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Review of the Basin and Range Carbonate Aquifer System Study (BARCASS)

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Summary

BARCASS is a Congressionally-mandated assessment of the groundwater resources in basins of White Pine County and adjacent areas. It compiles old and new geologic information including the determination of ten hydrologic units (different geologic formations having different hydrologic properties) and completes a consistent reassessment of water balance components including the prediction of interbasin flows.

The Great Basin consists of many topographically closed basins. Groundwater management in Nevada and Utah depends on the basin concept for balancing recharge with natural and anthropogenic discharge. The BARCASS geology analysis subdivided several basins into subbasins including Spring Valley into four subbasins, Snake Valley into five subbasins, and Cave Valley into two subbasins. High points in the underlying bedrock, some with outcrops through the basin fill, defined the new subbasins. The boundaries are not necessarily flow barriers but may constrict the flow depending on the conductivity of and the hydraulic connection between the basin fill and bedrock.

BARCASS discusses faulting through the study area but does not make hydrologic interpretations concerning the faults. It acknowledges that faults could be a conduit or a flow barrier, but that data is needed to make such an assessment.

Prior to BARCASS, the water balance of the basins had been estimated in various reconnaissance (recon) reports published by the USGS in the 1960s. The recon reports had used an empirical method, known as the Maxey-Eakin method, to estimate recharge. Evapotranspiration (ET) had been estimated using a groundwater evapotranspiration (GW ET) rate for the areas of phreatophytes.

Recharge Estimates

BARCASS updated the estimates from the recon reports using physically based models of the basins. Recharge was based on a basin characterization model (BCM), a water balance analysis of precipitation, evapotranspiration, soil water storage and runoff for the unsaturated soil above the groundwater table conducted for each of many small cells spread across the basins. Parameters include estimated soil and geologic properties based on remote sensing and climate input is from the PRISM model. The model was solved for recharge. Each parameter and input value is an estimate which includes a significant amount of uncertainty. Additionally, the model technique imparts additional uncertainty as follows:

- The monthly time-step tends to decrease runoff and allow more water to infiltrate.

- There is no interflow between cells. Water that exceeds the percolation capacity of the underlying bedrock remains as excess soil water until it percolates when in reality it would flow downgradient where it might become available for recharge or be lost to evapotranspiration (ET).

- The model also does not route runoff to adjoining cells where it might infiltrate and become ET. More could be lost to ET because the ET rate would increase downgradient.

- The rainfall input from PRISM overestimated precipitation by from 6 to 15 percent over a substantial portion of the BARCASS study area. A previous US Geological Survey study had essentially determined that PRISM is not appropriate for use in eastern Nevada, particularly in mountainous areas.

- BARCASS assumed that 15 percent of the runoff determined using the BCM becomes recharge but does not reference the source for the assumption. Other studies referenced in BARCASS show that the percent varies from 10 percent in the Death Valley flow system to 90 percent in the Humboldt River flow system. With such a variation, assuming one value for the entire BARCASS study area is inappropriate.

Parameter and input uncertainty along with the uncertainty imparted by the BCM model assumptions cause a large uncertainty for the overall model predictions which the BARCASS report does not adequately discuss. Concern with the uncertainty is amplified by considering that the same authors using the same model published a separate report just three years ago that had estimated recharge up to 25 percent different (mostly less) than estimated in BARCASS. BARCASS does not even discuss why there is a difference.

Discharge Estimates

BARCASS also estimated the discharge component of the basin water balance, ET. From the literature and onsite measurements, it used a range of ET rates for given ET units (vegetation types) across the study area dependent on site specific factors. For groundwater discharge, BARCASS subtracted the average annual precipitation from the ET to determine the GW ET. Because the precipitation rate is very close to the ET rate for the most common ET units, sparse, moderately dense and dense desert shrubs, the actual ET discharge estimate is very low, just a couple of inches per year. Although the variability in ET rate and precipitation is less than 25 percent, the variability in the difference between the two exceeds the total GW ET rate.

In addition to the high variability imparted by the method of determining the GW ET rate, the following factors impart additional uncertainty and may increase the discharge estimates to the high end of the possible range.

- It is unlikely that all irrigated lands had the same ET unit prior to becoming agricultural fields.

- Not all precipitation would be effective for meeting the ET demands of an ET unit because of runoff to playas and to areas not considered an ET unit.

- BARCASS used ET rates that were based partially on a study completed during the wettest decade in a century during a period that phreatophytes would have been transpiring at their maximum rates rather than at a long-term average.

BARCASS determined discharge amounts from most of the valleys that are just slightly higher than estimates from the recon reports, possibly due to the factors just presented. Snake Valley is an exception in that BARCASS estimated discharge to be 130,000 af/y which exceeds the recon report estimate by 50,000 af/y. Most of the difference appears to be in the ET units described in the recon reports as mixed greasewood and rabbitbrush and in BARCASS as dense, moderate and sparse desert shrubland with an area equal to 240,000 acres. The GW ET rate for mixed greasewood and rabbitbrush was 0.2 ft/y in the recon report and from 0.27 to more than 0.6 ft/y in BARCASS; some of the difference is just an inch of annual precipitation.

BARCASS did estimate the uncertainty associated with the three main parameters or inputs for the discharge estimates: precipitation, ET rate, and area of ET unit. The result was an overall coefficient of variation for the discharge estimate of about one-quarter which means that there is an approximate 67 percent chance that the actual discharge falls within plus or minus one quarter of the actual estimate. The small difference between ET rate and precipitation caused most of the variability because the magnitude of the difference in rates is close to zero.

Interbasin Flow

Because the recharge and discharge were estimated independently, they did not equal and the USGS assumed the difference to be interbasin flow. BARCASS used deuterium mass-balance analysis along with water balance accounting to estimate flow across various boundaries that the USGS had determined in the geologic analysis to either probably or possibly allow flow.

The biggest difference in interbasin flow between BARCASS and previous estimates is flow from Steptoe Valley. This is due to the substantially higher recharge estimate in Steptoe Valley. The flow from Steptoe enters Lake and Spring Valleys, and then enters Snake Valley. A portion of the flow to Snake Valley likely becomes discharge to the Greater Salt Lake Desert.

