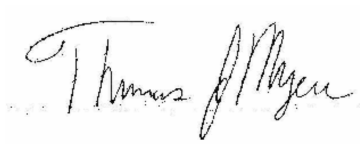
Review and Rebuttal of SNWA Submissions In Support of Applications for Groundwater From Cave, Dry Lake and Delamar Valley

For Submission to the Nevada State Engineer For the Cave Valley, Dry Lake, and Delamar Valleys Hearings

Prepared by:



Tom Myers, Ph.D.
Hydrologic Consultant
Reno, NV

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Summary and Conclusion

The Southern Nevada Water Authority (SNWA) submitted many reports and documents to the Nevada State Engineer in support of its applications for groundwater in Cave Dry Lake and Delamar Valleys (target valleys). For purposes of this rebuttal report, I will refer to those submissions collectively as SNWA (2007). Myers (2007) described the applications and provided hydrologic analysis and arguments as to why SNWA should not be granted any water from these valleys. This report reviews those SNWA documents.

The primary reason Myers (2007) concluded SNWA should not be granted any water rights from the target basins is that, considered as a whole, all of the groundwater in the White River Flow System (WRFS) is already appropriated. Other researchers have reached the same conclusion (Mayer 2007). Although there is little development in the target basins, the recharge and interbasin flow from those basins is already fully utilized downgradient. Myers (2007) found there is simply insufficient water in the WRFS to export any to the Las Vegas area.

The submittals by SNWA have provided no information to change that conclusion. In fact, once SNWA's analysis errors are reconciled, consideration of flows

to Lake Mead shows that the system is even more overappropriated than I previously have suggested.

SNWA's applications request water that simply is not available. The following sections provide discussion and rebuttals of the analysis provided by SNWA. The primary reasons the Nevada State Engineer should not grant SNWA any water rights in the White River Flow System are as follows:

- There is no available water in the WRFS for any more water rights to be granted.
- Groundwater originating in and emanating from the target basins is completely used and appropriated in downgradient basins.
- Appropriating groundwater in the target basins will affect discharge from downgradient springs that will be detrimental to the environment and to senior water rights.
- SNWA's analysis includes many errors that lead to overestimates of groundwater flow and recharge in the WRFS.
    - The estimate for groundwater flow to Lake Mead is grossly too high.
    - The constraint on flow from Cave to White River Valley, equal to 4000 af/y, is simply too low.
    - The precipitation estimates for the WRFS are up to ten percent too high.

Introduction

There are three primary aspects to SNWA's analysis that will be considered here. First and second, there are the recharge estimates and interbasin flow estimates. While I discuss them separately, the two are closely intertwined into a water balance analysis because SNWA utilized an optimization model to rout the flows through the entire WRFS. The optimization determines the necessary relationship between recharge and precipitation while meeting the constraints of specified evapotranspiration (ET) or limits on interbasin flow. Third, SNWA does not assess the effects of appropriating this water on either spring flow or downstream water rights.

White River Flow System Water Balance

SNWA (2007) does not discuss the published perennial yield for the basin other than to note that the reconnaissance reports set the PY low because of economic constraints on development. The tenor of SNWA's analysis appears to be that the applications are part of the White River Flow System (WRFS) and that water availability in that flow system is what matters. Myers (2007) demonstrated there was insufficient groundwater for these applications in the entire flow system and this report will better assess the availability within the WRFS.

Recharge Estimates

Flow Routing and Recharge Estimation by Optimization

SNWA used an optimization approach to determine "new" Maxey-Eakin type recharge efficiencies by balancing the flow in the WRFS. SNWA sets the sum of GW ET discharge estimates and groundwater flow to Lake Mead as equal to the recharge in the WRFS. SNWA also routs flow through the basins by setting interbasin flow in certain areas, constraining it to a maximum or minimum in others, and by setting the flow from a basin to equal the difference in recharge (including upstream interbasin flow) and discharge. The optimization model uses PRISM average annual precipitation estimates divided into one-inch zones throughout the WRFS and for each valley. Using an estimate of total precipitation for each band spread over the WRFS, the optimization model solves for an exponential relationship of recharge and precipitation.

$$R = a(P - 8)^b \qquad \textbf{(1)}$$

In this equation, R is recharge, P is the precipitation rate for the zone being considered, and a and b are coefficients resulting from solving for total R and the amount of precipitation for each one-inch precipitation zone. The threshold for any recharge is 8 in/y. Using the mid-point of each one-inch precipitation band, efficiencies for each band are determined with equation 1.

SNWA's estimates for each basin, made using the efficiencies determined for the entire WRFS, are higher than most of the estimates made by previous studies (Table 1). The difference is especially marked for Dry Lake and Delamar Valleys. Because of the significant differences, I examined some of the details of the optimization routing.

Table 1: Recharge Estimates from SNWA (2007) and other studies for the target basins.

	Previous Recharge (af/y) Estimates		
Study	Cave	Dry Lake	Delamar
Eakin (1966)	14,000	5,000	1,000
Kirk and Campana (1990)	11,000 to 14,000	5,250 to 7,500	2,000
Flint et al. (2004)	10,300	10,600	7,800
SNWA (2007)	**14,659**	**15,667**	**6,400**

The recharge efficiencies depend on two flow constraints: the outflow to Lake Mead and from the White River Valley (WRV). SNWA estimated the outflow to Lake Mead as "less than 25,000 af/y" (SNWA 2007, Part A, page D-19), but for the optimization they treat it as a minimum. One of the constraints in the Excel solver is "R9>=25,000" where R9 is the Excel cell for discharge to Lake Mead in the solver section. This appears to constrain the outflow to greater than SNWA had estimated. The constraint forces the optimization model to generate sufficient recharge somewhere within the WRFS to meet that flow requirement and still meet other GW ET discharges.

The solver used another limit of 6300<outflow from WRV to Pahroc<40,000, and calculated the outflow as the difference in recharge for WRV, Jakes Valley and Long Valley plus an assumed 4000 af/y inflow from Cave Valley and the GW ET discharge from the three named valleys. This constraint is very limiting because SNWA's total GW ET estimate from the three basins is 70,685 af/y, or slightly more than half of SNWA's total GW ET estimate for the WRFS. Just to reach the low end of the constraint range, recharge in the three basins must be 72,985 af/y (plus the 4000 af/y contribution from Cave Valley). This constraint effectively sets the recharge for more than half of the WRFS which means it has an inordinate effect on the recharge efficiencies established in the analysis.

The constraint for flow from WRV to Pahroc Valley may be reasonable, but the specifications for flow to meet that constraint are not. As will be discussed below in the section on interbasin flow, SNWA's estimate of 4000 af/y flow from Cave Valley to WRV appears to be much too low.

There are other constraints, but the two just listed are most important and potentially most unreasonable. Although the outflow to Lake Mead was set as a minimum value, SNWA's solution equaled 25,000 af/y to Lake Mead. The solution also yielded the low end of the WRV outflow range, 6300 af/y.

To test the constraints, I changed the outflow in the optimization model to Lake Mead to 40,000 and 7000 af/y, respectively. The solver handled the higher constraint and the outflow became 40,000 af/y. Recharge in the WRFS increased by 15,000 af/y, but the outflow from WRV remained at 6300 af/y; therefore, all of the recharge increase occurred in the rest of the basin, including the target basins. This illustrates how SNWA's assumption for discharge to Lake Mead controls the recharge in the target basins. However, testing a 7000 af/y flow limit to Lake Mead, the solver could not reach a unique solution; the estimate for outflow to Lake Mead decreased to 24,382 af/y. For the 7000 af/y outflow constraint, the total recharge estimate plus inflow to the basin minus outflow to Lake Mead, which should equal the GW ET, was about 17,000 af/y too high. This shows how the constraints in the model set a substantial constraint on the low range of recharge estimates.

