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National Park Service

Technical Review of Water-Resources Investigations of the Tule Desert, Lincoln County, southern Nevada

By David L. Berger, Keith J. Halford, Wayne R. Belcher, and Michael S. Lico

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Conversion Factors and Datum

Conversion Factors

Multiply	By	To obtain
acre	0.004047	square kilometer (km^2)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
inch (in.)	2.54	centimeter (cm)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
foot (ft)	0.3048	meter (m)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

Datum

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

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Abstract

The Nevada State Engineer in Ruling No. 5181 required Lincoln County and Vidler Water Company, Inc., to provide results from additional water-resources studies of Tule Desert in southern Nevada to support water-rights application 64692. As outlined by the ruling, the additional studies were to include the determination of the amount of ground water available from the Tule Desert basin, ground-water recharge to the Tule Desert, and the direction of ground-water flow. Results of these additional studies were published in five reports prepared for Lincoln County and Vidler Water Company, Inc. The National Park Service formally requested that the U.S. Geological Survey provide technical reviews of these five reports.

The scientific conclusions presented in the five reports generally are well documented and for the most part appropriate methods were used. The three major criticisms of the studies are use of precipitation data, inappropriate application of the Maxey-Eakin method for estimating ground-water recharge, and lack of calibration of the ground-water flow model. The simulated long-term average annual precipitation used to estimate recharge in the model is more than 1 inch greater than the average using 78 years of precipitation record. This suggests that the simulated ground-water recharge likely is higher than long-term recharge rates. The Maxey-Eakin method was applied incorrectly because the Hardman 1936 and 1965 precipitation distributions cannot be used interchangeably with the Maxey-Eakin coefficients. The ground-water model was not properly calibrated because simulated water levels do not match measured water levels, and simulated flux through the flow model is much larger than previous estimates in Lower Meadow Valley Wash (hydrographic area 205). A well calibrated ground-water flow model is needed to achieve an acceptable match to measured water levels and spring discharge, and previous estimates of the water-budget components, including ground-water flux.

Introduction

The Tule Desert Hydrographic Area covers about 195 mi^2 in the southeastern part of Lincoln County, Nevada (fig. 1), and currently (2008) is undeveloped. Based on a reconnaissance-level study of Tule Desert, Glancy and Van Denburgh estimated the average ground-water recharge from precipitation at 2,100 acre-ft/yr (1969, table 9, p. 38) and the perennial yield from the ground-water system at 1,000 acre-ft/yr (1969, table 18, p. 63). The Nevada State Engineer defines perennial yield as the “amount of usable water from an aquifer that can be economically withdrawn and consumed each year for an indefinite period of time. Perennial yield cannot exceed the natural recharge to that aquifer and ultimately is limited to the maximum amount of discharge that can be utilized for beneficial use” (*http://water.nv.gov/WaterPlanning/wat-fact/define.cfm#yield*, accessed July 28, 2008).

The Nevada State Engineer commonly uses perennial yield estimates to define the quantity of available ground-water resources in a basin.

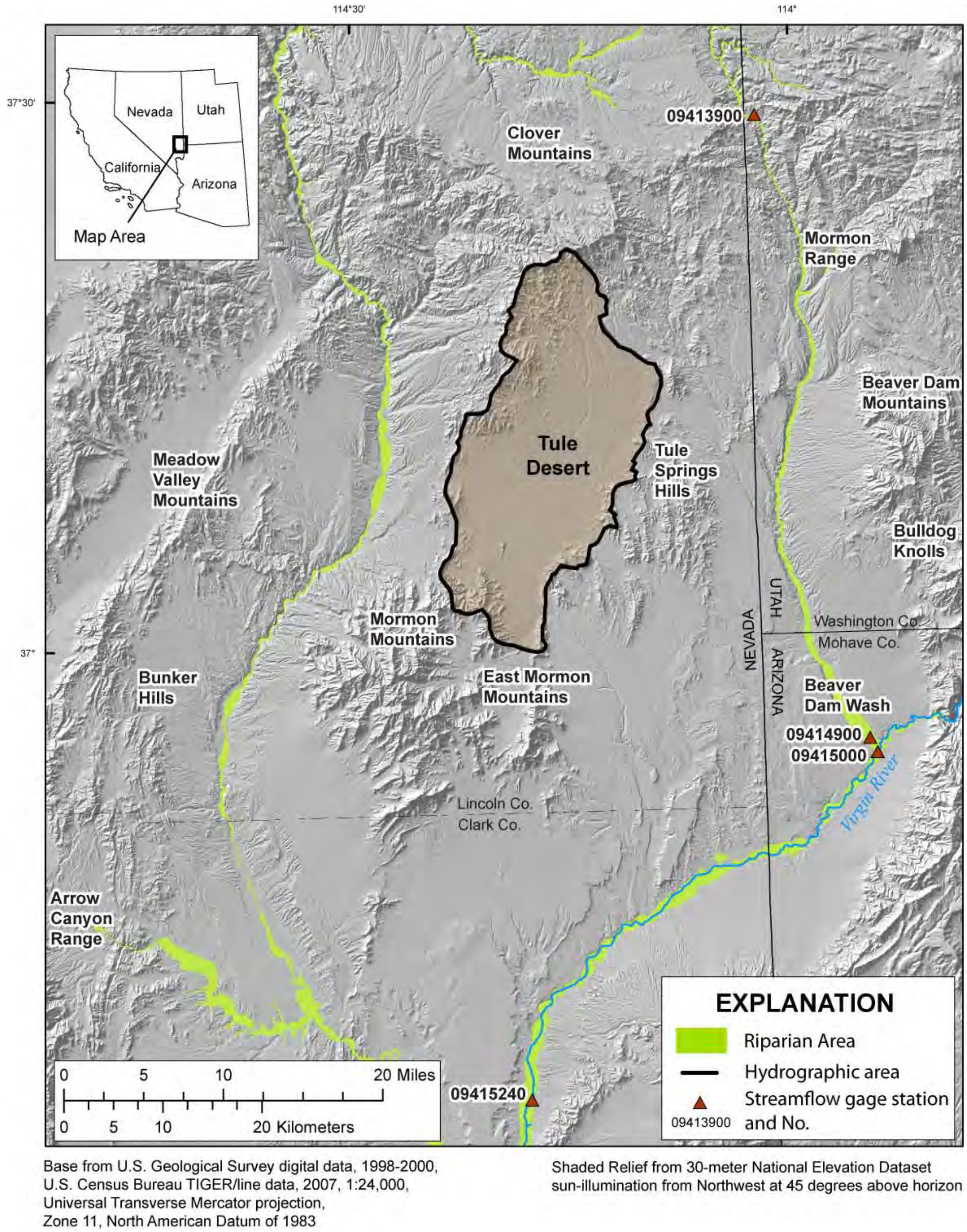

Figure 1. Location of Tule Desert hydrographic area, Lincoln County, southern Nevada.

In 1998, representatives of Lincoln County and Vidler Water Company, Inc., filed applications with the Nevada State Engineer for the appropriation of 14,500 acre-ft/yr of ground water from the Tule Desert (applications 64692 and 64693; 7,250 acre-ft/yr each). In Ruling No. 5181 (November 26, 2002), the State Engineer granted an annual appropriation of 2,100 acre-ft of ground water under application 64693. The State Engineer further ruled that application 64692 be held in abeyance until further water-resources studies in Tule Desert are made by Lincoln County and Vidler Water Company, Inc. As outlined by the ruling, the additional studies of Tule Desert must include the determination of the amount of ground water available from the basin, ground-water recharge to the basin, and direction of ground-water flow. The results of the additional studies are presented in five reports prepared for Lincoln County and Vidler Water Company, Inc.