The BARCASS flow estimates may actually have a higher variability than previous estimates because BARCASS relies on models with many uncertain parameters and inputs. The models are not calibrated or verified. Although some of the uncertainty is discussed, the primary graphics published in plates 1 through 4 provide a sense of precision in the estimates. The primary recommendations are for the USGS to calibrate the estimates wherever possible, such as for runoff from the BCM model, to determine the variability inherent based on all parameters and inputs, not just the select few used by BARCASS, and to present final graphics of the results that illustrate the uncertainty. There is a detailed list of recommendations included at the end of the report.

Introduction

BARCASS is a Congressionally-mandated assessment of the groundwater resources in basins of White Pine County and adjacent areas. It compiles old and new geologic information including the determination of ten hydrologic units (different geologic formations having different hydrologic properties) and completes a consistent reassessment of water balance components including the prediction of interbasin flows

The USGS published three primary reports and four plates for BARCASS. They are the summary BARCASS open file report and two scientific investigations reports presenting details of the recharge and evapotranspiration (ET) rates (Table 1). There were also several appendices for the main BARCASS and ET reports (Table 1). The Desert Research Institute (DRI) also published two reports. This report reviews the BARCASS reports referenced in Table 1.

This report reviews the supporting documents as though they are part of the BARCASS report even though only the main BARCASS report is issued in "draft" form. The USGS considers the supporting documents as final but it is not possible to review the discussions made in the summary report without considering the base science. Additionally, the summary BARCASS report includes some base science, such as ET rates for large-scale areas, so it is not reasonable to be able to review just some of the science.

The BARCASS report primarily estimates water balance components for the major hydrologic areas within the study area. It also reviews and provides new geologic information about the areas. Doing so, it divides the existing hydrologic areas defined on topographic basin boundaries, from one to four subbasins based on new geologic information. The subbasins tend to be based on areas of rock which are less pervious than the adjoining rock or valley fill aquifer.

There are two sections to this report, Geology and Water Balance, subdivided into specific components.

Table 1: Reports, data and maps published for BARCASS and reviewed in this report.

Reference in this review	Authors	Title	File Type
BARCASS	Welch, A.H. and D.J. Bright, ed	Water Resources of the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah – Draft Report; Open File Report 2007-1156	Pdf
Appendix A		Appendix A. Component estimates of recharge, discharge, water use, and aquifer storage	Xls
Appendix 1		Climate stations used to evaluate PRISM …	Pdf
Appendix 2		Recorded and PRISM estimated precipitation …	Pdf
Appendix 3		Actual and estimated elevations for climate …	Pdf
Appendix 4		Percent differences between PRISM est. …	Pdf
Appendix 5		Estimates of annual precipitation for hydro …	Pdf
BCM report	Flint, A.L. and L.E. Flint	Application of the Basin Characterization Model to Estimate In-Place Recharge and Runoff Potential in the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah; Sci Inv Rep 2007-5099	pdf
ET report	Moreo, M.T., R.J. Laczniak, and D.I. Stannard	Evapotranspiration Rate Measurements of Vegetation Typical of Ground-Water Discharge Areas in the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah, September 2005-August 2006	Pdf
ET report, Appendix A		Appendix A. Evapotranspiration data for the Basin and Range carbonate-rock aquifer system.	xls
Plate 1		Hydrogeologic map and Cross sections	Pdf
Plate 2		Altitude of water table in the basin-fill aquifer	Pdf
Plate 3		Potentiometric surface of the carbonate-rock aquifer	Pdf
Plate 4		Distribution of ground-water recharge and discharge, and evapotranspiration units	Pfd
Zhu et al	Zhu, J., M.H. Young, and M.E. Cablk	Uncertainty Analysis of Estimates of Ground-Water Discharge by Evapotranspiration for the BARCAS Study Area	Pdf – from DRI

Geology

The geology section presents substantial new information and/or interpretations of the geology in the study area. One of the biggest differences is the idea of intrabasin divides where pre-Cenozoic bedrock approaches the ground surface and either outcrops, as in Spring Valley near Hwy 50, or just renders the basin fill quite thin. These divides are not necessarily flow barriers, but they indicate potential changes in groundwater management. If a valley is divided, the effective perennial yield may be substantially different across the basin.

BARCASS presents a substantial change in previous thinking with regard to interbasin flow. Based on geology interpretations, BARCASS identifies areas that could allow flow through basin boundaries. Some are uncertain, and BARCASS identifies this. It should also be noted that the geology may consist of formations which are pervious enough to allow flow, but a groundwater divide could separate the basins. The BARCASS report should add a discussion about the location of groundwater divides with respect to areas of potential flow. This is important because it would aid an interpretation of how interbasin flow could change due to stresses. In other words, it is possible that pumping on one side of a range could draw flow from the other side by lowering the groundwater divide. This is particularly important in the south end of the Snake Range and in the south end of the Schell Creek Range where BARCASS indicates flow is possible but uncertain and may be constrained (elsewhere BARCASS indicates that water balance indicates flow through some of these boundaries).

The geology presentation would be substantially improved if in addition to the east/west cross-sections the report provided profiles along the crests of the major ridges. This would aid in the interpretation of the potential for interbasin flow. A good example is the Fortification Range. The south half of the range has thick tuff through which interbasin flow projected to occur there would flow. The northern part of the mountain range is carbonate, however, except for potential thin intervals of Chainman Shale (BARCASS, page 40, description of unit 9). A cross-section would help the reader better interpret how the USGS feels this could impede the flow.

A profile would also be useful along the Snake Range crest. BARCASS has shown there is the potential, but not high likelihood, for flow through the range between Wheeler Peak and the Limestone Hills. On the north, an impermeable granitic pluton underlies the peak; on the south, thousands of feet of carbonate rock form the Limestone Hills. A profile would interpret the transition between the two areas which would help with the interpretation of flow between valleys.

