Review of Evidence Provided by the Southern Nevada Water Authority And Minor Modification to Groundwater Model

White Pine and Lincoln County, Nevada

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Table of Contents

List of Figures

Executive Summary

The Southern Nevada Water Authority (SNWA) proposes to develop 91,200 af/y of groundwater in Spring Valley of eastern Nevada. This report is a reply to the evidence submitted by SNWA in support of its application and an update to the groundwater model previously submitted on behalf of protestants.

SNWA claims that perennial yield exceeds 100,000 af/y. However, SNWA's ET discharge estimate, 90,000 af/y, is too high because it is based on measurements made during the wettest decade in 100 years. The more appropriate ET discharge value is 71,000 af/y. SNWA also estimates 87,000 af/y of mountain block recharge and over 11,000 af/y of streamflow recharge. This contradicts another of their submitted studies, the groundwater model report, that uses 65,000 af/y of mountain block and simulates just over 18,000 af/y of streamflow recharge. Either this value or 75,000 af/y of both mountain block and alluvial fan recharge is more appropriate for Spring Valley.

SNWA's attempt to increase the perennial yield by inducing recharge from stream beds is dubious because it provides no plan to do so or proof that it could occur. Modeling completed as part of this report shows that many centuries are required before sufficient water can be induced to recharge to cause the system to come into steady state, a requirement for the development of a perennial yield. Also, most of the perennial streams begin to lose substantial amounts of water at the mountain front where they begin to flow across alluvial fans, therefore it seems unlikely that the groundwater connection with the streams is sufficient to induce substantial recharge.

Therefore, the best estimate of perennial yield for Spring Valley remains the 70,000 af/y estimated by Myers (2006). However, because developing PY requires taking discharge from wetlands and springs, the actual development of any portion of that PY will result in rapid changes in the ET discharge from the valley which means that phreatophytes and springs will dry.

SNWA argues only about 7000 af/y of underground water rights are actually committed. It claims the duty is much less than 4.0 ft/y and that, even if 4.0 feet is applied, only 2.5 feet is consumptively used. It claims the entire remaining amount is irrigation secondary recharge which can be salvaged. This ignores the actual conditions that limit the possibility of salvaging it. SNWA also claims that 4.0 feet is a maximum amount of water applied and may change from year-to-year. That is possible but years in which less is applied are likely years that it is not available. SNWA presents no data to support its contention that water rights with a 4.0 foot duty may actually pump less water. SNWA assumes also that of the 4.0 foot duty, only 2.5 feet is consumptively used, even though it cites other reports indicating much more would be consumptively used. Finally, SNWA bases its contention of using 2.5 feet of consumptive use on three state engineer rulings which are not comparable to the situation in Spring Valley because each involved a change in point of diversion, change in point of use, a change in the manner of beneficial use or a combination of the three.

SNWA also incorrectly claims that most of the groundwater rights are supplemental to either other groundwater rights or to surface water rights. Myers (2006) accounted for supplemental rights when he indicated that 18574.9 af/y of underground rights exist in Spring Valley. SNWA provides no source or citation nor any analysis for the statement that surface water is the primary source and that groundwater is supplementary. While it may be assumed that, due to pumping costs, the irrigator will use surface water when available, SNWA provides no information regarding the breakdown of usage between the surface and connected groundwater right. It must be assumed that the groundwater right will continue to be used when the surface water is unavailable and that that water cannot be appropriated by SNWA.

There are 46,035 af/y of certificated and permitted and 55,434 af/y of vested stream flow rights. Considering just the certificated and permitted streamflow rights and assuming that these rights are used all season, from April to September, for a six month irrigation season, and assuming that most stream flow from July through September is baseflow, half of the surface water rights, or 23,018 af/y, depend on groundwater. Also, by definition, spring discharge is a discharge of groundwater, therefore the 3779 af/y of certificated and permitted spring flow rights also depend on groundwater. It follows that all surface water rights either dependent on spring flow or stream baseflow depend on groundwater and is water not available for appropriation as a part of the valley's perennial yield. Based on this, at least 68,388 af/y of groundwater is already appropriated.

River boundaries were added to the original transient groundwater model used to predict the drawdown caused by SNWA's pumping proposal. The system reached steady state after approximately 22,000 years. After 2000 years, stream inflow had only reached 85 percent of the difference between pumpage and specified recharge, therefore the pumpage continued to remove water from storage. Flow from streams does not quickly match the excess of pumpage over recharge because they lie far from the wells.

Over the more than 22,000 years that elapses before steady state establishes, SNWA removes almost 118,000,000 af of transitional storage from the groundwater reservoir. Transitional storage is the quantity of water in storage in a particular ground water reservoir that is extracted during the transition period between natural equilibrium conditions and new equilibrium conditions under the perennial-yield concept of ground water development. SNWA's water rights applications remove more than two and a half times that much groundwater from storage in just one of the valleys before reaching equilibrium.

Drawdown occurring during the first 100 years of SNWA pumping is very similar to that predicted previously because the induced recharge from the streams reached only about 30 percent of the difference between recharge and pumpage. This indicates that the pumping plan has not induced sufficient recharge to substantially increase the perennial yield. Because other natural discharges continue, at the end of 100 years, approximately 56,600 af/y of groundwater continues to be removed from storage. Allowing stream recharge decreased the amount of water removed from storage within 100 years by just a few percent. Induced stream recharge accounts for most of the difference.

Stream recharge speeds recovery by adding an additional source of water, but even after 215 years of recovery, the stream recharge rate is substantial. Recovery requires a long time because the deficit concentrates near the pumping but the recharge from both mountain block and streams occurs a long distance from the pumping.

These recovery results continue to show that even with induced stream recharge, recovery at some points requires longer than it took to create the deficit. Monitoring and mitigation plans may therefore be insufficient to protect the spring and wetland resources of the valley; once drawdown caused by large-scale pumping begins to affect the springs, a long time period may pass before stopping the pumping will improve conditions. The same may be said for monitoring protecting interbasin flow. After 100 years, the flow to Hamlin Valley reduced by only 20 percent. A monitoring well at this point could identify the associated drawdown and trigger a cessation in pumping but it would take decades to have a significant mitigation effect.

Introduction

The Southern Nevada Water Authority (SNWA) proposes to develop 91,200 af/y of groundwater in Spring Valley of eastern Nevada. Myers (2006) assessed the hydrogeology of Spring Valley and predicted the impacts to the groundwater and environmental resources of the valley if the Nevada State Engineer grants the requested water rights to SNWA. This report is a reply to the evidence submitted by SNWA in support of its application and an update to the groundwater model submitted by Myers (2006) to include stream recharge.

SNWA (2006c) contains the primary arguments on behalf of SNWA's applications. It estimates the water budget and, depending on another report concerning water rights, claims that its applications will not exceed the variable water resources in Spring Valley.

SNWA provided a groundwater model and report as part of its evidence submittal, but the model results (SNWA 2006a) do not factor into its argument in support of its water right applications. SNWA does not use the model to predict the drawdown or water budget changes due to its applications. In fact, the model report contradicts the groundwater budget provided in SNWA (2006c).

Water Budget

Perennial Yield

SNWA derives a water budget and new perennial yield (PY) for the valley in SNWA (2006c), Chapter 7, based on new inflow and outflow estimates reviewed below. This primary argument depends on the applications for 91,200 af/y being less than that which is available from the valley. The following passage provides SNWA's basic groundwater balance on which it estimates the available water.

> The groundwater budget for Spring Valley is approximately 101,000 afy of inflow and outflow, and includes significant components of groundwater recharge within the mountain block (87,000 afy) and from secondary recharge and seepage losses from the perennial streams and irrigation ditches (11,750 afy), and a small amount of subsurface inflow from Tippet Valley (2,000 afy). The inflow is balanced by outflow from groundwater ET by natural vegetation (90,000 afy) and irrigated crops (5,780 afy), groundwater outflow to Hamlin Valley (4,000 afy), and other groundwater uses (346 afy). (SNWA 2006c, page 7-7).

SNWA (2006c) also estimates in chapter 8 that the PY is just more than 100,000 af/y, similar to the estimate by Rush and Kazmi (1965).

The following sections review the remainder of SNWA (2006c) and show that all of these estimates are too high and, in some cases, based on dubious assumptions. Regarding recharge, a SNWA consultant, in his groundwater model report (SNWA 2006a), used much lower values. SNWA's assumption that 25 percent of surface naturally recharges in addition to the standard mountain block, Maxey-Eakin, recharge estimates is also shown to be without reference and represent double-counting of mountain block recharge. SNWA (2006c) estimates 87,000 af/y of mountain block recharge and over 11,000 af/y of streamflow recharge but SNWA (2006a) uses 65,000 af/y of mountain block and simulates just over 18,000 af/y of streamflow recharge. The streamflow recharge resulted from calibration of a steady state groundwater model[1].

SNWA (2006a) also acknowledges that Rush and Kazmi's (1965) estimate of 75,000 af/y of recharge includes recharge from streamflow. Rush and Kazmi (1965) assumed that 1/3 of 90,000 af/y of streamflow could be salvaged by drawing down the groundwater table to induce recharge; they provided no plan for this. Myers (2006) argued that without a detailed plan proving that that inducing recharge was possible, it should not be counted for as perennial yield. SNWA also provides no plan in its applications for water rights in Spring Valley to induce this streamflow to recharge or proof that it could occur. Because most of the streams begin to lose substantial amounts of water at the mountain front where they begin to flow across alluvial fans, it seems unlikely that the groundwater connection with the streams is sufficient to induce substantial recharge. Also, SNWA (2006c) estimates that only 47,000 af/y of surface flow occurs which suggests that the Rush and Kazmi (1965) estimate is too high.

Also, as described below, SNWA's ET discharge estimate, 90,000 af/y, may be too high because it is based on measurements during the wettest decade in 100 years. SNWA (2006a) and Rush and Kazmi (1965) use 71,000 af/y of ET discharge

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[1] SNWA (2006b) presents the model as if it is steady state, but the input and output files provided with the model report shows that a 50-year transient simulation was also completed. This is discussed below.