The limits on flow from WRV along with the constant inflow set for Cave Valley, 4000 af/y, apparently set a requirement for a certain amount of recharge above WRV which cannot be met unless the flow to Lake Mead is unrealistically high. The discussion below on interbasin flow indicates that SNWA's estimated flow to Lake Mead and from Cave Valley to WRV shows that SNWA's estimates are unrealistic. These limits have biased the model to overpredict recharge in the overall basin. Because SNWA's recharge estimates for Dry Lake and Delamar Valleys are so much higher than previous estimates, the bulk of the overestimate resulting from these unrealistic constraints appears to occur there. The most error prone input to the model is the PRISM precipitation estimates. If the precipitation estimates for Dry Lake and Delamar Valleys are too high, then the recharge estimate for those valleys will also be too high. In other words, with recharge efficiencies highly dependent on recharge above WRV, when they are applied to Dry Lake and Delamar Valleys, they overestimate recharge. Assuming the recharge efficiencies do not vary as a function of latitude (Dry Lake and Delamar are south of most of WRV and other upper WRFS basins), the reason that Dry Lake and Delamar Valleys recharge are overestimated is that the precipitation estimates must be too high, as discussed in the next section.

Prism Precipitation Estimates

SNWA used PRISM for precipitation estimates. Myers (2007) reported that Jeton et al (2005) found that PRISM overestimated precipitation at many points in Nevada. However, SNWA asserted that PRISM data sets are "recognized world-wide as the highest-quality spatial climate datasets currently available" (SNWA 2007, Part A, page 4-2). This assertion is unreferenced and, based on my experience, completely unfounded. Apparently, SNWA (2007) used a more recent PRISM estimate, but it is unknown how this estimate compares with the estimate used by Jeton et al (2005). SNWA presented an estimate, with little discussion, of the percent difference between precipitation stations near the WRFS and PRISM precipitation stations. It showed that PRISM overestimated annual precipitation at 38 of 43 stations near the WRFS (Figure 1). This demonstrates exceptional inaccuracy on which SNWA certainly should not base its water balance model.

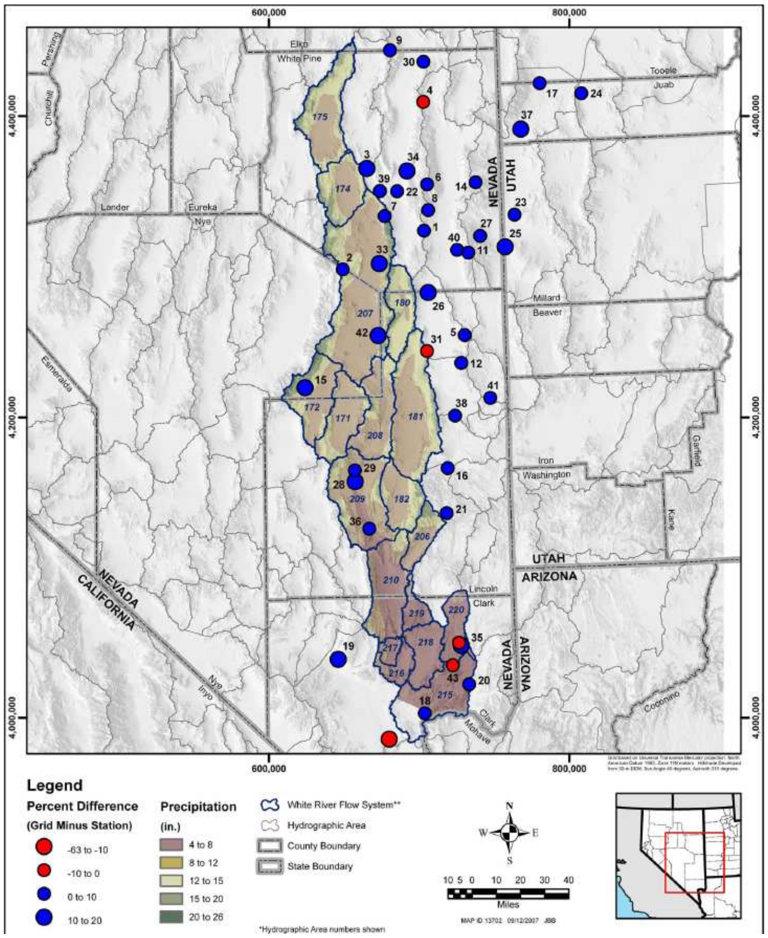

Figure 1: Snapshot of Figure 4-2 (SNWA 2007, Part A) comparing PRISM precipitation estimates with weather station data.

The only location where stations approximately balance each other out is in the south end near the Colorado River. The one station that PRISM underestimates average annual precipitation near Dry Lake Valley does not cancel the nine stations at the latitude of Dry Lake or Delamar Valleys which are overestimated. SNWA's comparison of PRISM with actual weather station data show that PRISM likely overestimates precipitation by up to ten percent, as indicated by Myers (2007).

The method of interpolating precipitation within the bands also overestimates precipitation. Using midpoint of the range as representative of the band overestimates the precipitation. A precipitation band is the area between two precipitation contours. SNWA describes this band as receiving average precipitation equal to the mid-point of the band, but this is wrong. There is more area within the band receiving less than the midpoint than there is in the band receiving more than the midpoint. This is because the perimeter of an area receiving less than the midpoint is larger than the perimeter of an area receiving more than the midpoint. This may be proven by considering the area of a frustum of a right circular cone (Figure 2). The lateral surface area may be described as:

$$A = \pi(a+b)\sqrt{h^2 + (b-a)^2}$$

or

$$A = \pi(a+b)l \qquad \textbf{(2)}$$

where A is area, a and b are the radii of the upper and lower circular surface, h is the vertical distance between the upper and lower circular surface and l is the distance along the surface between the upper and lower surfaces.

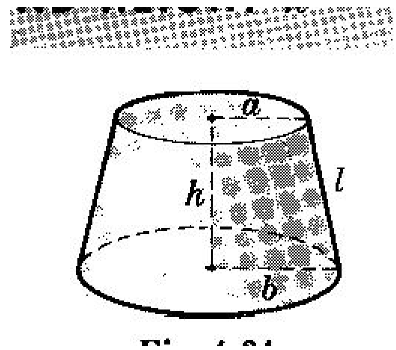

Figure 2: Diagram of a frustum of a right circular cone.

If the frustum is sliced in half horizontally in the middle so that each half is h/2 thick, the lateral area of the lower half will be larger than that of the upper half. The radius of the new surface vertically midway between the top and bottom is (a+b)/2, or the average of the two radii, and the difference in lateral area may be shown to be A_l-A_u as follows.

$$A_u = \pi(a + \frac{a+b}{2})\frac{l}{2} = \pi(\frac{3a+b}{2})\frac{l}{2} = l\pi\frac{3a+b}{4}$$

and

$$A_l = l\pi\frac{3b+a}{4}$$

The difference between A_l and A_u is:

$$A_l - A_u = l\pi\frac{3b+a}{4} - l\pi\frac{3a+b}{4} = l\pi\frac{3b+a-3a-b}{4} = \frac{l\pi}{4}(2b-2a) = \frac{l\pi}{2}(b-a) \qquad \textbf{(3)}$$

Because b is larger than a, the difference in area is a positive number. Therefore, the area corresponding with less than half of the midrange precipitation exceeds the area corresponding with more than half. Precipitation contours are not circular and the surface that could be constructed between the contours with a thickness equal to the difference in precipitation between the contours is not a perfect frustum, but the point remains the same. This is proof that using the midpoint of the range as the average overestimates the precipitation within the band; multiplying it with the recharge efficiency therefore overestimates the recharge estimate for that band.