Purpose and Scope

The National Park Service (NPS) formally requested (memorandum dated April 8, 2008) that the U.S. Geological Survey (USGS) provide technical peer review of the five reports (listed below) and formally document the review comments in a USGS Open-File Report. In response to this request, the USGS, in cooperation with the Nevada Division of Water Resources and NPS, provided a thorough technical peer review that primarily focused on the scientific merit of the methodologies and interpretations presented in the five reports prepared for Lincoln County and Vidler Water Company, Inc. The comments from the USGS technical peer review are included in this Open-File Report. The five reports reviewed are:

- Report 1. Tule Desert Groundwater Resources Study, Additional Data Submittal, by Vidler Water Company, Inc., January 16, 2008.
- Report 2. Technical Memorandum Supplement to Groundwater Geochemistry of the Tule Desert and Surrounding Hydrographic Areas in Southeastern Nevada and Potential Groundwater Interflow Between Basins, by CH2M Hill, December 24, 2007.
- Report 3. Mean Annual Recharge for the Tule Desert Hydrographic Basin, Lincoln County, Nevada, by Daniel B. Stephens and Associates, January 8, 2008.
- Report 4. Addendum to Mean Annual Recharge for the Tule Desert Hydrographic Basin, Lincoln County, Nevada, by Daniel B. Stephens and Associates, April 14, 2008.
- Report 5. Tule Desert and Surrounding Areas Numerical Groundwater Flow Model Report, by Peter Mock Groundwater Consulting, Inc., June 24, 2008.

The reviews focus on the strengths and limitations of techniques used in the additional studies as they relate to water-resources evaluations. All technical aspects such as adequacy of data, appropriateness of methods of investigation, and validity of conclusions were considered. The reviews do not necessarily include all editorial comments; however, consistent use of terminology was considered for clarity.

Technical Reviews

Five reports were submitted to USGS by Lincoln County and Vidler Water Company, Inc. for technical review. Reports 1, 2, and 5 were reviewed separately; reports 3 and 4 were reviewed together because both reports address techniques and estimates of ground-water recharge in the Tule Desert. A brief discussion on the effects of using precipitation distributions other than Hardman (1936) with Maxey-Eakin coefficients (Maxey and Eakin, 1949) is included in the review of reports 3 and 4.

Report 1. Tule Desert Groundwater Resources Study, Additional Data Submittal

Report 1 is a summary report of the other four reports and, therefore, did not require technical review. The report addresses the requests of the Nevada State Engineer in Ruling No. 5181, which were to determine the amount of ground water available from the Tule Desert basin, ground-water recharge to the Tule Desert, and direction of ground-water flow.

Report 2. Technical Memorandum Supplement to Groundwater Geochemistry of the Tule Desert and Surrounding Hydrographic Areas in Southeastern Nevada and Potential Groundwater Interflow Between Basins

Report 2 describes the geochemistry and thermal gradients of a substantial area surrounding the Tule Desert. No major revisions are recommended to the geochemistry portion of the report. Sufficient water-quality data were analyzed to support the conclusions. Overall, the conclusions presented are sound and supported by the data. Geochemistry can be used to determine if processes can occur, but must be used in conjunction with other physical and hydrologic data, all of which must point to the same conclusions.

Report 2 Specific Comments

The discussion of thermal gradients in the Tule Desert contains some useful information that supports the concept of systematic, regional water circulation to depths of a few kilometers as described by Sass and others (1971). The multiple regression equation (first equation on page 3) that relates water temperature with the top and bottom of the open intervals of wells is valuable. The relation shows the importance of water production from the bottom part of the open interval although the upper part of the open interval typically does not produce a significant portion of the water pumped from these wells. The simple linear regression equation (second equation on page 3) relating calculated temperature to DSC using the temperature derived from the multiple-regression equation is auto-correlated with the multiple-regression equation. This second equation is not needed and should be removed.

The shift in $\delta^{18}O$ (report 2, p. 9) from water sampled from well MW-6 is attributed to chemical reactions with metasediments. An alternate explanation for this shift could be the reaction of water with calcite in limestone that was formed in a marine environment. Drever (1988, p. 375) explains this as a common reason for a shift in $\delta^{18}O$. The discussion of mixing in wells MW-2D and MW-5 to create a minor shift in $\delta^{18}O$ should be changed. These two water samples plot directly on the local meteoric water line and thus have no shift in $\delta^{18}O$.

Discussion in report 2 (p. 11, bullet #4) uses the argument that rapid movement of water through the regional deep carbonate-rock aquifer allows the ground-water conditions in the aquifer to remain in an oxidizing condition. Another explanation could be related to the lack of organic carbon for reactions that would consume oxygen and produce reducing conditions.

Reports 3 and 4. Mean Annual Recharge for the Tule Desert Hydrographic Basin, Lincoln County, Nevada and Addendum to Mean Annual Recharge for the Tule Desert Hydrographic Basin, Lincoln County, Nevada

Reports 3 and 4 summarize previous regional ground-water recharge estimates and present results from site-specific investigations in the Tule Desert. Report 3 (January 8, 2008) evaluates several methods of estimating ground-water recharge from precipitation using, in part, site-specific data.

Report 4 (April 14, 2008) provides description and results of the distributed parameter watershed model applied in the Tule Desert to estimate ground-water recharge.

The effects of using precipitation distributions other than Hardman (1936) with Maxey-Eakin coefficients (Maxey and Eakin, 1949) was investigated by comparing precipitation volumes from Hardman (1936, 1965) and PRISM (1971–2000; Daly and others, 1994) in the hydrographic areas (HA) where the Maxey-Eakin technique was originally developed. Ground-water recharge estimates for a HA should represent long-term or steady-state conditions. Steady-state conditions did not exist during the periods (1971–2000 and 1981–2003) that were simulated with the water-balance model (report 3, table 8-1). Average annual precipitation for zone 3 of Nevada (NV03) during the simulated periods often exceeded the long-term average annual precipitation between 1930 and 2007 (fig. 2). Average annual precipitation for NV03 ranged between 8.63 and 8.33 in. during the two simulated periods, although the average for the entire 78-year period (1930–2007) was 7.72 in. This suggests that recharge during the simulated periods are biased above long-term recharge rates.

