HYDROGEOLOGY OF SPRING, CAVE, DRY LAKE, AND DELAMAR VALLEYS

IMPACTS OF DEVELOPING SOUTHERN NEVADA WATER AUTHORITY'S CLARK, LINCOLN, AND WHITE PINE COUNTIES GROUNDWATER DEVELOPMENT PROJECT

Presented to the Office of the Nevada State Engineer

on behalf of Protestants White Pine County, Great Basin Water Network, et al.

June, 2017

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Date

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Summary

The Southern Nevada Water Authority (SNWA) proposes to extract and export up to 91,200 af/y of groundwater from Spring Valley and up to almost 35,000 af/y of groundwater from Cave, Dry Lake, and Delamar Valleys of eastern Nevada under applications 53987 through 53992, inclusive and 54003 through 54021, inclusive. This report presents evidence which demonstrates that such a development cannot be accomplished without drying valuable groundwater resources and severely impacting existing water rights in the target and downgradient basins.

The analysis herein relies on the simulation of scenarios as considered in the Environmental Impact Statement (EIS) for the Clark, Lincoln and White Pine Counties Groundwater Development Project published by the Bureau of Land Management (BLM) in 2012. These scenarios include pumping the full application quantities from the application points of diversion, as well as pumping lesser amounts from distributed points of diversion. This report also considers whether the proposed pumping would return the groundwater system to equilibrium in a reasonable time, thereby avoiding a permanent groundwater mining situation.

Impacts from the proposed project would be severe and far reaching. Drawdown from all simulated scenarios would exceed tens or hundreds of feet, depending on location within the valleys, would reach into surrounding valleys within tens of years, and would continue to expand essentially in perpetuity. Most springs within Spring Valley would have their flow decreased and underground water rights in the southern three-quarters of the valley would have depth to water increased by hundreds of feet within 70 to 200 years from full project implementation. The pumping would alter interbasin flow, decreasing flow to Snake Valley and drawing groundwater from Steptoe Valley. It could also have significant effects on Big Springs and other springs in Snake Valley. In Cave Valley, Dry Lake Valley, and Delamar Valley, the pumping diverts interbasin flow, because there is no simulated natural discharge within the basins, preventing it from reaching downgradient valleys where most of the groundwater discharge occurs through springs which already are highly appropriated. Pumping in these three valleys would prevent water from reaching downgradient water rights and springs.

When developing a well field, it is essential that the groundwater system come to equilibrium within a reasonable time; otherwise the development would constitute groundwater mining. Coming to equilibrium requires that the pumping capture natural discharge in an amount equal to the pumping. Prior to reaching this equilibrium, the pumping removes groundwater from storage and lowers the water table. If equilibrium is not reached, the drawdown would continue to occur essentially forever, which is the definition of groundwater mining. Even after hundreds of years, scenarios considered herein demonstrate that the pumping would continue to remove groundwater from storage and the drawdown cone would continue to deepen and

expand. As demonstrated by the scenarios generated by the model that SNWA developed and the BLM relied on in the 2012 EIS, pumping these applications cannot be accomplished as proposed, or even at significantly reduced amounts, without causing severely damaging groundwater mining because the system will not come to equilibrium for thousands of years, if ever.

The State Engineer would require SNWA to develop monitoring, management, and mitigation plans to attempt to protect the environment or existing water rights in either the target basins or in downgradient basins or make up for a failure for the system to come into equilibrium. These plans will not be successful without an improved understanding of flowpaths and a commitment to more monitoring points. Analysis of simple monitoring examples show that monitoring points must be far upgradient of the point to be protected to have any chance of providing meaningful protection. Management plans designed to change or stop pumping when drawdown or flows drop below a specified trigger must account for the fact that drawdown will continue for substantial periods of time after changes to pumping are implemented. Due to complexities of the flow systems, it is unlikely that the critical pathway, either horizontally or vertically, can be identified without substantial additional exploration. To date, SNWA has not attempted to determine proper monitoring well placement as demonstrated by its lack of consideration of local conceptual flow models.

Developing these applications will cause irreversible environmental damage to springs and wetlands in Spring Valley and in basins downgradient from the CDD basins in White River Valley, Pahranagat Valley, and Muddy River basin. Developing a perennial yield is not possible without drying groundwater discharge points within a basin or interbasin flow system, and if those are valuable resources, they will be lost. Because the springs in these and in downgradient basins are highly appropriated, the NSE has acknowledged the importance of interbasin flow in supporting those springs and has previously denied applications to protect the flows and water rights in those springs. Consistent with his prior decisions, the NSE should continue to protect those springs and water rights by denying these applications.

Introduction

The Southern Nevada Water Authority proposes to develop up to 91,200 af/y of groundwater in Spring Valley and up to almost 35,000 af/y of groundwater in Cave, Dry Lake, and Delamar Valleys of eastern Nevada to support its proposed Clark, Lincoln, and White Pine Counties Groundwater Development Project. The Nevada State Engineer has scheduled a rehearing of SNWA's Groundwater Development Project applications in these four valleys commencing September 26, 2017. The upcoming rehearing is the result of the Nevada District Court's December 13, 2013, Decision which remanded the State Engineer's 2012 Rulings 6164 through 6167 on these same applications. That Decision directed the State Engineer to reconsider several issues including a recalculation of available water in the subject valleys such that the basins will reach equilibrium in a reasonable time and the preparation of a monitoring, management, and mitigation plan which includes defined standards, thresholds, and triggers so that mitigation of unreasonable effects may be accomplished. Although Rulings 6164 through 6167 did not grant the entire application amounts, in this report I presume the original applications are the starting point for this rehearing. The applications are as proposed and considered in the Final Environmental Impact Statement for the Clark, Lincoln and White Pine Counties Groundwater Development Project (FEIS) prepared by the Bureau of Land Management in 2012.