PRISM therefore overestimates precipitation by up to ten percent. The details of this overestimate may be realized by considering the area of the portions of the target basins that actually have recharge; it is generally considered that recharge does not occur for precipitation falling on the playas of the valleys. Table 2 shows the PRISM estimates lead to the inaccurate result that a high percentage of these basins have recharge. That percentage also does not significantly decrease with latitude, as would be expected because Dry Lake and Delamar Valleys are progressively lower and drier than Cave Valley. Dry Lake Valley, with its large basin fill and playa area, actually has a higher percent of its area with recharge than does Cave Valley. Delamar Lake's percentage is a little lower, but still appears very high as it should to anyone who has been on the valley floor of Delamar Valley which makes up far more than 25.1 percent of the valley.

Table 2: Target basin area and recharge statistics.

Basin No.	Basin Name	Area, sq. miles	Area (ac.)	Area with Recharge (ac)	Percent of Basin Area with Recharge	Lowest Isohyet with Recharge (in)
180	Cave Valley	362	231680	184752	79.7	11.5
181	Dry Lake Valley	882	564480	472343	83.7	9.5
182	Delamar Valley	383	245120	183475	74.9	10.5

Basin area from State Engineer Perennial Yield Tables, area with recharge and lowest isohyet with recharge from SNWA Excel Solver SNWA-WRFS-Groundwater-Budget-Solution. An isohyet is a contour of constant precipitation.

A second problem shown on Table 2 is that the lowest isohyet with recharge is higher than 8.5 in/y. This is impossible unless 100 percent of the area has recharge, meaning that the entire area receives more than the threshold precipitation for recharge, 8 in/y, and there must be a band with 8.5 in/y. The fact that there is no 8.5 in/y isohyet demonstrates that the calculation of recharge is in error. In fact, Sheet B in SNWA's Excel solver spreadsheet does not show any precipitation zones less than those shown in Table 2 for the target valleys, but other areas in Sheet B, such as Pahranagat Valley, have precipitation zones less than 8 in/y. This further demonstrates an error in SNWA's calculations. Table 2 suggests that SNWA's precipitation estimates for Dry Lake and Delamar Valleys are significantly overestimated.

In summary, two aspects of SNWA's precipitation estimates have caused the precipitation estimates to be too high. They are the averaging method for precipitation bands and the precipitation estimates for Dry Lake and Delamar Valleys.

SNWA's Comparison With Eakin (1962 and 1963)

SNWA's recharge estimate for the target valleys, as discussed above and below, is much higher than had been estimated in the reconnaissance reports (Eakin 1962 and 1963). Apparently suggesting that Eakin had determined the area for the precipitation zones incorrectly or had used the wrong Hardman map, SNWA (2007) recalculated the recharge using modern GIS techniques. SNWA appears to insinuate that Eakin's (1962 and 1963) estimates would have been higher, and closer to SNWA's (2007) current estimates, if he had only completed the analysis correctly. But their reanalysis has many errors.

SNWA digitized the Hardman map and compared it to the elevation contours, assuming that Eakin had assumed that the precipitation zones corresponded to contours. The correspondence was that less than 6000 ft msl has precipitation less than 8 in/y, from 6000 to 7000 ft msl corresponds to from 8 to 12 in./y, from 7000 to 8000 ft msl corresponds to from 12 to 15 in/y, from 8000 to 9000 ft msl corresponds to from 15 to 20 in/y, and above 9000 ft msl corresponds to greater than 20 in/y. The corresponding recharge efficiencies are 0, 3, 7, 15 and 25%, respectively (Maxey and Eakin 1949)). Eakin would have based the precipitation zones on elevation because it would be impossible to read precipitation contours accurately from a statewide map. SNWA also indicates there may have been personal communication between Eakin and Hardman regarding these elevation/isohyet relations (SNWA 2007, Part A, page 5-15. SNWA's digitizing of the isohyets did not result in a good match of isohyets and topographic contours (SNWA 2007, Part A, Figure 5-6). The Hardman precipitation zones appear skewed to the west. For example, the highest precipitation zone on the Schell Creek range bounding the east side of Cave Valley is west of the crest and therefore could not coincide with the highest elevations. On the Egan Range, especially on the south end on the southwest boundary of Cave Valley, the precipitation zone shown, 15 – 20 in/y, lies west of the crest; there is a significant pink color for the 12 – 15 in/y zone on the crest. Similarly, there are three 15 – 20 in/y zones lying almost entirely inside Dry Lake Valley on the east side rather than straddling the crest with Lake Valley. Also similarly, there is a large area of 12 – 15 in/y precipitation lying in Delamar Valley when realistically it should straddle the crest with Meadow Valley Wash.

All of the Hardman maps I have seen are at a statewide scale which would be difficult to digitize accurately; the only information on it that could be used for geo-referencing is latitude/longitude spaced at one degree. Any digitizing from this map would be very inaccurate when compared to modern mapping and GIS methods. This shift of precipitation contours could easily have occurred due to digitizing from a statewide map[1]. This easily, and much more plausibly, explains why the precipitation and subsequent recharge estimates SNWA made using the Hardman map are so much higher than the original Eakin estimates. Therefore, SNWA's apparent attempt to use the Hardman map to explain their much higher precipitation estimates and justify their higher recharge estimates must be rejected.

Interbasin Flow

Cave Valley to White River Springs

SNWA's estimate of flow to the southern third of the White River Valley, 4000 af/y, is a gross underestimate. SNWA based their calculation on the spring flow in southern WRV minus the calculated recharge for the watershed contributing to that small area. The implicit assumption, implicit since SNWA did not specify the necessary assumptions, is that all of the flow from Cave Valley discharges to those springs. They

[1] A reasonable argument could be that higher precipitation is expected on the west side of the crests because of orographic effects. However, it is unlikely that Hardman had attempted to show these nuances on a statewide map, especially if SNWA is correct that Hardman directed Eakin to use elevation contours.

completely ignore the amount of interbasin flow from Cave Valley that contributes to GW ET discharge in the southern end of the valley as discussed by Myers (2007).

SNWA calculated the transmissivity for a 4000 af/y flow from Cave Valley to White River Valley as 81,451 ft^2/d to justify its flow estimate. It was based on a gradient of 0.00111 for the water-level elevation between Monitor Well 180W501M in Cave Valley and Butterfield Spring. The water level in the monitoring wells was 5406 but this monitoring well may not represent adequately the carbonate water level. From SNWA's report on the hydrogeology of Cave Valley:

> In the northern sub-basin, a well constructed by SNWA and completed in carbonate rocks to a depth of 1,212 ft-bgs, has a depth-to-water of about 1,051 ft-bgs and water-level elevation of about 5,406 ft-amsl (Figure 3-1). **Groundwater production from this well was very limited** during air-lift development and subsequent pumping to purge the well before water-chemistry sampling, suggesting that **the hydraulic connection between the well and the regional carbonate aquifer is also very limited**. The water-level elevation most likely represents the hydraulic head of the nearby Shingle Pass Fault through which a small amount of inter-basin flow from Cave Valley to White River Valley is presumed to occur (Appendix D of Part A). This well is about 80 ft higher than the elevation of nearby local springs in adjacent White River Valley. (SNWA 2007, Part B, page 3-4, emphases added)

This statement indicates that the well SNWA used to calculate the gradient through Shingle Pass is not well connected to the regional carbonate aquifer. The statement about the water level in that well representing the hydraulic head of the fault is simply wrong if the well is not connected to the regional aquifer. The well cannot represent interbasin flow to a regional spring if it is not part of the regional carbonate aquifer.

