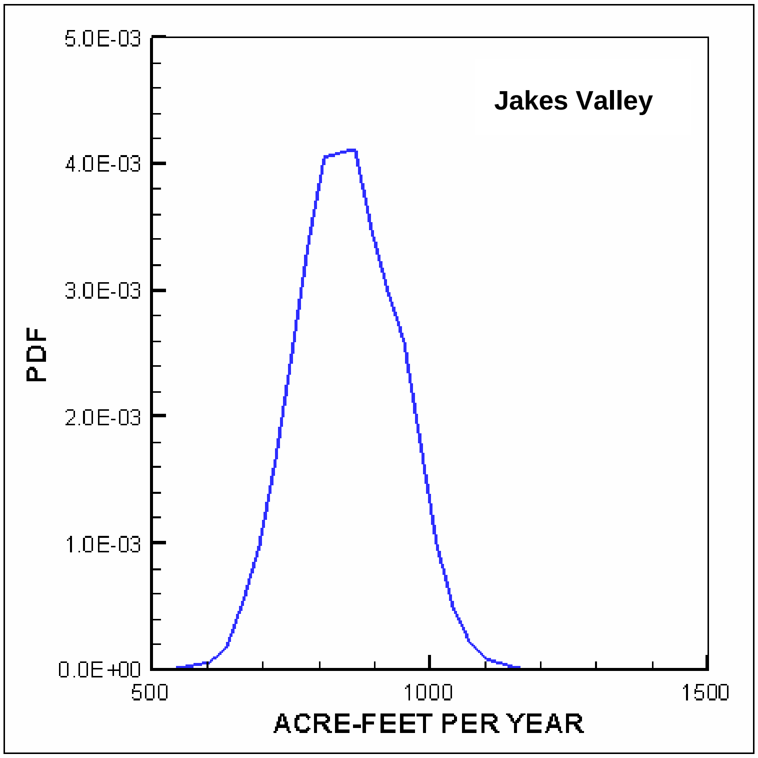

Figure 4. Probability density function generated from 10,000 realizations of simulated annual groundwater discharge from Jakes Valley.

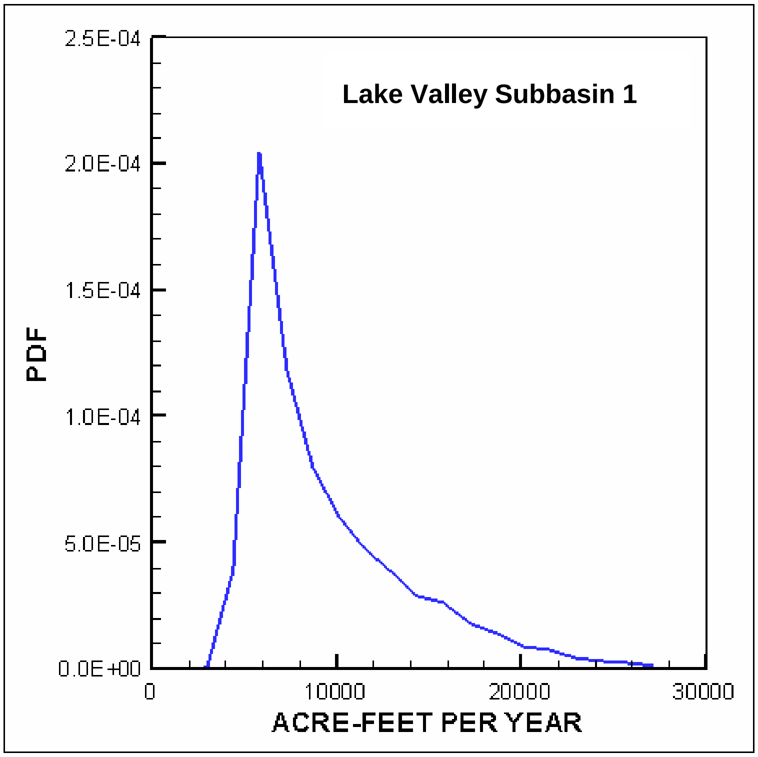

Figure 5. Probability density function generated from 10,000 realizations of simulated annual groundwater discharge from Lake Valley subbasin 1.

Figure 6 shows the probability density function of the ground-water discharge estimates for Long Valley. From Table 4, it can be seen that the valley was dominated by desert shrubland. Other ET units were of negligible size by comparison. Of the three desert shrublands, the moderately dense unit accounted for about two thirds of the acreage (see Table 4). For this desert shrubland unit, the difference between the annual ET and precipitation rates was only 0.065 ft, which resulted in a high uncertainty for the annual ground-water discharge calculation signified by CV = 0.884.