Therefore, the best estimate of perennial yield for Spring Valley remains the 70,000 af/y estimated by Myers (2006). However, because developing PY requires taking discharge from wetlands and springs, the actual development of any portion of that PY will result in rapid changes in the ET discharge from the valley which means that phreatophytes and springs will dry.

Recharge Estimate

Chapter 3 of SNWA (2006c) contains SNWA's updated recharge estimate equal to 87,000 af/y. This section explains how this estimate is too high and that the original Rush and Kazmi estimate of 75,000 af/y should be used as was done in SNWA (2006a).

SNWA's estimate is for mountain block recharge alone. It claims the estimate does not include the recharge which occurs from infiltrating streamflow, both perennial and ephemeral, but it should. It uses perennial streamflow at the mountain front, 47,000 af/y, to estimate additional inflow to the groundwater system from streambottom infiltration (SNWA 2006c, pages 7-2,3).

This additional recharge from streamflow overestimates the recharge portion of the water balance because, as Myers (2006) discusses, the Maxey-Eakin method already includes recharge from surface runoff. SNWA's consultant Tim Durbin agrees; in his discussion of mountain block recharge to the groundwater model he completed of the Spring Valley area, he wrote: "Except for Spring, Steptoe, and Snake valleys, the mountain-block recharges assigned to the model are the Maxey-Eakin recharges estimated by [SNWA (2006c)]. Spring, Steptoe, and Snake valleys are more complicated because [SNWA (2006c)] **also estimated mountain-front streamflow that is partly accounted for in the Maxey-Eakin recharge estimates**" (SNWA, 2006a, page 5-2, emphasis added). Thus, SNWA's consultant did not use the mountain block recharge and streamflow recharge estimates completed by other SNWA researchers because doing so would double-count some of the recharge as noted previously (Myers 2006). SNWA's statement that "Rush and Kazmi (1965) also state that although some of the runoff flows to the playa and evaporates, a 'large part seeps into the ground and recharges the ground-water reservoir', however, an estimate for this groundwater recharge component was not provided and is not accounted for in their water budget" (SNWA 2006c, page 8-2) is also wrong because Rush and Kazmi **did** account for it as part of their 75,000 af/y estimate. Recharge as determined with the Maxey-Eakin method, used by Rush and Kazmi, includes both mountain block and mountain front recharge (Avon and Durbin 1994, Stone et al 2001).

Stone et al (2001) redistributed Maxey-Eakin recharge so that 200 to 300 percent more recharge, in a groundwater model, was applied to the head of alluvial fans than would occur based strictly on the Maxey-Eakin method reflecting the run-off. They explain the details of how to separate the recharge from streamflow from the mountain block recharge calculated with the Maxey-Eakin method. It is clear from this description that considering additional recharge from streamflow would double-count the recharge.

> The subbasins serve to define the recharge zones within the model domain. Next, an empirical surface-runoff model … is used to estimate the average percentage of precipitation that results in runoff for each subbasin. The percentages are then used to calculate runoff for each subbasin, which is subtracted from the potential recharge in topographically upgradient subbasins and added to the potential recharge in "receiving" subbasins at lower elevations. (Stone et al 2001, page 810)

As described, Stone et al combine a runoff estimate with the Maxey-Eakin recharge method to redistribute the recharge calculated using Maxey-Eakin. Although the basin they studied has little perennial streamflow at the mountain front, the concept remains the same. Streamflow which results from runoff and baseflow discharging from local, perched aquifers infiltrates and recharges at the mountain front. Because Maxey-Eakin is based on an estimate of groundwater discharge from the basin, it is not relevant whether the recharge leading to that ET discharge resulted from mountain-block recharge or mountain front recharge of streamflow. This method has been applied to groundwater modeling completed at three major dewatering projects including Barrick's Goldstrike project (McDonald Morrissey Associates 1998), Homestake's Ruby Hills project, and Cortez's Pipeline Deposit project (described by Stone et al (2001)). **The Maxey Eakin method accounts for each type of recharge.**

SNWA cannot add recharge from the streams once they discharge onto the valley flow as additional recharge for the water budget and perennial yield estimate because stream recharge has already been included.

In the groundwater model, Tim Durbin used a head-dependent flux boundary to simulate recharge from streams (SNWA 2006a). But to avoid counting this in addition to the Maxey-Eakin method, he set the mountain block recharge equal to 65,000 based on the water budget in Rush and Kazmi (1965) which assumed that 10,000 af/y becomes deep recharge at the bedrock-alluvium contact. His model withdraws 18,400 af/y from the streams, an amount determined during calibration. Therefore, summing with the mountain block recharge, Durbin's total recharge just exceeds 83,000 af/y. While this exceeds the Rush and Kazmi estimate, used by Myers (2006), it is substantially less than the total recharge depended on by SNWA.

SNWA claims its 87,000 af/y estimate for mountain block recharge is a lower bound on the likely recharge range because recorded rain gage amounts are actually less than the true amount of precipitation. If the claim that rain gages underestimate precipitation is correct, it would also apply to the data used by Maxey and Eakin while developing the original method. If the precipitation ranges were actually increased by 5 to 25 percent, the amount that SNWA claims gages may underestimate the precipitation, the Maxey-Eakin recharge efficiencies (for example, 3 percent for from 8 to 12 inches) would have been lower because the valley discharge estimate by Maxey and Eakin would have been the same.

SNWA also argues that the assumption made by Rush and Kazmi that no recharge occurs below 6000 feet is wrong. Part of the basis for this assumption is the precipitation recorded at the Shoshone 5 gage, lying at less than 6000 feet, averages 9.73 inches. There are two reasons that this rain gage may overestimate the precipitation at low elevations. First, the gage lies on the east side of Spring Valley on an alluvial fan just below the 13,000 foot Wheeler Peak. The steepness of the Snake Range just east of the gage may cause an orographic effect on precipitation which affects this gage. Second, the period of record is 1988 through 2005, only 17 years. As shown below, the 1990s are the second wettest decade in 100 years and the 1980s are the wettest. As noted by SNWA (2006c, page 3-17), "[a] short period of record can be misrepresentative of the long-term average by including data collected during a mostly wet period or a mostly dry period." The precipitation at the Shoshone 5 gage collected during this period could easily be an overestimate of the long-term mean for Spring Valley.

Also, the regression used to estimate new precipitation values for Spring Valley includes widely disparate data. As stated by Nichols (2000, page C18), "[m]ultiple storm tracks and rainshadow effects preclude a simple relation between precipitation and local altitude". Nichols continues:

> The western and southern parts of the study area (which includes southern Spring Valley) … are influenced by a westerly winter storm track, but lie in the rainshadow of the Sierra Nevada … and the Toiyabe Range in central Nevada. The northern and eastern part of the study area (which includes the north half of Spring Valley) is affected to a greater extent by a northwesterly storm track. (Nichols 2000, page C18)

This statement by Nichols suggests that the regression of annual precipitation and elevation completed by SNWA includes rain gages with differing periods of record located from 50 miles north to 50 miles south of Spring Valley. This is a total north-south range of almost 220 miles. Data from such a range would include observations subject to completely different types of storm events. For the regression, this would be including data points drawn from different populations of data.

SNWA uses Nichols' (2000) recharge estimate to claim that its estimate is low. But, Nichols' recharge estimate may be too high because the basis for it, ET measurements, was made during the wettest period in 100 years as will be explained in the section on evapotranspiration. However, using his ET estimate, Nichols based his recharge estimate on a regression of precipitation bands with estimated discharge (ET and interbasin flow) from each basin; essentially, he recalibrated the Maxey-Eakin method. First, he estimated ET for 1985 and 1989 for 16 eastern Nevada valleys; there is no reason to suspect the measurements for Spring Valley to be incorrect, but there is a large variability there and in several of the other valleys he used. Using previous estimates of interbasin flow, he determined a total discharge for each valley. For Spring Valley, the estimate was 94,000 af/y (90,000 af/y ET and 4000 af/y interbasin flow). Nichols used these estimates to generate a regression relationship with new recharge efficiency estimates. Applying the new recharge efficiencies to the precipitation bands resulted in a predicted groundwater recharge equal to approximately 104,000 af/y. Thus, the recharge estimate from the regression is 10,000 af/y higher than the measured recharge. Nichols assigns this to interbasin flow in a water balance of the valley even though there is evidence only for minor interbasin flow to Hamlin Valley and from Tippets Valley.

For its estimate of streamflow recharge, SNWA makes a dubious assumption that 25 percent of the runoff becomes recharge:

> In estimating the budget component for the surface-water ET and evaporation, it was assumed that 75 percent of the annual average perennial streamflow is consumptively used by ET from irrigated crops, pastures and meadowlands, open-water evaporation, livestock, and natural vegetation transpiration. The remaining 25 percent of the perennial streamflow is assumed to infiltrate and recharge the groundwater system. SNWA field reconnaissance indicates that much of the water is diverted to small storage reservoirs for the controlled application of surface water to irrigate crops, or is used to flood irrigate pastures and meadowlands. Diverted water that is not consumed by ET or evaporation, or does not infiltrate and recharge the groundwater system, returns to the stream via irrigation drains and/or the natural drainage network. This return flow and any undiverted water ultimately flows to lowland areas, most notably the Yelland Dry Lake, where it pools and evaporates. (SNWA 2006c, page 7-3, emphasis added)

The amount is 11,750 af/y (SNWA 2006c, Table 7-2) which SNWA incorrectly, as discussed above, considers to be recharge in addition to that estimated by Rush and Kazmi (1965). There is no substantiation of the 75/25 breakdown between ET and recharge of surface water. SNWA also provides no data to support its field reconnaissance referenced in the quoted passage.