SNWA provides additional evidence that this well is not representative. Figure D.2-2 (SNWA 2007, Part 1, page D-8) shows four carbonate wells completed in the south half of Cave Valley, although three are very close together and have effectively the same water level. The water levels range from 5781 to 5849 ft msl, or several hundred feet above the level reported in north Cave Valley. Considering the general regional flow from higher elevations in the Schell Creek Range and Steptoe Valley southwest to White River Valley, the carbonate level in north Cave Valley should be a little higher than in south Cave Valley, contour maps completed by SNWA notwithstanding.

Because well 180W501M does not accurately represent flow through Shingle Pass well, the calculations for transmissivity for flow through the pass performed by SNWA (2007, Part 1, page D-7) may also not be representative of the actual flow. If the well is not representative, the gradient may be much higher. For example, the water level in Cave Spring, which discharges from the carbonate aquifer (Myers 2007), is 6496 ft msl (Welch and Bright 2007). This spring is on the east side of the valley, but it is very unlikely that the water level in the carbonate just several miles to the west is only 5400 ft msl.

Considering that the 80-foot drop claimed by SNWA through Shingle Pass causes a very flat gradient, an increase of just a few hundred feet in Cave Valley would be a substantial increase in gradient. If the drop is actually 240 feet, which would correspond with a water level almost 760 feet less than that observed in Cave Spring, the gradient would be five times greater than simulated and 12,000 af/y could pass with the transmissivity calculated by SNWA.

The north half of Cave Valley has more recharge than the south half as shown in SNWA Figure 5-2 (SNWA 2007, Part 1). The block that separates the north from the south, and causes the substantial drop in the valley floor, contains Mississippian Chainman Shale (SNWA 2007, Part 1, page 2-1) which is an impedance to flow (Figure 3 and Myers (2007, Figure 2)). The 1000-foot topographic north-south drop through the profile of Cave Valley is testament to the block's resilience. The flow barrier across the center of the valley would prevent most of the flow originating in the north half from reaching the south half. The only discharge point other than the GW ET discharge noted by Myers (2007) and SNWA (2007) must be Shingle Pass (Figures 3 and 4).

SNWA (2007) also suggests there is interbasin flow from Cave Valley to Pahroc Valley and that the amount is the difference of the residual between recharge and discharge and the 4000 af/y interbasin flow to WRV. Based on the geology at the south end of Cave Valley and the gradient between Cave and Pahroc Valley, such flow is possible. However, the amount is much likely less than estimated by SNWA (2007, Part 1, page D-11) because it is the discharge point for interbasin flow from the south half of Cave Valley which has less recharge and no hydraulic connection with the north half (Figure 3). However, because it would still end up in Pahranagat Valley where all available groundwater is fully appropriated, there is little difference in water availability whether flow from Cave Valley enters Pahroc Valley or the south end of White River Valley as assumed by Myers (2007). If it enters Pahroc Valley, it changes Myers' (2007) analysis only slightly. More flow from other sources in White River Valley would accommodate the existing water rights in the southern part of the WRV. The decrease in discharge from WRV would be the same and the inflow to Pahranagat Valley would also be the same (using Myers' (2007) recharge and discharge estimates).

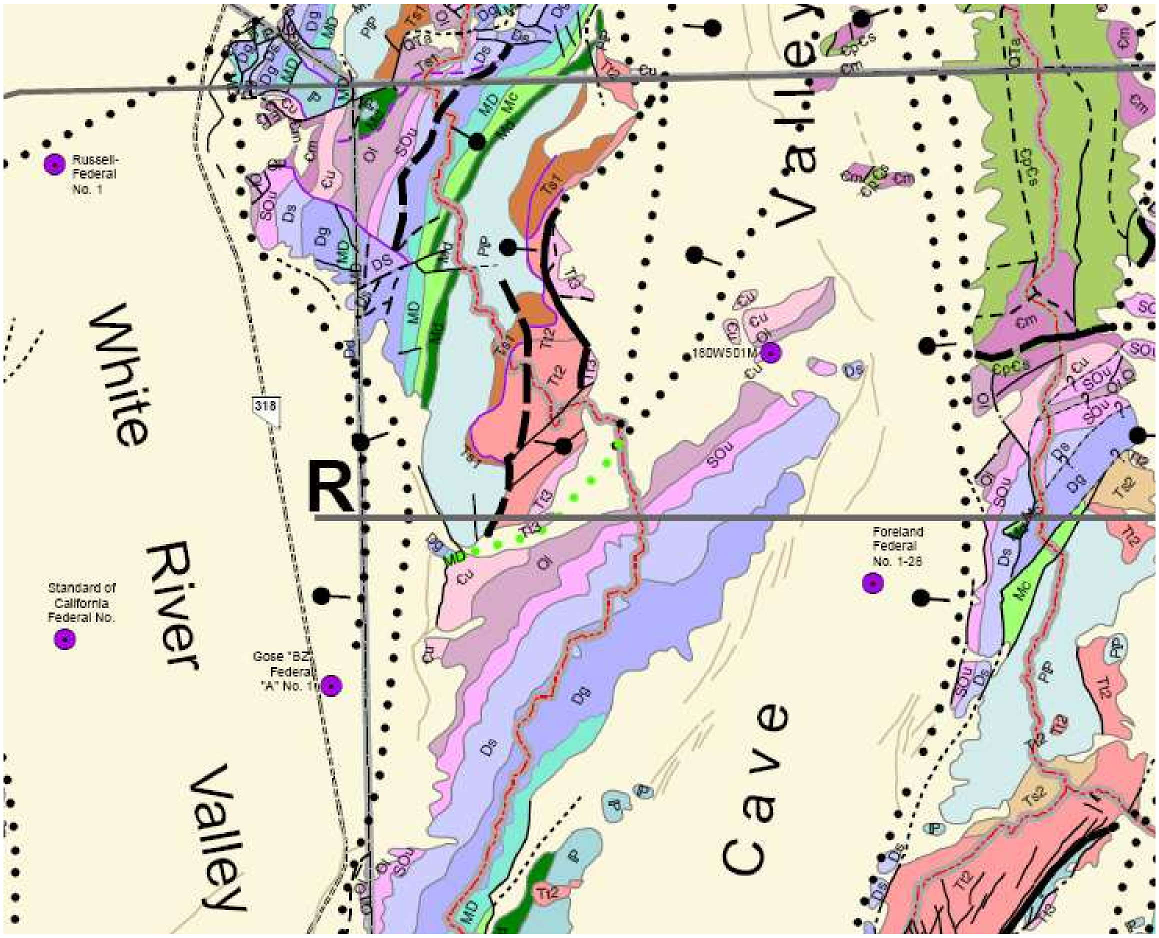

Figure 3: Snapshot of geology for Cave Valley near Shingle Pass from SNWA (2007) Plate 1. The figure shows the faults and distribution of volcanic and sedimentary rock, including carbonate rock as shown in Myers (2007) Figure 2. €u is Lower Ordovician and upper Cambrian limestone and shale, Ol is quartzite, SOu is dolomite, Tt3 and Tt2 are tuff, Dg are Upper and Middle Guilmite Formation.

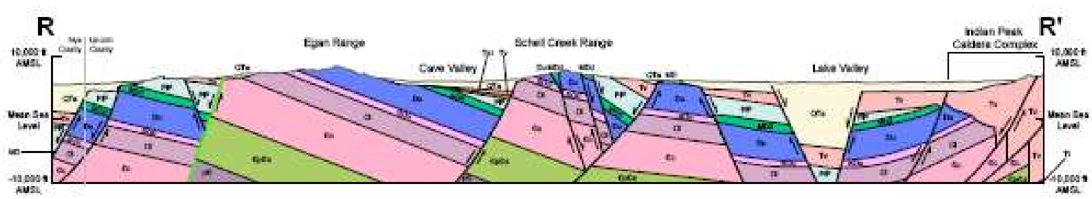

Figure 4: Snapshot of cross-section RR' from SNWA (2007) Plate 1. The figure shows the thickness of carbonate rock forming the base of the Egan Range in the vicinity of Shingle Pass.

