HYDROGEOLOGY OF CAVE, DRY LAKE AND DELAMAR VALLEYS

IMPACTS OF PUMPING UNDERGROUND WATER RIGHT APPLICATIONS #53987 THROUGH 53092

Presented to the Office of the Nevada State Engineer

On behalf of Great Basin Water Network

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INTRODUCTION

The Southern Nevada Water Authority (SNWA) proposes to develop up to almost 35,000 af/y of groundwater in Cave, Dry Lake and Delamar Valleys of eastern Nevada. This report was prepared on behalf of the Great Basin Water Network and a coalition of protestants to those water right applications. This report assembles evidence supporting the argument that pumping the proposed amount of groundwater will cause substantial drawdown and detrimental effects to the groundwater levels, spring discharge, wetland evapotranspiration (ET), and water rights in targeted and adjoining valleys.

This report is a revision of a report prepared in 2007 (Myers, 2007) in support of protestants in the first Cave Valley, Dry Lake, and Delamar Valley hearing. I have reviewed the material presented herein to assess whether it is still the best science. In particular, the reference to BARCASS (Basin and Range Carbonate Aquifer System Study) is updated to Welch et al (2008). Halford and Plume (2011) is an additional valuable reference because it is a use of the same model I utilized in 2007 to estimate drawdown and flux changes (Myers, 2007).

Figure 1 shows the general layout of Cave, Dry Lake, Delamar and surrounding valleys and SNWA's applications and Table 1 lists those applications and pumping rates. The 6 and 10 cfs applications were assumed to be fill and carbonate applications, respectively (Schaeffer and Harrill, 1995), but there is nothing in the applications that specifies the source aquifer. The applications total 11,583 afy for each of the three target valleys.

Table 1: SNWA's Water Rights Applications for Cave, Delamar and Dry Lake Valleys

Basin	Application	Legal Description	Div Rate (CFS)	Annual Duty (AFA)
	Cave Valley			
180	53987	SWNW S22 T06N R63E	6	4343.8
180	53988	SESE S21 T07N R63E	10	7239.7
	Delamar			
182	53991	SENE S4 T05S R63E	6	4343.8
182	53992	NENE S15 T06S R64E	10	7239.7
	Dry Lake			
181	53989	SESW S30 T02S R64E	6	4343.9
181	53990	NESE S8 T02S R65E	10	7239.8

The study area for this analysis is the entire Colorado River Flow System which includes the targeted basins (Figure 1), surrounding basins and downgradient basins which may receive interbasin flow originating in the targeted basins. The expansive study area is necessary because the valleys head the White River and Lower Meadow Valley Wash flow systems, and SNWA pumping could affect spring flow far downgradient in those systems.

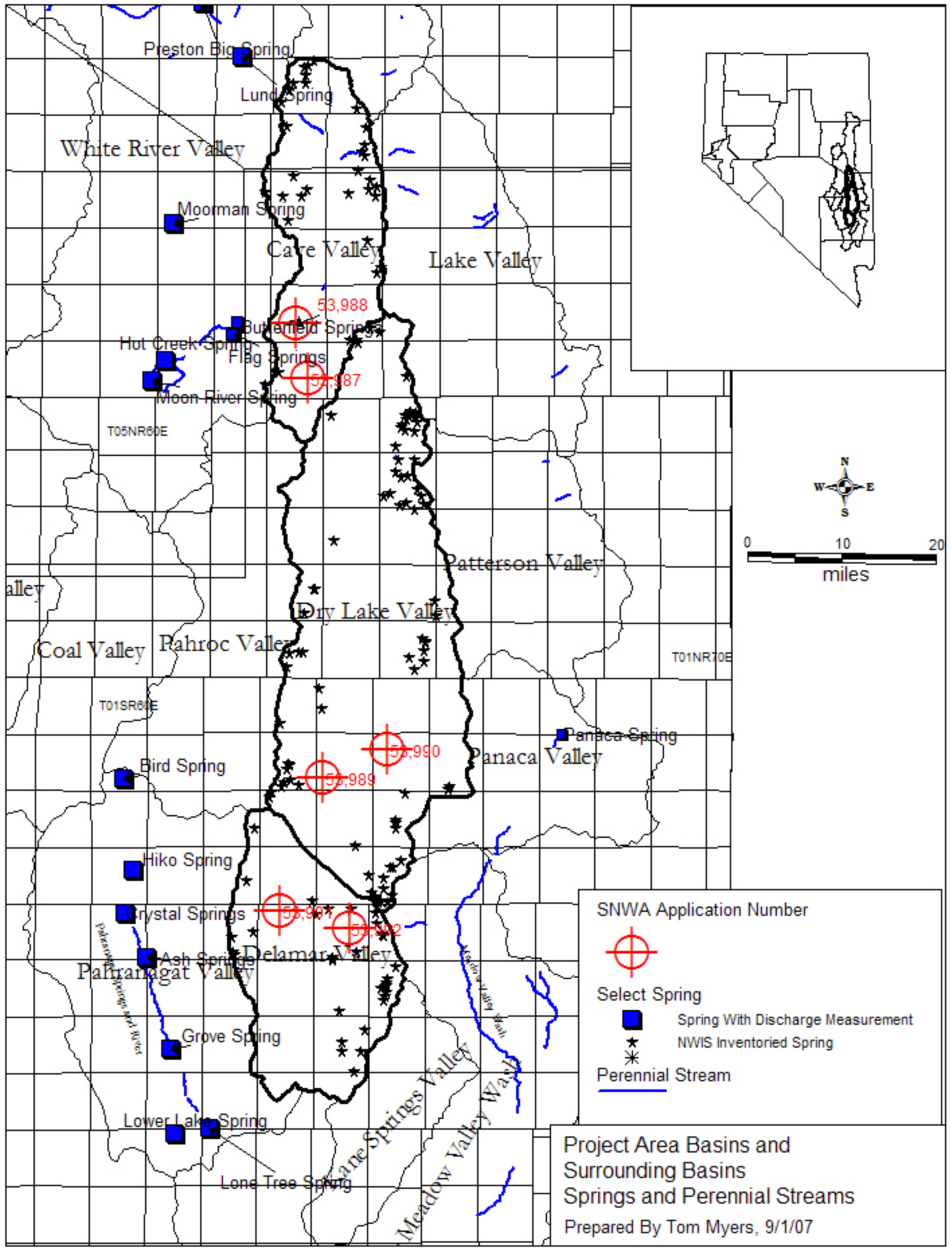

Figure 1: Location of target and surrounding basins, select springs, perennial streams, and SNWA's water rights applications (see Table 1 for description).

This report presents two types of evidence. The first is a conceptual model for flow in the targeted basins and the flow systems that depends on groundwater originating in the targeted basins. This includes a presentation of a water balance discussion for the flow system and a detailed discussion of recharge and the factors that control it in the targeted basins. The second line of evidence involves a simulation of SNWA's applications using a model developed by the U.S. Geological Survey (Prudic et al, 1995; Schaeffer and Harrill, 1995). The simulation estimated the effects of pumping spring flows and the time until the system comes to equilibrium with the pumping.

Much of the analysis depends on existing widely available research reports completed by the U.S. Geological Survey including studies completed as a part of the Regional Aquifer System Analysis (RASA) in the 1990s, the original reconnaissance reports completed by the USGS and Nevada Department of Conservation and Natural Resources (Eakin 1962, 1963 a, b and c), and reports prepared by LVVWD and SNWA in support of previous hearings or analyses completed in support of their applications (Brothers et al 1996, LVVWD 1992 and 2001, SNWA 2006). Also utilized are the BARCASS studies, including the final report to Congress (Welch et al 2008) and a series of scientific investigations reports issued in final form (Flint and Flint 2007, Moreo et al 2007).

Hydrology of the Study Area

Geology

The study basins are part of the eastern Great Basin portion of the Basin and Range provinces of the western United States. Topographically, the three basins have interior drainage. Alternating layers of sedimentary rock, characterized by either clastic rocks with minor amounts of carbonate rock or by carbonate rock with minor amounts of clastic rock form the primary bedrock of the eastern Great Basin (Harrill and Prudic 1998) and the study basins. The carbonate and clastic rock ranges from 5000 to 30,000 feet thick. Crystalline basement rock, commonly metamorphic and granitic rocks of Precambrian age, underlies the sedimentary rock. In some places, including the high points of the Schell Creek Range on the northeast bound of Cave Valley (Plate 1), these older rocks outcrop. In some areas there are substantial outcrops of intrusive igneous rocks; these include the eastern and southern bounds of the study basins (Plate 1).

Extensional faulting formed the present-day ranges and basins. The basins that formed during mountain building filled with eroded clastic deposits from the mountains. Faults, including high-angle normal, listric normal and low-angle normal faults bound the basins. Dry Lake and Delamar Valley lie in a "surficially closed trough" above the surrounding valleys (Eakin 1963a). They are grabens with basin bounding faults.

Carbonate rock outcrops bound Cave Valley (Figure 2), particularly on the west which is the Egan Range. The southeast side, in the Schell Creek Range is also carbonate. The southern end of the Schell Creek Range divides Cave Valley from Dry Lake Valley (Figure 2). In the middle of Cave Valley, a carbonate outcrop extends northeastward into the center of the valley. The faults tend to lie in a northeastward direction; the Shingle Pass fault effectively bent the Egan

Range and exerted significant controls on interbasin flow, discussed below. Granite forms the core of the Schell Creek Range on the valley's northeast bound. The south ends of the ranges consist mostly of volcanic tuff.

The Cave Valley basin consists of basin fill, eroded clastic deposits from the surrounding mountains. The southern portion contains a playa about 1000 feet below the northern portion; the north portion slopes southward and is carved by ephemeral streams emanating from the surrounding mountains. The basin fill is thickest under the playa, ranging from 5 to 6 km (Schierer 2005), or up to 18,000 feet. The northern basin fill is less than 1 km, or 3200 feet thick.

A mixture of tuffs, basaltic flows and carbonate rock bounds the west side of the north half of Dry Lake Valley (Figure 3); further south on the west, it is mostly tuffs and basaltic flows. Carbonate rock may underlie the volcanic rock as shown on the well log for well 22450 (Appendix 1) discussed below and as indicated by Plume (1995). There is also carbonate rock in the Schell Creek Range separating the north end of Dry Lake Valley, also known as Muleshoe Valley, from Cave Valley. Additionally, the volcanic rock is highly faulted (Scheirer 2005). The basin fill is mostly less than 1 km thick, but there is a trough in the basement rock just east of the center which thickens the basin fill to as much as 8 km (26,000 ft). The thickest part corresponds with the playa in the south half of the valley.

Primarily volcanic rock surrounds Delamar Valley (Figure 4). Substantial northeast trending faults fracture the volcanic rock in the southwest portion of the valley; this is known as the Pahranagat shear zone. The basin fill mostly ranges from 1 to 2 km thick, but reaches a 6.5 km thickness under the playa in the southwest portion of the valley.

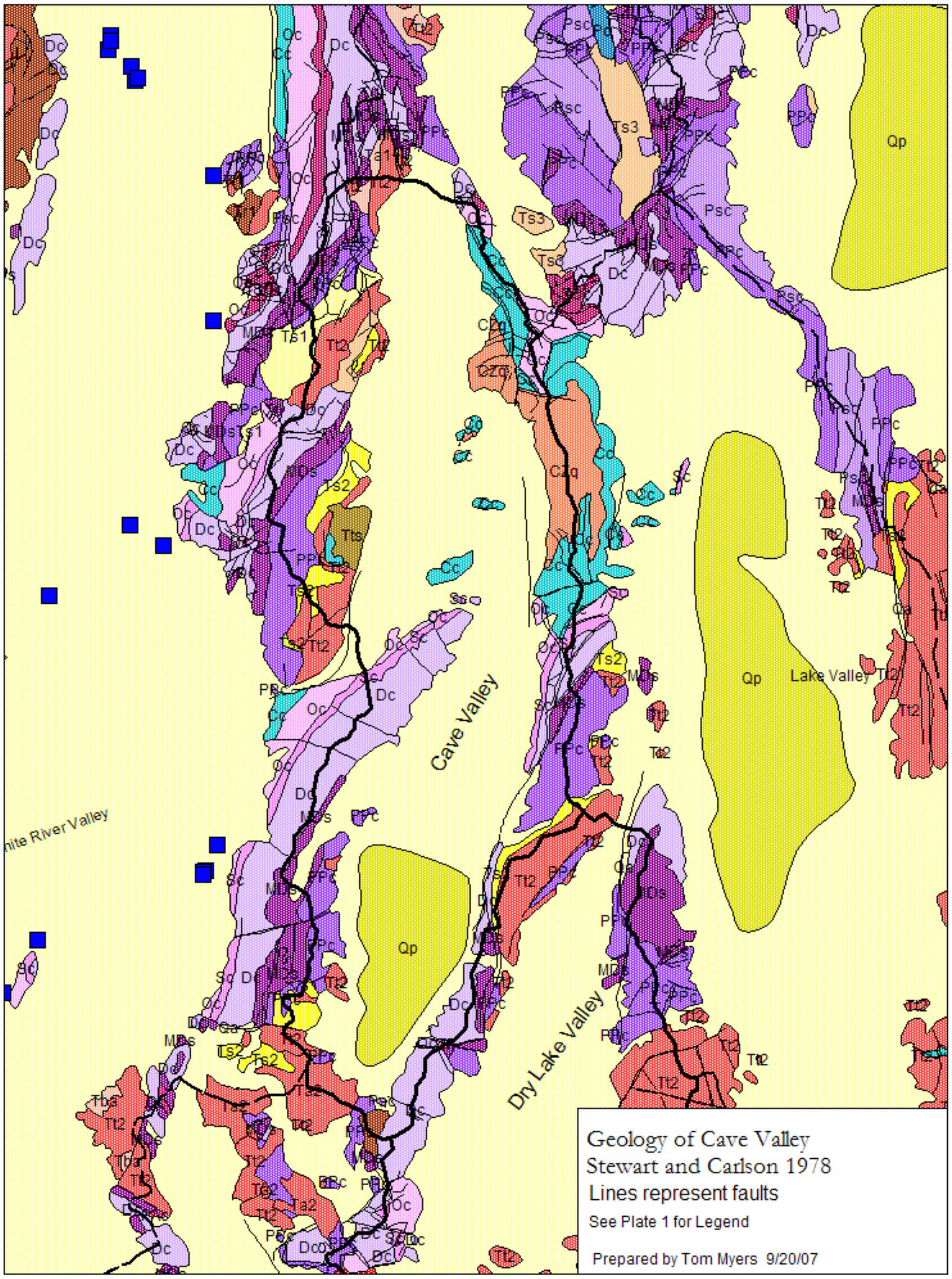

Figure 2: General geology of Cave Valley. Blue squares are springs (Figure 1).

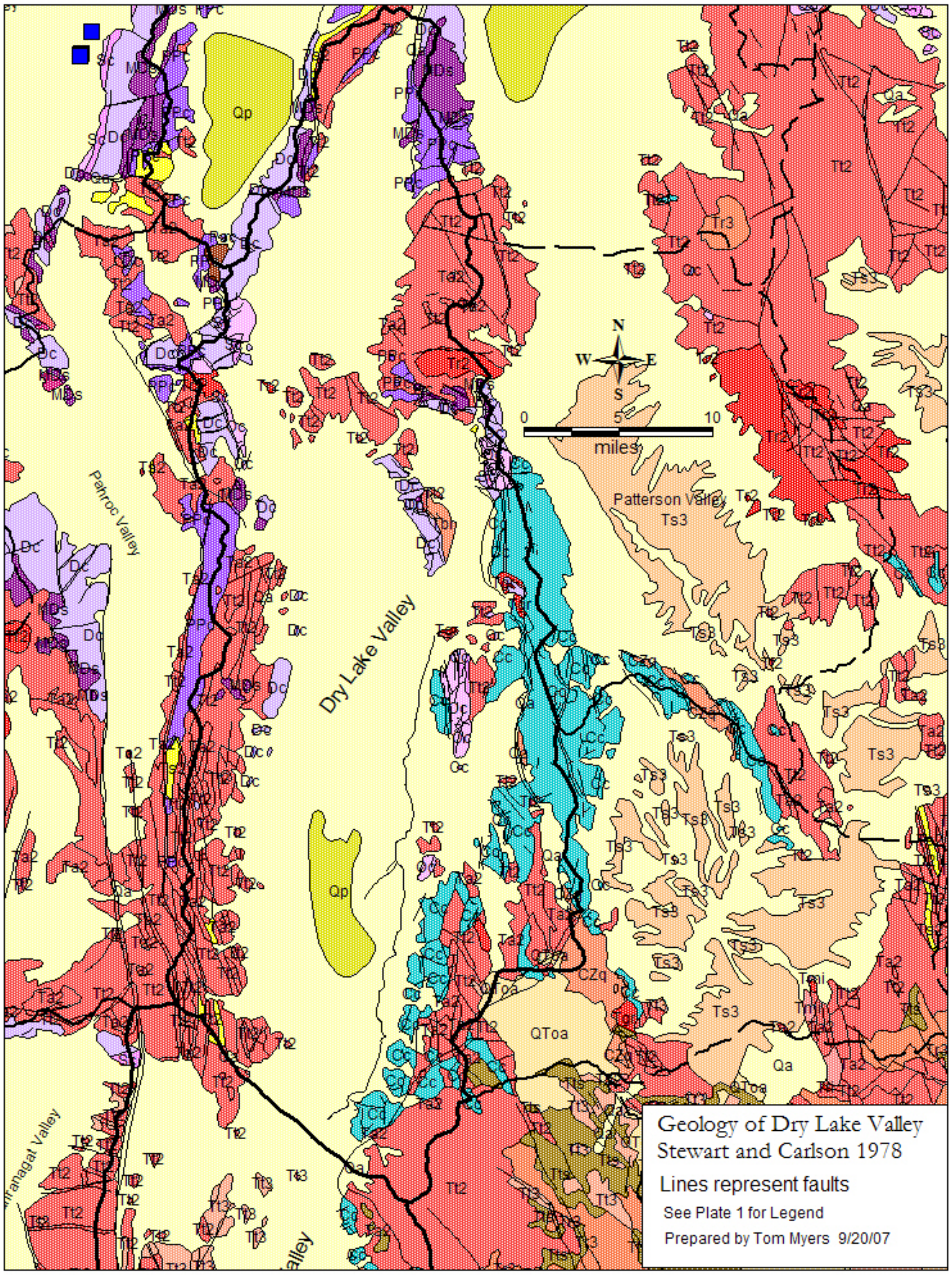

Figure 3: General geology of Dry Lake Valley. Blue squares are springs (Figure 1).