Water Balance

Recharge

Water Balance Method for Estimating Recharge

The BCM report details the Basin Characterization Model, water balance method, used to estimate recharge. The model divides each basin into 890 foot square cells and balances precipitation and ET to estimate recharge on each cell.

The water balance assumes that all precipitation, snowmelt and carry-over soil moisture is available water at the beginning of the time step. Potential evapotranspiration (PET) is removed from the available water, as is precipitation in the form of snow that does not melt. This water fills the soil water first: “[p]otential runoff was calculated as the available water minus the total storage capacity of the soil” (Flint et al 2004, page 165). Total storage capacity is the soil depth times the porosity. The potential runoff is subtracted from the available water to determine the amount of water available for recharge. Potential recharge is the remaining available water minus the field capacity of the soil. The maximum recharge rate is the "permeability of the bedrock" (Id.). If the available potential recharge exceeds this maximum recharge rate, the excess water remains in the soil until the next time step. One detail with the model not explained is whether the soil will always retain moisture at the minimum of the wilting point.

Parameters estimated for each cell include estimated soil and geologic properties based on remote sensing and climate input from the PRISM model. Each parameter and input value is an estimate which includes a significant amount of uncertainty for each cell (BARCASS, pages 8 and 52). In addition to parameter and input uncertainty, various shortcomings of the model technique as described in the BCM report further increase the variance on the estimated recharge. These potential problems are discussed next.

First, the model used a monthly time step for doing water balance calculations at each cell. This underestimates runoff by effectively spreading the precipitation and snowmelt out over the month. The infiltration capacity of the soil would really never be exceeded at this time scale. The only limit is the total storage capacity; for example, just 1 foot of soil with a 10 percent porosity would be able to store 1.2 inches of available water. However, a storm which drops just a third of this amount in an hour would likely generate runoff – water that does not enter the soil storage as assumed the BCM model. Except for bedrock outcrops, the example here probably represents a low amount of soil storage. Using a monthly time step minimizes runoff and maximizes potential storage which could lead to an overestimate of recharge.

Second, the BCM model ignores interflow between cells. The BCM model retains until the next month any potential recharge that exceeds the maximum recharge capacity which would, in reality, seep downgradient as interflow. It might become available for recharge at that point, or it might be lost to evapotranspiration. It is difficult to estimate whether considering interflow would increase or decrease recharge – but it would be more accurate.

This author has experience with another model that does similar calculations – the HELP model. This quasi- two-dimensional model is intended for designing landfills, but it can accept soil layers with any characteristics; it has been used to estimate recharge through backfilled open pit mines and natural recharge distribution in mountainous areas. The model uses a water balance between layers and calculates soil moisture, actual ET, and percolation in a manner that appears similar to the BCM model but on a daily basis. Additionally, it removes water that exceeds the capacity of the underlying layer. This is a means of removing interflow. In the experience of this reviewer, most recharge determined with HELP for natural conditions or backfilled pit occurs on just a few days of a wet month suggesting that recharge in these types of water balance analyses is more of a threshold phenomenon with breakthrough between layers, soil and bedrock, occurring on a daily basis. The BCM model might be improved if some of the characteristics of HELP were applied to it.

Third, the BCM model assumes that all runoff from a cell becomes available as mountain front recharge. The model does not route the runoff to adjoining cells where it might infiltrate and become ET. More could be lost to ET because the ET rate would increase downgradient. Higher ET would make more soil moisture capacity available downhill; more of the runoff could infiltrate and allow the ET rate to approach the potential ET. The lack of runoff routing definitely increases the runoff estimate but with the assumption that some runoff becomes recharge, it might increase the recharge as well.

Fourth, the BCM model used PRISM to estimate climate input to drive the model. The method has never been verified as accurately simulating eastern Nevada precipitation. In fact, a US Geological Survey study (Jeton et al 2005) essentially determined that PRISM is not appropriate for use in eastern Nevada, particularly in mountainous areas. The next paragraphs provide concerns about PRISM based on Jeton et al (2005) which discuss the method's precipitation overestimates.

Jeton et al (2005) stated that PRISM is essentially a black box whose details cannot be examined. "The precipitation data used in the development of PRISM, referred to as control points, is proprietary and has not been released to the public. Thus, there is uncertainty in what sources and periods of record were used, whether the data was modified to account for incomplete or poor data, and how the 30-year period mean was computed" (Jeton et al 2005, page 23).

Using precipitation estimates from PRISM for most of Nevada, Jeton et al (2005) determined that PRISM overestimates precipitation for Nevada by from 3 to 4 percent. For the BARCASS study area, the PRISM method overestimates precipitation by substantially more. Figures 6 and 7 in Jeton et al map the differences between PRISM estimates and National Weather Service and Western Regional Climate Center estimates, respectively, for 1960 through 1990. PRISM overestimates precipitation by a minimum of 6 percent for all of White Pine and northern Lincoln County, excepting one WRCC site shown in Figure 7. Figures 10 and 11 in Jeton et al show similar results for 1970 through 2000 with the exception that for the WRCC data, there is a slightly larger area where PRISM underestimates precipitation which includes Ward Mountain. PRISM substantially overestimates precipitation in the Schell Creek Range, with one site being overestimated by 37 percent (Jeton et al, Figure 10). This substantial precipitation overestimate could explain the higher recharge estimates in both Steptoe and Spring Valleys. Overall, these figures show a significant overestimate of precipitation with a 6 to 15 percent overestimate covering a substantial portion of the BARCASS study area.

The BCM report has a map which shows the precipitation estimated using PRISM for the BARCASS study area (Figure 4). The scale is very hard to read; based on the scale and the amount of blue shown on the map, there are rather large areas in the mountains with more than three feet of precipitation (the top of the scale is 3.5 ft/y, or 42 in/y). Even if the ridges receive this much (they do not), the large area with this amount illustrates how PRISM may overestimate the precipitation.

In summary, the use of PRISM for the precipitation input for the BCM model may cause the model to overestimate recharge.