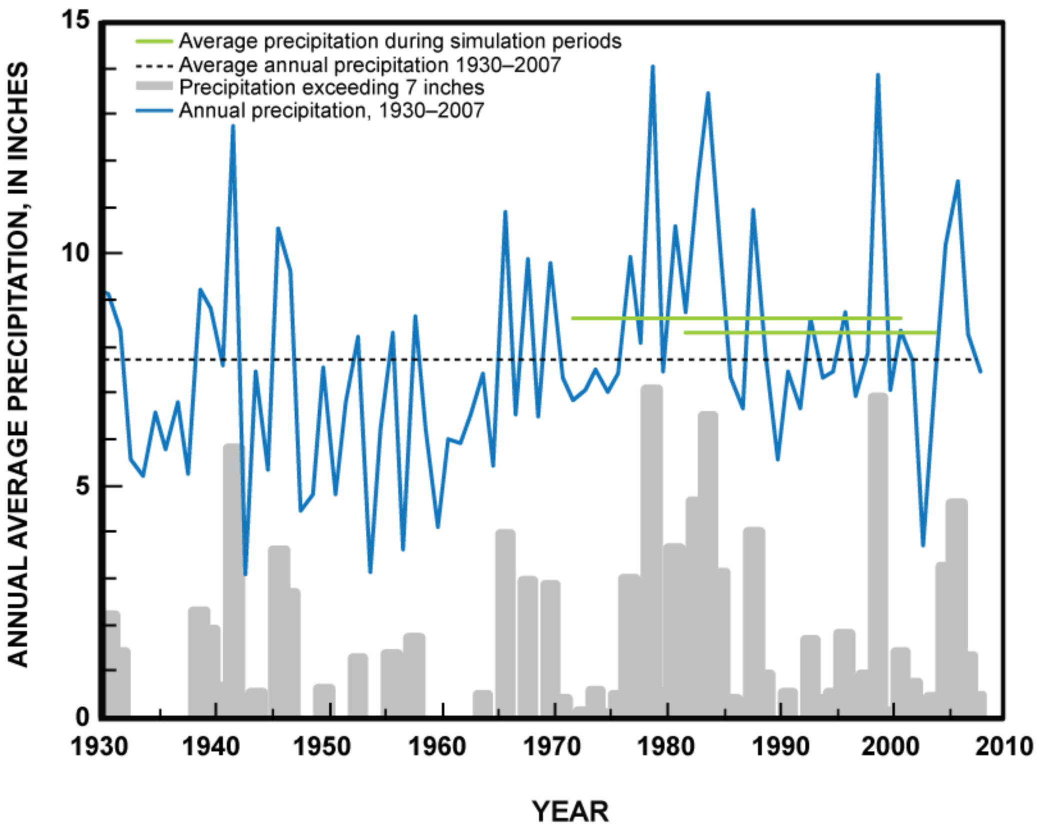

Figure 2. Average annual precipitation for 1930–2007, 1971–2000, and 1981–2003 and the amount of precipitation exceeding 7 inches (1930–2007) for zone 3 of Nevada.

The difference between simulated periods and the 78-year record are greater when precipitation in excess of a minimum (PEM) is compared (fig. 2). A PEM roughly simulates a threshold of annual precipitation where ground-water recharge from precipitation does not occur. PEM values of 6, 7, and 8 in. were applied to four time periods, including the simulation periods of 1971–2000 and 1981–2003 and water year 2007 (fig. 3). A 6-in. PEM approximates the ratio between recharge estimates derived from National Climatic Data Center (NCDC) 1971–2000 annual average precipitation and total precipitation for water year 2007. An 8-in. PEM approximates the Maxey-Eakin threshold. Long-term ground-water recharge will be less than recharge during 1961–90, 1971–2000, and 1981–2003 for any PEM between 6 and 8 in.

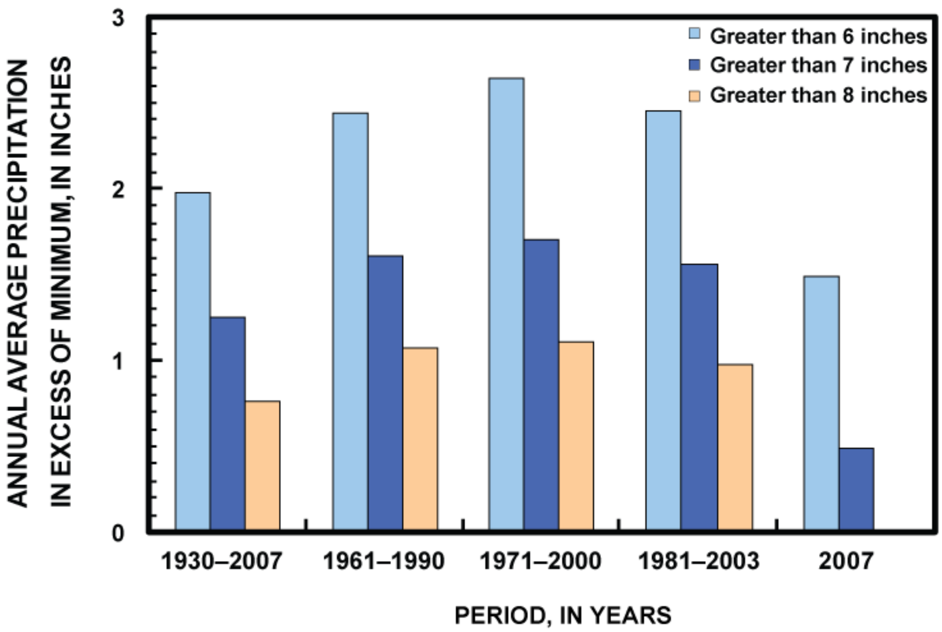

Figure 3. Annual average precipitation in excess of a minimum of 6, 7, and 8 inches for zone 3 of Nevada for selected time periods.

Average long-term recharge can be estimated from the simulated periods by relating annual recharge from the water-balance models to a threshold-limited power function. Annual recharge during the 78-year record can be extrapolated with this simple function after fitting to recharge estimates during the simulated periods: 1961–90, 1971–2000, or 1981–2003. This approach was applied previously in the BARCAS study (Welch and others, 2007) to estimate long-term recharge from a basin characterization model (Flint and Flint, 2007). Neglecting antecedent conditions from previous years introduced error, but minimally affected estimates of the average long-term recharge. Long-term recharge averaged 9 percent less than the recharge simulated during 1970–2004 (Flint and Flint, 2007).

Precipitation volumes in the 19 HAs used for the original Maxey-Eakin analysis were compared to test the effect of precipitation distributions on recharge estimates. However, some uncertainty persists regarding the measured volumes of ground-water discharge in these 19 HAs because Maxey and Eakin (1949) did not provide significant detail in their analysis. Additionally, ground-water discharge from a few of the 19 HAs that were used to develop the Maxey-Eakin coefficients may be poor controls. For example, ground water in Kawich Valley (HA 157) does not discharge within this HA. The 19 HAs can still serve as controls for comparing precipitation distributions even if the Maxey-Eakin coefficients were developed with a few less HAs.

The Hardman 1936 and 1965 precipitation distributions cannot be used interchangeably with the Maxey-Eakin coefficients primarily because the acreages in the discrete ranges of 8–12, 12–15, 15–20, and greater than 20 in. are quite different between the two precipitation distributions (fig. 4) even though the gross acreage in excess of 8 in. is comparable between the two precipitation distributions (report 4, fig. 21). Acreage in the 8–12 in. range on the 1965 map was less than the same range on the 1936 map, although acreage increased in the 12–15, 15–20, and greater than 20 in. ranges resulting in a ground-water recharge estimate that averaged 38 percent greater using the Hardman 1965 rather than the Hardman 1936 map when applied to the 19 HAs (fig. 5).