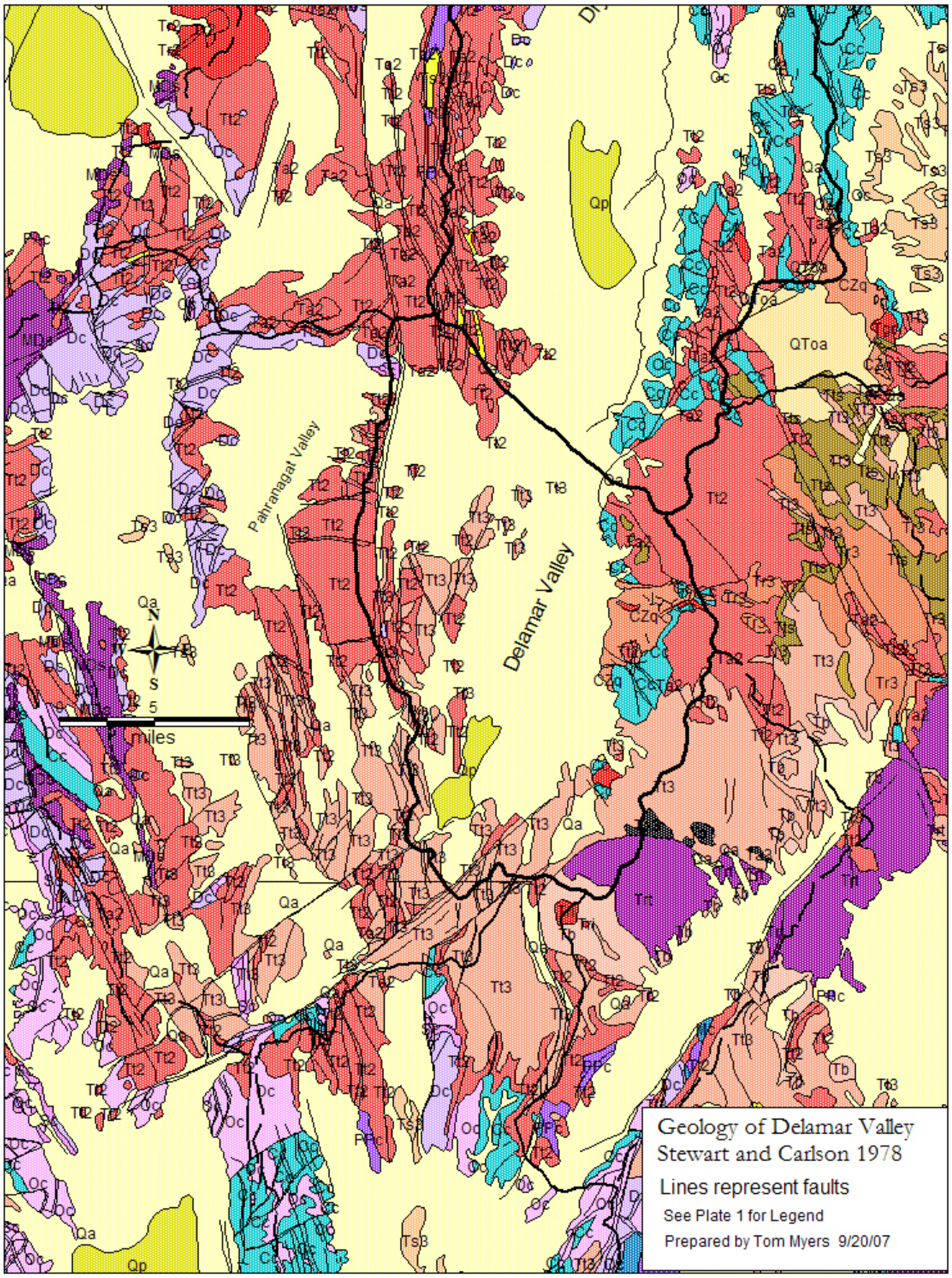

Figure 4: General geology of Delamar Valley. Blue squares are springs (Figure 1).

Hydrogeology

Harrill and Prudic (1998) define five types of hydrogeologic units in the eastern Great Basin: (1) metamorphic, igneous, and sedimentary rocks of Precambrian and Early Cambrian age, (2) carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, (3) sedimentary and igneous rocks of Middle Triassic to Quaternary age, (4) older basin-fill deposits, and (5) younger basin-fill deposits. BARCASS expanded those definitions, importantly by dividing the carbonate rock into upper and lower units (Welch et al, 2008). The aquifers are the carbonate-dominated rocks and the basin fill. The old metamorphic, igneous and sedimentary rocks are the lower boundary below which groundwater flow is minimal.

Carbonate aquifers are highly heterogeneous with little primary permeability but in areas with fractures very high secondary permeability which allows for very high transmissivity over short distances. Maps of transmissivity across the entire province illustrate the variability as determined by calibrating a steady state groundwater model (Prudic et al 1995; see Figure 24 and 25 below). Conductivity values from pump tests in carbonate rock spanned seven orders of magnitude (Belcher et al 2001); faulted and karstic carbonate rock conductivity values spanned five orders of magnitude with values as low as 0.01 m/d (0.032 ft/d). Pump test transmissivity values represent only the aquifer thickness affected by the test and should not be multiplied by a larger thickness in an attempt to represent a larger area (Fetter 2001).

Faults can affect flow significantly as flow barriers or pathways, due to fractures which can be either open or cemented with small particles. Away from the core, the fault fractures enhance the porosity allowing flow parallel to the fault. Durbin's (2006) groundwater model, that included Cave Valley, included numerous faults as part of the conceptualization and calibration. The mountain front fault along the Schell Creek Range north of Patterson Pass (fault 32 in SNWA (2006)) bends across the valley (fault 40) and intersects with the carbonate outcrop in the middle of the valley and attached to the Egan Range. Another mountain front fault (fault 31) extends south along the Schell Creek Range. The mountain front fault on the Egan Range extends north from Shingle Pass (fault 39) but not south. Faults along the north Schell Creek Range and north Egan Range have high leakance values indicating they do not substantially impede the flow. The fault spanning Cave Valley has a very low leakance indicating it effectively separates the north and south portions of the valley. The mountain front fault south of Patterson Pass along the Schell Creek Range (fault 32) also has a low leakance.

Conceptual Flow Model

The three valleys lie in the middle of the carbonate rock province (Harrill and Prudic 1998). Precipitation is much higher in the mountains and recharges there if the geology is sufficiently permeable and at the mountain front on the basin fill and alluvial fans where the runoff emerges from the mountains. Very little runoff reaches the playas in these valleys and that which does evapotranspires from the playa or surrounding vegetation rather than recharging the regional basin fill aquifer.

Basic flow pathways within the targeted valleys are relatively simple. Recharge occurs as described above but there is little discharge within the valleys because they drain to adjacent valleys, as described below. The lack of GW ET from areas around the Cave Valley playa (Welch et al, 2008; Moreo et al, 2007) reflects the fact that little groundwater flows from the north, where most recharge occurs, to the south end of the valley. In all three valleys, most of the discharge is to downstream basins rather than to GW ET.

At the regional scale, discharge from the carbonate aquifers occurs from large springs emanating from the carbonate aquifer all over the eastern Great Basin, to rivers bounding the province, and to basin fill aquifers. Discharge to the basin fill from the mountain bedrock supplements mountain front recharge by providing groundwater inflow to the basin fill aquifer. GWET occurs in valleys with shallow groundwater, where roots can reach the groundwater.

Basin fill aquifers tend to be phreatic, or unconfined, but layering causes high vertical anisotropy and flow in deep layers may resemble that in a leaky confined aquifer (Bear, 1979). Initially, pumping at flow rates exceeding the rate at which flow from upper layers can replace it lowers the potentiometric surface deep in the basin fill which causes a downward vertical gradient although the stresses may propagate quickly at depth. Fracture zones in carbonate and volcanic aquifers are confined because they are isolated by low permeability bulk media. The potentiometric surface in fracture zones can respond very quickly at great distances from the point of pumping when it occurs (Bear 1979).

Interbasin flow is a major part of the conceptual flow model of the area. The targeted basins lie at the "headwaters" of the White River Flow System (Eakin 1966). Cave Valley drains to White River Valley and/or Pahroc Valley; Dry Lake Valley drains to Delamar Valley which then drains to Pahranagat Valley (Figure 1). Faults with low leakances may help control the location of interbasin flow. The Pahranagat shear zone may affect the flow at the south end of the valleys by diverting groundwater to the southwest from Delamar to Pahranagat Valleys. Various large subsurface magnetic sources may correspond to granitic rock or crystalline basement rock and be flow barriers as well (Harrill and Prudic 1998). The northeast portion of Cave Valley, in the Schell Creek Range, has an outcrop of granitic rock which may impede flow to the east from Cave Valley, if the gradient in the water table would allow such flow.

Water Balance

The simple water balance for an aquifer system is as follows:

$$R + Qi = ET + Qo + \Delta S$$

Recharge is R, ET discharge is ET, Q_i is interbasin inflow and Q_o is interbasin outflow. ΔS is the change in storage. At steady state, ΔS equals 0. The following sections consider the components of this equation for each targeted basin and also consider aspects of it for the basins which receive interbasin flow from each targeted basin.

Recharge Estimates

Groundwater recharge is the meteoric water that reaches the regional groundwater in a basin. Recharge manifests as mountain-block or mountain-front recharge (Wilson and Guan 2004). Mountain-block recharge is the diffuse recharge that occurs near where the precipitation falls (Flint et al 2004; Flint and Flint 2007). Mountain-front recharge is primarily that which occurs near the mouth of ephemeral and intermittent streams on the alluvial fans. Recharge of streamflow from perennial streams may be secondary recharge if it had discharged from the groundwater into the stream. Underflow from the mountain block to the basin fill occurs where there is a hydraulic connection between.

Flint et al (2004) developed a basin characterization model (BCM) for the Great Basin which determines diffuse recharge based on the water balance of the soil layer with ET discharge and percolation into the underlying geologic formation considered recharge. Flint and Flint (2007) used the same method on the basins contained within or intersecting with White Pine County. They assumed that 15% of the runoff, based on literature values, becomes recharge, even though research has shown the percentage of runoff that recharges varies from very little to as much as 90 percent depending on the aridity of the basin and the amount of runoff. The sum of diffuse and runoff recharge is a basinwide estimate (Table 2).

In Nevada, the Maxey-Eakin method (Maxey and Eakin 1949) has been used for decades to estimate groundwater recharge for entire basins. Interestingly, the original report was a groundwater assessment for White River Valley, not a study of recharge methods. The entire method is described in less than a paragraph:

> [Determination of recharge] requires a determination or estimate of average annual precipitation for the drainage area, from which the recharge is calculated as a percentage. An estimate for the precipitation in the White River Valley was made from a precipitation map for the State of Nevada in which zones of average range of precipitation are designated. The zones are divided into the following ranges: less than 8 inches; 8 to 12 inches; 12 to 15 inches; 15 to 20 inches; and over 20 inches. The amount of water from the successive zones that reaches the ground-water reservoir is estimated as, 0, 3, 7, 15, and 25 percent of the precipitation in the respective zones. The percentages are adapted for this area from preliminary recharge studies in east-central Nevada. These studies consisted of estimating the ground-water discharge by natural losses from 13 valleys in east-central Nevada. The recharge for each valley was also estimated, using the rainfall-zone map as a basis. **The recharge estimates were**

> **then balanced by trial-and-error with the discharge estimates**. (Maxey and Eakin 1949, pages 40 and 41, emphasis added)

Maxey and Eakin (1949) does not list the 13 basins used for the analysis. The rainfall map was the Hardman map of precipitation in Nevada. The discharge from an entire basin was assumed equal to recharge from precipitation within that basin. They weighted the precipitation in the various zones by trial and error so that the sum from recharge in each zone equaled the discharge for the basin. The derived coefficients are often called recharge efficiencies but they are not measured recharge at a point and should not be assumed to represent the actual amount of precipitation that recharges within a specific precipitation band. The coefficients are unique to the precipitation estimate used for their derivation, the Hardman precipitation map[1].

Avon and Durbin (1994) found that the Maxey-Eakin method was reasonably accurate, even though the method does not consider soils or geology. Precipitation will either run off and become mountain-front recharge or infiltrate depending on the soil and geologic properties. The sum of the mountain-block and –front recharge is the estimate for a basin, as estimated with the Maxey-Eakin method. It does not matter where the recharge actually occurs as long as it is above the points of discharge, to springs, streams, and/or phreatophytes. Table 2 presents the recharge estimates for the targeted valleys determined using the Maxey-Eakin method.

Kirk and Campana (1990) estimated recharge rates within the White River Flow System using a simple mixing cell flow model calibrated with the spatial distribution of deuterium. Their conceptual models include at least three flow regimes not currently widely accepted, including no interbasin flow from Cave to White River Valley, discharge from Pahranagat Valley to the Death Valley flow system, and for two of their scenarios, no flow from Jakes Valley. These groundwater fluxes are too small to substantially affect their recharge estimates. Because their method essentially distributed system wide recharge among the various valleys, their estimates are also included in Table 2.

Cave Valley

Recharge estimates for Cave Valley range from 9380 to 19,500 af/y, but five of the estimates are 14,000 af/y or less (Table 2). The high estimate, (LVVWD, 2001), 19,500 af/y, is incorrect because it is based on using Maxey-Eakin coefficients with different, and significantly higher, precipitation estimates. The Flint et al (2004) recharge estimates are lower than the Maxey-Eakin estimates from the recon report and the Flint and Flint (2007) estimates (Table 2)[2].

Although the methods differ, the similarity in the estimates increases confidence in the estimate. This analysis will use 14,000 af/y. Cave Valley has little in-basin discharge, so there is no independent verification of the recharge estimate.

[1] Kane Springs Ruling, #5712, pages 12-14.
[2] The Flint et al (2004) method was the same as used by Flint and Flint (2007), except for different cell size. It is possible the methods used different precipitation estimates.

Table 2: Recharge estimates by various methods for the targeted basins.

Basin	Recon Report or Water for Nevada	Flint et al (2004) (mean year)	Flint et al (2004) (time series)	Flint and Flint (2007)	LVVWD (2001)	Kirk and Campana (1990)[2]
Cave Valley	14000	10264	9380	11000	19500	11999
Dry Lake Valley	5000	10627	11298		13300	6664
Delamar Valley	1000	7764	6404		4600	1926
White River Valley	38000	34925	30759	35000		35001
Pahroc Valley	2200	4432	4832			1994
Pahranagat Valley	1800	7043	7186			1508
Coyote Spring Valley[1]	1900	5184	5951			5344
Kane Springs[1]	500	5421	6328			997
Garden/Coal Valley	12000	21813	18669			10994
1 - The recon report estimated 2600 af/y for Coyote Spring and Kane Springs Valleys together. The estimates here are from Water for Nevada.						
2 - Values adjusted from m^3/s						

Dry Lake and Delamar Valleys

The recon reports estimate 5000 and 1000 af/y of recharge for Dry Lake and Delamar Valleys, respectively (Table 2), similar to the estimates determined with deuterium analysis (Kirk and Campana, 1990)[3]. One possible Flint et al (2004) estimated substantially more recharge is the BCM is driven by climate date derived from a statistical model, which has been shown to overestimate precipitation in the Great Basin (Jeton et al 2005). PRISM overestimates precipitation for Cave and Dry Lake Valley by from 6 to 15 percent (Jeton et al 2005, Figures 8 and 9). Halford and Plume (2011) found that estimates for Hamlin Valley were so high that their methods grossly overestimated recharge in that region. Myers (2011) found similar problems with precipitation in that area.

Overestimates in precipitation will cause the BCM to overestimate recharge because in carbonate outcrops the conductivity is likely high enough to accept as recharge all available precipitation. The following statement from the BCM report state as much: "Percent differences between BCM and Maxey-Eakin derived recharge were consistently greater for

[3] These basins were used in the analysis sponsored by the Las Vegas Valley Water District that concluded the Maxey-Eakin estimates for the 20 valleys that at the time targeted with water rights applications had a total uncertainty of only about 10 percent total (LVVWD 1992). The analysis showed these three valleys were in the group that had a variability expressed as a coefficient of variation of 0.25. This implies that 67% of the estimates of recharge would lie within one-quarter of the expected of the value. If the Maxey-Eakin estimate is the expected value, recharge for Dry Lake Valley has a 67% chance of being between 4750 and 6250 af/y; similar values for Delamar Valley are 750 and 1250 af/y.

basins in which limestone with high saturated hydraulic conductivities were prevalent in the adjacent mountain ranges." (Flint and Flint 2007, page 11).

Because Maxey-Eakin was constrained using discharge estimates, and because they have relatively low coefficients of variation (Avon and Durbin 1994, LVVWD 1992), the Maxey-Eakin method is probably the best estimate for these valleys. Estimates made with the deuterium method of Kirk and Campana (1990) support the Maxey-Eakin estimates.

Downgradient Basins

Recharge estimates for White River Valley cluster between 30000 and 38000 af/y. This is the smallest range proportional to the magnitude; the physically-based method provides a estimate similar to the Maxey-Eakin method (Maxey and Eakin 1949) which will be used here for consistency with the estimates for other valleys.

As with other southerly basins, Pahroc, Pahranagat, and Garden/Coal Valley Maxey-Eakin (1949) recharge estimates completed in the recon reports (Eakin 1963 b and c) are similar to the estimates made with the deuterium method (Kirk and Campana 1990). The Flint et al (2004) estimates are four times higher. Considering the topography and geology of the area, it is difficult to assess where almost four times as much recharge as estimated with the Maxey-Eakin method could go in Pahroc and Pahranagat Valleys. The mountains forming the rim of these valleys are predominately volcanic (Plate 1). More than 80 percent of Pahranagat Valley lies below the 8 inch precipitation contour. The BCM estimates (Flint et al, 2004) are too high and the reconnaissance level reports will be used herein.

Coyote Spring and Kane Springs Valley are different. In this case, the deuterium method estimates much higher recharge. As will be discussed below, if the interbasin flow from Pahranagat Valley is low or nonexistent, new sources of recharge for Muddy River Springs must be identified. Kirk and Campana (1990) argue that much more recharge to Coyote Spring Valley occurs in the Sheep Range than previous accepted. The Flint and Flint (2004) recharge estimate is similarly much higher than the Maxey-Eakin estimate, in part because of the recharge in the Sheep Range. For this analysis the Coyote/Kane Spring Valley area recharge will be set equal to 6000 af/y.

Discharge Estimates

Discharge from the groundwater aquifers in a basin occurs in two ways: through groundwater ET and through interbasin flow. This section focuses on the groundwater ET estimates from other studies.

Cave Valley

Eakin (1962) noted that groundwater discharge from Cave Valley is only a few hundred acre-feet/year, being limited to the "main drainage channel in the valley fill …, adjacent tributary channels, and along the channel in the upper parts of the alluvial apron where the water table is at shallow depth, …, and to the spring areas, …, and near the Gardner Ranch" (Eakin 1962, pages

12-13, omissions from the quote are legal descriptions). Most valley wells have water only at depth (Table 3). Welch et al (2008) calculated more than 1500 af/y of ET discharge with the primary ET units being meadowland, marshland and grassland (small amounts of dense and moderately dense shrubland) (Table 4). These units were in the Cave Valley subarea 1 which is north of Shingle and Patterson Passes. ET discharge areas in subarea 1 mapped in Moreo et al (2007, Figure 4) correspond with aerial photographs, which show riparian vegetation along the Cave Valley Wash at and north of Parker Station (Figure 5), along Haggerty Wash about 1 ½ miles southwest of Parker Station (Figure 6) and near the ranch at Cave Spring (Figure 7).

Table 3: Well logs including legal description and depth to static water level (ft bgs) for Cave Valley. All data from NV State Engineer Web page (8/31/07).

Log No.	TWN	RNG	SEC	QTR SEC	Owner	Total Depth	Water Level
71199	N11	E63	25	SE SE	KINGSTON, BILL	140	91
7871	N09	E64	27	SE SW	U S BUREAU OF LAND MANAGEMENT	315	258
8605	N10	E64	4	NW NW	WHIPPLE, KEITH	200	149
22581	N07	E63	14	SW NW NE	U S AIR FORCE	460	231
22582	N07	E63	14	SW NW NE	U S AIR FORCE	460	230
92077	N09	E64	5	SE SE	MULL, WILLIAM	150	0
92078	N09	E64	5	SE SE	MULL, WILLIAM		0
8954	N07	E64	19		GULF OIL CORP	265	220
72899	N07	E63	27	SE SE	SMITH, CONNELY P	290	168
72900	N07	E63	27	SE SW	SMITH, CONNELY P	245	157
72901	N07	E63	27	SE SE	SMITH, CONNELY P	320	183
78564	N07	E63	33	SE	CONNLEY P SMITH OP CO	300	192
62885	N06	E64	18	NW SW	SMITH, CONNELY D	500	400
62889	N07	E63	13	NW SE	SMITH, CONNELY D	250	180

Table 4: Cave Valley groundwater discharge calculations from BARCASS (Welch and Bright 2007, Appendix A).