Fifth, BARCASS assumes that 15 percent of the runoff determined using the BCM becomes recharge, but does not adequately reference the assumption. The BARCASS report references the BCM report, which in turn just states: "[a]lthough the percentage of potential runoff that becomes recharge can vary significantly, an assumed value of 15 percent is considered reasonable for central Nevada" (BCM report, page 11). It is not an assumption familiar to this author. In fact the next sentences indicate that the percent varies from 10 percent in the Death Valley flow system to 90 percent in the Humboldt River (*Id.*). In fact, more of the BARCASS study area is similar to the Humboldt system than to the Death Valley flow system. The 15 percent assumption could lead to an underestimate of recharge if the high end of the potential range is correct.

The only uncertainty estimate provided by BARCASS are whisker plots in figure 22 (BARCASS) based on the 10 to 90 percent range in runoff recharge estimates. The range presented in Figure 22 does not account for parameter or input uncertainty or for the potential modeling problems discussed above. These plots suggest only that the recharge could be much higher than reported rather than actually representing the potential uncertainty for the overall estimate. The upper end of the plot is based on runoff recharge being as much as 90 percent of the total runoff.

BARCASS' recharge estimates would be substantially improved if an actual estimate of uncertainty that considers all sources were included. This would be similar to the uncertainty estimates provided for the discharge estimates discussed below.

The BCM estimates runoff which can be compared with measured values which shows the inaccuracy of the BCM estimates. For Steptoe, Snake and Spring Valleys, the BCM estimated runoff is 72, 126 and 95 kaf/y, respectively, for the 1970 to 2004 period (BCM report, Table 1). These values are much higher than would be expected from gaging station data. The Cleve Creek near Ely gage averages 7580 af/y, Steptoe Creek near Ely averages 4900 af/y and Baker Cr near the Narrows averages 6573 af/y. These gages measure runoff from some of the largest drainages in their respective valleys but are only a small fraction of the BCM runoff estimates. Other estimates of runoff done for these valleys are also only a small fraction of that estimated with the BCM[1].

The high runoff estimates with the BCM may result from one or all of the issues discussed above: monthly time steps, not routing the runoff downhill from cell to cell, not considering interflow, or the use of PRISM. However, using both runoff estimated from measurements and the model estimates, the parameters of the model could have been adjusted to calibrate the model.

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[1] Specifically, the estimates made by the Southern Nevada Water Authority for the Baseline Characterization Study done for the upcoming DEIS on their proposed pipeline are much less than these estimates. Their estimates are based on spot measurements compared with gaging station measurements taken on the same day.

BARCASS failed to consider a previous report that suggests the current BCM model may overestimate recharge. The recharge estimates in BARCASS are much higher than the estimates made in a previous study by the same authors using the same model (Flint et al 2004) (Figure 1). Differences between the current study and the 2004 study include the new recharge estimate of 154 kaf/y in Steptoe Valley as compared to 111 and 94 kaf/y, 111 kaf/y in Snake Valley as compared to 93 and 82 kaf/y, and 93 kaf/y in Spring Valley as compared to 67 and 56 kaf/y. Smaller basins have similar proportional differences, although the very smallest actually have more recharge in the 2004 study (Little Smoky Valley). The BCM report or BARCASS should explain why the current estimates are so much higher than the previous estimates.

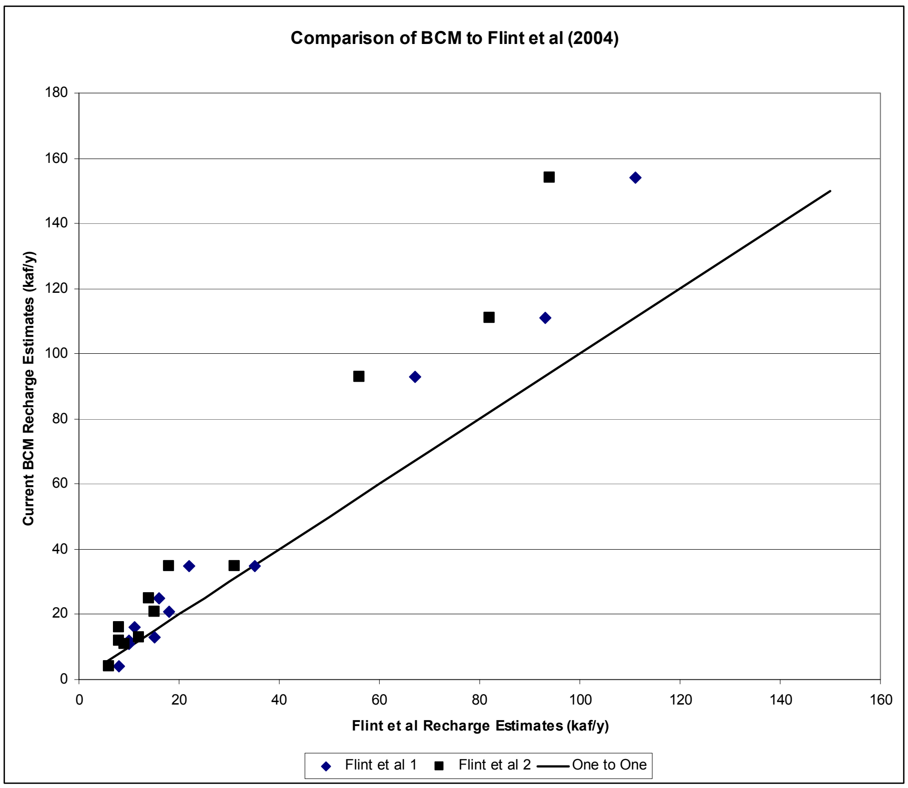

Figure 1: Comparison of recharge estimates from Flint et al (2004) with estimates in the BARCASS study. Flint et al (2004) have two estimates based on two different precipitation schemes - a mean year (1) and a time series (2).

Evapotranspiration

BARCASS determined discharge from groundwater by ET as the product of the area of an ET unit and an ET rate for that unit. The ET rate was determined from literature values and the precipitation for the unit was subtracted from that value to establish a groundwater discharge rate (BARCASS Appendix A). However, there are many inconsistencies in the analysis as will be discussed in this section.

