Hydrogeology of Cave, Dry Lake and Delamar Valleys
and
Effects of Groundwater Development
Proposed by the
Southern Nevada Water Authority

White Pine and Lincoln County, Nevada

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Executive Summary

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. The targeted valleys lie at the upgradient end of the White River Flow System. The three valleys are lightly developed, with just a few hundred acre-feet of underground rights in Cave and less than a hundred in Dry Lake and Delamar. But the basins downgradient from Cave, the White River Valley, and from Dry Lake and Delamar, the Pahranagat Valley, are fully developed. Their surface water systems, streams and springs, are fully appropriated. Interbasin flow from upgradient basins supports the spring systems in the downgradient valleys.

Recharge estimates to Cave Valley range from about 9000 to 19000 af/y, but the majority cluster around the Maxey-Eakin estimate of 14,000 af/y. Similarly, groundwater discharge estimates within Cave Valley range from 0 to almost 5000 af/y. The depth to groundwater water exceeds 100 feet in most of the basin, therefore most of the discharge results from two major spring systems and from mountain front recharge directly to the alluvium near Cave Valley Wash and totals about 1200 af/y. Capturing this discharge would require numerous wells spaced in specific locations in the valley, but the springs each have water rights to them. The remaining recharge is interbasin flow to White River Valley where it supports spring flow and underground water rights in the heavily developed southeast quadrant of the valley. Based on the amount of water rights and the evapotranspiration discharge rate, the southeast portion of the White River Valley depends on interbasin flow.

Dry Lake and Delamar Valleys have 5000 and 1000 af/y of recharge based on the Maxey-Eakin method, respectively. There is no discharge within the basins, so the entire amount discharges as interbasin flow to Pahranagat Valley. It is a major part of the interbasin flow supporting springs and water rights within that valley.

The perennial yield (PY) of a ground-water reservoir may be defined as the maximum amount of ground water that can be salvaged each year over the long term without depleting the ground-water reservoir. Perennial yield is ultimately limited to the maximum amount of natural discharge that can be salvaged for beneficial use. The published perennial yield for Cave Valley is 2000 af/y which, because it is so much less than the recharge estimates, reflects the difficulty in actually developing or capturing the interbasin flow from that valley. The published perennial yield for Delamar and Dry Lake Valleys is 3000 and 2500 af/y, respectively, which, based on the recharge estimates of 1000 and 5000 af/y, cannot be correct. If the perennial yield for Dry Lake Valley is half of the interbasin flow, then PY is 2500 af/y PY. If the PY in Dry Lake Valley is developed, only 2500 af/y would inflow to Delamar Valley. Combined with the recharge, there would be 3500 af/y left to be interbasin flow to Pahranagat Valley. If half of the interbasin flow is PY, the PY for Delamar would be 1750 af/y; the PY for Delamar can be 3000 af/y only if all of the interbasin flow from Dry Lake Valley remains. The total for the two valleys would be 4250 af/y if the total for Dry Lake Valley is developed.

Considering the uncertainties, it is reasonable to treat the valleys together with 6000 af/y of recharge and interbasin flow to Pahranagat Valley and state that total perennial yield from the two together is 3000 af/y.

The analysis herein considers two development amounts for the three valleys, the full application amounts approximating 11,500 af/y and the published perennial yield from each valley. There is insufficient water available in the White River Flow System to provide for these applications without substantially diminishing the groundwater available further downgradient. Either amount of development will decrease the interbasin flow from the basins and negatively affect downgradient water rights and spring flow (Table ES-1). Pahranagat Valley is the most downstream valley in the system; developing either SNWA's application amount or the published perennial yield will cause discharge from Pahranagat Valley to become negative once steady state becomes reestablished (Table ES-1).

Table ES-1: Water budget analysis for the White River Flow System for full development of SNWA's water rights applications in Cave, Dry Lake and Delamar Valleys. All flows in acre-feet/year.

Basin	Recharge	Interbasin Inflow	GW Discharge	GW Use	Outflow	To	Comments
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	49181	76700	8776	1705	Pahroc	48 kaf/y inflow from Steptoe and Jakes Valley
Pahroc Valley	2200	1705	0	30	3875	Pahranagat	
Pahranagat Valley	1800	-1777	25000	8692	-33670	Coyote Springs	
Coyote Spring/Kane Springs Valley	6000	-33670	0		-27670	Muddy Springs	

Recharge: Based primarily on reconnaissance reports
Interbasin inflow: Flow into the basin from one or more upgradient basins.
GW Discharge: Discharge from the regional aquifer within the basin – either by evapotranspiration or Springflow.
GW Use: consumptive use by water rights

Groundwater modeling using a widely accepted U.S. Geological Survey model shows that the impacts of developing these water rights will expand rapidly. Pumping SNWA's full applications would cause drawdown at the Dry Lake and Delamar proposed carbonate wells to exceed 200 feet after just 8 years; in Cave Valley drawdown would be 40 feet. The drawdown cone would expand quickly into White River Valley. Low permeability in the center of Cave Valley may prevent expansion of drawdown from the south half of Cave Valley, where the wells would be constructed, into north Cave Valley where the natural discharge from Cave Valley occurs. Drawdown expanded to the west substantially more than to the east as would be expected from the primary discharge being interbasin flow to the west. Topography and low transmissivity prevent the expansion of drawdown to the east for 100 years. The 20-foot drawdown approaches but does not fully encompass the springs in White River and Pahranagat Valleys. Even after 2000 years, the 20-foot drawdown will have expanded past the springs but will be less than 20 feet at the springs due to the high transmissivity near those springs.

Drawdown caused by pumping at the perennial yield rate is less than for pumping at the full application rate. The biggest difference is that the drawdown is not as great near the wells as it is for the full application rate. The rather small difference reflects the rapid spread of the drawdown cone and the rapid impact on surrounding springs.

Spring flow reductions occur quickly in response to the expanding drawdown. 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 dependent on the springs. Over 2000 years, the flow from Pahranagat Valley springs reduces by about one-third. Due to drawdown slowly expanding 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 natural conditions. For pumping the perennial yield, the impacts to Moon River and Hot Creek springs commence immediately but less precipitously. After 500 years the flow decrease is just 1 cfs; the total decrease after 2000 years 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. Any water that is developed will rapidly affect downstream springs. These applications should be totally denied.

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 (Figure 1). The Las Vegas Valley Water District (LVVWD) filed six water rights applications, which were later transferred to SNWA, within the three target basins in 1989 (Table 1), along with other applications for water rights in many other eastern Nevada basins. Numerous people and organizations protested these applications. The Nevada State Engineer began acting on them in 2004 when SNWA finally pushed for their consideration.

Currently, the Nevada State Engineer is considering the second set of applications. The first set regarded four valleys in the Death Valley flow system, Tickapoo North and South and Three Lakes North and South, were held (Nevada State Engineer Ruling 5465). The State Engineer then commenced hearings on applications in Spring Valley, Snake Valley, Cave Valley, Lake Valley and Delamar Valley. He held a protest hearing concerning applications in Spring Valley in September 2006 and issued a ruling in spring 2007 (Nevada State Engineer Ruling 5726). The State Engineer will hold a hearing for Cave Valley, Dry Lake Valley and Delamar Valley applications (Table 1) in February 2008. This evidence report provides data, analysis and reasoning for that hearing in support of the protestant's argument that the State Engineer should deny the applications.

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 are 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.

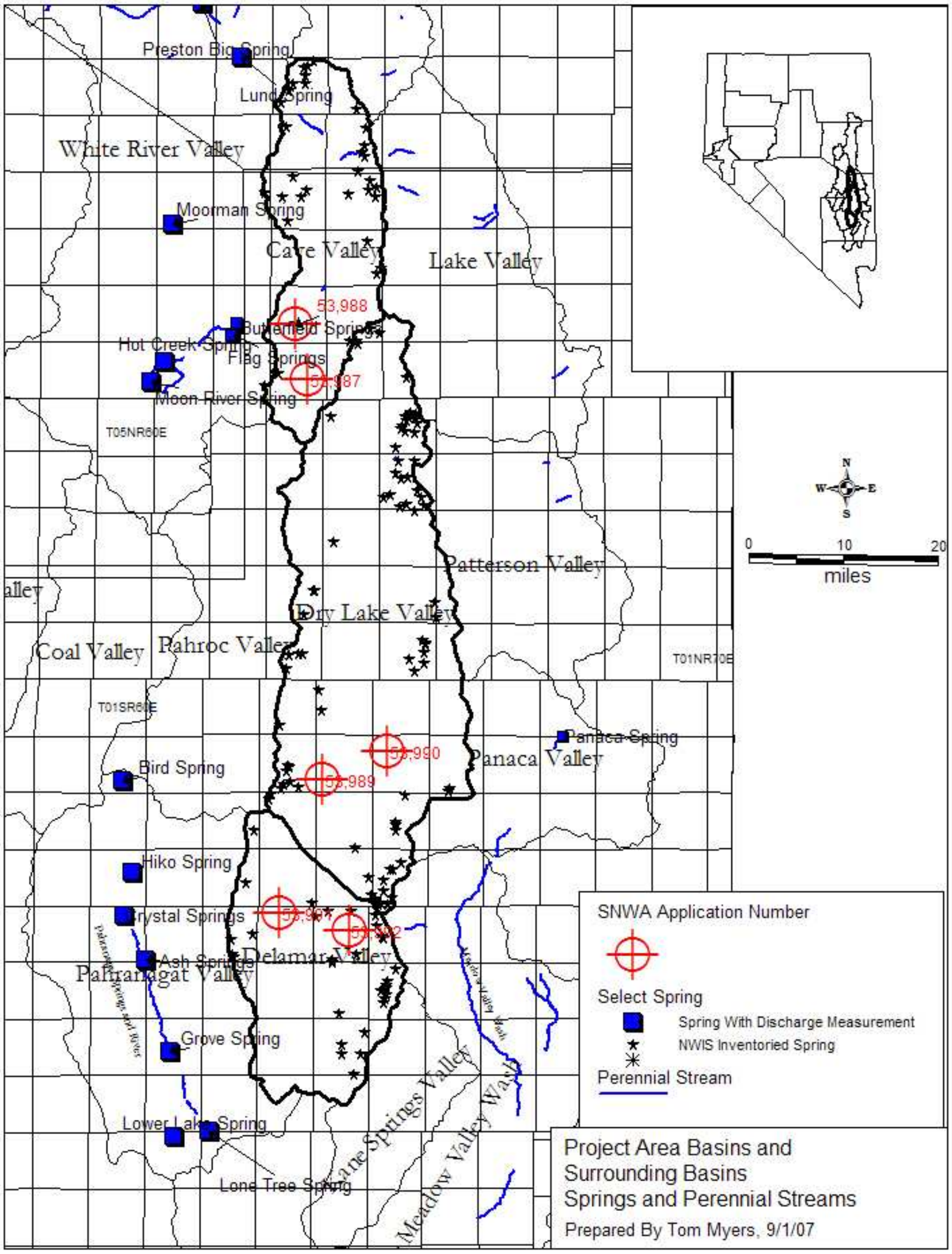


Figure 1: Location of target and surrounding basins, select springs, perennial streams, and SNWA's water rights applications (see Table 1 for description).

SNWA Water Rights Applications

The water rights applications show the diversion rate and annual duty as reported on Table 1 but Schaeffer and Harrill (1995) analyzed pumpage rates for Cave, Delamar and Dry Lake Valley of 2000, 3000, 2500 af/y, respectively, when analyzing the impacts of developing these applications. These pumpage values equal the published perennial yield values for the basins (NV State Engineer 1971) and were used based on a written communication from the Las Vegas Valley Water District. The applications total 11,583 afy for each of the three target valleys.

The only indication as to whether the application is for valley fill or carbonate water is the description on the application that says the source is “underground basin” or “underground rock aquifer”. The assumption is that underground rock aquifer is the carbonate aquifer. The three 10 cubic feet per second (cfs) applications are assumed to be for carbonate aquifer water; the others are for basin fill water.

Methods

Analysis presented in this report estimates whether there is water available to grant the applications and predicts the impacts of doing so. This includes consideration of the perennial yield (PY) in light of the water budget of the targeted and downstream basins. Predictions consider the effects of full development of the applications and of the amounts considered by Schaeffer and Harrill (1995). Specifically, it considers whether there is sufficient water for the proposed interbasin transfer by considering the water budgets of the three target valleys and those immediately downgradient as well as for the overall flow system. The report discusses recharge, discharge and interbasin flow as estimated by previous studies and field verified (for groundwater evapotranspiration (GW ET)) to determine the best estimate for a water budget.

The report considers the existing water rights and discusses the interdependence among underground (UG), stream and spring rights. Water rights for each valley were downloaded from the water rights database available on the State Engineer’s web page. The report considers the existing water rights as a part of the overall water budget.

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).

New studies completed by the USGS under Basin and Range Carbonate Aquifer System Study (BARCASS) are also included. BARCASS included a draft report to Congress (Welch and Bright 2007) and a series of scientific investigations reports issued in final form (Flint and Flint 2007, Moreo et al 2007).

Considering that water budget analysis shows that the groundwater originating in the target basins is used in downgradient basins, there is an impact analysis to determine how long it takes for the deficits to reach existing springs and water rights. Using an amended US Geological Survey groundwater model of the carbonate system (Prudic et al 1995), the analysis estimates the time for impacts to propagate, estimates drawdown in surrounding valleys, and predicts changes in flux to the springs. The original model had been obtained from Dr. Dave Prudic of the U.S. Geological Survey.

Perennial Yield

Perennial yield (PY) is the amount of groundwater that can be removed from an aquifer, usually a basin-wide aquifer system, without causing a long-term continuing drawdown, or without depleting the groundwater system. Pumping at rates up to the perennial yield will lower the water table, by removing transitional storage, so that other discharges from the system will decrease or cease. By replacing natural discharges with well discharges, a new equilibrium will theoretically become established. If the pumping exceeds the natural discharges, the water table will continue to lower and no equilibrium will be reached. In a large basin, the design of the pumping system may determine how fully the perennial yield can be developed or whether equilibrium will be approached even for pumping much less than the perennial yield.

Perennial yield has historically been considered to equal or approximate the natural recharge to the system (Bredehoeft 2007). This opinion has come about from the use of Maxey-Eakin recharge estimates in Nevada’s basin-by-basin reconnaissance (recon) reports (Eakin (1962) is a recon report for Cave Valley). The Nevada State Engineer published the 1992 Hydrographic Basin Survey which details the perennial yield for most Nevada basins. Many of the PY estimates were based on the recon reports and most of the recon report PY estimates were based on the recharge estimate. However, the Maxey-Eakin methodology was set based on the estimated discharge from the basin, so the reality is that PY has most often been set equal to the discharge. The State Engineer perhaps best described the procedure for determining PY in a recent ruling concerning applications in Granite Springs:

> The perennial yield of a ground-water reservoir may be defined as the maximum amount of ground water that can be salvaged each year over the long term without depleting the ground-water reservoir. Perennial yield is ultimately limited to the maximum amount of natural discharge that can be salvaged for beneficial use. The **perennial yield cannot be more than the natural recharge** to a ground-water basin and in some cases is less. If ground-water withdrawals exceed the perennial yield, ground-water levels will continually decline and steady-state conditions may not be achieved, a situation commonly referred to as ground-water mining. Additionally, withdrawals of ground water in excess of the perennial yield may contribute to adverse conditions such as water quality degradation, storage depletion, diminishing yield of wells, increased pumping lifts, and land subsidence.

> In most of Nevada's hydrographic basins, ground water is discharged primarily through evapotranspiration (ET). In closed hydrographic basins, the **perennial yield is approximately equal to the estimated ground-water ET**, the **assumption being that ground water lost to natural ET can be captured by wells** and placed to beneficial use. However, many of the basins throughout the state also discharge ground water via subsurface flow to adjacent basins. **In basins with substantial subsurface outflow, the perennial yield may include a portion of that outflow**; however, the amount of that subsurface discharge that can be readily captured by wells is highly variable and uncertain. Perennial yields for basins with no ground-water ET, that is, ground water is discharged solely by subsurface flow, has generally been established as equal to **one-half of the outflow**. In hydrographic basins with both ground-water ET and subsurface outflow, the perennial yield has most often been determined to be the sum of the ET and one-half of the subsurface outflow. However, there are **many exceptions to this general rule-of-thumb** based on considerations of local hydrology, as well as **prior rights appropriated in other basins within the same ground-water flow system**. (Nevada State Engineer Ruling 5782, page 9-10, emphases added).

The only factor left unexplained by this passage is how much of the interbasin flow into a basin may be considered perennial yield within the receiving basin. Otherwise, many descriptions of PY in ruling 5782 apply to the consideration of perennial yield for the basins being considered here. The next section considers the hydrogeology, including the water balance, of the basins so this section considers only the concepts and accepts the arguments in the recon reports (Eakin 1962 and 1963a).

There is little GW ET from each of the target basins. The recon reports (Eakin 1962, Eakin 1963a) found that all of the recharge, 14,000, 5000 and 1000 af/y in Cave, Dry Lake and Delamar Valleys, respectively, becomes interbasin flow. According to the procedure described in ruling 5782, the perennial yield of Cave Valley would be one-half of 14,000 af/y. But the published perennial yield is just 2000 af/y (Table 2) (NV State Engineer 1971). This is probably because capturing any interbasin flow would be almost impossible as described by Eakin (1962)

> The apparent substantial ground-water underflow out of Cave Valley further complicates the evaluation of perennial yield. Pumping from wells might not salvage much of this discharge unless the wells were drilled so as to intercept the discharge or unless pumping resulted in the removal of a substantial part of the ground water in storage in the valley fill. (Eakin 1962, page 13)

Eakin recognized that it would be necessary to lower the water table substantially to reverse flow gradients and prevent interbasin flow. He did not estimate the PY. The estimate 2000 af/y was apparently a compromise between saying that no water could be developed and recognition that developing the full recharge would require removal of most of the stored groundwater and groundwater mining.

There is also no GW ET from Dry Lake or Delamar Valleys; most of the recharge therefore discharges to Pahranagat Valley (Eakin 1963 a and c). Although not directly stated, the assumption by Eakin (1963a) is that groundwater flows from Dry Lake to Delamar Valleys. Considering the low divide between the valleys, it would probably be possible to capture some flow from Dry Lake to Delamar Valley. Because most of the 5000 af/y recharge in Dry Lake Valley probably discharges to Delamar Valley, the 2500 af/y PY estimate is reasonable.

Table 2: Some basins within the flow system including the target basin, and the published perennial yield and 1992 underground water rights. These values were determined in the Water for Nevada (NV State Engineer 1971)

Basin No.	Basin Name	Area, sq. miles (Nevada portion only)	Perennial Yield, AF/YR	Committed Resources		Designated (Yes/No)
				AF/YR	Date	
180	Cave Valley	362	2,000	13	Jun-92	N
181	Dry Lake Valley	882	2,500	56	Jun-92	N
182	Delamar Valley	383	3,000	7	Jun-92	N
204	Clover Valley	364	1,000	3,690	Jul-92	N
205	Lower Meadow Valley Wash	979	5,000	29,680	Jul-92	Y
206	Kane Springs Valley	234	Minor	0	Feb-92	N
207	White River Valley	1,607	37,000	25,007	Jul-92	N
208	Pahroc Valley	508	21,000	7	Jun-92	N
209	Pahranagat Valley	768	25,000	9,714	Jul-92	N
210	Coyote Spring Valley	657	18,000	0	Jun-92	Y
211	Three Lakes Valley	311	5,000	521	Jul-92	Y

*: The committed resources will be reconsidered below. The values were published in the source and must be updated.

However, the 3000 af/y PY estimate for Delamar Valley is not reasonable, unless there is no development in Dry Lake Valley. In other words, it appears that groundwater has been double-counted in the determination of PY for Dry Lake and Delamar Valleys. The sum of the recharge to Dry Lake Valley, 5000 af/y, and to Delamar Valley, 1000 af/y, is 6000 af/y. There is no discharge within these valleys, therefore the entire recharge discharges to Pahranagat Valley. If the PY of Delamar is half of the interbasin flow out of Delamar, then the 3000 af/y estimate is reasonable. However, it would not be possible to develop any water that would discharge to Delamar Valley from Dry Lake Valley; effectively, the PY of Delamar is 3000 af/y if and only if the PY in Dry Lake Valley is 0.

Alternatively, it could be assumed that 2500 af/y Dry Lake Valley interbasin flow reaches Delamar Valley with development in Dry Lake Valley. It is not clear based on ruling 5782 whether the entire interbasin flow minus the perennial yield should be considered inflow for the purpose of determining PY in the receiving basin. If it is, there would be 3500 af/y of interbasin flow from Delamar to Pahranagat Valley remaining after development of the PY in Dry Lake Valley. Based on using half of it, the PY for Delamar Valley would be 1750 af/y. This would reduce the long-term discharge to Pahranagat Valley to 1750 af/y from the original 6000 af/y. Developing the published perennial yield would reduce the long-term discharge to 500 af/y.

However, it is not clear that this development can actually occur. Eakin recognized that salvaging the natural discharge could be prohibitively expensive, as the following passage expresses:

> Whether the magnitude of perennial yield ultimately equals total recharge to the valley depends upon the relative location of the area of pumping with respect to the several areas of recharge to the valley, the relation of the area of pumping with respect to the principal area of ground-water discharge or underflow from the valley, and the altitude of economic pumping levels with respect to the altitude of natural discharge or underflow. In Dry Lake and Delamar Valleys, the costs of pumping relatively large quantities of ground water to modify appreciably the natural ground-water regimen to salvage all the natural discharge undoubtedly would be prohibitive for all but the most exceptional water requirements… However, it is conceivable that to salvage a large part of the estimate 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. (Eakin 1963a, page 19, emphasis added)

A 1500-foot drawdown is not likely consistent with the concept of developing perennial yield.

The perennial yield depends on estimates of discharge from the basins and the interbasin flow depends on the difference in estimates of recharge and discharge. There have been new estimates made of all components of the water balance of these three valleys since the recon reports. The next section addresses basic hydrology, the conceptual model of flow and water balance of the three targeted basins and the receiving basins. As quoted above from ruling 5782, demands in downstream basins may affect the perennial yield or the amount of perennial yield in upstream basins that may actually be developed. The next section also considers the water rights in the targeted and receiving basins.

Hydrology of the Study Area

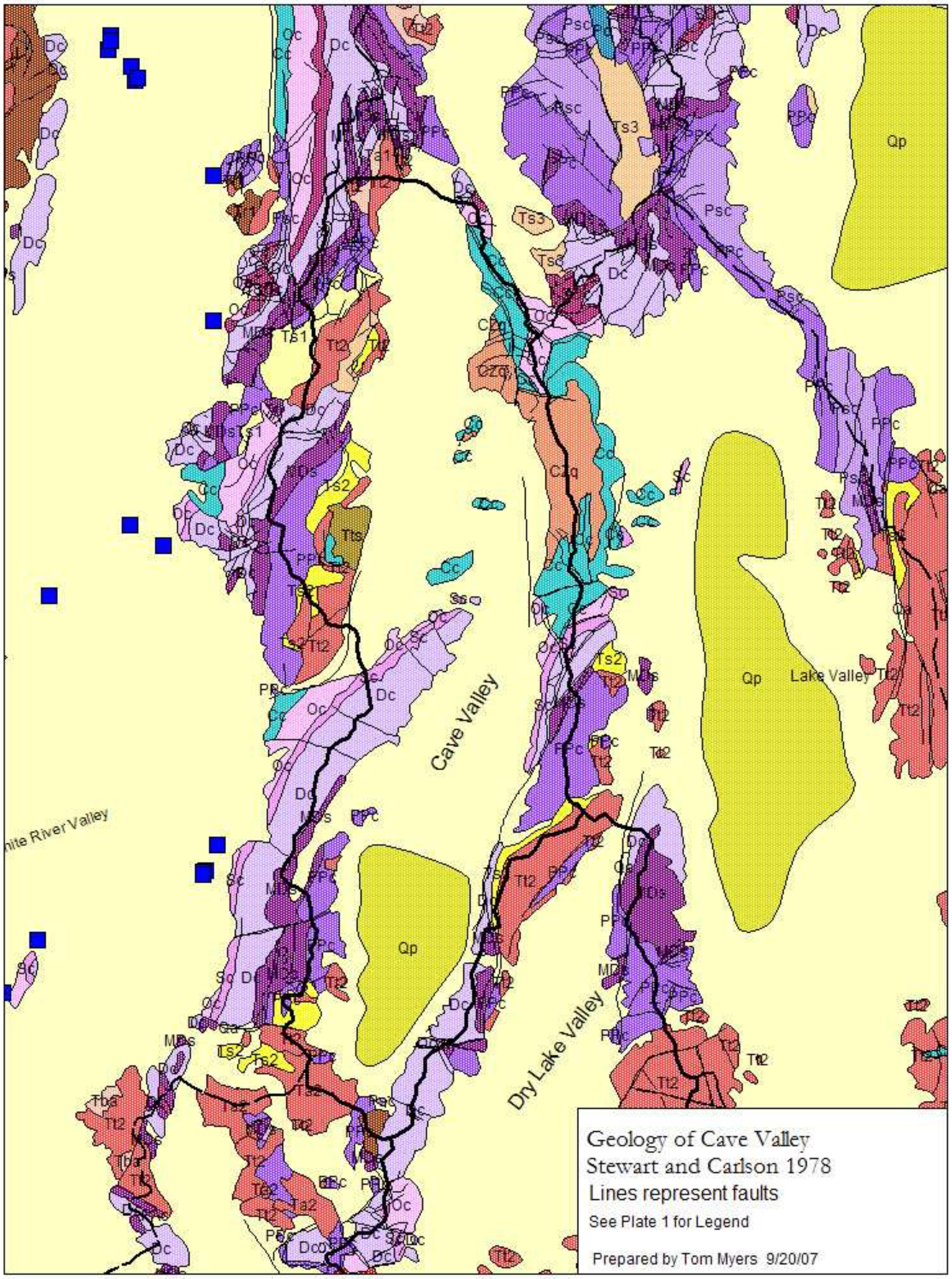
Geologic Setting

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.

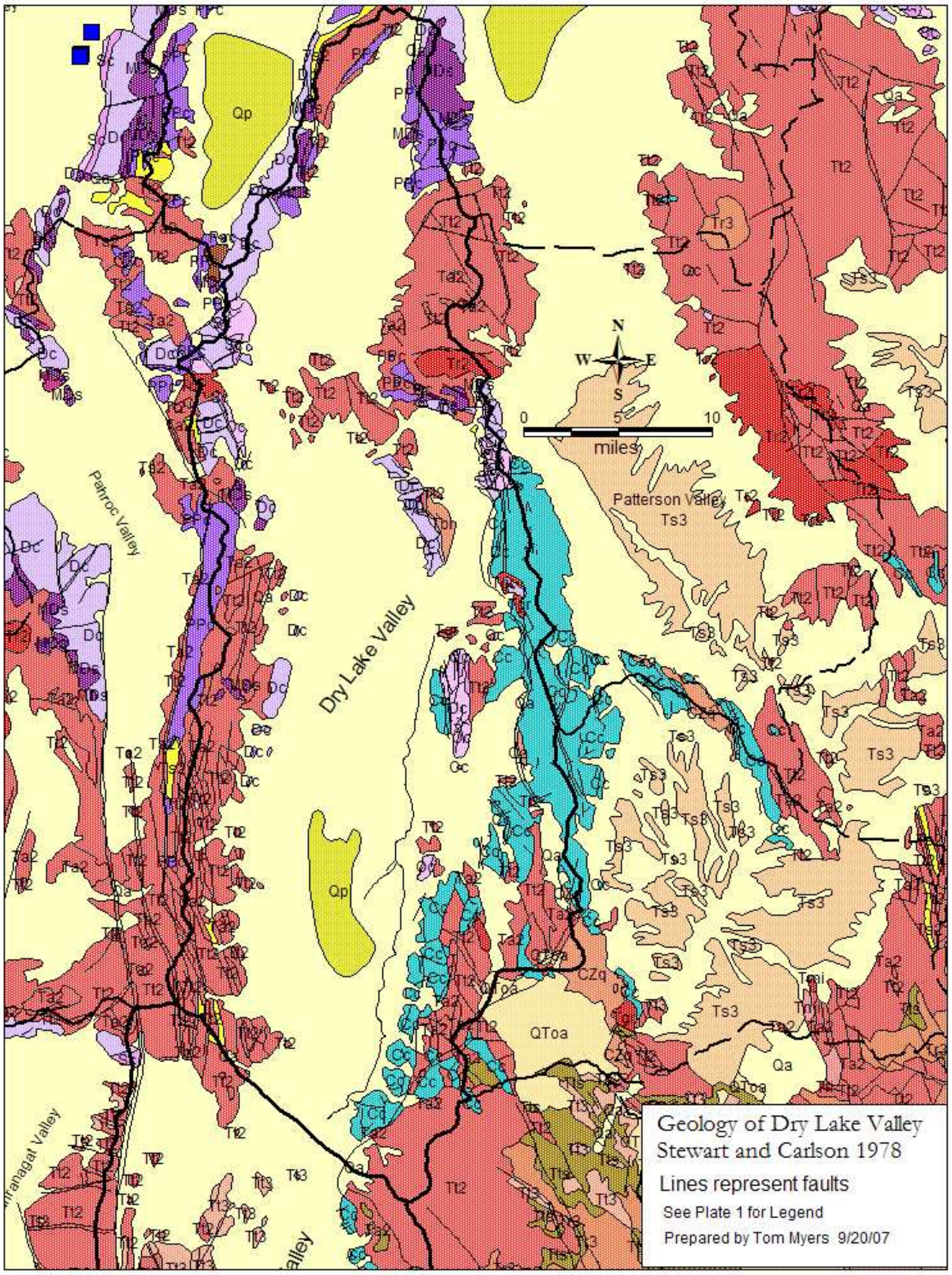


Geology of Cave Valley
Stewart and Carlson 1978
Lines represent faults
See Plate 1 for Legend
Prepared by Tom Myers 9/20/07

Figure 2: General geology of Cave Valley.