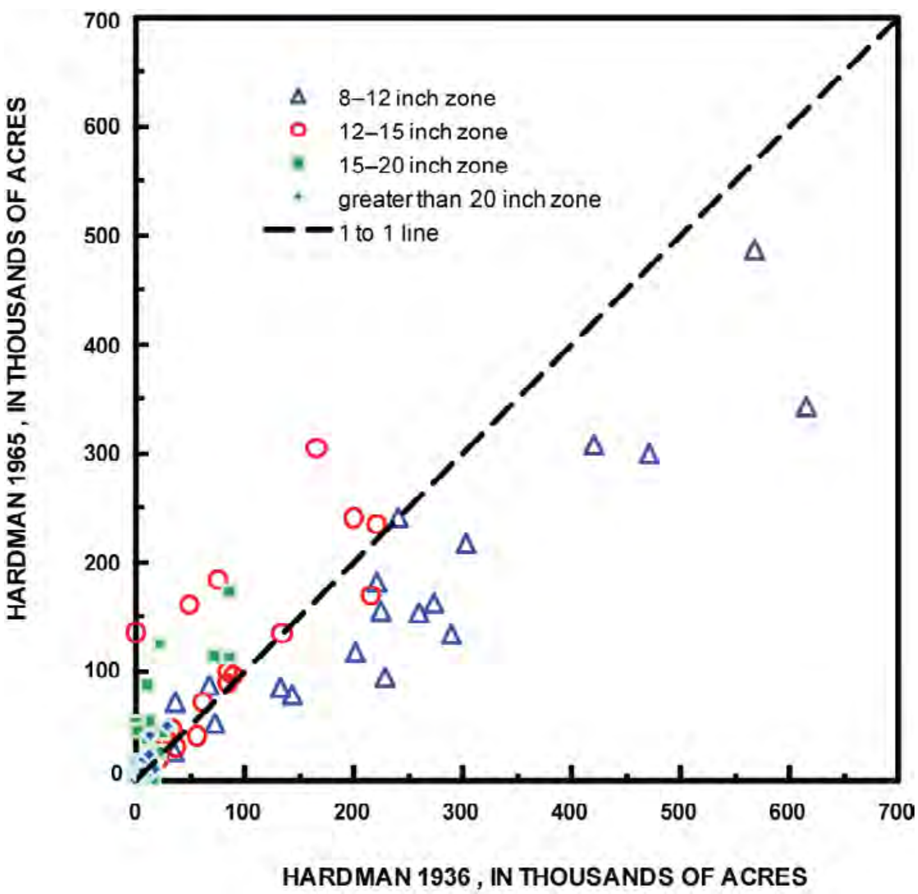

Figure 4. Comparison of areas in selected precipitation zones of Hardman 1936 and 1965 precipitation distribution within 19 hydrographic areas originally used in the development of the Maxey-Eakin method for estimating ground-water recharge from precipitation.

Total ground-water recharge is 570,000 acre-ft using the 1965 precipitation distribution, which is 47 percent more than 388,000 acre-ft using the 1936 precipitation distribution. Annual recharge estimates for the Tule Desert increased fivefold if Hardman 1965 is used instead of Hardman 1936, but remained less than 1,000 acre-ft. Existing errors in the attributes of the USGS digitized Hardman 1936 precipitation distribution were corrected and the revised map was used for this review. The corrections primarily affected areas along the eastern boundary of Nevada and particularly affected precipitation estimates in the Tule Desert.

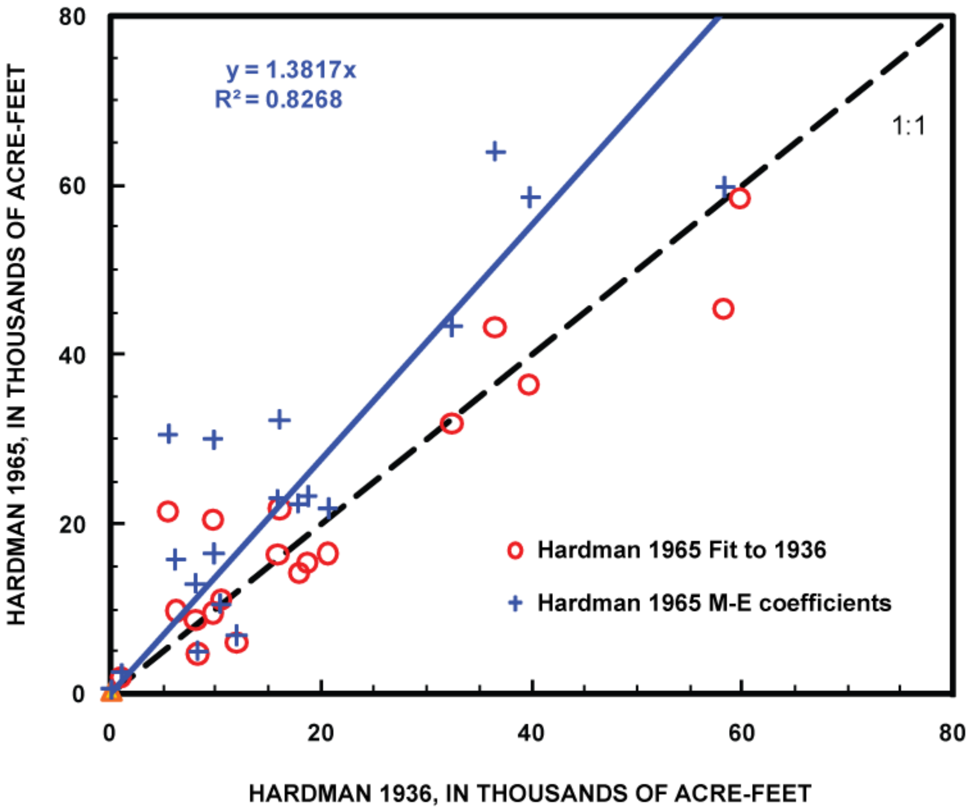

Figure 5. Comparison between ground-water recharge estimates using Hardman 1965 precipitation distribution with the original Maxey-Eakin coefficients and the Hardman 1965 precipitation distribution with second set of coefficients that preserves the original recharge estimates.

Sets of recharge efficiency coefficients were estimated for the Hardman 1965 precipitation distribution that preserved the recharge volumes calculated with the original Maxey-Eakin method in 19 HAs. The first set of efficiency coefficients was estimated by minimizing a Root-Mean-Square (RMS) objective function where recharge with the 1965 distribution was simulated, using recharge estimated from the 1936 distribution. Applying the original Maxey-Eakin assumption, the coefficient values were assumed to increase with a greater precipitation interval (table 1, column 3). A second set of coefficients also was estimated by adding an additional constraint such that the Hardman 1965 unconstrained coefficients and Maxey-Eakin coefficients differ as little as possible (table 1, column 4).

Recharge efficiency coefficients differ significantly for the Hardman 1965 distribution (table 1). Unconstrained estimates using Hardman 1965 precipitation distribution for the 8–12 and 12–15 in. ranges were both about 4 percent, and for the 15–20 and greater than 20 in. ranges were both 9.5 percent. The constrained estimate for the 12–15 in. range was about 3 percent, which is less than one-half of the 7 percent in the original Maxey-Eakin coefficients. Annual recharge to the Tule Desert was 280 and 469 acre-ft if the Hardman 1965 distribution was multiplied by constrained and unconstrained coefficients, respectively.