BARCASS ET Rates

ET rates were determined for 10 ET units ranging from playa soil to marshland. The ET Rate table in Appendix A shows different rates for marshland, meadowland, grassland, dense desert shrubland, moderately dense desert shrubland, and sparse desert shrubland. However, for moist bare soil, open water, dry playa and irrigated lands, the same rate is used for all basins and subareas. It is understandable that conditions such as aspect, elevation, and average temperature (local micrometeorological factors, BARCASS page 58) would cause the ET rate to vary for a specific ET unit for different subareas. However, these factors affect the evaporation from all ET units, not just the six mentioned (irrigated is a special case discussed below). The USGS should better explain how the different rates were determined and why site conditions would cause variation in some of the ET units but not in the others.

BARCASS used recent literature values from four separate reports to determine the average ET rate to apply to different types of phreatophytic vegetation (BARCASS, page 54). The range is shown on Figure 27 of BARCASS. Figure 27 also shows a single line for “area-weighted average-annual evapotranspiration rate” which is confusing because it implies there is a single value per ET unit used for the entire BARCASS area. As discussed in the previous paragraph, it appears that a range was used for some ET units rather than a single value; the USGS should fix this discrepancy.

A table with values from each literature source showing the value that could be used for each ET unit from that source would be more useful than the range shown on Figure 27. Our review of the sources suggests that ET units in those sources may have significantly varied from those described in BARCASS or the ET report. In other words, BARCASS may have used inappropriate ET units.

One of the referenced reports, Nichols (2000), estimated ET for various basins in 1985 and 1989. These years occurred during the second half of the wettest decade on record in the area. Based on statewide precipitation data downloaded from the National Climatic Data Center for Nevada and Utah and for Salt Lake City, the decade of the 1980s was extremely wet (www.ncdc.noaa.gov). For Nevada, the decade was the wettest; for Utah it was second wettest only to the 1990s (Table 2). In Salt Lake City, the nearest city included in the data base, the 1980s were also the second wettest. It is likely that the phreatophyte cover had expanded and its density had increased. The ET rates determined in that study would likely have reflected healthy vegetation. BARCASS should not rely on these estimates as accurate for long-term pre-development rates.

Table 2: Average decadal precipitation for Nevada, Utah and Salt Lake City from the National Climate Data Center.

Decade	Nevada (inches)	Utah (inches)	Salt Lake City (inches)
1901-10	9.0	11.2	
1911-20	8.6	11.5	
1921-30	7.6	11.5	
1931-40	8.2	11.0	
1941-50	8.9	12.2	14.9
1951-60	7.7	10.3	13.9
1961-70	9.2	11.6	16.0
1971-80	9.4	11.2	16.1
1981-90	**9.8**	**12.7**	**16.5**
1991-2000	**9.5**	**12.8**	**16.9**

Groundwater ET Rates

The ET units discharge water regardless of the source which may include precipitation, surface water run-on, or groundwater. The BARCASS report adjusted for sources to estimate groundwater ET. The GW ET rate was set equal to the ET rate minus the average precipitation for the site. The roll of run-on will be discussed below in following sections.

The GW ET rates are more variable across the BARCASS study area than are the total ET rates because of the variability in precipitation. The variation in ET rate for a given ET unit is just a couple inches per year but the precipitation component, which had been estimated with PRISM, varied from 6 to 13 in/y. The difference in ET rate and annual precipitation is close to 0, therefore the uncertainty for the GW ET is proportionally much higher than for the two rates used to calculate it.

Effective Precipitation

BARCASS assumed that all precipitation is effective for satisfying the ET requirements for a ET unit. This is truly an incorrect assumption because most precipitation in the valleys occurs in short-duration, high-intensity storms at rates that exceed the infiltration capacity of the soil. The gradient is toward the playas. The presence of rivulets in the soil that may be observed by any visitor these areas make it clear that runoff does occur. Not all of the precipitation is effective. BARCASS should adjust its GW ET rates to account for runoff.

ET Rates from Irrigated Areas

BARCASS assumed that irrigated acreage had a groundwater ET rate "that equaled the area-weighted average ET rate for all other phreatophyte units delineated in the study area" (BARCASS page 61). According to Appendix A, the BARCASS ET rate for irrigated areas equals 1.4 ft/y for all basins. The assumption appears to be that the irrigated land replaced phreatophytic vegetation similar to an average taken for the entire study area. It does not appear that there was any attempt to determine the actual ET unit which may have preceded irrigation in the specific valley. Because the total ET discharge from these exceeds 19,000 af/y, which is not insubstantial, the USGS should improve its discharge estimate by determining the actual ET unit that preceded irrigation.

Measured ET

As part of the BARCASS study, the USGS measured ET at six locations throughout the study area for a year (ET report). The measured groundwater ET at the sites monitored for a year in the study area varied substantially (Table 3) similar to the different variability in ET and GW ET rates discussed above for the ET units. At sites SNV-1 through WRV-2, all in "greasewood dominated shrubland" (BARCASS page 61), the ET varied from 10.02 to 12.77 in/y, a variation of just 25% compared to the average for the sites, 11.41 in/y. The groundwater ET, for which the precipitation at the site is subtracted from the ET, varied from 1.10 to 4.15 in/y, a variation of 108% compared to the average, 2.82 in/y.

Table 3: Tabulated ET, precipitation and groundwater ET for BARCASS ET sites. All data from Appendix A of the ET report.

Measured Parameter	ET Site					
	SNV-1	SPV-1	SPV-2	WRV-1	WRV-2	SPV-3
ET, in inches	10.03	10.02	12.07	12.77	12.18	26.94
Precipitation, in inches	6.03	8.33	8.90	8.62	11.08	7.74
GW ET, in inches	4.00	1.69	3.17	4.15	1.10	19.20

The depth to groundwater does not explain the variation in ET or groundwater ET rate (Figure 2). This seems counterintuitive because more ET might be expected with better access to groundwater. Because there is no correlation, groundwater does not explain the differences in Table 3.

It is apparent based on Table 3 and Figure 2 that the variation in measured GW ET rates for greasewood dominated shrubland depends primarily on the precipitation rate. Therefore, the effectiveness of the precipitation must be considered. If more precipitation falls and is effective, there will be less ET from the groundwater.