Sub	Marshland	Meadowland	Grassland	Dense desert shrub	Mod dense desert shrub	Sparse desert shrub	Moist bare soil	Open Water	Dry Playa	Irrigated Crops that occupy land that previously had phreatophytes	**Total**	**Basin Total**	**Notes**
1	81	503	280	842	354	6	0	0	0	0	2,066	**13,347**	**AREA (ac)**
2	0	0	2	534	7,005	3,546	0	0	194	0	11,281		
1	4.11	2.53	2.15	1.37	1.30	0.98	2.00	5.10	0.75	1.40			**ET Rates (ft/y)**
2	4.10	2.75	1.97	1.11	1.00	0.98	2.00	5.10	0.75	1.40			
1	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11			**Prec. Rate (ft/y)**
2	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08			
1	3.00	1.42	1.04	0.26	0.19	0.00	0.89	3.99	0.00	0.29			**GW ET Rate (ft/y)**
2	3.02	1.67	0.89	0.03	0.00	0.00	0.92	4.02	0.00	0.32			
1	332	1,271	603	1,156	460	6	0	0	0	0	3,828	**15,050**	**Total ET (af/y)**
2	0	0	5	591	7,005	3,475	0	0	146	0	11,222		
1	242	712	292	221	67	0	0	0	0	0	1,534	**1,550**	**GW ET (af/y)**
2	0	0	2	14	0	0	0	0	0	0	16		

Sub: subbasin number. For Cave Valley, 1 is north and 2 is south

Area is the total area within a subbasin for a specific ET unit, such as marshland, etc. ET rates are rates from all water sources including precipitation and groundwater. Precipitation rates are rates derived for the specific unit based on the PRISM method. GW ET is ET rate adjusted for precipitation; it assumes that all precipitation is effective and that the remainder comes from groundwater. There was no consideration given to depth to the water table. Total ET is the total volume of ET from all sources for an ET unit. GW ET is the total volume of ET from the groundwater for a give unity.

Figure 5: Phreatophytes along Cave Valley wash, observed to be dense shrubs dominated by rabbitbrush. The area extends from Parker Station on the south north about 2.5 miles along the wash, or about 720 acres.

Figure 6: Phreatophytes along Haggerty Wash about 1.5 miles southwest of Parker Station. Parker Station is in the green area on the upper right corner.

Figure 7: Phreatophytes and drainage patterns near springs in Cave Valley, including the drainage below Sheep Spring; the photo also shows ranch house and water impoundment. The southerly strip of green commencing south of the light area is Cave Valley Spring and drainage.

As observed during a site visit, the riparian system along Cave Valley Wash consisted mostly of dense shrubs dominated by rabbitbrush. The valley is narrow at this location; the surrounding uplands are steep, older gravel. Runoff from the many ephemeral tributaries would likely recharge through their stream bottoms. One well, 180 N10 E63 S25A, is just 20 feet deep and located in the alluvium along Cave Valley Wash (National Water Information System web page). The depth to water in this alluvium was 17.8 feet bgs in 1958, but between 2005 and 2007 it was less than 14 feet (Table 5). The rabbitbrush was drought-stressed, but not dead, during late September 2007. The water level apparently fluctuates seasonally as would be expected in an alluvial aquifer recharged by ephemeral surface flows. The low recent groundwater levels would be consistent with water table lowered during a year with little mountain front recharge. Because mountain front recharge is recharge to the basin, discharge from riparian vegetation along the wash should be considered groundwater discharge from the basin. The area from Parker Station to about 2.5 miles north and spanning the width of the lower terraces is about 740 acres. There were no indications of recent irrigation along this area.

Table 5: Groundwater Level observations for well 180 N10 E63 25A. Data source USGS NWIS web page, 8/31/07.

Obs Date	Static Water Level (ft bgs)
7/15/1958	17.8
8/16/2005	9.14
8/16/2005	10.94
9/22/2006	13.9
11/15/2006	13.83
2/21/2007	13.4
5/29/2007	13.46

The area near Haggerty Wash is about 100 acres of dense shrubs. Haggerty Wash is a tributary to the basin fill in the center of the valley and any streamflow infiltration would be to the isolated aquifer along that tributary. Infiltration to the tributary alluvium would be considered recharge to the valley's basin once it discharges from shallow groundwater along the channel to the basin fill in the middle of the valley, and becomes available to the valley-wide basin.

Moreo et al (2007, Figure 4) shows a substantial area of discharge near the playa in the south half of Cave Valley. LVVWD (2001, page 4-36) mentioned GW ET from a "healthy stand of greasewood" near the playa. During the site visit, this author found this to be an area of shrubs north of the playa best described as sparse shrubland following the Moreo et al (2007) nomenclature (Figure 8). References to a "monitoring well constructed on the southwest side of the playa within the greasewood assemblage showed the water table to be about 30 feet below land surface" as proof of groundwater discharge (LVVWD, 2001) do not include the well identification or water level hydrograph, and should be discounted.

Figure 8: Sparse shrubland north of the Cave Valley playa. Photo by Tom Myers, 9/25/2007.

Springs are part of the estimated discharge from a basin if the spring discharges from a regional aquifer. Most springs are in the northern portion of the valley (Figures 9 and 10), and the BARCAS database has only one flow measurement – Cave Spring - estimated to be 700 gpm, or about 1100 af/y – this estimate is too high. It was an average of two measurements, 400 and 1000 gpm (Welch et al, 2008, Appendix B). The water temperature is cold, about 52°F, suggesting the water does not circulate to significant depth. The spring water right 4881, certificate 1060, dated 1/31/1918, is for 0.751 cfs with a duty of 225.57 AFS, which would be 543.7 AF over an entire year. The spring emanates from unconsolidated sediment at the valley margin (Welch et al 2008). During the site visit, the author observed the spring emanating from a small cave of which the back could not be seen with a standard flashlight. The map (Figure 11) shows it located at the base of a 200 foot outcrop in the middle of the valley – the light shaded area in Figure 7. The outcrop is Pole Canyon limestone and Pioche Shale which probably controls the spring (Figure 2). The drainage below Cave Spring was dry with just a few acres of cottonwood and willow. During the author's site visit, the flow was visually estimated based on channel width, depth and velocity to be about 5 gpm. Based on experience, water rights associated with springs usually exceed the average flow values. Considering the observed spring discharge, the lack of riparian vegetation and the failure of both Eakin (1962) and LVVWD (1993) to mention the spring, it is likely that the average discharge should be considered to be much less, probably no more than 250 af/y.

The database also lists Sheep Spring (Figure 9), but does not provide discharge measurements. The temperature is 57.2°F and the spring is upland at almost 7400 ft msl. It apparently emanates from unconsolidated sediment. The map also shows two unnamed springs along the drainage below the spring. The geology maps show a Pole Canyon limestone outcrop just north of the drainage; the unnamed springs could emanate from that or be secondary recharge of Sheep Spring water. The aerial photograph (Figure 7) shows substantial riparian areas that appear to be dense shrubland. A vested spring water right, V02692, dated 11/25/1970, for 0.414 cfs, or 300 af/y, in section 9 of T9NR63E, is actually downstream of the spring. This is about 300 af/y. There is also a vested streamflow right, V01680, dated 1/8/1920, for 1 cfs used for stockwater. Other springs shown in Figures 9 and 10 are either upland or at the base of the mountains emanating from a drainage channel. Aerial photos show thin strips of green, but field reconnaissance indicates most are seeps and/or from perched aquifers.

In summary, there are three sources of groundwater discharge within Cave Valley: Cave Spring, the riparian area along Cave Valley Wash and the riparian area along the channel below Sheep Spring. As discussed above, the discharge from Cave Spring is about 250 af/y. The two riparian areas are both dense shrubs. The estimated GW ET rate for dense shrubs in Cave Valley is 0.89 ft/y (Welch et al 2008). The Cave Valley Wash has 720 acres, therefore the GWET from Cave Valley Wash is 640 af/y. The 360 acres along Sheep Spring would have GWET equal to 320 af/y. The total discharge from Cave Valley estimated for this analysis therefore approximates 1200 af/y.

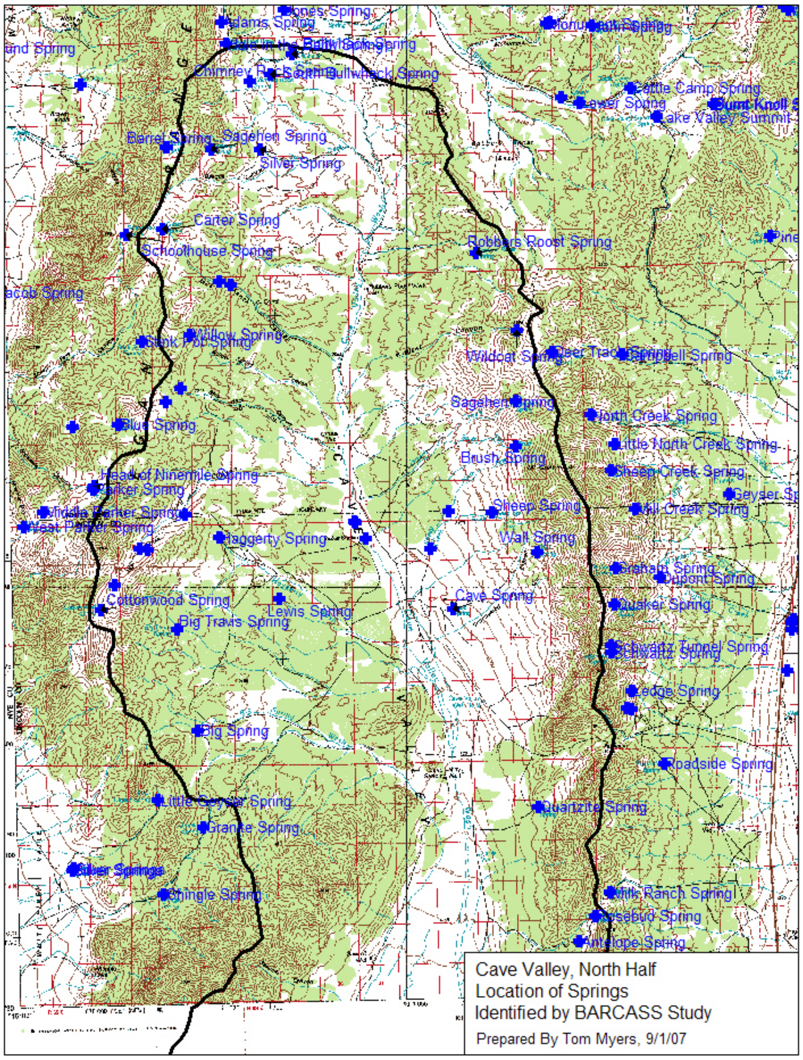

Figure 9: Map of northern Cave Valley showing location of springs from Welch and Bright (2007). Basemap USGS 1:100000 scale Garrison UT.

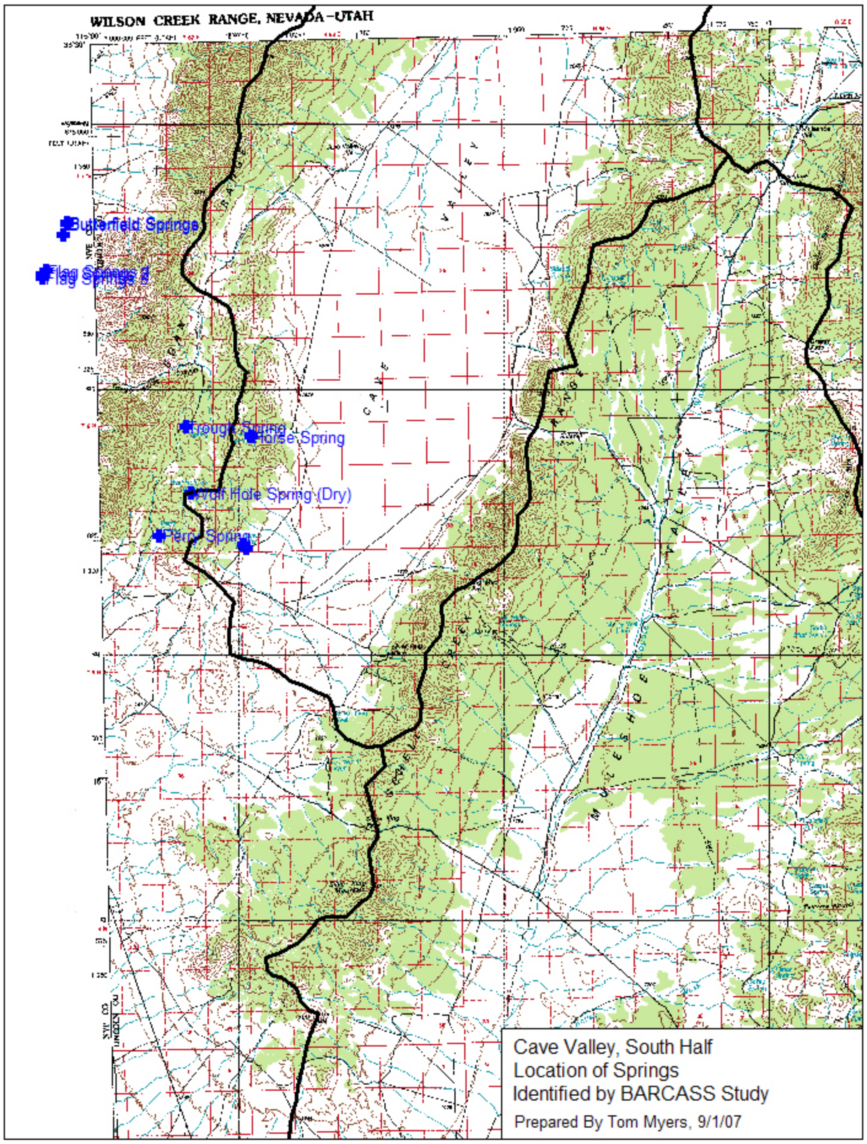

Figure 10: Map of southern Cave Valley showing location of springs from Welch and Bright (2007). Basemap USGS 1:100000 scale Wilson Creek Range.

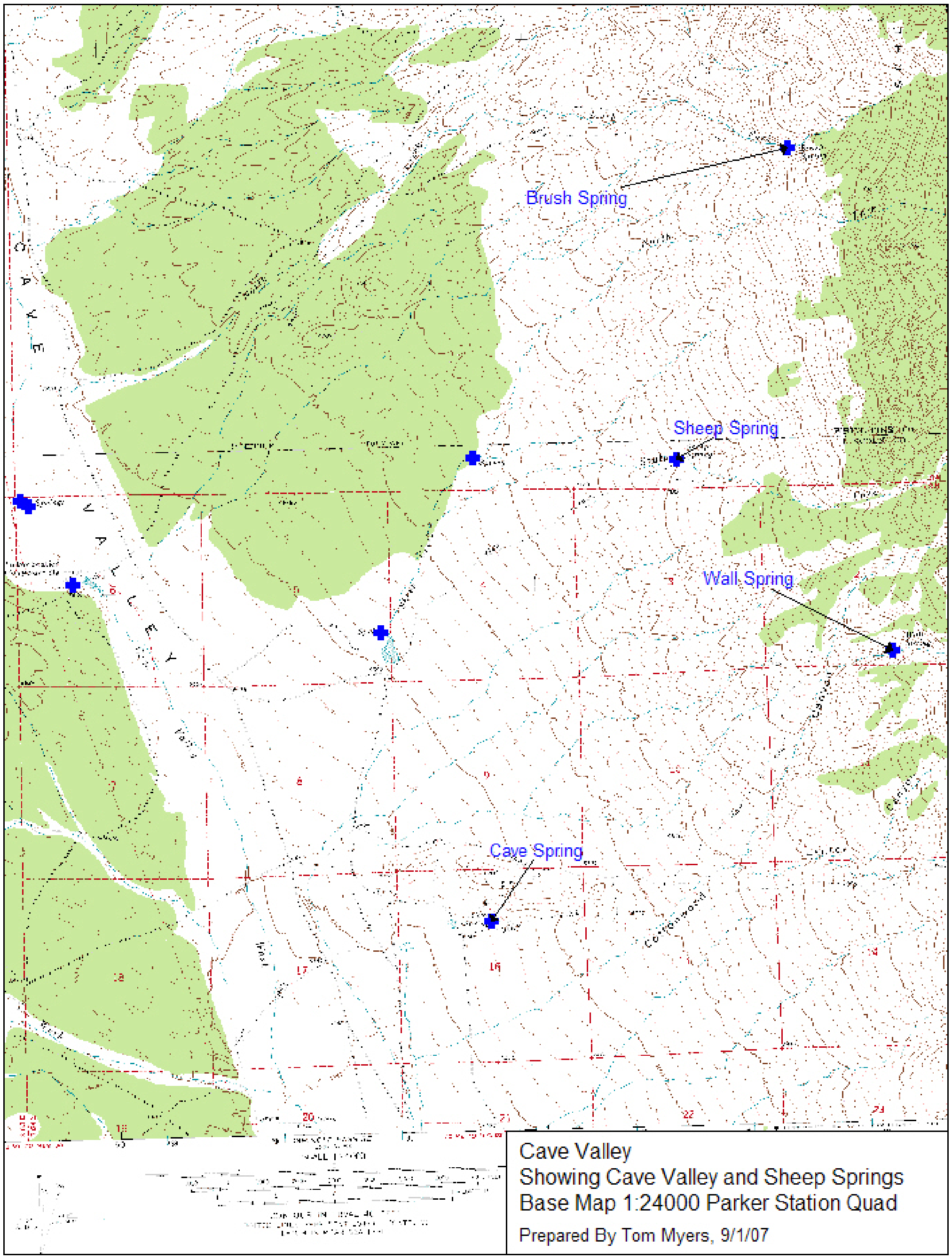

Figure 11: Map of northern Cave Valley showing location of springs from Welch and Bright (2007).

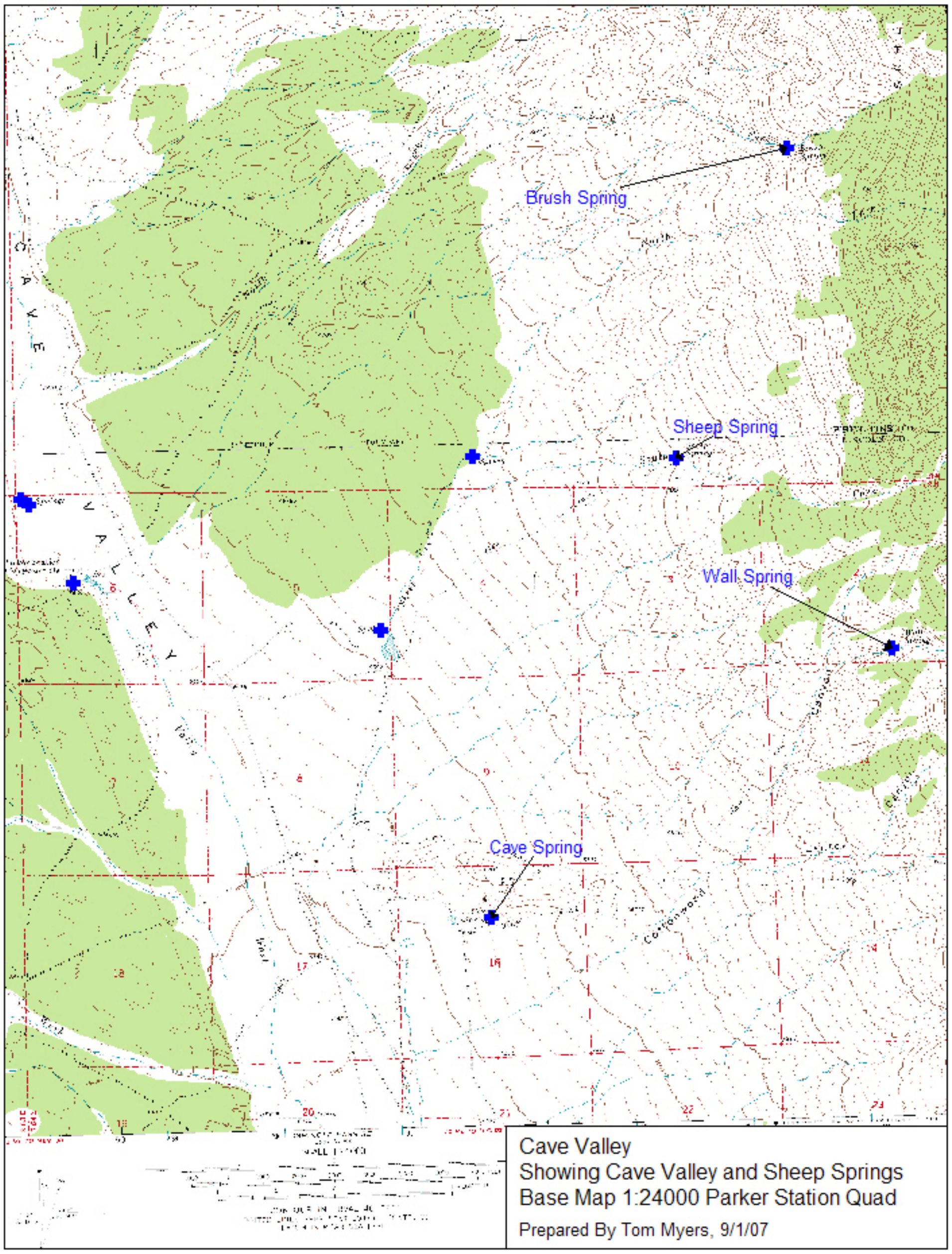

Figure 12: Detailed topographic map of Cave Spring, Sheep Spring and vicinity. Note that the map does not show green riparian areas.