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.



Geology of Dry Lake Valley
Stewart and Carlson 1978

Lines represent faults

See Plate 1 for Legend

Prepared by Tom Myers 9/20/07

Figure 3: General geology of Dry Lake Valley

Primarily volcanic rock surrounds Delamar Valley (Figure 4). Substantial northeast trending faults fracture the volcanic rock in the southwest portion of the valley. Brothers et al (1996) referred to fault zone 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.

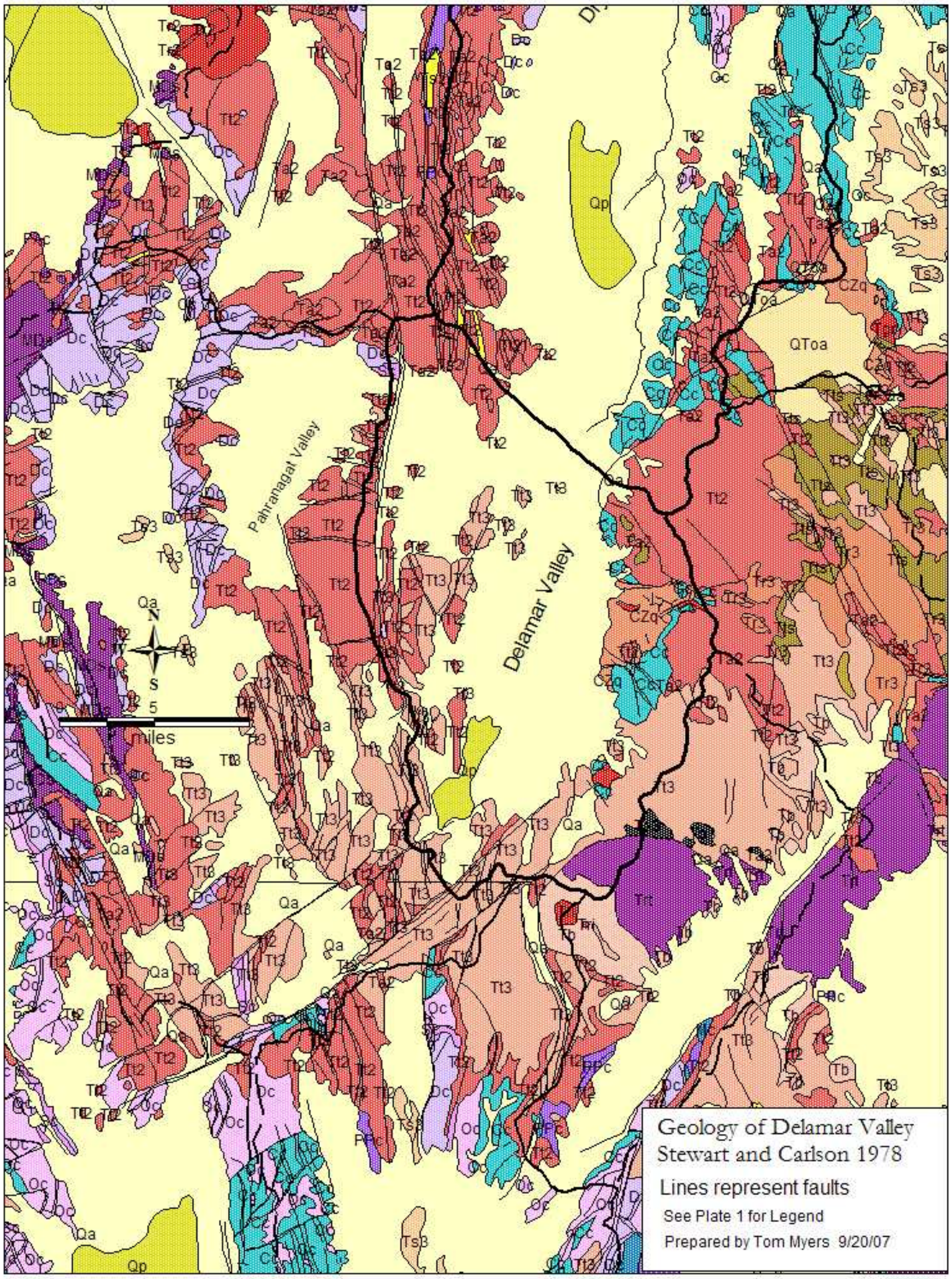


Figure 4: General geology of Delamar Valley

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. The primary water bearing rocks, or aquifers, are the carbonate-dominated rocks and the basin fill. The old metamorphic, igneous and sedimentary rocks primarily form the lower boundary below which groundwater flow is non-existent or at least not relevant. Intrusive igneous rocks, if fractured, also form excellent aquifers. Harrill and Prudic (1998) note a large volcanic aquifer west of the study area in the Death Valley flow system.

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 with some being flow barriers to transverse flow and high conductivity zones along the fault. The fault core often is compressed with fractures causing small particles and low porosity and permeability. Away from the core, the fault fractures enhance the porosity allowing flow parallel to the fault. SNWA (2006) calibrated a groundwater model centered on Spring Valley but including the surrounding basins, including Cave Valley. The model included numerous faults; the flow through the faults was part of the calibration of the model. Both the Egan and Schell Creek Ranges have mountain front faults. 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 outcropping 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. SNWA (2006) calibrated the leakance values for these faults in steady state. Those 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 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, as in all of the Basin and Range, is much higher in the mountains than in the valleys. The precipitation recharges in the mountains where 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.

Flow within the targeted valleys is relatively simple. Recharge occurs as described above but there is little discharge within the valleys because they drain to adjacent valley, as described below. In Cave Valley, the lack of GW ET from areas around the playa (Welch and Bright 2007) reflects the lack of groundwater flow through the valley from north, where there is more recharge, to south. 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. In areas where the water table in the basin fill is sufficiently close to the surface, there is GW ET from phreatophytic plants whose roots reach the shallow groundwater.

Basin fill aquifers tend to be phreatic, or unconfined. Because layering causes high vertical anisotropy, groundwater flow in deep layers may resemble that in a leaky confined aquifer. 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 below the water table above it; this causes a vertical gradient that drives flow vertically downward but the stresses may propagate quickly at depth. Carbonate and fractured volcanic aquifers are confined because the flow tends to be through fractures and conduits where dissolution occurs. Low primary conductivity confines the fracture zones. The potentiometric surface in fracture zones can respond very quickly at great distances from the point of pumping when it occurs (Bear 1979).

Flow between basins, or interbasin flow, is a major part of the conceptual flow model the area. The targeted basins lie at the “headwaters” of a flow system, often referred to as 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 may be a flow barrier and 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. There are two sources within a basin in the basin and range region of the Southwest and Great Basin: the mountain-block recharge and mountain-front recharge (Wilson and Guan 2004). The relative importance of the two varies with geology. Mountain-block recharge is the diffuse recharge that occurs near the point the precipitation falls (Flint et al 2004; Flint and Flint 2007). Wilson and Guan (2004) break down mountain front recharge into its components including infiltration of streamflow, mostly ephemeral in the arid Southwest, infiltration of diffuse runoff from small watersheds with undefined channels and direct rainfall, and underflow from the adjacent mountain block through both fractures and porous media.

Underflow from the mountain block to the basin fill recharges the basin fill aquifer; this occurs where there is a hydraulic connection between the basin fill and bedrock. Runoff from the mountains usually percolates through the channel bottom and becomes recharge at and downstream from the mountain front. Flint et al (2004) developed a basin characterization model (BCM) 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. They applied their model across the Great Basin. Flint and Flint (2007) used the same method on a smaller portion of the Great Basin, the basins contained within or intersecting with White Pine County. They assumed that a certain proportion of the runoff, based on literature values, becomes recharge as well. 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, but the (Flint et al 2004, Flint and Flint 2007) chose 15 percent to represent the ratio for all basins within the Great Basin. The sum of diffuse and runoff recharge is the estimate for a given basin. Table 3 presents recharge estimates from both Flint et al (2004) and Flint and Flint (2007) for the study area basins.

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. Importantly, the discharge from an entire basin was assumed equal to recharge within that basin and the recharge was assumed to be from precipitation within the basin. The precipitation in the various zones was weighted, by trial and error, with a proportion so that the recharge in each zone summed to the total recharge for the basin. The derived coefficients are the amount of precipitation within the various precipitation bands that become recharge. They are often called recharge efficiencies but they are not based on measured recharge at a point and should not be assumed to represent the actual amount of precipitation within a specific precipitation band that recharges. Because the Maxey-Eakin coefficients were determined by balancing precipitation estimates with discharge estimates, the coefficients are unique to the precipitation estimate method used for their derivation. The Nevada State Engineer has ruled that the Maxey Eakin method should only be used with precipitation estimates from the Hardman precipitation map[1].

Avon and Durbin (1994) found that the method was reasonably accurate as compared with other basins, although the method may be criticized because it does not consider soils or geology. At the point where rain falls or snow melts, the water will either run off or infiltrate depending on the soil properties; it will percolate if the underlying geology is sufficiently conductive (Stone et al 2001). If the bedrock is not conductive, the percolation will be rejected and become interflow or runoff – each flow pathway may lead to stream channels. Much of the runoff may then become recharge by percolating into the stream channel – the majority of which occurs at the mountain front where the stream discharges from the mountains to the valley (Wilson and Guan 2004).

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[1] Kane Springs Ruling, #5712, pages 12-14.

It does not matter where the recharge actually occurs as long as it is above the point of discharge which tends to be in the center of the valleys where the groundwater approaches the surface and the phreatophytes are concentrated. The relations defined by Maxey-Eakin are therefore accurate if the appropriate precipitation estimates are used. But the recharge estimates must be considered basinwide, not at a point (Stone et al 2001). It is not appropriate when modeling to force an amount of recharge into the ground at a point when it may actually run downhill and recharge at a more conducive point. Table 3 also 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 estimates are also included in Table 3.

After Table 3, the recharge estimates for each of the targeted valleys are discussed and the best estimate for each is chosen.

Table 3: 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	5000	10627	11298		13300	6664
Delamar	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

Cave Valley

Recharge estimates for Cave Valley have a relatively small range, from 9380 to 19,500 af/y, but five of the estimates are 14000 af/y or less (Table 3); the 14,000 af/y estimate of the reconnaissance report (Eakin 1962) was used for both of the published groundwater models that include the basin (Brothers et al 1993, SNWA 2006). The high estimate by LVVWD (2001), 19,500 af/y, is not correct 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 3)[2]. Flint and Flint (2007, page 11) remark that Cave Valley is one of the only valleys in which the estimates are very similar.

Although the methods differ, the similarity in the estimates lends support to each. A recharge of 14,000 af/y will be adopted for this analysis. Most of the recharge flows to other valleys, as will be discussed below, and there is no way to independently compare the ET discharge with recharge as in a truly closed system.

Dry Lake and Delamar Valleys

The recon reports estimate 5000 and 1000 af/y of recharge for Dry Lake and Delamar Valleys, respectively (Table 3). These estimates were similar to the estimates determined with a deuterium analysis (Kirk and Campana, 1990). Flint et al (2004) and Flint and Flint (2007) estimated substantially more recharge.

These three 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). Although there are problems with the methodology, 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.

The BCM is physically based in that it does deterministic water balance modeling to determine percolation through the soil to become recharge. Being physically based, it could be considered more accurate than Maxey-Eakin. However the input to the model, climate data, results from a statistical model. PRISM-estimated precipitation, used by Flint and Flint (2007) overestimates the precipitation by varying amounts across 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).

Parameters for the model, soil and geologic properties, could be described with a probability distribution. For example, the hydraulic conductivity of the underlying rock may have a wide variability but the BCM uses a single value. If conductivity is high enough to allow recharge, it is likely that most increases in the precipitation in the model will become recharge. Therefore, if PRISM overestimates precipitation, it likely also overestimates recharge. This may be reflected in the following statement from the BCM report: "Percent differences between BCM and Maxey-Eakin derived recharge were consistently greater for basins in which limestone with high saturated hydraulic conductivities were prevalent in the adjacent mountain ranges." (Flint and Flint 2007, page 11). These basins also had higher precipitation estimates.

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[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.

Because Maxey-Eakin was constrained using discharge estimates, and because it has been found to have relatively low coefficient 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 similar estimated 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 much 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. For example, the highest part of the Pahroc Valley is the Seaman Range which is well vegetated, including a stand of Ponderosa pines[3]. Weeping Spring is a discharge point with evapotranspiration for some of the recharge in the Seaman Range. In Pahranagat Valley, more than 80 percent of the valley lies below the 8 inch precipitation zone which means there is no recharge in those areas. For reasons described above concerning Dry Lake and Delamar Valleys, the Flint et al (2004) estimates are considered 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. For this analysis the Coyote/Kane Spring Valley area recharge will be set equal to 6000 af/y. (Kane springs ruling, #5712)

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.

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[3] This is a personal observation by the author.

Cave Valley

Eakin (1962) noted that groundwater discharge from Cave Valley is only a few hundred acre-feet/year. “Ground-water discharge by evapotranspiration probably does not exceed a few hundred acre-feet a year. Evapotranspiration of ground water is limited to the area along the main drainage channel in the valley fill …, adjacent tributary channels, and along 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 quote are legal descriptions). US Geological Survey 1:24000 scale maps (Parker Station, Cave Valley Well, Bullwhack Summit, and Shingle Pass SE) do not show any green, indicating phreatophytes, along the lower stream channels which suggests the amount of phreatophytes is limited.

One reason to expect little GW ET is that most evidence indicates that the water table is not sufficiently close to the surface for groundwater ET. For example, the static water level in all of the well logs available on the web page of the Nevada State Engineer show the depth to water in all of them exceeds 90 feet; the two wells 92077 and 92078 were essentially dry and abandoned (Table 4). While not uniformly distributed across the valley, the well level in these wells indicate that the groundwater level is too far below the ground surface for there to be groundwater ET discharge.

Welch and Bright (2007) 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) (Welch and Bright 2007, Appendix A) (Table 5). 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 green areas observed from aerial photographs as described below. Aerial photographs show substantial areas of green 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). These are the primary potential discharge sites within Cave Valley.

Table 4: 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	Static 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 OPERATING 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 5: 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.

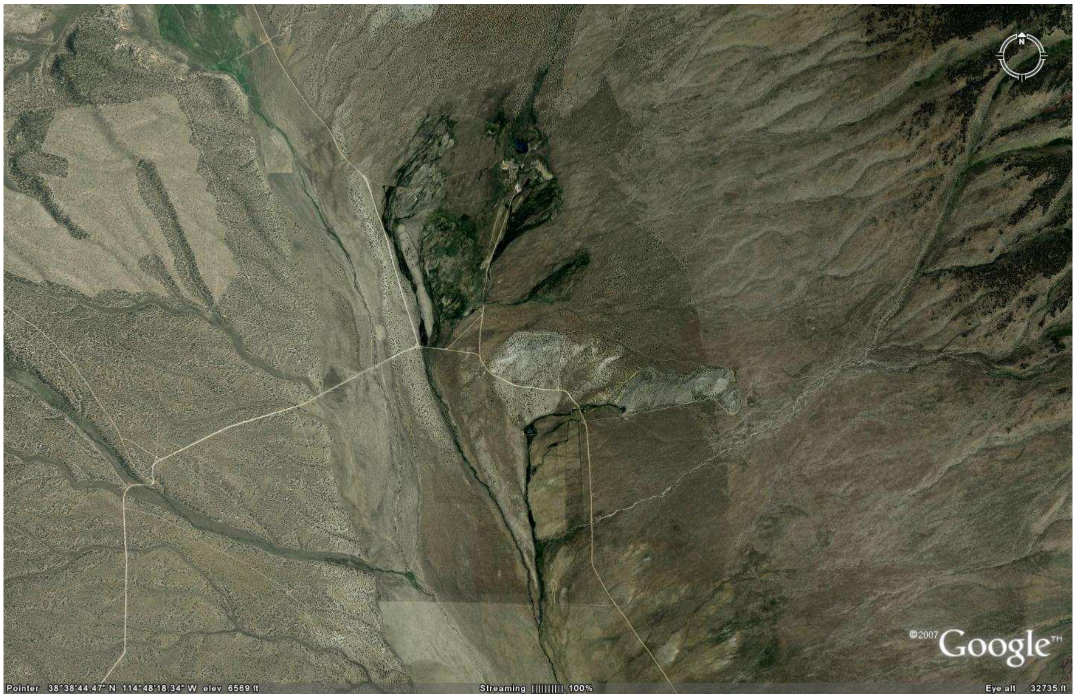

Figure 7: Phreatophytes and drainage patterns near springs in Cave Valley. The northerly greenish area is the drainage below Sheep Spring; the photo also shows ranch house and water impoundment. The southerly strip of green commencing south of the light area is Cave Valley Spring and drainage. See USGS 1:24000 scale map, Parker Station for details in Figure 12.

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 6). 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. 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 6: 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. Following Wilson and Guan (2004), 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. This is because water in this tributary alluvium is not readily available to valley-wide basin and development thereof until it reaches the main valley aquifer. In summary, streamflow losses, not groundwater ET discharge, support this riparian area.

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). LVVWD (*Id.*) mentioned 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. The report provides neither the well identification, water level hydrograph nor a reference for this well. LVVWD (*Id.*) acknowledges that other wells in the area have depths over 100 feet to water, therefore their monitoring well apparently is in a perched aquifer.

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

Springs are part of the discharge from a basin if the spring is from the regional aquifer. Welch and Bright (2007) published a table of springs in the study area. The database appears to have been derived from the USGS NWIS data base. The springs spread around the valley, but most are in the north half (Figures 9 and 10).

Only one spring in the database for Cave Valley – Cave Spring - has a flow measurement, estimating average discharge to be 700 gpm, or about 1100 af/y. This was an average of two measurements, 400 and 1000 gpm (Welch and Bright 2007, Appendix B). The water temperature is cold, about 52°F, suggesting the water does not circulate to significant depth. There is a spring water right 4881, certificate 1060, dated 1/31/1918 is for 0.751 cfs with a duty of 225.57 AFS. The discharge rate would provide 543.7 AF over an entire year. The spring emanates from unconsolidated sediment at the valley margin (Welch and Bright 2007). 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. Cave

Valley Spring would be a significant portion of the water budget if the 1100 af/y flow rate is representative. 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 for 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. This estimate is based on professional judgment based on observed flows, the channel below the spring, and the water right.

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 Sheep Spring water that reinfiltrated only to discharge further down on the drainage. The aerial photograph (Figure 7) shows substantial riparian areas, equaling approximately half of a section (360 acres), but the map does not (Figure 11). This appears to be dense shrubland. There is a vested spring water right, V02692, dated 11/25/1970, for 0.414 cfs in section 9 of T9NR63E, which 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. Many discharge from perched aquifers and are not considered groundwater discharge from the basin because the water had never recharged the regional aquifer system. The water discharging from a perched spring could become recharge to the basin fill.

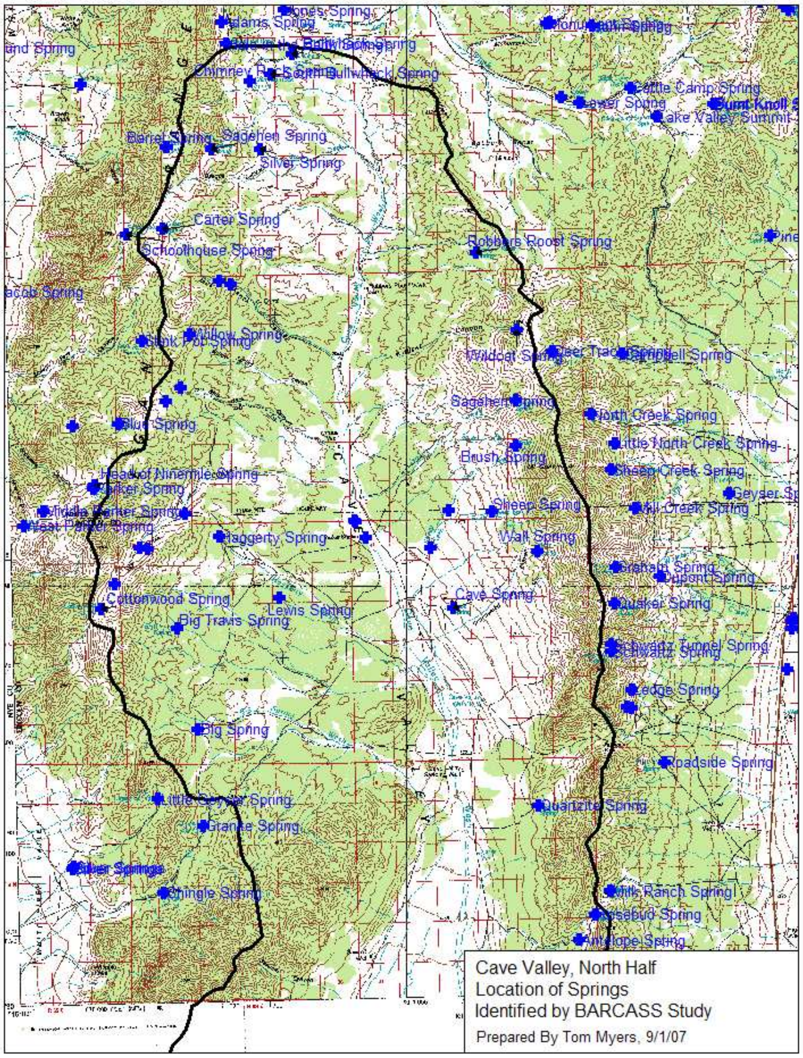

Figure 9: Map of northern Cave Valley showing location of springs from Welch and Bright (2007). Basemap USGS 1:100000 scale Garrison UT.

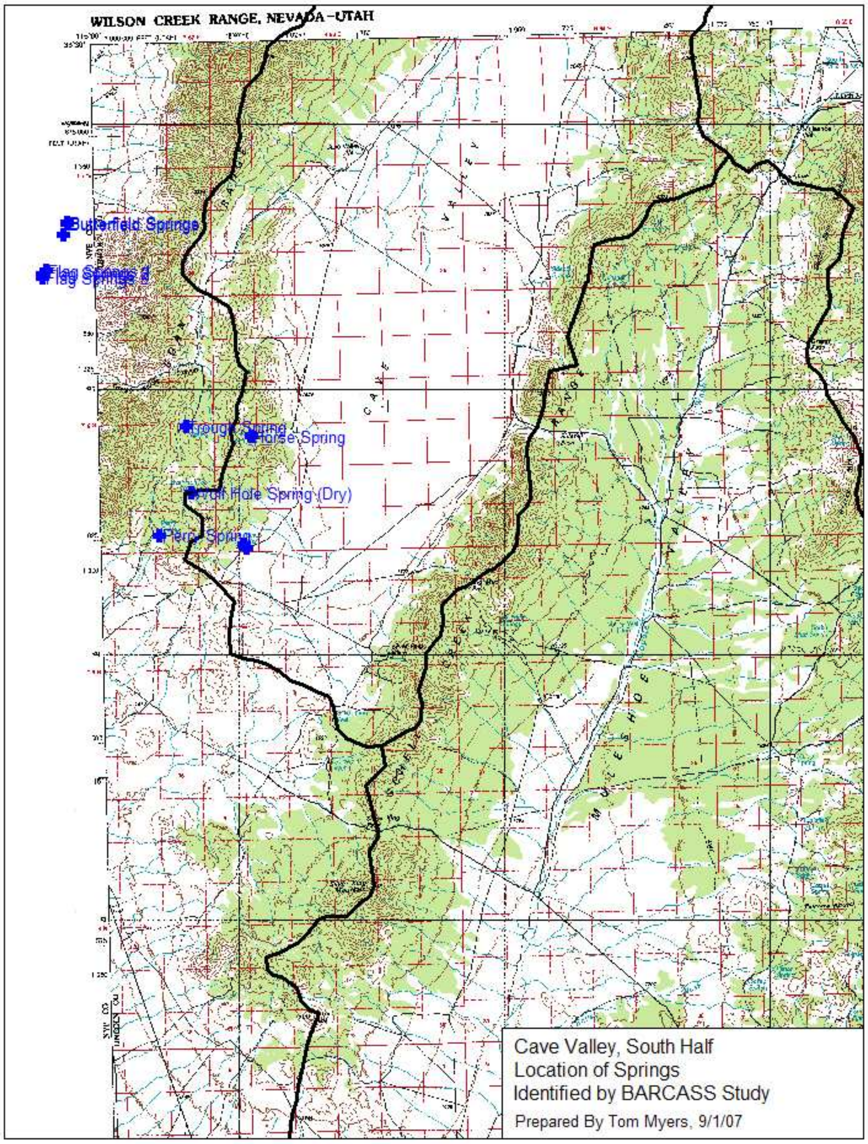

Figure 10: Map of southern Cave Valley showing location of springs from Welch and Bright (2007). Basemap USGS 1:100000 scale Wilson Creek Range.

In summary, three source discharge from Cave Valley groundwater: 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 and Bright 2007). The rate is based on the ET rate for the specific vegetation type and estimated precipitation rate. The Cave Valley Wash has 720 acres, therefore the GW ET from Cave Valley Wash is 640 af/y. The 360 acres along Sheep Spring would have GW ET equal to 320 af/y. The total discharge from Cave Valley estimated for this analysis therefore approximates 1200 af/y.

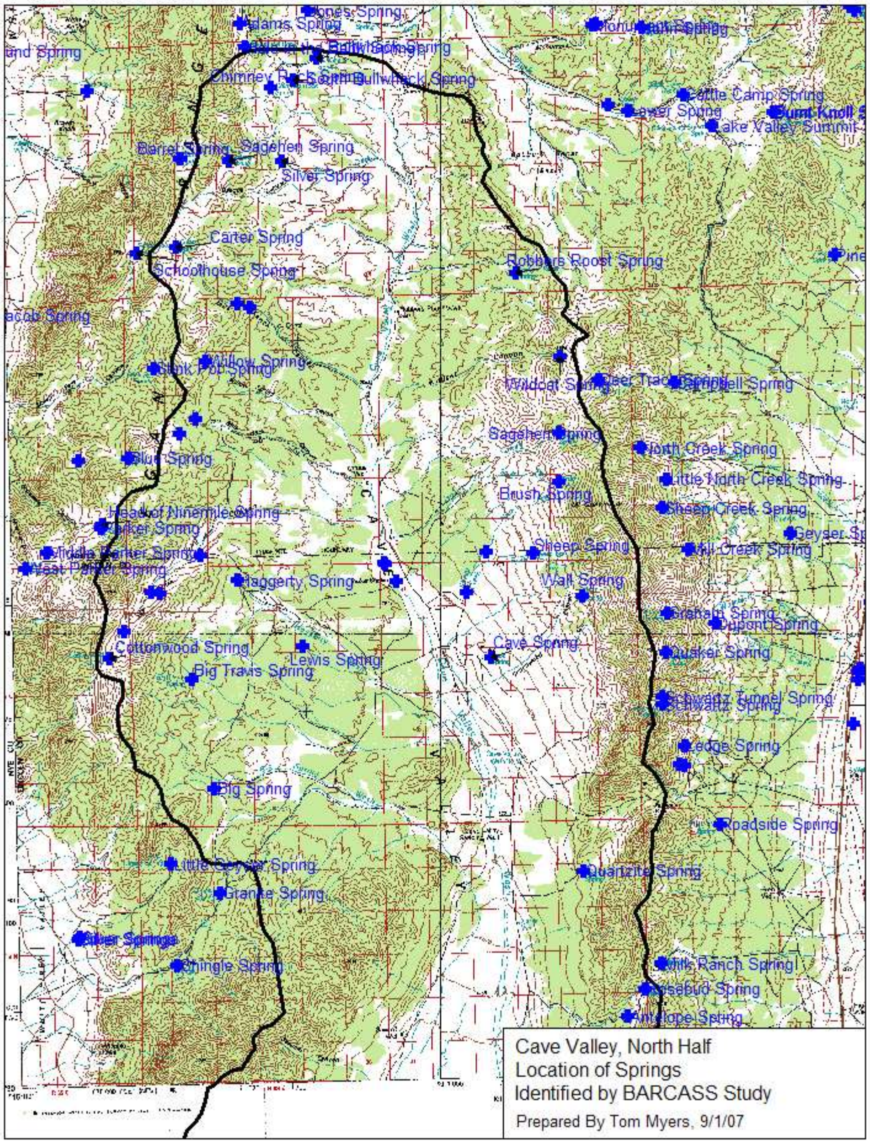

Figure 11: Map of northern Cave Valley showing location of springs from Welch and Bright (2007). Basemap USGS 1:100000 scale Wilson Creek Range.

Properly spaced wells could intercept this discharge. The alluvium along Cave Valley Wash would probably require several shallow wells to lower the water table over the 720 acres. One well in the carbonate near Cave Springs would lower the water table to intercept that flow. A series of wells along the Sheep Spring channel would also induce infiltration and take most of the discharge from the springs. Therefore it is possible to capture the estimated discharge. SNWA's applications for Cave Valley are both in the south half of Cave Valley. As proposed, these applications would not capture any of the natural groundwater discharge from the basin.