The short-term spatial variability for measured precipitation at the ET sites is likely much greater than the variability would be for a long-term average annual precipitation. Spatial variability resulting from one or two storms could cause substantial variability within a single year such as the year of the study. The variability for annual averages would be much less. The ET rate depends on the available energy, a quantity that is much less variable both spatially and temporally than the average annual precipitation. Therefore the average GW ET rate of 2.8 in/y (0.23 ft/y) may be more representative of the overall study area than is the result of any attempt to account for the myriad sources of variation over such a short study period.

The USGS assumed that spring flow is included as groundwater evapotranspiration (BARCASS page 54). "Springflow is not considered a separate component of the total ground-water discharge. Water discharging from springs is either lost through ET or recharges shallow ground-water flow systems" (Id.). We agree that ET rates do not vary with the source of the water and that because groundwater discharges from springs, it is appropriate to not separate the two.

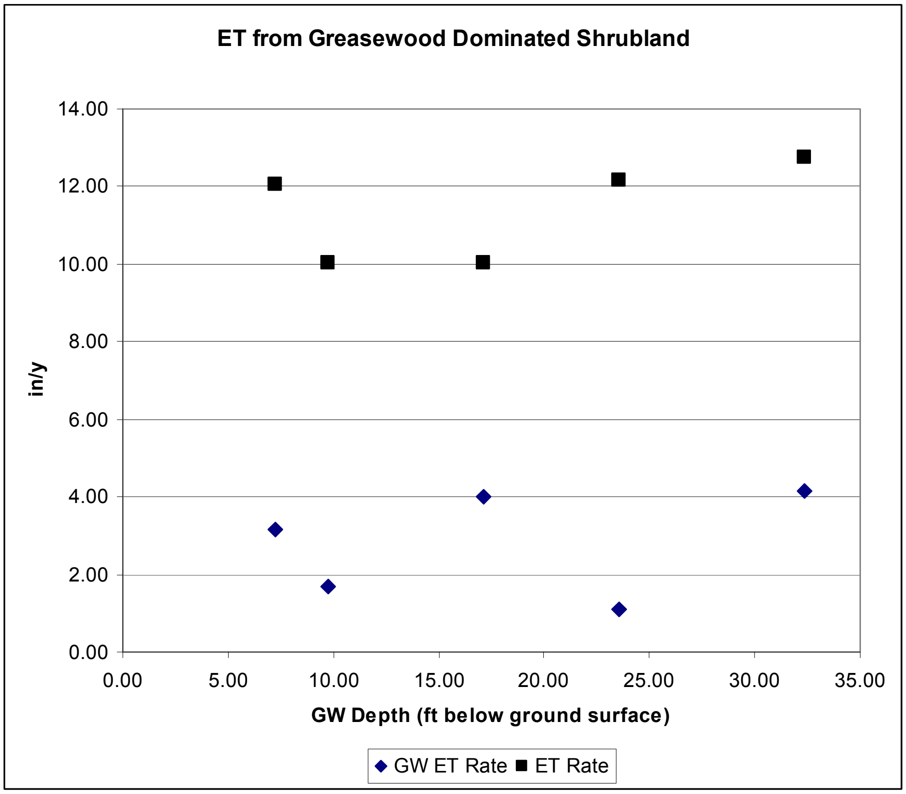

Figure 2: Relation of ET and Groundwater ET for BARCASS study sites in greasewood dominated shrubland. All data from Appendix A from the ET Rate study.

Open Water

The USGS includes groundwater discharge from open water area. Presumably, this means playa lakes and open water in wetlands throughout the valleys. The ET rate ranges from 4.6 to 5.6 ft/y and is considered to be discharge from groundwater (BARCASS page 54). Open water accounts for just 0.1 percent of all ET units and only a few hundred acres. However, the reality is that not all evaporation from open water sources is from groundwater. Surface runoff, especially during storm periods and snowmelt, reaches the open water areas in these valleys. BARCASS assumes that surface water runoff that reaches "fine-grained playa sediments is assumed to evaporate and for the purpose of the water budget does not contribute to either ground-water recharge or discharge" (BARCASS, page 64). It seems that surface water runoff to any open water area would add to area for ET discharge estimates and that the methods used in BARCASS overestimated GW ET discharge by including surface water evaporation.

Area of Irrigated Lands

BARCASS states that consumptive use estimate for irrigation in the study area is 2.9 ft/y, but that number is not what was used to calculate the total irrigation consumptive in Appendix A. Values ranged from 2.78 ft/y for Butte Valley to 3.08 ft/y for Little Smoky Valley (Table 4). Snake Valley is 2.99 ft/y while Spring Valley is 2.81 ft/y. The BARCASS report should not state that one value was used when there was actually a range.

Table 4: Irrigation consumptive use back-calculated from values reported in Appendix A, water use table.

Hydrographic area	**Irrigated acreage (acres)**	**Irrigation consumptive use (acre-feet)**	Consumptive Use (feet)
Butte Valley	193	537	2.78
Cave Valley	0	0	
Jakes Valley	178	504	2.83
Lake Valley	4,360	13,347	3.06
Little Smoky Valley	1,207	3,712	3.08
Long Valley	0	0	
Newark Valley	2,078	6,234	3.00
Snake Valley	9,200	27,554	2.99
Spring Valley	4,888	13,728	2.81
Steptoe Valley	3,742	10,420	2.79
Tippett Valley	0	0	
White River Valley	6,078	18,031	2.97
Total	**31,923**	**94,067**	2.95

BARCASS used a higher acreage for calculating groundwater discharge through ET than for calculating consumptive use for irrigation. This may be seen by comparing the area used for calculating GW ET discharge from irrigated fields with the area reported as irrigated acreage in the Water Use Table of Appendix A, and shown in Table 4. For example, the reported Snake Valley irrigated acreage from the Water Use Table is 9200 acres while the Acreage table of Appendix A shows that for subbasins 1 through 4 of Snake Valley, subbasin 5 has no irrigation, the irrigated acreage is 9932 acres for calculating ET discharge. Thus, there is an unexplained discrepancy in the total irrigated area in Snake Valley between the value used for ET discharge and the value used for irrigation consumptive use.