Table 1. Recharge efficiency coefficients for Hardman 1936 and Hardman 1965 precipitation distributions that preserve Maxey-Eakin recharge in the 19 control hydrographic areas.

[Transferability of precipitation distributions was tested by estimating alternative coefficients. Recharge volumes should not be estimated with these results]

Precipitation range, in inches	Original Maxey-Eakin coefficients based on Hardman 1936 precipitation distribution, in percent	Hardman 1965 unconstrained coefficients, in percent	Hardman 1965 constrained by Maxey-Eakin, in percent
8 - 12	3.0	4.2	2.4
12 - 15	7.0	4.2	2.9
15 - 20	15.0	9.5	12.3
Greater than 20	25.0	9.5	23.7
Root-Mean-Square error, in acre-feet =		6,234	7,325

Differences among the precipitation distributions are significant enough that transferability of the published Maxey-Eakin coefficients result in unrealistic ground-water recharge estimates. In the Tule Desert, the root mean square error is large relative to recharge and more than 6,000 acre-ft of scatter was introduced by substituting Hardman 1965 for Hardman 1936. Although not a conclusive analysis, this result casts doubt on transfer method estimates of less than 10,000 acre-ft. Therefore, recharge estimates based on methods of Budyko (1949), Maxey and Eakin (1949), Nichols (2000), Walker (2002), and Wilson and Guan (2004) should be reported, but not included in the dataset.

An averaging procedure should be used to determine the long-term recharge estimate for the Tule Desert (report 3, table 8-1) and should be limited to an average of the results from the water-balance model, chloride mass balance, and composite analysis because the methodologies used to determine these estimates have been explained. Prior to averaging, the recharge estimates from each method should be appropriately adjusted to represent long-term or steady-state conditions. The uncertainty of these estimates also should be estimated and reported.

Ground-water discharge along reaches of Beaver Dam Wash and the Virgin River (fig. 1) averaged less than 8,000 acre-ft (table 2) from January 1, 2003, to December 28, 2004. Annual evapotranspiration in excess of local precipitation averaged 39,300 acre-ft in the riparian areas between the two pairs of gaging stations (fig. 1) during 2003 and 2004 (DeMeo and others, 2008). The reaches lost 31,800 acre-ft between gaging stations during the same 2-year period. Ground-water discharge to the washes averaged 7,500 acre-ft if storage changes were minimal and other sources were eliminated. The estimate of 7,500 acre-ft (table 2) could range between 5,000 and 10,000 acre-ft given the error associated with discharge and evapotranspiration measurements.

Long-term ground-water discharge along reaches of Beaver Dam Wash and the Virgin River likely equals the average discharge during January 1, 2003, to December 28, 2004. Ground-water discharge from the Tule Desert to these reaches likely varies less than a few percent. This is because water levels in the Tule Desert varied less than a few feet during water years 2006 and 2007 and ranged from 200 to 900 ft higher than water levels in discharge areas along Beaver Dam Wash and the Virgin River. Long-term variability of ground-water discharge is inconsequential relative to the error in the ground-water discharge estimate.

Table 2. Average water-budget components on reaches of Beaver Dam Wash and the Virgin River near the Tule Desert hydrographic area, Nevada.

[All values in acre-feet; Period analyzed: January 1, 2003 – December 28, 2004]

Site No. and name (fig. 1)	Average volume	Average loss between gaging stations	Evapotranspiration minus local precipitation	Average ground-water discharge to washes between gaging stations
09413900-Beaver Dam Wash near Enterprise, Utah	3,900			
09414900-Beaver Dam Wash at Beaver Dam, Arizona	2,100	1,800		
			8,500	
Total				6,700
09415000-Virgin River at Littlefield, Arizona	101,900			
09415240-Virgin River near Overton, Nevada	71,900	30,000		
			30,800	
Total				800
Grand total		31,800	39,300	7,500

Nearly all ground-water discharge from the Tule Desert occurs as subsurface outflow. Recharge in the Tule Desert is less than the average regional ground-water discharge to Beaver Dam Wash and Virgin River despite any uncertainty. This is because part of Beaver Dam Wash is upgradient of the Tule Desert and some water recharges east of Beaver Dam Wash (fig. 1).

Report 3 Specific Comments

1.2 Precipitation, p. 2, 2nd paragraph

The text states that "Jeton and others (2006) found that the precipitation for the Tule Desert derived from the Hardman map differed more than 100 percent when compared to the precipitation derived from PRISM." Neither precipitation distribution was assumed to be correct.

3.5.3 Wilson and Guan Modification of the Maxey-Eakin Method, p. 15, 1st paragraph

Wilson and Guan should be reported but not used. Equation 3-3, $R = 9 \times 10^{-9} Pm^{3.72}$, demonstrated that Maxey-Eakin approximated a power-law relation (Wilson and Guan, 2004). Wilson and Guan (2004) did not apply equation 3-3 and did not discuss that Maxey-Eakin coefficients are tied to the Hardman 1936 precipitation map. Equation 3-3 does not approximate Maxey-Eakin where precipitation is less than 8 in., which is more than 90 percent of the Tule Desert on the Hardman 1936 map. Large differences exist because recharge occurs where annual precipitation on the Hardman 1936 map exceeds 4 in. rather than 8 in. (fig. 6).

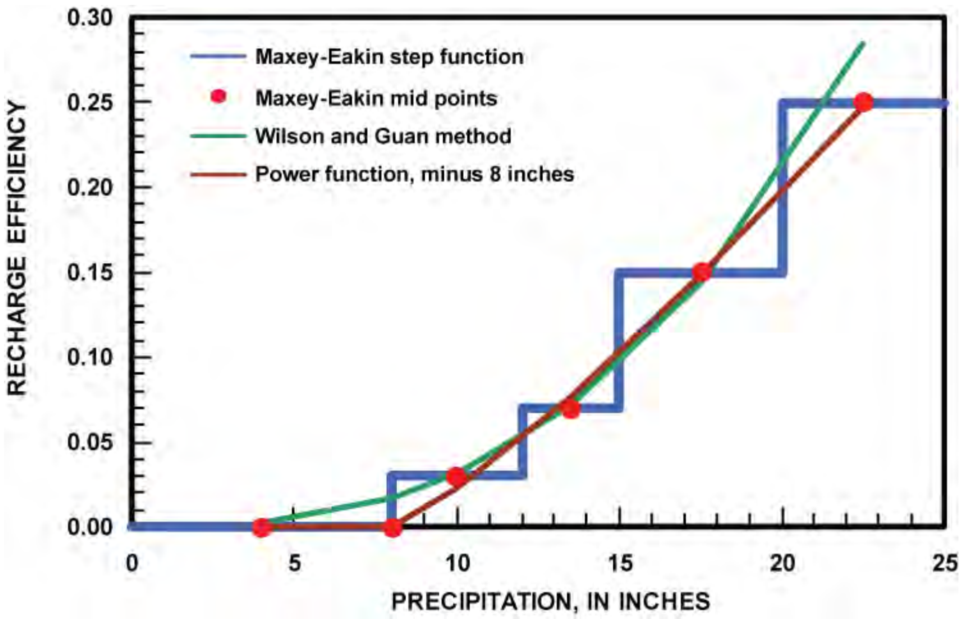

Figure 6. Relation between precipitation and recharge efficiency for Maxey-Eakin and Wilson-Guan methods and a power function for precipitation minus 8 inches.