Plotted in Figure 7 is the probability density function for Little Smoky Valley. In the valley, only subbasin 1 contributed to ground-water discharge. The three desert shrubs of different densities also represented dominant vegetation in the subbasin. Because Little Smoky Valley received the smallest mean annual precipitation of all valleys in the BARCAS study area (0.522 ft, see Table 5), the annual ET rates for the dominant shrubs in the valley had significantly higher mean annual ET rates than the precipitation rate. Therefore, the ground-water discharge probability density followed a normal distribution, with a small CV value of 0.139.

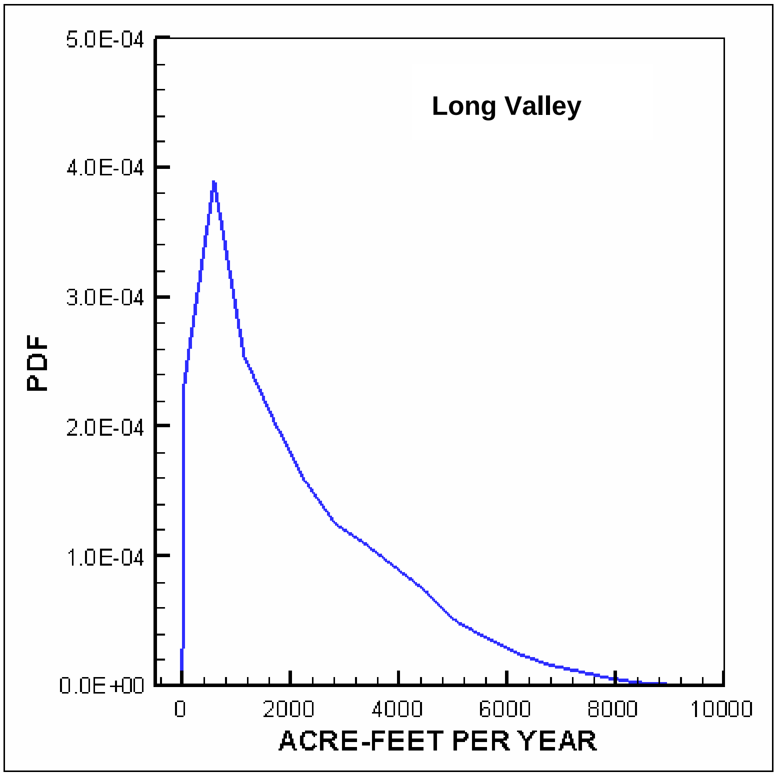

Figure 6. Probability density function generated from 10,000 realizations of simulated annual ground-water discharge from Long Valley.

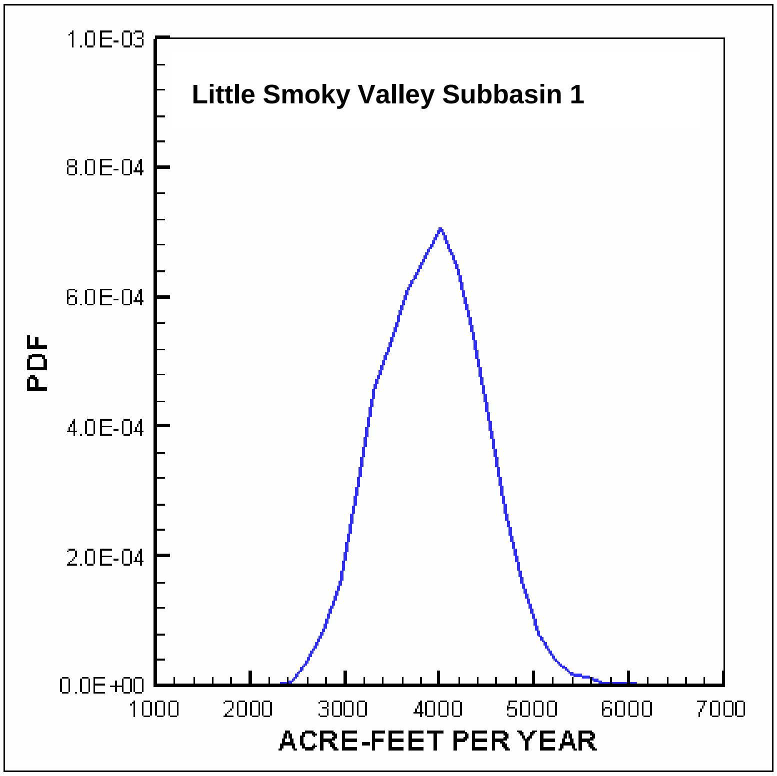

Figure 7. Probability density function generated from 10,000 realizations of simulated annual ground-water discharge from Little Smoky Valley subbasin 1.