Pahroc to Dry Lake Valley

SNWA estimates without citation that there is 2000 af/y of flow from Pahroc to Dry Lake Valley (SNWA 2007, pages D-11 and -13). The reasoning provided is based on assumed water levels. However, the recharge which would occur on Silver King Mountain, the south end of the Schell Creek Range which divides Pahroc Valley from Muleshoe Valley, would form a groundwater divide preventing flow to the north end of the Dry Lake Valley hydrographic basin. The facts do not support SNWA's supposition of interbasin flow to Dry Lake Valley.

Delamar to Dry Lake Valley

SNWA indicates the entire recharge in Dry Lake Valley is interbasin flow to Delamar Valley. This is correct, although the amounts calculated by SNWA are too high because of the recharge estimates.

Delamar to Pahranagat or to Coyote Spring

SNWA argues that groundwater flow is from Delamar to Coyote Spring Valley, but their argument does not make sense and it disagrees with previous work such as Brothers et al (1996).

The elevation in the southern, lower elevation, part of Delamar Valley is about 4500 ft msl while in Pahranagat Valley the elevation at the south end of the valley is about 3300 ft msl. Depths to water in Delamar Valley, at least for the regional water table, are large – as much as 800 feet (Eakin 1963). The connection between the areas would be along the faults of the Pahranagat Shear Zone (Figure 5). Surface elevations in Coyote Spring Valley range from 3200 ft msl at the north near the boundary with Pahranagat Valley to 2600 ft msl near the intersection with Kane Springs Valley. The depth to water in Coyote Spring Valley would probably cause there to be a steeper gradient between Delamar and Coyote Spring Valley. The connection would be across the Pahranagat Shear Zone (Figure 5).

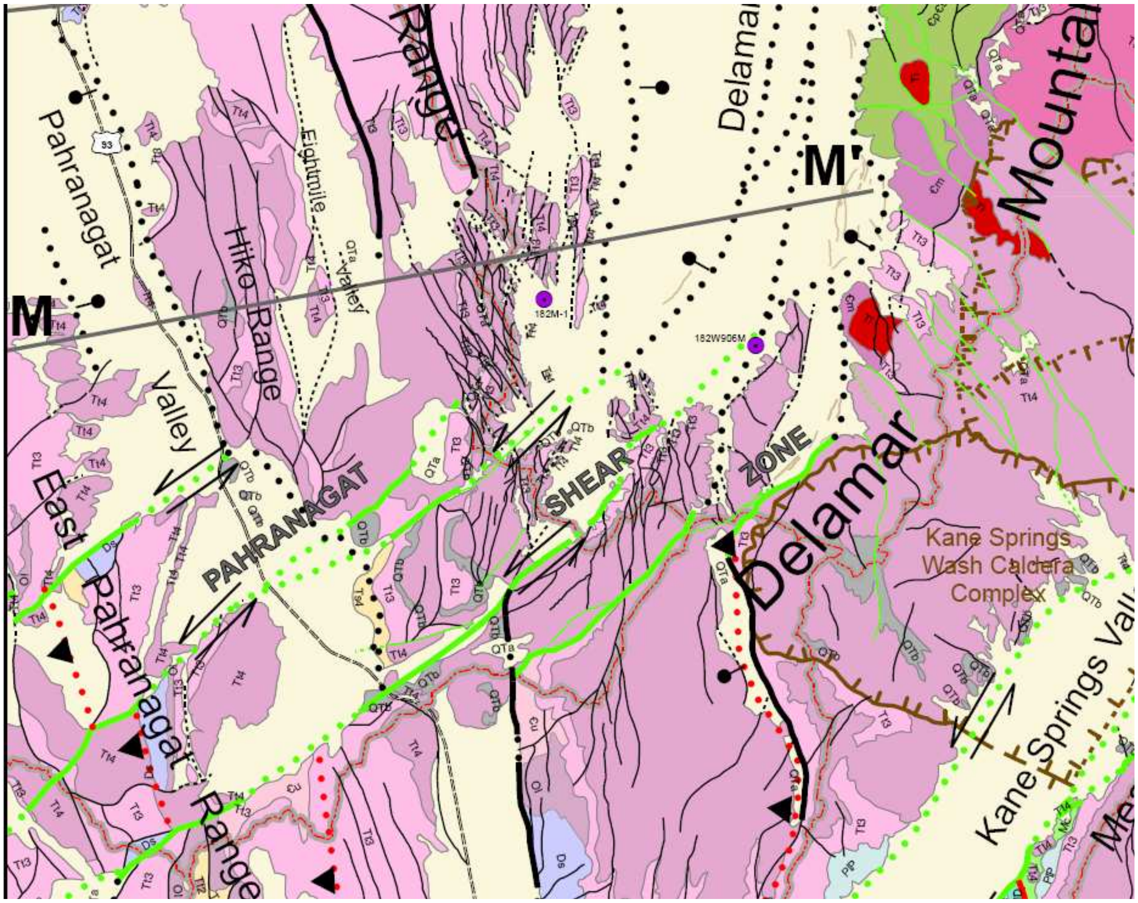

Figure 5: Snapshot of section of SNWA (2007) Plate 1 showing the south end of Delamar and Pahranagat Valleys and the north end of Coyote Spring Valley.

SNWA ruled out flow to Pahranagat Valley from Delamar Valley due to range front faults.

> Groundwater flows from Dry Lake to Delamar Valley where flow is controlled by the Caliente and Kane Springs Wash caldera complexes to the east, and the South Pahroc Range and associated range-front faults to the west. The geologic framework in this area **precludes flow** to Pahranagat Valley to the west and Lake and Patterson Valleys to the east. (SNWA 2007, page ES-13, emphasis added)

In other locations, SNWA claims that the range front faults promote flow, such as along the east side of Cave Valley (SNWA 2007, Part B, pg 3-4). SNWA cannot have it both ways.

The Pahranagat shear zone bounds the south end of both Delamar and Pahranagat Valleys. Several faults trending northeast along the shear zone, shown in green in Figure 5, borrowed from SNWA (2007), apparently connect the valleys. The Pahranagat Shear Zone does not include the range front faults that SNWA claims would prevent the flow to the south end of Pahranagat Valley (Figure 5). In order for flow to occur from Delamar to Coyote Spring Valley, it would need to cross transversely the faults in the shear zone.

It is far more likely that the faults in the southwest Delamar Valley are a conduit for groundwater flow from Delamar to Pahranagat Valley.

Interbasin Flow to Colorado River (Lake Mead)

SNWA estimated that flow from the WRFS to the Colorado River is “less than 25,000 af/y” (SNWA 2007, Part A, page D-19). This estimate is critical for SNWA’s optimization program and recharge estimate discussed above. Although SNWA set the **upper limit** for this discharge equal to 25,000 af/y in the excel recharge optimization program, the final estimate was 25,000 af/y. The new recharge values were based on this upper limit.

SNWA’s estimate is high compared to other studies (Harrill and Prudic 1998). Harrill and Prudic (1998, page 46) estimated much lower discharge to the Colorado River – 7000 af/y split between the Virgin River (5000 af/y) and Lake Mead (2000 af/y). This occurred through a zone of high transmissivity in the bottom layer of the Prudic et al’ (1995) groundwater model. Rush (1968) estimated the groundwater flow along Lower Moapa Valley to equal 1100 af/y.

LVVWD (2001), in a very confusing description of the flow regime, estimated a 36,000 af/y discharge to the Colorado River across two faults. “Even though these fault structures act as barriers to ground-water flow, permeabilities across the fault zone are sufficient to allow a flow of about 36,000 af/y to leave the area” (LVVWD 2001, page 4-21). This is a huge flow to occur across a fault barrier with a flat gradient. LVVWD does not provide calculations for this flow.