This report was prepared on behalf of White Pine County, Nevada, the Great Basin Water Network, and the rest of a coalition of protestants to SNWA's water right applications. This report presents evidence that pumping the proposed amount of groundwater will cause substantial drawdown and detrimental effects to the groundwater levels, spring discharge, wetland evapotranspiration (ET), and water rights in targeted and adjoining valleys. This includes evidence that pumping the applications either as filed or under scenarios that have been proposed to lessen the impacts and reach equilibrium more quickly will neither reduce the severity of the harmful impacts to a reasonable level or allow the groundwater systems to reach equilibrium even after thousands of years. This report discusses what is necessary for a monitoring, management, and mitigation (3M) plan and considers SNWA's 2011 3M proposals. Finally, the report also critiques the groundwater model used for the FEIS and 2011 hearing on these applications.

Method of Analysis

This report presents evidence developed from multiple sources to assess the impacts of SNWA's proposed groundwater development in eastern Nevada. Primary sources include reports developed for the FEIS, including reports describing the groundwater flow system and numerical groundwater model for the project (SNWA 2012, 2010b, 2009a and d). After describing the study area and proposed water rights applications briefly, I describe the conceptual flow model (CFM) for the four target basins and the two regional flow systems they are part of. The CFM descriptions summarize recharge, discharge, and interbasin flow estimates as developed by previous researchers. I emphasize the uncertainty in the model's predictions and its problematic reliance on assumptions not well grounded in fact. Also, as part of the CFM review, I present the variations in hydrogeologic parameters associated with each formation.

Next, I discuss the concept of perennial yield (PY) and factors related to its capture, including the time necessary to capture and whether and how the groundwater system comes to equilibrium. I utilized output from the FEIS groundwater model as reported in the FEIS or in SNWA reports (2012, 2010a, b, 2009d) and various model output specific files to describe predicted drawdown and to discuss the length of time the flow system requires to reach equilibrium in each of the relevant scenarios. This discussion shows both the massive extent of drawdown caused by pumping at 200 years from full project buildout and that the system is not even close to equilibrium at that time. Simulated water budgets for the relevant valleys and overall flow systems were obtained from FEIS Appendix F3.3.16. Use of the water budgets as presented in the FEIS does not indicate agreement with the presented fluxes, but only that they are sufficiently accurate to assess the relative magnitude of impacts and the length of time the system will require to reach equilibrium. For example, recharge is the only specified flux, and it was determined external to the modeling. So, while I consider results based on that recharge rate adequate for the analysis conducted in this report, that does not indicate that I agree with the estimated recharge rate.

I present results from FEIS alternatives E and F because they represent an attempt to spread the pumpage around the targeted valleys without pumping from Snake Valley. These alternatives have less drawdown than FEIS alternative B which involved pumping at the application points of diversion. Distributed pumping should capture the discharge more quickly with less drawdown at each diversion point, allowing the system to come to equilibrium sooner. Differences between FEIS alternative B and alternatives E and F were that drawdown near the points of diversion for alternative B was significantly greater than for alternatives E and F because pumping for alternative B did not capture as much discharge to ET/springs as did pumping for alternatives E and F. The difference in capture may be seen by comparing F3.3.16-7B with Table F3.3.16-3B in FEIS Appendix F3.3.16. Drawdown at the points of diversion under alternative B is very high and would be infeasible in practice.

The FEIS no action alternative as analyzed includes existing pumping in Snake Valley, although interbasin effects of that pumping into Spring Valley or other project valleys should be minimal. The FEIS no action alternative is the base for comparison with project pumping. I also discuss this in reference to pumping to equilibrium questions.

