Groundwater Resources and Modeling Rebuttal Report of Frank A. D'Agnese, Ph.D. for Cave, Dry Lake, and Delamar Valleys

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Introduction

In his expert report, Myers (2007) utilizes the Carbonate-Rock Province (CRP) ground-water models developed by the U.S. Geological Survey as part of the Great Basin RASA program to conduct an effects analysis of the proposed SNWA water-right applications. The CRP models include the original steady-state model constructed and calibrated by Prudic et al. (1995) and the transient simulation conducted by Schaefer and Harrill (1995).

For clarity it is important to note that in the transient simulation, Schaefer and Harrill (1995) do not actually calibrate a transient model by changing model parameters such as transmissivity, to match time-variant water-level observations or ground-water discharge estimates. Instead, they assign storage-parameter values from existing literature available at the time of their investigation. Storage-parameter values are assigned based on the dominant type of hydrogeologic unit occurring in a model cell. The Schaefer and Harrill model has often been misinterpreted as being a calibrated transient ground-water flow model. It is not.

Myers (2007) correctly states early on in his effects analysis that the RASA model was developed to test broad concepts of regional ground-water flow in the Great Basin. He also cites Schaefer and Harrill in describing their transient simulation as being a first approximation. Unfortunately, he does not heed the warning of both sets of authors and proceeds to spend approximately 20 pages of his expert report interpreting some very specific and very local-scale results from his own use of these models.

Both sets of authors of the CRP models state in numerous places throughout their reports that the model is appropriate only "to present a ***conceptual evaluation of ground-water flow*** in the carbonate-rock province" (Prudic et al., 1995, page D5, column 2, paragraph 1, emphasis added). Also, they provide very clear reasons why the model is

> "***not suited to predict accurate water-level declines that would result from pumping*** ground water in the province," and that "the model is ***not suited to predict the accurate rate of change in natural discharge caused by pumping*** because the model has not been calibrated to any transient simulations (Prudic et al., 1995, page D93, column 1, paragraph 4, emphasis added)."

Unfortunately, these are exactly the type of predictions for which the CRP model is being used by Myers.

In fact, there are three basic limitations described or endorsed by both sets of CRP model authors that justify not using it to predict water-level declines or the rate of change in natural discharge. They include: (1) the very coarse discretization of the model; (2) the uncertainty in water budget components of the model; and (3) the steady-state nature of the model. These limitations are described in detail below.

Very-Coarse Model Discretization

Prudic et al. (1995) specifically caution the readers of their report not to draw too many conclusions regarding detailed hydrogeology from their model. In fact, early in their report they state:

> "Computer models are tools that can be used effectively to help understand complex ground-water flow systems. However, rarely are computer models used to simulate ground-water flow over such a large and geologically complex area as the carbonate-rock province. Endless arguments could be invoked as to the validity of the assumptions and hydrologic values used in simulating ground-water flow within the carbonate-rock province. For this reason, it must be stressed that the computer simulation discussed in this report is conceptual in nature. ***Only broad concepts and large-scale features can be inferred from the results of this study.*** Although a fairly detailed analysis of ground-water flow will be discussed, it does not intend to indicate that the study results presented here are adequate; in fact, the objective in presenting a detailed analysis of ground-water flow is to examine the possibility of the relatively shallow flow regions being interconnected by deep flow through carbonate rocks, and how regional geologic features might affect the direction of flow and water levels (Prudic et al., 1995; page D15, column 2, paragraph 1; emphasis added).

Further, they specifically address the issue of model discretization when discussing the assumption of homogeneity in model cells stating that "…the model grid used to simulate regional flow results in the averaging of hydraulic properties over 37.5-mi^2 areas. However, not enough information is available for the study area to substantiate the assumption" (Prudic et al., 1995; page D15, column 2, paragraph 2).