4.1.2 Walker (2002), p. 19, 1st paragraph

Recharge estimates from Walker (2002) should not be used to compute an average annual recharge volume because the Maxey-Eakin method was misapplied. The Maxey-Eakin coefficients are tied to the Hardman 1936 precipitation map.

5.2.1 Runoff, p. 27, 2nd paragraph

The fact that between 40 and 70 percent of the precipitation during water year 2007 was estimated from regression equations needs to be included in the discussion. Report that the coefficient of determination (r^2) of the regression equations, 0.78 to 0.87, and the maximum error between simulated and measured monthly precipitation, 1.05 in. The *y*-intercept of the regression equations between the three precipitation stations and the Garden Spring DRI station should be 0.

5.2.3.1 Precipitation, p. 34, next to last paragraph

"Yucca Flats" in table 5-6 should be "Yucca Flat".

5.2.4.2 Hydraulic Properties, p. 37, 2nd paragraph

The labels for the wash and between-wash moisture retention curves in figure 5-31 appear to be transposed.

6.2.3 Bedrock, p. 41, 4th paragraph

Saturated horizontal hydraulic conductivity estimates are shown in Welch and others (2007, table 3). These estimates provided a broad range and were not applied directly in the BARCAS study. The correct citation for the BARCAS study, which supersedes OFR 2007-1156 is Welch, A.H., Bright,

D.J., and Knochenmus, L.A., eds., 2007, Water resources of the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2007-5261, 96 p.

Flint and Flint (2007, table 2) reports the range of hydraulic conductivities in the Basin Characterization Model (BCM) model that is controlled by vertical hydraulic conductivities. The reported saturated hydraulic conductivities for the BCM were, in fact, effective hydraulic conductivities that were affected by partially saturated conditions. The reporting of hydraulic conductivities from Flint and Flint (2007) are incomplete and should be explained further.

6.3.1 Adjustment for Elevation, p. 46, 2nd paragraph

Report that air temperature is spatially distributed in this section so it is clear that a precipitation event can add snow and rain.

6.3.4 Evapotranspiration, p. 50, 2nd paragraph

Coefficients *Ke*, *Ks*, and *Kcb* are introduced in equation 6-8, but are not explained. *Ks* eventually is defined in equation 6-14. More detailed definitions for equation variables should be included. No explanation is given for *Ke* and *Kcb*. Ranges of specified values need to be reported. Explain if the coefficient varies daily, monthly, or seasonally. Reporting a table of annual ET rates, precipitation, and acreage for the simulated land covers would greatly help dispel doubts.

6.3.4 Evapotranspiration, p. 50 - 55

Section 6.3.4 on evaporation is tedious and forces the reader to review FAO-56. Much of the discussion seems extraneous. Topics such as air temperature, solar radiation, slope, azimuth, and albedo are relevant parameters for computing ET. The reader cannot assess their relevance without the equations for translating these parameters into ET or ET_0.

Report 4 greatly clarifies the explanation presented in section 6 of report 3. Variable explanations such as “e0 =function described above” (report 4, p. 55) should specify the descriptive name and defining equation number. For example, “e0 = mean saturation vapor pressure” (report 4, p. 34). Section 6 of report 3 should be replaced with section 2 of report 4.

7.1.3.5 Discussion, p.62, 1st paragraph

The recharge estimate for 2007 is reasonable, but not representative of the long-term recharge rate. Please rephrase to, “Recharge estimates during water year 2007 were less than long-term average recharge rates because precipitation during water year 2007 was below average.”

7.2 Diffuse Recharge, p. 63, 1st paragraph

Change “approximately 91 acre-ft/yr” to “less than 100 acre-ft/yr”.

7.3.1 Chloride Mass Balance Analysis, p. 63, 3rd paragraph

The variability of recharge estimates from the chloride mass balance method should be presented in this section or in section 5. Show the 95-percent confidence limits by computing and sorting all the permutations from chloride concentrations in precipitation and ground-water samples. Variations in precipitation are minor compared to the variability of chloride concentrations and can be neglected. The error band should be added to the summary figure 8-1.

7.3.3 Discussion, p. 65, 1st paragraph

The text "This local recharge on the valley floor where precipitation may be less than 8 in/yr is not explicitly recognized in total recharge estimation models such as the Maxey-Eakin model or its various modifications", makes an inappropriate comparison and should be deleted. Maxey-Eakin extrapolates total recharge between basins and does not address spatial distribution within a basin.

8. Summary and Conclusions, p. 67, 1st paragraph

Your best estimate of recharge should be reported as a single value in the first sentence of the first paragraph. Qualify afterwards.

Report 4 Specific Comments

2. Model Description, pp. 3 - 62

The explanation of your watershed model is improved greatly in section 2 of this report.

3.1.2 Results, p. 65, 3rd paragraph

Average annual recharge of 5,300 acre-ft from the NCDC 1971–2000 precipitation distribution in table 8-1 most closely agrees with an average recharge 5,600 acre-ft. Please specify which model in table 8-1 of the original report (report 3) is being tested.

3.2.2 Results, p. 70, 3rd paragraph

Faust and others (2006) is cited, but a reference does not exist. A Flint reference for the BCM model does not exist either. Please correct.

3.2.2 Results, p. 70, 4th paragraph

Adding another component to a model adds more variables to adjust which usually increases uncertainty, even if the mean answer is improved. This runs contrary to the statement "If the Faust et al (2006) analysis had modeled runoff, they may have found a smaller range in net infiltration for the various PTFs." Please explain further.

4. Review of Maxey-Eakin Method, p. 72

Comparing the precipitation volumes in the Maxey-Eakin HAs is a good approach, however, the method of comparison is flawed. The analysis should be revised or the section should be eliminated. The precipitation volumes in the 8–12, 12–15, 15–20, and greater than 20 in. ranges need to be compared rather than lumped into greater than 8-inch volumes. The 8-12-in. range is the only interval that is significant to the Tule Desert and the lumped comparison masks bias in particular ranges. Kawich Valley HA (number 157) should be excluded because ground water does not discharge from this HA.

4.2 Comparison of Hardman and PRISM Precipitation Maps for the Maxey-Eakin Basins, p. 74

The comparison between Hardman and PRISM precipitation surfaces was not reviewed because the method of comparison was found deficient in section 4.1.

Report 5. Tule Desert and Surrounding Areas Numerical Groundwater Flow Model Report

Results of a numerical ground-water flow model for the Tule Desert and surrounding areas are presented in report 5. The purpose of the flow model, which is clearly presented, is to provide a first-order estimate of the impact of pumping in the Tule Desert. The major criticism of the flow model is the fact that little attempt was made to calibrate the model. A calibrated numerical flow model would be more accurate as a predictive tool and useful in terms of understanding the conceptualization of the ground-water flow system in the Tule Desert (Reilly and Harbaugh, 2004). Part of model calibration includes modification of input data so the model more closely matches measured ground-water levels and flows. Simulated water levels do not match well with measured levels and the water budget does not agree with previous information. Simulated ground-water flux into the model from the west is much larger than previously estimated. Comparison of estimated ground-water flux with simulated flux should be made and included in the discussion. Additional effort should be made to produce a calibrated model that matches water levels, spring discharge, and previous estimates of the water budget, including ground-water flux. Sensitivity analyses also should be done to test the input values of hydraulic properties (hydraulic conductivity and storage) used in the model.