Perennial Streamflow

SNWA (2006c) discusses perennial streamflow in Chapter 4. It presents miscellaneous measurements from many perennial streams around Spring Valley and uses statistics at the Cleve Creek near Ely gage to determine an average annual flow from the ungauged streams. The method relates proportionally the average annual flow rate at a gauging station to the ratio of flows measured on the two streams at the same time. SNWA (2006c, page 4-7) provides an equation describing the method and recommends that to overcome differences in surface-runoff characteristics that affect the shape of the runoff hydrograph that only measurements obtained during baseflow conditions be used. The problem with this method is that those surface-runoff characteristics could result in substantially different runoff amounts for the same area. These differences include underlying geology and drainage basin geomorphology.

SNWA also determines baseflow based on the flow hydrograph at Cleve Creek. Because the Cleve Creek basin is much larger and the stream parallels the range crest for several miles, baseflow may commence much later than many of the streams. Also, Table 4-1 in SNWA (2006c) shows substantial differences among the geologic characteristics underlying the streams. Therefore, the ratio of flows between basins, even if both represent baseflow, could have been taken during a much different portion of the recession leg of the hydrograph.

SNWA's Table 4 provides simple regression analyses of the measurements in the ungauged streams with the average daily flow on Cleve Creek. Because these regressions are based on baseflow, the relative high coefficient of determination should be expected. This relation between streams at baseflow does not explain in any way the hydrograph resulting from spring or storm runoff.

For example, one of the problems could be with the average annual flow estimate for Swallow Creek which flows off the east side of the Snake Range. Most of the flow emanates from Swallow Canyon spring for which Myers (2006) provided a hydrograph. Essentially, SNWA (2006c, Table 4-3) estimates spring discharge rather than drainage basin runoff. Baseflow in such a spring unlikely emulates the baseflow from Cleve Creek due to the lag time for recharge reaching the spring. Based on the size of the drainage area and the geology of the area, it is likely that Swallow Canyon Spring discharges water that recharged in more than just its drainage.

SNWA bases its estimate of perennial flow from ungauged basins in Spring Valley on relatively few measurements. SNWA treats these flows at the mountain front as water it can potentially induce to recharge thereby increasing the recharge and perennial yield. Considering the uncertainty in extrapolating from these few measurements and the magnitude of the decision about water rights applications, SNWA should have contracted with the U.S. Geological Survey to install gauging stations at each of these locations to obtain accurate measurements of annual runoff rather than the highly uncertain estimates presented in SNWA (2006c).

Evapotranspiration

SNWA (2006c) estimates groundwater discharge through ET in Chapter 5. It summarizes previous work by Rush and Kazmi (1965) and Nichols (2000) and introduces new work contracted by SNWA and completed by Devitt et al (2006). The chapter summarizes by accepting Nichols (2000) 90,000 af/y ET estimate. It ignores the discharge used by its consultant in SNWA (2006a) equal to 71,000 af/y. For various reasons, the estimate used by SNWA may be high.

Devitt et al (2006) estimated all ET occurring from the phreatophyte and open water zone of Spring Valley to equal 307,225 af/y. This includes both precipitation, groundwater and surface-water sources (Devitt et al 2006, page 5-7). They adjust this total ET value to groundwater ET by subtracting precipitation recorded at one of their Spring Valley stations equal to 1.07 feet as explained in this extensive quote:

> The ET estimates were adjusted to exclude precipitation using the depth of precipitation measured at Site 2 and as reported by Devitt et al. (2006). As stated previously, precipitation at this location was measured at 1.07 ft during the period

of data collection. To calculate the volume of precipitation for each corresponding area, it was assumed that this depth occurred uniformly over the entire area. The volume of precipitation for each area was calculated by multiplying the area by 1.07 ft. The volume of precipitation was then subtracted from the corresponding ET estimate. Using the 150,030 acres that represent the phreatophytic zone and wetland meadows area, the volume of precipitation was calculated to be approximately 160,500 af. The Devitt et al. (2006) ET estimate for this area was reduced by this amount to account for precipitation and yielded a value of approximately 147,000 af, or nearly 50 percent of the total ET estimate. Open-water evaporation was adjusted to account for precipitation in the same manner. The consumptive-use estimate for the agricultural areas was not adjusted because the precipitation component is already accounted for in the derivation of the annual duty. These values are summarized in Table 5-2 and include the estimate of groundwater evaporation from the playa.

> For 2005, the total ET from groundwater and surface-water sources is estimated to be approximately 159,000 af. Simplifying assumptions were made in deriving the ET estimates listed in Table 5-2. First, it was assumed that the depth-of-precipitation occurred uniformly over the entire discharge area. This assumption is probably not an accurate reflection of the actual precipitation, which varies spatially. However, given the central location of the precipitation gage (Site 2) and the fact that the topographic relief within the discharge area is minimal, this is a reasonable assumption. Second, it was **assumed that the precipitation that reached the valley floor within the discharge area was fully consumed by ET by the end of the year**. This is a conservative assumption as it is plausible that some of the precipitation could have recharged the groundwater system during this period, particularly since the precipitation was at least 20 percent above normal near the discharge area ("Shoshone 5 N" gage). (SNWA 2006c, page 5-7, emphasis added)

Devitt et al (2006) does not subtract surface run-on from the total ET to obtain groundwater ET. Each of the perennial streams that is not ditched at the mountain front, irrigation return flow, ephemeral stream flow, and springs all are surface flow that reaches these phreatophyte zones. Without estimating these other sources, it is not really possible to compare the Devitt et al estimates with other ET estimates.

Nichols' (2000) ET estimate is an average of two substantially different annual ET estimates, 102,000 and 77,500 af/y in 1985 and 1989, respectively. Overall, for the 16 valleys Nichols studied, the ET in 1989 was substantially higher than in 1985 even though 1985 followed three wet years. Assuming the annual estimates are correct, it is difficult to account for the differences. Spring Valley is the only valley that experienced a substantial decrease from 1985 to 1989; Steptoe and Ruby Valleys experienced substantial increases.

Regardless of the reasons for the differences between 1985 and 1989, neither SNWA nor Nichols considered whether climatic conditions during those years were representative of long-term steady state conditions. Based on statewide precipitation data downloaded from the National Climatic Data Center for Nevada and Utah and for Salt Lake City, the decade of the 1980s was extremely wet (www.ncdc.noaa.gov/oa/climate/research/cag3/state.html). For Nevada, the decade was the wettest; for Utah it was second wettest only to the 1990s (Table 1). In Salt Lake City, the nearest city included in the data base, the 1980s were also the second wettest. Because both of the measurements made by Nichols occurred in the second half of the wettest decade on record in the area, it is likely that the phreatophyte cover had expanded and its density had increased. It is likely therefore, that the ET observed during the 1980s when Nichols completed this study was higher than that which occurred during previous decades, at least back to 1900, when many of the reconnaissance surveys, including Rush and Kazmi (1965) were being made.

Table 1: Average decadal precipitation for Nevada, Utah and Salt Lake City from the National Climate Data Center.

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

Nichols ET estimates for 1985 and 1989 are likely correct, but because the period during which he made them was the wettest in 100 years the average of the estimates should not be used as an estimate of long-term steady state recharge. SNWA's reliance on the average of these estimates lead it to overestimate the ET.

Groundwater Movement

SNWA discusses the movement of groundwater within Spring Valley and between valleys in Chapter 6. The assessments within that chapter are correct based upon the available data. The conceptual model is essentially the same as in Myers (2006). The primary difference is that Myers did not consider 2000 af/y flow from Tippet Valley to Spring Valley. Importantly, SNWA concludes that there is no flow between Spring Valley and Steptoe Valley or between Spring Valley and Snake Valley. SNWA estimated that 4000 af/y flows from Spring Valley into Hamlin Valley; this is the same value used in Myers (2006). SNWA chapter 6 essentially concludes that Spring Valley is isolated from other nearby valleys.

SNWA (2006c) did not use a groundwater model to simulate these flows as part of its assessment, although it did submit a groundwater model of pre-development conditions. Because of the similarity between conceptualizations used by SNWA (2006a) and Myers (2006), it is likely that results obtained from predictive simulations with the SNWA would have been similar to those by Myers (2006) and modified in this report.

Water Rights

SNWA also submitted a study of water rights in Spring Valley to justify a much lower estimate of committed underground water rights than was otherwise published by the State Engineer (SNWA 2006b). Myers summarized the water rights for Spring Valley.

Duty

The State Engineer uses a 4.0 ft/y duty, but SNWA (2006b) argues that the duty in Spring Valley is much less than 4.0 ft/y. It argues that even if 4.0 feet is applied, only 2.5 feet is consumptively used, and that entire remaining amount is irrigation secondary recharge (SNWA 2006b, pages 2-4,5). SNWA's argument is problematic for several reasons.

First, SNWA claims that 4.0 feet is a maximum amount of water applied and that it may change from year-to-year. That is possible but years in which less is applied are likely years that it is not available. SNWA presents no measurement or other data to support its contention that water rights with a 4.0 foot duty may actually apply less water.

SNWA assumes also that of the 4.0 foot duty, only 2.5 feet is consumptively used, even though it cites Soil Conservation Service studies showing that much more water is consumptively used: "The SCS (1981) data supports crop consumptive use in the range of 66 percent for pasture and 80 percent for alfalfa, and by difference, a secondary recharge fraction in the range of 20 percent for alfalfa to 34 percent for pasture." (SNWA 2006b, page 2-5). This equals 3.2 and 2.64 ft/year for alfalfa and pasture, respectively. Using the SCS values, 3.2 and 2.64 feet are consumptively used if the irrigator applies 4.0 feet. SNWA assumes that less water is consumptively used than determine in its' own citation.

