Rebuttal Report: Part 2, Review of SNWA Groundwater Model and Comparison with the Myers Spring/Snake Valley Groundwater Model

Presented to the Office of the Nevada State Engineer

On behalf of Great Basin Water Network and the Confederated Tribes of the Goshute Reservation

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The Southern Nevada Water Authority (SNWA) developed a groundwater model in support of the Clark, Lincoln, and White Pine Counties Groundwater Development Project Draft Environmental Impact Statement (BLM, 2011). SNWA is also using this model, known as the Central Carbonate Rock Province model (CCRP) for hearings before the Office of the Nevada State Engineer. This rebuttal report reviews the CCRP model in detail, but first compares it with the Myers model (2011a) of Spring/Snake Valley, showing that the Myers model provides more detail and is more accurate for modeling the impacts of pumping SNWA's Spring Valley water rights applications.

Comparison of Myers Model and SNWA CCRP Model

There are numerous differences between the Myers Spring/Snake Valley model and SNWA's CCRP model. Three of the most crucial differences are discretization, model layers, and the means of simulating the layers.

1. The Myers model decreases the size of the model cells in the primary pumping zones in Spring and Snake Valleys to be just 1320 ft square while the CCRP model has all cells 3281 ft square. Myers' cells are just 16% as large as SNWA's. This finer discretization allows for a more accurate depiction of drawdown near the wells. D'Agnese (2011, p. 2) pointed out that the simulation of drawdown at a pumping well improves with improved discretization, which supports the idea that the Myers' model would be more accurate. The Myers model should simulate drawdown near pumping wells more precisely than the CCRP model.
2. The Myers model has a better vertical discretization near the ground surface where it is most important; its layers are thinner so that they better represent the hydrogeology of the near-surface aquifers. The CCRP model layer thickness varies from 328 to 984 feet over layers 2 through 5, from 328 to 6562 feet for layer 1, and 984 ft or thicker for layers 7 through 11; the total model thickness varies but the bottom is about 10,000 feet below sea level so at the center of Spring Valley, thickness would be about 16,000 ft. Myers' top five layers, if below 6580 ft above mean sea level (amsl), are 80, 120, 200, 400, and 1200 feet; if above 6580 amsl layer 1 may be much thicker because the layer top is the ground surface. These thicknesses allow a much more accurate simulation of circulation, both vertical and horizontal, in the model near the surface where it is more important to predictions of the impacts. This allows a better interchange of flow for evapotranspiration (ET) and DRAIN discharge and more accurate drawdown predictions. Myers' lower two layers are quite thick, but there is no need for accurate simulation of vertical circulation thousands of feet below ground surface (bgs). Halford and Plume (2011) generally did not simulate an overall model thickness more than 4000 ft because they expected little deep circulation.
3. SNWA simulated all layers as confined, including layer 1 (SNWA, 2009, p. 4-2, 4-4). They did this because of model convergence issues. Myers simulated layer 1 as unconfined, as it should be to improve the simulation of water released from storage under transient simulation. SNWA set the top of layer 1 to coincide with the top of the water table so that the layer had a constant transmissivity. They did not change the layer type during transient simulation which means that layer-1 transmissivity remains constant through the simulation even though the thickness is

significantly decreasing. There are areas where the simulated drawdown exceeds 328 feet, so the layer should go dry; SNWA's assumption would maintain the transmissivity and flow even when simulating heads below the bottom of the layer. Myers's model allows the water surface and transmissivity to drop and even allows the layer to go dry if drawdown extends below the layer bottom. The near-ground-surface simulation is much more accurate in the Myers' model.

One statistical method of comparing the Myers and CCRP modes is to consider unweighted residual statistics (Table 1). The mean, mean absolute error, root mean square error, and standard deviation all indicate the Myers model more accurately simulates the head values around the model domain. SNWA's data range was significantly larger, therefore the RMSE is a much smaller proportion of the range. SNWA's range is high although there are very few observations in the south end, and lower 2000 feet, of the domain (SNWA, 2009, Figure 6-9). Also, Figure 19 (Myers, 2011a) shows a much better distribution of residuals around the domain than shown in SNWA (2009) (see discussion below).

Table 1: Comparison of Myers and CCRP model residual statistics.

Statistic	Myers (2011a)	CCRP
Mean	1.01	15
Mean Absolute Error	39.4	45
Root Means square error	57.95	91
Standard Deviation	57.94	90
Data Range	2321	6461
RMSE/Range	2.5	1%
Count	561	2707

Review of SNWA CCRP Model

SNWA emphasizes the value of using "weighted" observations to calibrate the model. Myers (2011a) used unweighted observations, except that obvious perched wells were removed from the calibration. Weighting is an attempt to account for the accuracy of the observation measurement and may be based on many things, from the method of determining the ground surface elevation or the depths to water to the seasonal variability of a series of measurements (from which a variance for the observed values can be determined). Ultimately, setting a "weight" is as fraught with uncertainty as the observation itself. Halford and Plume (2011) set weights based on the source of the observations, but described weighting individual observations as a "fool's errand" because model-discretization error "typically dominates measurement error".

SNWA presented unweighted residuals, in Figure 6-9 (SNWA, 2009). This figure shows extreme bias in distribution of residuals. In the area of Dry Lake and Pahroc Valleys, six residuals are between -440 and -220; five more are between -200 and -50 (Figure 1). Just east of Dry Lake Valley, in a trend that looks very much like the PRISM precipitation overestimates in Patterson, Lake, and Cave Valleys are at least ten residuals from 200 to 955 and another ten from 20 to 200 (Figure 1). The CCRP model ranges from gross overestimation of head in Dry Lake/Pahroc Valleys (simulated exceeds observed in a negative residual) to gross underestimate of heads 10 to 20 miles to the east.