Dry Lake and Delamar Valleys

These valleys are similar because neither has significant GWET (Eakin 1963a). The dryness of the area manifests in very large depths to groundwater. "The great depth to water below the playa areas of Dry Lake and Delamar Valleys precludes evapotranspiration losses from the ground-water reservoir in these valleys, except for extremely small amounts adjacent to scattered springs in the mountains" (Eakin 1963a, page 13). He estimated a spring near the Meloy Ranch discharged at about 20 gpm in March 1963. No such areas were identified in Delamar Valley.

LVVWD (2001) estimated that both Dry Lake and Delamar Valleys have 1000 af/y of GW ET discharge. It calls the amount a token "to account for local spring discharge that is consumed including evaporation from bare soil" (LVVWD 2001, page 4-38). Based on Eakin (1963a), this "token" discharge is a gross overestimate.

Downgradient Basins

Groundwater flow through White River Valley is complicated, because there is apparently much more in-basin discharge than recharge, indicating that interbasin flow supports most of the discharge. Kirk and Campana (1990) found this valley to the only one for which groundwater flowed from the carbonate to the basin fill aquifer. Welch et al (2008) estimated 39,700 af/y Maxey and Eakin (1949, p 42) estimated 40,000 af/y springflow. That the Welch et al (2008) estimate includes many additional years of flow rates (and a few additional small springs) reflects the consistency and regional origin of the spring flow, although with seasonal variation (Figures 13 and 14).

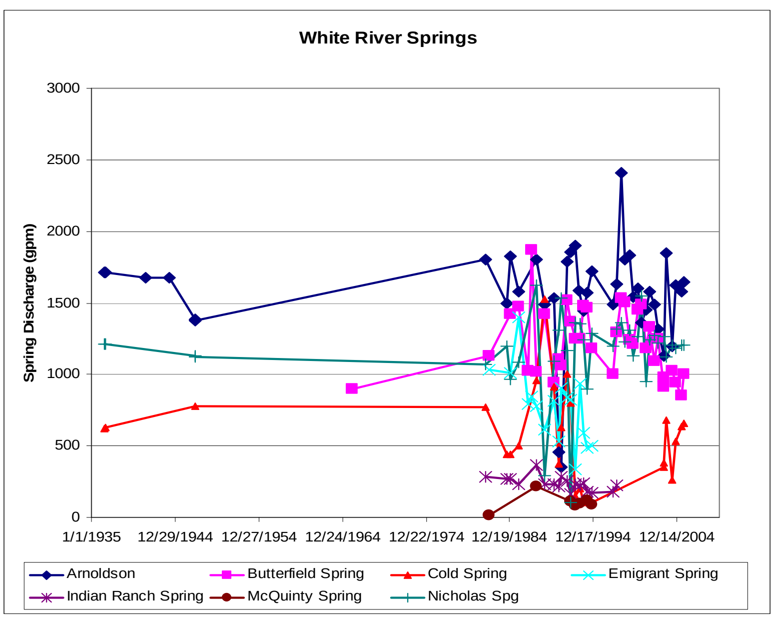

Figure 13: Discharge hydrographs from selected springs in White River Valley.

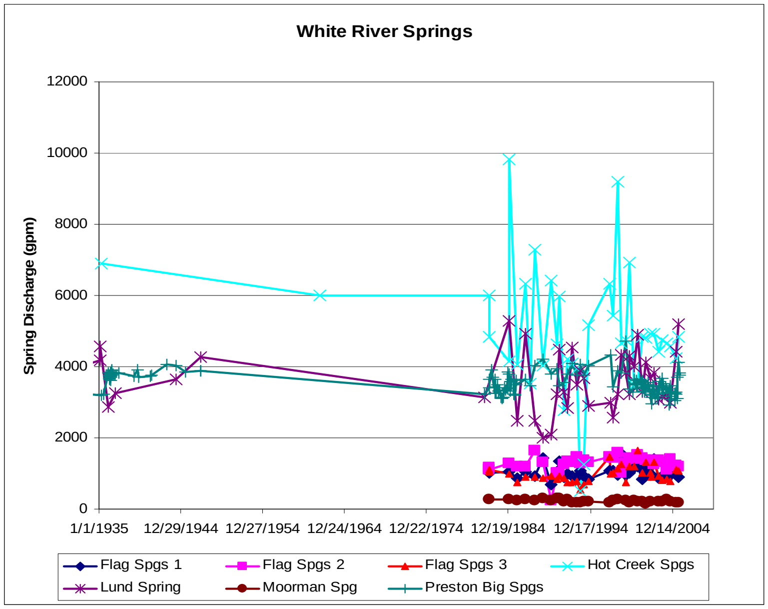

Figure 14: More discharge hydrographs from selected springs in White River Valley.

The Welch et al (2008) GW ET estimate for White River Valley, 76,700 af/y is much higher than other estimates, which include 34,000 (Maxey and Eakin, 1949) and 37,000 (NV Div Conservation and Natural Resources, 1971). They used satellite photographs to measure the 128,508 acres with phreatophytes or irrigated areas that once had phreatophytes, more than 3 ½ times that estimated by Maxey and Eakin (1949). The biggest difference is 119,101 acres of phreatophytic shrubs in subarea 4, the southeast portion of the valley. Welch et al (2008) applied an ET rate to the different areas utilizing up-to-date research; the rate estimates are less than those used by Maxey and Eakin (1949). They also estimated (Welch et al 2008, Appendix A) that there were 6078 acres of irrigated agriculture with 18,031 af/y of consumptive use. The increase in irrigated agriculture coincides with the increase in water rights in the valley, particularly of groundwater (Figure 15).

Spring flow in White River Valley would become secondary recharge, if not diverted, and support phreatophyte transpiration throughout the valley. Areas near the springs or the channels below the springs would have had phreatophytes or been irrigated with spring flow. Springs support most of the stream water rights as discussed below; most spring and stream water rights were issued prior to 1949 (Figure 15).

The BARCAS GWET estimate is more accurate and a preferable long-term pre-development estimate that can be used for water budget and perennial yield analysis. Actual increases since 1949 would be due to the much increased groundwater pumpage (Figure 15) and the ongoing irrigation with spring water which could raise the water table or otherwise cause the phreatophyte area to expand.

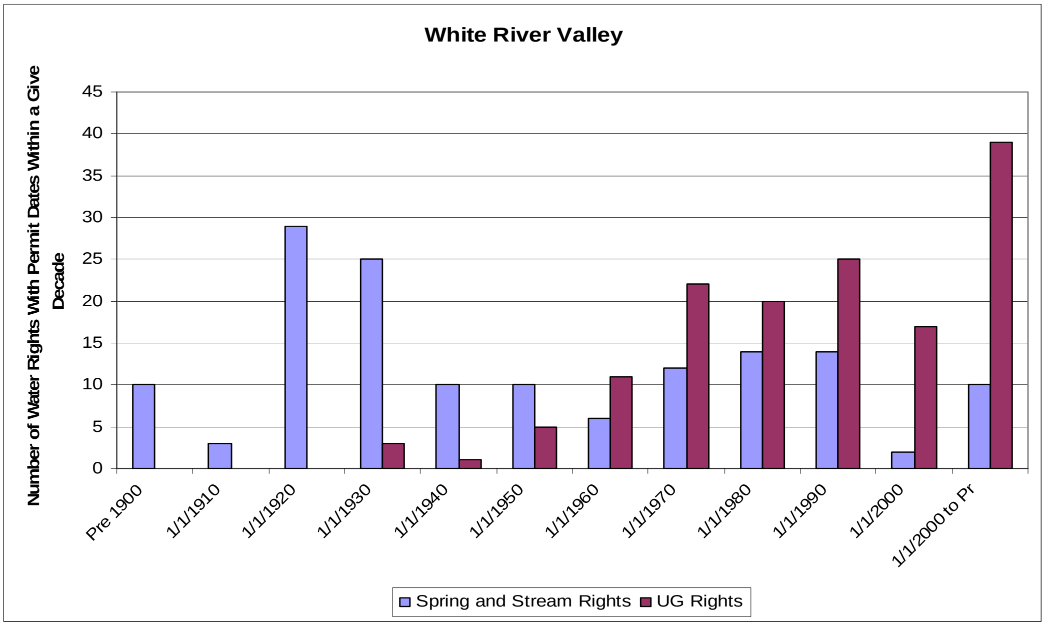

Figure 15: Application dates of water rights in the White River Valley. The figure shows that stream and spring rights were developed first and that UG rights were developed later.

Water levels in White River Valley were considered in several ways to determine whether the 2007 GW ET estimate from Welch et al (2008) represents the long-term conditions. This included an assessment of water levels around the valley, the location of most wells, and hydrographs of well levels throughout the valley.

Static water levels become shallower in the south portion of the valley where GW ET is higher (Figure 16). Simple regression of static water level with township from the south, starting with township 6N, had a coefficient of 2.36 ($p=0.032$) indicating that on average the static water levels are 2.36 feet deeper for each township moving north from the zone of township 6N.

A large majority of the wells constructed since 1949 were in the north part of the valley; of the 342 wells in the data base, there were 190 wells in the zone of Township 12 N (Figure 16). This is outside of the primary area of ET discharge.

In the southernmost portion of White River Valley, depth to water either did not trend or a slight trended to shallower levels (Figure 17). Groundwater levels in the well with the least depth to water, in Murphy Meadows in the middle of the large phreatophyte zone, remained less than ten feet. Depth to water at two other wells increased from greater than 60 feet to less than ten feet since the 1980s. There is little irrigation in this area, so the trend toward shallower groundwater may not be due to irrigation return flow.

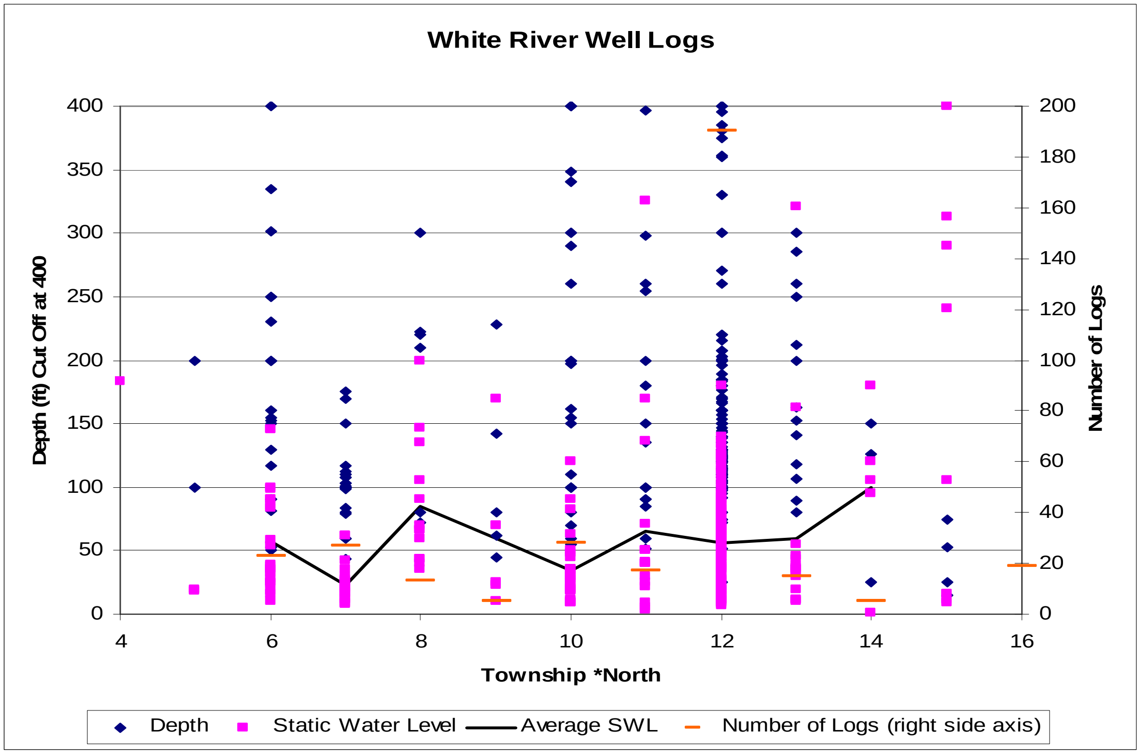

Figure 16: Location, depth and depth to water of wells as a function of their north-south location as defined by township in the White River Valley.

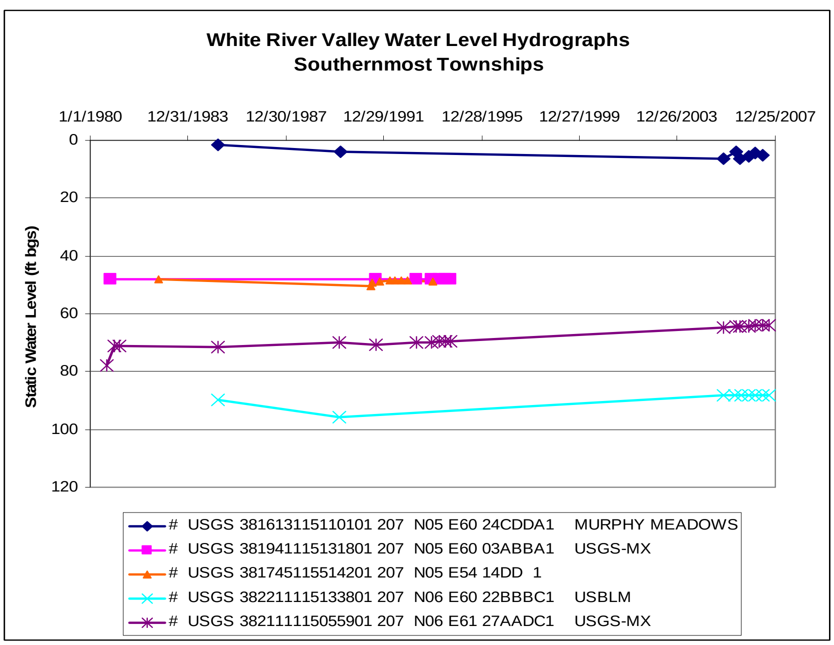

Figure 17: Hydrograph of five wells in the southern part of White River Valley. Water level data from the National Water Information System.

None of the wells in the central part of the valley showed long-term trends (Figure 18). During a wet year, the public domain well # 25 increased to the ground surface from its long-term tendency to vary between 8 and 15 feet; these variations appear to be due to wet-dry cycling. The Wilson Meadows West well has dropped ten feet since its first reading, but this could reflect the initial water level, likely the static water level recorded after well construction, not being equilibrated prior to the first reading. In fact, changes such as this suggest that the well may have caused a hydraulic connection between two shallow layers through an area with high vertical anisotropy.

In the northernmost wells, only seasonal or annual wet-dry cycling is apparent (Figure 19). This area has extensive well development, but the water levels indicate that the well development has not yet depleted the groundwater storage.

Groundwater level trends in the White River Valley do not explain the changes in phreatophyte area or the increase in GW ET discharge since 1949 reported in BARCASS. The higher estimates must be due to improved delineation of phreatophyte area in the White River Valley, although the GW ET rates in Welch et al (2008) are less than assumed by Maxey and Eakin (1949). The conclusion then is that groundwater discharge from the White River Valley for the purpose of this analysis is 76,700 af/y.

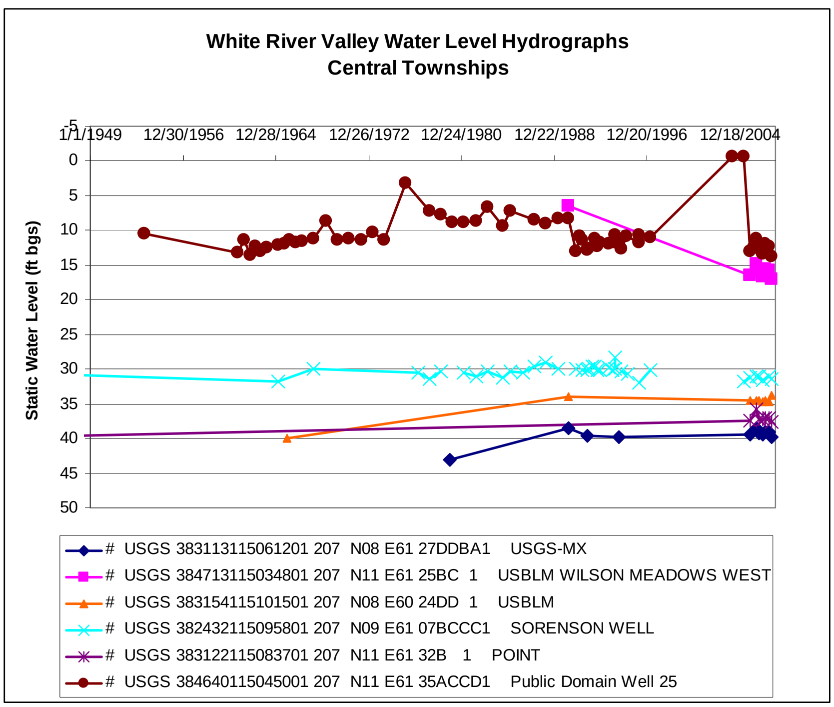

Figure 18: Hydrograph of six wells in the central part of White River Valley. Water level data from the National Water Information System.

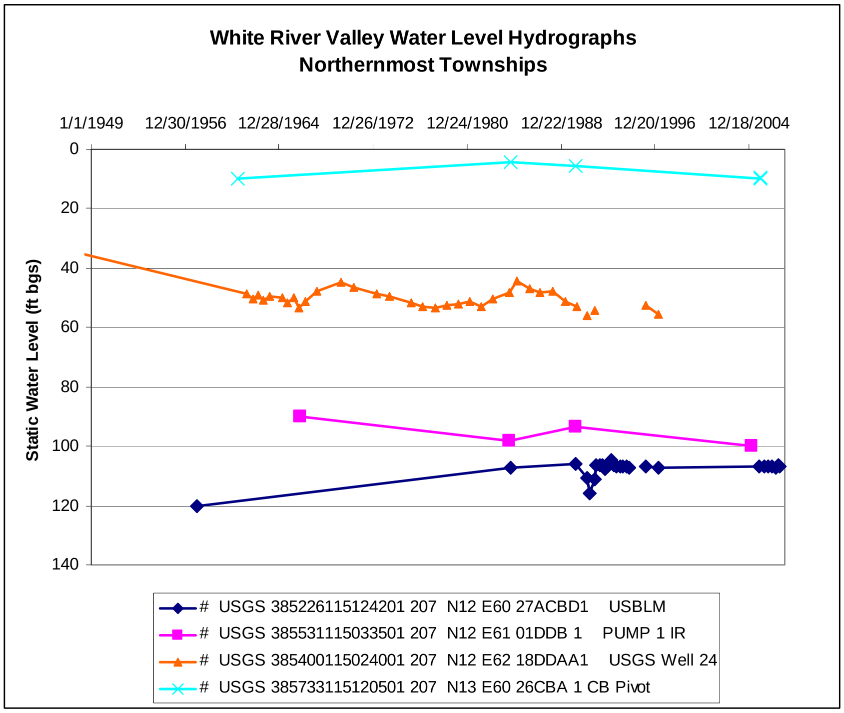

Figure 19: Hydrograph of four wells in the north part of White River Valley. Water level data from the National Water Information System.