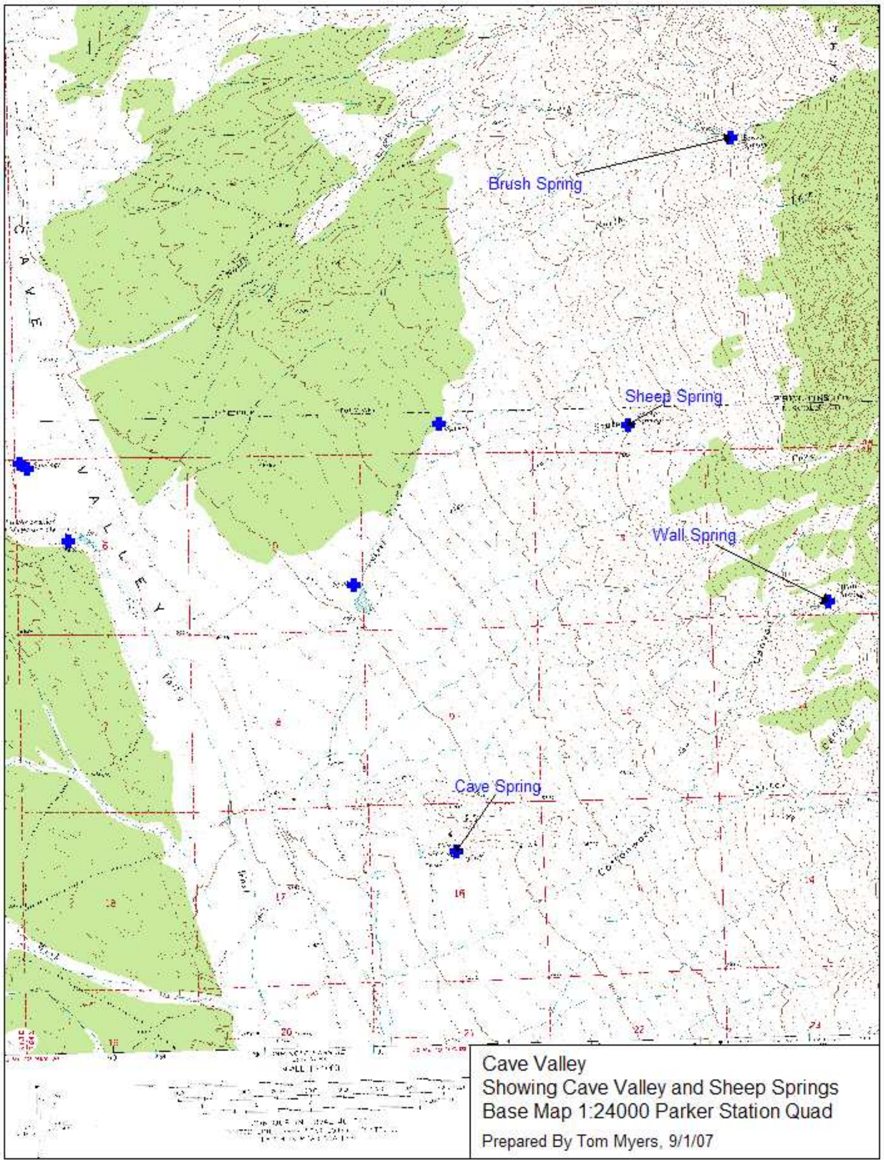

Figure 12: Detailed topographic map of Cave Spring, Sheep Spring and vicinity. Note that the map does not show green riparian areas.

Dry Lake and Delamar Valleys

These valleys may be grouped for the discussion of GW ET discharge because neither has significant GW ET discharge and because they are discussed in the same reconnaissance report (Eakin 1963a). The dryness of the area manifests in very large depths to groundwater and in essentially no GW ET discharge. "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). Regarding those scattered springs, he summarizes the annual discharge to be very little as follows: "[o]nly a very small amount of ground water is discharged from Dry Lake and Delamar Valleys by evaporation and transpiration. Areas where ground water evaporates from soil or from free-water surfaces or is transpired by vegetation are restricted to isolated areas adjacent to the few small springs" (Eakin 1963a, page 18). He estimated a spring near the Meloy Ranch discharged at about 20 gpm in March 1963. No such areas were identified in Delamar Valley.

A well log query for Dry Lake Valley on the State Engineer's web page found two relatively shallow wells, logs 10702 and 10864, with static water level just three feet below ground surface. The actual log is difficult to read, however, and the water right permit for each, numbers 23978 and 22477, respectively, show these wells are in Panaca Valley, basin 203. The legal descriptions from the query are in areas that are unlikely to have wells (no roads and on steep land). Therefore, it is concluded that these well logs do not indicate shallow groundwater in Dry Lake 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). The springs are in the mountains and are very small; they certainly do not discharge flow close to 1000 af/y. They are also perched which means they are not a part of the basin's groundwater system; discharge from the mountain-block springs should not be included as GW ET discharge from these valleys. Considering that the "token" is a large proportion of the estimated recharge, it should not be used as the discharge from the groundwater in these valleys..

GW ET discharge from both Dry Lake and Delamar equals essentially 0 for this analysis, as found by Eakin (1963a).

Downgradient Basins

White River Valley is a complicated valley. Considering the basin receives 38,000 af/y of recharge and more than that quantity of interbasin flow under natural (pre-development) conditions, there was substantial natural discharge from the basin. The interbasin flow supported many springs in White River Valley. The total average White River Valley spring flow reported in Welch and Bright (2007) is 24,700 gpm (39,700 af/y). This flow rate is close to the 40,000 af/y reported by Maxey and Eakin (1949, page 42). That the Welch and Bright (2007) estimate includes many additional years of flow rates (and a few additional small springs) but the total remains very close to that estimated in 1949 reflects the consistency and regional origin of the spring flow. Spring flow varies both seasonally and annually, but the long-term average is stable (Figures 13 and 14). The flow measurements do not coincide sufficiently to plot a meaningful hydrograph of total flow for the valley.

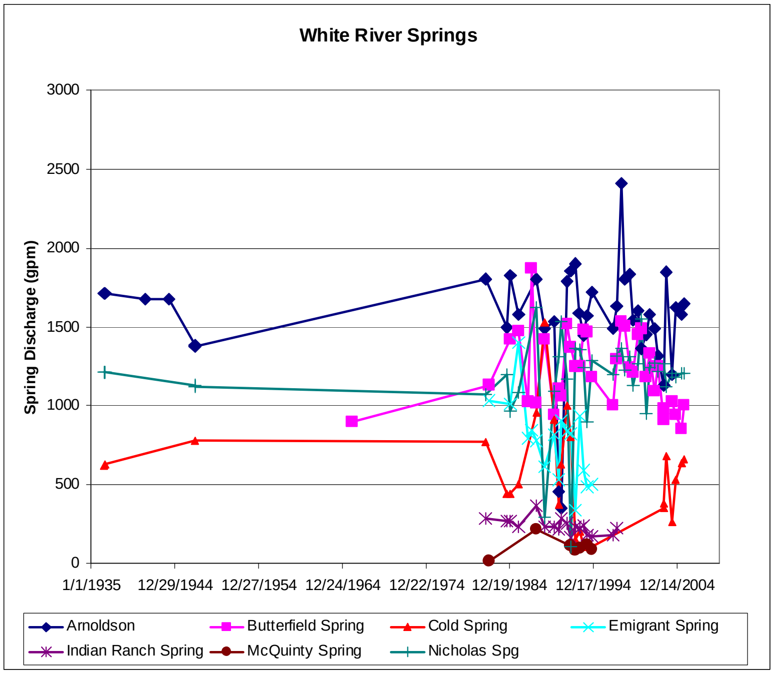

Figure 13: Discharge hydrographs from selected springs in White River Valley.

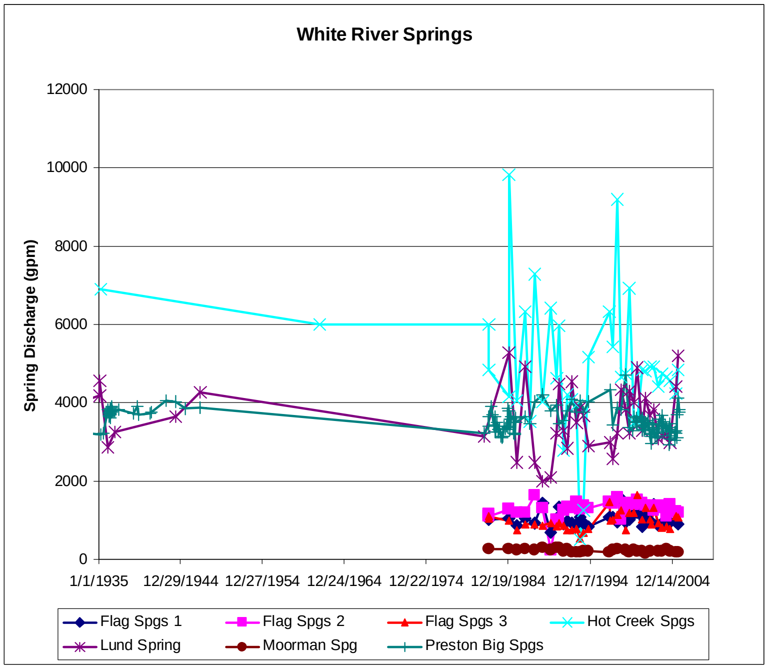

Figure 14: More discharge hydrographs from selected springs in White River Valley.

Under natural conditions, this spring flow would have become secondary recharge supporting phreatophyte transpiration throughout the valley. Maxey and Eakin (1949) estimated the total annual GW ET equaled 34,000 af/y and included both native phreatophytes and cultivated plants; the Water for Nevada report estimated GW ET to be 37,000 af/y. Secondary recharge of the spring flow likely supported high water tables and the 36,000 acres of phreatophytes observed by Maxey and Eakin (1949). 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 Welch and Bright (2007) GW ET estimate for White River Valley is 76,700 af/y, which is much higher than other estimates. Welch and Bright (2007) used satellite photographs to measure the area with phreatophytes or irrigated areas that once had phreatophytes and found that GW ET potentially occurred over 128,508 acres, or more than three and half 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 and Bright (2007) 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 in the Water Use section (Welch and Bright 2007, Appendix A) that there were 6078 acres of irrigated agriculture and 18,031 af/y of consumptive use from that agriculture. The increase in irrigated agriculture coincides with the increase in water rights in the valley, particularly of groundwater (Figure 15).

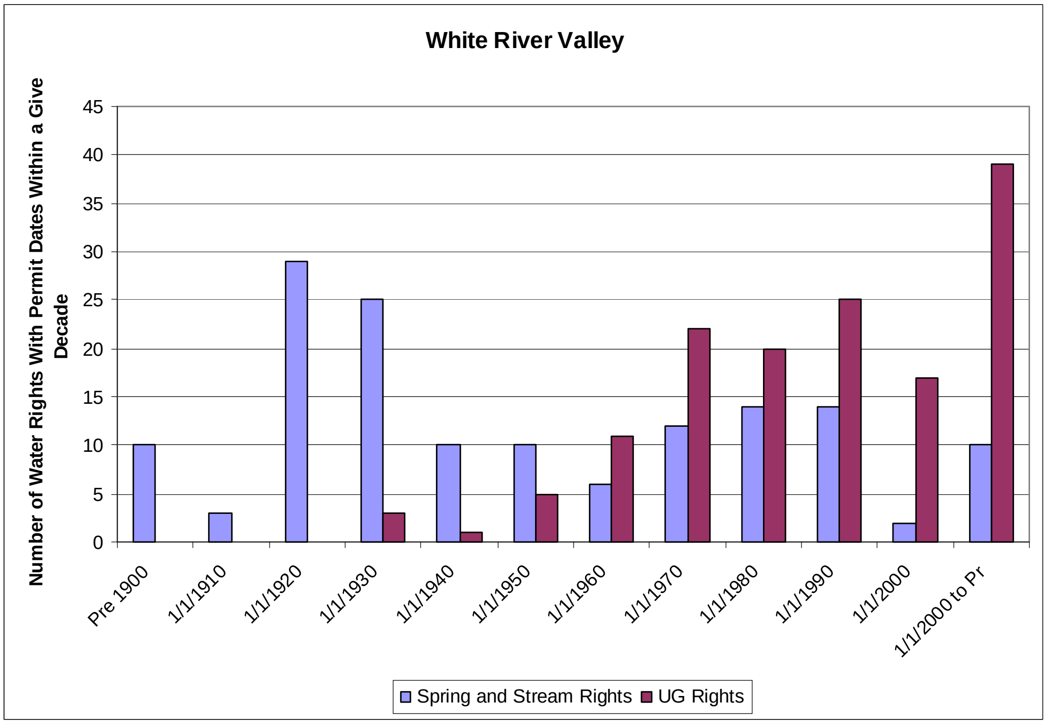

Figure 15: Application dates of water rights in the White River Valley. The figure shows that stream and spring rights were developed first and that UG rights were developed later.

The determination of water availability in the White River Valley and the entire flow system depends on an accurate estimate of GW discharge. It must be assumed that the recent estimate, in BARCASS, is more accurate because of the modern technology and research. Unless it can be determined that the phreatophyte area likely increased since 1949, it must be assumed that the current estimate is a preferable long-term pre-development estimate that can be used for water budget and perennial yield analysis. Any increase from 1949 to the present is likely due to the much increased groundwater pumpage or the ongoing irrigation with spring water if it is used in a way that the return flow raises the water table or otherwise caused the phreatophyte area to expand. Most UG rights have been permitted or certificated since 1949 (Figure 15). Trends in the water levels could represent changes in the phreatophyte areas.

Water levels in White River Valley were considered in several ways to determine whether the 2007 GW ET estimate from Welch and Bright (2007) 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.

A summary of static water levels from the Nevada State Engineer’s web page showed a slight trend toward shallower water levels in the south portion of the valley near the location of high GW ET (Figure 16). The static water level line shows a varying trend toward deeper levels with township moving north. A 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. These results show the groundwater is shallower in the south where most of the GW ET occurs.

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.

Also considered was the water level trend throughout the valley. If water levels had become shallower, the phreatophyte area may have expanded since 1949. This could have been due to anthropogenic effects including secondary recharge from irrigation raising the water levels in one part of the valley. This could be increased recharge of surface water or redistribution of groundwater which would have occurred due to pumping in one area and irrigating in another. Trends in water level were considered using hydrographs downloaded from the National Water Information System (NWIS) which includes water levels from many of the wells in White River Valley. For this analysis, all hydrographs with more than two observations and with one of them being collected since 2000 were considered for trends. There were many wells with three observations but with the third (most recent) being 1990; that is not representative of 2007 conditions and these wells were not utilized. Also, the first observation in many of the hydrograph apparently is the static water level determined upon well construction.

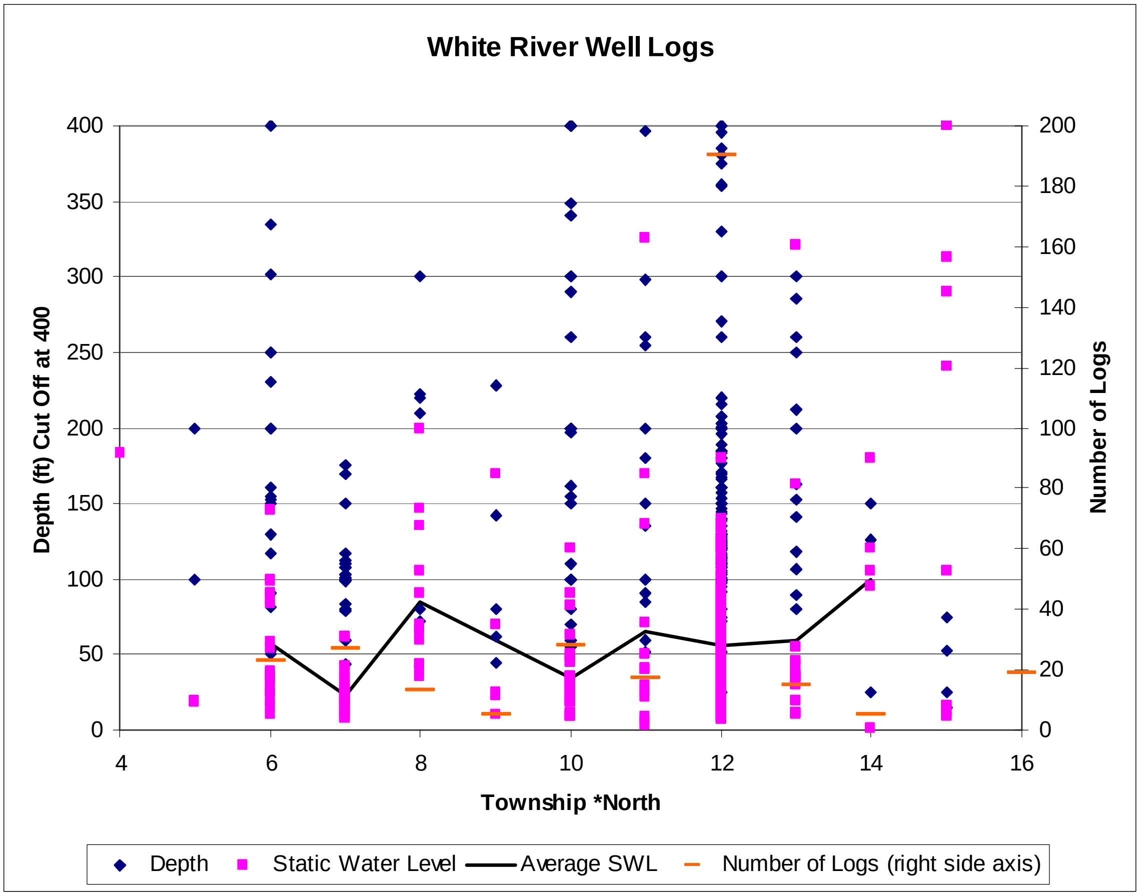

Figure 16: Location, depth and depth to water of wells as a function of their north-south location as defined by township in the White River Valley.

In the southernmost portion of White River Valley, the water levels either show no trend or a slight trend to shallower levels (Figure 17). Groundwater levels in the well with the shallowest level, in Murphy Meadows in the middle of the large phreatophyte zone, remained at less than ten feet. This would continue to support phreatophytes. Two other wells with static levels exceeding 60 feet trended upwards less than ten feet since the 1980s; the depth of each of these is about 100 feet and both lie within five miles west of the Kirch Wildlife Management Area. With the upward ground slope to the west, the water level near the springs near the wildlife management area is relatively flat. But the trend has occurred in an area without substantial irrigation suggesting the trend may not be due to irrigation return flow.

None of the wells in the central part of the valley showed any 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 indicate areas of shallow groundwater in the well draining into more conductive zones deeper in the well; effectively the well may have causes 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 is the area of extensive well development, but the water levels indicate that the well development has not yet depleted the groundwater storage.

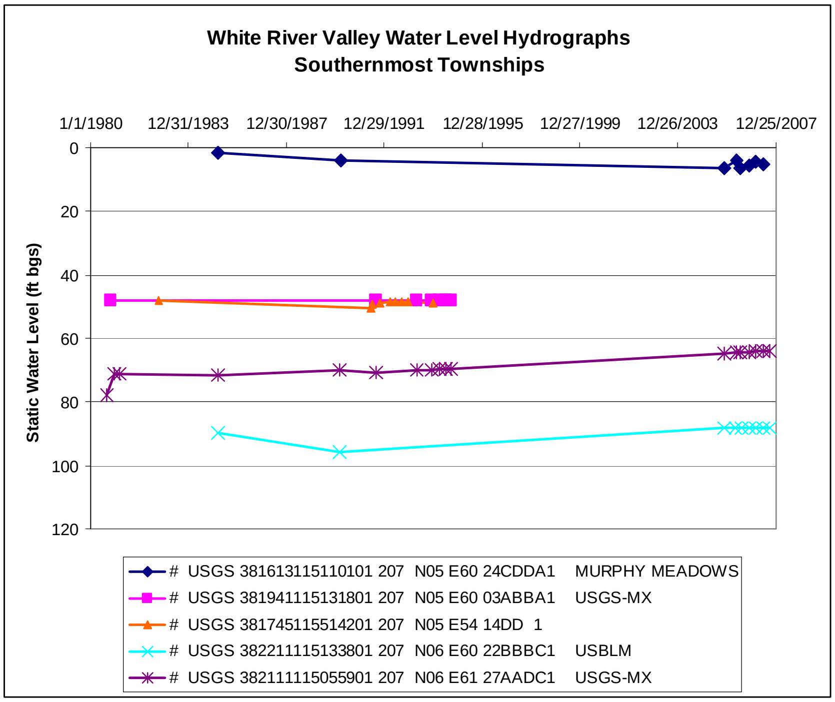

Figure 17: Hydrograph of five wells in the southern part of White River Valley.

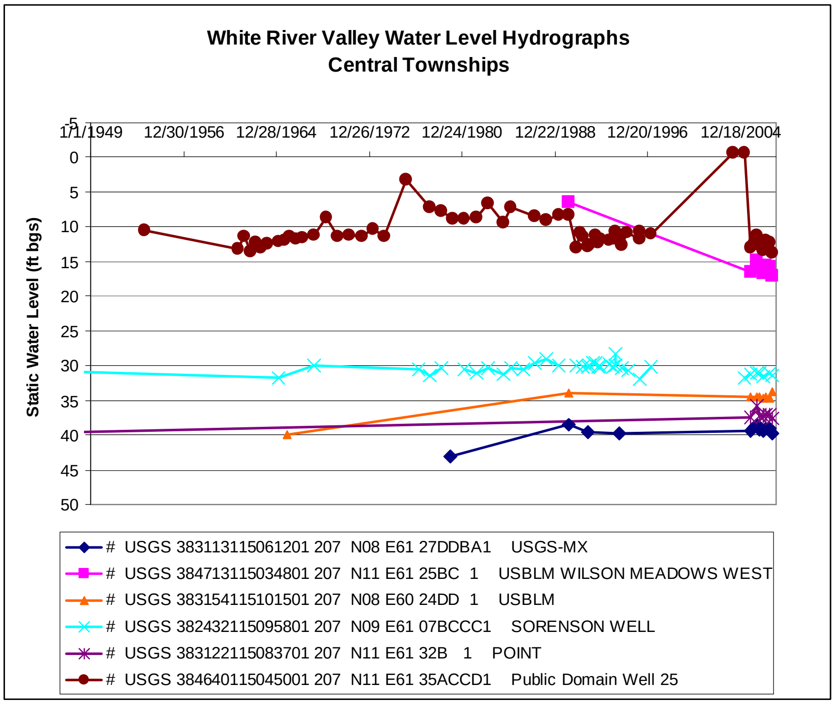

Figure 18: Hydrograph of six wells in the central part of White River Valley.

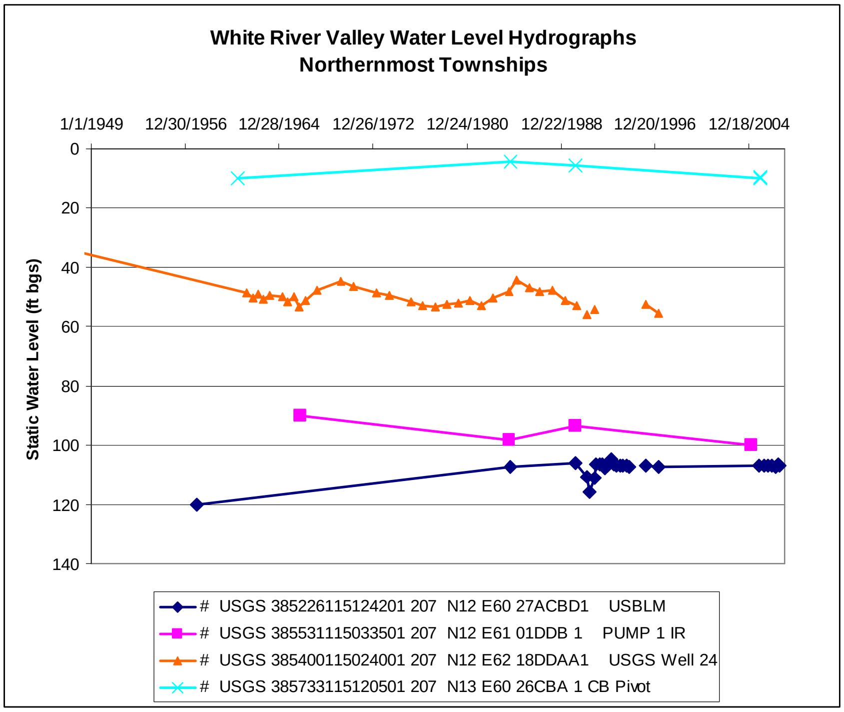

Figure 19: Hydrograph of four wells in the north part of White River Valley.

Groundwater level trends in the White River Valley do not explain the changes in phreatophyte area or the increase in GW ET discharge 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 and Bright (2007) 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.

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 a unique situation because almost all of the available water, both surface and groundwater, depends on interbasin groundwater flow. Local recharge is minor, but total spring discharge is approximately 25,000 af/y (Eakin 1963c), as is published perennial yield. The springs contribute to baseflow in several streams and provide the water that supports wetlands and lakes on the Pahranagat National Wildlife Refuge. Eakin (1963c) estimated there were 20,000 af/y of GW ET from phreatophytes and 5000 af/y of lake evaporation.

Welch and Bright (2007) did not estimate GW ET from Pahranagat Valley because it was not in the study area. However, the area of discharge in Pahranagat Valley appears to be better defined. Eakin (1963c) found that there are about 8000 acres of valley lowland south of Hiko. This shows well on an aerial photograph of the area (Figure 20). He also found that about 6000 acres had a shallow water table which would have a 3.0 foot per year GW ET rate with 1.0 ft/y on the remaining 2000 acres. The valley is well confined with sandstone and volcanic outcrops, therefore it is not likely, as it was in White River Valley, that there substantial amounts of additional phreatophytes. Additional areas were not noticed during a site visit. Much of the riparian area below Hiko includes large cottonwood trees and other woody vegetation; the rate used by Eakin (1966) may be low for this vegetation type but the rate may also account for a low density observed in the area. For this study, the GW ET discharge from Pahranagat Valley is 25,000 af/.

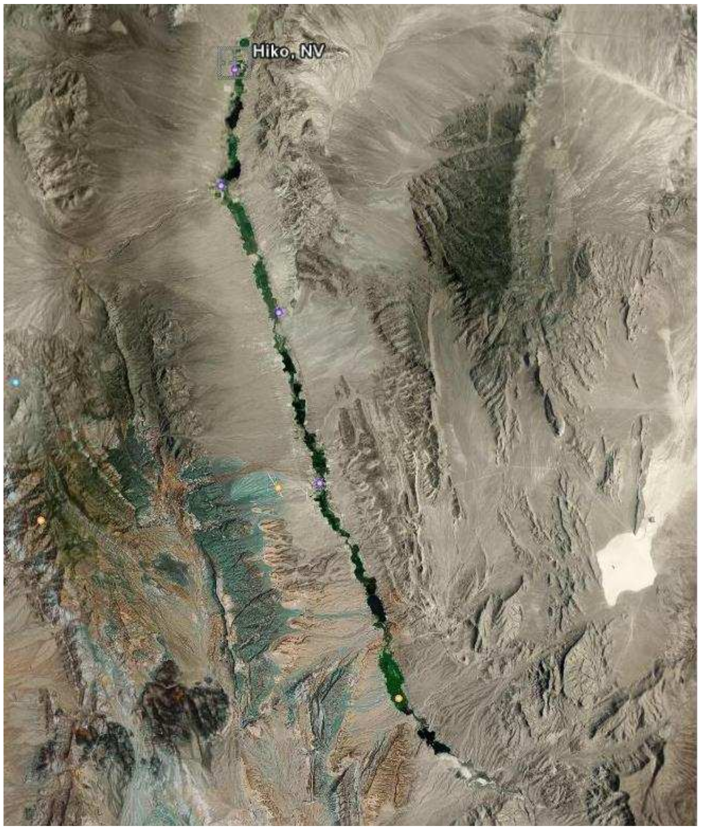

Figure 20: Phreatophytes and narrow riparian zone along the Pahranagat River between Hiko and Pahranagat Lakes.

Interbasin Flow Estimates

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: White River and Pahranagat Valleys. This section considers the geologic and hydrologic constraints on interbasin flow to assess where the recharge may go.

Cave Valley

Most researchers have considered Cave Valley to not receive inflow from surrounding basins (Eakin 1962). Welch and Bright (2007, Plate 1) suggests that flow between Steptoe and Cave Valleys is possible because there are no geologic barriers but also that there is a groundwater divide between the valleys. High mountains and the consequent higher recharge cause the groundwater divide. Because there is no barrier, however, significant pumping in the north end of Cave Valley could lower the groundwater divide and divert water from Steptoe Valley. The groundwater divide between Cave and Steptoe Valley creates a gradient which could have groundwater flowing to the northwest to White River Valley as well. Based on this gradient, most recharge in the Egan Range portion of Cave Valley would reach White River Valley without becoming part of the main aquifer system in Cave Valley.