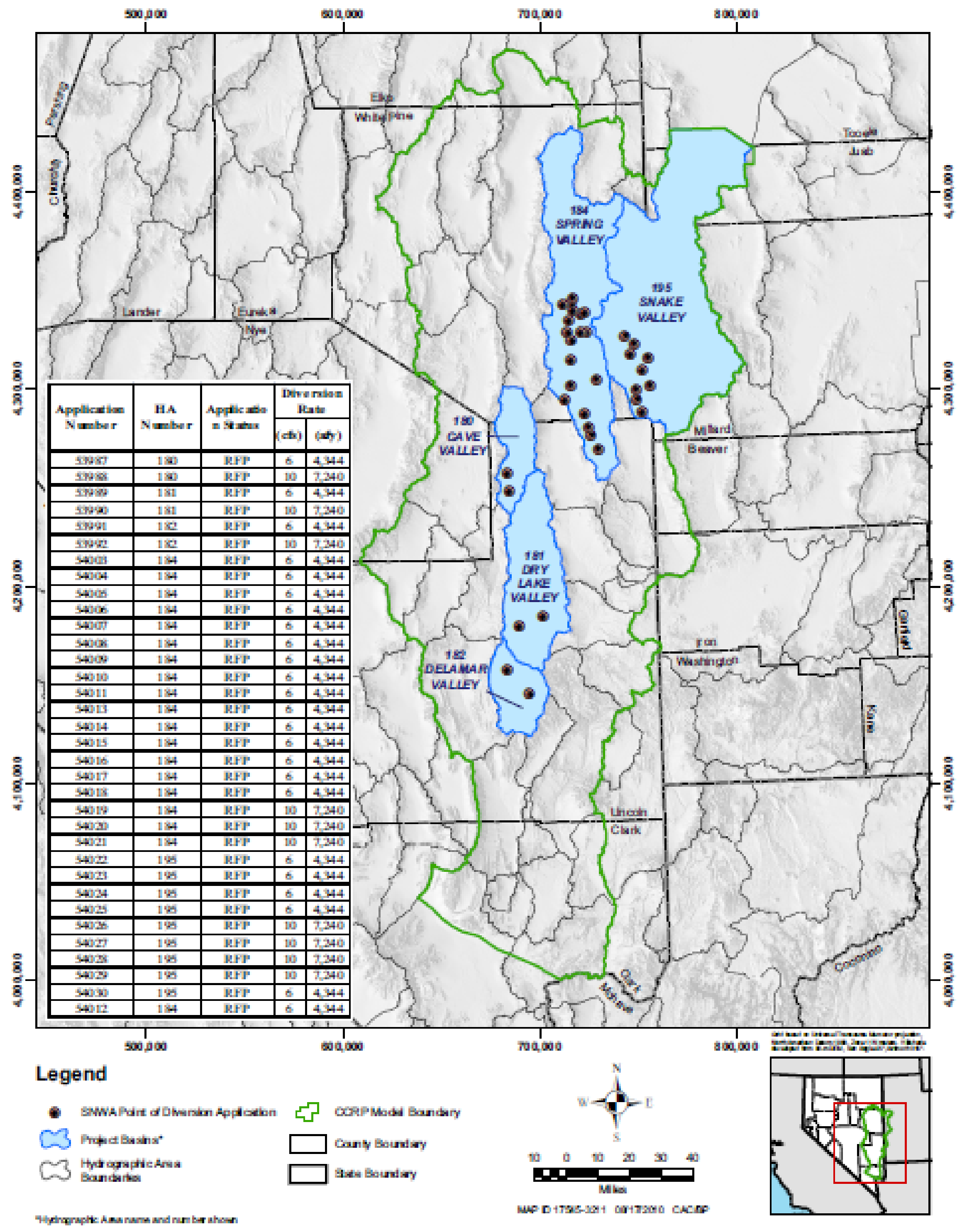
This report assesses the 3M approach proposed by SNWA in relation to generally accepted requirements for 3M plans. After some basic theory, I review the 3M proposal presented for the FEIS, which was the same as what was presented in the 2011 State Engineer hearings on these applications.

This report also reviews drawbacks of the 2011 SNWA groundwater model which was used for the FEIS. Presumably, the model will have been updated for this hearing, and I will review the changes as part of a future rebuttal report.

Study Area

There are two parts to the study area. First are the four valleys containing the points of diversions of SNWA's water rights applications being considered in this remand hearing. These targeted valleys are Spring, Cave, Dry Lake, and Delamar Valleys (Figure 1). Spring Valley is part of the Great Salt Lake Flow System (GSLFS), and the other three are part of the White River Flow System (WRFS) (Figure 2). Throughout this report, I refer to the four valleys as the target valleys.