There are no phreatophytes in Pahroc Valley other than a few near perched springs. GW ET discharge for this basin is effectively zero.

Pahranagat Valley is unique because most of the available water, both surface and groundwater, depends on interbasin groundwater flow. Total spring discharge and published perennial yield is approximately 25,000 af/y (Eakin 1963c), or about 14 times recharge. The springs contribute to baseflow which supports wetlands and lakes on the Pahranagat National Wildlife Refuge (Kirk and Campana, 1990). Eakin (1963c) estimated there were 20,000 af/y of GW ET from phreatophytes and 5000 af/y of lake evaporation. This suggests that to develop perennial yield, the lakes would dry. Bedrock constrains the phreatophye area (Figure 20) so the estimate is accurate.

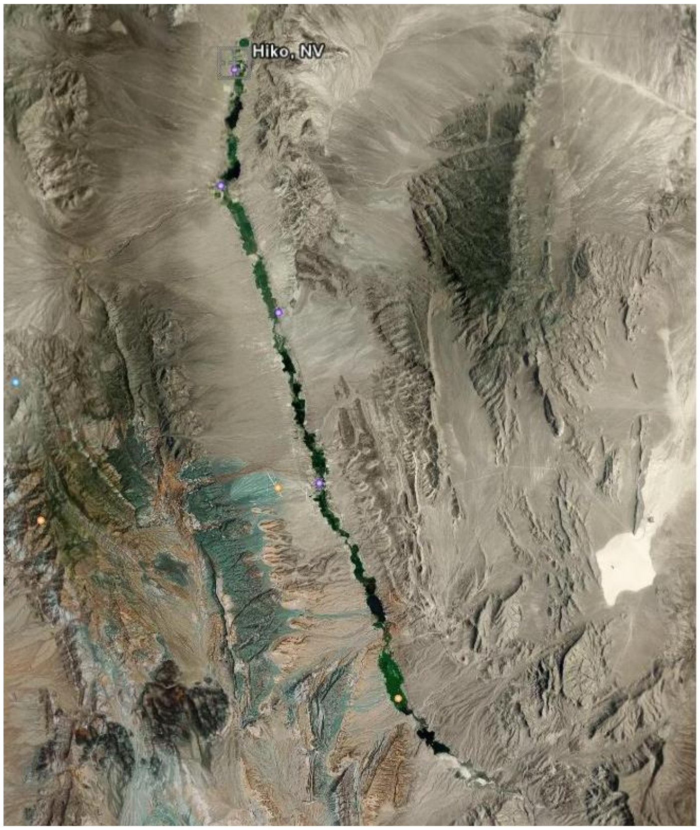

Figure 20: Phreatophytes and narrow riparian zone along the Pahranagat River between Hiko and Pahranagat Lakes.

Interbasin Flow Estimate

The recharge estimates in Cave, Dry Lake and Delamar Valleys exceed the in-basin discharge estimates substantially. The excess groundwater, the amount that recharge exceeds discharge, becomes interbasin flow to downgradient basins. This section considers the geologic and hydrologic constraints on interbasin flow to assess where the recharge may go.

Cave Valley

Cave Valley does not receive interbasin flow because it is at the head of the flow systems. There are no geologic barriers but there is a groundwater divide caused by recharge between Cave and Steptoe Valleys. Significant pumping in the north end of Cave Valley could lower the groundwater divide and divert water from Steptoe Valley.

Interbasin flow from Cave Valley is to White River Valley to the west, with very little flow south toward Dry Lake or Pahroc Valley. The geology, groundwater gradients, and location of discharge in White River Valley all support this conclusion.

Carbonate groundwater contours show a significant clope to the southwest and west, from Cave Valley to White River Valley (Figure 21). This is primarily through carbonate rock forming the Egan Range (Figure 2). Volcanic rock on the south end of Cave Valley would impede flow toward Pahroc Valley. Welch et al (2008) estimated a flow of 9000 af/y to the White River Valley based on water balance as verified with geochemistry. Other estimates of flow from Cave Valley to White River Valley are much higher. Durbin (2006) estimated that the entire recharge, 14,000 af/y, flows through the Egan Range to the White River Valley. Eakin (1962) indicated that almost all of the recharge in Cave Valley becomes interbasin flow flowing toward Lund and Hot Creek Springs, due to the lack of discharge in Dry Lake and Delamar Valleys (Eakin 1962, page 10).

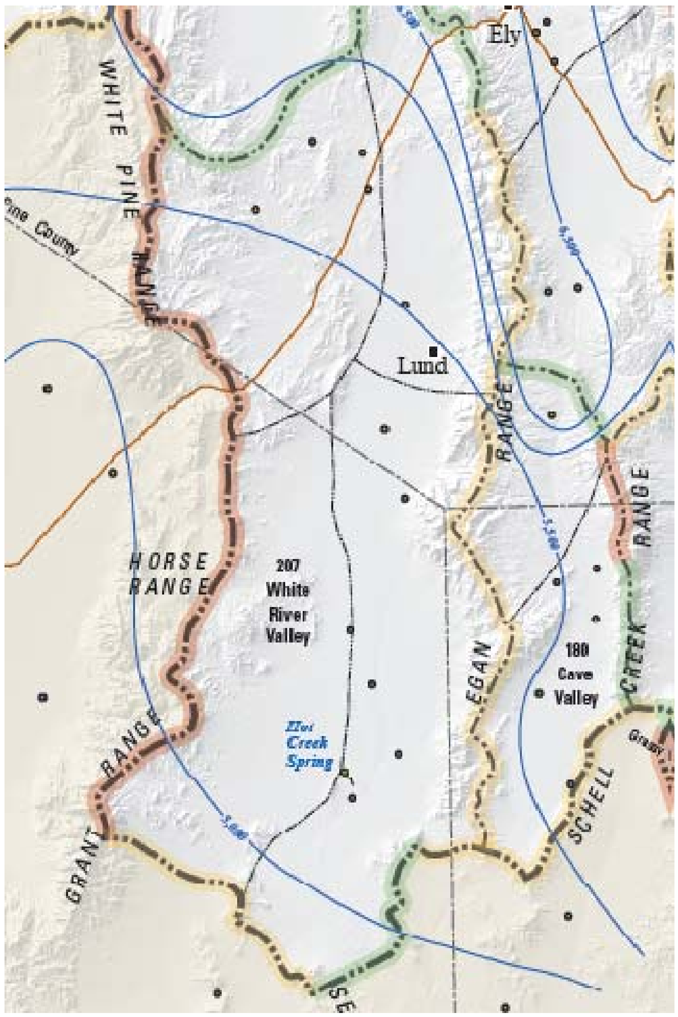

Figure 21: Groundwater contours in the carbonate aquifer as snipped from Welch et al (2008), Plate 3.

Most of the discharge in White River Valley occurs in the southern two-thirds of the valley, with the bulk being from the southeast quarter as delineated in BARCAS (Figure 22). In that quarter, BARCAS estimated 57 kaf/y of discharge with just 7 kaf/y of recharge, meaning that most of the discharge depends on intra- and interbasin flow. That portion of White River Valley is a convergence of groundwater in the basin fill aquifer (Welch et al, 2008, Plate 2) with groundwater discharging from the carbonate into the fill (Kirk and Campana, 1990). Cave Valley is the closest and most apparent source, based on geology, topography, and location of recharge. Based on recharge and discharge estimates above, the interbasin flow to White River Valley is the difference between recharge and GWET, or 12,800 af/y, with no interbasin flow to Dry Lake Valley

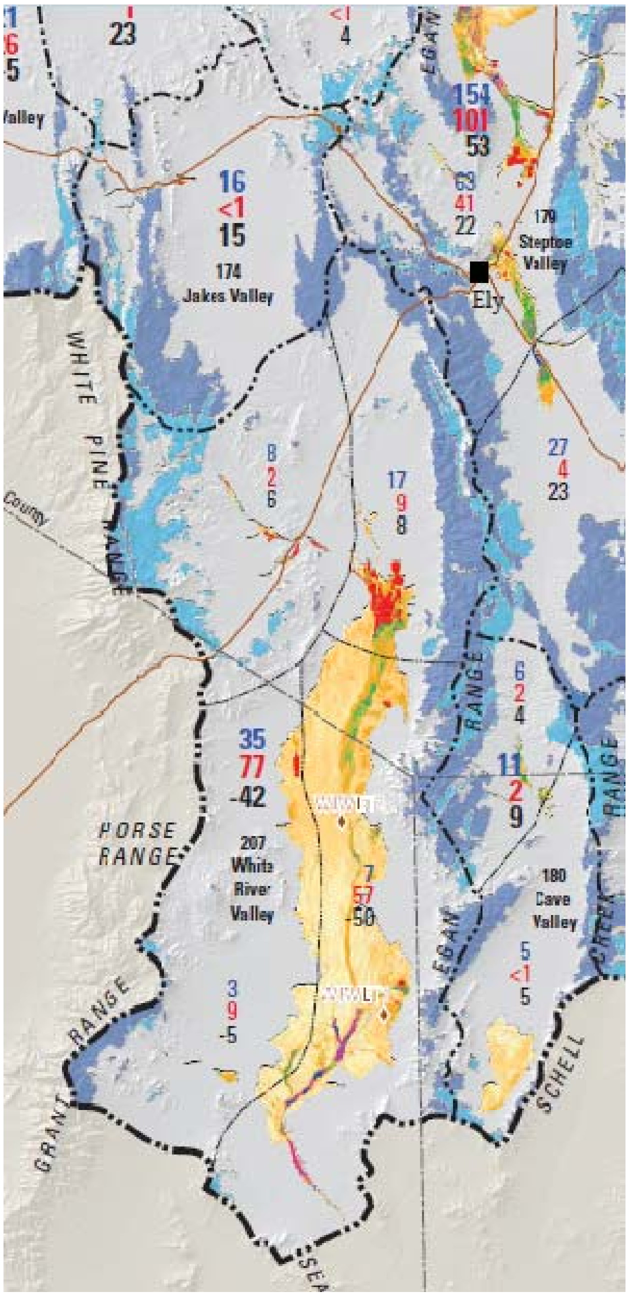

Figure 22: Water balance fluxes for White River Valley snipped from Welch et al (2008), Plate 4.

Delamar/Dry Lake Valley

The west side of the north half of Dry Lake Valley is bounded by a mixture of tuffs, basaltic flows and carbonate rock (Figure 3); further south on the west, it is mostly tuffs and basaltic flows. Carbonate rock may underlie the volcanic rock, as suggested by well log 22450 (Appendix 1) which shows only 145 feet of volcanic rock overlying almost 2000 feet of carbonate rock. The water level is 853 feet below ground surface and the water temperature was 80°F (Bunch and Harrill, 1984) which indicates deep circulation. The well is cased to 2395 feet, therefore the water level represents pressure occurring at that depth in the carbonate rock. Groundwater flow to the west, to Pahroc or Pahranagat Valley could occur along the western bound of the valley.

Delamar Valley is surrounded primarily by volcanic rock (Figure 4). However, substantial northeast trending faults occur in the southwest of the valley. It is through this zone, often referred to as the Pahranagat shear zone (Brothers et al 1996), that groundwater is most likely to flow to Delamar Valley.

Dry Lake and Delamar Valleys lie in a "surficially closed trough" above the surrounding valleys (Eakin, 1963a). They are grabens with basin bounding faults. The elevation may preclude interbasin inflow from the east. Based on gradients observed by Eakin within the centerline profile of the valleys, Eakin (1963) determined that groundwater probably flows from Dry Lake to Delamar Valley. Eakin (1963a) concluded that interbasin flow to the east, to Meadow Valley Wash, was not likely because the water level was near the ground surface in Meadow Valley Wash which would make for a flat gradient and because the mountains separating the valleys were high enough that recharge would likely cause a groundwater divide. The mountains on the west side were low enough that no groundwater divide would likely form, and contain sufficient carbonate rock to allow flow, therefore the discharge from both valleys is west to Pahranagat and Pahroc Valleys. Eakin (1966) indicates the flow would be to just Pahranagat Valley. Because there is effectively no groundwater ET discharge within these valleys, the discharge to the west essentially equals the total recharge, the various estimates of which were discussed above.

White River Regional Flow System

Total interbasin flow to White River Valley from upstream valleys, including Cave, Steptoe, and Jakes Valleys, is 75,800 af/y (Table 6). With the recharge and GWET estimates above, approximately 37,100 af/y of interbasin flow leaves White River Valley to reach Pahroc Valley. Inflow to Pahranagat Valley from Pahroc is 39,300 af/y, and includes a small amount of recharge in Pahroc Valley; Garden and Coal Valleys and Dry Lake and Delamar Valleys add 12,000 and 6000 af/y, respectively, so that inflow to Pahranagat is 57,300 af/y. With the small recharge and significant GW ET in Pahranagat Valley, there is approximately 34,100 af/y discharge to Coyote Spring or Kane Springs Valley. With no discharge there, approximately 40,100 af/y flows to the Muddy Springs; no water is assumed to flow toward Hidden Valley.

Table 6 : Water budget accounting for the study area basins under pre-development conditions. All flows are in af/y.

	Recharge	Interbasin Inflow	GW Discharge	Interbasin outflow	To
Garden/Coal Valley	12000		0	12000	Pahranagat
Cave Valley	14000		1200	12800	White River
Dry Lake	5000		0	5000	Delamar
Delamar	1000	5000	0	6000	Pahranagat
White River Valley	38000	75800	76700	37100	Pahroc
Pahroc Valley	2200	37100	0	39300	Pahranagat
Pahranagat Valley	1800	57300	25000	34100	Coyote Springs
Coyote Spring/Kane Springs Valley	6000	34100	0	40100	Muddy Springs
48 kaf/y inflow from Steptoe and Jakes Valley, Welch et al (2008)					

The flow estimates through the system do not include the effects of development. After determining the water rights consumptive uses, the actual flow through the system after it has returned to steady state from the existing stress, a theoretical concept only, will be considered.

Current Basin Development

The higher and wetter of the three targeted valleys, Cave Valley, has the most existing water rights with a total duty for all types of water rights being 971 af/y, with a majority being for spring rights with a duty totaling 626 af/y. Streamflow rights, totaling 276 af/y certificated and vested stream rights, apparently depend on runoff not directly linked to GW discharge. There were eight certificated or permitted UG rights totaling 69 af/y but adjusting for supplemental water rights, the total is 35.4 af/y. All are stock rights which are considered to be fully consumptively used and therefore represent the only non-spring use of UG water in the valley.

Delamar Valley has just 7.4 af/y of UG rights; the numerous spring and reservoir rights do not apparently depend on groundwater. Dry Lake Valley has just 57 af/y of UG rights; also, the numerous spring rights emanate from perched aquifers and should not be considered part of the valley groundwater system. Except for one (certificate 566 for 663 afa), the duties are very small. Most are for stock water.

White River and Pahranagat Valleys are the most developed, from an irrigation perspective, basins downgradient from the targeted basins but upstream from the Pahranagat Shear Zone. Both White River and the Pahranagat Valley Springs are considered fully appropriated[4].

[4] Final Decree: In the Matter of the Determination of the Relative Rights in and to the Waters of White River and its Tributaries in White Pine County, Nevada, Seventh Judicial District Court, White Pine County.

The development in WRV relies primarily on surface or spring water, the total duty of which approximates 64,000 af/y (Table 7). UG water is used as supplemental or to develop some areas not served by springs. Surface water rights are approximately 2/3rds of the total because the diversions occur downstream from the actual spring. The total UG water rights duty in WRV is 36,457 af/y, which is reduced to 23,255 af/y after adjusting for supplemental water rights (Table 7). Where the UG and other rights coincide with phreatophyte zones, it is accurate to conclude that water rights development will replace some of the GWET so that the water rights development in the long run does not exceed the GWET. Development around the townships near T12N is not supported by springs, so the UG development will create an additional draw on the groundwater. There are 22,662 af/y of UG irrigation rights - adjusted for supplemental rights there are 12,337 af/y – in the T12 N zone. Assuming consumptive use of 0.7, the total irrigation consumptive use is 8635 af/y. Adding 141 af/y of non-irrigation consumptive use, the total UG consumptive use in T12N is 8776 af/y. The long-term groundwater discharge is the sum of the natural GWET, which will either continue or be captured for irrigation, and the consumptive use in T12N. The total is 85,476 af/y.

Table 7: Water rights in White River Valley. Data from Nevada State Engineer's online database, 2007.

Stream	**Number**	**Duty (af/y)**
CER	26	24643
PER	1	152
VST	7	16306
Subtotal	34	41102
Spring		
CER	74	16149
DEC	12	102
RES	1	
PER	11	3596
VST	24	2755
Subtotal	122	22602
Underground		
CER	122	25354
PER	37	11103
VST	1	0
Subtotal	160	36457
UG total adj for Sup		23255
Total	316	86959

Pahranagat Valley is unique because of the dependence of the valley on interbasin groundwater flow as manifest in the springs, which discharge approximately 25,000 af/y. The springs contribute to baseflow in several streams and provide the water that supports wetlands and lakes on the Pahranagat Wildlife Refuge. Much of the spring flow becomes surface flow,

Cited in State Engineer Ruling 3640 Denying water rights application for irrigation water from the White River.; Ash Springs/ Pahranagat Lakes Decree of October 14, 1929.

but both become secondary recharge utilized by water rights and riparian vegetation further downstream.

There are a total 35,430 af/y of water rights in Pahranagat Valley, as of 2007 (Table 8). About 3000 af/y are for stream or lake rights. Spring water and UG rights total 21,463 and 13,022 af/y, respectively, with 8326 of UG rights being supplemental. The actual groundwater duty is 4695 af/y accounting for supplemental rights. The total duty for water rights in the basin is 29,231 af/y accounting for supplemental rights (Table 8).

The total consumptive use for irrigation is 8692 af/y, or only about 30 percent of the total duty for the valley. The amount from UG sources is 70% of the 3288 af/y of nonsupplemental UG rights, or 2302 af/y. Because the GWET discharge is focused along a strip near the Pahranagat River, most irrigation occurs on terraces, perhaps 10 to 40 feet above the river. Prior to irrigation, this would not have been dense riparian vegetation as along the strip near the river. Irrigation with spring/surface water displaces natural discharge whereas irrigation with groundwater, 2302 af/y draws from storage and diverts interbasin flow.

Table 8: Water rights summary for Paharanagat Valley. Data from Nevada State Engineer's online database, 2007.

Pahranagat Valley Water Rights Summary		
Stream	Number	Duty (af/y)
CER	3	761
VST	1	184
Subtotal	4	946
Lake		
CER	2	2127
VST	5	0
Subtotal	7	2127
Spring		
CER	21	5646
DEC	17	14535
RES	2	4
VST	4	1278
Subtotal	44	21463
Underground		
CER	41	9886
PER	24	3088
VST	5	48
Subtotal	70	13022
Total	118	35430

Other basins in the WRFS above Pahranagat Valley are only lightly developed. Coal Valley has few water rights. The spring rights are to perched spring and not part of the groundwater system; there are no stream rights. The 33 af/y of UG rights is the consumptive use for this valley. Garden Valley has approximately 2500 af/y of water rights from all sources, including 166 af/y of spring rights which are perched and not part of the system. Of the 559 af/y of UG rights, all but 4 af/y are used for irrigation. The irrigation consumptive use is 388 af/y which is the consumptive use for the valley.