SNWA’s 25,000 af/y estimate was the sum of groundwater flow equal to 16,000 af/y flowing along the Lower Moapa Valley through the cross-section outlined on Figure D.3-2 (SNWA 2007, Part 1), 7000 af/y groundwater discharge calculated as part of the flow at the Muddy River near St. Thomas gage, and 2000 af/y through the Black Mountains area. There are problems with summing these three flow estimates and calling the sum the total discharge from the WRFS.

First, some of the flow must be double-counted. Based on measured flow at the St. Thomas gage between 1913 and 1916, SNWA estimated “[f]or this analysis, it is estimated that about half of the flow was groundwater discharge, or 7,000 afy” (SNWA 2007, Part A, page D-21). The total flow was the mean annual flow for 1914 (*Id.*), the only year with a complete record. This gaging station is less than five miles directly downstream on the Muddy River from the cross-section used to calculate groundwater flow along the Muddy River in the Lower Moapa Valley (Figure 6). The 7000 af/y must be part of the 16,000 af/y flow estimated at the cross-section.

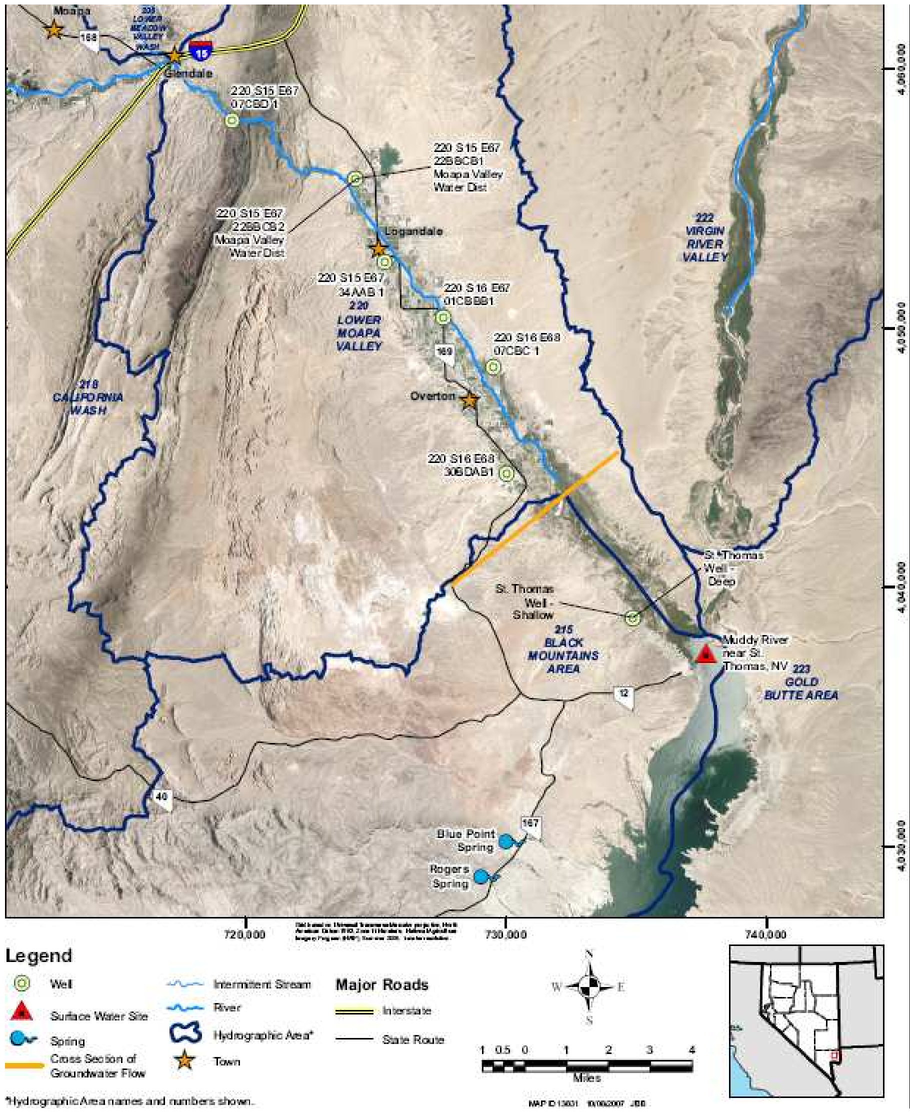

Figure 6: Snapshot of SNWA (2007, Part A) Figure D.3-2.

Second, SNWA describes the 7000 af/y in such a way as to presume it to be underflow along the river (SNWA 2007, Part A, page D-21). The estimate is half of the flow at the St. Thomas gage which SNWA expected to become groundwater flow before it reached the confluence with the Virgin River. Surface water flow on the Muddy River primarily originates as flow from the Muddy River Springs, therefore the flow has already been counted as discharge from the WRFS.

Third, the cross-section used for the 16,000 af/y component of the estimate is 26,500 feet wide. Using a transmissivity of 17,000 ft^2/d (SNWA 2007, Part A, page D-22) and an average gradient based on various wells next to the river of 0.00432 (SNWA 2007, Part A, page D-23), the flow estimate was 16,000 af/y (*Id.*). This estimate is too high because the cross-section is much longer than would be representative of the actual hydrologic properties and the transmissivity is too high. Considering the geologic map in Figure 7, the cross-section would span the Ts5 and Qa geologic formation just upstream from where the Muddy River enters Lake Mead. Because the wells were near the river, it is not appropriate to treat the Ts5 material as having the same transmissivity. Page et al (2005) describe Ts5 as sedimentary rocks, unit 5.

> The primary unit is the Muddy Creek Formation (11 to 5 Ma). Muddy Creek Formation is soft to moderately consolidated, tan, gray, and pink, fluvial and lacustrine, tuffaceous sandstone, mudstone, gypsum, halite, and conglomerate that fills fault-block basins. Other named and unnamed units of the same general age fill many other basins … The unit also includes age-equivalent basin-fill deposits in the Lake Mead area consisting of conglomerate, sandstone, siltstone, mudstone, limestone, and gypsum. Maximum thickness at least 1,000 m, but may be 3,000 m or more in deeper basins. (Page et al 2005, pages 11, 12).