The potentiometric surface for the carbonate aquifer published in Welch and Bright (2007, Plate 3) shows a general gradient from east to west from Cave Valley to the White River Valley. This also reflects the elevation difference between valley floors in Cave Valley (from 7000 feet in the north to 5500 feet in the south) and the White River Valley (from less than 6000 feet in the north to 5000 feet in the south). Welch and Bright (2007) estimated a flow of 7000 af/y to the White River Valley based on water balance and geochemistry (Welch and Bright 2007). Based on the just the recharge and discharge within Cave Valley determined in BARCASS, the flow would have been 9,300 af/y (Welch and Bright 2007, Plate 4).

Most other estimates of flow from Cave Valley to White River Valley are much higher than those in BARCASS. SNWA (2006) estimated that the entire recharge, 14,000 af/y, flows through the Egan Range to the White River Valley. LVVWD (2001, Table 6-1) estimated that 15,000 af/y flows from Cave Valley to White River Valley, but this estimate was based on very high recharge and ET estimates (see discussion above). Eakin (1962) indicated that almost all of the recharge in Cave Valley becomes interbasin flow. Because no regional springs occur in Dry Lake or Delamar Valleys, and because those valleys lie above the surrounding valleys thereby creating a gradient to the west, Eakin (1963a) implies that most flow is to the regional springs, such as Lund and Hot Creek Springs (Eakin 1962, page 10). Eakin (1963a) does not expressly address flow from Cave Valley. Eakin (1966) noted that interbasin flow enters White River Valley. This conclusion countered an earlier assessment he made that all of the interbasin flow into White River Valley was from the north, specifically from Jakes Valley (Maxey and Eakin 1949).

No previous or current studies conclude that, under natural conditions, there is groundwater inflow to Cave Valley. The difference between recharge and GW ET discharge is interbasin flow to WRV. Based on recharge and discharge estimates in this analysis, the interbasin flow to White River Valley is 12,800 af/y. There is no interbasin flow to Dry Lake Valley.

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 2); further south on the west, it is mostly tuffs and basaltic flows. However, carbonate rock may underlie the volcanic rock. The well log for well 22450 (Appendix 1), drilled to 2395 feet, shows only 145 feet of volcanic rock overlying almost 2000 feet of carbonate rock. The water level is 853 feet below ground surface, therefore the volcanic rock would not prevent flow. The log does not show the elevation, but Bunch and Harrill (1984) list the water surface elevation to be 4539 feet msl; the water temperature was listed as 80°F therefore there is evidence of deep circulation. The well is not screened, but rather is cased to 2395 feet. This suggests 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 bounds 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.

Eakin (1963a) indicates that Dry Lake and Delamar Valley lie in a "surficially closed trough" above the surrounding valleys. 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

In the White River system, interbasin flows have long been known to support GW discharge in receiving basins (Eakin 1966). The disparity in recharge and ET discharge in the basins illustrates that groundwater must flow among basins. The estimates of interbasin flow have changed since 1966; the estimates of recharge, discharge, and interbasin flow presented herein lead to the conclusion the total interbasin flow to White River Valley from upstream valleys including Cave Valley is 60,800 af/y (Table 7). With the recharge and GW ET estimates above, approximately 22,100 af/y of interbasin flow leaves White River Valley to reach Pahroc Valley. Inflow to Pahranagat Valley from Pahroc is 24,300 af/y, which 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. With the small recharge and significant GW ET in Pahranagat Valley, there is approximately 19,100 af/y discharge to Coyote Spring or Kane Springs Valley.

Table 7 : Water budget accounting for the study area basins under pre-development conditions. All flows are in af/y.

	Recharge	Flow from Outside study area	Interbasin flow from Inside study area			GW ET Discharge	Interbasin outflow
Garden/Coal Valley	12000					0	12000
Cave Valley	14000					1200	12800
Dry Lake	5000					0	5000
			Dry Lake				
Delamar	1000		5000			0	6000
		Steptoe, Jakes	Cave Valley				
White River Valley	38000	48000	12800			76700	22100
			White River Valley				
Pahroc Valley	2200		22100			0	24300
			Pahroc Valley	Garden/Coal	Delamar		
Pahranagat Valley	1800		24300	12000	6000	25000	19100
Coyote Spring/Kane Springs Valley	6000		19100			0	25100

The estimates for flow through the system are for pre-development or steady state conditions and do not include consumptive use for irrigation or other beneficial uses. Therefore, the interbasin flow estimates also do not include the effect of development. The next section details the water rights in the basins and how they affect their discharge. A part of the analysis is to determine how much of the consumptive use of water rights in the basins is a new discharge from the system and how much is a replacement of pre-development GW ET. These estimates depend in part on professional judgment. 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.

Water Rights

This section considers water rights in the target valleys: Cave, Dry Lake and Delamar Valleys. Also considered are the water rights for White River, Pahroc and Pahranagat Valleys because these basins may depend on the interbasin inflow. Because they are tributary to Pahranagat Valley, two additional valleys, Coal and Garden Valleys are also considered; interbasin flow from these valleys could help to meet the demands in Pahranagat Valley.

The groundwater budget supports water rights connected to groundwater. These include all underground (UG) rights, but also include most spring rights and some surface water rights. This section estimates the consumptive use of the existing water rights to show the amount of groundwater remaining for development in the overall flow system.

Spring flow is a discharge of groundwater that at one point had recharged into the system. Mountain springs, usually with low or ephemeral flow, discharge from perched aquifers not considered part of a basin's groundwater system. Secondary recharge from the channels below ephemeral springs may be a part of the mountain front recharge which is part of a basin's total recharge. Nevada reconnaissance reports typically reported the discharge from large valley-bottom springs as discharge from the basin's groundwater reserve because the spring discharge either evaporates directly or supports shallow groundwater systems and wetlands which are included in calculations of GW ET discharge. Therefore, the discharge from regional springs is a discharge of recharge within the basin, of interbasin flow from upgradient basins, or a combination of the two. Spring water rights therefore depend on groundwater.

The same logic applies to some of the surface water rights. Surface water rights that depend on baseflow in the stream also therefore depend on the groundwater. Baseflow is "return flow from groundwater" (Mosley and McKerchar, 1992, page 8.1) and should be considered a discharge from the groundwater system of a basin. This is apparent in the southeastern part of White River Valley because the perennial streams depend on flow from the springs and therefore discharges from the groundwater. Water rights to stream base flow therefore depend on groundwater as well.

New water rights applications should be considered in light of all of the demands on the system. New groundwater pumping that relies on diverting spring flow or seeps as a mean of developing perennial yield will diminish surface water flow. Spring or stream water rights may therefore be harmed by grants of UG rights that diminish surface water flows.

Stream rights that depend on runoff or perched springs do not depend on the groundwater system. Streams that emanate from the mountains may not depend significantly on the groundwater system; it is possible that perched aquifers support their baseflow. Streams on the valley floors that discharge from regional springs depend on the groundwater system, as do the water rights to those streams.

Supplemental water rights are used when a primary water right is not available. Typically, an UG right supplements a surface water right. In the two large downgradient valleys, White River and Pahranagat Valleys, the surface water depends on spring flow and therefore is a discharge of groundwater. In the other valleys, the small amount of UG rights considered supplemental are a small amount of flow. In neither case are supplemental rights considered because the primary rights already mostly depend on groundwater.

Irrigation water is not completely consumed. For this analysis, the consumptive use determined by the Nevada State Engineer in the Spring Valley ruling, #5476, will be used. Consumptive use for irrigation water rights is 0.7 and for other uses will be assumed to be 1.0. The valleys analyzed here are lower than Spring Valley and probably have a higher consumptive use rate. If so, using a low value will be conservative.

Cave Valley

The higher and wetter of the three valleys targeted, Cave Valley, has the most existing water rights. Most of the water rights are to spring water (Table 8). The total duty for all types of water rights is 971 af/y.

The groundwater system supports the spring rights because they are a discharge from the regional groundwater system – the system supported by recharge within Cave Valley. Most spring rights are to Cave Valley springs on the east side of the valley near the base of the Schell Creek Range near carbonate outcrops. Cave Spring, the water right for which was discussed above, discharges from a limestone cave. Lowering the groundwater table in the vicinity of these springs would likely intercept their flow, although the current location of SNWA's applications will not likely capture this discharge. The total spring rights have a duty totaling 611 af/y. Streamflow rights are not included because they, totaling 276 af/y certificated and vested stream rights, apparently depend on runoff not directly linked to GW discharge. Some of the stream water rights may intercept and use water that is part of the mountain front recharge to the system.

There are 8 certificated or permitted UG rights totaling 69 af/y but not including supplemental water rights, the total is just 35.4 af/y. All are stock rights which are considered to be fully consumptively used.

Of the total spring rights, 510 af/y is used for irrigation. Applying the 0.7 consumptive use factor, the total committed spring water rights is 358 af/y. The remaining spring rights used for stock water are considered to be fully used. The total consumptive use of spring water rights in Cave Valley dependent on UG water is 473 af/y. Adding the UG rights, the total water rights in Cave Valley dependent on UG water is 508 af/y. This does not include the spring rights listed as a diversion rate without a duty (Table 8). However, only the 35 af/y of UG rights consumptively used is a new discharge from the system; the springs have water rights but the beneficial use merely replaces the natural use.

Dry Lake and Delamar Valleys

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.

Table 8: Water Rights Summary for Cave Valley

Stream	Number	Duty (af/y)*			
CER	2	276			
VST	7	0	There are 5.25 cfs of diversion for rights without a duty listed.		
Subtotal	9	276			
Spring					
CER	13	499			
RES	3	0			
PER	1	80			
VST	32	47			
Subtotal	49	626	There are 3.5 cfs of diversion for rights without a duty listed.		
Underground			Supplemental	Sup. Duty	Difference
CER	5	35.4			
PER	3	33.6	3	33.6	0
Subtotal	8	69			
Total	66	971			

Committed Water Rights			**Irrigation****	**Irrigation Consumptive Use**	
Stream	0	0	0	0	Stream rights not from regional springs
Spring	472.76	626	510.8	357.56	
Underground	35.4	35.4	0	0	
Total Committed	508.16	661.4	510.8	357.56	

*: in the database, duty is either afa or afs. Here it is reported as af/y.

Garden and Coal Valleys

Garden and Coal Valley provide interbasin inflow to Pahranagat Valley and therefore may support flows within that valley. 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 approximate 2500 af/y of water rights from all sources (Table 9). There are just 166 af/y of spring rights and these are perched and not part of the system. Stream rights represent the majority of water rights in this basin; they total 1774 af/y. These are to perennial streams that drain the Quinn Canyon Range. High flow from these streams provides recharge to Garden Valley, but the water rights are primarily in the mountain range. They utilize water that during predevelopment conditions would have been transpired from riparian areas. These water rights are not likely part of the groundwater system.

There are also 559 af/y of UG rights with all but 4 af/y used for irrigation. This irrigation consumptive use of 388 af/y is considered the consumptive use for the valley.

Table 9: Water rights summary for Garden Valley.

Spring	**Number**	**Duty (af/y)***
CER	8	96.9
VST	4	69.7
Subtotal	12	166.6
Stream		
CER	12	1129
PER	1	160
VST	6	485
Subtotal	19	1774
Underground		
CER	9	454
PER	2	104.8
Subtotal	11	558.8
Total	42	2499.4

Committed Water Rights			**Irrigation****	**Irrigation Consumptive Use**
Spring	153.52	166.6	43.6	30.52
Stream	1252.72	1774	1737.6	1216.32
Underground	392.45	558.8	554.5	388.15
Total Committed	388.15	2499.4	554.5	388.15

*: in the database, duty is either afa or afs. Here it is reported as af/y.

Downgradient Valleys

White River and Pahranagat Valleys both have substantial regional springs which support irrigation and other development. The total water rights in White River and Pahranagat Valleys are 100,161 and 35,430 af/y, respectively (Table 10 and 11). The amount for Pahroc Valley is insignificant (Table 12), although there are many applications. Because of the importance of regional springs and the interbasin flow which supports those springs, the water rights sources are closely intertwined. This section considers the water rights in the downgradient valleys and their dependence on interbasin flow from the targeted valleys.

Table 10: Water Rights Summary for White River Valley

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			**Supplemental**	**Sup. Duty**	**Difference**
CER	122	25354	38	11156	14198
PER	37	11103	13	2046	9057
VST	1	0			
Subtotal	160	36457			
UG total adj for Sup		23255			
Total	316	86959	Accounts for the amount of supplemental GW		
Water Rights Total, T5 to 11N, R61 to 62E			**Irrigation Fr**	**Irrigation Consumptive Use**	
Stream	22442	29458	23388	16372	
Spring	8414	11851	11458	8021	
Underground**	6803	9654	9503	6652	
Total	**37658**	50963	44349	31044	
Committed Water Rights Relying on UG Water			**Irrigation****	**Irrigation Consumptive Use**	
Stream	30594	41102	35026	24518	
Spring	17808	22602	15980	11186	
Underground***	16368	23255	22956	16069	Entire valley not counting supplemental.
Total Committed	**64770**	86959	73962	51773	

*: in the database, duty is either afa or afs. Here it is reported as af/y.

**- The total for SE WRV has accounted for supplemental rights

*** - Both the total and the irrigation total has accounted for supplemental rights

Table 11: Water Rights Summary for Pahranagat Valley

Source/Status	Number	Duty (af/y)*	Supplemental	Sup Duty	Difference
Stream					
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	17	6475	3411
PER	24	3088	9	1851	1236
VST	5	48			
Subtotal	70	13022			
Total	118	35430			

Committed Water Rights	Total Consumptive Use	Duty (af/y)*	Irrigation**	Irrigation Consumptive Use
Stream	718	946	759	531
Lake	1489	2127	2127	1489
Spring	19590	21463	6243	4370
Underground **	3709	4695	3288	2302
Committed	**25506**	29231	12417	8692

total consumptive use is duty minus return flow from irrigation

*: in the database, duty is either afa or afs. Here it is reported as af/y.

**: does not include supplemental

Table 12: Water Rights Summary for Pahroc Valley

Source/Status	Number	Duty (af/y)
Spring		
CER	8	23
RES	1	1
Subtotal	9	25
Underground **		
CER	2	19
PER	1	11
VST	1	
Subtotal	4	30
Total	13	55

*: in the database, duty is either afa or afs. Here it is reported as af/y.

White River Valley

Water rights are permitted by the basin, but the State Engineer also considers whether granting an application will harm existing water rights, including in downgradient basins (Nevada State Engineer Ruling 5750). An application may affect downgradient water rights even if the targeted basin is lightly developed and downgradient basins are heavily developed with water rights dependent on the interbasin flow. Interbasin flow from Cave Valley enters White River Valley. Additional water rights in Cave Valley can be permitted only if the interbasin flow from Cave Valley is not depended on in White River Valley (or further downgradient). Water sources in the southeastern portion of White River Valley likely depend on interbasin flow from Cave Valley (Figure 21).

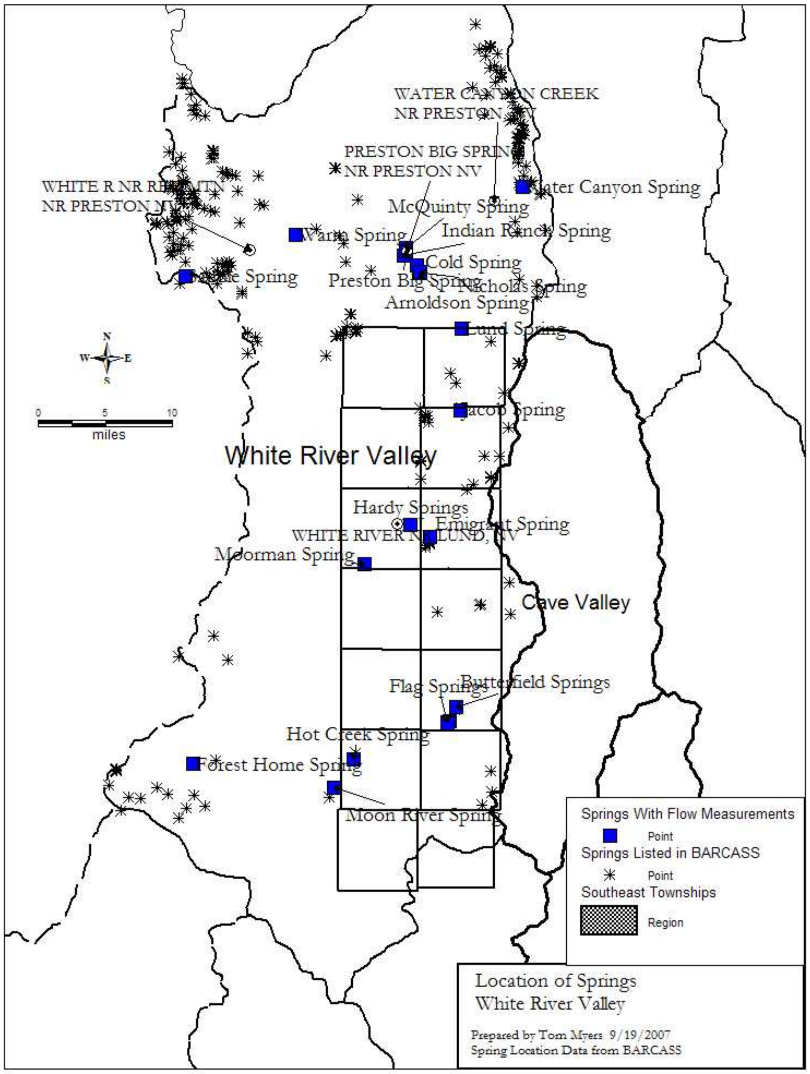

Figure 21: Location of springs in White River Valley and the southeastern townships likely dependent on flow from Cave Valley.

White River Valley has 22,602 af/y of spring water rights (Table 10). Considering just those in the southeastern townships, spring rights total more than 10,000 af/y (Figure 21). The springs near Preston are north and higher than those in the southeastern townships. These are almost exclusively from regional springs and therefore clearly depend on groundwater. Spring rights in the southeast portion of the valley clearly depend on interbasin flow from the east including Cave Valley.

Within the White River Valley, there is a total 41,101 af/y of stream rights. The White River is considered fully appropriated[4]. In the northwest portion of the valley, where the White River emerges from the White Pine Range and above Preston Big Springs, there are 1875 af/y of certificated and vested stream rights (app 7328, 15763, and V00715) which is about 31 percent of the runoff in the White River (see discussion concerning recharge in White River Valley above). Most of the stream water rights are below the point where most of the White River runoff has infiltrated and recharged the groundwater. The gage near Lund was dry most of the time which reflects both the recharge and the diversions. There is just one small water right on Water Canyon Creek.

The spring flow rates are almost twice the spring water rights (Table 10). The spring flow is apparently too great for diversion from the spring discharge point. Below the springs there are perennial streams. Moon River Spring or Hot Creek Spring are good examples. Ranchers divert many stream water rights from these channels downstream from the regional springs. Based on field observations, this is particularly true on the east side of the valley. The proportion of stream rights of the total spring and stream rights in the valley indicates that stream rights depend on spring rights. For example, in the zone Township 6N, stream rights are the majority of the total stream and spring rights (Figure 22). The White River near Lund gage is dry most of the time; the stream rights are on channels downstream from the springs. One vested water right, V01351, accounts for 11,600 af/y of stream water right. The Nevada Department of Wildlife owns this water right. Another cluster of springs and development occurs in the zone Township 12N. The stream rights are a high proportion of the total stream and spring rights in this area as well (Figure 22). This is downstream from Preston Big Springs.

Other than the stream rights in the northwest portion of White River Valley, most of the stream rights depend on spring flow. Subtracting the 1875 af/y from 41,101 af/y approximately 39,226 af/y depend on spring flow (not accounting for minor rights in Water Canyon other areas). The conclusion regarding stream rights is that most depend on spring flow.

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[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. Cited in State Engineer Ruling 3640 Denying water rights application for irrigation water from the White River.

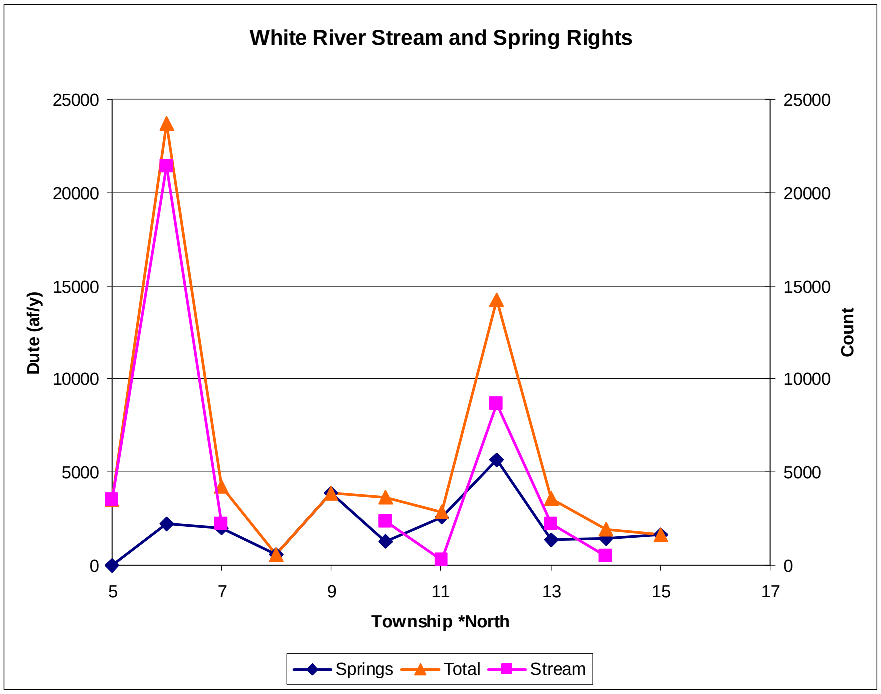

Figure 22: Location of stream and spring water rights in White River Valley defined by township north and south.

Interbasin flow from Cave Valley contributes interbasin flow which supports many springs in White River Valley. The spring and stream water rights downgradient from Cave Valley, those that occur in the townships outlined in Figure 21, are considered to depend, at least partially, on interbasin flow from Cave Valley. As shown in Table 10, there are 41,309 af/y of stream and spring rights in townships T5-11N and R61-62E. Considering the springs within the southeast townships (Figure 21) and below 6400 feet msl (to eliminate perched springs), the average spring discharge (Welch and Bright 2007) is about 27,000 af/y. This exceeds estimates of flow from Cave Valley, therefore the spring discharge must include local recharge and interbasin flow from further north. However, the total water rights dependent on the spring flow exceeds the average discharge by 14,000 af/y. Interbasin flow not discharging from the springs probably supports the basin fill aquifer. Within the southeast townships, there are 11,038 af/y of UG water rights. The cumulative duty of water rights in the southeastern portion of White River Valley totals 52,347 af/y (Table 10).

Most water rights in White River Valley are for irrigation. If the supplemental water rights are removed from the total water rights, the water rights total, from all sources, in the valley is 86,959 af/y, adjusted for supplemental rights. The total dedicated to irrigation, not counting supplemental rights, is 73,932 af/y, or 85 percent of the total water rights in the valley. Most of the remainder is for stock watering. Consumptive use for irrigation is 51,773 af/y. The total dedicated consumptive use from water rights in the basin is 64,770 af/y.

The GW ET discharge from the valley of 76,700 af/y and dedicated water rights consumptive use is 64,770 af/y. The total discharge from the valley through phreatophyte and water rights consumptive use therefore is as much as 141,470 af/y. However, there may be substantial overlap. Return flow from cropped fields probably support phreatophytes; this is particularly true where pumpage has intercepted groundwater which may have reached the phreatophytes. Overlap however does not occur in the area around Township 12N (Figure 22) because most of the GW ET estimated in Welch and Bright (2007) is five or six townships south. For the purpose of flow system accounting, GW ET and the UG consumptive use from T12N will be considered. There are 22,662 of UG irrigation rights; adjusted for supplemental rights there are 12,337 af/y. The consumptive use then 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 total water rights commitment far exceeds the locally available water if local recharge and interbasin flow is the primary source. The recharge in the southeast portion of White River Valley, as estimated by Flint and Flint (2007), is just 6900 af/y while the local ET discharge is 56,900 af/y. Interbasin flow from Cave Valley is 14,000 af/y or less, depending on the reference. Consumptive use of dedicated water rights in this area is 37,658 af/y or just less than twice the water available near that portion of the valley. This does or will require intrabasin flow from the north to support the water rights. Decreased flow from Cave Valley will reduce the locally available groundwater for water rights and spring flows in southeast White River Valley and increase the amount required from further north in the valley.

Pahranagat Valley

Pahranagat Valley is unique because of the prevalence and dependence of the valley on interbasin groundwater flow as manifest in the springs. Total spring discharge in Pahranagat Valley is approximately 25,000 af/y, as is published perennial yield. 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, but both become secondary recharge.

There are a total 35,430 af/y of water rights in Pahranagat Valley (Table 11). About 3000 af/y are for stream or lake rights. Spring water rights are the majority at 21,463 af/y. UG rights total 13,022 af/y, but a substantial amount are 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 11).

The total consumptive use for irrigation is 8692 af/y, or only about 30 percent of the total duty for the valley. The total consumptive use then is 25506 af/y, or approximately the entire spring discharge to the valley. Pahranagat Valley Springs are considered fully appropriated under the Ash Springs/Pahranagat Lakes Decree of October 14, 1929.

As discussed above, the GW ET discharge from the valley is focused along a strip near the Pahranagat River; for GW ET discharge, the study utilized Eakin's (1963c) estimate based on 6000 acres. However, much of the irrigation occurs on terraces, perhaps 10 to 40 feet above the river. Prior to irrigation, there would not have been dense riparian vegetation as assumed by Eakin for the strip near the river. The area between Pahranagat Lakes and Hiko within a quarter mile of the river is about 16,000 acres. The irrigation therefore likely replaces shrubland. The total committed water rights consumptive use from Pahranagat Valley for consideration of the interbasin flows is the irrigation consumptive use.

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. Two of the nine basins are fully developed with water rights approximating the available water. The developed water rights have not captured the remaining GW ET discharge fully because the systems have not yet reached steady state. Therefore the current discharge from the system exceeds the pre-development discharge because it includes natural GW ET and some of the consumptive use for beneficial uses (Table 13). In other words, current development has not yet replaced the natural discharges so the existing situation is one of discharge from GW ET, irrigation and interbasin flow exceeding the inflow. The other seven basins are lightly developed with low amounts of groundwater use and depletion.

Current commitments within the system will decrease the interbasin flow from Pahranagat Valley from 19,100 to 1138 af/y if the system with current developments comes to steady state. The flow from Pahranagat Valley has probably been only lightly affected to date, although to the extent that confined aquifers have been tapped, the effect could have expanded quickly.

Table 13: 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	Comments
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	60765	76700	8776	13289	Pahroc	48 kaf/y inflow from Steptoe and Jakes Valley
Pahroc Valley	2200	13289	0	30	15459	Pahranagat	
Pahranagat Valley	1800	32973	25000	8692	1081	Coyote Springs	
Coyote Spring/Kane Springs Valley	6000	1081	0		7081	Muddy Springs	

If SNWA develops its' full application from each of the three targeted basins, there will be effectively 11,500 af/y of groundwater use subtracted from each targeted basin in the budget in Table 13. This reduces the interbasin outflow from Cave Valley to 1181 af/y (Table 14). More critically, the interbasin outflow from Dry Lake and Delamar Valleys becomes negative because the applications substantially exceed the local recharge. Most critically, the discharge from Pahranagat Valley becomes negative, equaling -27670 af/y.

Table 14: Water budget for the White River Flow System with SNWA's full application amount added to the groundwater use.

Basin	Recharge	Interbasin Inflow	GW Discharge	GW Use	Outflow	To	Comments
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	49181	76700	8776	1705	Pahroc	48 kaf/y inflow from Steptoe and Jakes Valley
Pahroc Valley	2200	1705	0	30	3875	Pahranagat	
Pahranagat Valley	1800	-1777	25000	8692	-33670	Coyote Springs	
Coyote Spring/Kane Springs Valley	6000	-33670	0		-27670	Muddy Springs	
Recharge: Based primarily on reconnaissance reports Interbasin inflow: Flow into the basin from one or more upgradient basins. GW Discharge: Discharge from the regional aquifer within the basin – either by evapotranspiration or Springflow. GW Use: consumptive use by water rights							

If SNWA develops only the published perennial yield from each basin as analyzed by Schaeffer and Harrill (1995), the groundwater use will be as shown in Table 15. There will still be positive interbasin flow from Dry Lake to Delamar and to Pahranagat Valley from Delamar. However, the discharge from Pahranagat Valley still becomes negative, equaling -6419 af/y.

Table 15: Water budget for the White River Flow System with a reduced SNWA application added to the groundwater use. 2000, 2500, and 3000 af/y for Cave, Dry Lake and Delamar Valleys, respectively.

	Recharge	Interbasin Inflow	GW Discharge	GW Use	Outflow	To	Comments
Garden/Coal Valley	12000		0	421	11579	Pahranagat	
Cave Valley	14000		1200	2035.4	10765	White River	
Dry Lake	5000		0	2557	2443	Delamar	
Delamar	1000	2443	0	3007.4	436	Pahranagat	
White River Valley	38000	58765	76700	8776	11289	Pahroc	48 kaf/y inflow from Steptoe and Jakes Valley
Pahroc Valley	2200	11289	0	30	13459	Pahranagat	
Pahranagat Valley	1800	25473	25000	8692	-6419	Coyote Springs	
Coyote Spring/Kane Springs Valley	6000	-6419	0		-419	Muddy Springs	

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).