Similar discrepancies occur in other valleys (Table 5). The biggest discrepancy is for Lake Valley which has 4360 acres with irrigation but none for ET discharge. This is possible if the irrigated lands had not been phreatophytic. In addition to Snake Valley, Spring Valley, Steptoe Valley, and White River Valley have substantially higher acreages for ET discharge than for irrigated consumptive use. If the area used for calculating ET discharge was less than the total irrigated acreage, the discrepancy could be explained by understanding that some of the irrigated acres were not in phreatophyte zones. But this is not the case as seen in Table 5. The USGS should correct the discrepancies or at least explain why the discrepancies do not represent a major error in the GW ET discharge estimates.

Table 5: Comparison of irrigated cropland with area from ET discharge tables developed using data from the Water Use Table and Acreage Table of Appendix A. If subbasin is not shown, there is no irrigated acreage.

Hydrographic area	Hydrographic area subbasin	Irrigated cropland	Hydrographic Basin Area (acres)	Hydrographic Basin as Reported on the Water Use Table (irr. acres)
Butte Valley	1	202		
Butte Valley	2	0	202	193
Jakes Valley	--	187	187	178
Lake Valley	2	0	0	4,360
Little Smoky Valley	--	216		
Little Smoky Valley	--	0	216	1,207
Newark Valley	1	208		
Newark Valley	2	285		
Newark Valley	3	0	493	2,078
Snake Valley	1	1,785		
Snake Valley	2	1,138		
Snake Valley	3	5,136		
Snake Valley	4	1,873		
Snake Valley	5	0	9,932	9,200
Spring Valley	2	2,867		
Spring Valley	3	2,492		
Spring Valley	4	0	5,359	4,888
Steptoe Valley	1	2,766		
Steptoe Valley	2	2,354		
Steptoe Valley	3	0	5,120	3,742
White River Valley	1	841		
White River Valley	2	490		
White River Valley	3	4,965		
White River Valley	4	295	6,591	6,078
		28,100		

Uncertainty Estimates for ET Discharge

BARCASS lists various potential sources of uncertainty, some of which were discussed above, and provides (page 55) uncertainty bands around the GW ET discharge estimates (figure 34, BARCASS) based on a Monte Carlo analysis done by Zhu et al. The Monte Carlo method considered the variability of ET rate (95% variance in the published ET ranges), precipitation (coefficient of variation, standard deviation divided by mean, (CV) on the annual precipitation), and area of ET unit (CV equals 10%). Zhu et al assumed these followed a normal distribution. Using 10,000 simulations to estimate GW ET as GWET = (ET – P)*A where ET is ET rate, P is annual precipitation and A is area of each ET unit, for each basin, Zhu et al estimated the distribution of potential discharge estimates. For each of the 10,000 simulations, each parameter has the uncertainty applied to it from the Monte Carlo simulation.

Zhu et al reported the uncertainty results as a CV. The closer CV is to 0, the lower is the variability in the distribution of the estimate. Zhu et al reported that the CV for the overall BARCASS study area is 0.241 which they described as "moderate" (Zhu et al, page 13). This means there is approximately a 67% chance that average discharge from the whole BARCASS study area will range from 336,000 to 550,000 af/y. CV varies substantially among subbasins; Zhu et al note that smaller basins tended to be more variable. For example, the four Snake Valley subbasins 1 through 4 have CV equal to 0.351, 0.231, 0.247, and 0.199, respectively; three of the basins are higher than the study area average and subbasin 5 has no discharge. This is expected because summing over the subbasins evens out some of the variability; in other words, estimates below the mean in one subbasin are balanced by estimates above the mean in other subbasins.

This estimation of uncertainty is important because it helps the user to understand the variability of the estimates. It indicates that the knowledge of available water as estimated by ET is highly uncertain.

Snake Valley ET Discharge

Snake Valley has the highest ET discharge in the study area and is the one basin for which BARCASS estimates ET to be substantially higher than previous recon estimates. For Snake Valley, including round-off, the reconnaissance report estimated ET discharge equaled 80,000 af/y (Hood and Rush 1965) while BARCASS estimates it to be 132,825 af/y. This section considers why the new estimate is so much higher than the previous estimate.

Hood and Rush (1965) estimated total acreage to equal 317,500 acres; the BARCASS total acreage summed in the Area table (Appendix 1) is 325,443 acres. The area difference is too small to explain the different ET estimates.

It is not easy to compare the BARCASS discharge estimate with that of Hood and Rush. They used meadow grass and rabbitbrush, wet meadow, mixed greasewood and rabbitbrush, flooded playas and dry playas (Table 6). Mixed greasewood and rabbitbrush describes the largest area, at 240,000 acres. BARCASS describes the desert shrubland similarly but breaks it into dense, moderate and sparse which total almost exactly 240,000 acres (Table 7). BARCASS ET rates for dense, moderate and spare desert shrubland for the five subbasins in Snake Valley range from 0.53 to 0.7, 0.41 to 0.55, and 0.19 to 0.31 ft/y, respectively. The BARCASS ET discharge for these three areas is 89,594 af/y. This exceeds the total estimated by Hood and Rush for the entire valley and is almost 40,000 af/y more than the 50,000 af/y determined by Hood and Rush for mixed greasewood and rabbitbrush area (Table 6).

Table 6: Snake Valley area and evapotranspiration rates and volume from Hood and Rush (1966)

Phreatophyte	Area (ac)	Depth to Water (ft)	Rate (Ft)	Volume
Meadow grass and rabbitbrush	3300	2 to 10	0.5	1700
Wet meadow	11000	0 to 5	1.75	19000
Mixed greasewood and rabbitbrush	240000	10 to 50	0.2	50000
Flood playas	3200	0 to 15	0.75	2400
Dry playa	60000	0 to 30	0.1	6000
Total	317500			79100

Table 7: Snake Valley area and GW ET summed from BARCASS Appendix A and average rate calculated from these totals.