SNWA bases its contention of using 2.5 feet of consumptive use on three state engineer rulings, 5066, 5167, and 5491, which it claims establishes the precedent of using the Alpine Decree consumptive use as 2.5 feet of a total duty of 4.0 feet. These rulings are not comparable to the situation in Spring Valley. Each ruling involved a change in point of diversion, change in point of use, a change in the manner of beneficial use or a combination of the three. In each ruling the State Engineer used the consumptive use to determine the duty that could be pumped at a specific new location or the amount which could be placed to a new place of use or type of use. The intent was to insure that hydrologic conditions at the existing point of diversion and use did not change, not to determine an additional amount that could be diverted. This use of the Alpine Decree consumptive use did not apply to applications to divert and export from the basin the secondary return flow from existing rights.

Assuming that all of the secondary irrigation recharge is available for appropriation is also dubious because it requires that water applied to the field not consumptively used percolates directly to the groundwater reservoir. This ignores several additional losses to that return flow.

- First, as pointed out by SNWA in its groundwater model report (SNWA 2006b), there is substantial vertical anisotropy. The percolating water will spread horizontally and create a mound. This requires that substantial amounts of water go to wetting previously unsaturated soil.

- Second, the horizontal flow causes the water to move substantial distance in a lateral direction where it may emerge as a new spring or seep or mix with water of poor quality as may occur near a playa. In either case, the water may be effectively removed from the groundwater reservoir and unavailable for appropriation.

- Third, the vertical anisotropy may actually cause a perched groundwater mound which would not be available for appropriation.

- Fourth, much of the return flow may be on the ground surface where it additionally supports ET from phreatophytes or, because it occurs intermittently, evaporates from a free water surface.

SNWA presented no arguments or data to show that return flow could actually be available, therefore an appropriation of this water without proof of its availability may be an appropriation of non-existent water.

Supplemental Underground Water Rights

Some of the underground water rights in Spring Valley are supplemental to other rights. Myers (2006, Table 6) indicated that 18574.9 af/y of underground rights exist in Spring Valley. This amount already accounted for those rights listed as supplemental in the State Engineer's water rights data base. However, SNWA goes much further in arguing that additional water rights are supplemental and represent amounts of water that should be available for appropriation. SNWA's argument is most dubious by assuming that surface water rights are the primary water right for a piece of land and that all groundwater rights applied to the same land are supplemental:

> In Spring Valley, surface water resources (streams and springs) are the primary developed source, and groundwater commonly supplements surface water resources, but at some locations groundwater is independently developed. In cases where water rights do not define a total duty, the maximum diversion rate has

> been assumed for the full period of allowed usage (commonly the entire year). Although used in this evaluation, this approach over estimates actual use. (SNWA 2006b, page 2-2).

There is no source or citation nor any analysis for the statement that surface water is the primary source and that groundwater is supplementary. While it may be assumed that, due to pumping costs, the irrigator will use surface water when available, SNWA provides no information regarding the breakdown of usage between the surface and connected groundwater right. It must be assumed that the groundwater right will continue to be used when the surface water is unavailable and that that water cannot be appropriated by SNWA. In fact, SNWA proposes to cause surface water to infiltrate the stream bottom to add to the recharge reaching the groundwater (SNWA 2006c); the efficacy of this dubious plan has been discussed above. However, if it is successful, it is likely that the surface water that SNWA's plans will cause to infiltrate would have gone to meet the surface water rights, therefore the supplemental groundwater will be even more important to the irrigator.

By assuming that it can appropriate all groundwater that supposedly is supplemental to surface water or other underground rights, SNWA grossly overestimates the amount of groundwater available.

Connection of Underground, Spring and Stream Water Rights

SNWA's arguments that it can pump groundwater to induce surface water to recharge (SNWA, 2006c) depend on a connection between surface and groundwater. Groundwater discharges sustain both stream and spring flow. As much as 6.5 cfs for six months is baseflow that discharges from groundwater (Rush and Kazmi, 1965). Because groundwater originated as recharge, this stream baseflow must already be accounted for as groundwater recharge.

Myers (2006) found there are 46,035 af/y of certificated and permitted and 55,434 af/y of vested stream flow rights. Considering just the certificated and permitted streamflow rights and assuming that these rights are used all season, from April to September, for a six month irrigation season, and assuming that most stream flow from July through September is baseflow, half of the surface water rights, or 23,018 af/y, depend on groundwater. A water right to stream baseflow is essentially a water right to groundwater.

By definition, spring discharge is a discharge of groundwater, therefore the 3779 af/y of certificated and permitted spring flow rights also depend on groundwater. A water right to spring water is also essentially a water right to groundwater.

Committed Underground Water

It follows that all surface water rights either dependent on spring flow or stream baseflow depend on groundwater and is water not available for appropriation as a part of the valley's perennial yield. Based on this, **at least 68,388 af/y of groundwater is already appropriated**. This amount does not include vested rights which could add substantially to the amount of surface water rights dependent on groundwater. It does not exclude irrigation return flow or consider groundwater rights to be supplemental to surface water rights.

SNWA apparently relies on induced recharge from streams to reach a pumpage of 91,200 af/y because most estimates of natural basin recharge are less than the proposed pumpage. SNWA does not estimate that drawdown caused by this pumpage or the amount of water removed from storage. The following section, Drawdown Estimates, Transitional Storage and Groundwater Model, discusses the lack of predictions by SNWA and updated predictions from the model of Myers (2006) regarding the impacts of the pumping and total amount of water removed from storage.

Drawdown Estimates, Transitional Storage and Groundwater Model

SNWA Groundwater Model

SNWA provided a report of a groundwater model of Spring Valley and surrounding valleys as a part of its evidence documentation, but its Water Resources Assessment Report does not even reference the model.

SNWA's model used the code FEMFLOW3D version 2.0. This model was originally developed by Tim Durbin and others while at the U.S. Geological Survey. Durbin has subsequently modified the code as part of his work at consulting companies including his current Timothy Durbin and Associates. The U.S. Geological Survey no longer provides the code or supports it; I could not locate it on the USGS software website during early July 2006. SNWA provided the Fortran code, executable files and a manual for the program as part of its June 30, 2006 submission. SNWA (2006a) notes that FEMFLOW3D may be used with GMS, the Groundwater Modeling System developed for the Corps of Engineers (SNWA 2006a, page 1-12). Using it with GMS would be convenient because GMS provides an on-screen graphical means for viewing the model. However, the FEMFLOW3D is not supplied with GMS as may be seen from the following quote from the web page of the company that distributes GMS, Environmental Modeling Systems Incorporated:

> GMS is a comprehensive software package for developing computer simulations of groundwater problems. GMS is the most sophisticated and comprehensive groundwater modeling pre- and post-processor available today. GMS is used at thousands of sites including federal, state, private and, international sites.
>
> GMS is a comprehensive package which provides tools for every phase of a groundwater simulation including site characterization, model development, post-processing, calibration, and visualization. GMS is the only system which supports TINs, solids, borehole data, 2D & 3D geostatistics, and both finite element and finite difference

models in 2D & 3D. Currently supported models include MODFLOW, MODPATH, MT3D, RT3D, FEMWATER, and SEEP2D.

GMS is distributed commercially through Environmental Modeling Systems Incorporated (EMS-I). EMS-I also sponsors regularly scheduled training courses featuring GMS. If you are interested in downloading, evaluating, or purchasing GMS, please visit the EMS-I site. (http://www.emrl.byu.edu/gms.htm)

FEMFLOW3D is therefore a reasonably widely used model by certain hydrologists but it is not **freely** available to the public.

The model report and output provides sufficient information to review parts of the model. It appears to have been correctly conceptualized and adequately calibrated. The conceptual model is almost identical to that used by Myers (2006). The model domain includes the Spring Valley area which included Spring Valley and five surrounding valleys, Snake Valley, Steptoe Valley, Cave Valley, Hamlin Valley and Tippets Valley and parts of others. Hydraulic conductivities for the valley fill and carbonate aquifers are similar to those developed in Myers (2006); SNWA (2006a) devotes an entire chapter to the discussion of hydraulic conductivity.

Although the report (SNWA 2006a) discusses steady state flows in the water budget, the model output shows that the model was run in transient mode. For example, the model output file, historical.flx, contains the following section.

```
               SPECIFIED FLUX TABLE:
LOCAL TABLE NUMBER.....................          1
GLOBAL TABLE NUMBER....................          1
NUMBER OF ENTRIES IN TABLE.............         10
SWITCH FOR INTERPOLATION METHOD.........          1

             POINT      TIME      RATE
               1  1.82E+03  0.00E+00
               2  3.65E+03 -1.67E+03
               3  5.48E+03 -1.23E+04
               4  7.30E+03 -1.23E+04
               5  9.12E+03 -1.23E+04
               6  1.10E+04 -1.23E+04
               7  1.28E+04 -1.23E+04
               8  1.46E+04 -1.23E+04
               9  1.64E+04 -1.23E+04
              10  1.82E+04 -1.23E+04
```

This specified flux table shows flux specified at ten different times. The tenth time is 1.82e+04, presumably days which is the same as 50 years. This is important because it suggests the model is calibrated for transient conditions which includes specific storage values. SNWA (2006a) does not discuss specific storage at all.

Even though the model was calibrated for transient simulation, the model was not run in forward predictive mode to illustrate the potential effects of the proposed development.

The most important part of the model report is the water budget. Fluxes specified by SNWA (2006b) for recharge and ET contradict the water budget used by SNWA (2006c) to justify its water rights applications. I discussed the details of these water budget components above in the section on the water budget. Except that SNWA (2006a) allowed a small amount of recharge from the valley's streams in the model, the fluxes used by SNWA (2006a) were the same as Myers (2006). Additionally, the interbasin flow values specified in SNWA (2006a) for the Spring Valley section were also the same with the exception of the small inflow from Tippets Valley.

Myers Groundwater Model

Myers (2006) conceptualized and calibrated a model of Spring Valley and used it to predict effects of pumping. Myers (2006) provided maps of drawdown and hydrographs of both flux and water level showing that drawdown rapidly exceeds 50 feet and reaches greater than 350 feet after 1000 years of pumping.