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 19,100 af/y (Table 12). The biggest reason for this difference is the higher GW ET discharge from the White River Valley estimated in the Welch and Bright (2007); if the discharge from the recon report had been used, the discharge to Coyote Spring Valley would be close to 50,000 af/y. As discussed, with development proposed by SNWA, the discharge to Coyote Spring Valley may become negative. 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 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, the State Engineer referred to 37,000 af/y entering Coyote Spring from Pahranagat Valley[6]. The calculations herein suggest this is a substantial overestimate due to new discharge estimates and upstream water rights.

The report, Water for Nevada, indicated that the interbasin flow is about 37,000 af/y (NV State Engineer 1971). Table 3 in Water for Nevada shows that inflow to Pahranagat Valley from Pahroc Valley is 42,000 af/y; almost all of this interbasin flow originated in White River Valley and basins tributary to White River Valley. It is also almost the difference between Welch and Bright (2007) and Maxey and Eakin (1949) discharge estimate. With very little recharge in the Muddy River Springs Area, the discharge from the Muddy River Springs depends almost exclusively on the interbasin flow from Pahranagat and largely from White River Valley.

However, evidence since 1971 may change the estimates of interbasin flow and sources of water for Muddy River Springs. Welch and Bright (2007) estimated that just 9000 af/y flows from White River Valley to Pahroc Valley which means the flow from Pahranagat Valley to Coyote Spring Valley is much less than assumed based on the Water for Nevada report. If the remaining estimates in Water for Nevada are correct, then the interbasin inflow to Pahranagat Valley is 25,000 af/y and the outflow would be negligible. If this is correct, there must be another source of groundwater flow to Muddy River Springs. Kirk and Campana (1990) indicate that source may be the Sheep Range and Lower Meadow Valley Wash. The Sheep Range could supply as much as 9600 af/y to Coyote Springs Valley.

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

[6] Kane Springs Ruling No. 5712.

Water Availability

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

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 from the system. The system will experience of 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 imposed discharges take flow away from existing discharge point – the wetlands, springs and seeps in the basin and basins downgradient. The pumping removes groundwater from storage to lower the water table and dry up the natural discharges. The amount of groundwater removed 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.

There are different ways to complete such an analysis ranging from simple Theis equations to sophisticated groundwater models. Theis analysis is inappropriate in this case because:

- The method requires homogeneity and the system is heterogeneous.
- The method requires isotropic conditions. This means that conditions are the same in all directions. Due to the fault trends, there are definite anisotropic conditions in a horizontal plane. Consequently, impacts expand more in one direction than in the other. The Theis method cannot accommodate these conditions.
- The method assumes there is an infinite aquifer. While this is never the true situation, the boundaries that occur due to faults and geologic zone transitions limit the aquifer extent substantially.
- The largest impacts are likely to be to downgradient basins, yet the Theis method cannot assess impacts beyond the boundaries of the source basin to which it is applied.

For the consideration of the impacts of a possible large stress as proposed by SNWA in a complicated system, a numerical groundwater model is usually the best method to apply. Because of the springs and interbasin flow, much of the flow is probably concentrated in small areas. The discharge from individual springs in White River Valley is of the same order of magnitude as the total recharge in Cave Valley. This implies that the source of flow to those springs, the recharge zone, is very large. The fracture network in the bedrock collects the recharge and funnels it to the discharge points.

The best way to analyze this situation would be with a fracture flow model. Although the trend of fractures can be surmised from the faulting in the system, their location is poorly known. Modeling with a fracture flow model would be educated guesswork.

A finite difference groundwater model, such as MODFLOW (McDonald and Harbaugh 1988), implicitly assumes that the hydrologic properties of each model cell are homogeneous; the parameters for the cell represent the various properties of the actual media within that cell area. Hydraulic conductivity effectively blends the matrix primary permeability with the fracture-caused secondary permeability. It must represent as a whole cell the flow which may primarily be through a fracture. If well done, the calibration of a model of such an area will represent the general flow patterns through the area well. Often, however, the propagation of a stress is much slower in the model than in reality because stress propagates quickly in a confined fracture system. Therefore, the use of a finite difference model to estimate the time for propagation may underestimate the speed with which impacts propagate.

Even with the difficulties, poorly understood geology and fracture flow, a finite difference model is the best choice for estimating the future impacts of this proposed project. To analyze the impacts of SNWA’s proposed project, we have utilized a groundwater model developed by the U.S. Geological Survey for the carbonate aquifer system of the Great Basin during its RASA study (Prudic et al 1995).

RASA Groundwater Model

The RASA groundwater model 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. The report presented a detailed discussion “of ground-water flow … to examine the possibility of the relatively shallow flow regions being interconnected by deep flow through carbonate rocks, and how regional geologic features might affect the direction of flow and water levels” (Prudic et al 1995, page D15).

Schaefer and Harrill (1995) used the RASA model (Prudic et al 1995) 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 in 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).

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.

The goals for using the RASA groundwater model for impact analysis are as follows:

- Estimate the amount of transitional storage and drawdown depth and extent caused by SNWA pumping in the target valleys.
- Estimate the propagation of drawdown into surrounding valleys.
- Estimate the change in flow rates at various regional springs.
- Estimate the time for change to occur.

RASA Model Details

The original RASA model had two layers and 61 rows and 60 columns of rectangular cells (Figure 23) and a north-northeastward trend that follows the trend of the fault-block mountains (Prudic et al 1995, page D18); figures of the model grid and boundaries herein do not show the trend. The cells are 5 miles in an east-west direction and 7.5 miles in a north-south direction. The developers of the model attempted to balance accuracy with available computer power, which was much less at that time than it is today. It used general head boundaries for rivers and lakes and used drain boundaries for springs (Figure 23; refer to Prudic et al 1995 for head levels and conductance for each boundary cell).

The rivers and lakes are all at least seven, and most are more, grid cells from the target valleys. They are not considered likely to be affected. However, Panaca Warm Spring, Pahranagat Valley, Blue Eagle and Tom Springs, Moon River and Hot Creek Springs, Mormon Hot Springs, Northern White River and Muddy River springs are all within five cells from the target basins and could potentially be affected.

Both layers were simulated as confined. Transmissivity values were used and the aquifer thickness was not (necessarily) considered beyond consideration of the reasonableness of the transmissivity. The drawdown simulated herein is substantially less than that simulated by Schaeffer and Harrill (1995) because we are not considering the valleys with extremely high pumpage.

The RASA model used the units of feet and seconds; these were maintained for the simulations herein. All fluxes including pumping rates are in cfs.

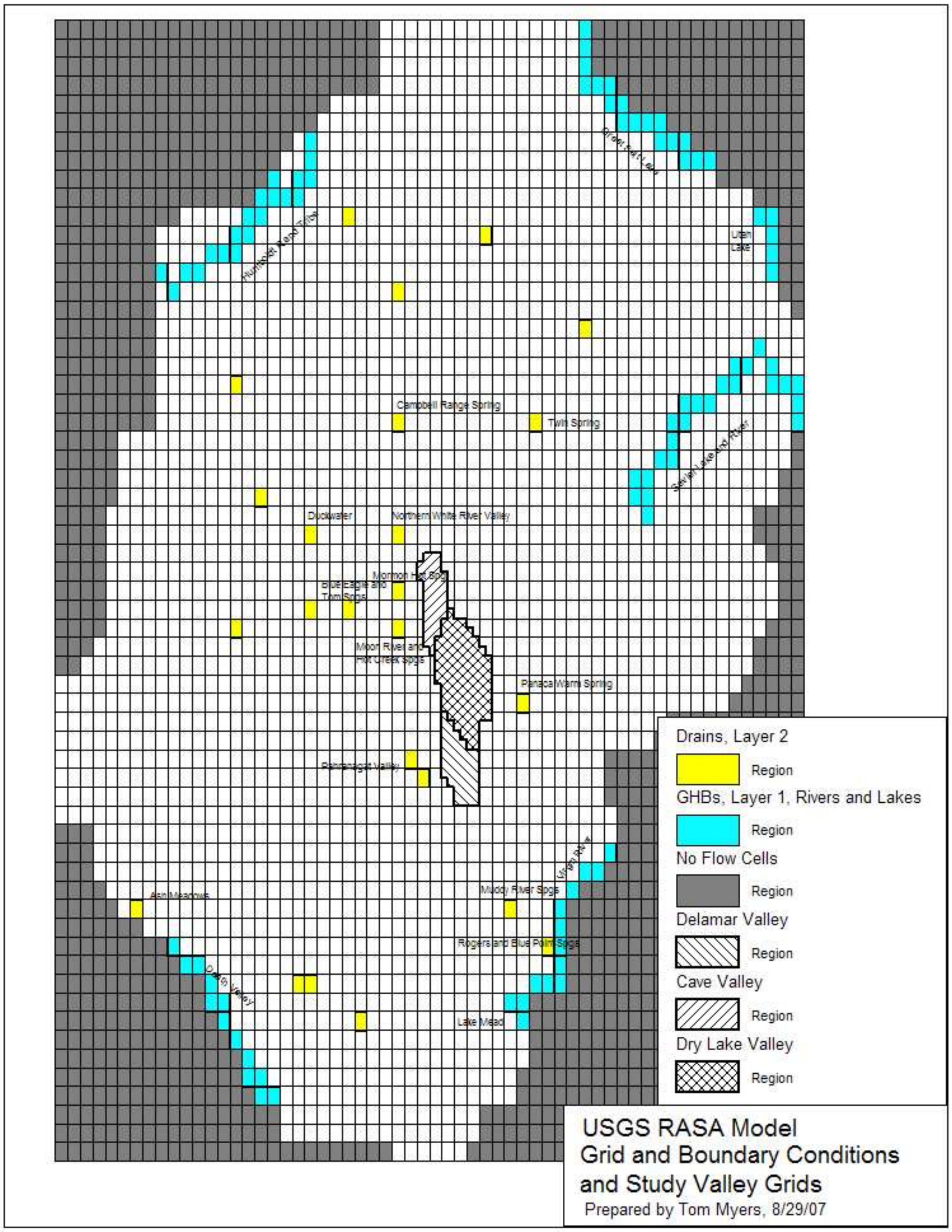


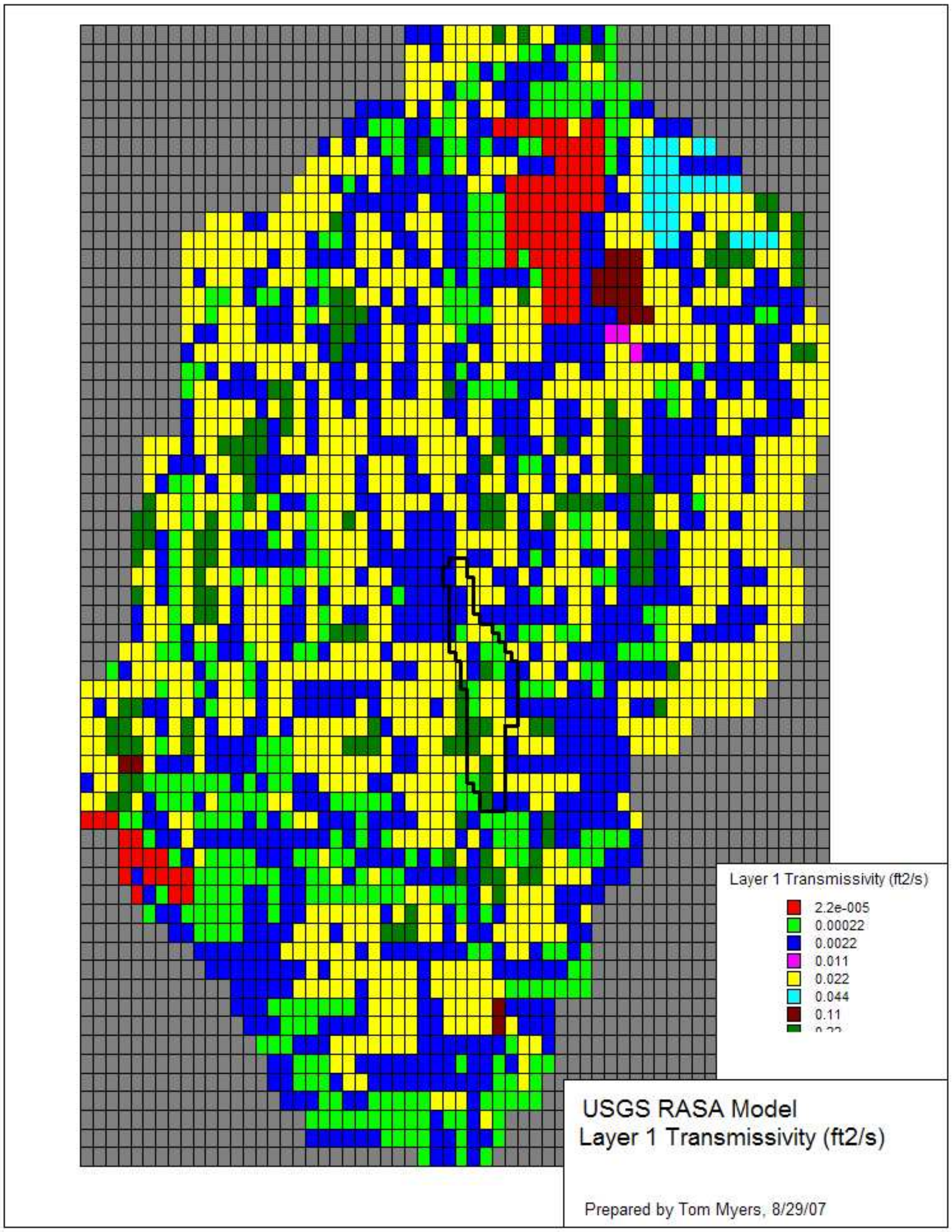
Figure 23: USGS RASA Model: Grid, Boundary Conditions and Study Basins. The grid is the original discretization. The study basin grid is from the telescoped model.

The upper layer models the basin fill valleys, which likely have high transmissivity, and intervening mountain ranges which have consolidated bedrock with variable but mostly lower transmissivity values (Figure 24). The lower layer represents primarily the distribution of carbonate aquifers with some low transmissivity volcanic rock included (Figure 25). Prudic et al (1995) discuss the distribution of transmissivity around the overall model domain. Their transmissivity values resulted from steady state calibration using observed heads and fluxes with pre-knowledge of the locations of various geologic formations. Faults were not directly considered. If they were barriers or conduits sufficient to affect head levels or fluxes, the authors assumed the transmissivity will reflect this because there would be head drops across the fault to identify it. Prudic et al (1995, page D39) indicated that zones of high transmissivity in a layer often reflect the high flow springs; high transmissivity in the surrounding cells was needed to provide sufficient water to the springs to match the observed flows – the high transmissivity near Fish Springs is an example of this. This high transmissivity may correspond to faults.

In the target basins, transmissivity in the center of the valleys generally is 0.022 ft^2/s (yellow), a mid-range value corresponding to that calibrated for basin fill. Between Dry Lake Valley and Cave Valley is a low transmissivity zone in both layers which may correspond to the transverse zone that extends east-west across the north end of Dry Lake Valley (Welch and Bright 2007, Plate 1).

In general, the west sides of the valleys have higher transmissivity than the east side (Figures 24 and 25). This reflects the dominance of carbonate rock on the west side of Cave Valley and the fractures on the west side of the other valleys as compared to the volcanics on the east side. It may also reflect the higher recharge in the mountains on the east which may cause a hydraulic divide between the target basins and those to the east.

Just south of the basins is a zone of low transmissivity in layer 1 (Figure 24); this would divert the flow to the west into Pahranagat Valley. Layer 2 has moderate transmissivity values (Figure 25) but those to the west are higher which reflects the spring discharge in Pahranagat Valleys.



USGS RASA Model
Layer 1 Transmissivity (ft2/s)

Prepared by Tom Myers, 8/29/07

Figure 24: Transmissivity in layer 1 of the RASA carbonate system model.

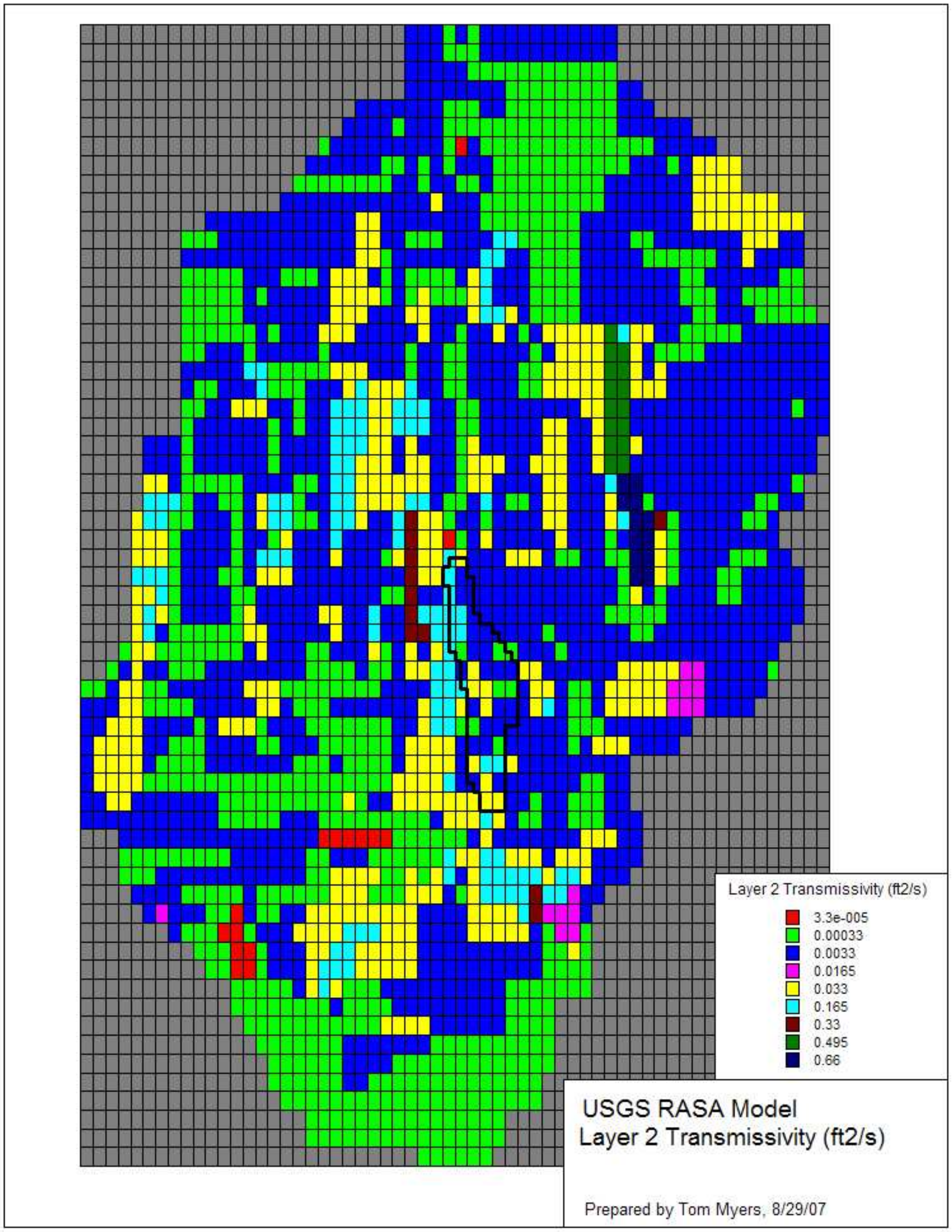


Figure 25: Transmissivity in layer 2 of the RASA carbonate system model.

The RASA model simulates steady state flow through carbonate aquifers and the adjacent basin fill aquifers. In general, the groundwater levels in layer 1 show ridges near the areas of high recharge (and high elevation) (Figure 26). In layer 2, the head is much less than that in the ridges in layer 1 (Figures 26 and 27) which drives the recharge into the lower layer (bedrock). Near the mountains the head difference between layers is positive (and large in places) (Figure 28); in the valleys there are places where the head in the lower layer exceeds that in the upper layer, representing GW ET discharge, as illustrated by the negative contours (Figure 28). In valley areas with little to no discharge, the head difference is near 0; this is the case in southern Cave Valley, Dry Lake and Delamar Valleys (Figure 28) where there is almost no discharge. In northern Cave Valley, the difference is positive (Figure 28) reflecting a potential for recharge.

Groundwater contours just west of the study area show a minor trough (Figure 27). This corresponds with the White River and Pahranagat Valley springs (Figure 23). The contours do not converge on a single point though which reflects the continued interbasin flow to the south of the study area. Springs occur wherever the head in the aquifer exceeds the elevation of the ground surface; in the model, spring discharge occurs from the drain cells if the groundwater level exceeds the specified level. The trough bends eastward south of the target basins. The deepest part of the trough (Figure 27) coincides with the Muddy River Springs (Figure 23).

Prudic et al (1995) simulated the discharge from various springs discharging from the carbonate system. Table 15 provides the discharges from the model. Almost 80 percent of the recharge to the system becomes groundwater ET discharge; another 14 percent becomes spring discharge of which almost all also evaporates within the system. A net of about six percent discharges to the various rivers. The Muddy River spring flow becomes most of the flow in the Muddy River.

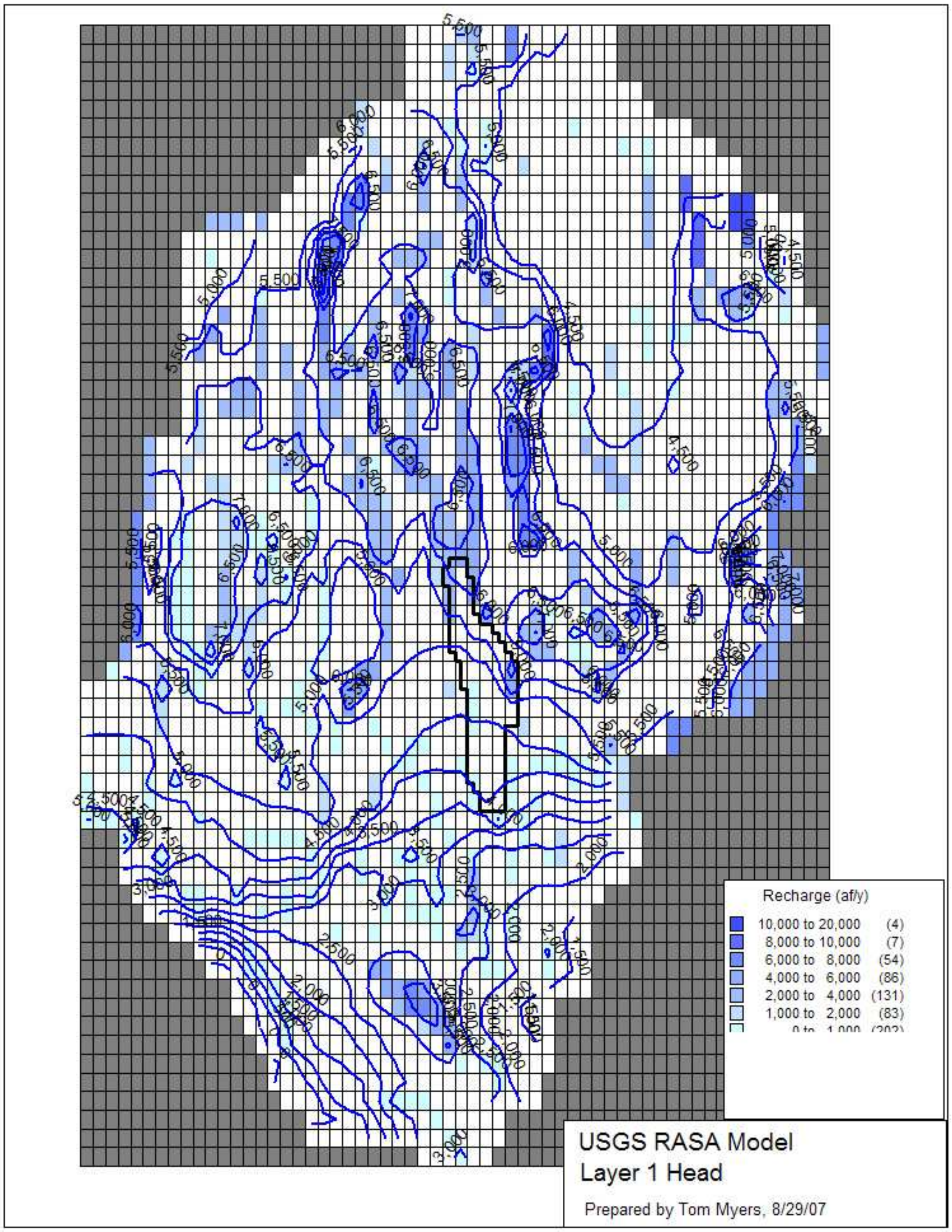


Figure 26: Steady state head in Layer 1 of the RASA model. The figure also shows the location of recharge.

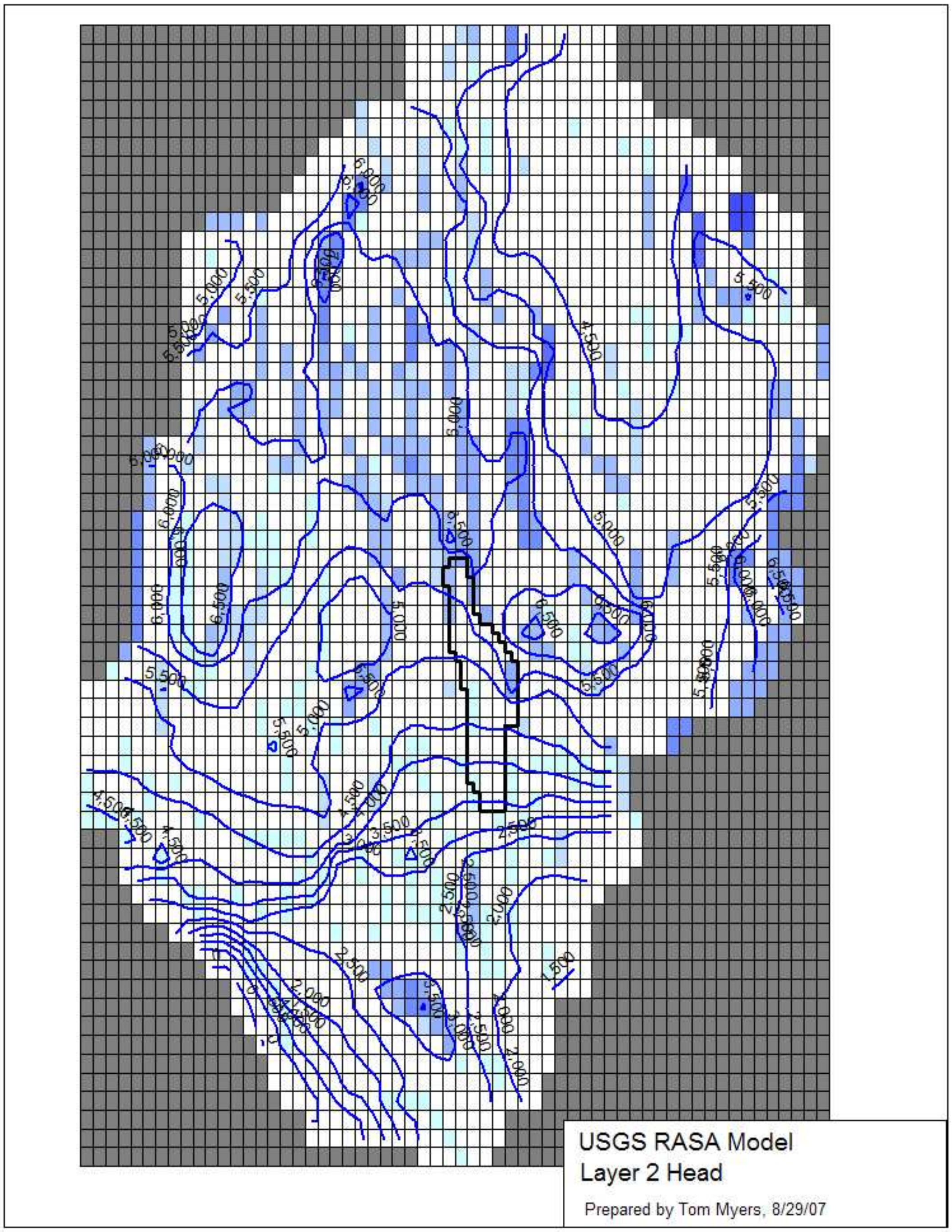
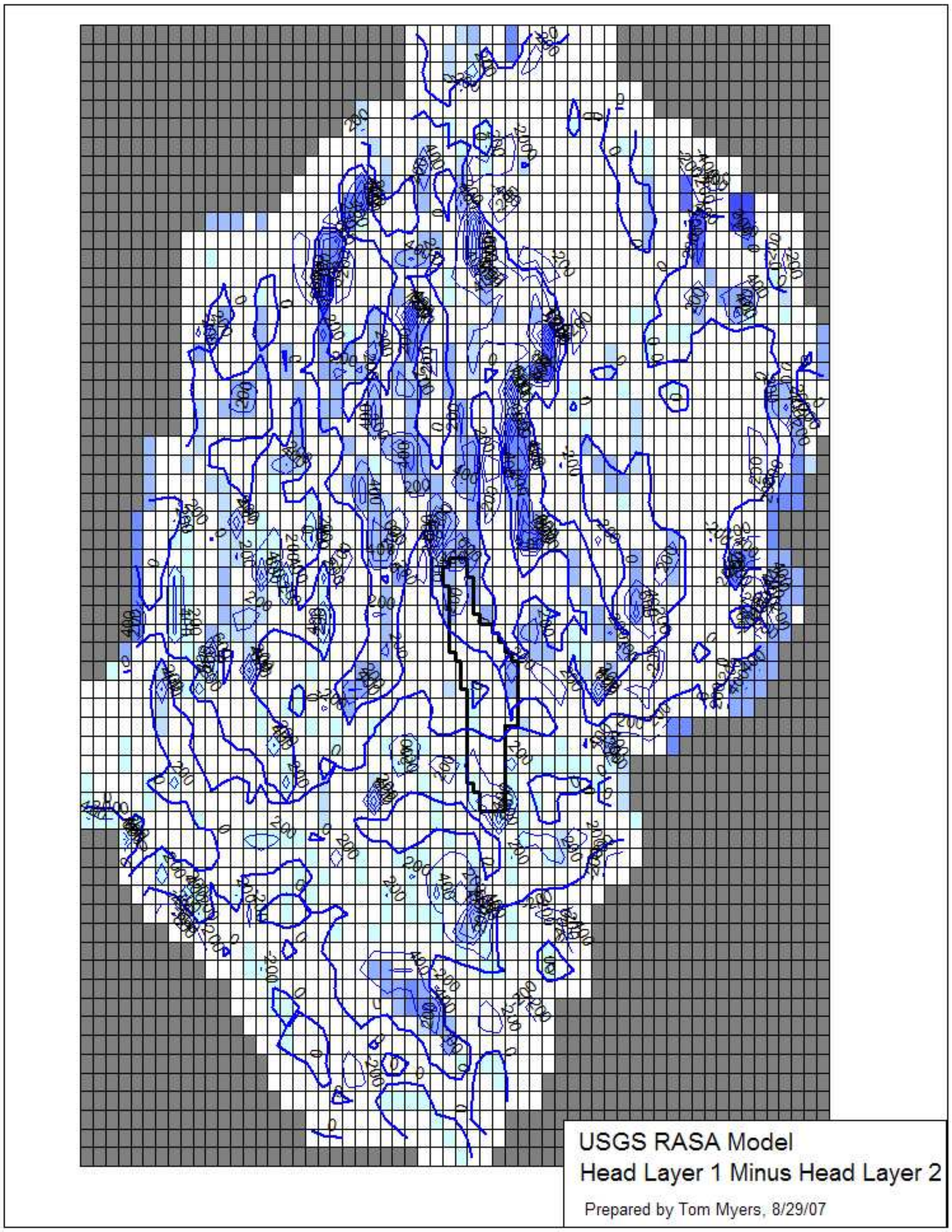


Figure 27: Steady state head in layer 2 of the RASA model. The blue represents zones of recharge – see Figure 26 for a legend.