Ultimately, model discretization affects final estimated transmissivity values and the simulated water levels used in any predictions made with the model. Here again the authors caution the reader:

> Locally, transmissivities could be changed an order of magnitude, and model results might still be reasonable with respect to areas of estimated water levels and quantities of simulated discharge. Large cell sizes and the generalization of transmissivities result in a more gradual change in simulated water levels than might be expected from abrupt lateral and vertical changes in geologic units observed in the study area. Where geologic structures are barriers to flow in south-central Nevada, water-level differences between adjacent valleys are as much as 2,000 ft (Winograd and Thordarson, 1975, p. 63). With cell sizes of 5 mi by 7.5 mi, the model tends to smooth such large differences (Prudic et al., 1995; page D38, column 2, paragraph 2).

And, further, they state that "errors in transmissivities are unknown, but the estimates could be off by a factor of 5 or more" (Prudic et al., 1995; page D38, column 2, paragraph 2).

The issue of model coarseness is also addressed by Prudic et al. (1995) in the section describing model calibration.

> The model was deemed calibrated when simulated discharge approximated the mapped distribution and estimated discharge in each hydrographic area. In addition, computed water levels were matched as closely as practical with estimated values. For the best-fit simulation, ***86 percent of the simulated water levels (666 out of 773 model cells) were within 250 ft of the estimated water levels for the upper layer and 76 percent (109 out of 144 cells) were within 250 ft for the lower layer.***
>
> The 250-ft criterion used for calibration purposes is only 3 percent of the total water-level difference in the model. The maximum simulated water level is more than 7,000 ft above sea level, along the eastern side of the model; in contrast, the minimum is below sea level, in Death Valley. Water-level differences between adjacent model cells commonly exceed 250 ft; in a few locations, they exceed 500 ft (Prudic et al., 1995; page D32, column 2, paragraphs 3 and 4, emphasis added).

Prudic et al. (1995) are stating through these two paragraphs that the required match of simulated water levels in the CRP model to observed water levels in the field is 250 ft. As long as the model-simulated water level was within 250 ft of the field-observed water level the model was considered accurate in that model cell. This is a very important point particularly when one considers that the predicted drawdowns described by Myers in his effects analysis are on the order of 20 to 100 ft. These drawdowns are well within the acceptable calibration error of the original CRP model; therefore a prediction of drawdown less than 250 ft should be viewed only as a qualitative indicator that drawdown may occur. The absolute amount is uncertain because of the coarseness of the model.

Myers also states that the largest predicted drawdowns are on the order of 200 ft. Unfortunately, he does not remind the reader that this 200-foot drawdown occurs at the pumping well and that finite-difference models cannot accurately represent the drawdown at a pumping well. This problem with finite-difference models and the inability to accurately represent the drawdown at a well is described rather clearly in the ground-water modeling text by Anderson and Woessner (1992) where they state the following:

> The diameter of a well is typically much smaller than the dimensions of the (model) cell. To represent the effects of a point sink more accurately, small cells around pumping nodes are preferred. But field problems generally require large grids and can seldom accommodate cells as small as the actual well diameter.
>
> A finite difference model does not simulate this gradient accurately because the model extracts or injects water to the entire cell rather than to the nodal point. The head calculated by the model is not a good approximation of the head in the well, but heads at nodes away from the point source or sink are correct. (Anderson and Woessner, 1992; page 147, paragraph 3).

Finally, although Myers does refine the grid resolution of the CRP model before conducting his simulations. This telescoping of the grid does nothing to improve the resulting calibration or accuracy of prediction. It merely provides added interpolation of the head calculations at each model node so that the resulting simulated potentiometric surface is smoother than in the original, published version of the model.

Water Budget Components

Prudic et al. (1995) also provide recommendations regarding appropriate model use when describing the various estimates for regional water budget components. They emphasize that:

> Results from the model simulation are only approximate because uncertainties exist in the distribution and quantity of recharge and because water levels in the consolidated rocks are unknown over much of the area. Although discussed in detail, the model results are conceptual because actual values are not known for any of the variables in the ground-water flow equation. In particular, other, equally valid, distributions of transmissivity may be found that permit the model to be calibrated to the existing information (Prudic et al., 1995; page D38, column 1 paragraph 2).