The model does not reach steady state, however, because the pumpage exceeds the recharge, a specified flux boundary. SNWA relies on induced recharge from surface water to increase the perennial yield. SNWA (2006a), however, used a head dependent flux boundary to simulate recharge from the valley's streams. To consider the potential for inducing stream recharge, this report updates the Myers (2006) model to include the possibility of inducing recharge from streams to obtain an estimate of the time to steady state and an estimate of transitional storage.

Adding River Boundaries

The modification was done by adding river boundary cells corresponding with the perennial streams that reach the top of the alluvial fans bounding the valley. These may be seen in Figure 1 in Myers (2006). Table 1 shows the stream, row and column of each new cell boundary. Calibration consisted of setting the river boundary head to equal the approximate average head for the cell observed during steady state calibration. Minor adjustments were made so that the net inflow from the streams to the model was close to 0. No other parameters were changed. The inflow and outflow from river boundaries was 107,000 and 117,000 af/y during this recalibration. Each is about 1.2 percent of the total flux (mostly recharge and ET) in the system; the net is negligible.

There was no additional calibration completed with the added river boundaries, therefore the conductivity zones reported by Myers (2006) remained the same. Adding the river boundaries slightly decreased the accuracy of the original calibration as shown by comparing the following table with the descriptive statistics in Myers (2006). The average residual became slightly more negative. A negative residual means that the model predicts a head that exceeds the observed head.

Table 2: Model location, head and reach number for river boundary cells added to the model. Conductance for all reaches was 52,800 ft^2/d.

Row	Column	Calibrated Water Level (ft msl)	Reach Number
58	8	5780.	11
58	9	5700.	11
56	10	5670.	12
39	10	5604.	13
41	9	5960.	14
42	10	5760.	15
45	10	5775.	16
46	10	5790.	17
48	10	5860.	18
50	10	5850.	19
52	10	5780.	20
53	10	5770.	21
62	8	5745.	22
56	19	5843.	23
56	18	5760.	23
56	17	5715.	23
72	16	5795.	24
72	15	5791.	24
73	16	5795.	25
77	18	6430.	26
77	17	6102.	26

Table 3: Descriptive statistics of the calibration statistics resulting from the steady state calibration with river boundaries.

Residual Mean	-6.4
Res. Std. Dev.	50.7
Sum of Squares	1878900
Abs. Res. Mean	38.2
Min. Residual	-123.3
Max. Residual	156.2
Range	1089
Std/Range	0.05

Drawdown and Storage Change with River Boundaries

The river boundaries as calibrated in steady state were then added to the original transient model. The model was run with pumping the full SNWA development rates until it reached steady state to determine the time to steady state and the transitional storage. Steady state occurs when the change in storage approaches 0 af/y. This requires approximately 22,000 years (Figure 1). By this time, inflow from the river boundaries exceeded 16,000 af/y, the difference between the specified recharge and pumpage. After 2000 years, the pumpage and recovery time simulated by Myers (2006), however, river inflow had only reached 13,000 af/y and the groundwater in storage continued to decrease. Induced flow from streams does not quickly match the excess of pumpage over recharge because many of the streams lie far from the wells.

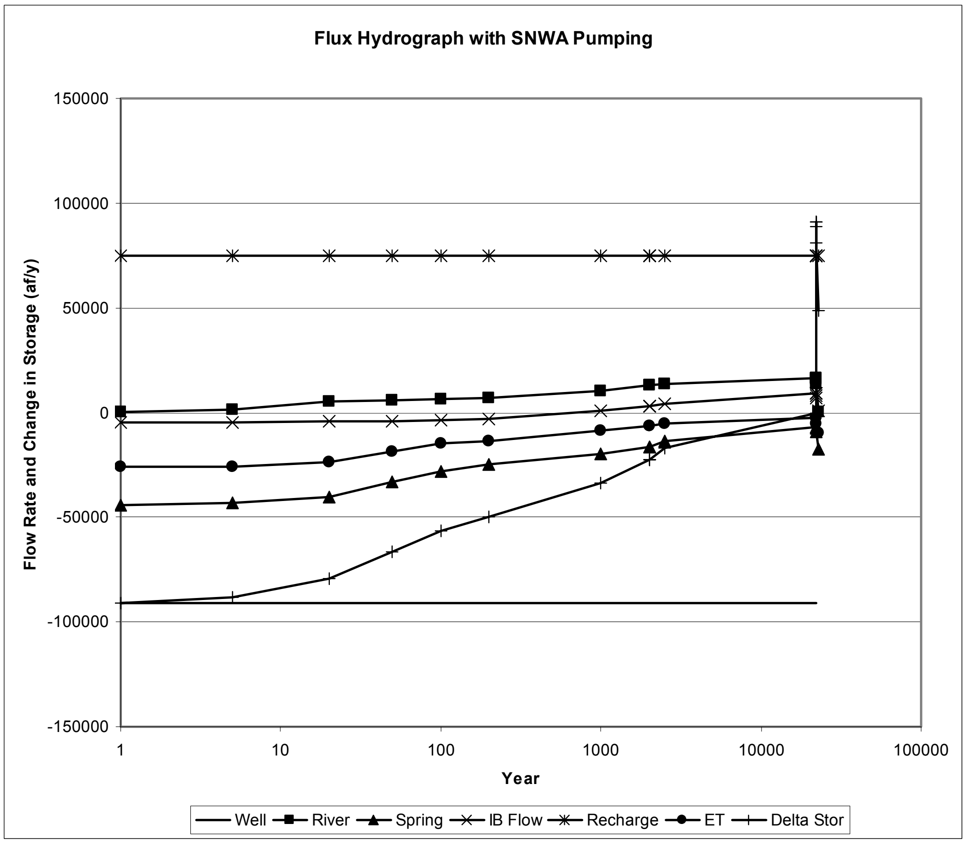

Figure 1: Flux hydrograph with SNWA pumping.

Over the more than 22,000 years that elapses before steady state establishes, SNWA removes almost 118,000,000 af of water from the groundwater reservoir. After this period, layer 1 is dry south of Cleve Creek. The hydraulic link with many river cells is broken so that the stream inflow is constant at 105,600 ft^3/d (1.2 cfs). Layers 2 and 3 have over 500 feet of drawdown, therefore the total drawdown exceeds 600 feet which accounts for large amount of water removed from storage.

Transitional storage is "the quantity of water in storage in a particular ground water reservoir that is extracted during the transition period between natural equilibrium conditions and new equilibrium conditions under the perennial-yield concept of ground water development" (NDWR 1971, page 13). The Central Region "is by far the largest hydrographic region of Nevada; it covers about 46,783 sq. mi. in 12 counties, which is 42 percent of the state. The region includes 89 valleys that are generally large in size, medium to high in altitude, and are mostly isolated, though some have interflow of surface." (NDWR 1971, page 11). NDWR (1971, Table 1a) indicates that the Central Region has 45,000,000 af of transitional storage[2]. Spring Valley is part of the Central Region. SNWA's water rights applications remove more than two and a half times that much groundwater from storage in just one of the valleys before reaching equilibrium (Figure 2).

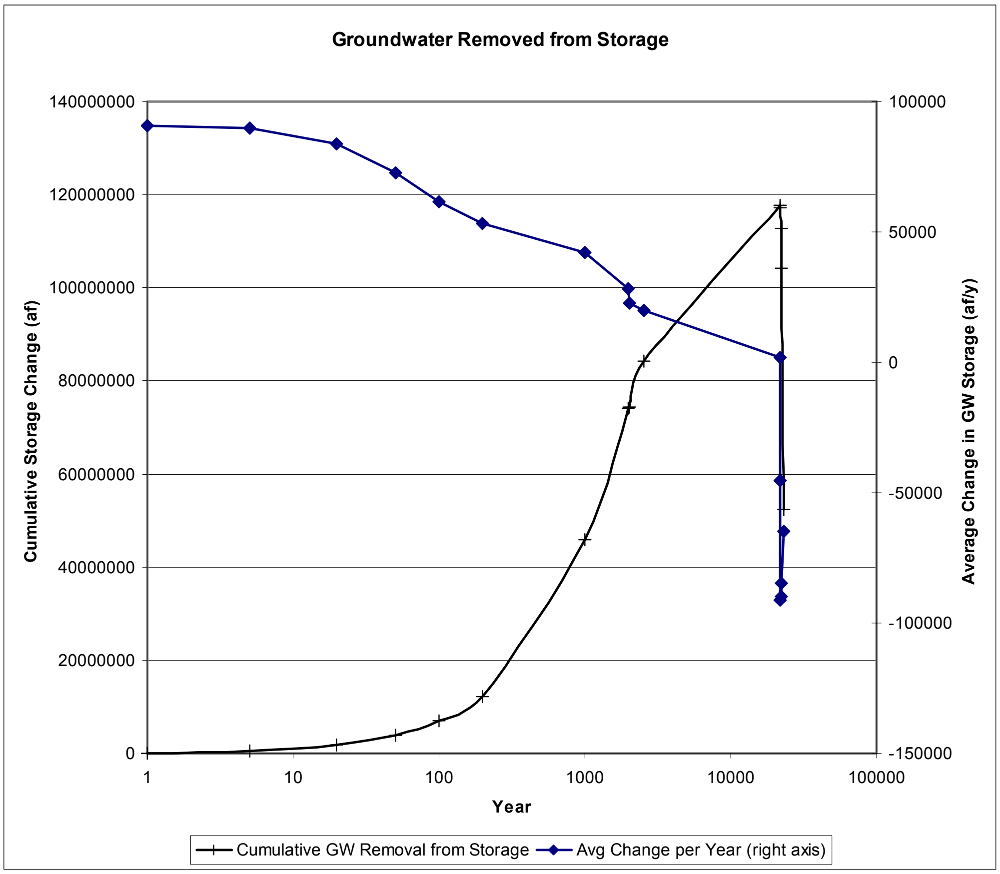

Figure 2: Change in and cumulative groundwater removed from storage.