USGS RASA Model
Head Layer 1 Minus Head Layer 2
Prepared by Tom Myers, 8/29/07

Figure 28: Difference in head between layer 1 and layer 2 for steady state conditions for the RASA model. The figure shows locations whether the gradient is downward and upward. The blue represents recharge – see Figure 26 for a legend.

Table 16: 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.

Adjustments to the RASA Model

Prudic et al (1995) prepared the RASA model at a coarse scale, 7.5 by 5.0 mile rectangular cells. For this analysis, the discretization of the model was decreased to improve the precision of the calculation of drawdown due to pumping (Figure 29). This is known as telescoping the grid. Essentially, in the area of the three target valleys, the cell boundary lengths were decreased to one-half of their previous size. Cells on either side of the valleys were also decreased to improve the accuracy of the flow calculation for flow to the springs; the spacing was adjusted so that cell size changes were not too substantial between adjacent cells because this could cause numerical instability. None of the property parameters were changed, however.

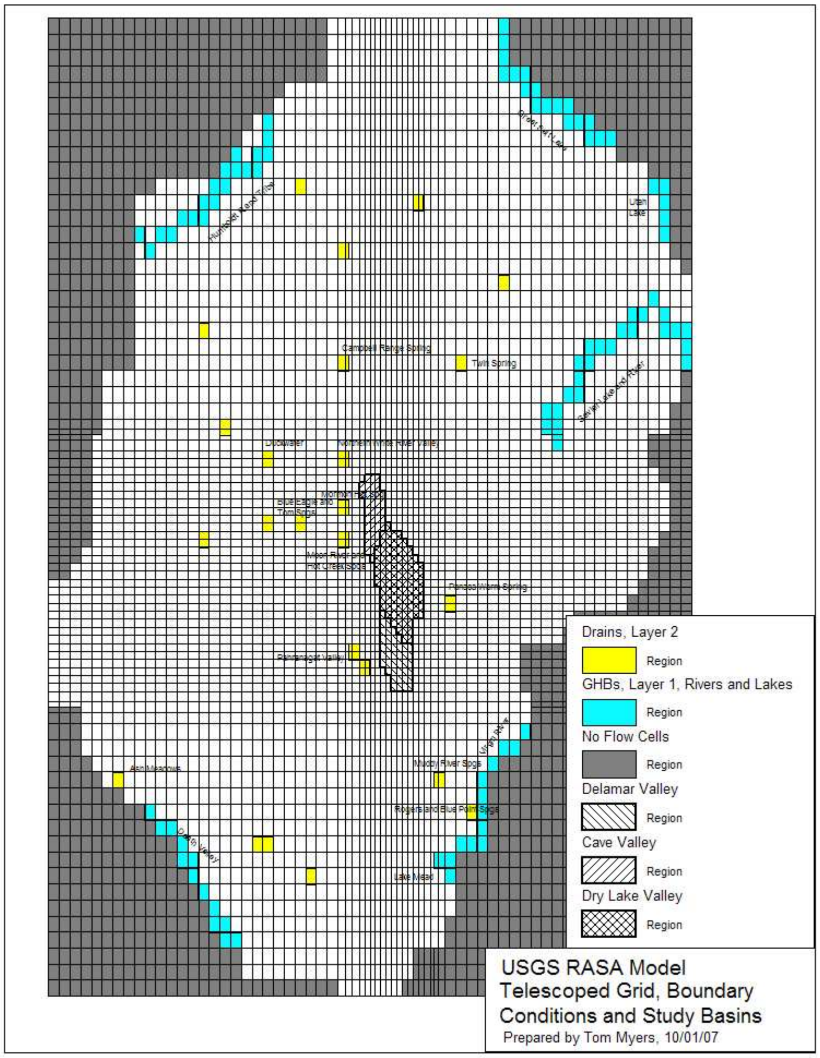


Figure 29: Telescoped grid for the RASA model.

Water Balance in Target Basins

The telescoped model was used to determine steady water balance for the target basins (Figure 29, Tables 17 through 19). Model recharge, based on Maxey-Eakin estimates (Prudic et al 1995), depends on the grid with rectangular cell boundaries that do not correspond well with basin boundaries. For example, cells on the east divide, for example, include recharge that occurs in Lake Valley.

The largest flux from Cave Valley is to the west and south; the flow to the south reflects flow from the southern end of the valley (Figure 25) and the south gradient to the flow that discharges from the west side of the valley. The high flux to the south from

Delamar Valley (Table 19) reflects flow through the southwest portion of the basin (Figure 4). In Cave and Delamar Valleys, the flux magnitude is similar in the two layers. In Dry Lake Valley, however, there is almost twice as much flux in the upper layer which reflects the significantly lower transmissivity in layer 2 within the Dry Lake domain.

Table 17: Steady state water balance for Cave 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	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	
ERROR	0.00				

Layer 1

Description	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	
ERROR	0.00				

Layer 2

Description	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	
ERROR	0.00				

Table 18: 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
ERROR	-0.01			

Layer 1

Description	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
ERROR	-0.01			

Layer 2

Description	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
ERROR	0.00			

Table 19: 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
ERROR	0.02			

Layer 1

Description	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
ERROR	0.02			

Layer 2

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
ERROR	0.00			

Simulating SNWA's Applications

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. There has been no indication that SNWA will decrease its application even though the pumping rates far exceed the published perennial yield and Schaeffer and Harrill (1995) simulated rates equaling the perennial yield apparently at SNWA's request. This impact analysis will bracket the impacts by considering pumpage at the applied-for rate and at the perennial yield.

The locations of 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 20).

Table 20: 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 Valley	1	41	33	1.035959	6	1
53988	Cave Valley	2	38	33	1.726598	10	2
53989	Dry Lake Valley	1	47	36	1.294949	6	3
53990	Dry Lake Valley	2	46	38	2.158248	10	4
53991	Delamar Valley	1	52	36	1.553938	6	5
53992	Delamar Valley	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

Pumping occurred for 2000 years and was followed by recovery for 2000 years. Initial heads were those determined with a steady state model run using the telescoped grid; these head values equaled those determined using the original RASA model. 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 second. None of the tests resulted in water balance errors or had issues with model convergence.

Drawdown

Pumping at the Full Application Rate: Drawdown occurred much more rapidly in layer 2 than in layer 1. After just eight years of pumping at the full application rate, drawdown in layer 2 approached 200 feet near SNWA's proposed wells in Dry Lake and Delamar Valleys; drawdown near the proposed well in Cave Valley was about 40 feet. The primary difference is the additional recharge in Cave Valley. In layer 1 after 8 years, the drawdown is less than 40 feet. The higher storage coefficient in layer 1 means that much more water is released for a given head drop, or the same pumping lowers the head much less in layer 1.

Between 8 and 100 years, the drawdown at the wells in layer 2 did not increase substantially, but the extent of the 40- and 20-foot drawdown contours increased substantially. Drawdown near the wells in layer 1 began to increase significantly after 100 years. In Cave Valley, the layer 1 well is in south and the drawdown extends southeast into Dry Lake Valley. But while the drawdown is about 100 feet, the expansion of the cone to the west extended about two cells (or five miles). The 20-foot drawdown extended about 7.5 miles along the west side of Cave Valley. After 2000 years, the 20-foot drawdown extended just four cells north into Cave Valley due to the higher ground surface elevation and the low transmissivity in the middle of the valley.

Substantially more drawdown occurs to the west than to the east as expected from the primary discharge being from the valleys to the west. Up to 100 years, the drawdown barely reached east of the boundaries of Dry Lake and Cave Valleys (Figures 31 and 32). But this limitation was due more to topography and to transmissivity differences than to flow barriers caused by faults or impervious intrusive rock. The drawdown eventually expands to the east as the water levels in the targeted valleys decreases. As it does so, the drawdown extends under the mountains bounding the east side of the valley. The drawdown expands eastward more than westward in the long-term analysis, between 200 and 2000 years (compare Figures 33 and 34 with Figures 35 and 36). Eventually, drawdown affects all of Dry Lake and Delamar Valleys.

The springs within Dry Lake and Delamar Valleys will all eventually lie within the 20-foot drawdown cone. These include many small springs in the Bristol Range and Highland Range on the east side. If there is a hydraulic connection between the springs and the saturated groundwater, the spring flow could be affected.

The 20-foot drawdown approaches but does not fully encompass the springs in White River and Pahranagat Valleys. After 2000 years, the 20-foot drawdown will have expanded past the springs but still be less than 20 feet at the springs (Figures 35 and 36). This is due to the high transmissivity near those springs (Figures 24 and 25) which allows groundwater to reach the springs even as their source from the east (the targeted valleys) is cut off.

Pumping at the Perennial Yield Rate: Drawdown caused by pumping at the perennial yield was less than that caused by pumping at the full application rate (Figures 37 through 40). However, the general shape of the drawdown cones is similar to those for pumping the full application. The biggest difference is that the drawdown is not as great near the wells as for the full application rate. This is particularly true in layer 2 where the drawdown in layer 2 for Dry Lake Valley ranges from 40 to 80, respectively, between 8 and 2000 years (Figures 37 and 40). The rather small difference reflects the rapid spread of the drawdown cone and the rapid impact on surrounding springs.

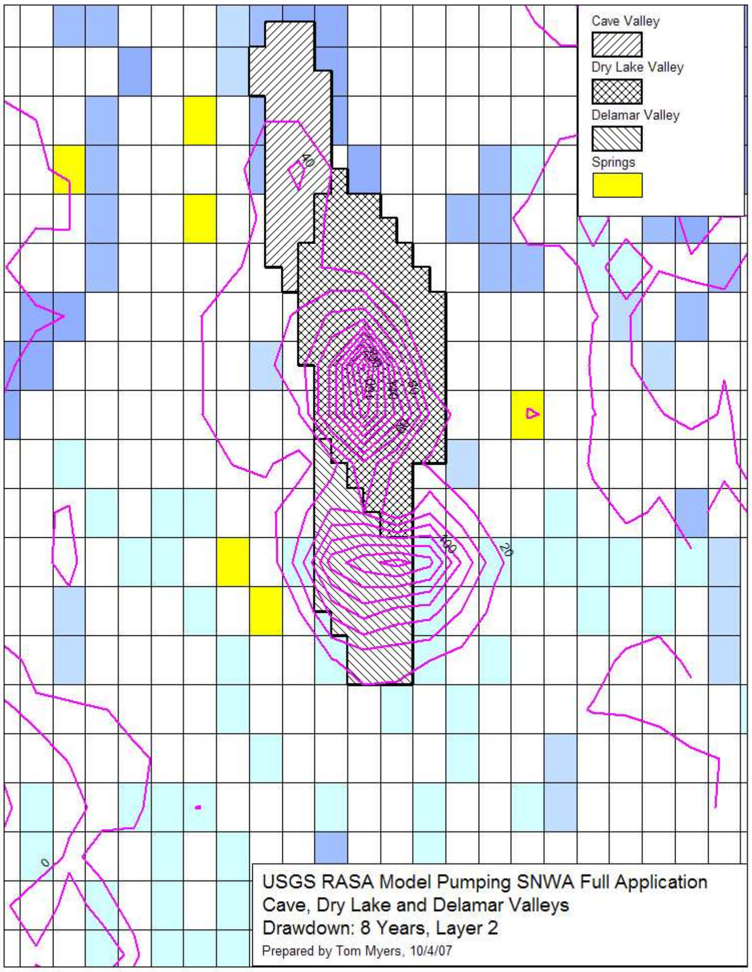


Figure 30: Drawdown in layer 2 after 8 years of pumping SNWA's full application.

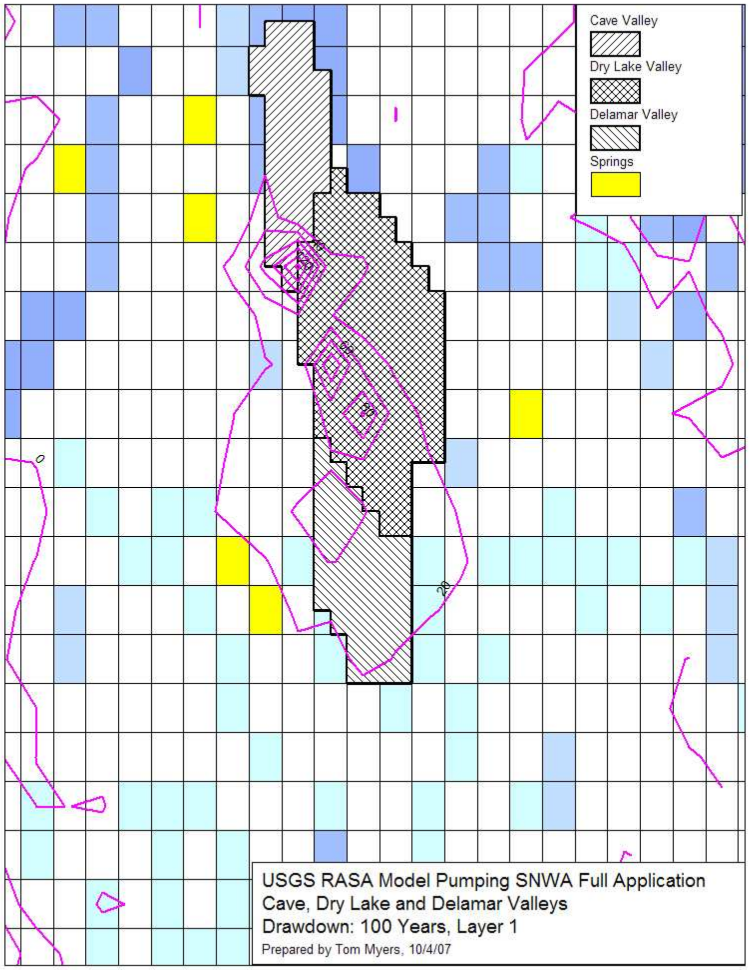


Figure 31: Drawdown in layer 1 after 100 years of pumping SNWA's full application.

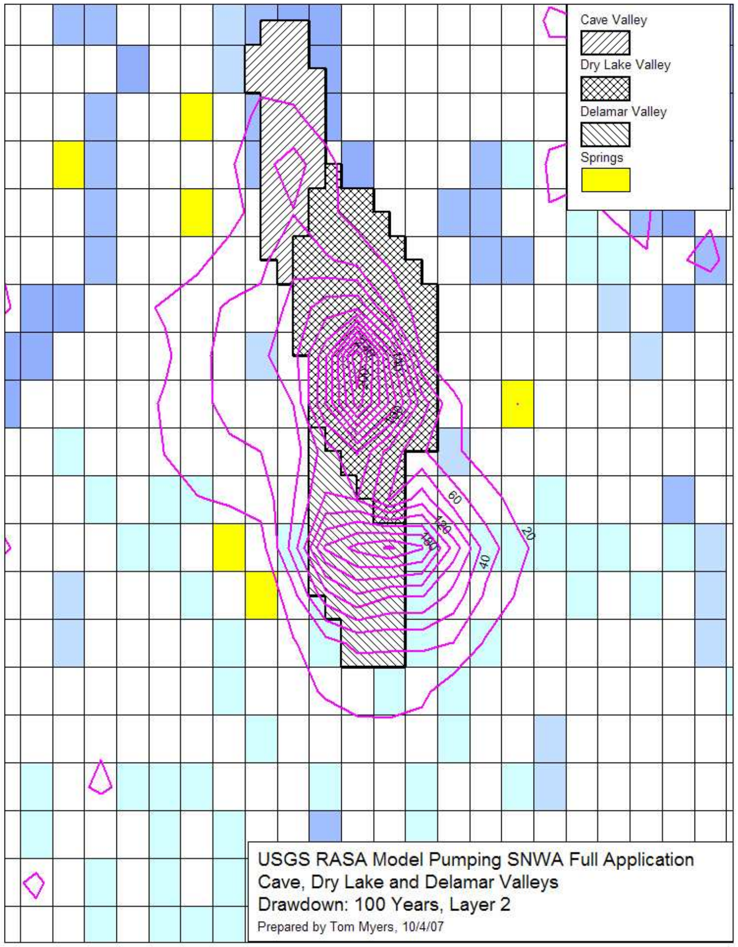


Figure 32: Drawdown in layer 2 after 100 years of pumping SNWA's full application.

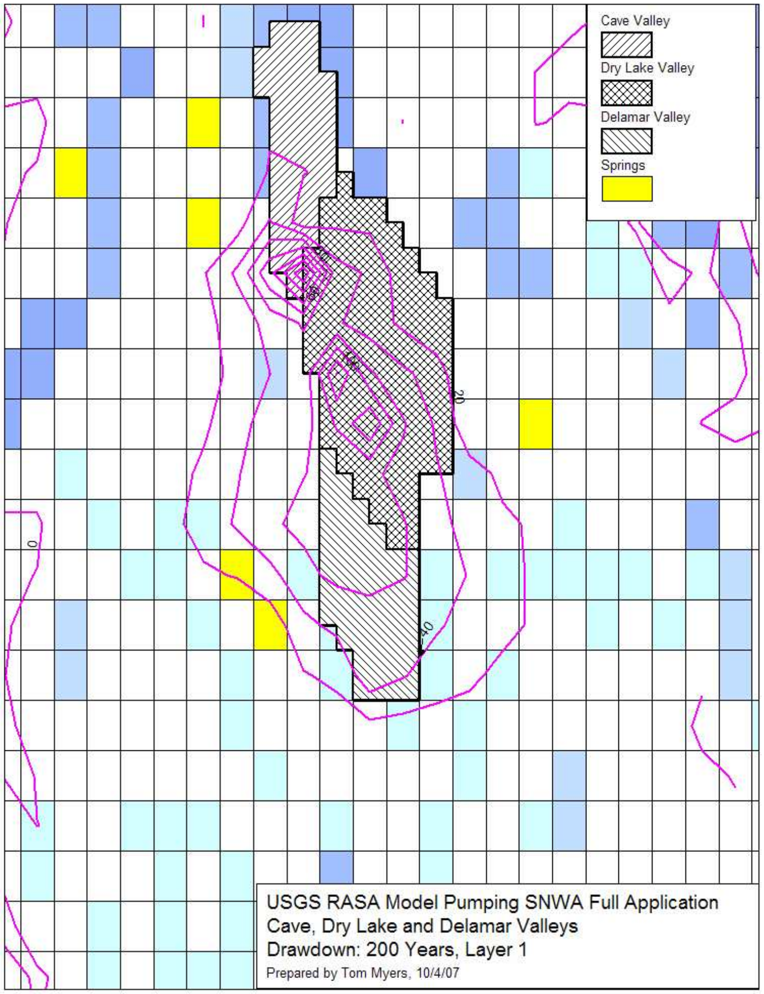


Figure 33: Drawdown in layer 1 after 200 years of pumping SNWA's full application.

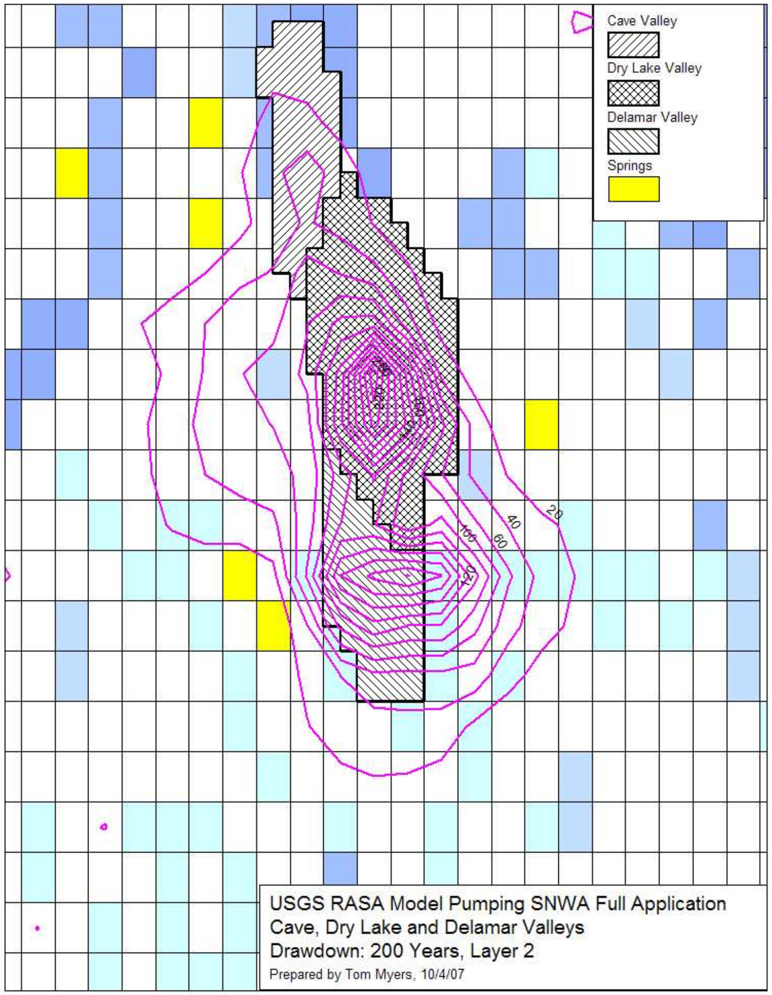


Figure 34: Drawdown in layer 2 after 200 years of pumping SNWA's full application.

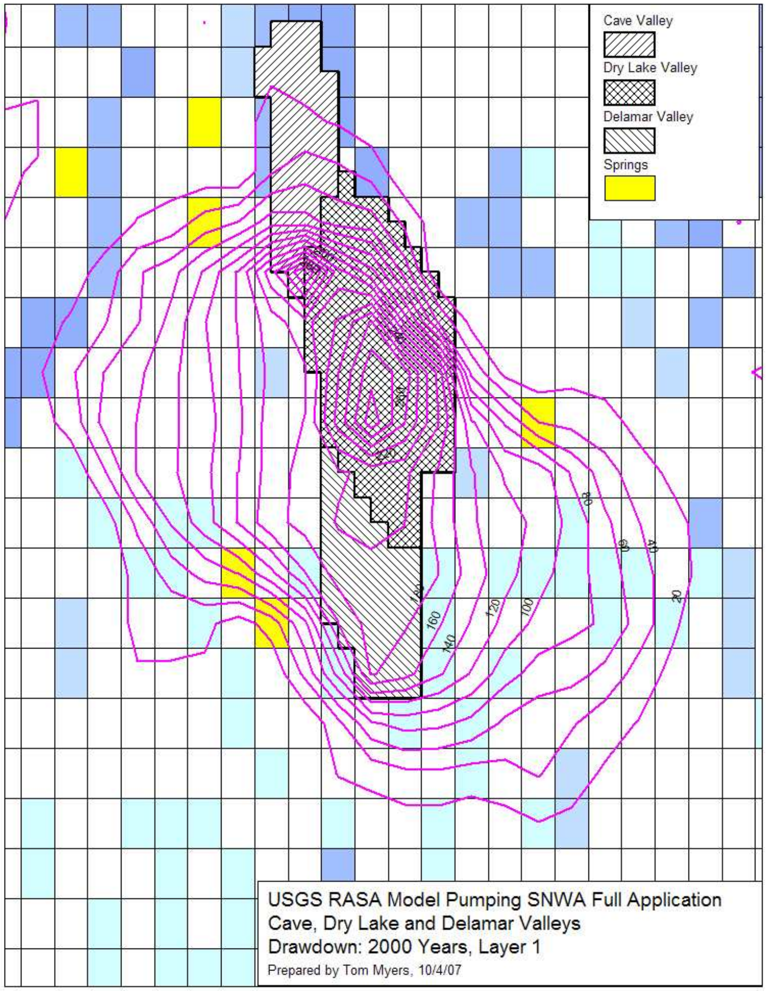


Figure 35: Drawdown in layer 1 after 2000 years of pumping SNWA's full application.

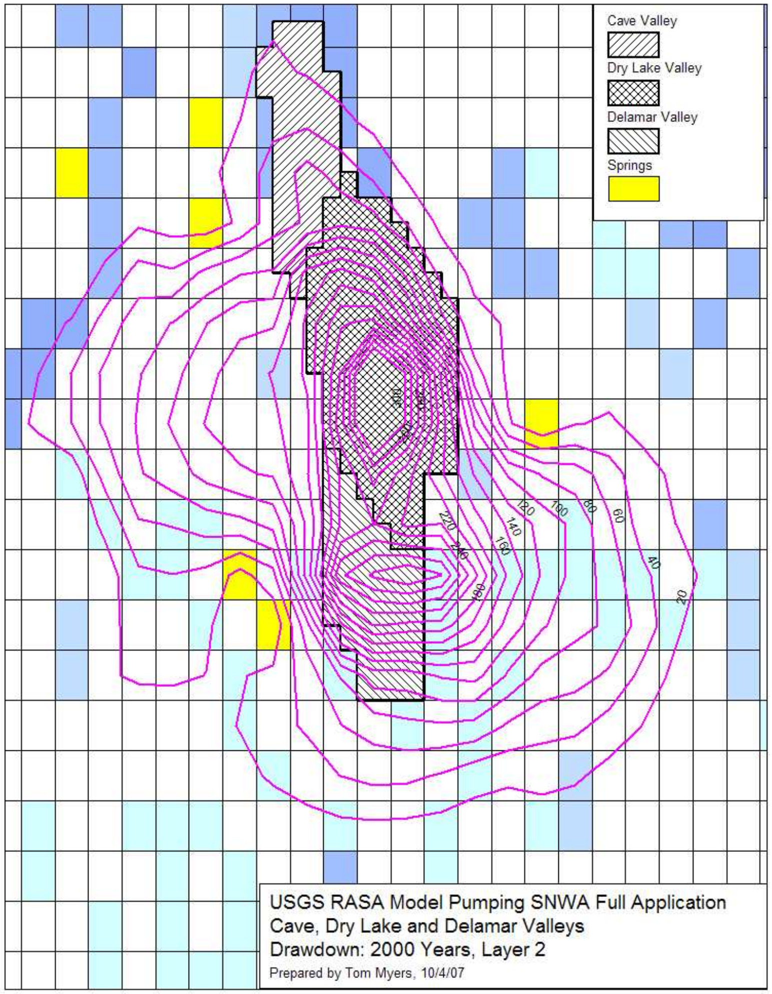


Figure 36: Drawdown in layer 2 after 2000 years of pumping SNWA's full application.