SNWA's numerical model report addresses the residual problem between Patterson and Dry Lake Valley (SNWA, 2009, p 5-8). They used two low-K horizontal flow barriers (HFBs) to force the head to drop over 1000 feet between the valleys, but just were unable to do this which resulted in the high residuals. (The steady state model simulates 1600 af/y from Patterson to Dry Lake Valley, an amount not discussed in Burns and Drici (2011)). This should have caused SNWA to reconsider the overall conceptual model for the area. The problem is that their model simulates too much recharge in Dry Lake Valley, most specifically in the mountains on the east side of the valley between Dry Lake and Patterson Valleys; the model cannot cause sufficient head drop between valleys because there is too much flux included.

Two other obvious problems are the high positive residuals in north Spring Valley and along the mountain front in Snake Valley (Figure 1). This indicates the model does not accurately simulate the water table in the higher elevations along the boundary of the valleys. Such a poor connection would limit the simulated drawdown in these areas, potentially biasing the predicted results.

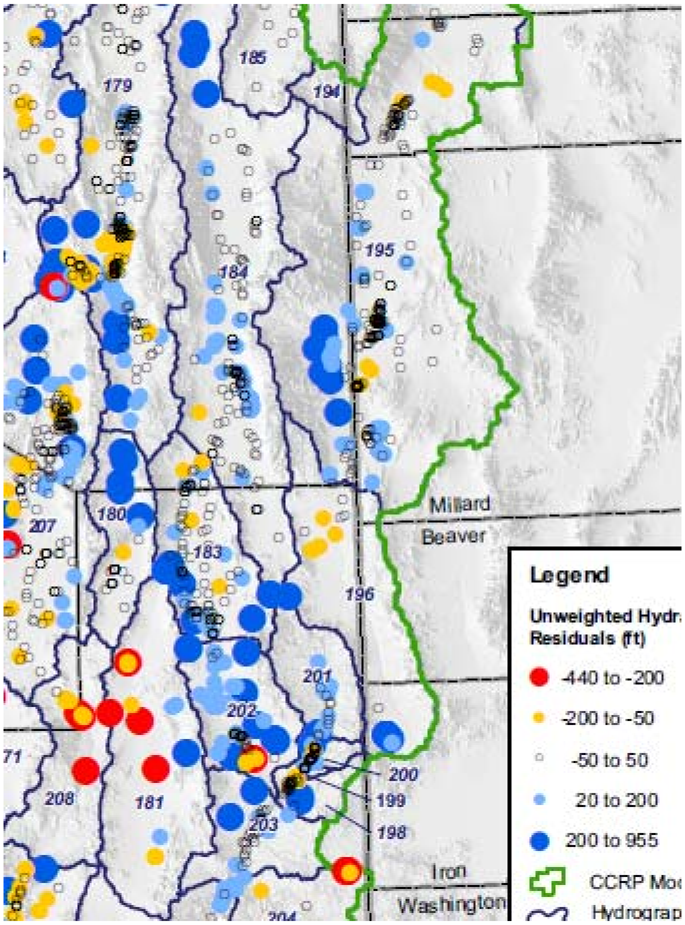

Figure 1: Snapshot from Figure 6-9 (SNWA, 2009) showing unweighted residuals.

The SNWA model handles faults in a way that may be biased because there is very little data to support their ultimate parameter choices. The following describes some of the problems.

The Pahranagat shear zone causes a head drop of about 700 feet across one model cell, as represented by the blue in the hydrogeology at column 62 **(**Figure 2); this is modeled with a series of HFBs. Further east (right) in column 72 is a conductive fault in LC3 (lower carbonate rock). The conductivity (K) in the fault ranges from 17 to 62 ft/d, over 3281 feet, while the surrounding LC3 cells have K about 0.5 ft/d. The high K fault runs north/south through Coyote Spring Valley to just south of the Pahranagat Shear zone (Figure 3); the fault is shown on Figure 3 just east of the highway; it ends approximately where it intersects the shear zone. Based on K, this fault zone would transport vastly more groundwater than the surrounding rock.

Further south three faults converge in Coyote Spring Valley which allows groundwater to move to the Muddy River Springs area through a zone of very high K LC3 rock. Figure 4 shows two of the faults and high K zones right of the faults; Figure 5 shows the convergence of these faults and the fault on the east which impedes the flow causing it to surface at the springs. Figure 6 shows the three faults north of the springs near their convergence into the broad high K LC3 material. These figures demonstrate how a model simplifies complex geology as mentioned by D'Agnese (2011, p. 10). The problem with this is the broad zones with very high K cover as much as 20 model rows by 15 columns, or about 300 square kilometers. There is no geologic evidence for such a broad fractured zone in this area. Such a zone may bias the results for this area. The springs probably discharge from a narrow highly conductive fracture zone which could be drained sooner by pumping than would a 300 square km, 10,000 feet thick zone, with high K.

SNWA should use different storage coefficients for the high K zones. Clearly, highly fractured areas would have different storage properties than unfractured media.