[2] In an introductory letter to Report 3, State Engineer Roland Westergard writes: "This report constitutes an inventory of the water resources of the State and represents the water supply presently available to Nevada."

Uncertainty

The most uncertain parameters in the Spring Valley model are the storage coefficients. They are uncertain because there is little pumpage data to calibrate to in transient mode. For this reason, the estimates of time to steady state and transitional storage contain significant uncertainty. Therefore, an uncertainty analysis, adjusting the specific storage and specific yield values to reflect reasonable upper and lower limits, bracketed the change in and cumulative storage. Table 4 shows the original (Myers 2006) and the upper and lower values used for this uncertainty analysis.

Table 1: Calibrated specific storage (Ss) and specific yield (Sy) and high and low envelope values

Aquifer Material	Original Ss	Original Sy	Low Ss	Low Sy	High Ss	High Sy
Valley Fill	0.0001	0.1	0.00001	0.08	0.01	0.2
Carbonate	0.00003	0.05	0.000003	0.04	0.003	0.1
Other bedrock	0.000001	0.01	0.0000001	0.01	0.0001	0.05

Pumping with the lower specific storage values removes less water and reaches effective equilibrium in about 2000 years when the amount of water removed from storage equals about 450 af/y or just 0.4 percent of the pumpage (Figure 3). Continuing the pumpage until 22,000 years, the time to equilibrium required using the original calibrated storage coefficients, less than 450 but more than 0 af/y continued to be removed from storage because of the location of springs and recharge.

Effective equilibrium was reached within 2000 years because more drawdown occurs for a unit amount of pumpage. Therefore, the drawdown cone expands more quickly, eliminating spring flow quicker and causing the streams to make up the difference between pumpage and recharge more quickly. ET and spring flow responds quickly. After 2000 years, 29,400,000 af of water has been removed; over the following 20,000 years, only 400,000 af more is removed (Figure 4).

Higher specific storage values caused equilibrium to not be reached within 22,000 years (Figure 5). Pumpage removes groundwater almost exclusively from storage for at least 100 years because drawdown occurs very slowly. Drawdown after 100 years in layer 2 is only about 20 feet and in layer 1 is just a couple of feet. Springflow and ET are only slightly affected until the 200th year. The total amount of water removed over 22,000 years is more than 420,000,000 af (Figure 6).

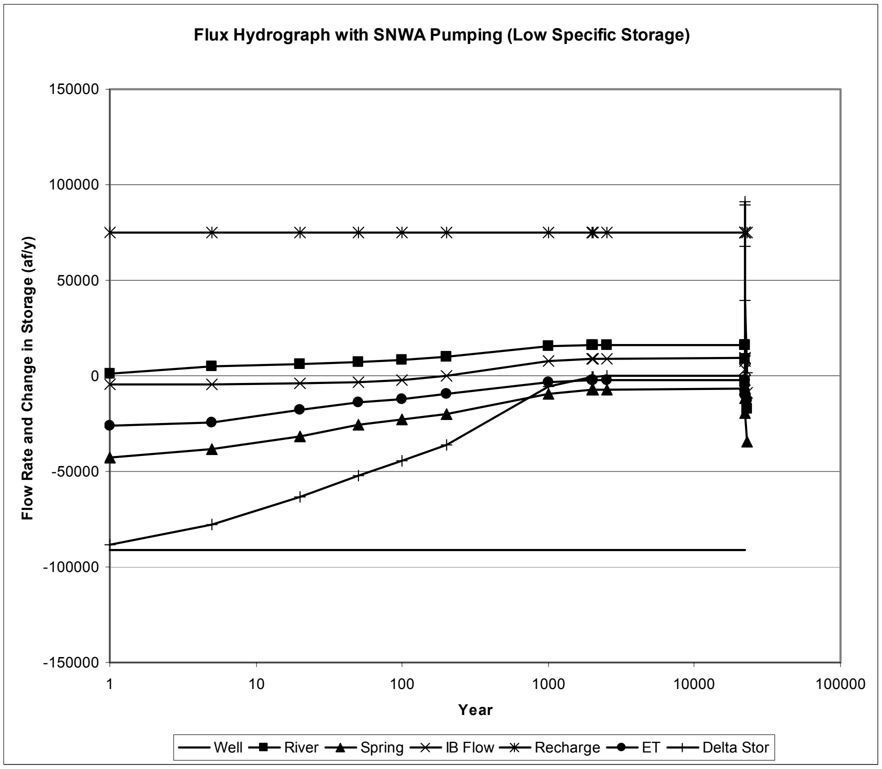

Figure 3: Flux hydrograph with SNWA pumping for low specific storage envelope.

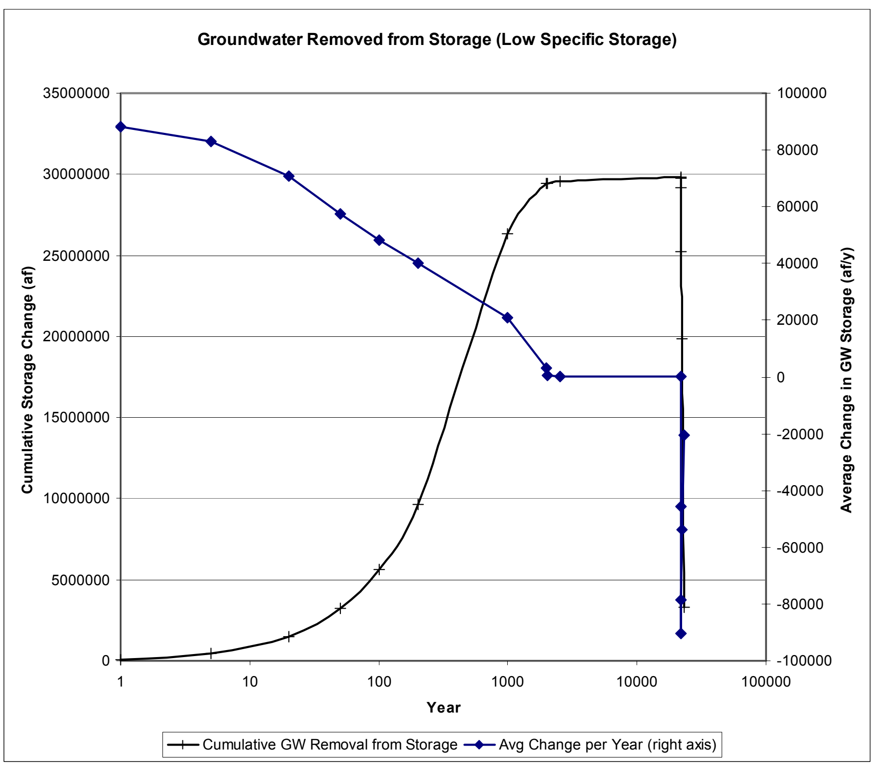

Figure 4: Change in and cumulative groundwater removed from storage with SNWA pumping with low specific storage values.

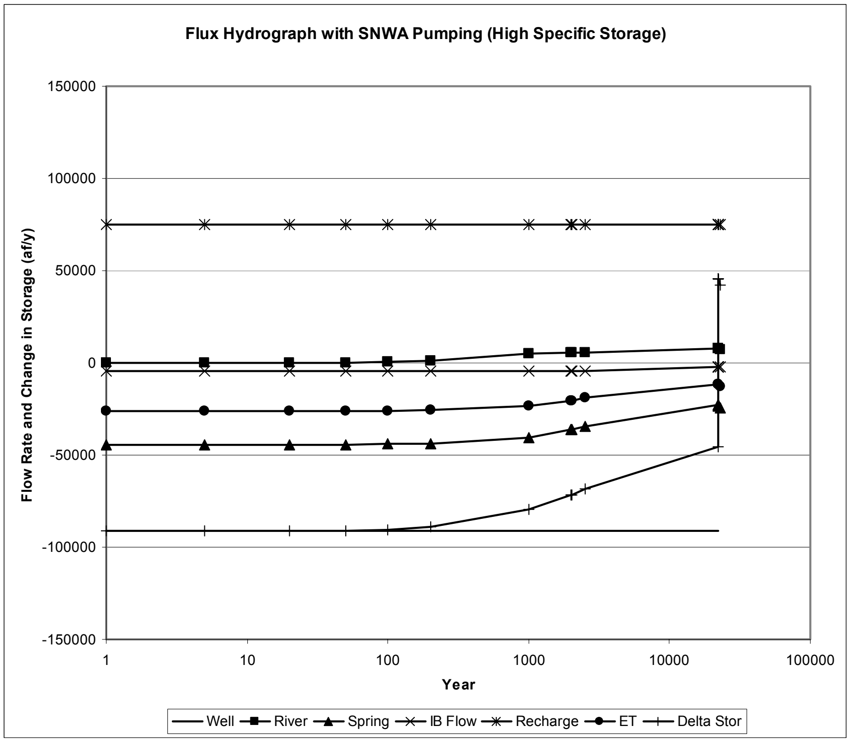

Figure 5: Flux hydrograph with SNWA pumping for high specific storage envelope

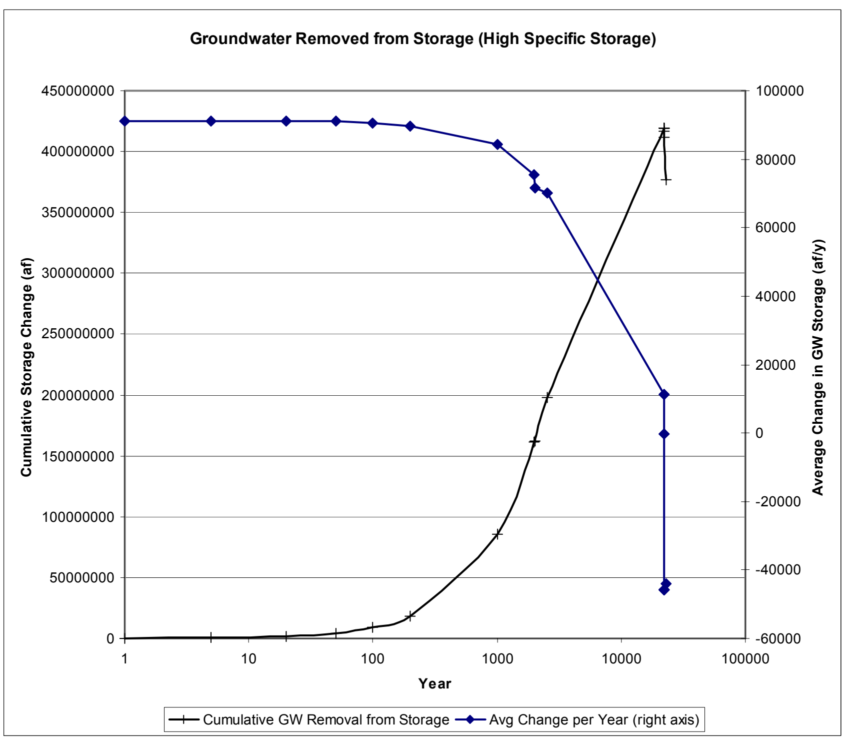

Figure 6: Change in and cumulative groundwater removed from storage with SNWA pumping with high specific storage values.