Figure 8 shows probability density functions for the three subbasins in Newark Valley. In subbasin 1, the three desert shrubs of different densities also represented the main vegetation (see Table 4). For the two dominant shrub densities (moderately dense and dense), the annual ET rates were significantly higher than the annual precipitation rate in the subbasin. As a result, the ground-water discharge data have a near-normal distribution. For subbasin 2, dry playa also constituted a significant acreage (see Table 4) besides the three desert shrub ET units. In fact, the dry playa had the second largest acreage, after the moderately dense desert shrub. For these two ET units, the differences between the annual ET and precipitation rates were both 0.142 ft. Therefore, ground-water discharge in subbasin 2 had a relatively large CV value of 0.516. For subbasin 3, while the largest ET unit in the area (moderately dense shrub) had a significantly higher mean annual ET rate than the mean annual precipitation rate (1.3 ft versus 0.783 ft), the second largest unit (sparse desert shrub) showed similar mean ET and precipitation rates (0.74 ft versus 0.783 ft, see Table 2 and Table 5). As a result, the CV of ground-water discharge in subbasin 3 was between the CV values for subbasins 1 and 3 (see Table 6).

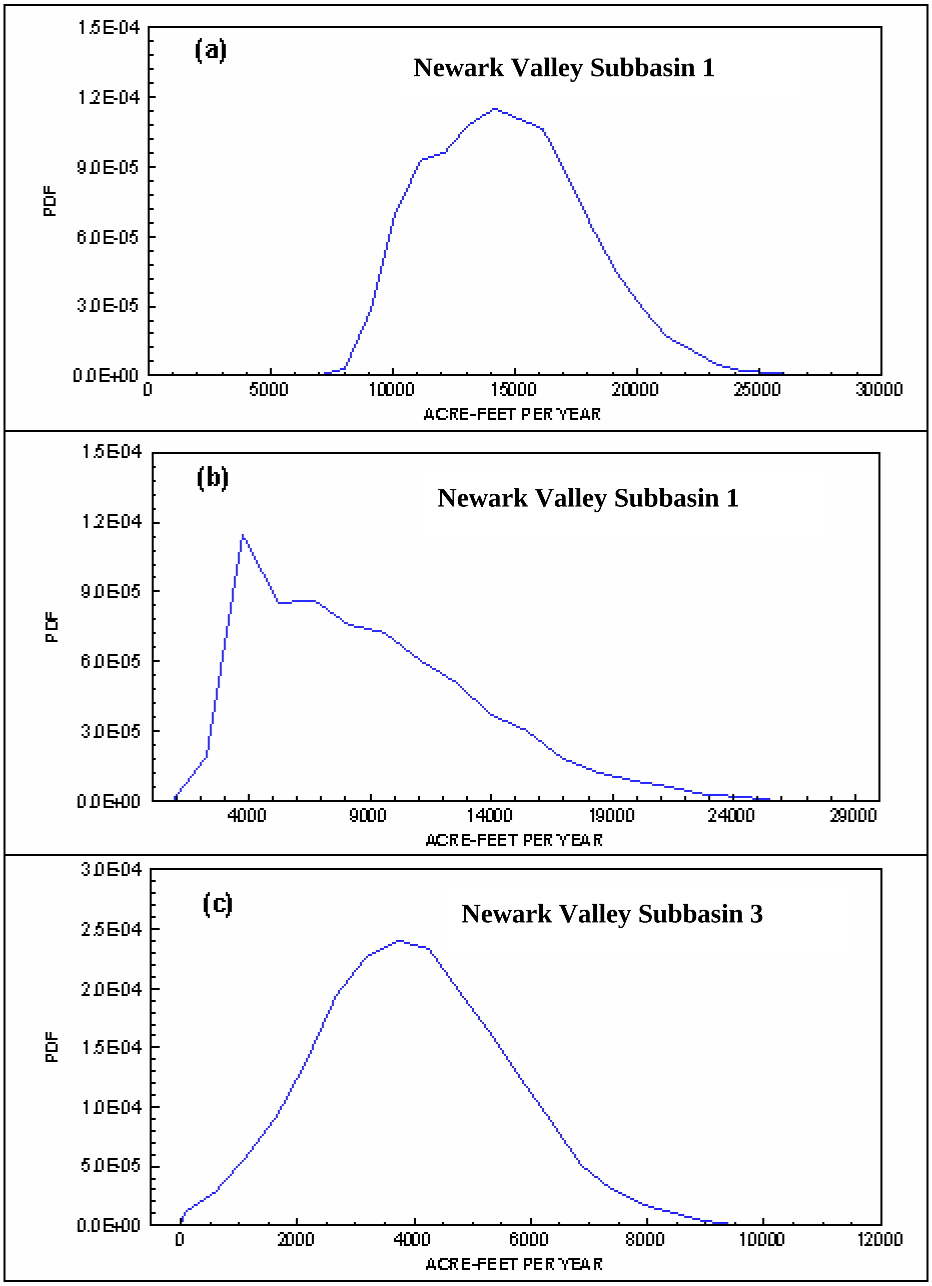

Figure 8. Probability density function generated from 10,000 realizations of simulated annual ground-water discharge from Newark Valley, (a) subbasin 1, (b) subbasin 2, and (c) subbasin 3