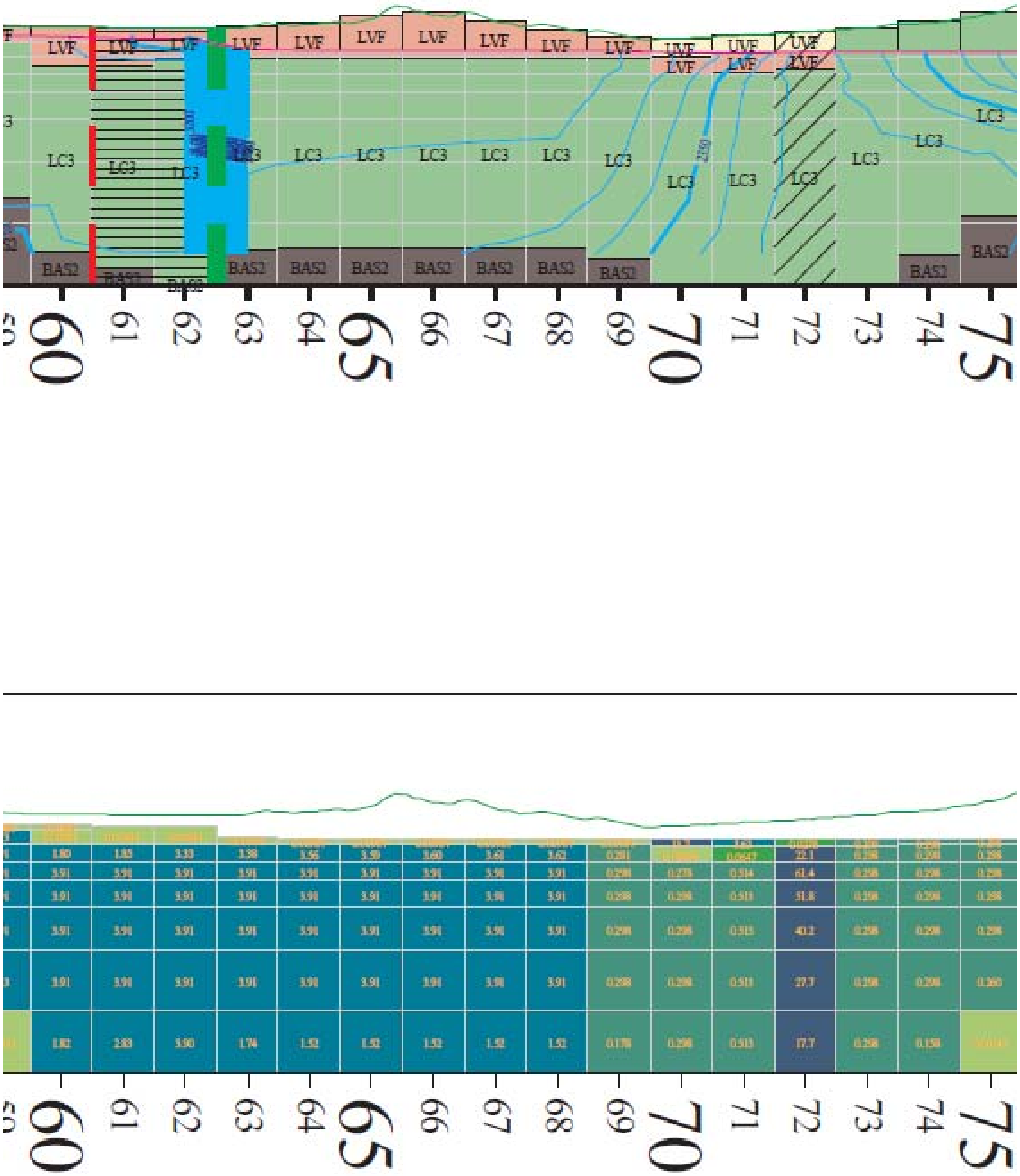

Figure 2: Snapshot of hydrogeology and calibrated K, model row 359. This section crosses Pahranagat and Coyote Spring Valley. (file xs_rum_rows-rev2-7o-map-hd-kh-s-1lay-ucth814-1-4748.pdf)

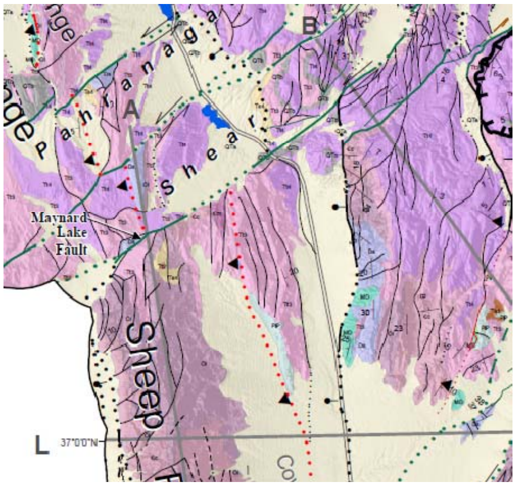

Figure 3: Snapshot from Plate 2, Rowley et al (2011).