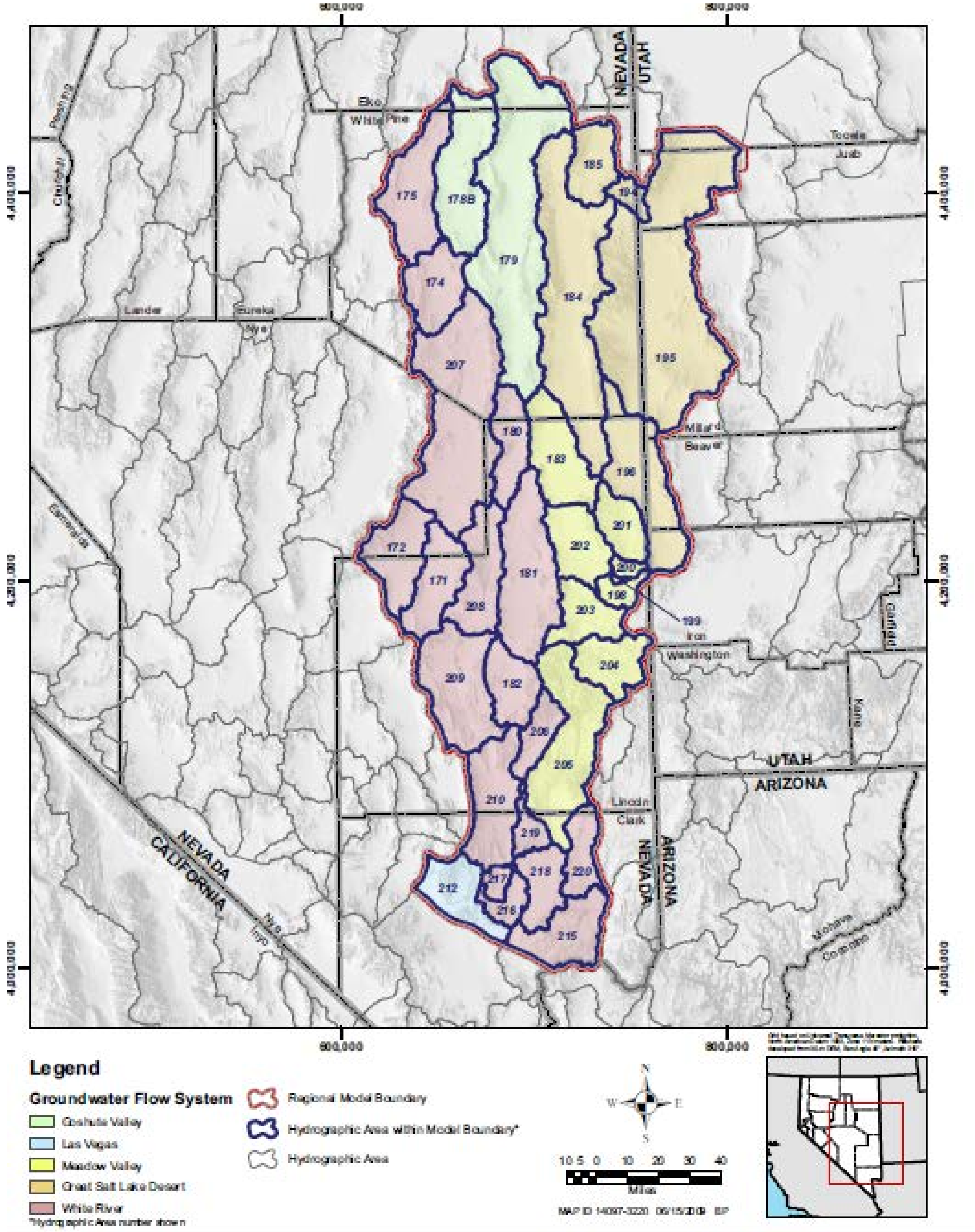
The second part of the study area is the Central Carbonate Rock Province (Central Carbonate Flow System or CCFS) as analyzed in the FEIS. The full area labeled in Figure 2 shows the outline of the CCFS as well as the regional flow systems within the CCFS.



Application Number	HA Number	Application Status	Diversion Rate	
			(cfs)	(afy)
53987	180	RFP	6	4,344
53988	180	RFP	10	7,240
53989	181	RFP	6	4,344
53990	181	RFP	10	7,240
53991	182	RFP	6	4,344
53992	182	RFP	10	7,240
54003	184	RFP	6	4,344
54004	184	RFP	6	4,344
54005	184	RFP	6	4,344
54006	184	RFP	6	4,344
54007	184	RFP	6	4,344
54008	184	RFP	6	4,344
54009	184	RFP	6	4,344
54010	184	RFP	6	4,344
54011	184	RFP	6	4,344
54013	184	RFP	6	4,344
54014	184	RFP	6	4,344
54015	184	RFP	6	4,344
54016	184	RFP	6	4,344
54017	184	RFP	6	4,344
54018	184	RFP	6	4,344
54019	184	RFP	10	7,240
54020	184	RFP	10	7,240
54021	184	RFP	10	7,240
54022	195	RFP	6	4,344
54023	195	RFP	6	4,344
54024	195	RFP	6	4,344
54025	195	RFP	6	4,344
54026	195	RFP	10	7,240
54027	195	RFP	10	7,240
54028	195	RFP	10	7,240
54029	195	RFP	10	7,240
54030	195	RFP	6	4,344
54012	184	RFP	6	4,344

Figure 1-2
Location of Project Basins and Current Points of Diversion

Figure 1: Portion of Figure 1-2 (SNWA 2010b) showing proposed project wells in the target basins as well as in Snake Valley.



e: See Plate 1 for more details.

Figure 2-2
Regional Flow Systems within Study Area

Figure 2: Figure 2-2 from SNWA (2009a) showing the overall Central Carbonate Rock System, regional flow systems and individual basins.

Water Rights Applications and Proposed Pumping Scenarios

The remand hearing for which this report has been prepared is to reconsider the SNWA water rights applications originally considered by the State Engineer in hearings in 2006, 2008, and 2011, as reflected in Figure 1, above. Following the 2011 hearing the State Engineer issued Ruling Nos. 6164, 6165, 6166, and 6167 (for Spring, Cave, Dry Lake, and Delamar Valleys, respectively), which granted 61,127 af/y in Spring Valley subject to staged development, 5235 af/y in Cave Valley, 11,584 af/y in Dry Lake Valley, and 6042 af/y in Delamar Valley, for a total grant of 83,988 af/y. The State Engineer's 2012 rulings (Ruling Nos. 6164, 6165, 6166, and 6167, for Spring, Cave, Dry Lake, and Delamar Valleys, respectively) that followed the 2011 hearing granted 61,127 af/y in Spring Valley subject to staged development, 5235 af/y in Cave Valley, 11,584 af/y in Dry Lake Valley, and 6042 af/y in Delamar Valley, for a total grant of 83,988 af/y. These rulings required biological and hydrological monitoring plans for each valley.