White River Flow System: Water Budget and Water Availability

The WRFS considered herein has nine basins, not counting Jakes and Steptoe Valleys, which eventually drain to Moapa Valley and the Muddy River Springs (Eakin, 1966). Two of the nine basins upstream from Moapa Valley, Pahranagat and White River Valley, are fully developed as described above; the total GWET, including UG water right consumptive use, exceeds the natural GWET alone. Current commitments within the system will decrease the interbasin flow from Pahranagat Valley from 34,100 to 16,081 af/y once pumping the current developments comes to equilibrium (Table 9).

Table 9: Water budget for the White River Flow System with existing groundwater use. All units af/y.

	Recharge	Interbasin Inflow	GW Discharge	Groundwater Use	Interbasin outflow	To
Garden/Coal Valley**	12000		0	421	11579	Pahranagat
Cave Valley	14000		1200	35.4	12765	White River
Dry Lake	5000		0	57	4943	Delamar
Delamar	1000	4943	0	7.4	5936	Pahranagat
White River Valley*	38000	75765	76700	8776	28289	Pahroc
Pahroc Valley	2200	28289	0	30	30459	Pahranagat
Pahranagat Valley	1800	47973	25000	8692	16081	Coyote Springs
Coyote Spring/Kane Springs Valley	6000	16081	0		22081	Muddy Springs
* - 48 kaf/y inflow from Steptoe and Jakes Valley, Welch et al (2008)						
** - Groundwater use is sum of 388 af/y in Garden and 33 af/y in Coal Valley						

If SNWA develops its' full application from each of the three targeted basins, 11,500 af/y of groundwater use will be effectively subtracted from each targeted basin in the budget in Table 9. Once equilibrium is reached, the interbasin outflow from Cave Valley will decrease to 1181 af/y and from Dry Lake and Delamar Valleys becomes negative (Table 10). Most critically, the discharge from Pahranagat Valley becomes negative, equaling -18,670 af/y.

Table 10: Water budget for the White River Flow System with SNWA's full application amount added to the groundwater use.

	Recharge	Interbasin Inflow	GW Discharge	Groundwater Use	Interbasin outflow	To
Garden/Coal Valley	12000		0	421	11579	Pahranagat
Cave Valley	14000		1200	11618.9	1181	White River
Dry Lake	5000		0	11640.5	-6641	Delamar
Delamar	1000	-6641	0	11591.1	-17232	Pahranagat
White River Valley	38000	64181	76700	8776	16705	Pahroc
Pahroc Valley	2200	16705	0	30	18875	Pahranagat
Pahranagat Valley	1800	13223	25000	8692	-18670	Coyote Springs
Coyote Spring/Kane Springs Valley	6000	-18670	0		-12670	Muddy Springs
48 kaf/y inflow from Steptoe and Jakes Valley, Welch et al (2008)						

The analysis of water rights development in the WRFS shows that Eakin was correct when he recognized in the first reconnaissance report written for Pahranagat Valley that upgradient development could affect downgradient springs.

> However, although most of these valleys are several tens of miles distant, substantial development in them in time might intercept some of the supply now reaching Pahranagat Valley. The result, of course, would be a decrease in the natural discharge. If it is assumed that all the evapotranspiration loss can be salvaged for beneficial use, the perennial yield of Pahranagat Valley can be related to present and future patterns of development as follows: (1) Under the existing conditions of development in the gross ground-water system, the yield of Pahranagat Valley would be a least 25,000 acre-feet per year; and (2) under future conditions, **if substantial development in upgradient valleys intercepts underflow supplying the springs in Pahranagat Valley, the yield of Pahranagat Valley could be expected to decrease** – the magnitude of the decrease would be directly proportional to the magnitude of the water intercepted. (Eakin 1963c, page 22, emphasis added).

Any development upstream of Pahranagat Valley will come at the expense of water rights and the national wildlife refuge within Pahranagat Valley. The State Engineer has denied water right applications within Pahranagat Valley to protect flow from the springs recognizing that recharge from other basins support this spring discharge. For example, the State Engineer denied irrigation water rights applications to protect Crystal Springs in 1984.

> Ground water in the Pahranagat Valley Basin is stored and transmitted in the Paleozoic carbonate rocks beneath the valley fill. Hiko, Crystal and Ash Springs issue from the Paleozoic carbonate rocks and play a dominate role in the economy of Pahranagat Valley. The magnitude of the combined discharge, acreage about 35.0 cfs. (25,000 acre-feet annually), is far in excess of the amount that might be supplied by recharge from

precipitation within the defined surficial area of the valley (estimated average 1800 acre-feet annually). This indicates that **much of the ground water discharged by the springs is derived from beyond the drainage** divide of the valley (State Engineer Ruling 3225, page 2, emphasis added)

The ruling denied two applications for water rights because they would intercept flow of "source water to Crystal Springs" (Nevada State Engineer Ruling 3225, page 3). Furthermore, order 1199 has Pahranagat Valley has closed to future irrigation waters permitting.

The State Engineer has denied applications in one basin to protect rights in another basin in different parts of Nevada. For example, in the Amargosa basin, the perennial yield is 24,000 af/y based on the ET discharge from that basin, but most of the recharge to that basin is from interbasin flow from upgradient basins. Discharge from Amargosa Basin to Death Valley, equaling approximately 19,000 af/y, is not considered a potential part of the perennial yield in Amargosa Valley. The State Engineer recently protected the outflow to Death Valley because there was insufficient water available for appropriation[5]. This denial may be especially prescient for these applications because the time for any impact to manifest in Death Valley may be long.

The analysis in this report shows that much less than 50,000 af/y may enter Coyote Spring Valley from northern basins; the amount estimated herein was 34,100 af/y (Table 8). The biggest reason for this difference is the higher GW ET discharge from the White River Valley estimated in the Welch et al (2008). With development proposed by SNWA, the discharge to Coyote Spring Valley may become negative (Table 10). SNWA's proposal will have negative consequences for the flow from Muddy River Springs.

The discussion here is critical in light of the State Engineer's Carbonate Order 1169 which put into abeyance numerous water rights applications until the flow through the carbonate system and among the basins is better understood. The order recognized testimony in the Kane Springs hearing that 50,000 af/y enters Coyote Spring Valley from northern groundwater basins, that 37,000 af/y discharges from the Muddy River Springs area, that the Muddy River Springs discharge is fully appropriated pursuant to the Muddy River Decree and that approximately 16,000 to 17,000 af/y flows to basins further south (State Engineer Order 1169, page 5). In the Kane Springs Ruling 5712, the State Engineer referred to 37,000 af/y entering Coyote Spring from Pahranagat Valley. The water balance calculations herein suggest the flow rates discussed in Order 1169 and Ruling 5712 are substantial overestimates and that the SNWA development will eventually divert water used on the Muddy River.

Water Availability

Most of the groundwater that recharges in the three valleys, Cave, Dry Lake and Delamar, flows through carbonate rock to the White River and Pahranagat Valleys. Only Cave

[5] Nevada State Engineer Ruling 5750 denying water rights applications 59532, 62529, 66072, 66078, 66079 and 66081, July 16, 2007.

Valley has significant GW ET discharge, determined in this report to be about 1200 af/y; Dry Lake and Delamar have very little GW ET discharge.

Because of the small GW ET discharge from the basins, to avoid long-term drawdown to the basins, the applications would have to capture interbasin flow. The apparent inability to capture the recharge in the mountains which flows from the basin through carbonate rock led Eakin (1962) to conclude the perennial yield of Cave Valley could be only 2000 af/y. Eakin (1963a, page 19) did not estimate the perennial yield for Dry Lake or Delamar because he determined that only for "the most exceptional water requirements" would the cost for developing an amount of water close to the interbasin discharge from the valleys occur. He concluded that to develop a "large part of the estimated 6,000 acre-feet of average annual discharge from the valley, water levels might have to be drawn down as much as 1,500 feet below land surface" (*Id.*). These old analyses demonstrate the inability to actually develop any significant amount of groundwater in these basins. Drawdown would occur and continue to increase for a very long time, probably on the order of centuries. This will be considered in the next section.

Simple water budget analysis has shown that all of the groundwater entering the downgradient valleys is utilized in those valleys. Developing groundwater in the target basins will decrease the inflow to the downgradient basins and cause drawdown within those valleys. Current water rights holders within White River and Pahranagat Valley already utilize all of the inflow to the basin. There is simply no water available to develop a significant exportation project from the targeted basins. Because of the downgradient dependence on the interbasin flow from the targeted valleys, the PY of Cave Valley should be set at 1200 af/y and the PY of both Dry Lake and Delamar Valley is negligible.

Conclusion of Water Budget Analysis

There are six major conclusions obvious from the steady state water budget analysis for the pre-development, current, and proposed future conditions. They are:

- There is no available water in the targeted basins because most recharge in the targeted basins becomes interbasin flow to downgradient basins where it is completely used by water users with water rights.
- The groundwater system in White River and Pahranagat Valleys is completely appropriated and dependent on interbasin flow from upgradient valleys including the targeted basins.
- Most spring and surface water rights in White River and Pahranagat Valleys depend on groundwater including interbasin flow.
- The existing level of water rights development in the valleys will decrease the discharge from Pahranagat Valley to almost zero.
- If granted, the proposed applications will reduce the interbasin flow from Pahranagat Valley to much less than zero.

- The published perennial yield for Dry Lake and Delamar Valleys is substantially too high. It should be zero due to the depth to water and the downstream dependence on flow originating within those valleys.

Impact Analysis

The steady state water balance clearly shows there is no available water for appropriation in the overall White River Flow System if flows from the regional springs are to be maintained. Developing water rights by pumping wells imposes a stress on a groundwater system by adding new discharges to the system. The system will experience a period of change during which groundwater storage is removed and the natural discharges adjust to the new discharges. The system will eventually approach a new steady state if the new discharges do not exceed the recharge and can replace natural discharges. The amount of groundwater to reach equilibrium is the transitional storage.

Impact analysis determines how long it will take for impacts to occur, the amount of transitional storage, the total and expansion of the drawdown cone, and the amount that discharge from natural discharge points will be decreased. Because there are few discharges within the targeted basins, the impacts will mostly occur in downgradient basins. Simple methods to estimate impacts, such as simple Theis equations, are inappropriate in this case because it cannot estimate past the bounds of the aquifer, and even then can only be used if the aquifer can be assumed to be infinite.

For the consideration of the impacts of a possible large stress as proposed by SNWA, a numerical groundwater model is usually the best method to apply. In this case, the objectives of the modeling are as follows:

- ✓ Estimate the time for the system to come to equilibrium after the pumping commences.
- ✓ Estimate the amount of groundwater ultimately removed from storage.
- ✓ Estimate the time until downstream basins are affected by loss of upstream water.
- ✓ Estimate the effect on springs that depend on interbasin flow from the targeted basins.

Myers (2007) used a groundwater model developed by the U.S. Geological Survey to consider the impacts of pumping this groundwater. The RASA groundwater model (Prudic et al, 19955) was developed to refine the concepts of flow within the carbonate province and between the surface basin-fill aquifers and the consolidated bedrock aquifers, primarily the carbonate and volcanic aquifers. It was developed as a conceptual model to improve understanding of the system. Schaefer and Harrill (1995) used the RASA model to estimate the effects of the water rights applications as proposed by the Las Vegas Valley Water District, now held by SNWA. While they acknowledged the large grid spacing and the basin being a regional-scale conceptualization of groundwater flow, they considered the model "adequate to develop first approximations of probably regional-scale effects", but not detailed predictions (Schaeffer and Harrill 1995, page 2).

Halford and Plume (2011) recently used the model to estimate the effect of pumping SNWA's water rights applications in Snake Valley. They made some modifications to the model and used new data to improve the model calibration in their area of interest, but the basic concepts of the model were unchanged. Additionally, Wittman and Kelson (2011) recently spoke of the value of using RASA models to consider impacts at points where these models were developed all around the country. As they wrote: "This presentation will describe our work in various parts of the country where we have taken the time to revise previously developed and well-documented USGS groundwater flow models. We have reawakened and refined these regional models to gauge local impacts of new wells and to consider long term water availability." (Wittman and Kelson, 2011, abstract).

Because a primary interest of the analysis herein is regional-scale impacts such as changes in spring flow and head miles from the wells in adjacent or even further downstream valleys, the use of the RASA model, with some modification to improve computation near the wells, is appropriate. As concluded by Schaeffer and Harrill (1995, page 46), "[i]rrespective of the obvious limitations of this model, the results of the simulation provide valuable insight regarding the regional-scale response to pumping and can serve as a basis for the development of a more detailed analysis of pumping effects." Because interbasin flow is a primary consideration of this impact analysis of SNWA's applications, it is appropriate to consider flows using this model as long as the low precision of those estimates is understood.

Myers (2007) described the original model and how he updated it for use in that hearing. For this evidence report, simulations from that model are used to address the issues discussed above.

Table 11 is the water balance for the original RASA model, presented as a baseline for comparison. Figure 23 shows how I had adjusted the model by telescoping the grid and the target basins. The water budget values in Tables 12 through 14 are a baseline against which changes caused by pumping can be compared.

SNWA's water rights applications total more than 11,500 af/y from each of the three target basins. Each basin has two applications and therefore two points from which water would be pumped. For implementing them into the RASA model, SNWA's applications were plotted on a GIS map and matched to the cells in the model as done by Schaeffer and Harrill (1995). However, some of the applications plotted in very low transmissivity zones but adjacent cells were found to have much higher transmissivity. Initial model runs pumping at the application rate found extreme drawdown at the wells with low transmissivity. In these cases, the well was moved to adjacent cells with higher transmissivity (Table 15).

Table 11: Water Balance for the Original RASA Steady State Model. All flows from the model run completed for this study.

Spring	Model Reach	Discharge (af/y)	River or other Boundary	Flux (af/y)	Recharge (af/y)	ET Discharge (af/y)
Manse Springs	1	-3909.7	Humboldt River	-24845.	1523666.	-1213054.
Ash Meadows	2	-16996.3	Great Salt Lake	-2954.3		
Rogers and Blue Point Springs	3	-1166.5	Utah Lake	-22296.		
Muddy River Spgs	4	-37402.0	Sevier River 1	-16074.		
Grapevine and Stainigers Spgs	5	-735.3	Sevier River 2	-6163.8		
Pahranagat Valley	6	-23841.8	Sevier Lake	-11145.		
Panaca Warm Spring	7	-9922.7	Virgin River	-4843.5		
Hot Creek Ranch Spgs	8	-2004.3	Death Valley	-8269.0		
Lockes	9	-2813.9	Lake Mead	-2468.2		
Blue Eagle and Tom Springs	10	-3209.8				
Moon River and Hot Creek Springs	11	-12853.2				
Mormon Hot Spring	12	-2198.8				
Northern White River Valleys spgs	13	-10279.8				
Duckwater	14	-13245.6				
Fish Creek Spring	15	-2775.0				
Twin Spring	16	-4005.1				
Campbell Ranch Spring	17	-7377.5				
Shipley Hot Spring and Bailey Spring	18	-4379.9				
Fish Springs	19	-25710.0				
Nelson Spring	20	-1817.0				
Blue Lake and Little Salt Springs	21	-20100.0				
Warm Springs	22	-4956.1				
		-211700.2		-99061.	1523666.	-1213054.

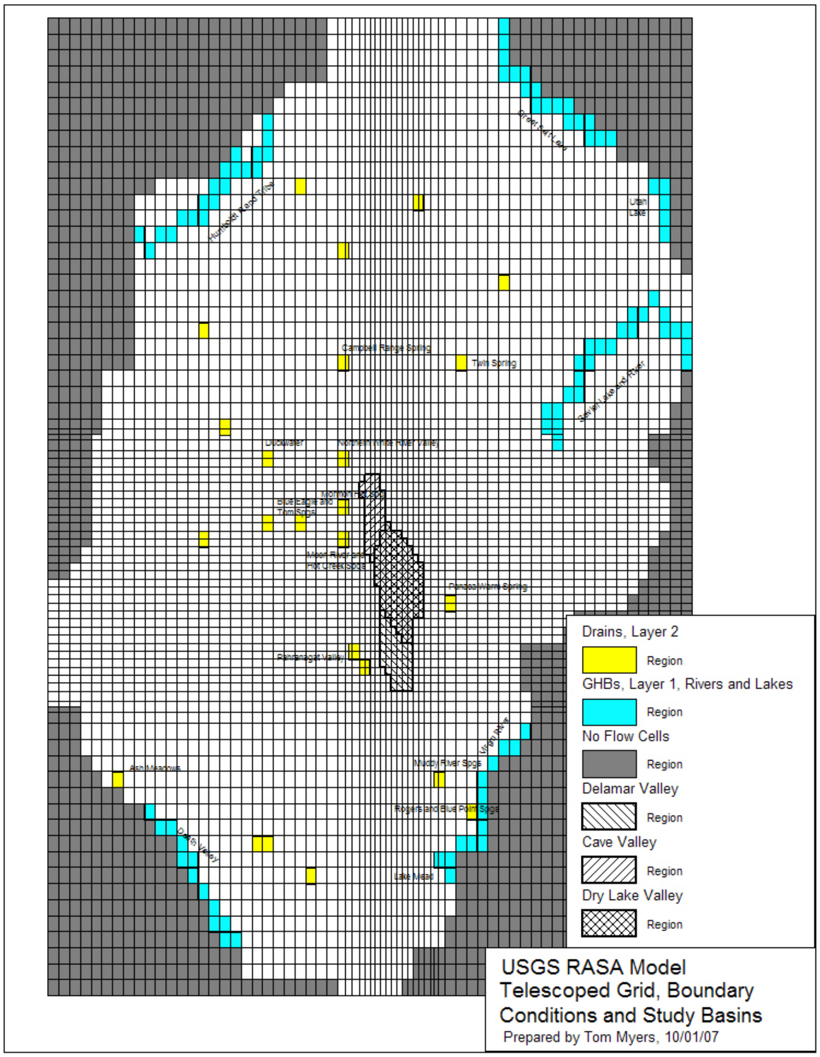

Figure 23: Telescoped grid for the RASA model.

Table 12: Steady state water balance for Cave Valley determined with the USGS RASA model using the telescoped grid.

Total	Inflow (ft3/s)	Outflow (ft3/s)	Inflow (af/y)	Outflow (af/y)	
Xmin	0.66	14.23	479.4	10299.9	West
Xmax	9.93	2.09	7191.6	1511.9	East
Y top	11.00	0.00	7964.0	0.0	North
Y bottom	0.00	21.03	0.0	15223.9	South
Recharge	15.75	0.00	11400.3	0.0	
ET	0.00	0.00	0.0	0.0	
Drain	0.00	0.00	0.0	0.0	Springs
GHB	0.00	0.00	0.0	0.0	Rivers
TOTAL	37.34	37.34	27035.3	27035.6	
Layer 1	**Inflow (ft3/s)**	**Outflow (ft3/s)**	**Inflow (af/y)**	**Outflow (af/y)**	
Xmin	0.59	2.81	426.3	2036.5	West
Xmax	3.27	2.08	2368.9	1508.4	East
Y top	4.11	0.00	2975.3	0.0	North
Y bottom	0.00	3.16	0.0	2290.7	South
Z top	0.00	0.00	0.0	0.0	
Z bottom	0.37	16.03	271.0	11606.3	
Recharge	15.75	0.00	11400.3	0.0	
ET	0.00	0.00	0.0	0.0	
Drain	0.00	0.00	0.0	0.0	
GHB	0.00	0.00	0.0	0.0	
TOTAL	24.09	24.09	17441.8	17442.0	
Layer 2	**Inflow (ft3/s)**	**Outflow (ft3/s)**	**Inflow (af/y)**	**Outflow (af/y)**	
Xmin	0.07	11.41	53.1	8263.4	West
Xmax	6.66	0.00	4822.7	3.4	East
Y top	6.89	0.00	4988.8	0.0	North
Y bottom	0.00	17.86	0.0	12933.2	South
Z top	16.03	0.37	11606.3	271.0	
Z bottom	0.00	0.00	0.0	0.0	
Recharge	0.00	0.00	0.0	0.0	
ET	0.00	0.00	0.0	0.0	
Drain	0.00	0.00	0.0	0.0	
GHB	0.00	0.00	0.0	0.0	
TOTAL	29.66	29.66	21470.9	21471.0	

Table 13: Steady state water balance for Dry Lake Valley determined with the USGS RASA model using the telescoped grid.