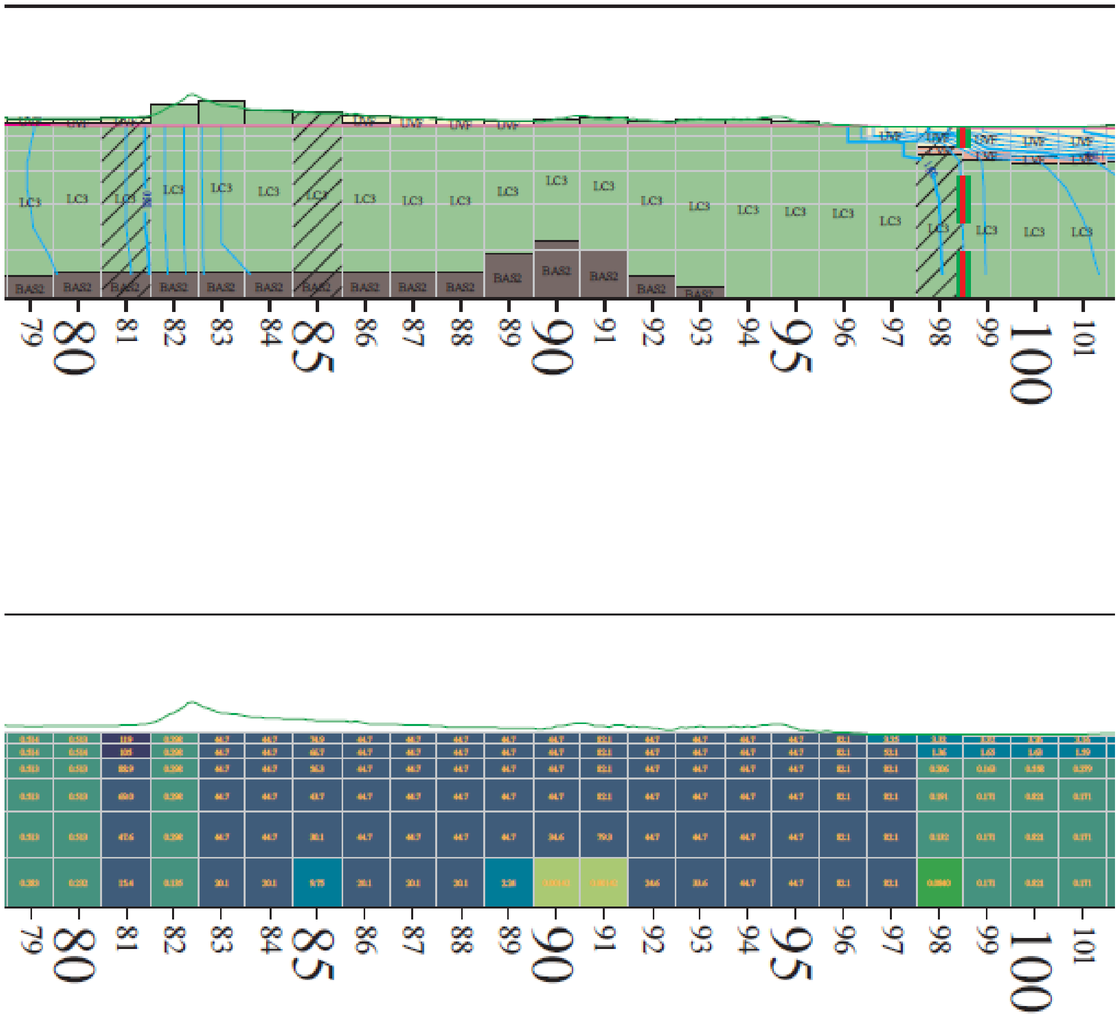

Figure 4: Hydrogeology and K values for row 407. (file xs_rum_rows-rev2-7o-map-hd-kh-s-1lay-ucth814-1-4748.pdf)

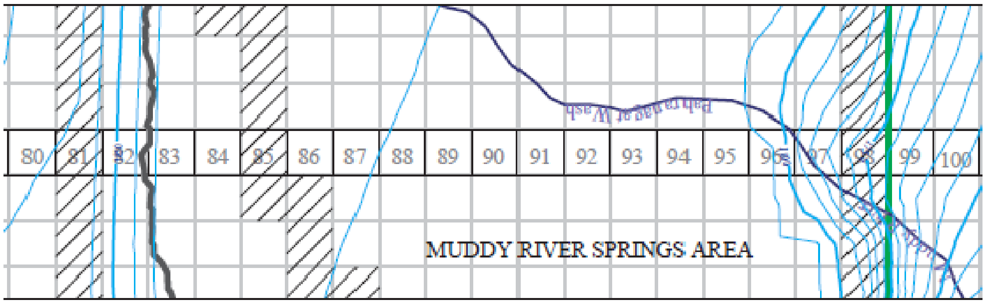

Figure 5: Model area near row 407 showing faults. (file xs_rum_rows-rev2-7o-map-hd-kh-s-1lay-ucth814-1-4748.pdf)

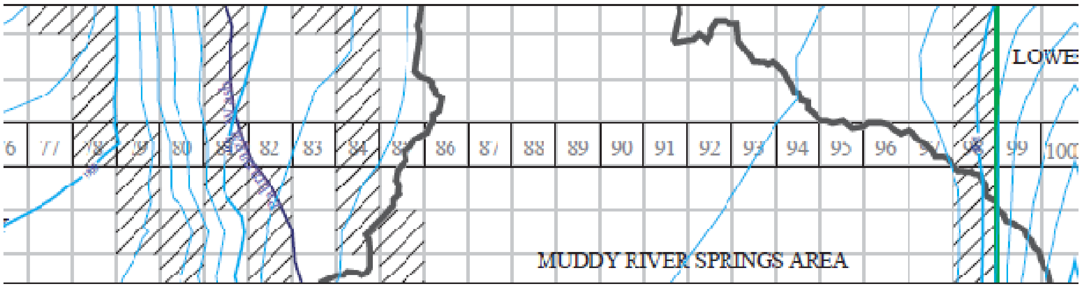

Figure 6: Model area near row 397 showing the collection of faults, all with high K but also the cells to the east have high K. (file xs_rum_rows-rev2-7o-map-hd-kh-s-1lay-ucth814-1-4748.pdf)

The CCRP model simulates Spring Valley with faults on each side, but only the normal fault on the west side has a significant effect. An HFB runs between the bedrock and fill, causing significant head drop from the bedrock to the fill. The bedrock is all low K, therefore the flow into the fill is probably not very high; the northern portion of Spring Valley is a section with mostly mountainfront recharge. The east side fault shows as large displacement, but the K is not significantly different from the surrounding rock.

The carbonate rock that underlies northern Spring Valley extends into Tippett Valley, under the Antelope Range. The K under Tippet Valley is almost two orders of magnitude higher, and the normal faults along the boundaries of Tippet Valley have high K.

SNWA simulates the fill in Spring Valley as high to very high K, similar to Myers (2011a). The primary feature is that the fill is modeled as a bowl in both models, with high K fill surrounding by bedrock.