Figure 9 shows probability density functions of ground-water discharge estimates for the four subbasins in Snake Valley. Ground-water discharge appeared to follow normal distributions with relatively small CV values. Among the four subbasins in the valley, ground-water discharge in subbasin 1 deviated most significantly from a normal distribution, with the largest CV value (0.351). This was mainly from the fact that subbasin 1 was dominated by dry playa, which had a mean annual ET rate of 0.63 ft compared to the mean annual precipitation rate of 0.55 ft. In the other three subbasins in the valley, the three desert shrub units were the most dominant categories and the shrubs had significantly higher mean annual ET rates than the small precipitation rates typical for the entire valley. Therefore, the ground-water discharge distributions were normal and accompanied by small CV values.

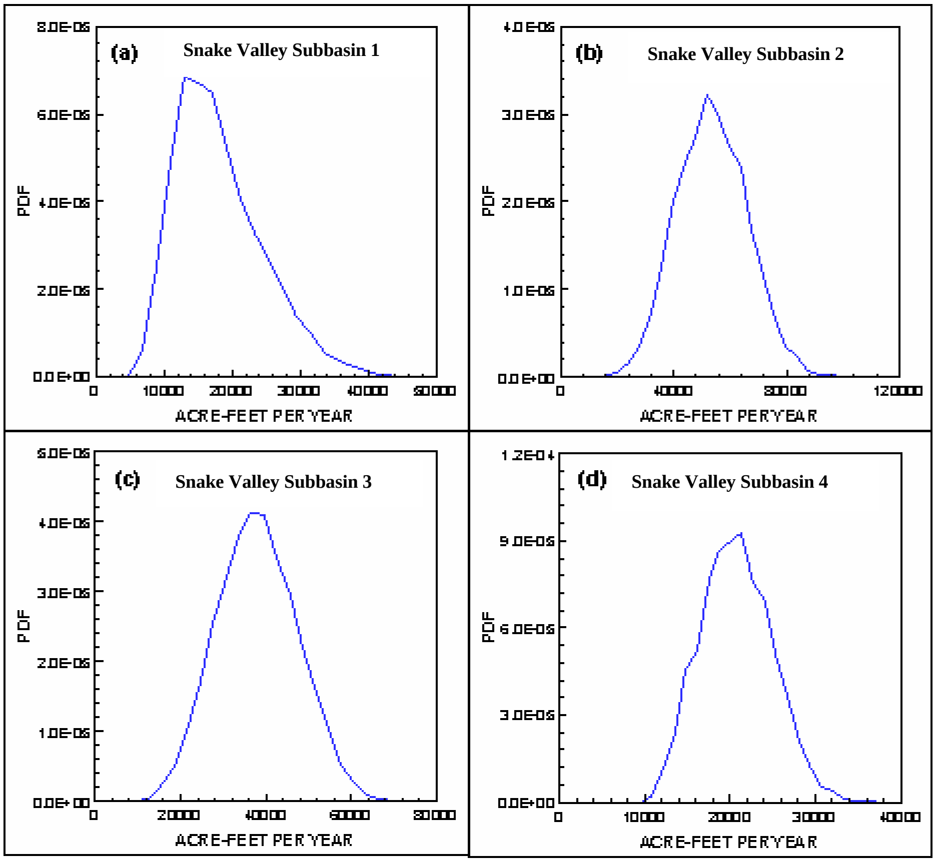

Figure 9. Probability density function generated from 10,000 realizations of simulated annual ground-water discharge from Snake Valley, (a) subbasin 1, (b) subbasin 2, (c) subbasin 3, and (d) subbasin 4.

Figure 10 shows probability density functions for the three subbasins in Spring Valley. Ground-water discharge also generally followed normal distributions with relatively small CV values. The most significant ET units (once again the desert shrubs) in the subbasins typically had mean annual ET rates higher than the precipitation rate. This would explain the normal ground-water discharge distributions in the valley.