They specifically target estimates of recharge to stress their point.

> Errors in the estimates of recharge are unknown but locally could be well in excess of 100 percent. If recharge is increased in the model by 100 percent, a similar distribution of water levels could be simulated by proportionately increasing transmissivities and vertical leakances (Prudic et al., 1995; page D38, column 1 paragraph 5).

The issue of water budget and model error is also illustrated in Table 1 of Prudic et al. (1995) where the authors compare the simulated ground-water discharge to the estimated (or field-observed) ground-water discharge. In the table, it is clear that 15 out of the 22 simulated springs exceed 10 percent error with some springs being in as much as 50 percent in error (see Table 1).

These calibration errors should be considered and discussed with each prediction made from the model. Myers does not address this model error when presenting the results of his effects analysis. Specifically, Myers should describe his predictions of spring-flow reduction within in the context of the original model error so that the reader can consider the relevance of these.

Steady-State Assumption

Prudic et al. (1995) also describe the steady-state nature of their model with acute clarity. They caution the reader to understand the limitations of the model because of this basic assumption and provide several reasons why the model should not be used for predictive purposes. The most noteworthy and relevant to this proceeding include the following statements:

- Model simulations assume steady-state conditions prior to development, in which estimates of current recharge (1950-80) equal estimates of natural discharge prior to ground-water development. That is, the model does not include ground-water withdrawals. Whether current recharge equals natural discharge is unknown (Prudic et al., 1995; page D15, column 2, paragraph 3).

Table 1
Estimate Discharge of Regional Springs Compared with Simulated Discharge Following Model Calibration

Regional Spring	Map No.	Discharge (acre-feet per year)		Source of Discharge Estimate	Absolute Residual (afy)	cfs	% of Est.
	(fig. 11)	Estimated	Simulated				
Manse Springs	1	4,300	3,900	Maxey and Jameson, 1948, p. 9-10	400	0.55	9%
Ash Meadows area (several springs)	2	17,000	17,000	Winograd and Thordarson, 1975, p. C78-C80	0	0.00	0%
Rogers and Blue Point Springs	***3***	***1,500***	***1,200***	***Rush, 1968b, p. 39***	***300***	***0.41***	***20%***
Muddy River Spring Area	4	36,000	37,000	Eakin, 1966, p. 264	1,000	1.38	3%
Grapevine and Stainigers Springs	***5***	***1,000***	***720***	***Miller, 1977, table 4***	***280***	***0.39***	***28%***
Pahranagat Valley (several springs)	6	25,000	24,000	Eakin, 1963, p. 20	1,000	1.38	4%
Panaca Warm spring	***7***	***7,900***	***9,900***	***Rush, 1964, table 9***	***2,000***	***2.76***	***25%***
Hot Creek Ranch Springs	***8***	***1,800***	***2,000***	***Rush and Everett, 1966a, table 9***	***200***	***0.28***	***11%***
Lockes (several springs)	***9***	***2,400***	***2,800***	***Van Denburgh and Rush, 1974, p. 23, 50-52***	***400***	***0.55***	***17%***
Blue Eagle and Tom Springs	***10***	***3,700***	***3,200***	***Van Denburgh and Rush, 1974, p. 25, 50-51, Mifflin 1968, table 4***	***500***	***0.69***	***14%***
Moon River and Hot Creek Springs	11	13,000	13,000	Maxey and Eakin, 1949, p. 37	0	0.00	0%
Mormon Hot Spring	***12***	***3,100***	***2,200***	***Maxey and Eakin, 1949, p. 37***	***900***	***1.24***	***29%***
Northern White River Valley (several springs)	***13***	***12,000***	***10,000***	***Maxey and Eakin, 1949, p. 39***	***2,000***	***2.76***	***17%***
Duckwater (Big and Little Warm Springs)	***14***	***11,000***	***13,000***	***Van Denburgh and Rush, 1974, p. 23, 50-52***	***2,000***	***2.76***	***18%***
Fish Creek Spring	***15***	***3,900***	***2,800***	***Rush and Everett, 1966a table 9***	***1,100***	***1.52***	***28%***
Twin Spring	***16***	***2,900***	***4,000***	***Hood and Rush, 1965, table 9***	***1,100***	***1.52***	***38%***
Campbell Ranch Spring	17	7,700	7,400	Eakin et al., 1967, table 4	300	0.41	4%
Shipley Hot Springs and Bailey Spring	***18***	***5,700***	***4,400***	***Harrill, 1968, p. 31***	***1,300***	***1.79***	***23%***
Fish Springs	19	27,000	26,000	Bolke and Sumsion, 1978, p. 10	1,000	1.38	4%
Nelson Springs (Currie Springs)	***20***	***2,200***	***1,800***	***Eakin et al., 1967, table 4***	***400***	***0.55***	***18%***
Blue Lake and Little Springs	***21***	***18,000***	***20,000***	***Gates and Kruer, 1981, table 8***	***2,000***	***2.76***	***11%***
Warm Springs	***22***	***3,300***	***5,000***	***Eakin et al. 1951, p. 108***	***1,700***	***2.35***	***52%***
Total discharge, all regional springs (rounded)		210,000	211,000				