SNWA models specific storage in lower layers of the fill, 5000 ft bgs, as 0.015. This imparts a huge bias on the predicted results because much more water is released for a unit drop in head than is realistic. I used 0.001 in this area to more accurately reflect the storage-head drop relationship (Myers, 2011a). Anderson and Woessner (1992, Table 3.4) specified a range of specific storage values ranging from 0.02 to 0.000049 m^{-1} for material ranging from clay through dense sandy gravel; the high range is for plastic clay, not the type of material found in Spring Valley. Halford and Plume (2011) used a specific storage of $2x10^{-6}$ ft^{-1} for their layers 2 through 4. These references support the use of a lower specific storage than was used by SNWA (2009). SNWA's choice would improperly minimize the predicted drawdown by causing the model to release more water to pumping for a given drawdown than is realistic. It biases the drawdown prediction to be much lower than would occur in reality.

SNWA (2009, p 3-2) notes that measured storage properties may not convert to model scale storage properties. This is similar to the scale issues for K as discussed by authors such as Schulz-Makoch et al (1999). It is reasonable that storage coefficients would increase with scale as the volume under consideration includes more connected fractures, but the issue with SNWA's choices in the previous paragraph refers to fill for which porous-media flow is more predominant and scale issues much less important.

SNWA uses high K cells on the boundary in the uppermost layers (Figure 7). These presumably were set to allow recharge into the zone, perhaps in relation to the manual adjustment they made to their runoff pathways (SNWA, 2009, p. 5-14). Underlying the high K cells, the K is an order of magnitude lower, which causes the groundwater to pond, as shown in the contours on upper Figure 7.

Groundwater contours along row 160 show a gradient through carbonate rock from Steptoe to Spring Valley (Figure 8). The model includes an HFB, but no mounding of contours. This is an example of how the SNWA model does not reflect the geology by Rowley et al (2011). Many more rows also show flow in this direction. However, the uppermost layers show a modest mounding of flow so that contour maps may suggest there is a divide. Figure 9 and 10 demonstrate how a groundwater level contour map can show a divide while there is clearly flow at depth.

Big Springs appears to be simply sourced using a large expanse of carbonate rock that has K very near 0.413 ft/d. The carbonate rock extends through the thickness of the model meaning the upgradient transmissivity is very high. A fault forces groundwater to surface.

SNWA sources the Pahranagat springs with a highly conductive fault running down the middle of Pahranagat Valley which gathers and transports groundwater from the north and west; K in the carbonate rock ranges to 30 ft/d for one or two column widths. The Pahranagat shear zone is simulated with a series of HFBs which prevent much of the flow from passing and also force groundwater to surface and form the springs. This central part of Pahranagat Valley does not receive much inflow from the east because of a normal fault that bounds the east side of the valley. The head drop across the HFB is about 300 feet (row 336); some flow occurs during steady state conditions but the HFB would be slow to respond to upgradient pumping; the HFB protects the Pahranagat Springs.

The recharge estimates used in SNWA's model do not constrain the recharge for a given basin according to SNWA's conceptual model, which had estimated recharge by basin. The conceptual model determined recharge efficiencies (which are for potential recharge) by flow system based on PRISM precipitation, specified discharge rates, and ranges of interbasin flow estimates, resulting in a flow-system-wide estimate of efficiencies. Applying these to the precipitation within a basin resulted in an estimate of a basin-specific recharge. The method for distributing recharge described for the numerical model (SNWA, 2009, p. 4-62 – 4-64) somewhat reshuffles the recharge distribution so that the recharge can meet the discharges specified from the model. In other words, SNWA started the process over during their numerical model calibration but did not constrain the estimates by basin as did the conceptual model Excel solver. This explains the differences in recharge by basin and difference in interbasin flow for the numerical model as compared to the conceptual model.

There also was a problem with too much interbasin flow from Hamlin to Snake Valley (SNWA, 2009, p. 3-3). This was due to the PRISM precipitation estimate for that area being much too high. This corresponds with issues regarding PRISM discussed in Myers (2011c).