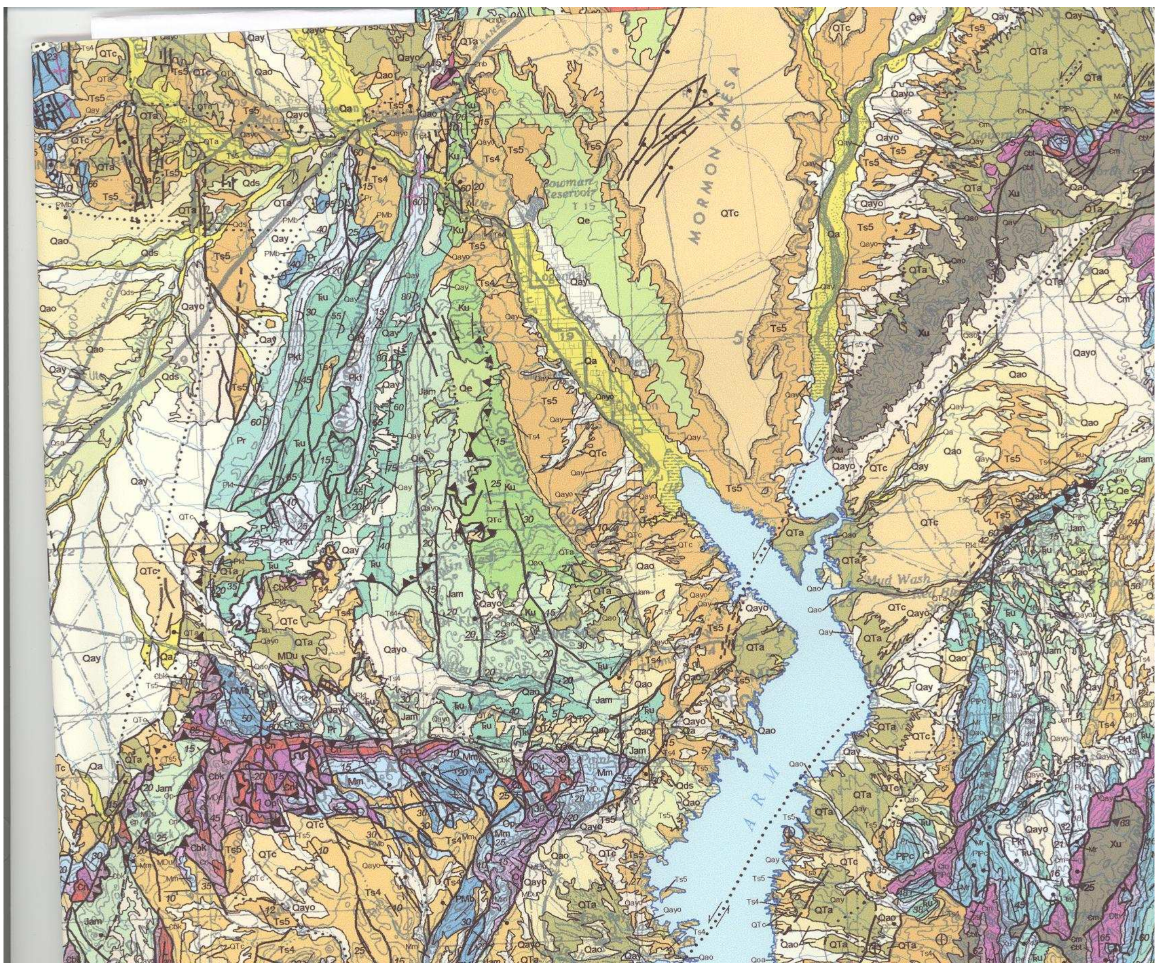

Figure 7: Scan of portion of geologic map from Page et al (2005).

The description by Page et al (2005) does not suggest a highly conductive zone that can be treated as homogeneous across a 26,500 foot wide cross-section. And the transmissivity used for the calculation is probably much too high because it is based on very shallow wells next to the river.

For the determination of transmissivity, SNWA uses the average of transmissivity estimates from two Moapa Valley Water District wells near Logandale, but the discussion is quite confusing.

> Groundwater outflow via the subsurface from Lower Moapa Valley to the Colorado River has the greatest uncertainty of the outflow components due to the lack of hydraulic information related to the basin-fill aquifer(s) underlying the valley floor. Rush (1968) estimated an outflow of 1,100 afy from the alluvial basin but did not report an estimate for the consolidated rocks. Specific capacity data for wells within the valley indicate that the underlying materials are transmissive. Moapa Valley Water District (MVWD) constructed a production well (Well No. 1) completed in bedrock (sandy limestone) to 154 ft-bgs near Logandale, Nevada. This well had a specific capacity of 105 gpm/ft (Rush, 1968, Table 19). A second MVWD well (Well No. 2) was constructed and completed in bedrock (porous limestone) to a depth of 154 ft-bgs and had a specific capacity of 24 gpm/ft (Figure D.3-2). An estimate of groundwater outflow to the Colorado River was derived using Equation D.2-1. (SNWA 2007, Part A, page D-21)

SNWA mentions the greatest uncertainty is due to the lack of data on the basin-fill aquifer, but then determines a transmissivity for two wells completed in bedrock. As explained in the next paragraph, the transmissivity estimates are suspect and likely too high to yield a correct flow rate through the entire cross section.

These transmissivity estimates may be high for use in considering the entire cross-section. The wells are very near the Muddy River and there is a good possibility that the presence of that river may have provided more water and allowed less drawdown. SNWA (2007) cites Rush (1968, Table 19) data for these two wells. However, the table shows specific capacity and drawdown supposedly based on the well logs, but the actual well logs do not provide this information[2]. Rush (1968, Table 19) indicates that log 9714 (it was actually 9719, see footnote 2) shows the principle aquifer is from 152-154 ft bgs and that log 9716 shows the principle aquifer is from 60-154 ft bgs. The logs, attached in Appendix 1, both show the aquifer is from 60-154 ft bgs. In fact, except for the fact that the well recorded in log 9719 was stopped at 154 ft bgs and the log contains a slight difference in the description of the rock at that depth, there appears to be no difference in the wells; even the static water level is the same at 22 ft bgs. Neither indicates the perforations. It is unlikely that the large difference in specific capacity indicated by Rush (1968) is correct and therefore, the estimate of transmissivity by SNWA for flow from Lower Moapa Valley is likely wrong.

SNWA used a well near St. Thomas as one of the wells to estimate gradient. They indicated that an 805-foot deep well had first encountered water at 30-ft-bgs but that this source was cased off for further drilling. The final depth-to-water was 284 ft bgs. For their gradient analysis, SNWA used the average depth to water including the

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[2] Rush (1968, Table 19) indicates these wells are logs 9714 and 9716, however, log 9714 in the NV State Engineer database is not for this well. Rather it appears that Rush meant to refer to log 9719.

final level and the first depth to water observation (SNWA 2007, Part A, page D-23). However, their analysis misinterprets reality in that the multiple levels represent a vertical gradient and suggest that the shallow water level observation could be perched. Rush (1968) does not indicate whether the entire formation below the first water encounter was saturated. Either way, it indicates that SNWA's assumption concerning the saturated thickness for flow through the Lower Moapa Valley prior to the filling of Lake Mead may be too high.

Interbasin Flow in the Optimization Mass Balance

SNWA's flow balance calculations completed as part of the optimization program (Excel file SNWA-BARCASS-WRFS-Groundwater-Budget-Solution) mixes surface and groundwater in such a way as to count it twice. The section Muddy River Springs Area shows 41803 af/y interbasin inflow and 35,857 interbasin outflow; there is 5989 af/y discharge. In reality, there is about 37,000 af/y of discharge from the Muddy River Springs. It is not all consumptively used but it becomes Muddy River surface flow. SNWA shows it discharging to California Wash where it combines with interbasin flow from Garnet and Lower Meadow Valley Wash to become 51,706 af/y interbasin flow mostly to Lower Moapa Valley (also a small amount to Black Mountain Area). In Lower Moapa Valley, SNWA shows there is 25,311 af/y of GW ET discharge, leaving 24,432 af/y to discharge to Lake Mead (in combination with 568 af/y from Black Mountain Area). The total discharge to Lake Mead is calculated to be 25,000 af/y, which equals SNWA's estimates above for what they characterize as three different groundwater pathways to Lake Mead.

Consideration of the details of SNWA's flow balance shows just how wrong their analysis is. The interbasin flow calculations result in 24,432 af/y leaving Lower Moapa. But a major part of the interbasin flow leaving Muddy River Springs Area is surface water; that includes the interbasin flow into Lower Moapa. Most of the flow is surface water, but SNWA has treated it as groundwater.

SNWA's groundwater balance for the lower part of the WRFS is completely wrong because it includes surface water. SNWA's estimate of groundwater flow to Lake Mead is much too high because it double-counts groundwater in its inflow estimate and does not distinguish between groundwater and surface water in its groundwater balance. The estimate of 25,000 af/y is based mostly on supposition and little data. Because of the constraints this required flow to Lake Mead puts on the optimization program, recharge in the WRFS is much too high which leads to recharge efficiencies which are also too high.