The authors have done a good job of assembling the relevant information and constructing a numerical model of the ground-water flow system, especially the hydrogeologic framework model (which appears to accurately represent the interpreted structural geology). However, the report should be re-organized to present all conceptual and framework information on the flow system first in a separate section from the model implementation.

Report 5 Specific Comments

Executive Summary, p. 2

A purpose statement needs to be added indicating that the resulting model is not a calibrated model, but rather a somewhat more sophisticated approach than an analytical solution.

Introduction, p.3, 2nd paragraph

Additional text needs to be added regarding the purpose of the flow model (see previous comment).

Introduction, p. 3, 5th paragraph

USGS disagrees with the statement that the “conceptual model” of Prudic and others (1995) is “not realistic”. This statement seems to confuse Prudic and others’ conceptual model (interbasin flow, etc.) with the implementation of the flow model in a regional numerical model. Although Prudic and others (1995) numerical flow model may not be entirely accurate (not accounting for all features, events, and processes in the flow system), the model is a reasonable approximation of the carbonate-rock province flow system given the regional nature of the model, the state of knowledge at that time, and the computer technology of the time.

Introduction, p. 4, 1st paragraph

Regarding the Page and others (2005, 2006) publications, the statement that these publications “were prepared specifically in support of a future groundwater modeling effort for the National Park Service “ is incorrect. The ground-water modeling effort is ongoing and currently being finalized. Please modify the text accordingly.

Introduction, p. 4, 3rd paragraph

Please clarify that the ground-water flow model is not calibrated.

Model Grid and Layers, general comment

The discussion of the layering of the flow model is very confusing. Unclear if there are 9, 12, or 13 layers. This discussion needs to be clarified.

Model Grid and Layers, p. 5, 1st paragraph

A reference to figure 2 in the first sentence should be added.

Active and Inactive Cells, p. 7, 1st paragraph

The text states that inactive cells represent two conditions. Yet, four paragraphs previous, it is stated that cells that "up dip above the outcrop and down dip into the basement complex" also are inactive. The text should be modified to eliminate this apparent inconsistency.

Hydrostratigraphic Units, p. 9, 3rd paragraph

The paragraph is redundant and should be removed.

External Boundary Conditions, general comment

Consider adding the boundaries used in the flow model to figure 4 to enhance the description in the text.

External Boundary Conditions, p. 10, 1st paragraph

Why are only "selected" measurements of carbonate-rock aquifer water levels presented? Should not all data available be used or presented?

External Boundary Conditions, p.10, 4th paragraph

The major conceptual model of the Great Basin is interbasin flow. It may be inappropriate to have no-flow boundaries in the model. The rationale for assigning this type of boundary needs to be further explained. Furthermore, it is unclear where the no-flow boundaries were applied (see general comment, External Boundary Conditions).

Recharge, general comment

Why was not the basin characterization model (Flint and Flint, 2007) for the BARCAS study used for estimating recharge?

Springs, p. 12, 2nd paragraph

Recognizing that the flow model was not calibrated, how accurate is the simulated flow at Blue Point and Rogers Springs?

Evapotranspiration, p. 12, 2nd paragraph

Please explain why a more sophisticated representation of evapotranspiration is not required for the study?

Evapotranspiration, p. 12, 3rd paragraph

Why was evapotranspiration from Muddy Springs, Blue Point Springs, and Rogers Spring not simulated?

Stream Channel Discharge, p. 12-12, 1st paragraph

Why was the discharge of ground water into Beaver Dam Wash not simulated? Is the reader to assume that discharge to Beaver Dam Wash is considered negligible? Please clarify.

Hydraulic Parameters, p. 14, 2nd paragraph

Replace “Death Valley Flow System” with Death Valley Regional Ground-Water Flow System (DVRFS) to be more consistent with later usage (p. 17).

Hydraulic Parameters, p. 17, last paragraph

Replace “Death Valley Flow System” with DVRFS.

Hydraulic Parameters, p. 18, 1st paragraph

The sentence states that the differences between the calibrated hydraulic conductivity values in the DVRFS model and the central tendency of the USGS compilations were not discussed in the DVRFS report. The USGS does not agree with this statement. Tables F-8, F-9, F-10, and F-11 in Faunt and others (2004) clearly present a comparison of the range in values from Belcher and others (2001) and the calibrated horizontal conductivity values.

Hydraulic Parameters, p. 19, 4th paragraph

The text states that it is not clear whether faults are barriers to ground-water flow or conduits because of a lack of direct hydraulic testing. Can the hydrologic nature of the faults be inferred based on water levels (essentially the same water level indicating flow across the fault and differences in water levels indicating a barrier)?

Hydraulic Parameters, Table 1

Please arrange the table (as best as possible) so that hydrostratigraphic units are presented in the same order as described in the text.

Simulation of Current Conditions, p. 20, 2nd paragraph

The last two sentences of this paragraph state that a 100 ft residual between simulated and measured water levels is reasonable. Please explain the basis for these statements.

Table 2, p. 21 and discussion in text

It may be inappropriate to discuss the water budget for a non-calibrated flow model. This can be potentially misleading to the audience. The USGS would strongly recommend adding the values used by the Nevada State Engineer to table 2. Modify the discussion in the text to compare the simulated values with the Nevada State Engineer values.

Projection of Pumping Impacts, p. 22, 1st paragraph

Please define what “significant magnitudes” indicates.

Projection of Pumping Impacts, p. 22, 2nd paragraph

Please correct the misspelling of “pumping”.

Projection of Pumping Impacts, general comment

Please explain how a flow model with residuals of 100 ft can accurately depict pumping impacts.

Projection of Pumping Impacts, Hydraulic Parameters, general comment

The impact of pumping is strongly dependent on the value used for storage. The USGS strongly encourages some sort of sensitivity analysis on the storage parameters to assess how they would influence the simulated pumping impacts.

Figures (all)

Please add an explanation to all figures, explaining features presented. For example, what are the green lines and the red box in figure 2? And the blue and black lines and blue squares in figure 3?

Figure 19

Suggest posting the Page and others (2005, 2006) geologic cross sections alongside the sections through the framework model to make it easier for the readers to compare.

Figures 19-32, 34-46

Please label the contours. Also, in figures 19-32, please post the measured water levels appropriate for each model layer as well as the residual.

Figure 33

Why does this figure only represent five water levels when figure 4 clearly shows many more measurements in the carbonate-rock aquifer within the model domain?

Summary

The Nevada State Engineer under Ruling No. 5181 required the Lincoln County and Vidler Water Company, Inc., to complete additional water-resources studies in the Tule Desert before granting water rights application 64692. The additional studies, based on the ruling, are designed to determine the amount of ground water available from the Tule Desert basin, ground-water recharge to the Tule Desert, and direction of ground-water flow. Results of these additional studies were published in five reports prepared for Lincoln County and Vidler Water Company, Inc. The National Park Service formally requested that the U.S. Geological Survey provide technical review of these five reports and publish the reviews in a USGS Open-File Report.

Report 1 addresses the questions in Nevada State Engineer’s ruling and provides a general summary of the results presented in the other four reports; therefore, report 1 was not technically reviewed. Reports 2 and 5 were reviewed separately, and reports 3 and 4 were reviewed together because both reports address techniques and estimates of ground-water recharge. A brief discussion on the effects of using precipitation distributions other than Hardman (1936) with the Maxey-Eakin coefficients (Maxey and Eakin, 1949) is included in the review of reports 3 and 4.