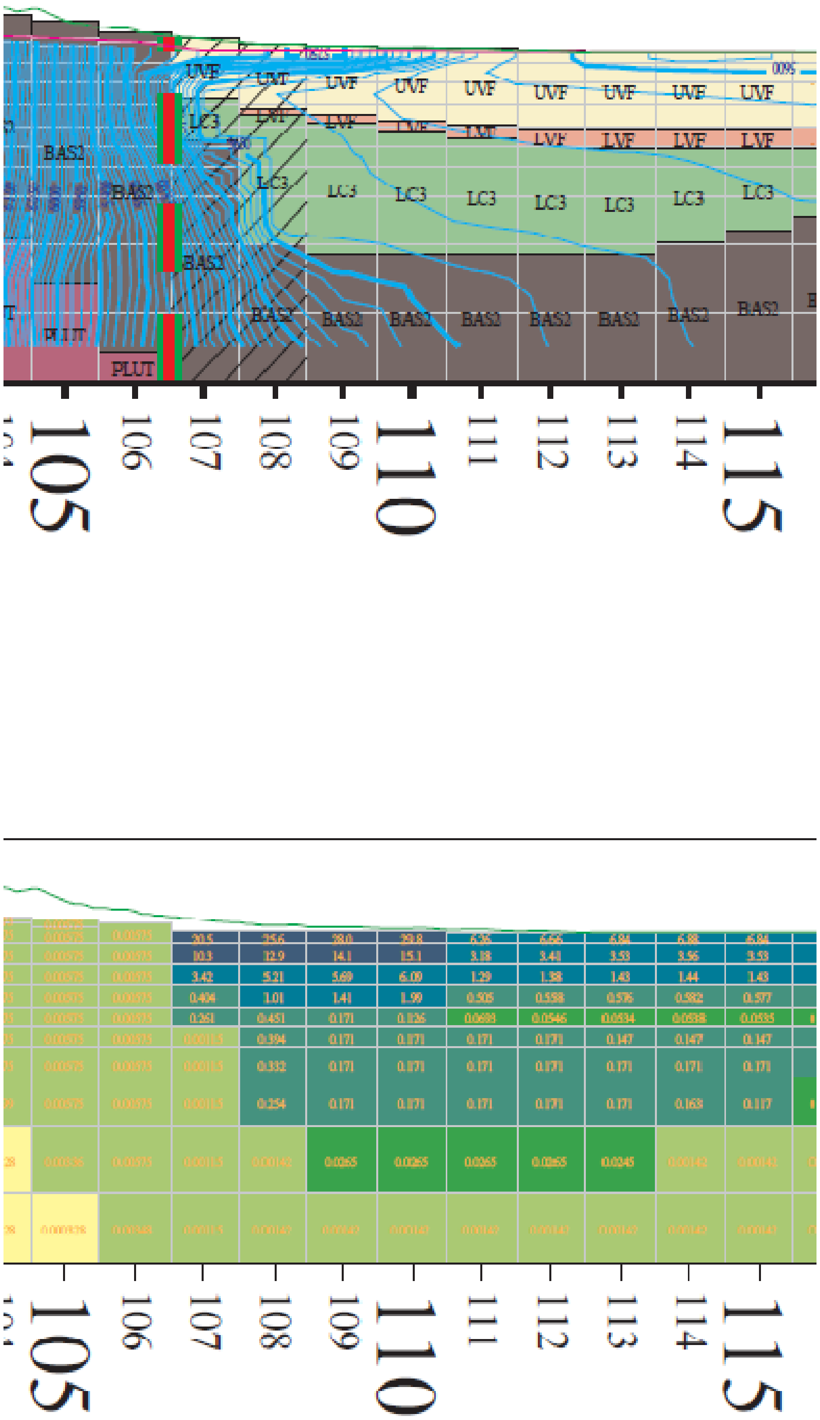

Figure 7: Snapshot of portion of row 128 in center of Spring Valley showing hydrogeology (upper) and K (lower). (file xs_rum_rows-rev2-7o-map-hd-kh-s-1lay-ucth814-1-4748.pdf)

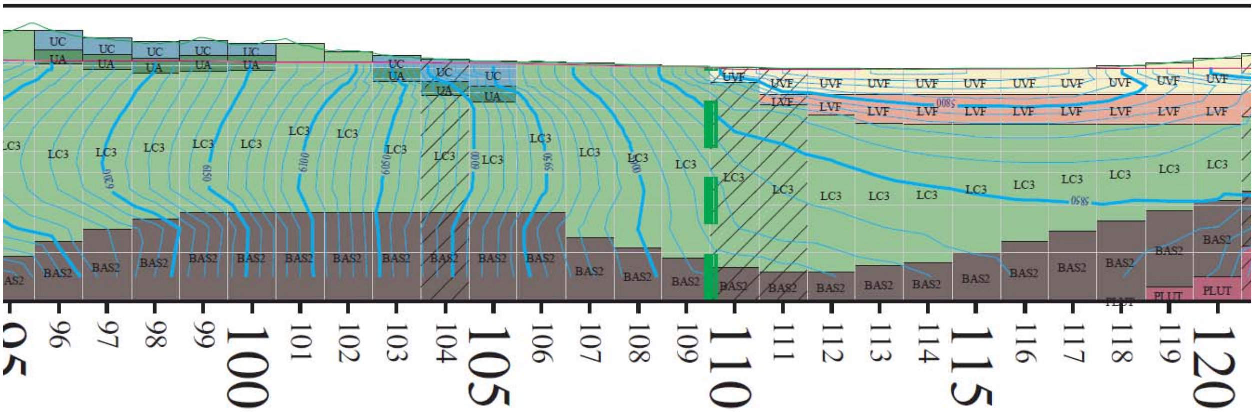

Figure 8: Snapshot of row 160 showing hydrogeology from Steptoe Valley (left) to Spring Valley. (file xs_rum_rows-rev2-7o-map-hd-kh-s-1lay-ucth814-1-4748.pdf)

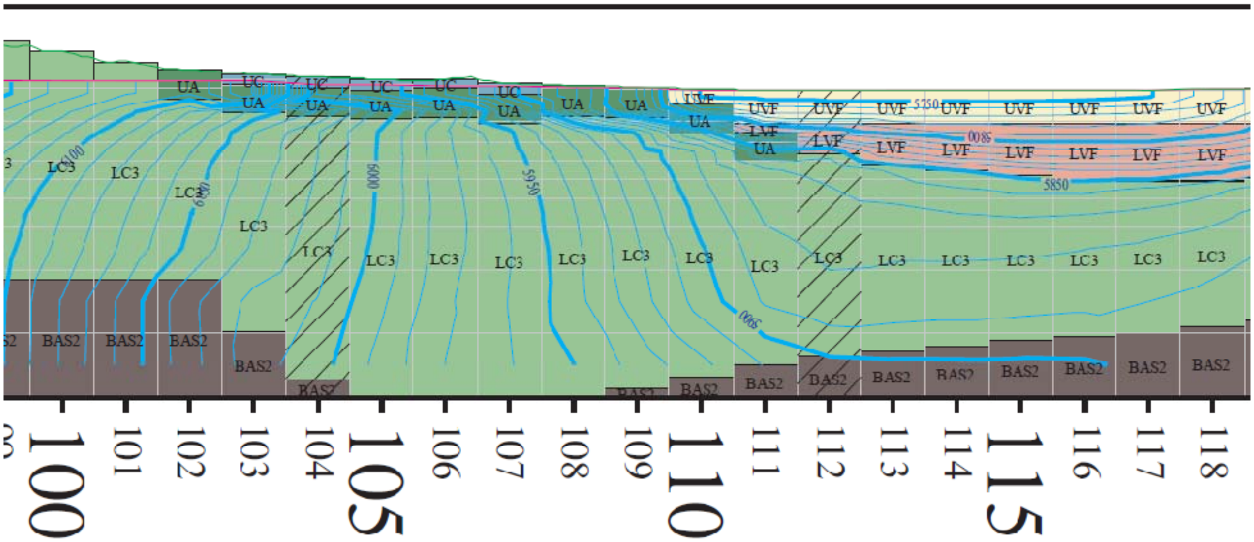

Figure 9: Snapshot of Row 166 showing hydrogeology from Steptoe Valley (left) to Spring Valley. (file xs_rum_rows-rev2-7o-map-hd-kh-s-1lay-ucth814-1-4748.pdf)