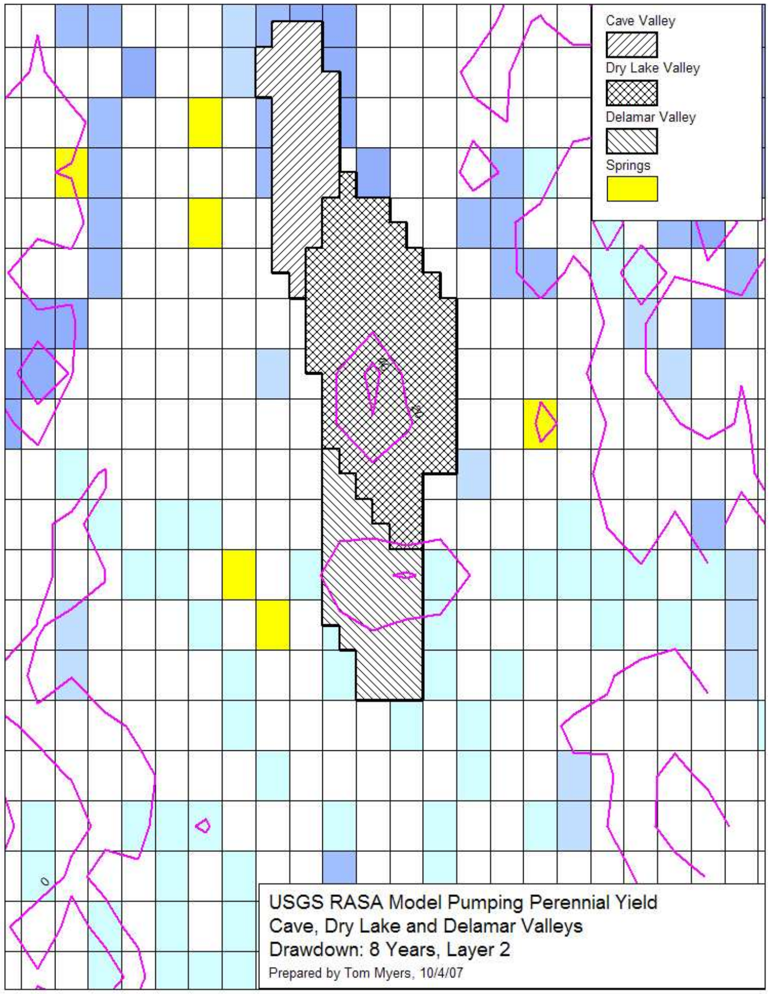


Figure 37: Drawdown in layer 2 after 8 years of pumping the perennial yield from each valley.

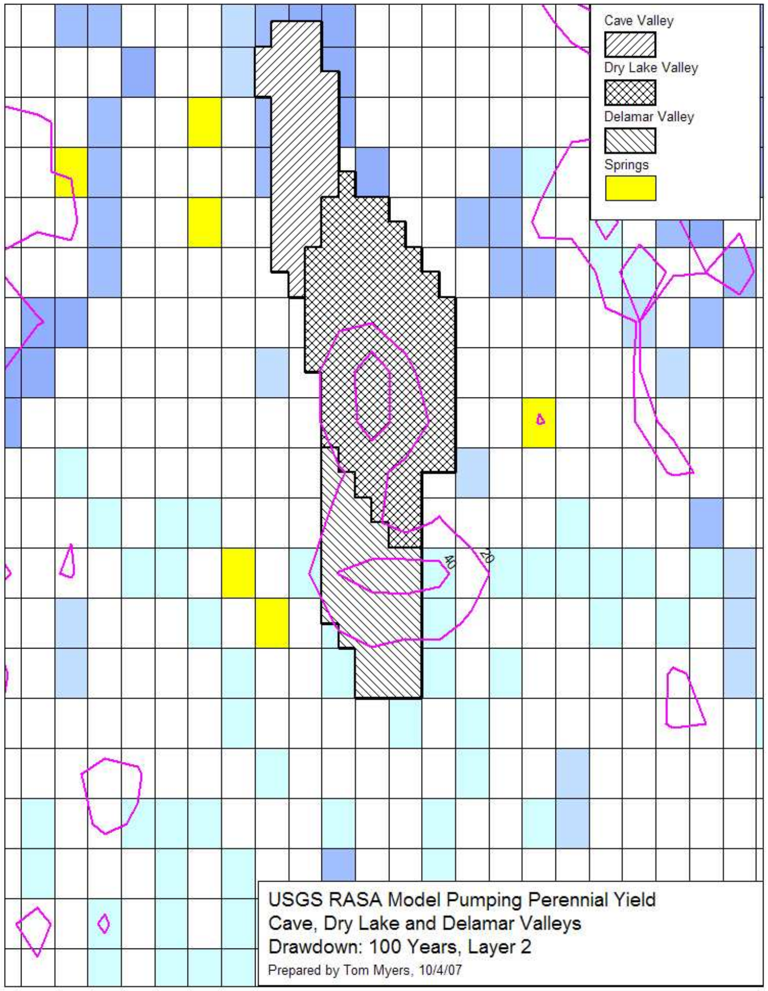


Figure 38: Drawdown in layer 2 after 200 years of pumping the perennial yield from each valley.

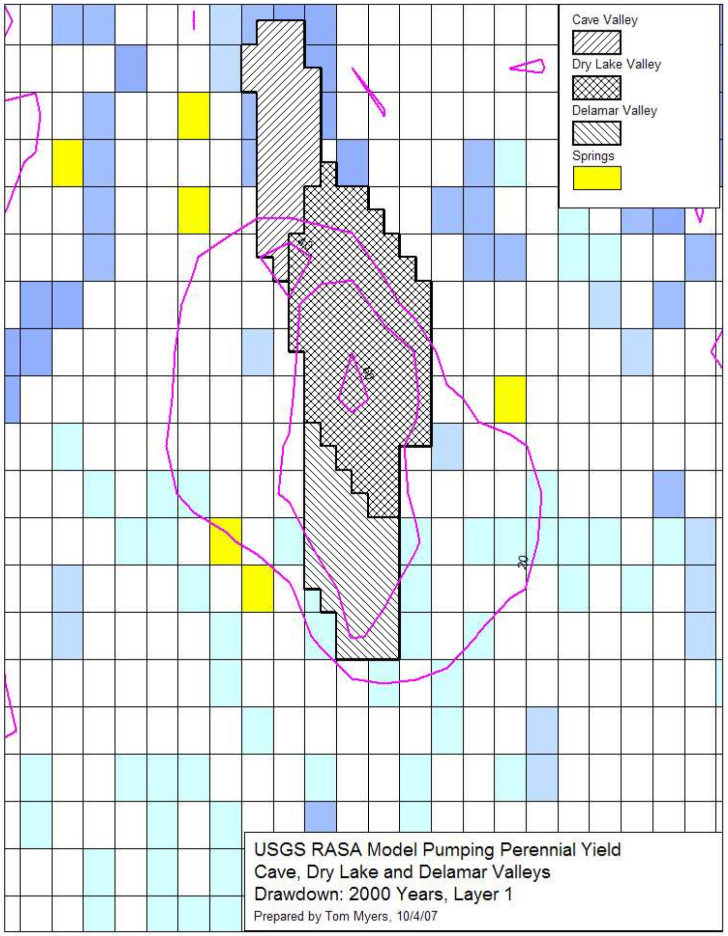


Figure 39: Drawdown in layer 1 after 2000 years of pumping the perennial yield from each valley.

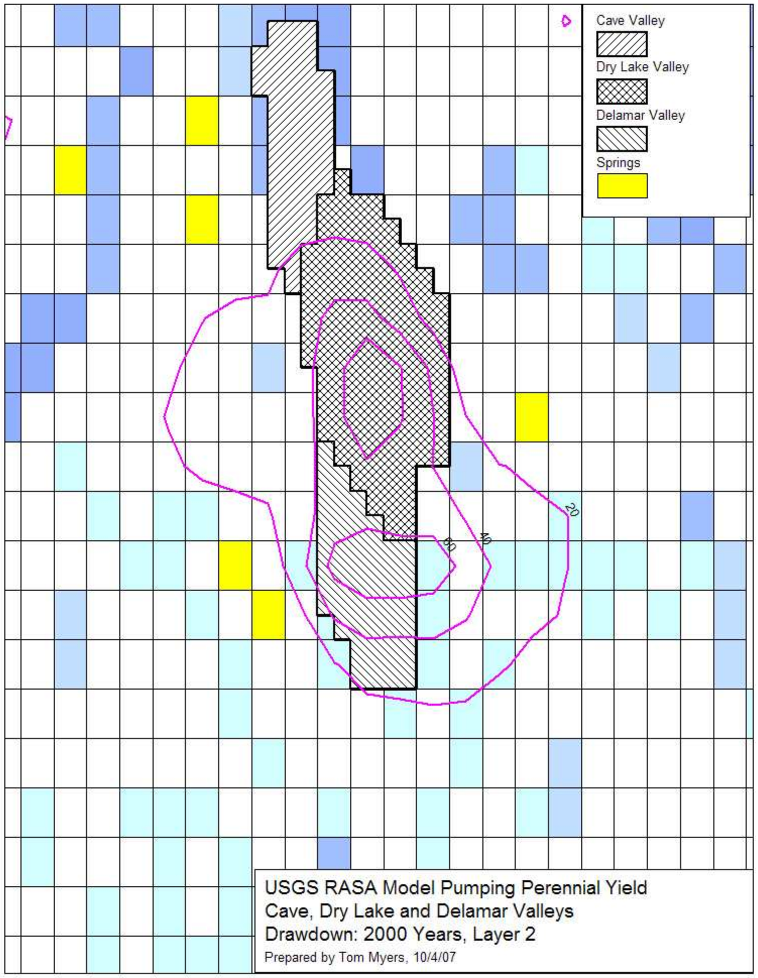


Figure 40: Drawdown in layer 2 after 2000 years of pumping the perennial yield from each valley.

Changes in Flux

Pumping at the Full Application Rate: The proposed pumping adds a flux to the water balance of the valleys. The stress removes groundwater from storage and will do so until a new equilibrium establishes. The equilibrium is between discharge and recharge. Except for Cave Valley, the pumping exceeds the recharge within the individual valleys, therefore to reach steady state, the drawdown must become sufficient to draw groundwater from surrounding valleys. This was seen in the long-term pumping drawdown maps (Figures 35, 36 and 40).

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 41). Considered in more detail (Figure 42), it is apparent that the change in flux to the west occurred within five years. 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 41). Inflow from the west did not increase as quickly as the outflow to the west decreased (Figure 41). The long-term increase in flow to the south (Figure 41) mirrors a long-term increase in flow from the north to Dry Lake Valley (Figure 45). The change in storage requires almost 500 years to reach almost 0 cfs (Figure 41), but it decreased from negative 15 to about 2 cfs within just ten years. This reflects the rapid drawdown at the wells followed by the slow expansion.

Downgradient from Cave Valley, the Moon River and Hot Creek springs are most affected by the pumping (Figures 43 and 44). After 1800 years, these springs go dry (Figure 43); flow rates decrease by a third within three years and by a half within 20 years (Figure 44). 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 in the model and in reality because of the low gradient driving flow. In other words, the head at the spring is close to the groundwater surface, so small changes make significant changes in the flow.

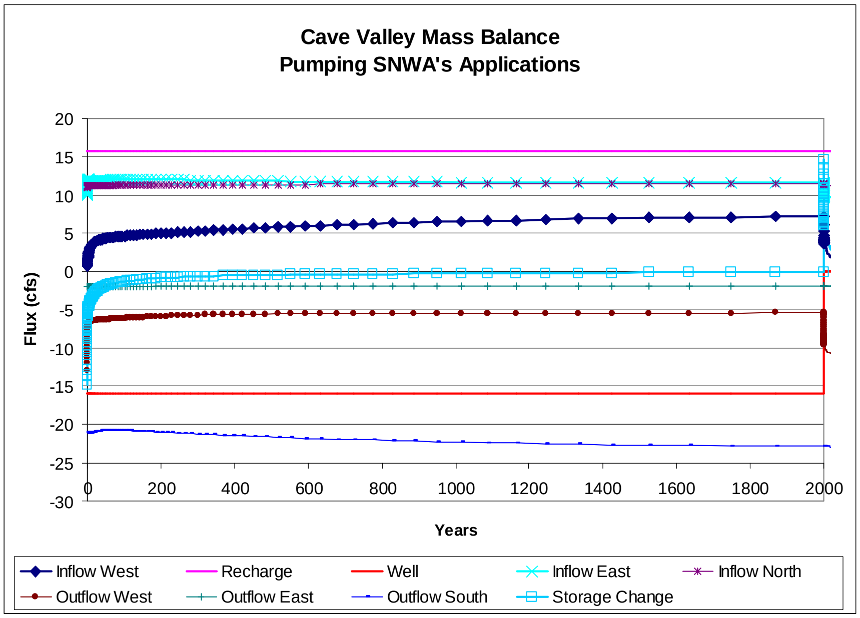


Figure 41: Hydrograph of flux into and out of Cave Valley for pumping SNWA's entire application amount; includes change in storage. 2000 years of pumping.

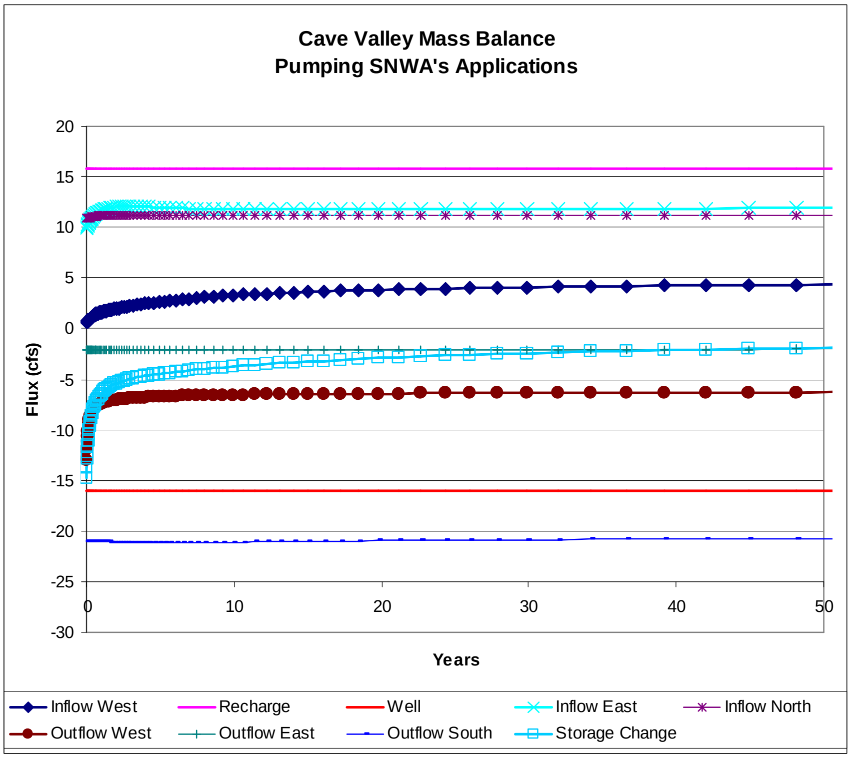


Figure 42: Hydrograph of flux into and out of Cave Valley for pumping SNWA's entire application amount; includes change in storage. 50 years of pumping.

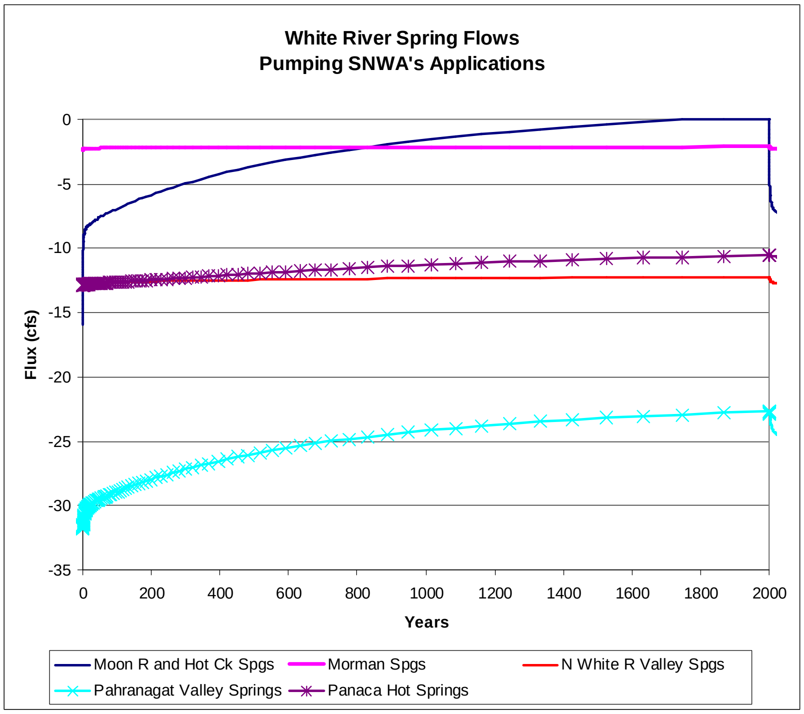


Figure 43: Hydrograph of flux from nearby springs. 2000 years of pumping.

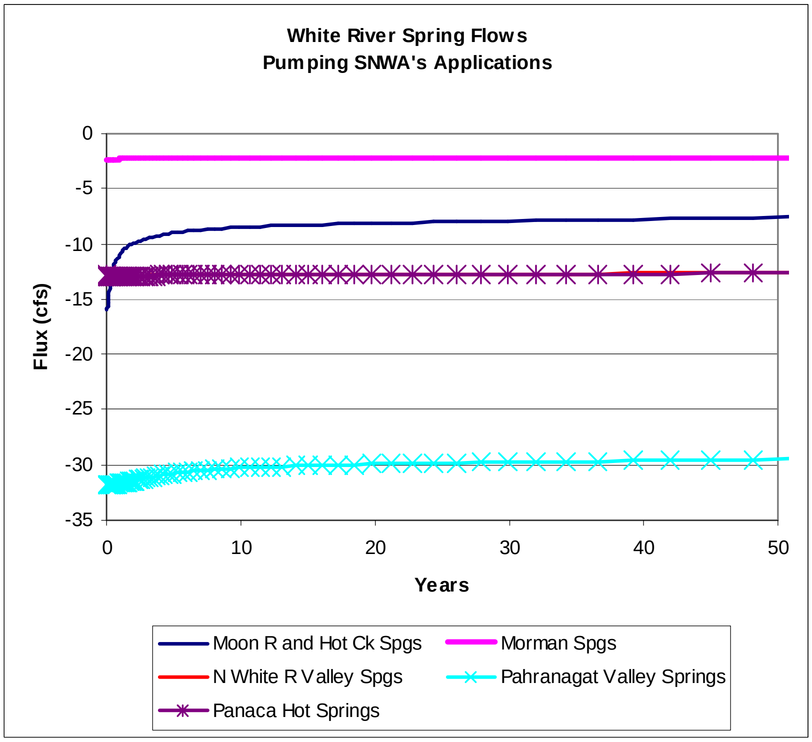


Figure 44: Hydrograph of flux from nearby springs. 50 years of pumping.

Fluxes do not reach steady state in either Dry Lake or Delamar Valleys within 2000 years (Figure 45 and 47). In Dry Lake Valley, after 2000 years, approximately 2 cfs continues to be removed from storage (Figure 45). In Delamar Valley, the similar value is about 1 cfs (figure 47). These rates are approximately 14 and 7 percent of the pumping rates. Also, continuing pumping draws from surrounding basins further indicating that conditions are not approaching steady state. Cave Valley has much more recharge which helps conditions to approach steady state. In Dry Lake Valley, the discharge to downgradient basins does not decrease proportionately as much as it does from Cave Valley. In fact, outflow to the west increases initially due to pumping from the south end of Cave Valley which is west of the north end of Dry Lake Valley (Figure 45); overall, the outflow rate decreases just 20 percent. The increase in inflow from the west is more substantial, from 4 to about 13 cfs over 2000 years (Figure 45) but with an initial doubling within 15 years (Figure 46).

Very slowly, outflow to and inflow from the east decrease and increase about 10 percent (Figure 45and 47), respectively. Discharge from Panaca Springs reflects this change, decreasing about 15 percent over 2000 years (Figure 43). The flow changes very little within 50 years (figure 44). The slow change at the Panaca Hot Springs reflects the expectation that there might be no effect to the east, as discussed above, due to topography and geology. But, as drawdown increases in Dry Lake Valley, the gradient causes flux from Lake Valley to reach Dry 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 the valleys and that there is more tendency, due to transmissivity, for flow to the west.

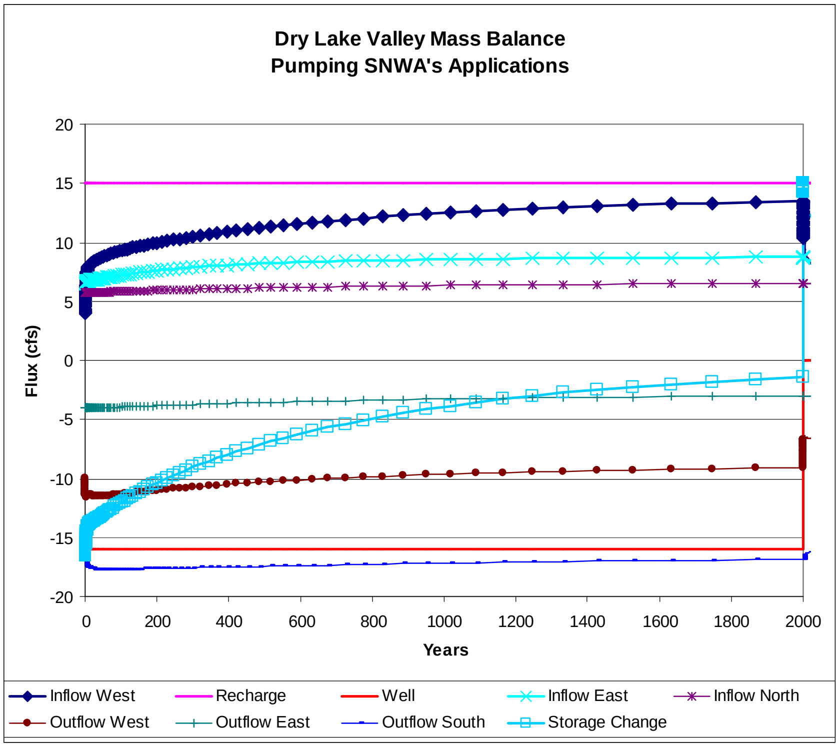


Figure 45: Hydrograph of flux into and out of Dry Lake Valley for pumping SNWA's entire application amount; includes change in storage. 2000 years of pumping.

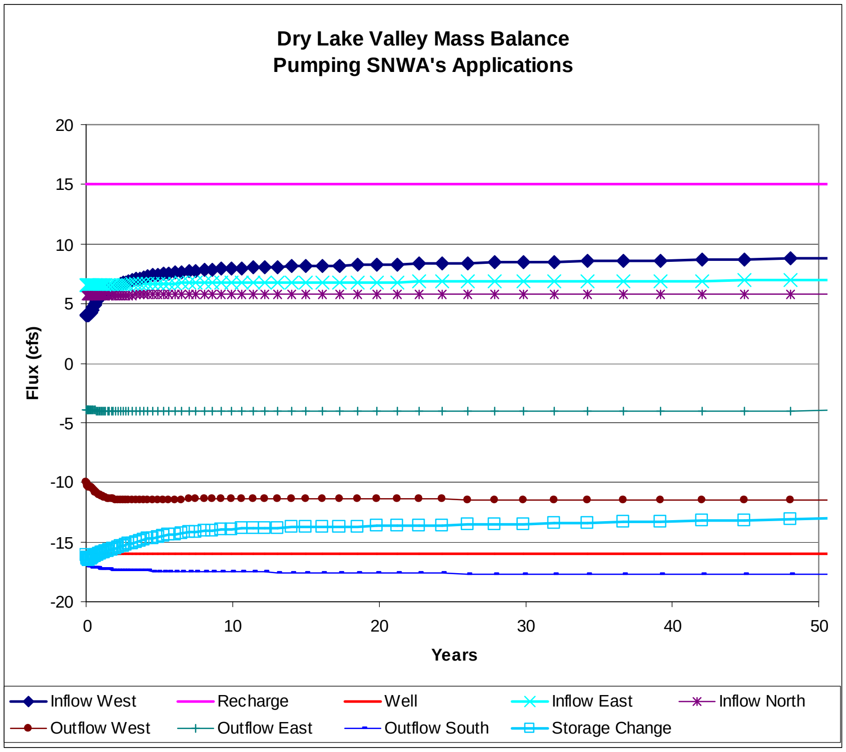


Figure 46: Hydrograph of flux into and out of Dry Lake Valley for pumping SNWA's entire application amount; includes change in storage. 50 years of pumping.

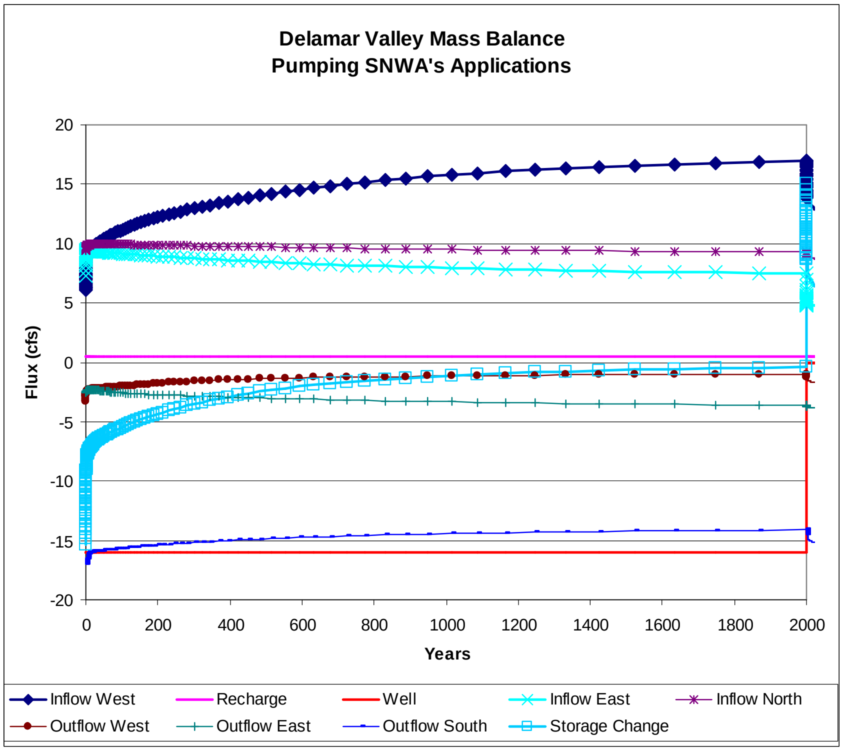


Figure 47: Hydrograph of flux into and out of Delamar Valley for pumping SNWA's entire application amount; includes change in storage. 2000 years of pumping.

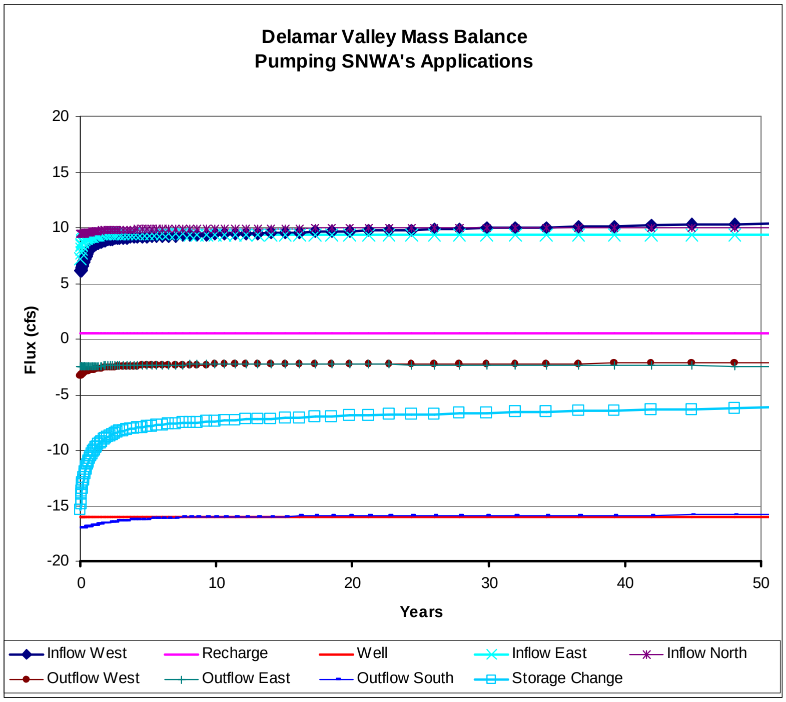


Figure 48: Hydrograph of flux into and out of Delamar Valley for pumping SNWA's entire application amount; includes change in storage. 50 years of pumping.

Neither Dry Lake nor Delamar Valleys approach steady state within 2000 years (Figures 49). 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 storage decreases in surrounding valleys.

Pumping at the Perennial Yield: If SNWA pumps at the published perennial yield values, the changes in water balance fluxes and decreases in spring flow will be substantially less. Because the modeling is effectively linear (because of the confined aquifer assumption), the flux differences between scenarios vary in an amount proportional to the difference in pumping rates. In Cave Valley, the changes are the least because the perennial yield is just 2000 af/y or about 1/6th of the application rate. As expected, outflow to and inflow from the west decreases and increases by about that amount (Figure 50). The Moon River and Hot Creek Springs also decrease flow by about 1/6th (Figure 53), rather than eventually drying as occurred with pumping at the full application. At this rate, steady state is approximately reached in 150 years.