Description	Inflow (ft3/s)	Outflow (ft3/s)	Inflow (af/y)	Outflow (af/y)
Xmin	4.02	9.46	2910.2	6849.9
Xmax	6.49	3.98	4699.7	2878.0
Y top	5.29	0.27	3832.3	194.9
Y bottom	0.00	17.00	0.0	12307.5
Recharge	15.08	0.00	10914.0	0.0
ET	0.00	0.18	0.0	128.5
Drain	0.00	0.00	0.0	0.0
GHB	0.00	0.00	0.0	0.0
Storage	0.00	0.00	0.0	0.0
TOTAL	30.88	30.88	22356.1	22358.9
Layer 1	**Inflow (ft3/s)**	**Outflow (ft3/s)**	**Inflow (af/y)**	**Outflow (af/y)**
Xmin	2.84	5.28	2056.0	3824.2
Xmax	4.10	1.98	2966.7	1431.1
Y top	4.10	0.27	2966.9	194.9
Y bottom	0.00	13.44	0.0	9733.0
Z top	0.00	0.00	0.0	0.0
Z bottom	2.67	7.64	1932.7	5527.5
Recharge	15.08	0.00	10914.0	0.0
ET	0.00	0.18	0.0	128.5
Drain	0.00	0.00	0.0	0.0
GHB	0.00	0.00	0.0	0.0
Storage	0.00	0.00	0.0	0.0
TOTAL	28.78	28.78	20836.3	20839.2
Layer 2	**Inflow (ft3/s)**	**Outflow (ft3/s)**	**Inflow (af/y)**	**Outflow (af/y)**
Xmin	1.18	4.18	854.2	3025.7
Xmax	2.39	2.00	1733.0	1447.0
Y top	1.20	0.00	865.3	0.0
Y bottom	0.00	3.56	0.0	2574.5
Z top	7.64	2.67	5527.5	1932.7
Z bottom	0.00	0.00	0.0	0.0
ET	0.00	0.00	0.0	0.0
Drain	0.00	0.00	0.0	0.0
GHB	0.00	0.00	0.0	0.0
TOTAL	12.40	12.40	8980.0	8979.8

Table 14: Steady state water balance for Delamar Valley determined with the USGS RASA model using the telescoped grid.

Description	Inflow (ft3/s)	Outflow (ft3/s)	Inflow (af/y)	Outflow (af/y)
Xmin	6.08	3.34	4404.8	2416.7
Xmax	6.71	2.50	4861.1	1810.0
Y top	9.43	0.00	6827.2	0.0
Y bottom	0.02	16.94	12.9	12261.9
Recharge	0.53	0.00	386.0	0.0
ET	0.00	0.00	0.0	0.0
Drain	0.00	0.00	0.0	0.0
GHB	0.00	0.00	0.0	0.0
TOTAL	22.78	22.78	16492.0	16488.6
Layer 1	**Inflow (ft3/s)**	**Outflow (ft3/s)**	**Inflow (af/y)**	**Outflow (af/y)**
Xmin	4.89	0.85	3543.4	616.1
Xmax	3.75	2.43	2715.3	1758.7
Y top	8.43	0.00	6101.8	0.0
Y bottom	0.02	0.24	12.9	176.8
Z top	0.00	0.00	0.0	0.0
Z bottom	0.03	14.12	19.6	10224.4
Recharge	0.53	0.00	386.0	0.0
ET	0.00	0.00	0.0	0.0
Drain	0.00	0.00	0.0	0.0
GHB	0.00	0.00	0.0	0.0
TOTAL	17.65	17.65	12778.9	12776.1
Description	**Inflow (ft3/s)**	**Outflow (ft3/s)**	**Inflow (af/y)**	**Outflow (af/y)**
Xmin	1.19	2.49	861.4	1800.7
Xmax	2.96	0.07	2145.9	51.2
Y top	1.00	0.00	725.4	0.0
Y bottom	0.00	16.69	0.0	12085.1
Z top	14.12	0.03	10224.4	19.6
Z bottom	0.00	0.00	0.0	0.0
Recharge	0.00	0.00	0.0	0.0
ET	0.00	0.00	0.0	0.0
Drain	0.00	0.00	0.0	0.0
GHB	0.00	0.00	0.0	0.0
TOTAL	19.28	19.28	13957.1	13956.5

Table 15: Location of SNWA applications in the adjusted model.

Application		Layer	Row	Column	Rate 1 (ft3/s)	Rate 2 (ft3/s)	Well Reach Number in the Model
53987	Cave V	1	41	33	1.035959	6	1
53988	Cave V	2	38	33	1.726598	10	2
53989	Dry Lake V	1	47	36	1.294949	6	3
53990	Dry Lake V	2	46	38	2.158248	10	4
53991	Delamar V	1	52	36	1.553938	6	5
53992	Delamar V	2	54	39	2.589897	10	6
reach 1 adjusted one cell south and reach 4 adjusted one cell west so that they were not in low transmissivity material.							
reach 1 had been in the playa material							
reach 4 was in low T volcanics							

Simulated pumping lasted for 2000 years and was followed by recovery for 2000 years. I only completed simulations pumping at the full application amount. Initial heads were those resulting from a steady state model run using the telescoped grid. The transient model run included two stress periods because the wells were either pumping at the given rate, application or perennial yield, or were off. Storage coefficients were as determined by Schaeffer and Harrill (1995). Following Prudic et al (1995), the units were seconds. A stress period then was 6.3072×10^{10} seconds with 130 time steps and a multiplier of 1.07. The time steps and multiplier were adjusted so that initial steps were not too short. For example, using a multiplier of 1.20 resulted in the first step, with 130 time steps, being just a few seconds. None of the tests resulted in water balance errors or had issues with model convergence.

Changes in Flux

The proposed pumping removes groundwater from storage and will do so until a new equilibrium between discharge and recharge becomes established. Except for Cave Valley, the pumping exceeds the recharge simulated within the individual valleys, therefore, the drawdown must become sufficient to draw groundwater from surrounding valleys.

The biggest change in Cave Valley was the outflow to the west which dropped from about 13 cfs to about 6 cfs in 100 years but stabilized at near 5 cfs in 500 years (Figure 24). This reduction in flow to White River Valley is about 5800 af/y. Considered in more detail (Figure 25), it is apparent that the change in flux to the west occurred within five years, indicating that spring flow in that valley could change very soon once pumping commences. Additionally, inflow from the west increased from near 0 cfs to greater than 5 cfs after about 400 years and continued to increase after as long as 1200 years (Figure 24). Inflow from the west did not increase as quickly as the outflow to the west decreased (Figure 24). The long-term increase in flow to the south (Figure 24) mirrors a long-term increase in flow from the north to Dry Lake

Valley. The change in storage requires almost 500 years to reach almost 0 cfs (Figure 24), but it decreased from negative 15 to about 2 cfs within just ten years. This reflects rapid drawdown at the wells followed by slow expansion.

Downgradient from Cave Valley, the Moon River and Hot Creek springs are most affected by the pumping (Figures 26 and 27). After 1800 years, these springs go dry (Figure 26); flow rates decreased by a third within three years and by a half within 20 years (Figure 27). The rapid flow decrease coincides with only small head changes near the springs. As occurs in confined aquifers, stress propagates through the aquifers quickly. Spring flow is sensitive to head changes. The head at the spring is close to the groundwater surface, so small changes cause significant changes in the flow.

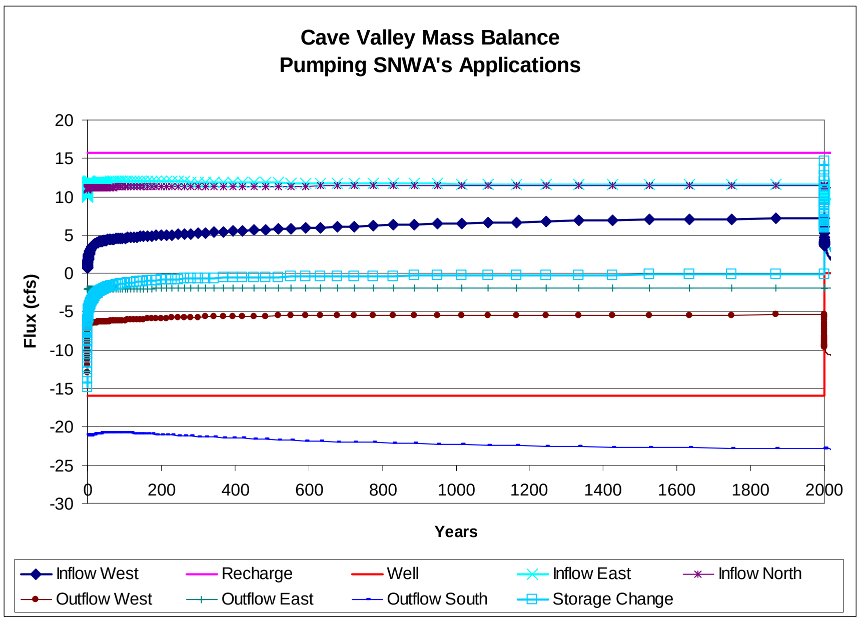

Figure 24: Hydrograph of flux into and out of Cave Valley for pumping SNWA's entire application amount; includes change in storage. 2000 years of pumping.

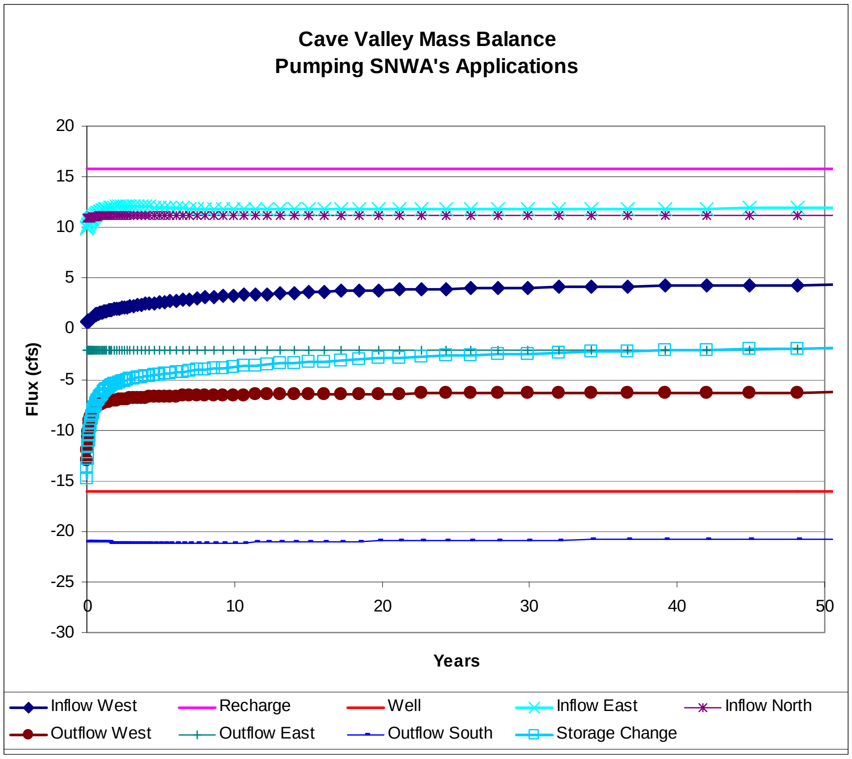

Figure 25: Hydrograph of flux into and out of Cave Valley for pumping SNWA's entire application amount; includes change in storage. 50 years of pumping.

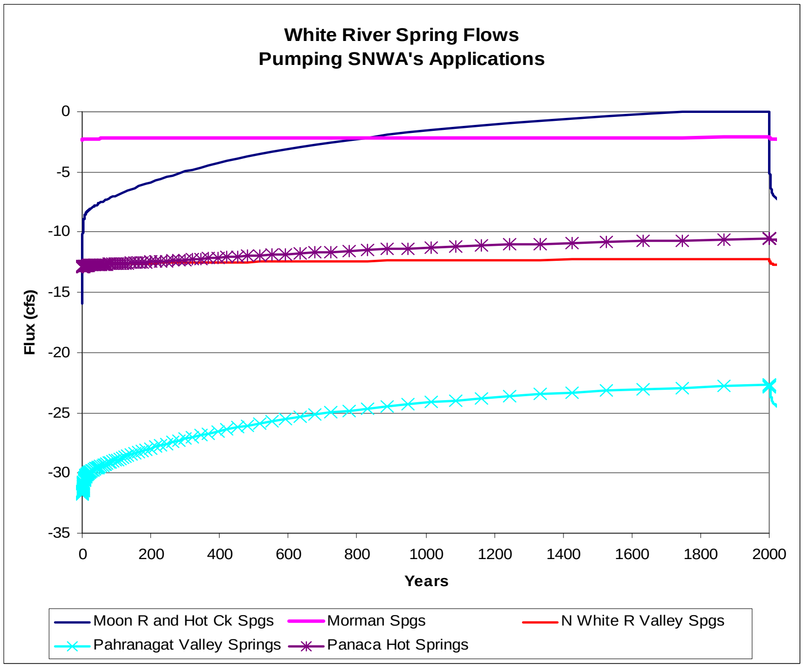

Figure 26: Hydrograph of flux from nearby springs. 2000 years of pumping.

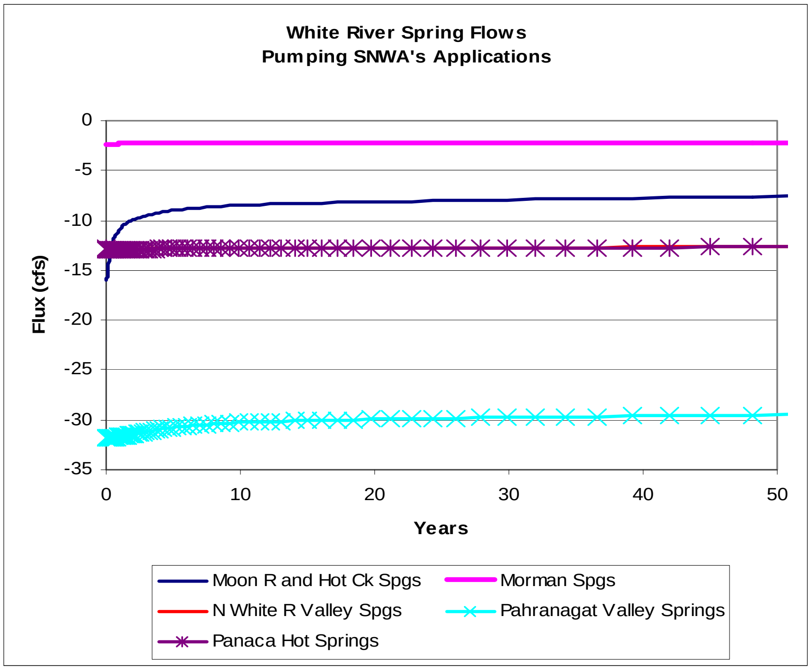

Figure 27: Hydrograph of flux from nearby springs. 50 years of pumping.

Fluxes do not reach steady state in either Dry Lake or Delamar Valleys within 2000 years (Figure 28 and 29). In Dry Lake Valley, after 2000 years, approximately 2 cfs continues to be removed from storage (Figure 28). In Delamar Valley, the similar value is about 1 cfs (figure 29). These rates are approximately 14 and 7 percent of the pumping rates. Also, continued pumping draws from surrounding basins further indicating that conditions are not approaching steady state. In Dry Lake Valley, the discharge to downgradient basins does not decrease proportionately as much as it does from Cave Valley. The increase in inflow from the west is more substantial, from 4 to about 13 cfs over 2000 years (Figure 28) but with an initial doubling within 15 years.

Very slowly, outflow to and inflow from the east decrease and increase about 10 percent (Figure 28), respectively. Discharge from Panaca Springs reflects this change, decreasing about 15 percent over 2000 years (Figure 26), although changes are slight for the first 50 years (Figure 27). The slow change at the Panaca Hot Springs reflects the expectation that pumping these valleys may not significantly affect water levels or spring flows to the east, as discussed above, due to topography and geology. But, as drawdown increases in Dry Lake Valley, the flux is drawn from Lake Valley. After an initial increase, there is also a very small decrease in flux to the south. This reflects the fact the Delamar Valley wells are more than ten miles south of the divide between Dry Lake and Delamar Valley.

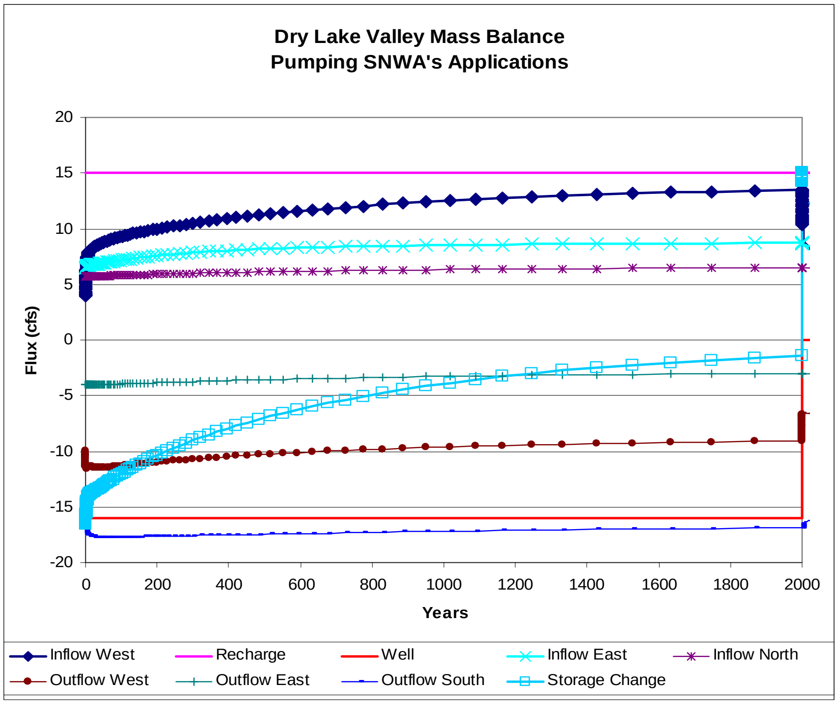

Figure 28: Hydrograph of flux into and out of Dry Lake Valley for pumping SNWA's entire application amount; includes change in storage. 2000 years of pumping.

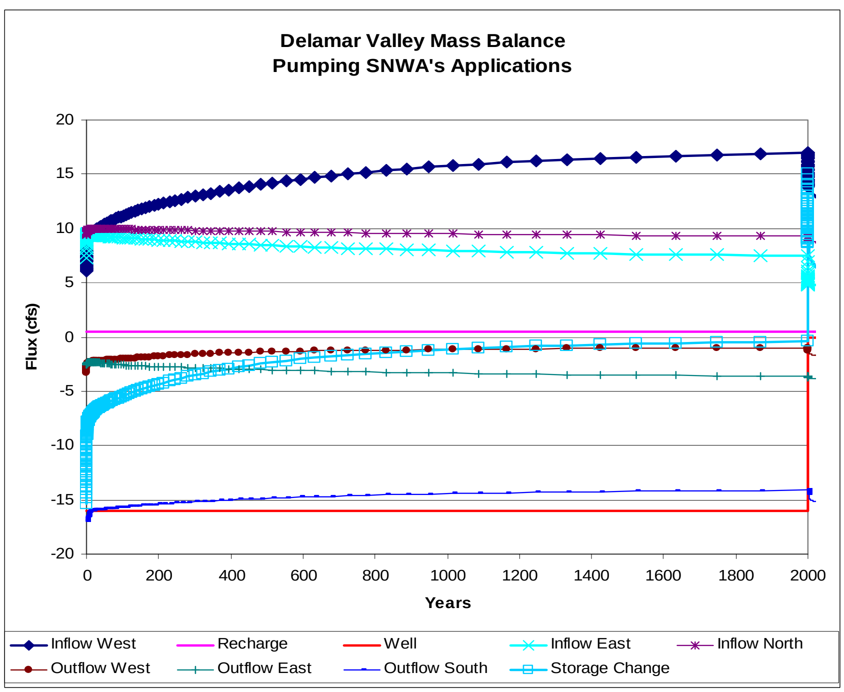

Figure 29: Hydrograph of flux into and out of Delamar Valley for pumping SNWA's entire application amount; includes change in storage. 2000 years of pumping.