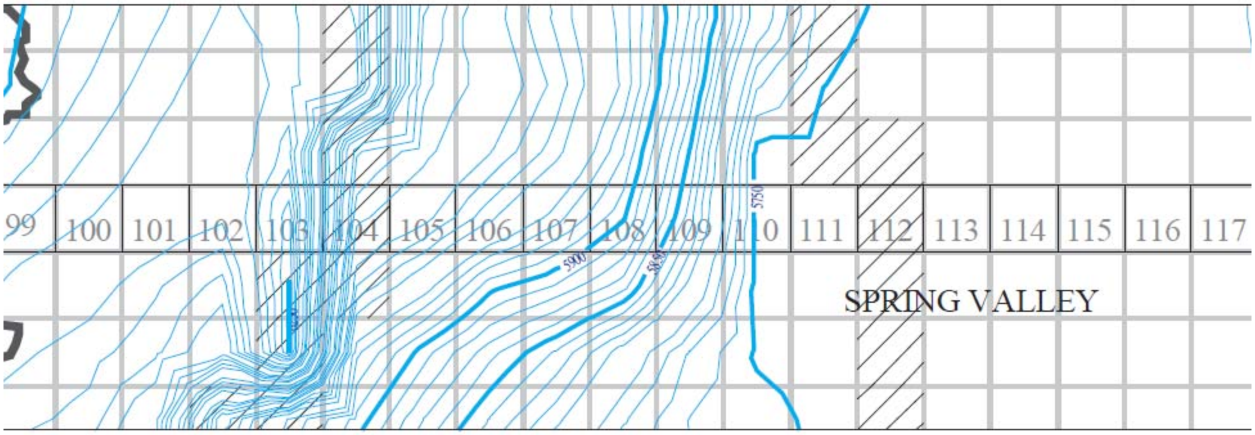

Figure 10: Snapshot of Row 166 showing groundwater contours from Steptoe Valley (left) to Spring Valley. (file xs_rum_rows-rev2-7o-map-hd-kh-s-1lay-ucth814-1-4748.pdf)

The model conceptualization of Shingle Pass is as complicated as any in the model, with several formations including carbonate rock and several faults (Figure 11). The faults within Cave Valley are simulated with HFBs which prevent flow from leaving Cave Valley. The mountain front faults on the east side of White River Valley have very high K, being high displacement faults. The high K zones extending north and south along the west side of the Egan Range capture substantial recharge from the mountains and deliver it to the spring areas. However, these faults do not have an HFB which would force water to surface in to the springs. Thus, SNWA biases the model to prevent Cave Valley flow from supporting the springs in two ways – HFBs within Cave Valley preventing flow to White River Valley and high K faults along the east side of WRV that brings water from the north to the springs along with no barrier to cause the water to surface at these points.