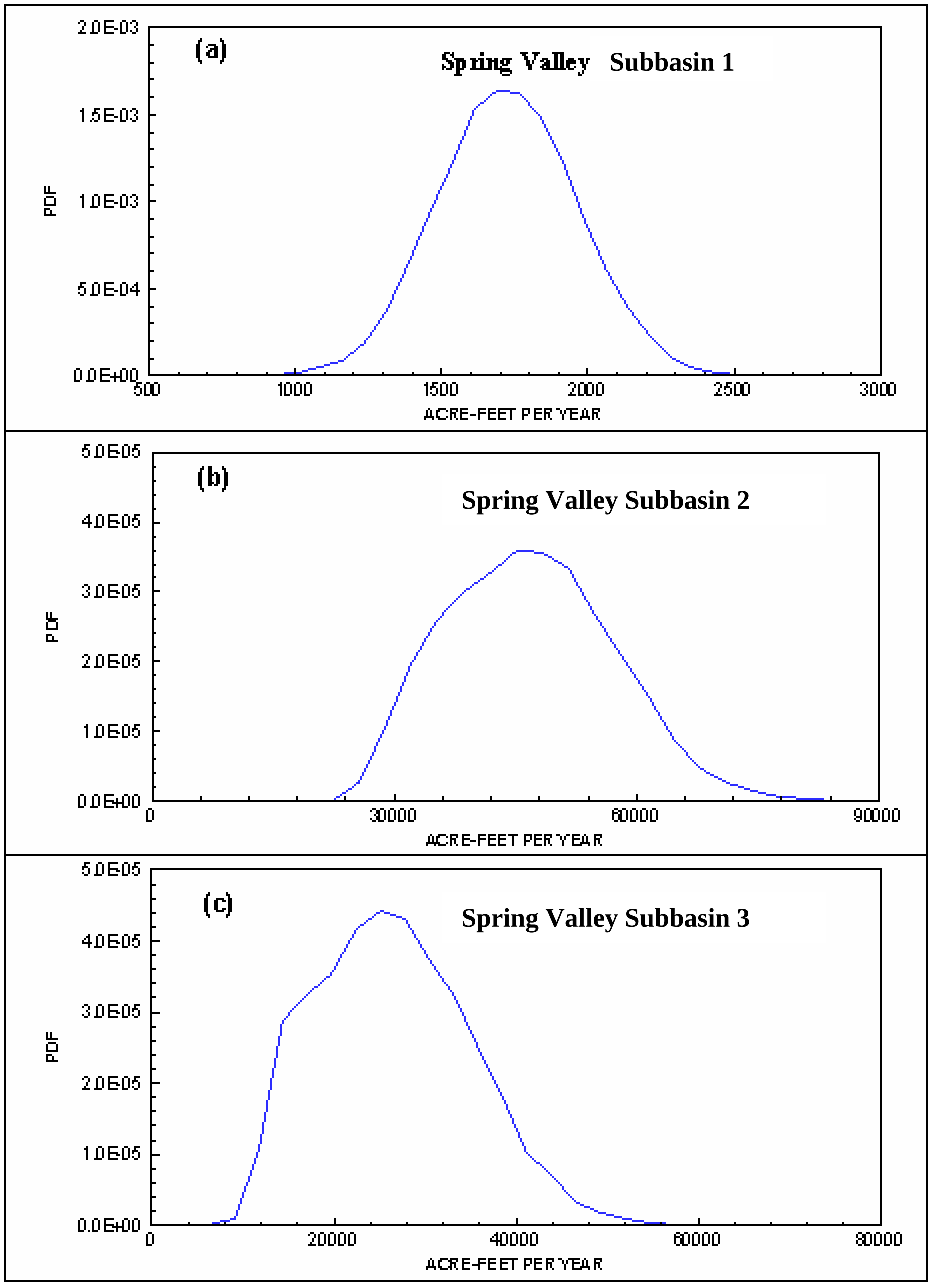

Figure 10. Probability density function generated from 10,000 realizations of simulated annual ground-water discharge from Spring Valley, (a) subbasin 1, (b) subbasin 2, and (c) subbasin 3.

Figure 11 shows plot of probability density functions for the three subbasins in Steptoe Valley. Ground-water discharge followed normal distributions with relatively small CV values. In all subbasins, the dominant ET unit was always one of the desert shrubs (moderately dense desert shrub for subbasins 1 and 2, dense shrub for subbasin 3, see Table 4). Since those ET units typically had significantly higher mean annual ET rates than the mean annual precipitation rates, the resulting ground-water discharge rates were normally distributed.