- Ground-water levels and spring discharge may not be in equilibrium with the present-day recharge because of the long distances between areas of recharge and discharge (Prudic et al., 1995; page D17, column 1, paragraph 1).

- Because estimates of hydraulic properties and the length of flow through the consolidated rocks are generally unknown, deeper flow through carbonate aquifers may not be in equilibrium throughout the province. If deeper flow is not in equilibrium, then present-day discharge may be responding to residual water levels related to recharge from previous wet periods, such as the last glacial epoch, and the analysis of flow presented herein may not represent actual flow everywhere (Prudic et al., 1995; page D17, column 1, paragraph 1).

Through these statements the authors are emphasizing that while the model may be good for conceptual evaluations at the scale of the Carbonate-Rock Province, it is not appropriate for use on a scale of an individual hydrographic area because in many basins throughout the Carbonate-Rock Province steady-state conditions do not exist and that this violation of the steady-state assumption has significant effects on simulated flow-paths, water-levels, and fluxes.

Ultimately, Prudic and his coauthors explicitly offer a recommendation on what the CRP model should, and should not be, used:

> …the model greatly simplifies flow through a complex geologic region. Simulation results are based on assuming recharge to the province is known with the distribution of transmissivities simulated to match the general distribution of water levels and estimates of discharge. However, water levels in consolidated rocks are generally unknown, and estimates of recharge and discharge are known only approximately. Consequently, other, equally valid distributions of transmissivities may be found that permit the model to be calibrated to the existing water-level data and estimates of recharge and discharge. The model may be best suited for:
>
> - Simulating alternative transmissivity distributions to evaluate potential source areas of regional springs,
>
> - Simulating the effects of differing recharge rates on regional ground-water flow, and
>
> - Simulating the effects of changing location of discharge on regional ground-water flow.
>
> Therefore, the potential uses of the model are limited. The model is not suited to predict accurate water-level declines that would result from pumping ground water in the province. Also, the model is not suited to predict the accurate rate of change in natural discharge caused by pumping, because the model has not been calibrated to any transient simulations (Prudic et al., 1995; page D93, column 1, paragraph 2-4).

Additional Limitations from Transient Simulations

In their report, Schaefer and Harrill reiterate the basic assumptions and limitations presented by the original authors of the CRP model. They also emphasize that the model they are presenting is not a calibrated steady-state model and that any results of simulations presented should be regarded as generalizations.