Neither Dry Lake nor Delamar Valleys approach steady state within 2000 years (Figure 30). Summing the storage change for the three valleys, pumping at the applied-for rate does not allow conditions to reach steady state within 2000 years. Although almost 7,300,000 af are removed from storage in Dry Lake Valley, this is just 30 percent of the total volume pumped. The 2,600,000 and 640,000 af removed from storage in Delamar and Cave Valley are 11 and 2.7 percent, respectively, of the total pumpage; the remainder is a decrease in discharge from springs or groundwater drawn from surrounding valleys.

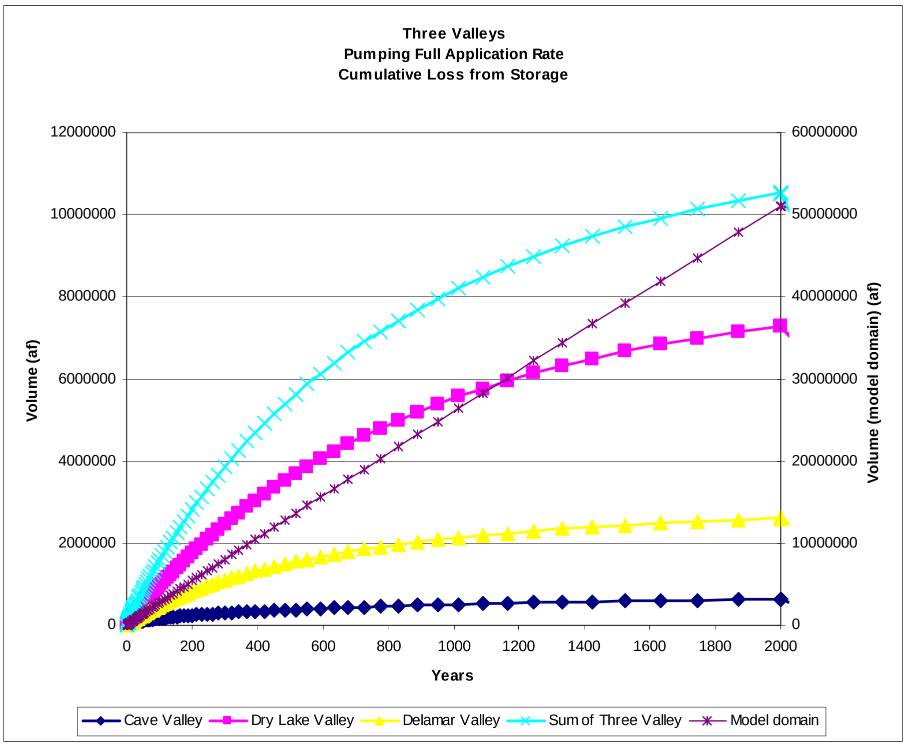

Figure 30: Cumulative storage lost and recovered in Cave, Dry Lake and Delamar for pumping the full application amount from each valley. 2000 years of pumping.

Effects on Regional Springs: After 100 years, the total regional spring discharge had decreased by 13 cfs, or about 27.8 percent of the 48 cfs of total pumping (Figure 36). After 2000 years, the springs had decreased by 29 cfs, or 60.4 percent from their pre-development discharge rate. The spring discharge does not recover quickly; overall spring discharge is less than the pre-development rates after 2000 years of recovery. After 2000 years, the total flow lost from the springs was 75 percent of the total that would be lost for the entire 4000-year analysis period (Figure 36). The 2000-year point is an inflection point at which the rate of increase in the decrease of spring flow begins to decrease because pumping ceased.

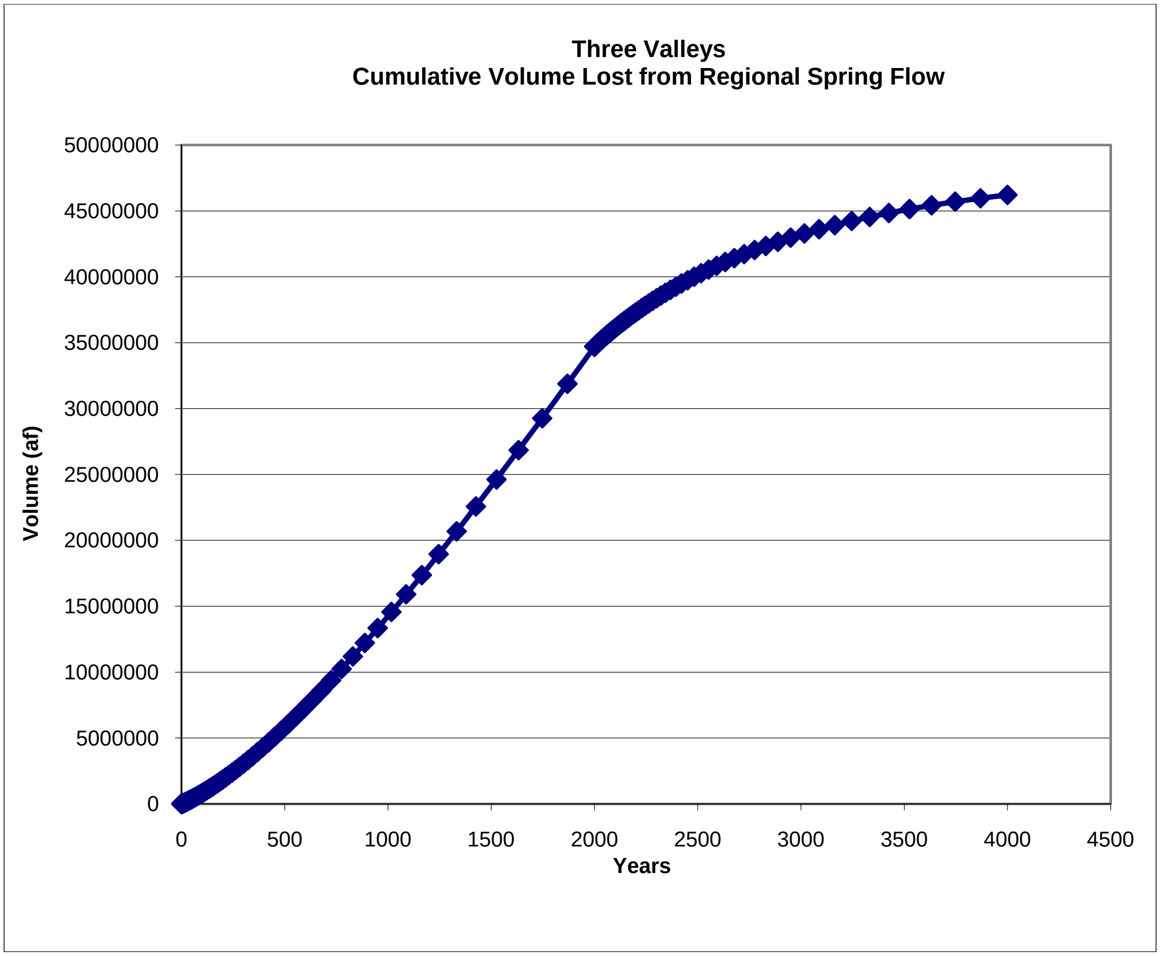

Figure 31: Cumulative flow lost from the regional springs, including the Muddy River springs (which decreased by up to 0.5 cfs).

Much of the flow pumped for these applications will eventually be lost to downgradient springs, although there is a significant lag time. As discussed above, the Moon River and Hot Creek Springs will experience initial decreases quickly. Overall, within 100 years, about one quarter of the pumping rate is lost from the springs; this increases to almost 60 percent within 2000 years. Losses will continue for more than another 2000 years if the pumping ceases after 2000 years.

Conclusion from Model Analysis

There are three major conclusions obvious from this analysis of flows and changes caused by SNWA's proposed pumping, as simulated with the US Geological Survey's RASA groundwater model. First, the flow system does not come to equilibrium with pumping within 2000 years. Second, the changed interbasin flow and expanding drawdown decreases the flow from regional springs downstream from the targeted basins. Some springs experience changes very quickly, with half of the long-term decreases in spring flow in the nearest springs occuring in just five to twenty years. Spring flow remains less than its predevelopment steady state for more than twice the pumping period, or for 2000 years beyond the end of pumping in this analysis.

Third, most of the new groundwater pumpage will cause reduced flow from the regional springs. The pumping will not capture sufficient amounts of GWET discharge from downgradient basins. Because all new discharges must eventually result in decreased discharge somewhere, it is reasonable to expect that the decreases will occur to regional springs.

Conclusion

SNWA's applications for up to 34,500 af/y of groundwater from Cave, Dry Lake and Delamar Valleys vastly exceed the published perennial yield, discharge from, and recharge in the valleys.

The proposed application amount exceeds the available water in all of the White River Flow System. Permitting them would cause flow from the WRFS to eventually cease. Both White River Valley and Pahranagat Valley depend on interbasin flow to support existing water rights and still have flow leaving Pahranagat Valley to support uses further downgradient. Both the White River and Pahranagat Valley springs are currently fully appropriated and the discharge from these springs depends on groundwater and interbasin flow. Existing development has reduced the steady flow from Pahranagat Valley to about a third of its pre-development value. Developing either SNWA's application amount or the published perennial yield will cause discharge from Pahranagat Valley to become negative once steady state becomes established.

Simple groundwater modeling has shown that the impacts of developing these water rights will expand very rapidly. Spring flow reductions occur quickly in response to the pumping. Full development of the applications will cause Moon River and Hot Creek Springs to lose a third of their flow within three years; eventually these springs go dry. The Pahranagat River Springs lose about 2 cfs within 20 years, likely harming water rights' holders who depend on the springs. Over 2000 years, the flow from Pahranagat Valley springs reduces by about one-third.

Because drawdown slowly expands east, the Panaca Hot Springs flow will be reduced by 0.5 cfs; this occurs in a valley which does not have an interbasin flow interchange with the targeted basins under steady state conditions. For pumping the perennial yield, the impacts to Moon River and Hot Creek springs commence immediately but not as precipitously. After 500 years the flow decrease is just 1 cfs; the total decrease after 2000 year is just 2.5 cfs. Similarly, the total decrease for Pahranagat Valley springs is just 2 cfs after 2000 years.

There is not sufficient groundwater available to grant any water rights from these applications. Developing any new water in these basins will rapidly affect downstream springs. These applications should be totally denied.

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Appendix 1: Well Logs

WHITE—DIVISION OF WATER RESOURCES
CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY

STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLERS REPORT

Please complete this form in its entirety

OFFICE USE ONLY
Log No. 22450
Permit No.
Basin DRY Lake Valley

1. OWNER U.S. Government Air Force ADDRESS MX Ballistic Missile office
by Fugro Inc - 3777 Long Beach Blvd - Long Beach Calif.

2. LOCATION NE 1/4 SW 1/4 Sec. 27 T. 3N R. 63 E. Lincoln County
PERMIT NO. in Dry Lake Valley 8 miles East of Hwy 93.

3. TYPE OF WORK
New Well ☐ Recondition ☐
Deepen ☐ Other ☒ Exploratory

4. PROPOSED USE
Domestic ☐ Irrigation ☐ Test ☒
Municipal ☐ Industrial ☐ Stock ☐

5. TYPE WELL
Cable ☐ Rotary ☒
Other ☐

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
See attached Lithologic Log from J. J. Kleinfelder and associates.				
(Test were not completed on this well until Jan of 81)				
Alluvium		0	195	
Volcanics		195	340	
Limestone & or dolomite -		340	2180	
Limestone & silty Limestone		2180	2395	

Date started Oct. , 1980
Date completed Jan , 1981

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump
See attached copy of test made by Rhodes Bros.			

BAILER TEST

G.P.M. .... Draw down .... feet .... hours
G.P.M. .... Draw down .... feet .... hours
G.P.M. .... Draw down .... feet .... hours

8. WELL CONSTRUCTION

Diameter hole 9 7/8 inches Total depth 2395 feet
Casing record 10" 347'
Weight per foot .... Thickness 1/4 - .188

Diameter	From	To
13 3/4 + inches	0 feet	347 feet
10 inches	casing feet	347 feet
9 7/8 inches	347 feet	995 feet
8 inches	casing feet	995 feet
7 7/8 inches	995 feet	2395 feet
inches	feet	feet

Surface seal: Yes ☒ No ☐ Type Cement Grout
Depth of seal 347' feet
Gravel packed: Yes ☐ No ☒
Gravel packed from .... feet to .... feet

Perforations:
Type perforation None.
Size perforation ....
From .... feet to .... feet
From .... feet to .... feet
From .... feet to .... feet
From .... feet to .... feet
From .... feet to .... feet

9. WATER LEVEL

Static water level 853 Feet below land surface
Flow .... G.P.M. 50'
Water temperature 80 ° F. Quality good

10. DRILLERS CERTIFICATION

This well was drilled under my supervision and the report is true to the best of my knowledge.

Name Walter Rodney Miller
Address P.O. Box 818 Fallon Nev
Nevada contractor's license number 005380
Nevada driller's license number 961
Signed Walter Rodney Miller
Date Feb. 16 1981

APPENDIX 2: Abstract from NGWA Conference

Using Existing Regional Groundwater Models for Local Problems

Jack Wittman, Ph.D., CGWP and Vic Kelson, Ph.D., CGWP, Layne Hydro

All over the country as cities, industrial water users and farmers are attempting to deal with water shortages and water supply conflicts, groundwater professionals are helping to evaluate the potential for additional aquifer use. If surface water supplies are unreliable and aquifers are available, it is likely that others have collected data and developed a consistent interpretation of the hydrologic system. If work has been done in the area there is an opportunity for knowledge of the system to evolve and improve. Good scientific practice suggests that wherever possible, new work should always build upon previous studies. In the United States, groundwater investigations often begin with a review of the literature and with any luck the area has been studied and reports are available. In some areas the previous work includes modeling work that was done in the last one or two decades. However, most modelers would rather read the old reports and review the data as a starting point when they develop their own "fresh" model with their own tools. It is often simpler (or more tractable) to redo the work than attempt to debug and run a 10-year old groundwater flow model. However, rebuilding from scratch is time consuming and mistakes are hard to avoid.

This presentation will describe our work in various parts of the country where we have taken the time to revise previously developed and well-documented USGS groundwater flow models. We have reawakened and refined these regional models to gauge local impacts of new wells and to consider long term water availability.

Biographical Sketches

Dr. Wittman has a B.S. in Environmental Studies and a M.S. In Watershed Science from Utah State University, and a Ph.D. in Environmental Science from Indiana University, Bloomington. Prior to founding WHPA, Dr. Wittman was a Senior Research Scientist in the School of Public and Environmental Affairs at Indiana University (Indianapolis), a Senior Research Hydrologist at Indiana University (Bloomington), a private consultant in Washington State, the Associate Director of the Utah High Level Nuclear Waste Office, and a drinking water treatment plant operator in Salt Lake City, Utah. Jack is now the Director of GeoSciences for Layne Christensen Company.

Vic has a B.S. in Chemical Engineering from the Colorado School of Mines and a Ph.D. in Environmental Science from the School of Public and Environmental Affairs at Indiana University. He started his career as a process engineer in industrial settings and since graduating from IU, Vic has developed (and patented) several new computational groundwater flow models. In addition to his own codes he has developed models for the USEPA, the U.S. Army Corps of Engineers, and several collaborative projects with the USGS.

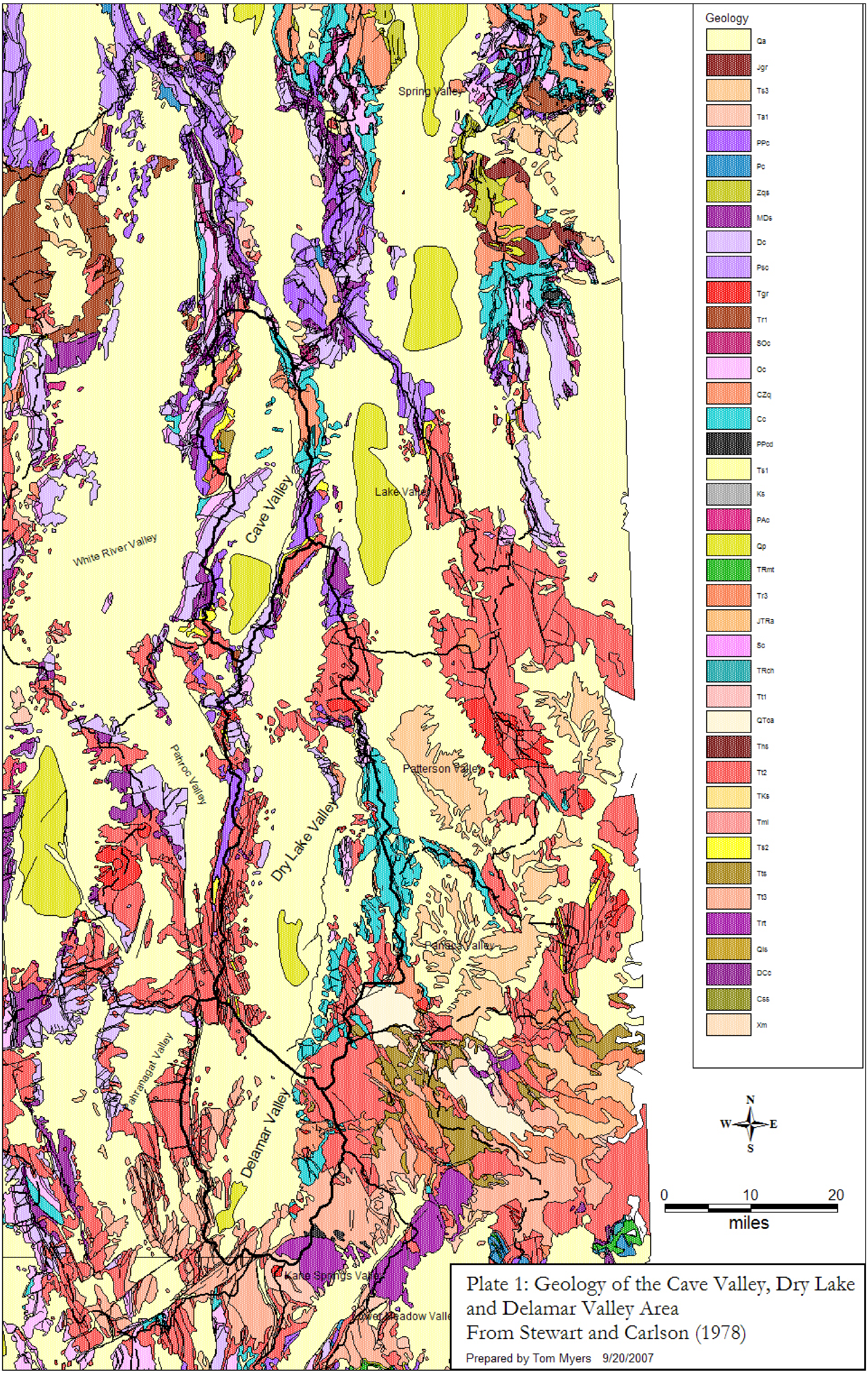

Plate 1: Geology of the Cave Valley, Dry Lake and Delamar Valley Area
From Stewart and Carlson (1978)
Prepared by Tom Myers 9/20/2007