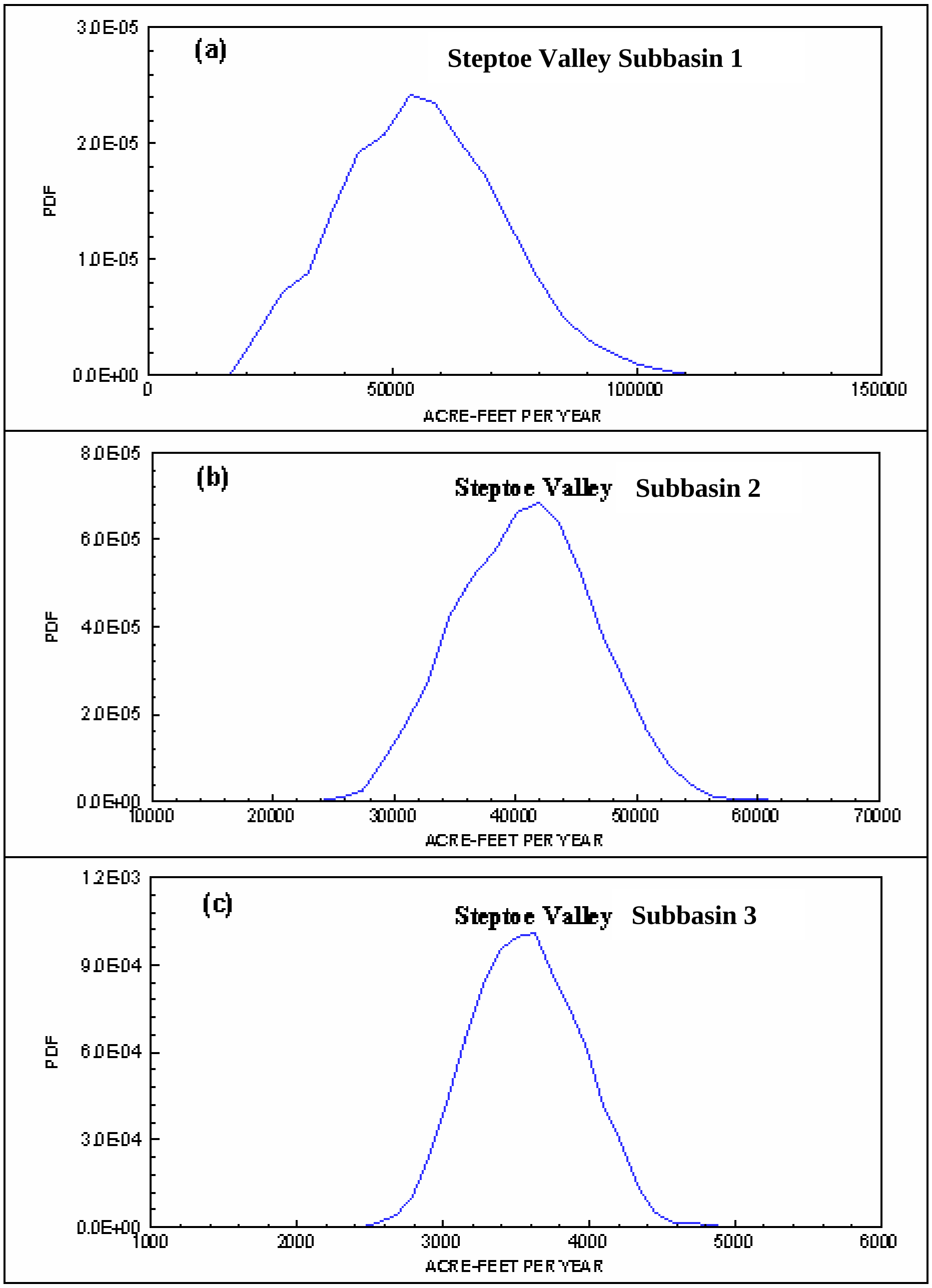

Figure 11. Probability density function generated from 10,000 realizations of simulated annual ground-water discharge from Steptoe Valley, (a) subbasin 1, (b) subbasin 2, and (c) subbasin 3.

Figure 12 shows the probability density functions of ground-water discharge for Tippet Valley. For the two largest ET units (moderately dense desert shrubland and sparse desert shrubland), the differences between the annual ET and precipitation rates were 0.202 and 0.182 ft, respectively, which resulted in a relatively large ground-water discharge CV value of 0.481.