Schaefer and Harrill also provide additional emphasis on the storage parameters that are used in the transient simulations. These storage parameters are assigned based on literature that was available at the time the simulations were conducted. They are not optimal storage parameter values that are derived from a transient calibration. Schaefer and Harrill describe the issue in the description of flow model assumptions. They state that…

> …storage values used for transient simulations for the upper layer were based on the predominant aquifer material in each cell, determined from surficial maps. This distribution may not be totally correct because the material may be different at depth in the zone of saturation. Storage coefficients in the upper layer also assume dewatering of the sediments.
>
> Rock and deposit types were divided into three categories--basin-fill materials, carbonate rocks, and other consolidated rocks. Distribution of these units is shown by Prudic et al. (1993, fig. 15). Average values for storage coefficients in layer one were assigned to each of these materials.
>
> For basin-fill material, a value of 0.1 was assigned on the basis of average values of specific yield used in U.S. Geological Survey reconnaissance evaluations of ground-water resources in most basins of the study area. For carbonate rocks, a value of 0.05 was assigned on the basis of an average porosity value of 0.047 determined from geophysical logs of five wells in the Coyote Spring Valley area (Berger, 1992, p. 18). For other rocks, a value of 0.01 was assigned on the basis of a range of values for fractured rocks given by Snow (1979, table 1) (Schaefer and Harrill, 1995; page 8, column 1, paragraph 2).
>
> The storage values for both the basin-fill and carbonate aquifers are not well known, and ***may cause the results of the model to vary significantly***. Changing the storage values of the upper layer by a range of +/- 50 percent, and changing the storage values of the lower layer to the two endpoints of 7.6E-5 and 1.2E-3, were assumed to give a reasonable test of how results might change. The model was rerun using these adjusted storage values… (Schaefer and Harrill, 1995; page 36, column 1, paragraph 2, emphasis added).

The sensitivity analysis conducted by Schaefer and Harrill actually demonstrates that predicted drawdown resulting from pumping can change anywhere from 1 foot to almost 100 ft in some areas. The sensitivity exercise actually provides additional insight into the importance of deriving storage parameter values though a transient calibration.

In fact, a review of other ground-water flow models in the Great Basin suggests that in many cases the storage parameters used by Schaefer and Harrill for the basin fill materials in their transient simulations and subsequent sensitivity analyses are actually rather conservative (see Table 2). These conservative storage parameter values ultimately have an impact on model predictions of this kind. In general, decreasing the storage parameters causes drawdown to get larger and evapotranspiration and spring flows to be captured more quickly. A more appropriate exercise by Myers would have used the full range of Storage parameters bracketing the simulation with a suite of storage parameters on the high-end and the low-end of the currently published Great Basin area models.

Table 2

Great Basin Models	Author	Date	Material	Sp Y (min)	Sp Y (max)
Pahrump Valley, NV-CA	Harrill	1986	Basin Fill	0.10	0.25
Smith Creek Valley, NV	Thomas et al.	1989	Basin Fill	0.06	0.15
Stagecoach Valley, NV	Harrill and Preissler	1994	Basin Fill	0.05	0.30
Las Vegas Valley, NV	Morgan and Dettinger	1996	Basin Fill	0.08	0.10
Carson Valley, NV	Maurer	2002	Basin Fill	0.15	0.15
Milford area, UT	Mason	1998	Basin Fill	0.15	0.15
DVRFS, NV-CA	Faunt et al.	2004	Basin Fill	0.19	0.20
CRP, NV-UT-CA	Schaefer and Harrill	1995	Basin Fill	0.10	0.10
			Average	0.11	0.18

Finally, Schaefer and Harrill conclude that the "adequacy of the model in simulating the effects of the proposed pumping will remain untested until actual pumping stresses have been in place long enough to cause measurable effects within the system. This would allow for calibration of transient simulations that was not possible with the previous model (Schaefer and Harrill, 1995; page 42, column 2, paragraph 4).

Conclusion

Ultimately, the exercise conducted by Myers (2007) is inappropriately misleading. It attempts to draw very detailed conclusions from a model that is inherently conceptual and was never intended to be and should never be used as a predictive model.

Likewise, the supporting testimony provided by Bredehoeft (2007) attempts to bolster an exercise that inadequately examines the full range of possible outcomes. In so doing, Bredehoeft fails to uphold his own publications in which he encourages ground-water modelers to place their work in an appropriate probabilistic framework.

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