One reason for the remand from the Nevada District Court is that simulated pumping from the application points of diversion did not reach equilibrium in a reasonable period, as described in the next section. The proposed action in the FEIS was an option to pump up to the full application amounts from points distributed about the basins, including Snake Valley because the FEIS considered the four basins analyzed here and Snake Valley. The analysis presented in this report follows the reasoning of the FEIS and focuses on pumping scenarios that ostensibly could allow the system to reach equilibrium sooner with potentially less impact. As noted above, I have adapted much of the analysis presented here from the FEIS. Scenarios mentioned in this report included the following.

No action: This alternative would assume none of the proposed project's water rights would be developed, but that existing pumping would continue. The total pumpage for the entire CCFS simulated during the no action alternative is 104,000 af/y, and includes 8000 af/y associated with SNWA agricultural properties in Spring Valley and 11,300 af/y for permits held by Tuffy Ranch Properties, LLC. During simulations, pumpage other than SNWA's applications from Spring Valley was 9000 af/y.

Alternative B: This alternative would pump the full application amount from the proposed points of diversion (Figure 1).

Alternative E: This alternative would pump up to 78,755 af/y from distributed locations within Spring, Delamar, Dry Lake, and Cave Valleys, as shown in Figure 2. The total pumped from Spring, Cave, Dry Lake, and Delamar Valleys would be 60,000, 4700, 11,600, and 2500 af/y, respectively, or a little less than granted by the State Engineer in 2012, also as shown in Figure 3.

Alternative F: This alternative would pump up to 114,129 af/y from distributed locations within the same four valleys, also as shown on Figure 3. It differs from Alternative E only in the amount pumped. The amount pumped from Spring, Cave, Dry Lake, and Delamar Valleys would be 84,400, 11,500, 11,600, and 6600 af/y, respectively, or close to the amount requested in the full applications. The full rate of pumpage would be reached 75 years after full build-out.

Full buildout for the proposed action would occur in 2049. For alternatives E and F, full buildout occurs in 2042 and 2049, respectively (SNWA 2012, 2010b). The longer period for alternative F presumably is because it is for a higher pumpage and therefore requires more wells and pipeline. The simulations ran for 200 years beyond full buildout, or up to 2249. The no action scenario simulation ran from 2005 to 2049. The graphs used for analyzing basin water budgets reflect these time frames, although the water budget tables specify full buildout and 75 or 200 years after full buildout. Therefore, the graphs reflect times that differ by seven years due to differing time to full buildout.