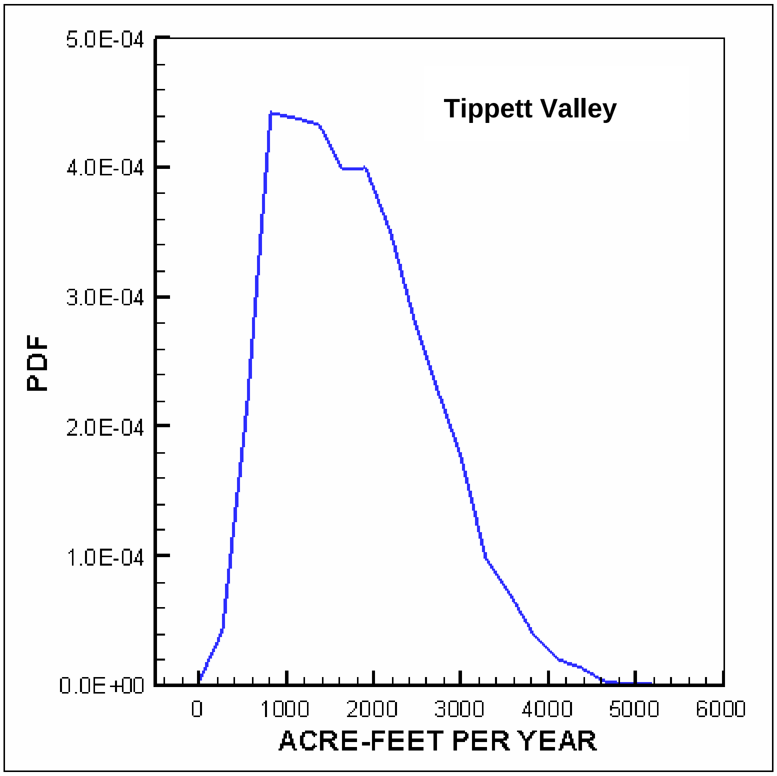

Figure 12. Probability density function generated from 10,000 realizations of simulated annual ground-water discharge from Tippet Valley.

Figure 13 shows probability density functions of ground-water discharge for the four subbasins in White River Valley. For all the subbasins, ground-water discharge followed normal distributions with relatively small CV values. From Table 5, it can be seen that subbasin 1 had the highest mean annual precipitation, which was quite close to the mean annual ET rates for the moderately dense and sparse desert shrubs. But irrigated cropland was also a significant landscape feature in subbasins 1 and 3, and the cropland had a higher mean annual ET rate. As a result, subbasins in this valley typically had normal distributions for ground-water discharge.

Figure 14 shows the probability density function of ground-water discharge generated for the entire BARCAS study area, which includes all the subbasins that contributed to ground-water discharge. Although ground-water discharge distributions were positively skewed and have quite high CV values for some subbasins, their contributions to the overall uncertainty of ground-water discharge for the BARCAS study were not significant, because ground-water discharges for most realizations in those subbasins were close to zero. Overall, their contribution to the total ground-water discharge was small, and therefore, their contribution to total ground-water discharge uncertainty was also small. As a result, the ground-water discharge for the entire BARCAS study area followed a near-normal distribution.

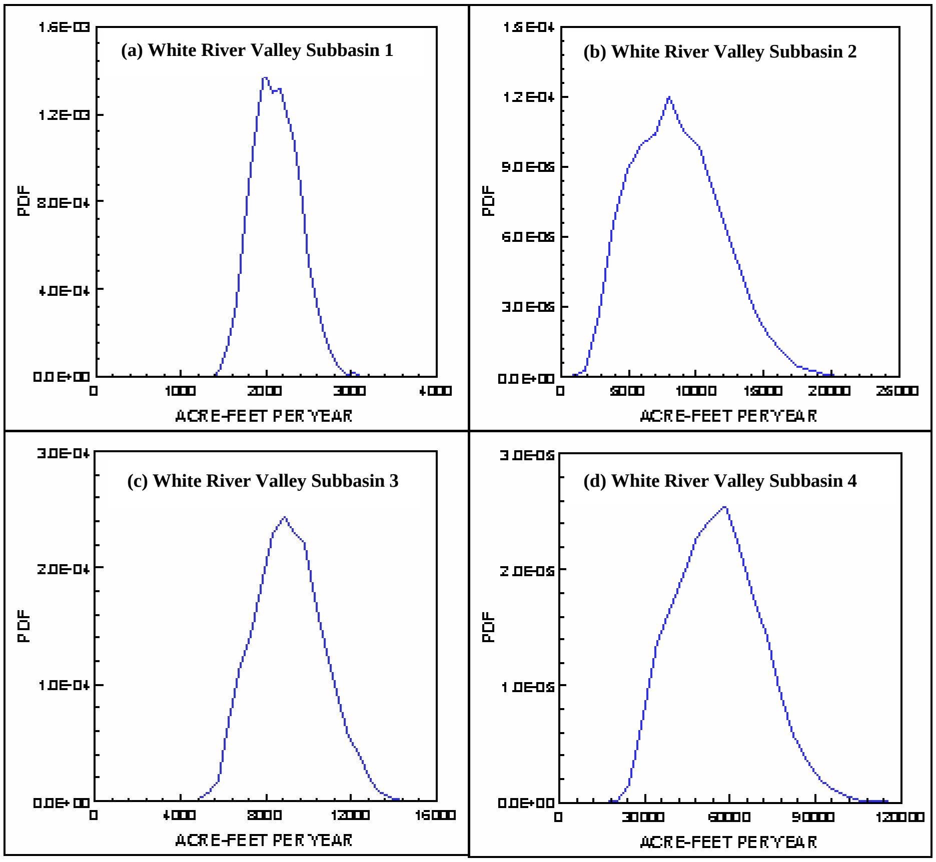

Figure 13. Probability density function generated from 10,000 realizations of simulated annual ground-water discharge from White River Valley, (a) subbasin 1, (b) subbasin 2, (c) subbasin 3, and (d) subbasin 4.