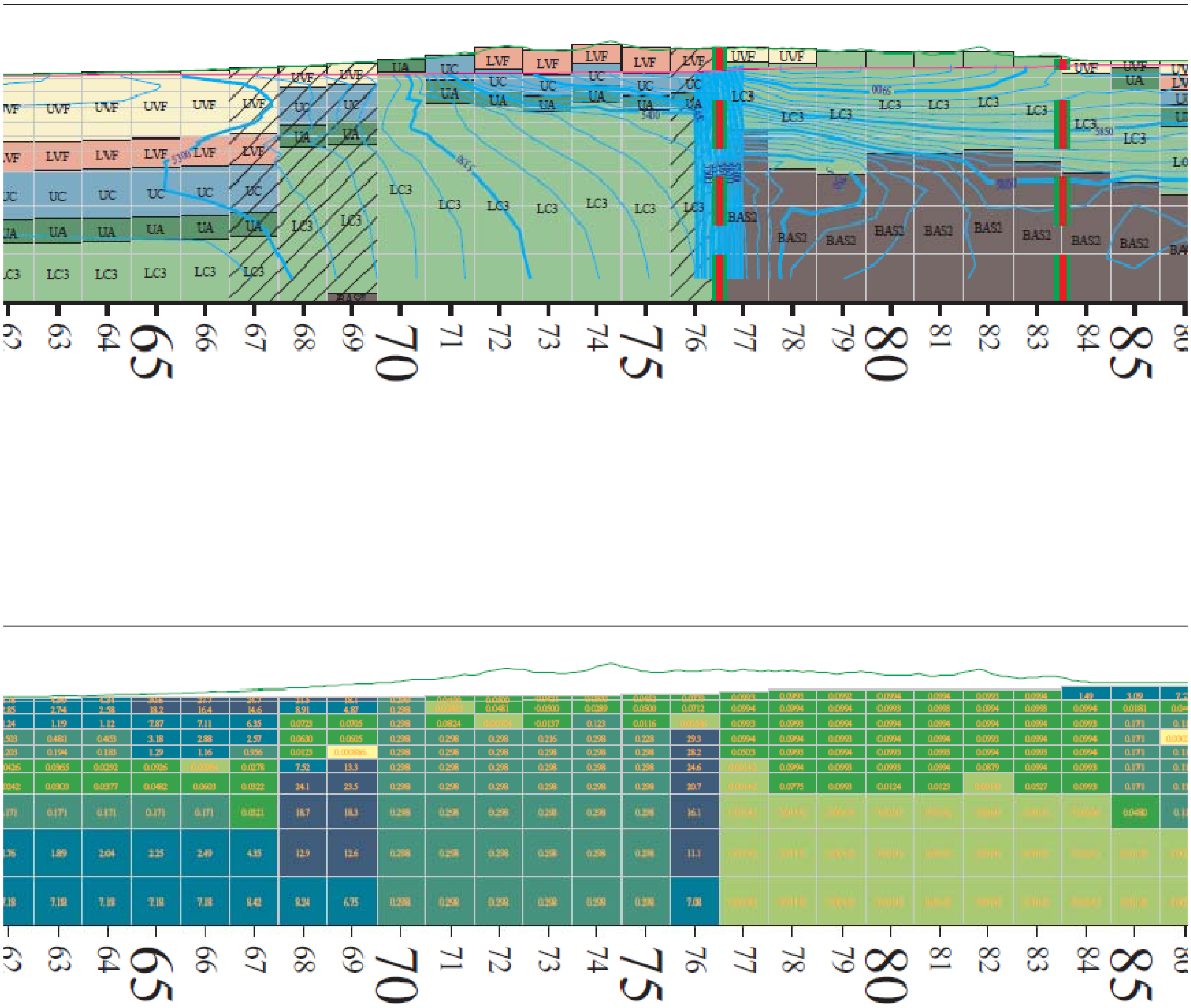

Figure 11: Snapshot of row 202 showing hydrogeology (top) and K values near Shingle Pass. (file xs_rum_rows-rev2-7o-map-hd-kh-s-1lay-ucth814-1-4748.pdf)

SNWA added a constant head boundary between Pahranagat and Tickaboo Valleys to “allow some of the discharge to flow out of the model area” which was necessary because “discharge by groundwater ET from Pahranagat Valley tended to be larger than expected” (SNWA, 2009, p. 5-13). In other words, they needed a release valve even though the Death Valley Flow System (DVFS) analyses had not included such an outflow. The reason a “release valve” was needed was, once again, that SNWA estimated far too much recharge in the WRFS, mostly in Dry Lake and Delamar Valleys (Myers, 2011c).

SNWA estimated the parameters for each cell over their thick layers (discussed above) using the HUF2 routine which determines a weighted average for the properties of each hydrogeologic unit intersected by the cell (SNWA, 2009, p. 4-6). This means that if the top half of the cell has k1 and the bottom half k2 K, the K for the cell would be (k1+k2)/2. This is reasonable unless k1 and k2 are grossly different. This is reasonable for weighting two units that have similar flow and K, such as the upper and lower valley fill unit, but if the averaging combines fill with lightly fractured carbonate, the averaging combines different flow types – media and fracture. For cells with averages that combine significantly different units, the average is a meaningless number.

The numerical model simulated flow from Fish Springs Flat into Snake Valley (SNWA, 2009, p. 5-13). This goes against most other reports, which SNWA cites, showing that because of the high discharge from the springs there must be inflow from elsewhere. Myers (2011a) simulated interbasin flow from Snake Valley into the Fish Springs area.

The D'Agnese (2011) report mentions that the CCRP overlaps with the Death Valley Flow System (DFVS) model and the RASA Great Basin model (D'Agnese, 2011, p. 1). It is a stretch to argue there is an overlap between the CCRP and DVFS. SNWA developed the CCRP using baseline hydrogeologic data from the DVFS, such as initial parameter estimates for hydrogeologic units, but the systems are fairly different.

D'Agnese (2011, p.2) is correct that the CCRP is too coarse for detailed predictions. That is one of the big differences between the Myers Spring/Snake model and the CCRP – Myers (2011b) developed his model to provide more precise estimates of impacts in those two valleys.

The CCRP was developed using "accurate predevelopment steady-state groundwater budgets…." (D'Agnese, 2011, p. 2), but SNWA's water resources report (Burns and Drici, 2011) has substantially different values. See Myers (2011c).

Conclusion

SNWA used a regional groundwater flow model to make predictions of drawdown to be expected from pumping their water rights applications in Spring, Cave, Dry Lake, and Delamar Valley. It had been developed to make coarse predictions at a regional scale for a programmatic DEIS (BLM, 2011). It is inappropriate for use in predicting detailed drawdown impacts due to pumping from specific PODs for many reasons documented in this report, including the following:

1. The model cells are too coarse for detailed drawdown predictions.
2. The model layers are too thick and the model domain extends much deeper than necessary for simulating the details of pumping their applications.
3. SNWA simulated all layers, including layer 1, as confined. This biases the simulation to underpredict drawdown in Spring Valley because it does not adjust the transmissivity as the water table lowers.
4. The conceptual model used for the numerical model is substantially different from the conceptual model used to develop the numerical model.
5. The numerical model structure was far too complex for the quantity and quality of hydrologic data used to calibrate it.
6. The model relies on faults to control the flow even though there is little collaborating hydrologic data.

The Myers (2011a) model provides more accurate and more precise predictions for the Spring and Snake Valley portions of the study area. This report has documented many reasons, but the following are some of the Myers' model more important advantages over the SNWA model.

1. It has a finer discretization so that the flow predictions near the wells are more precise.
2. The top five layers of the Myers model provide a more detailed representation of the water table and the interactions of the water table with discharge features, including springs and wetlands.
3. It properly simulates the difference between unconfined and confined aquifers.
4. It has a more accurate calibration for water level.
5. It uses more realistic storage coefficients.

Myers (2011b and d) presented simulations of drawdown for the area that extend further into the future and provide a range of scenarios. SNWA failed to do this. The NSE should use the Myers model to consider both short- and long-term impacts of pumping in Spring Valley.

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