Phreatophyte Type	Area (acres)	ET Discharge (af/y)	Average Rate (ft/y)
Marshland	1842	6477	3.52
Meadowland	5951	11551	1.94
Grassland	3443	5385	1.56
Dense desert shrubland	**21521**	**13455**	**0.63**
Mod dense desert shrubland	**85477**	**39661**	**0.46**
sparse desert shrubland	**133139**	**36479**	**0.27**
Moist bare soil	578	817	1.41
Open Water	427	1927	4.51
Dry playa	63133	4535	0.07
Irrigated Cropland	9932	8085	0.81
Total	325443	128371	0.39

The difference is clearly due to the difference in the rates, especially the GW ET rate which is very sensitive to the low precipitation estimate. Hood and Rush' estimates apparently accounted for precipitation, although it is not specifically stated in the document, as did BARCASS' estimates. The low precipitation estimates in BARCASS for Snake Valley, less than 7 in/y, may have caused the GW ET rates to be higher than used by Hood and Rush.

The CV discussed above for Snake Valley subbasins is potentially higher than for the overall study area. Therefore, the high discharge estimate for Snake Valley may be quite variable; based on the high CV, there is a significant probability that the actual discharge could be closer to the recon discharge rate.

Interbasin Flow

The difference between recharge and discharge for specific basins was set equal to interbasin flow to or from that basin. BARCASS used water balance accounting and deuterium mass-balance analysis to estimate flow across the various boundaries that the USGS had determined in the geologic analysis to either probably or possibly allow flow.

The methods are appropriate and limited only by the accuracies in the recharge/discharge estimates and the accuracy of the deuterium measurements.

The biggest difference in interbasin flow between BARCASS and previous estimates is flow from Steptoe Valley. This is due to the substantially higher recharge estimate in Steptoe Valley. The flow from Steptoe enters Lake and Spring Valleys, and then enters Snake Valley. A portion of the flow to Snake Valley likely becomes discharge to the Greater Salt Lake Desert.

BARCASS discusses that the input to the water balance accounting has inherent uncertainties (BARCASS, page 74). However, it does not attempt to put a distribution around the estimated interbasin flow values. Utilizing the distributions determined for discharge and that should be determined for recharge, as recommended above, BARCASS should place uncertainty bands around the interbasin flow estimates. Failing to do so, the interbasin flow numbers shown on plate 4 will be considered as exact estimates.

Plate 4 shows interbasin flow from the Snake Valley through the Confusion Ranges. This appears to be separate from the interbasin flow from Snake Valley to the Great Salt Lake Desert. The map shows the entire boundary as likely to transmit groundwater. This flow may be the primary inflow to the Fish Springs Flat basin which features the substantial discharge at Fish Springs. BARCASS should estimate the flow east through the Confusion Range.

Specific Errors in Text or Maps

The BCM report mentions in many places that the grid scale is 82.3 feet or 270 meters. The two numbers do not convert to each other.

The difference in irrigated area for water use and for ET discharge has already been noted, but still represents an error.

Plate 4 shows recharge/discharge estimates by basin and by subbasin. However, the values for subbasins sometimes do not add to the total for the basins. For example for Steptoe Valley, the recharge for subbasins is 67,700, 63,300, and 27,000 af/y which sums to 158,000 af/y. The map and Table 6 each reports 154,100 af/y. The ET for the subbasins correctly sums to the reported total. This suggests the error is in the reporting for the subbasins.

Conclusion

BARCASS has completed estimates of recharge, discharge and interbasin flow based on physically-based modeling and accounting. Because all of the parameters and inputs are uncertain, the variability around the estimates is very high. BARCASS presented no calibration of the models mostly because there are no measured output values to use for calibration (the exception may be runoff). The estimates effectively depend on the judgment of the modeler as to which parameter set and input stream to use.

Due to the uncertainty, the BARCASS estimates for available water may be more uncertain than was perceived for previous estimates due to the lack of calibration. For example, the high discharge estimate for Snake Valley has been shown to have a broad range due to the high CV. Therefore, there is a significant probability that the actual discharge is closer to or even less than the recon discharge rate.

Recommendations

BARCASS would be improved if some analyses were reconsidered or added, if improved explanations were given, or textual errors corrected as listed below. Specifics about these recommendations were discussed in the text above.

- The specific textual and mathematical errors listed above should be corrected.

- The BARCASS report should discuss the location of groundwater divides with respect to areas of potential flow.

- The geology presentation would be substantially improved if in addition to the east/west cross-sections the report provided profiles along the crests of the major ridges.

- The explanation of the BCM model should include an explanation of whether the soil always retains moisture at the minimum of the wilting point.

- Figure 4 in the BCM should be reprinted so that the amounts for a given area can be better read.

- The BCM model should be calibrated using runoff estimated from gaging station measurements and other independent estimates of the ungaged runoff in the various basins.

- The BCM model should be improved to accommodate the shortcomings identified above including decreasing the time step, including interflow and runoff routing, and improved precipitation estimates (rather than the overestimates obtained using PRISM).

- The BCM recharge estimates should have uncertainty estimates included that would accommodate the parameter and input variability. This would be similar to the uncertainty estimates provided for the discharge estimates discussed below.

- The BCM report or BARCASS should explain why the current recharge estimates are so much higher than previous estimates completed with the same model and by the same authors.

- BARCASS should improve its discharge estimate from irrigated areas by determining the actual ET unit that preceded irrigation.

- BARCASS should better explain how the ET unit ET rates were set.

- BARCASS should adjust its GW ET rates to account for runoff.

- The USGS should correct the discrepancies between the area used for GW ET from irrigated areas and for water use or explain why the discrepancies do not represent a major error in the GW ET discharge estimates.

- BARCASS should estimate the interbasin flow east through the Confusion Range shown on Plate 4.

- Utilizing the uncertainty estimates determined for discharge and that should be determined for recharge, BARCASS should determine and show the uncertainty around the interbasin flow estimates.

- The graphics presenting recharge and discharge results should include the uncertainty, otherwise the general user will assume the presented numbers are the exact values.

References

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