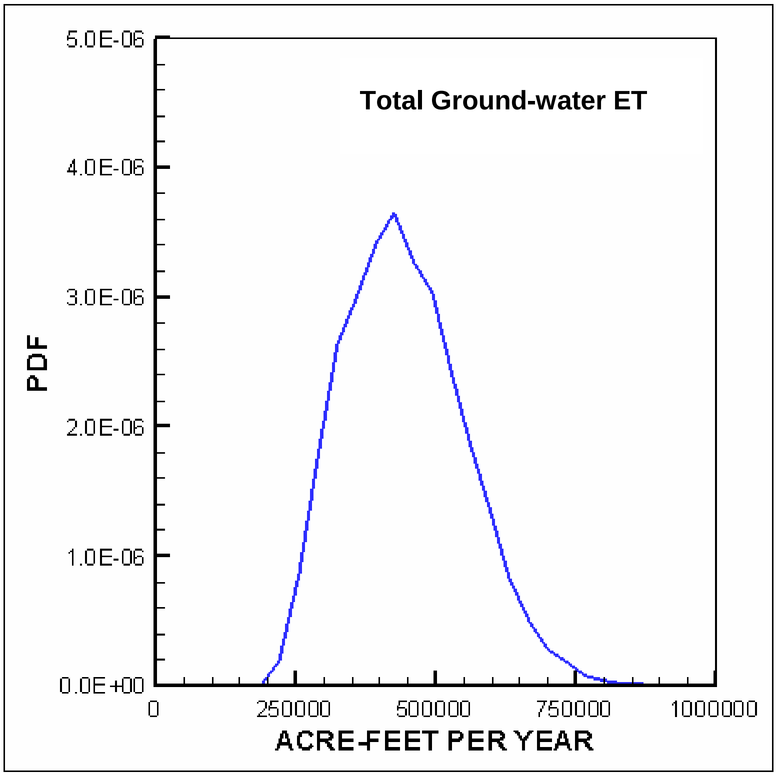

Figure 14. Probability density function generated from 10,000 realizations of simulated total annual ground-water discharge from the BARCAS study area.

SUMMARY

The coefficient of variation of total ground-water discharge, given the assumptions employed in the uncertainty analysis, had a moderate value of 0.241, although for some subbasins in the BARCAS study area, the CV of ground-water discharge estimates could be as high as 1.5. Typically, subbasins with high uncertainty of ground-water discharge estimates had mean annual ET rates for the dominant vegetation similar to mean annual precipitation rates. In these cases, the total ET for those subbasins would be supported mainly by the local precipitation. Those subbasins only contributed to a small portion of the total ground-water discharge, and therefore a high uncertainty in these valleys did not translate into high uncertainty of the total ground-water discharge estimates for the entire BARCAS study area.

It should be noted again that the ranges and uncertainties of input parameters (ET rate, acreage, and precipitation rate) used in this study were obtained from the USGS staff involved in the BARCAS study. The key assumptions used in this uncertainty analysis were: (1) the CV for the acreage of each ET unit is 10 percent, and (2) the ranges of ET rates reported in the literature and determined in this project represent ±2 standard deviations of a normally distributed variable (i.e., 95% of the measurements were assumed to be contained in this range). Since ground-water ET was calculated as the difference between total ET and local precipitation, the interplay between vegetation ET rate and local precipitation played an important role in determining the uncertainty in ground-water discharge. Specifically, because the BARCAS study area was dominated by desert shrubs, which covered over 80 percent of the total area, the relative magnitudes of the ET rates for these three desert shrub categories (dense, moderately dense, and sparse) and the local precipitation rate were the dictating factors in determining the ground-water discharge and the associated uncertainty.

The four largest valleys (Snake, White River, Spring, and Steptoe) accounted for nearly 80 percent of the total ground-water discharge area. For these four valleys, mean annual local precipitation rate was typically much lower than the mean annual ET rates for areas populated by desert shrub communities. As a result, ground-water discharge mainly followed normal distributions for these valleys. Finally, the total ground-water discharge distribution was also normally distributed, although the uncertainty (illustrated by CV) was slightly elevated due to many small yet highly uncertain valleys in the BARCAS study area.

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