Considered together, enveloping the storage coefficients shows the accuracy of the transient calibration in Myers (2006). The lower specific storage values are close to those used by Schaeffer and Harrill (1998). During transient calibration of the original model I determined that the drawdown occurred unrealistically quickly and increased the coefficients by an order of magnitude (Myers 2006). Increasing it significantly more in this sensitivity analysis shows that almost no drawdown occurs although very substantial amounts of water are removed from storage. The seasonal changes in the few monitored wells in the valley indicate that these specific storage values are incorrectly high.

The predictive model therefore is most sensitive to specific storage, but the analysis herein further indicates that substantial drawdown will occur due to this pumpage. This is inevitable for a plan that pumps at or above the perennial yield of the basin. There is substantial variability around the predictions, but little uncertainty that the drawdown in the valley will be significant, extensive, and commence very quickly.

Recovery

Stream recharge could also affect the recovery time from the pumping. To test this, I ran the transient model with the calibrated storage coefficient for 100 years and allowed 1000 years of recovery as in Myers (2006).

Drawdown occurring during the first 100 years, while SNWA pumping occurs, is very similar to that predicted by Myers (2006) (Figures 7 through 9). Induced recharge from the streams reached 6480 af/y by the end of 100 years (Figure 10) which indicates that the pumping plan has not induced sufficient recharge within 100 years to substantially increase the perennial yield. Because other natural discharges continue, at the end of 100 years, approximately 56,600 af/y of groundwater continues to be removed from storage. Without stream recharge, approximately 7,300,000 af of water had been removed from storage within 100 years (Myers 2006) and with stream recharge approximately 6,960,000 af of water had been removed (Figure 11). Induced stream recharge accounts for most of the difference but the small difference, less than 5 percent, shows that inducing recharge from the streams does not increase the perennial yield significantly.

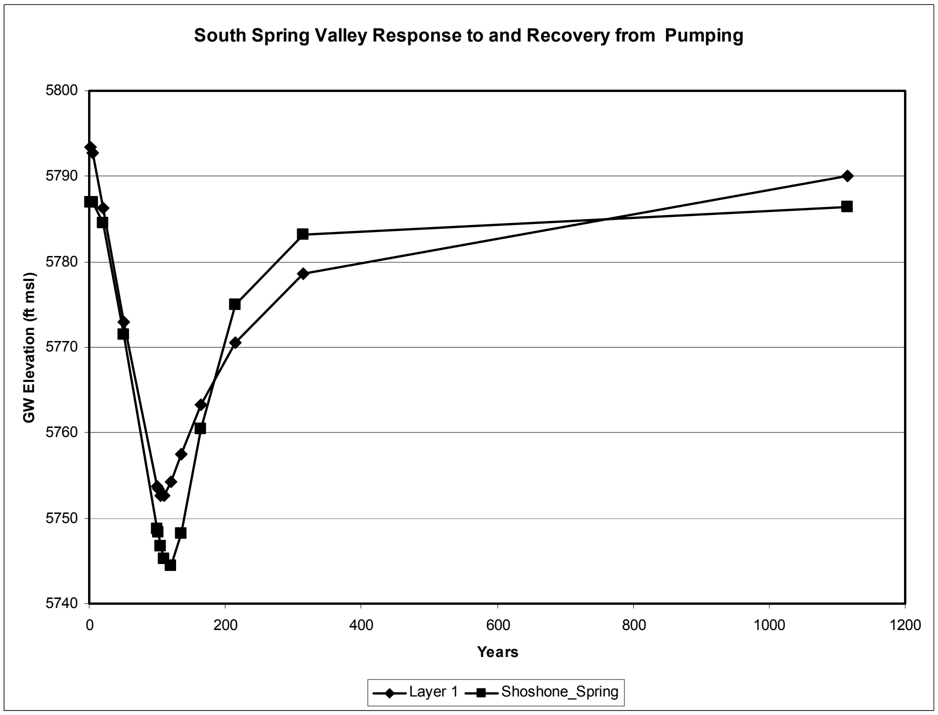

Figure 7: Observation well hydrographs for points in the southern Spring Valley. Refer to Myers (2006) for locations.

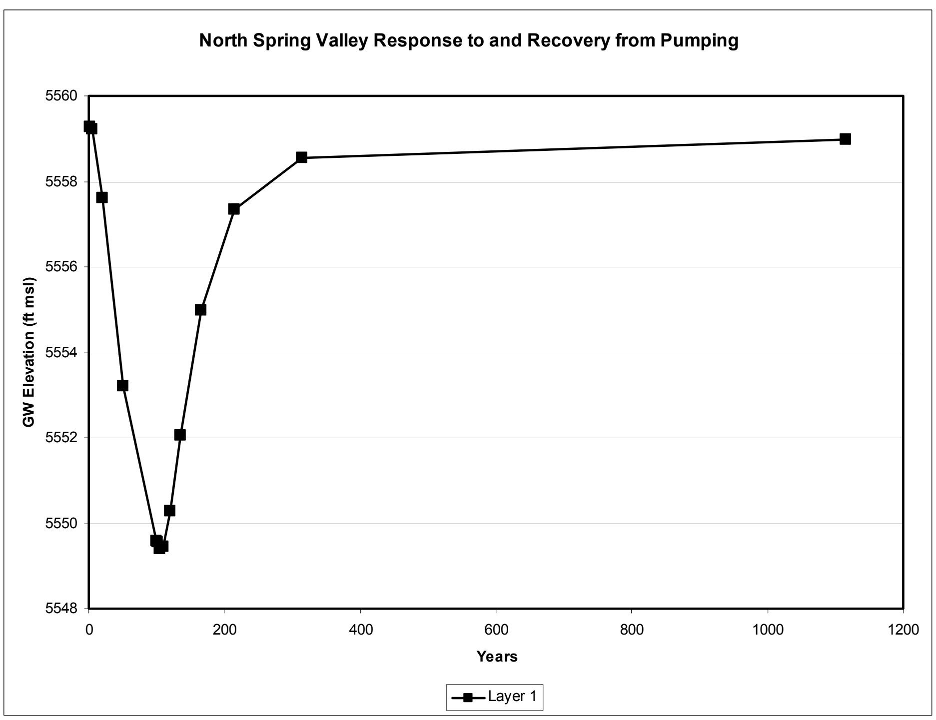

Figure 8: Observation well hydrographs for points in the northern Spring Valley. Refer to Myers (2006) for locations.

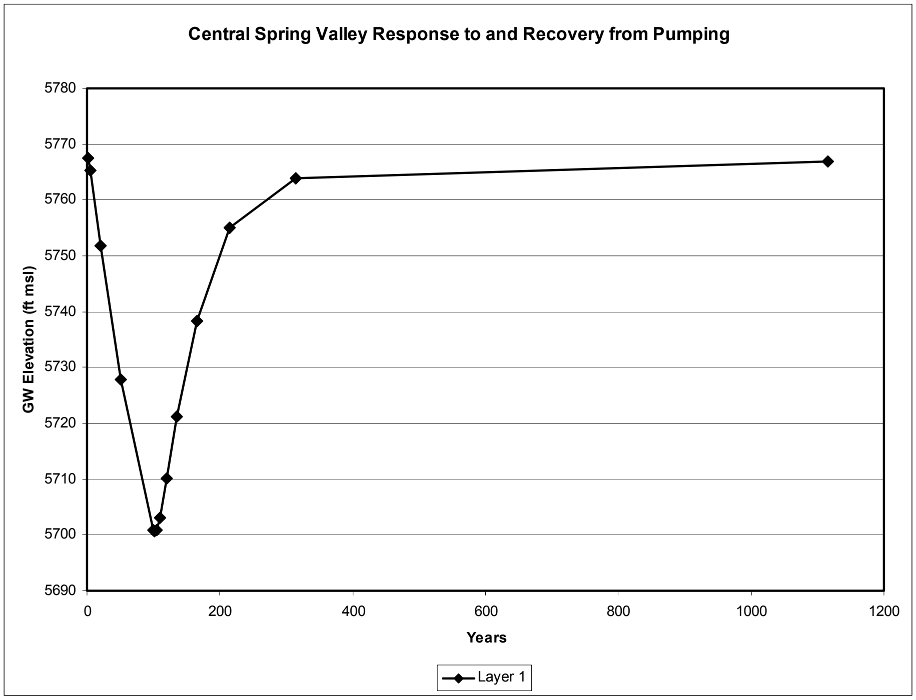

Figure 9: Observation well hydrographs for points in the central Spring Valley. Refer to Myers (2006) for locations.