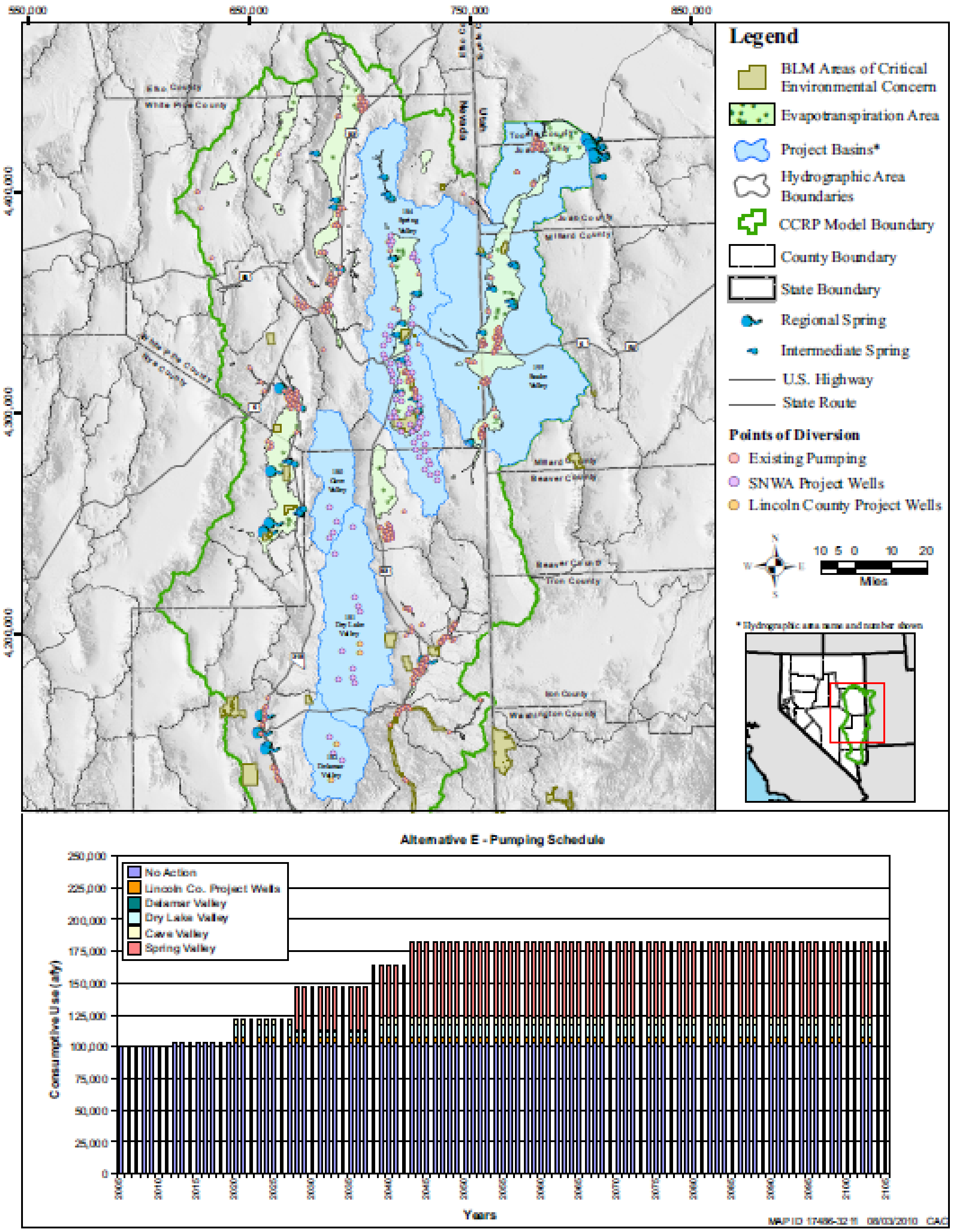


Figure 3-8
Pumping Distribution for Alternative E - Delamar, Dry Lake, Cave, and Spring Valleys

Figure 3: Figure 3-8 from the FEIS numerical modeling report (SNWA 2010b) showing pumping locations and amounts for Alternative E.

Conceptual Flow Model

A CFM is a description of the flow sources, sinks, and pathways in a hydrologic system. For a groundwater system, a CFM describes the sources of recharge. Interbasin flow would include two or more basins with groundwater flow entering from upgradient basins and flowing to downgradient basins. Figure 4 presents a generalized depiction applicable to an individual basin without interbasin flow and a flow system with interbasin flow.

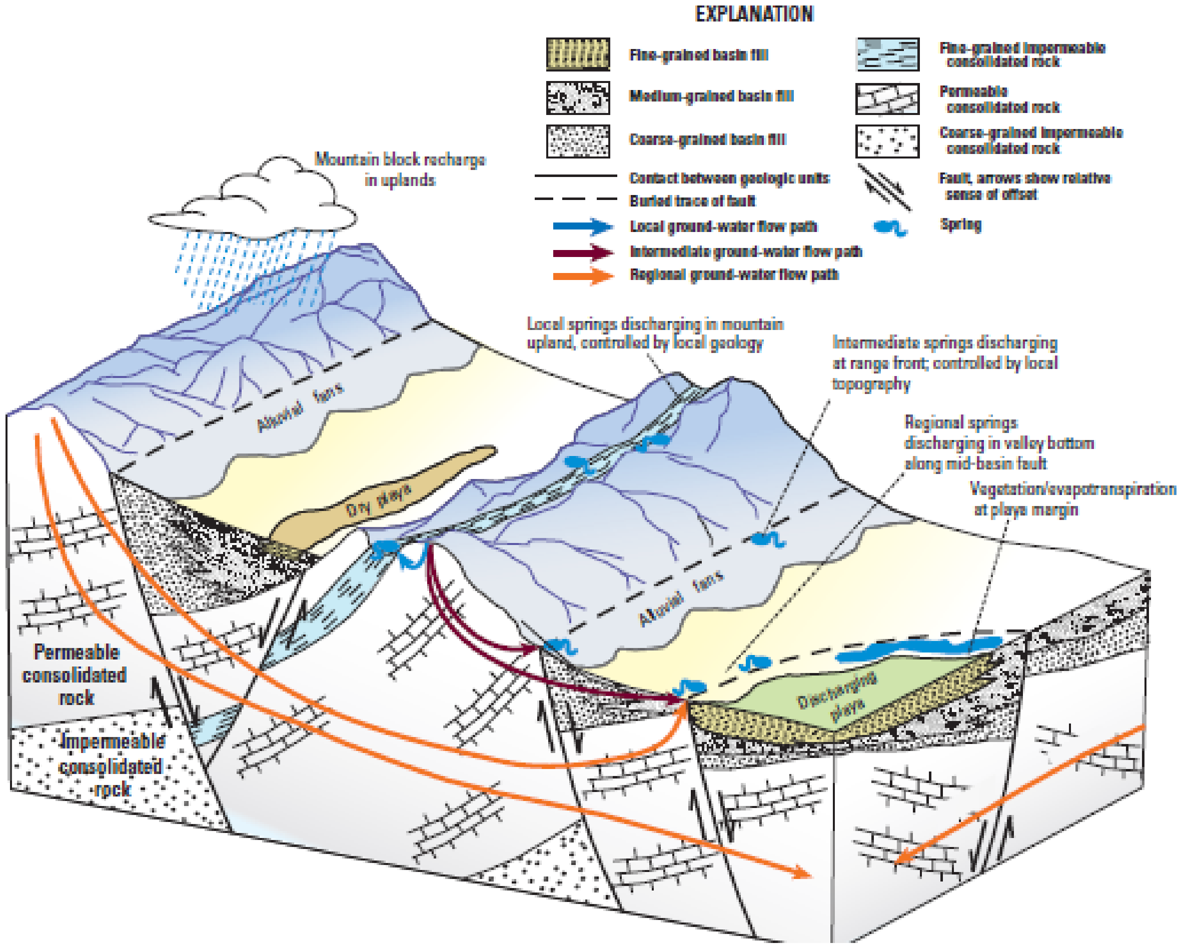


Figure 4: Figure 16 from Welch et al (2008) showing conceptual flow systems for the Great Basin.