Report 2 describes the geochemistry and thermal gradients of the Tule Desert and surrounding area. No major revisions are recommended to the geochemistry portion of the report and sufficient water-quality data are provided to support the conclusions. Although the relation relating water temperature to open intervals of wells is constructive, the second relation using calculated temperature is auto-correlated with the first and should be removed. A shift in $\delta^{18}O$ may have an alternative explanation that should be considered and is related to reaction of water with limestone.

Reports 3 and 4 document ground-water recharge estimates. Estimates of ground-water recharge from precipitation should represent long-term conditions. Average annual precipitation values used for estimating recharge during two simulation periods are about 1 inch greater than the long-term average based on 78 years. This suggests that ground-water recharge during the simulated periods are biased above long-term recharge rates.

The Hardman 1936 and 1965 precipitation distributions cannot be used interchangeably with the Maxey-Eakin coefficients. Acreages in discrete precipitation intervals between the two precipitation distributions are quite different and result in 38 percent more recharge using Hardman 1965. Results from all transfer Maxey-Eakin style methods may not be reasonable in the Tule Desert because the errors in the methods exceed the recharge estimates.

The resultant recharge estimate for the Tule Desert should be limited to an average based on the water-balance model, chloride mass balance, and the composite analysis. The recharge estimate should be appropriately adjusted to represent long-term conditions before averaging. However, recharge to the Tule Desert is limited to the average annual volume of regional ground-water discharge to Beaver Dam Wash and Virgin River from January 1, 2003, to December 28, 2004.

Report 5 presents the results of a numerical ground-water flow model for the Tule Desert and surrounding areas. The major criticism of the flow model is the lack of calibration. Simulated water levels do not match measured ground-water levels and simulated flux into the model from the west is much larger than previously estimated. Additional effort should be spent to produce a calibrated model that matches water levels, spring discharge, and previous estimates of the water budget, including ground-water flux. To assist in a logical presentation, the report should be re-organized to present all conceptual and framework information on the flow system first in a separate section from the model implementation.

References Cited

Belcher, W.R., Elliot, P.E., and Geldon, A.L., 2001, Hydraulic-property estimates for use with a transient ground-water flow model of the Death Valley Regional Ground-Water flow System, Nevada and California: U.S. Geological Survey Water-Resources Investigations Report 01-4120, 29 p., accessed November 3, 2008, at *http://pubs.usgs.gov/wri/wri014210/index.html*.

Budyko, M.I., 1949, Evaporation under natural conditions: Gidrometeoizdat, Leningrad, English translation by IPST, Jerusalem.

Daly, Christopher, Neilson, R.P., and Phillips, D.L., 1994, A statistical-topographic model for mapping climatological precipitation over mountainous terrain: Journal of Applied Meteorology, v. 33, no. 2, p. 140-158.

DeMeo, G.A., Smith, J.L., Damar, N.A., and Darnell, Jon, 2008, Quantifying ground-water and surface-water discharge from evapotranspiration processes in 12 hydrographic areas of the Colorado Regional Ground-Water Flow System, Nevada, Utah, and Arizona: U.S. Geological Survey Scientific Investigations Report 2008-5116, 22 p., accessed November 3, 2008, at *http://pubs.usgs.gov/sir/2008/5116*.

Drever, J.I., 1988, The geochemistry of natural waters (2d ed.): New Jersey, Prentice Hall, Inc., 437 p.
Faunt, C.C., Blainey, J.B., Hill, M.C., D'Agnese, F.A., and O'Brien, G.M., 2004, Transient numerical model, *in* Belcher, W.R., ed., Death Valley regional ground-water flow system, Nevada and California—Hydrogeologic framework and transient ground-water flow model: U.S. Geological Survey Scientific Investigations Report 2004-5205, chap. F, p. 257 – 352 accessed November 3, 2008, at *http://pubs.usgs.gov/sir/2004/5205/*.
Flint, A.L., and Flint, J.A., 2007, 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: U.S. Geological Survey Scientific Investigations Report 2007-5099, 20 p.
Glancy, P.A., and Van Denburgh, A.S., 1969, Water-resources appraisal of the lower Virgin River Valley area, Nevada, Arizona, and Utah: Nevada Division of Water Resources Reconnaissance Report 51, 87 p.
Hardman, George, 1936, Nevada precipitation and acreages of land by rainfall zones: University of Nevada, Reno, Agricultural Experiment Station report, 10 p. and map.
Hardman, George, 1965, Nevada precipitation map: Nevada Division of Conservation and Natural Resources Report, 27 p.
Jeton, A.E., Watkins, S.A., Lopes, T.J., and Huntington, Justin, 2006, Evaluation of precipitation estimates from PRISM for the 1961-90 and 1971-2000 data sets, Nevada: U.S. Geological Survey Scientific Investigations Report 2005-5291, 35 p.
Maxey, G.B., and Eakin, T.E., 1949, Ground water in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada: Nevada State Engineer, Water Resources Bulletin 8, 53 p.
Nichols, W.D., 2000, Regional ground-water evapotranspiration and ground-water budgets, Great Basin, Nevada: U.S. Geological Survey Professional Paper 1628, 82 p.
Page, W.R., Dixon, G.L., Rowley, P.D., and Brickey, D.W., 2005, Geologic map of parts of the Colorado, White River, and Death Valley ground-water flow systems, Nevada, Utah, and Arizona: Nevada Bureau of Mines and Geology Map 150, 23 p., 1 pl.
Page, W.R., Scheirer, D.S., and Langhenheim, V.E., 2006, Geologic cross sections of parts of the Colorado, White River, and Death Valley ground-water flow systems, Nevada, Utah, and Arizona: U.S. Geological Survey Open-File Report 2006-1040, 23 p., 1 pl.
Prudic, D.E., Harrill, J.R., and Burbey, T.J., 1995, Conceptual evaluation of regional ground-water flow in the carbonate-rock province of the Great Basin, Nevada, Utah, and adjacent states: U.S. Geological Survey Professional Paper 1409-D, 102 p.
Reilly, T.E., and Harbaugh, A.W., 2004, Guidelines for evaluating ground-water flow model: U.S. Geological Survey Scientific Investigations Report 2004-5038, 30 p.
Sass, J.H., Lachenbruch, A.H., Munroe, R.J., Greene, G.W., and Moses, T.H., Jr., 1971, Heat flow in the western United States: Journal of Geophysical Research, v. 76, no. 26, p. 6376-6413.
Walker, Steve, 2002, Analysis of annual recharge for the Tule Desert Hydrographic Basin, Lincoln County, Nevada: Prepared for Vidler Water Company, LLC.
Welch, A.H., Bright, D.J., and Knochenmus, L.A., eds., 2007, Water resources of the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigation Report 2007-5261, 96 p.
Wilson, J.L., and Guan, H., 2004, Mountain-block hydrology and mountain-front recharge, *in* Hogan, J.F., Philips, F.M., and Scanlon, B.R., eds., Groundwater recharge in a desert environment--the southwestern United States: American Geophysical Union, Water Science and Applications Series, v. 9, p. 113 - 137.