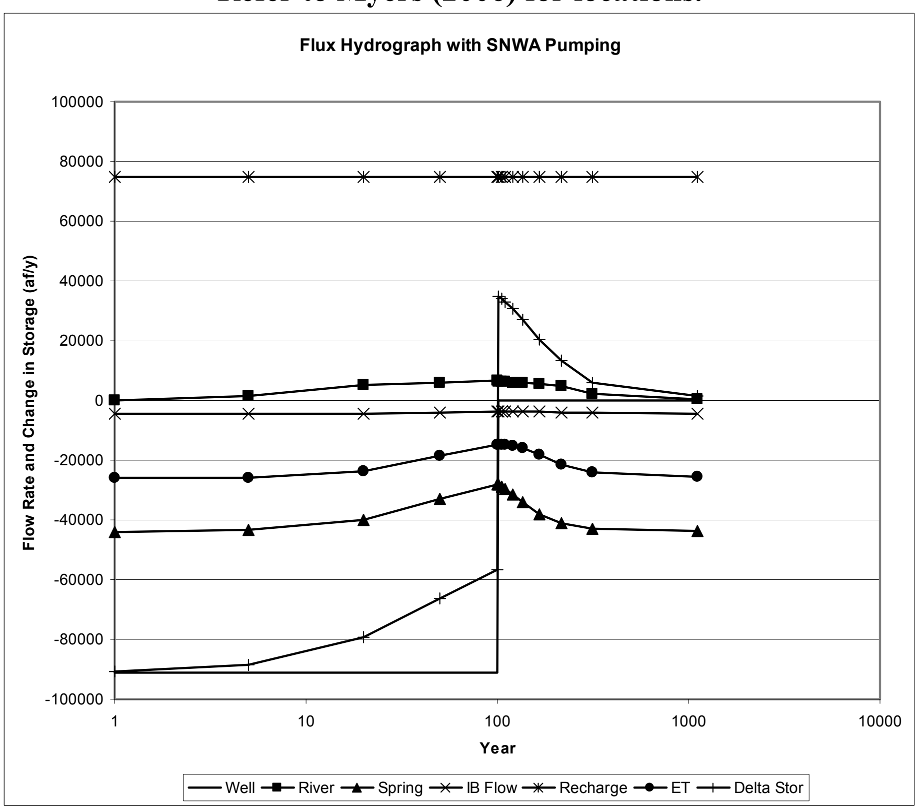

Figure 10: Flux hydrograph and change in storage for 100 years of SNWA pumping and 1000 years of recovery.

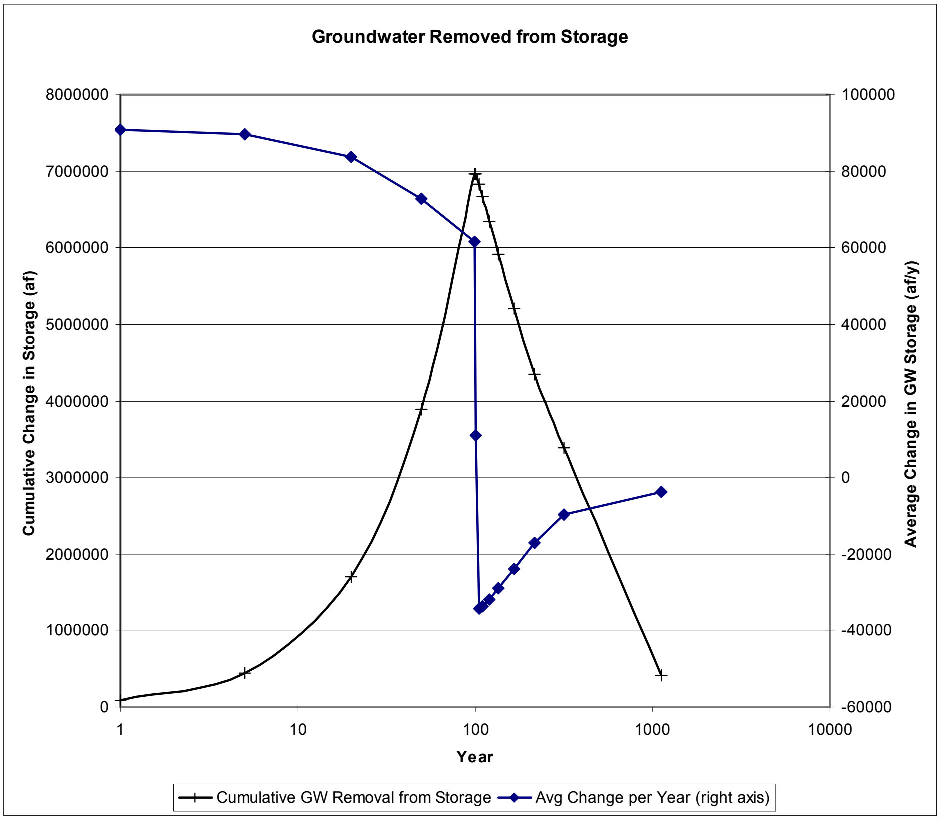

Figure 11: Average annual and cumulative change in storage for 100 years of SNWA pumping and 1000 year of recovery.

Stream recharge speeds the recovery by adding an additional source of water, but even after 215 years of recovery, the stream recharge rate is 4800 af/y (Figure 10). Recovery requires a long time because the deficit concentrates near the pumping but the recharge from both mountain block and streams occurs a long distance from the pumping. Shallow drawdown continues to expand as the deep drawdown near the wells recovers; the initial recovery of deep drawdown results from rearranging the groundwater storage. Small areas of wetlands not affected during the 100 years of pumping may be affected during a short period after the pumping ceases as the shallow drawdown expands.

Even with induced stream recharge, recovery at some points requires longer than it took to create the deficit because the rate of removal from storage during pumping exceeds the rate that natural processes, including recharge from the streams, replenishes it. Monitoring and mitigation plans may therefore be insufficient to protect the spring and wetland resources of the valley; once drawdown caused by large-scale pumping begins to affect the springs, a long time period may pass before stopping the pumping will improve conditions.

The same may be said for protecting interbasin flow. After 100 years, the flow to Hamlin Valley (interbasin flow in Figure 10) reduced from the calibrated 4600 af/y to

3700 af/y. Interbasin flow continues to decrease slightly for a year and after 65 and 215 years, respectively, has recovered to only 3880 and 4145 af/y.

Summary for Adding Stream Recharge

Stream recharge allows the pumping to eventually, after 22,000 years, approach steady state. But the transitional storage removed, almost 118,000,000 af, far exceeds the published transitional storage for the entire central region of Nevada. Inducing stream recharge is not very effective at increasing the available water because of the location of those streams. Stream recharge also speeds the recovery, but not much. Unless the point of concern is close to a stream, the streams will not help recovery.

Conclusion

The best estimate of perennial yield in Spring Valley is 70,000 af/y. SNWA's estimate is too high because it is based on ET and recharge estimates which are too high.

SNWA's ET discharge estimate, 90,000 af/y, is too high because it is based on measurements during the wettest decade in 100 years. The more appropriate ET discharge value is 71,000 af/y. SNWA also estimates 87,000 af/y of mountain block recharge and over 11,000 af/y of streamflow recharge. This contradicts another of their submitted studies, the groundwater model report, that uses 65,000 af/y of mountain block and simulates just over 18,000 af/y of streamflow recharge. Either this value or 75,000 af/y of both mountain block and alluvial fan recharge is more appropriate for Spring Valley.

SNWA's attempt to increase the perennial yield by inducing recharge from stream beds is dubious because it provides no plan to do so or proof that it could occur. Many centuries will pass before sufficient water can be induced to recharge to cause the system to come into steady state, a requirement for the development of a perennial yield. Most of the perennial streams lose substantial amounts of water at the mountain front where they begin to flow across alluvial fans, therefore it seems unlikely that the groundwater connection with the streams is sufficient to induce substantial recharge.

There are 46,035 af/y of certificated and permitted and 55,434 af/y of vested stream flow rights. Considering just the certificated and permitted streamflow rights and assuming that these rights are used all season, from April to September, for a six month irrigation season, and assuming that most stream flow from July through September is baseflow, half of the surface water rights, or 23,018 af/y, depend on groundwater. By definition, spring discharge is a discharge of groundwater, therefore the 3779 af/y of certificated and permitted spring flow rights also depend on groundwater. All surface water rights dependent on spring flow or stream baseflow depend on groundwater and is water not available for appropriation as a part of the valley's perennial yield. Based on this, at least 68,388 af/y of groundwater is already appropriated in contradiction to SNWA's estimate of less than 7000 af/y.

Transient groundwater modeling using river boundaries to allow induced stream recharge showed that the system reached steady state after approximately 22,000 years. After 2000 years, stream inflow had only reached 85 percent of the difference between pumpage and specified recharge, therefore the pumpage continued to remove water from storage. Flow from streams does not quickly match the excess of pumpage over recharge because they lie far from the wells.

Over the more than 22,000 years that elapses before steady state establishes, SNWA removes almost 118,000,000 af of transitional from the groundwater reservoir. This is more than two and a half times the transitional storage specified by Nevada State Engineer Report 3 as being available in the entire central region of Nevada.

Drawdown occurring during the first 100 years of SNWA pumping is very similar to that predicted previously because the induced recharge from the streams reached only about 30 percent of the difference between recharge and pumpage. This indicates that the pumping plan has not induced sufficient recharge. Inducing stream recharge decreased the amount of water removed from storage within 100 years by just a few percent. Stream recharge speeds recovery by adding an additional source of water, but even after 215 years of recovery, the stream recharge rate is substantial. Recovery requires a long time because the deficit concentrates near the pumping but the recharge from both mountain block and streams occurs a long distance from the pumping.

Even with induced stream recharge, recovery at some locations requires more time than had been required to create the deficit. Monitoring and mitigation plans would therefore be insufficient to protect the spring and wetland resources of the valley; once drawdown caused by large-scale pumping begins to affect the springs, a long time period may pass before pumping cessation will allow sufficient recovery.

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