Mountain precipitation recharges in the mountains where the geology is conducive, such as fractured carbonate or volcanic rock, or runs off to potentially recharge at the mountain front, typically on the alluvial fans (Wilson and Guan, 2004). Spring Valley (Figure 5) contains a substantial amount of carbonate rock in the Schell Creek Range between Steptoe and Spring Valley, as well as between the southern and northern portions of Spring Valley and Snake Valley. While most of the Fortitude Range is volcanic rock, the northern portion of the range between Spring and Lake Valley is carbonate rock. The highest rates of in-place recharge occur in the south end and middle portion of the Snake Range and in the northern half of the Schell Creek Range where precipitation is highest and there is carbonate rock (Figure 5). Almost no recharge occurs in the mountains where the outcrops are siliciclastic or intrusive rock (Figure

6). These estimates are made by completing a soil water balance, the basin characterization model (BCM) for model cells distributed across the basins (Flint and Flint 2007). The method uses simulated climate data with broad-scale soil and geologic parameter estimates, to make it a physically based model that is applicable at any given point.

Water that runs off mountains may recharge at the mountain front. Perennial streams that reach the valley bottom also recharge on the alluvial fans. Often in the Great Basin, groundwater discharge into streams and springs will recharge downstream, becoming secondary recharge.

The basin fill water levels in Spring Valley slope generally to the north from a groundwater divide in the southern third of the valley, with a lowest contour of 5600 feet AMSL being open to the north (Figures 7 and 8). At this point, the water surface level is about 4800 to 4900 ft AMSL directly to the east in Snake Valley. At the south end of the valley, the 5800 ft contour forms a groundwater ridge from which the slope is to the southeast (Figure 8).

Groundwater contours in the carbonate aquifer are generally highest in the Schell Creek Range on the west side of Spring Valley (Figure 9). The contours on the west side of Spring Valley are about 6000 feet and on the east side of the Snake Range about 5500 feet, which indicates the presence of a gradient from west to east.

Basin fill thickness, or depth to bedrock, is highly variable through Great Basin valleys, including Spring Valley. Spring Valley has three primary troughs, with the deepest, up to 15,000 feet, being in the north centered between the Antelope and north Schell Creek Ranges (Figure 10). A long trough exceeding 3000 feet extends south to about Rattlesnake Knoll, which is structurally high, effectively dividing the valley into southern and northern portions (Watt and Ponce, 2008). South of this high point, the fill thickens to at most 3000 feet.