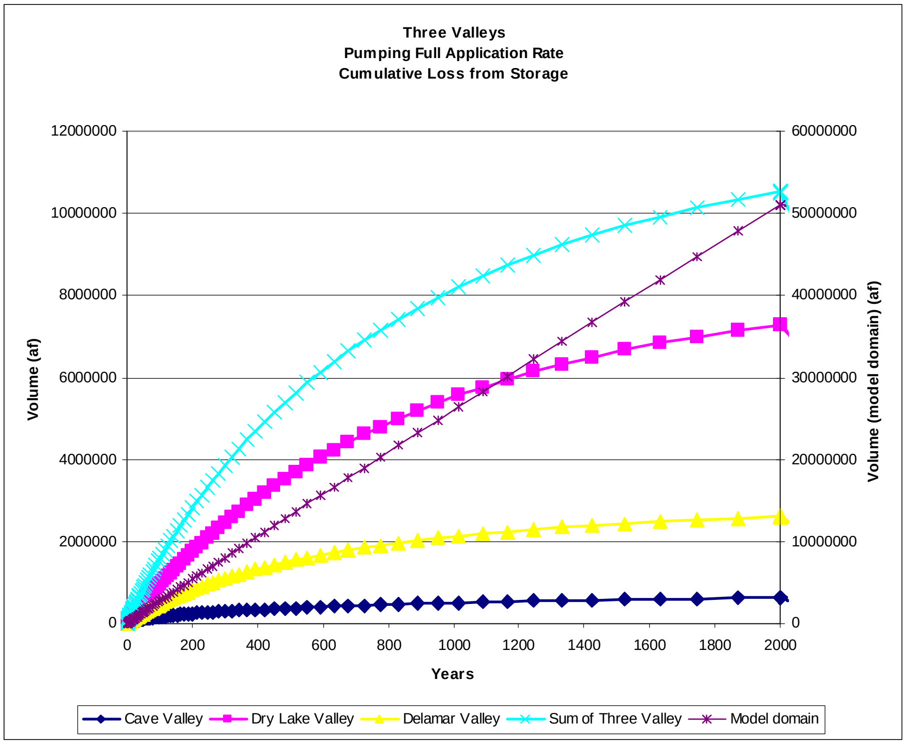


Figure 49: Cumulative storage lost and recovered in Cave, Dry Lake and Delamar for pumping the published perennial yield from each valley. 2000 years of pumping.

Similar changes to pumping at the full application rate also occurred in Dry Lake and Delamar Valleys. In Dry Lake the pumping rate of 2500 af/y is 1/5th of the applications and the flux changes are proportionate (Figure 51). In Delamar, the pumping rate is more than 1/4th that of the full application amount. The flux changes are greater in Dry Lake and Delamar valleys because, as for the full application pumping rate, there is less recharge (Figures 51 and 52). The pumping removes a larger amount of water from storage. In Dry Lake Valley, steady state is approached within the 2000 year period. In Delamar Valley, steady state is almost reached within 1500 years although an additional 10 percent of the total storage is removed in the last 500 years of the 2000-year period.

Flux from the fully appropriated Pahranagat Valley Springs decreases by about 2 cfs overall with the majority of the decrease reached with 500 years (Figure 54). There is little observable effect on the flux from Panaca Hot Springs at this pumping rate.

The changes caused by the proposed pumping on the regional springs are the most important impacts caused by SNWA's applications. Removing the transitional storage lowers the water table and reduces the discharge from the system. There is no GW ET discharge from the three targeted valleys, therefore the well pumping must be displaced by decreasing discharges outside of the three valleys. Much of the pumping discharge is displaced from the regional springs (Figures 43, 44 and 54).

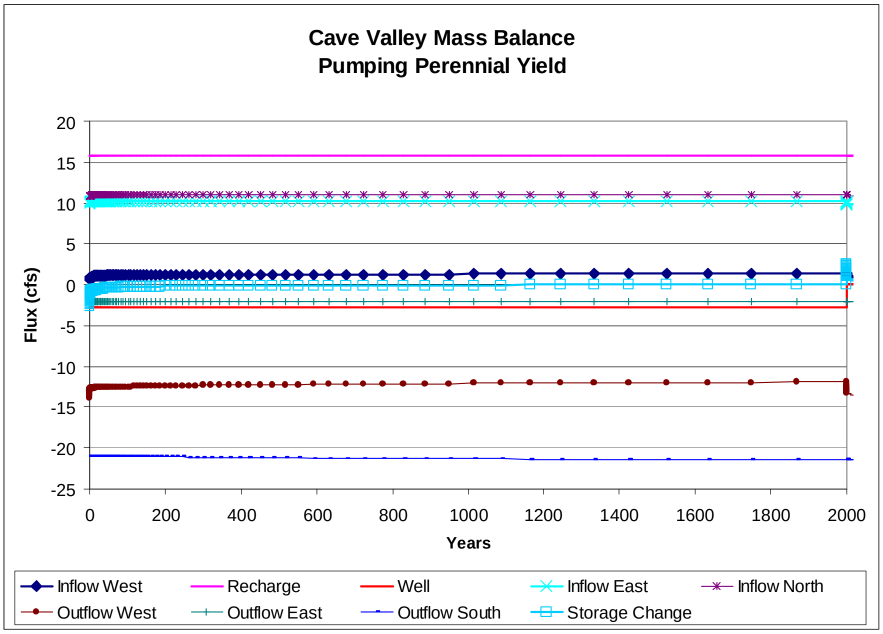


Figure 50: Hydrograph of flux into and out of Cave Valley for pumping the published perennial yield from each valley; includes change in storage. 2000 years of pumping.

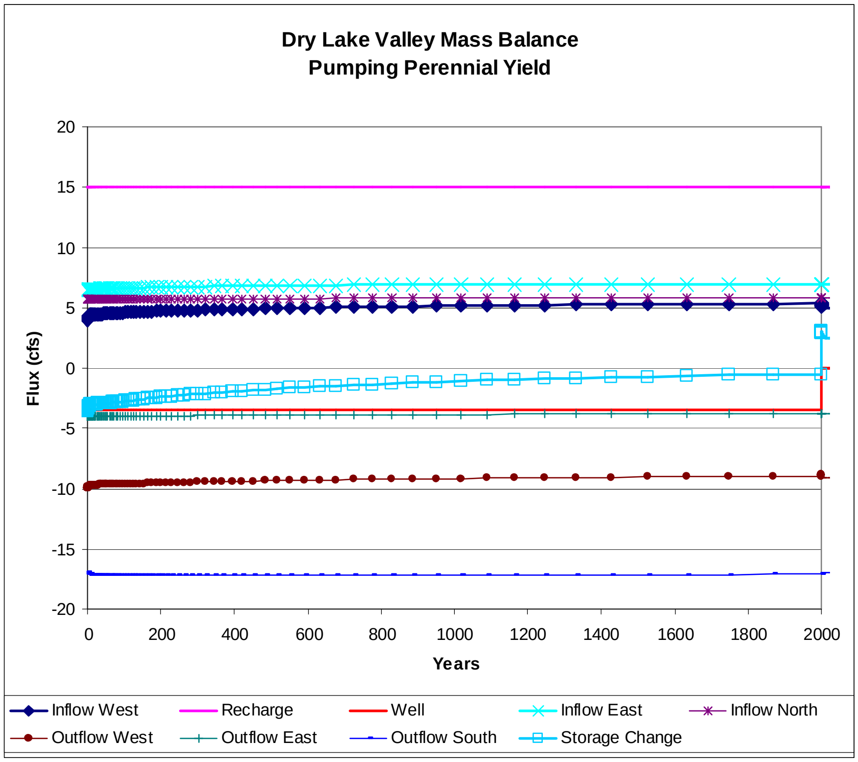


Figure 51: Hydrograph of flux into and out of Dry Lake Valley for pumping the published perennial yield from each valley; includes change in storage. 2000 years of pumping.

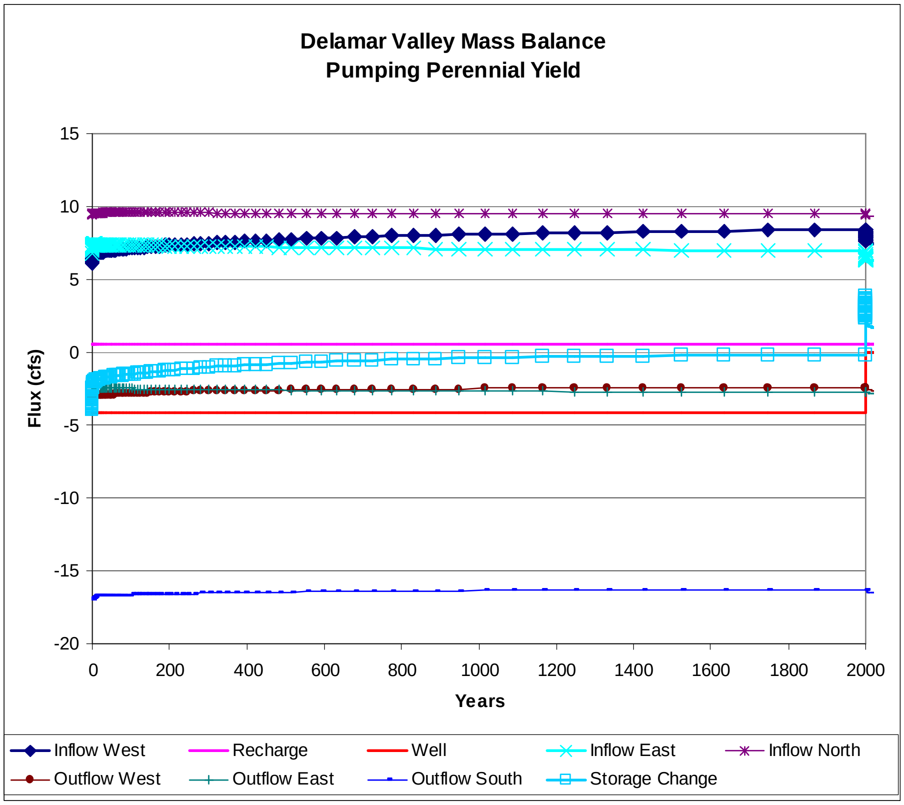


Figure 52: Hydrograph of flux into and out of Delamar Valley for pumping the published perennial yield from each valley; includes change in storage. 2000 years of pumping.

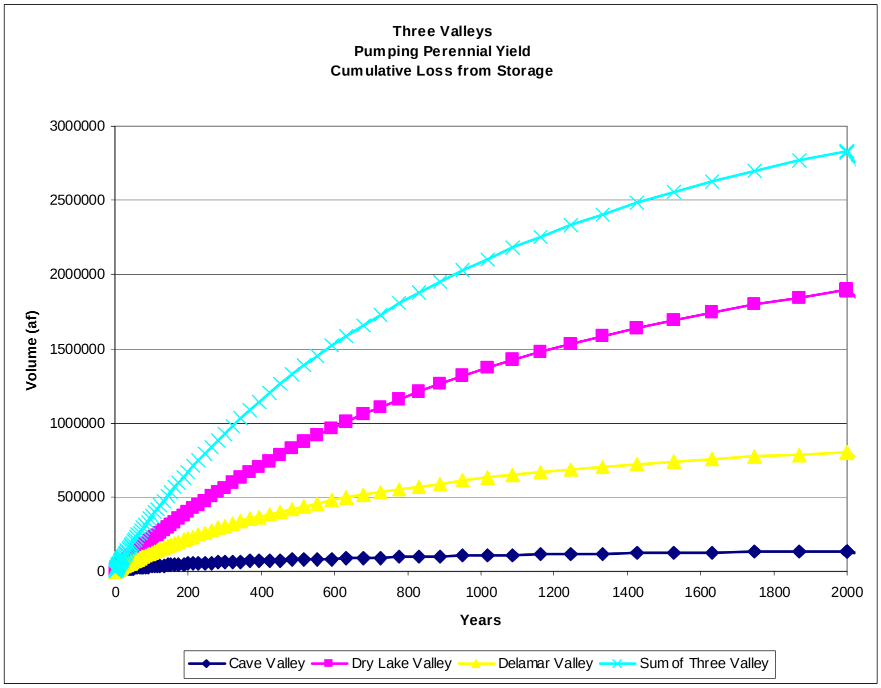


Figure 53: Cumulative storage lost and recovered in Cave, Dry Lake and Delamar Valleys due to pumping the published perennial yield from each valley. 2000 years of pumping.

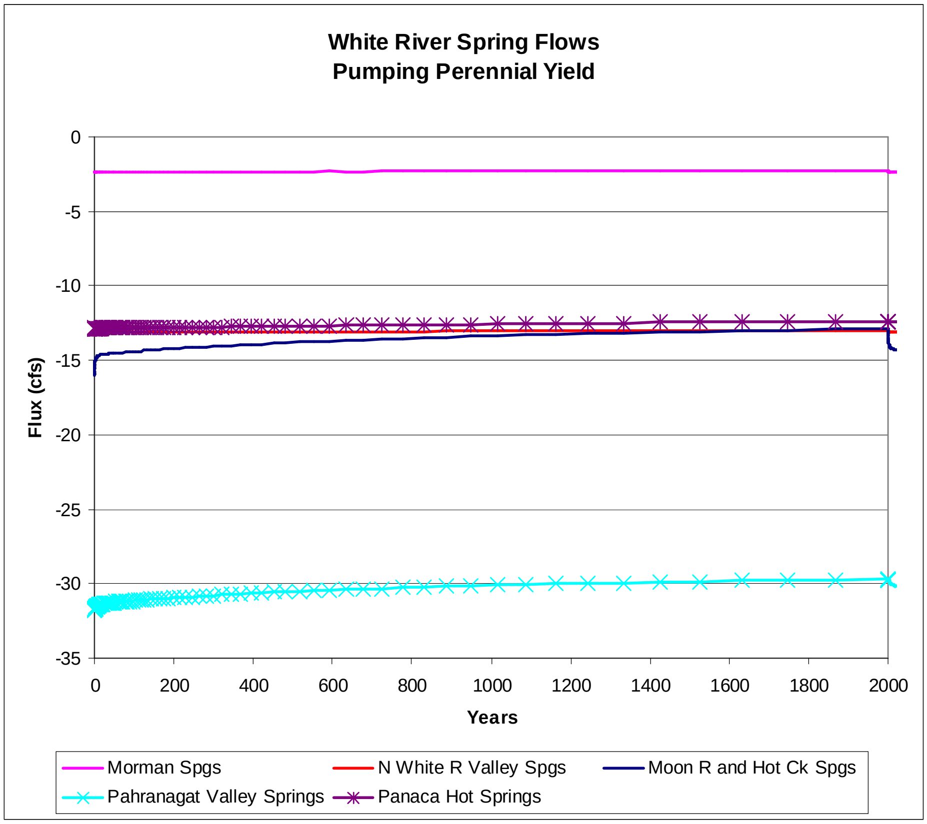


Figure 54: Hydrograph of flux from nearby springs due to pumping the published perennial yield from Cave, Dry Lake and Delamar Valleys. 50 years of pumping.

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. After 2000 years, the springs had decreased by 29 cfs, or 60.4 percent from their pre-development discharge rate. Contrary to many changes in the flux hydrographs discussed above, the spring discharge does not recover quickly; it remains decreased from pre-development rates for more than another 2000 years. 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 55). The 2000-year point is an inflection point at which the rate of increase in lost spring flow begins to decrease. For pumping at the perennial yield rate, totaling 10.36 cfs, after 100 years, the total regional spring discharge had decreased by 2.3 cfs or 22.2 percent (Figure 55). After 2000 years, the spring flow discharge had decreased by 6.1 cfs or 58.9 percent. The percent decreases are very similar for the different pumping rates which reflects the linear nature of the modeled system. After 2000 years of pumping the perennial yield, the total flow lost from the springs was 71 percent of the total that would be lost for the entire 4000 year analysis period; again, the closeness of this value to that determined for pumping the application rate demonstrates the system linearity. In fact, the slight differences probably reflect the different pumping rates for each valley as a percentage of recharge that occurs in the specific valley.

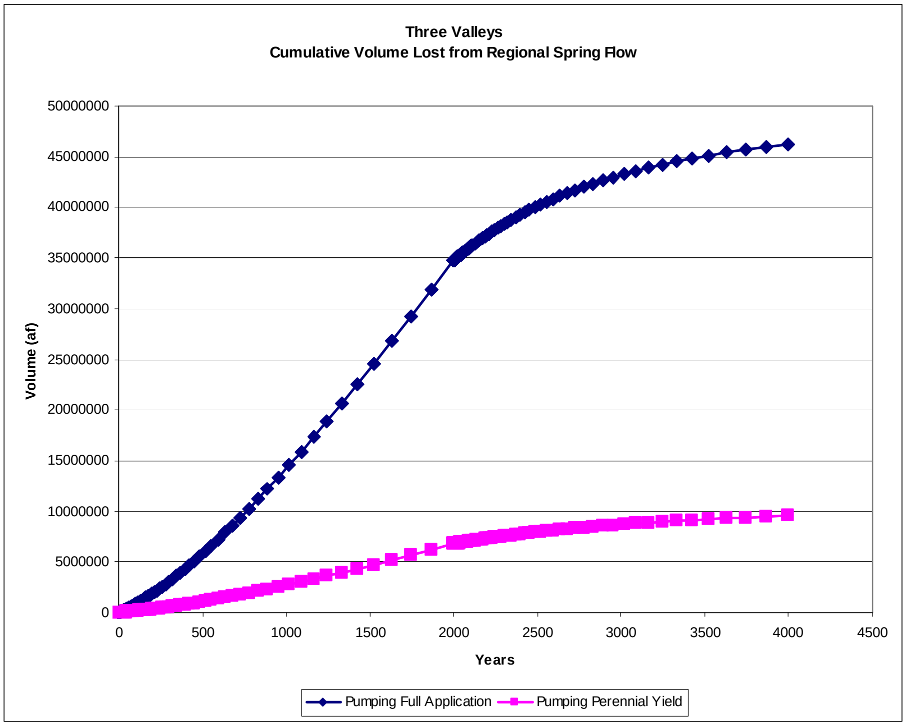


Figure 55: Cumulative lost flow from the regional springs, including the Muddy River springs (which decreased by up to 0.5 cfs).

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

Four major conclusions are obvious from this analysis of flows and changes caused by SNWA's proposed pumping with the US Geological Survey's RASA groundwater model.

- Drawdown at the wells increases quickly while the drawdown cone expands slowly as the amount of transitional storage removed by pumping increases.
- The expanding drawdown cones affects the fluxes across the basin boundaries. Outflow from the targeted basins decreases and inflow increases or is caused to commence.
- The changed interbasin flow and expanding drawdown causes the flow at regional springs downstream from the targeted basins to be decreased. Some springs experience changes very quickly because they lie near a zone of higher transmissivity between the basins. Groundwater modeling shows that the effects of pumping will begin to show at downgradient springs very quickly. Half of the long-term decreases in spring flow in the nearest springs show up in from five to

twenty years. Because of the lag for recovery, the 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.

- Eventually, most of the new groundwater pumpage will cause reduced flow from the regional springs because there are almost no GW ET discharge sites within the valleys. The drawdown in downgradient basins is not sufficient to capture sufficient amounts of GW ET discharge from them. 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 proposal to develop up to 34,500 af/y of groundwater from Cave, Dry Lake and Delamar Valleys vastly exceeds the published perennial yield in the valleys. Further, for Delamar and Dry Lake Valleys, the published perennial yield is substantially overestimated.

The proposed amount exceeds the available water in all of the White River Flow System. 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 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.

Groundwater modeling has shown that the impacts of developing these water rights will expand very rapidly. For pumping SNWA's full applications, drawdown at the Dry Lake and Delamar wells in layer 2 exceeded 200 feet after just 8 years; in Cave Valley it was 40 feet. This drawdown at the wells causes the cone to quickly expand into White River Valley. Low permeability in the center of Cave Valley prevented expansion of drawdown into north Cave Valley. But, substantially more drawdown occurs to the west than to the east as expected from the primary discharge being to the valleys to the west. Topography and low transmissivity prevent the expansion of drawdown to east for 100 years. The 20-foot drawdown approaches but does not fully encompass the springs in White River and Pahranagat Valleys. Even after 2000 years, the 20-foot drawdown will have expanded past the springs but still be less than 20 feet at the springs due to the high transmissivity near those springs.

Drawdown caused by pumping at the perennial yield rate is less than for pumping at the full application rate. The biggest difference is that the drawdown is not as great near the wells for the full application rate. The rather small difference between impacts at more distant sites fro pumping at the full application rate and the perennial yield rate reflects the rapid spread of the drawdown cone and the rapid impact on surrounding springs.

Spring flow reductions occur quickly in response to the expanding drawdown. 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 dependent on the springs. Over 2000 years, the flow from Pahranagat Valley springs reduces by about one-third. Due to drawdown slowly expanding 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 natural 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. Any water that is developed will rapidly affect downstream springs. These applications should be totally denied.

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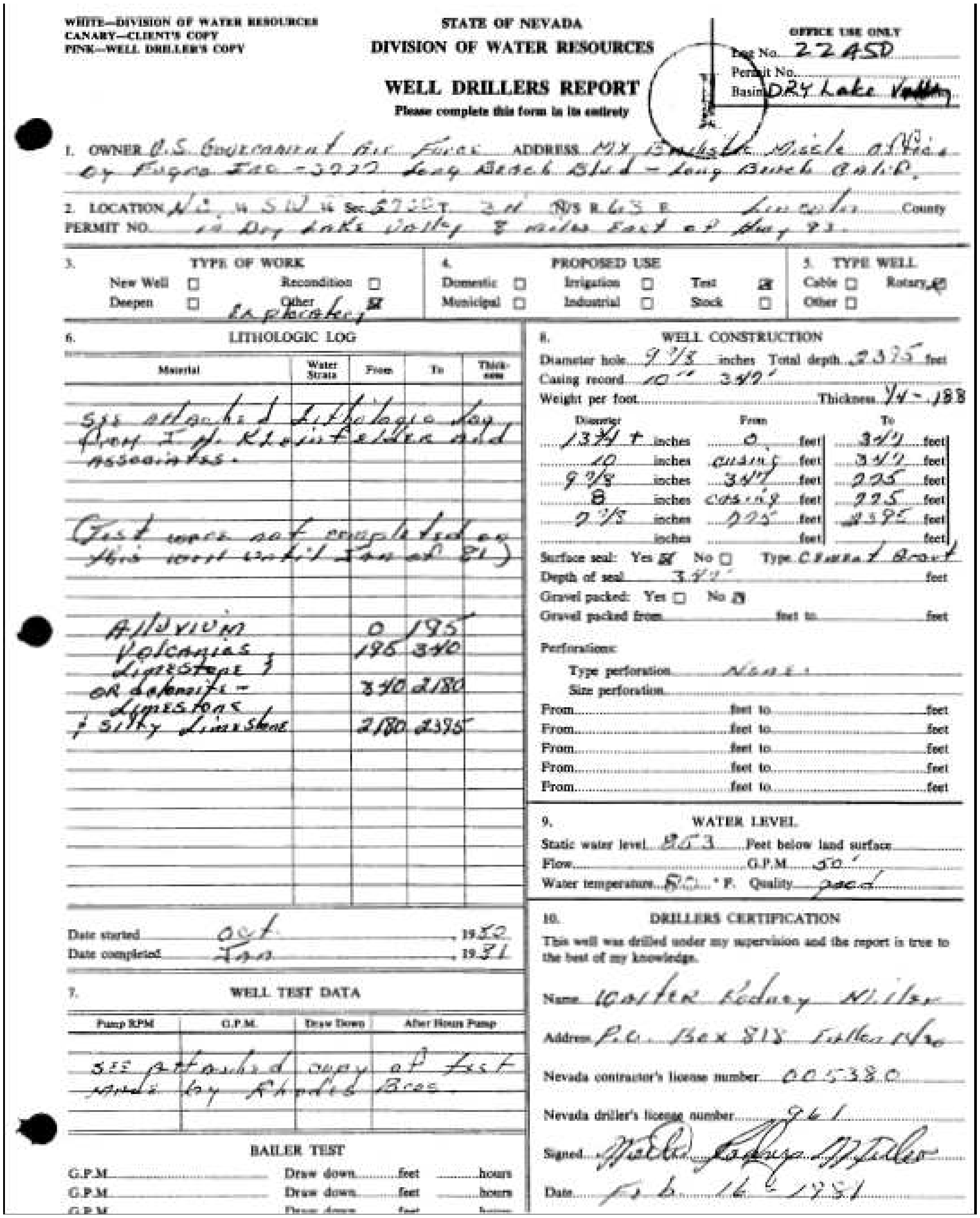
Appendix 1: Well Logs



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 ¼ SW ¼ Sec. 27 T. 3N N/S 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 I. J. Kleinfelder and associates.				
(Test were not completed on this well until Jan of 81)				
Alluvium		0	195	
Volcanics		195	340	
Limestone & OR dolomite - Limestone		340	2180	
& 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" 342'
Weight per foot Thickness ¼ - .188

Diameter	From	To
13¾ + inches	0 feet	342 feet
10 inches	casing feet	342 feet
9 7/8 inches	342 feet	225 feet
8 inches	casing feet	225 feet
7 7/8 inches	225 feet	2395 feet
inches	feet	feet

Surface seal: Yes ☒ No ☐ Type Cement Grout
Depth of seal 342' 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

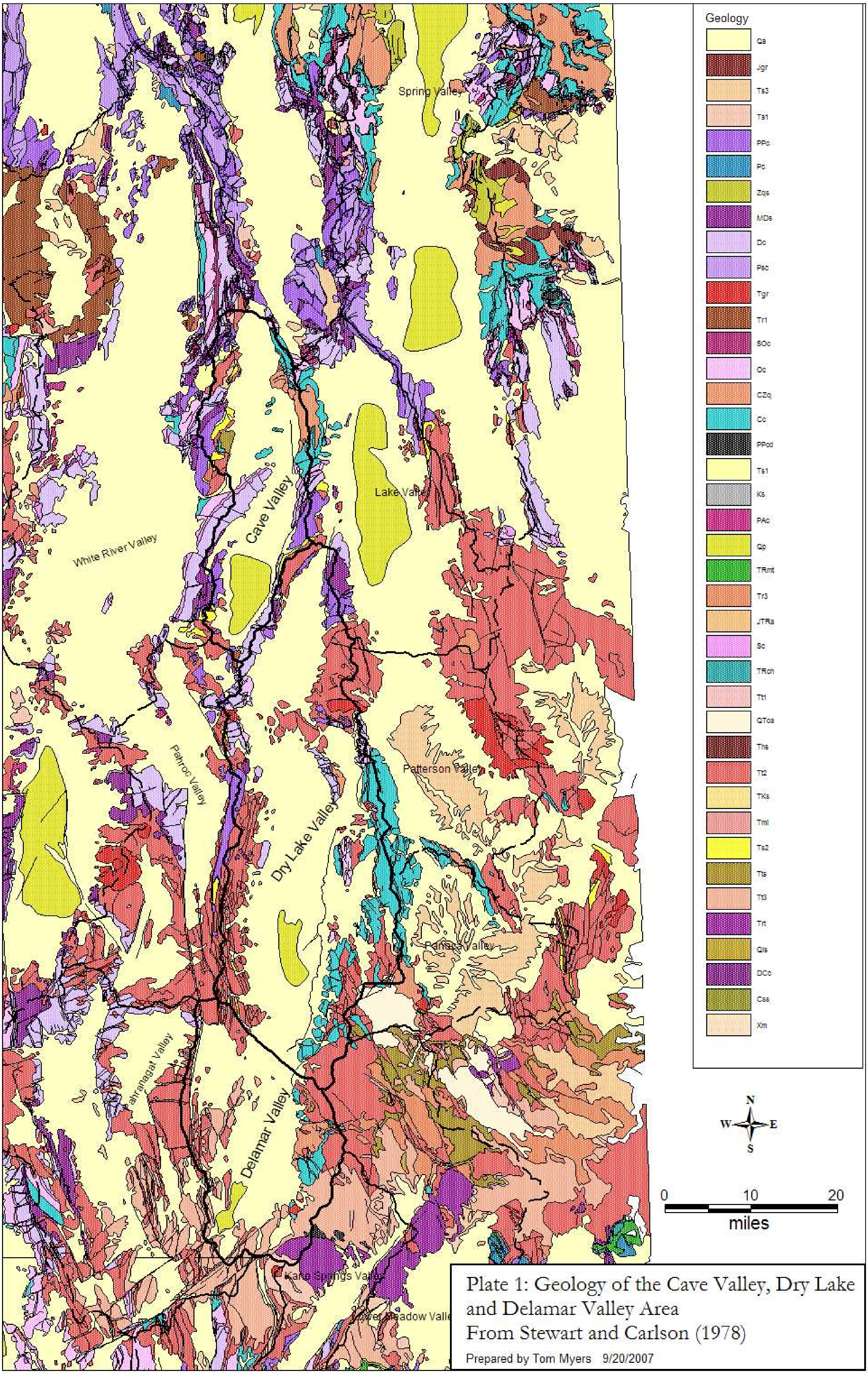


Plate 1: Geology of the Cave Valley, Dry Lake and Delamar Valley Area
From Stewart and Carlson (1978)

Prepared by Tom Myers 9/20/2007