It also is important to recognize that the Muddy River surface water flows are completely appropriated (Myers 2007). It was difficult to decipher what SNWA did in its optimization and mass balance program, but it is clear that it utilized Muddy River surface water as part of the inflow to Lake Mead that it depends on for flows in the WRFS.

Effects Analysis

SNWA's Theis analysis violated all of the assumptions required for that type of analysis to be accurate. SNWA's list of those assumptions is complete (SNWA 2007, Part C, page 3-8). Myers (2007) also listed most of those assumptions as reasons not to complete such an analysis.

The biggest problem with the Theis analysis is that it is limited to only the target valleys. SNWA assumed the east/west boundaries are impervious and used an image well analysis to simulate the additional drawdown within the target valleys. The reality is that there is significant drawdown, even as calculated with SNWA's Theis analysis, at the boundaries. In Cave Valley and southern Delamar Valley, interbasin flow to downgradient valleys occurs. The drawdown will propagate through those fractured bedrock zones to the downgradient valleys. Myers (2007), using the groundwater model of Prudic et al (1995), found that drawdown propagating through the Egan Range will quickly affect springs in White River Valley. The effect also occurred to springs in Pahranagat Valley and Muddy River Springs. SNWA's method of analysis was designed to not consider these impacts.

Putting SNWA's other problematic assumptions to the side, SNWA's analysis still would result in a low estimate of the drawdown because it assumes no connection between basin fill and carbonate aquifers. Pumping the carbonate aquifer, especially with the transmissivity being as much lower than that of the basin fill aquifer as shown on Table 3-3 (SNWA 2007, Part C, page 3-13), would cause significant drawdowns and establish a gradient across the connection between the carbonate and basin fill aquifers. This would likely draw groundwater downward from the basin fill. SNWA's analysis completely ignores this probable effect. Bredehoeft (2007) discusses more details of the Theis analysis.

SNWA (2007) did not consider the effects of appropriating groundwater on downgradient basins, such as White River Valley, Pahranagat or Coyote Spring, or the effect on spring flows which are fully appropriated and a valuable environmental resources (Myers 2007, Mayer 2007). In fact, there is no discussion at all in SNWA (2007) concerning the full amount of appropriations within the WRFS.

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well #2

WELL LOG AND REPORT TO THE STATE ENGINEER OF NEVADA

Log No. 9716
Rec. Oct 6 1967
Well No.
Permit No. 23873
Do not fill in. CARD 24008

PLEASE COMPLETE THIS FORM IN ITS ENTIRETY

Owner: Moapa Valley Water Co. Driller: D. E. Sides
Address: Logan Dale Nev Address: Alamo Nev Lic. No. 458
Location of well: NW 1/4 NW 1/4 Sec 22, T 15 N/S, R 67 E, in Clark County
or 827' EAST, 860.9' FROM N.W. CORNER - SEC. 22 T.15 S. E.M.D.B&M
Water will be used for: City & Irrig. Total depth of well: 163
Size of drilled hole: 24 in to 54 ft - 16 in to 162 Weight of casing per linear foot: 43 lb
Thickness of casing: 1/4 or .250 Temp. of water: 68
Diameter and length of casing: 16 I.D.
(Casing 12" in diameter and under give inside diameter; casing 12" in diameter give outside diameter.)
If flowing well give flow in c.f.s. or g.p.m. and pressure
If nonflowing well give depth of standing water from surface: 22 ft
If flowing well describe control works
(Type and size of valve, etc.)
Date of commencement of well: May - 11 - 67 Date of completion of well: May - 28 - 67
Type of well rig: 1936 Fort Worth Spudder Cable tool

LOG OF FORMATIONS

From feet	To feet	Thickness feet	Type of material
0	27	27	Small Boulders & top Soil
27	48	21	Silt Sand fine Gravel
48	57	9	Soft lime Rock
57	70	13	hard Rock
70	89	19	Porous lime) water
89	94	5	Sand Rock
94	120	26	white lime Stone Porous
120	134	14	Course Gravel Strong water
134	154	20	Rock with hard Streaks
154	160	6	Course Gravel water
160	163	3	Showing Red & Blue Clay
			Stop Drilling

Water-bearing Formation, Casing Perforations, etc.

Chief aquifer (water-bearing formation) from 60 to 154 ft.
Other aquifers
First water at 60 feet.
Casing perforated from none ft.
Size of perforations: none

(OVER)

919

LOG OF FORMATIONS—Continued

From feet	To feet	Thickness	Type of material

CASING RECORD

Diam. casing	From feet	To feet	Length	REMARKS—Seals, Grouting, etc.
				Set 24 in Casing to 52 ft Drill to 162. ft Set 67 ft of 16 in Casing, Cemented with 14 yrds Ready mix

GENERAL INFORMATION—Pumping Test, Quality of Water, etc.

WELL DRILLER'S STATEMENT

This well was drilled under my jurisdiction and the above information is true to my best information and belief.

Signed: D. E. Sides
Well Driller

By

License No. 458

Dated 5-31-, 1967

(Not to be filled in by Driller)

well # 1

WELL LOG AND REPORT TO THE STATE ENGINEER OF NEVADA

Log No. 9719
Rec. Oct 6 1967
Well No.
Permit No. 23872
Do not fill in. 240.08

PLEASE COMPLETE THIS FORM IN ITS ENTIRETY

Owner: Moapa Valley Water Co. Driller: D.E.SIDES
Address: Logan Dale Nev. Address: ALAMO NEV Lic. No. 458
Location of well: NW ¼ NW ¼ Sec. 22, T. 15 N/S, R. 67 E, in Clark County
or 0° 27' East, 860.9' From NW Corner sec 22 T.15s R.27 E.M.D.B& M
Water will be used for: CITY & IRRIG PURPOSE Total depth of well: 154 ft
Size of drilled hole: 24in to 60ft 16 154 ft Weight of casing per linear foot: 42 lb
Thickness of casing: ¼ or 250 Temp. of water: 68° Degree
Diameter and length of casing: 16 I.D. (Casing 12" in diameter and under give inside diameter; casing 12" in diameter give outside diameter.)
If flowing well give flow in c.f.s. or g.p.m. and pressure:
If nonflowing well give depth of standing water from surface: 22 ft
If flowing well describe control works: (Type and size of valve, etc.)
Date of commencement of well: 4-10-67 Date of completion of well: 4-24-67
Type of well rig: 1936 Model Fort Worth Spudder Cable tool

LOG OF FORMATIONS

From feet	To feet	Thickness feet	Type of material
0	27	27	Small Boulders & top Soil
27	48	21	Silt Sand fine Gravel
48	57	9	Soft lime Rock
57	70	13	Very hard Rock
70	89	19	Porous lime Stone water
89	94	5	Sand Rock
94	120	26	white lime Stone Porous
120	134	14	Coarse Gravel Strong water
134	150	16	Very hard Rock
150	154	4	Cravice) tools fell In wedge, Stop Drilling

Water-bearing Formation, Casing Perforations, etc.

Chief aquifer (water-bearing formation) from 60 to 154 ft.
Other aquifers:
First water at 60 feet.
Casing perforated: from 0 to 80 ft.
Size of perforations: none

(OVER)

919

LOG OF FORMATIONS—Continued

From feet	To feet	Thickness	Type of material

CASING RECORD

Diam. casing	From feet	To feet	Length	REMARKS—Seals, Grouting, etc.
				Drilled 24 In hole to 54 ft then Drilled 16 In hole to 154 ft Set 70 ft 16 In Casing used 14 yds Cement to Stop all Contomnation & top water

GENERAL INFORMATION—Pumping Test, Quality of Water, etc.

WELL DRILLER'S STATEMENT

This well was drilled under my jurisdiction and the above information is true to my best information and belief.

Signed: D.E. Sides, Well Driller
By:
License No. 458
Dated: 4-24-, 1967

(Not to be filled in by Driller)