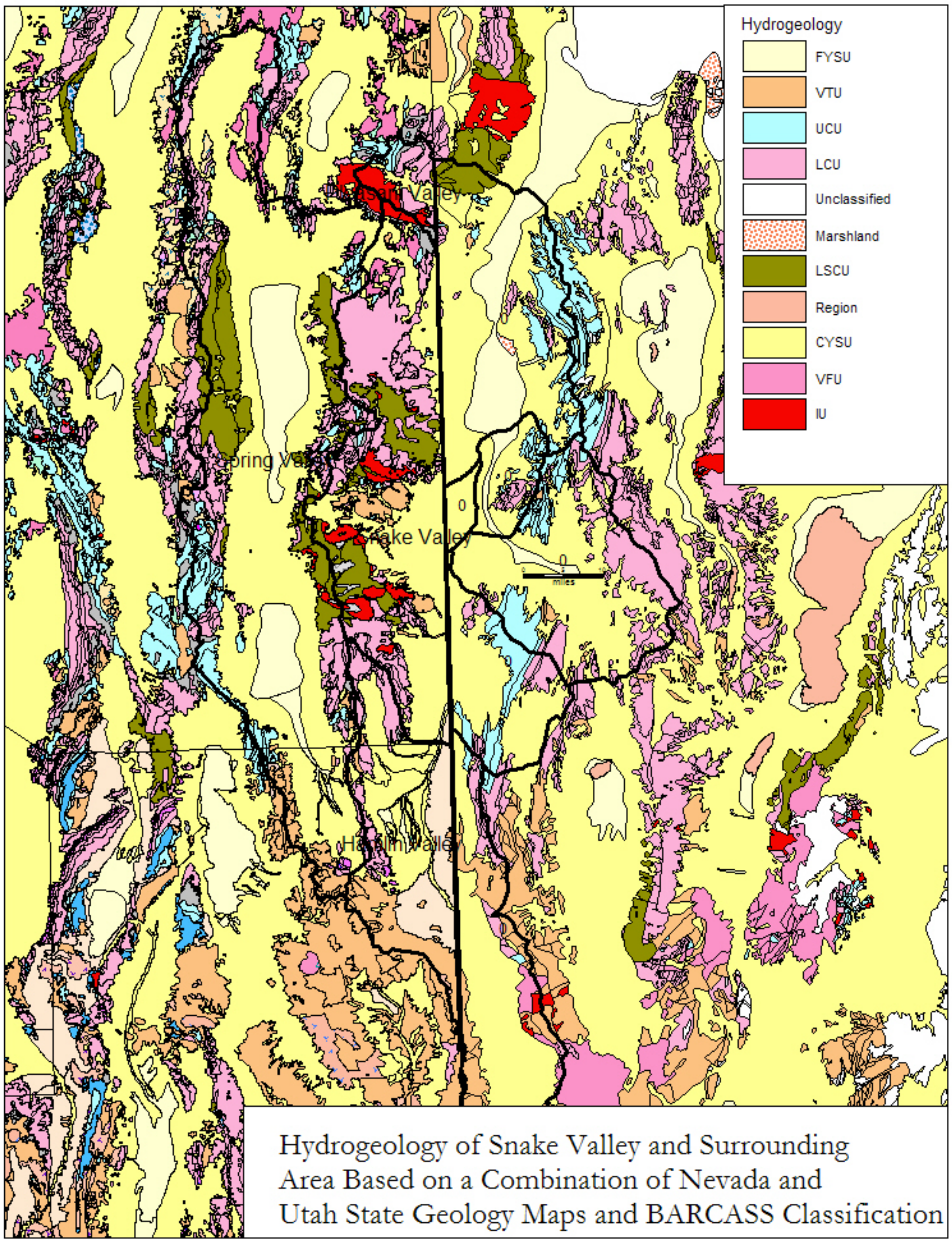
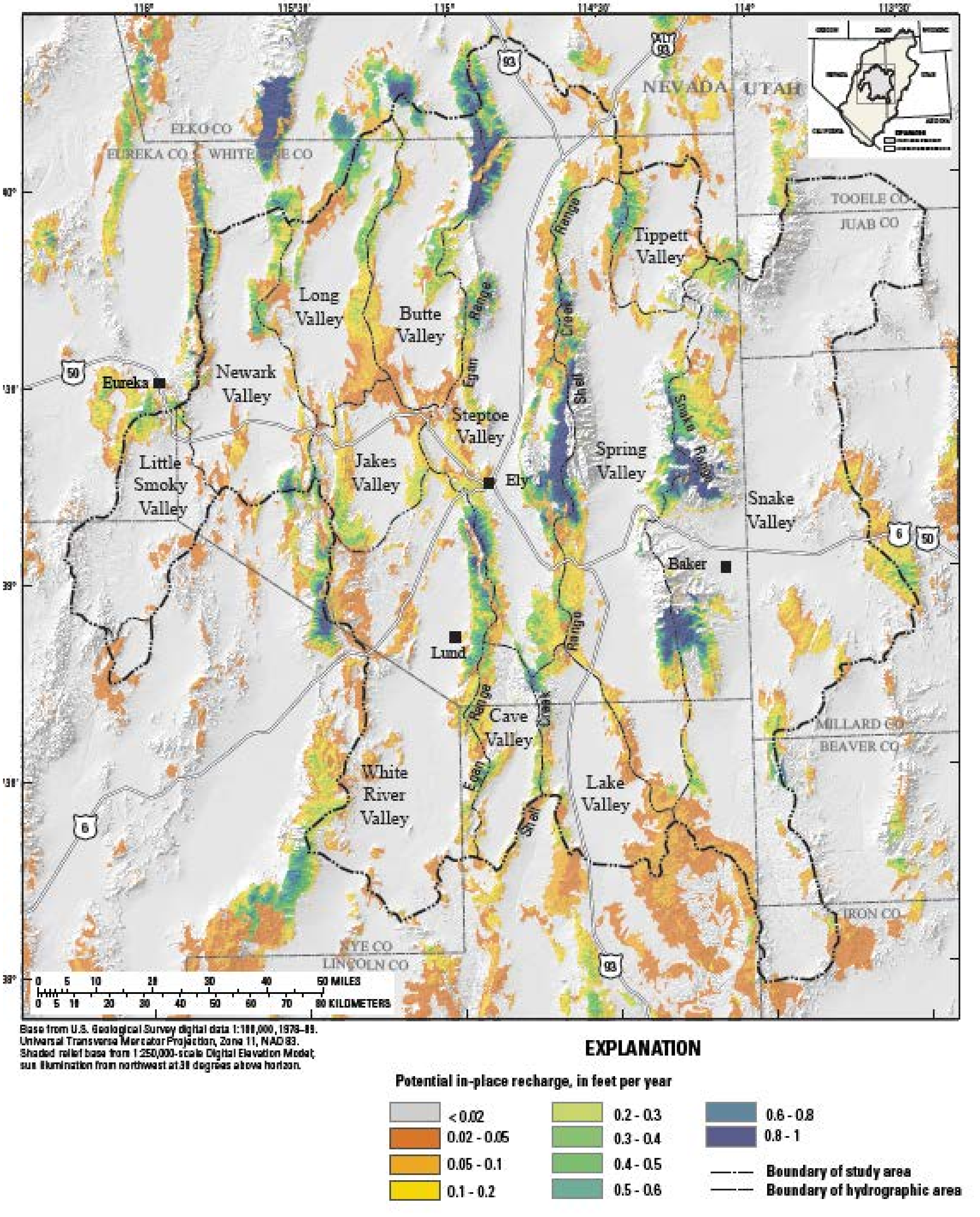


Figure 5: Figure 9 from Myers (2011b). Hydrogeology of Spring and Snake Valley study area. See Table 1 for a description of the hydrogeology. Geology base prepared from Crafford (2007) and Hintze et al (2000).



Base from U.S. Geological Survey digital data 1:100,000, 1978–89. Universal Transverse Mercator Projection, Zone 11, NAD 83. Shaded relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon.

Figure 6. Potential in-place recharge enerated using the Basin Characterization Model, Basin and Range carbonate-rock aquifer system study area and vicinity, Nevada and Utah.

Figure 6: Figure 6 from Flint et al (2007) showing the distribution of potential in-place recharge around many of the basins in the CCFS, including Spring and Snake Valleys. Recharge is based on the basin characterization method.

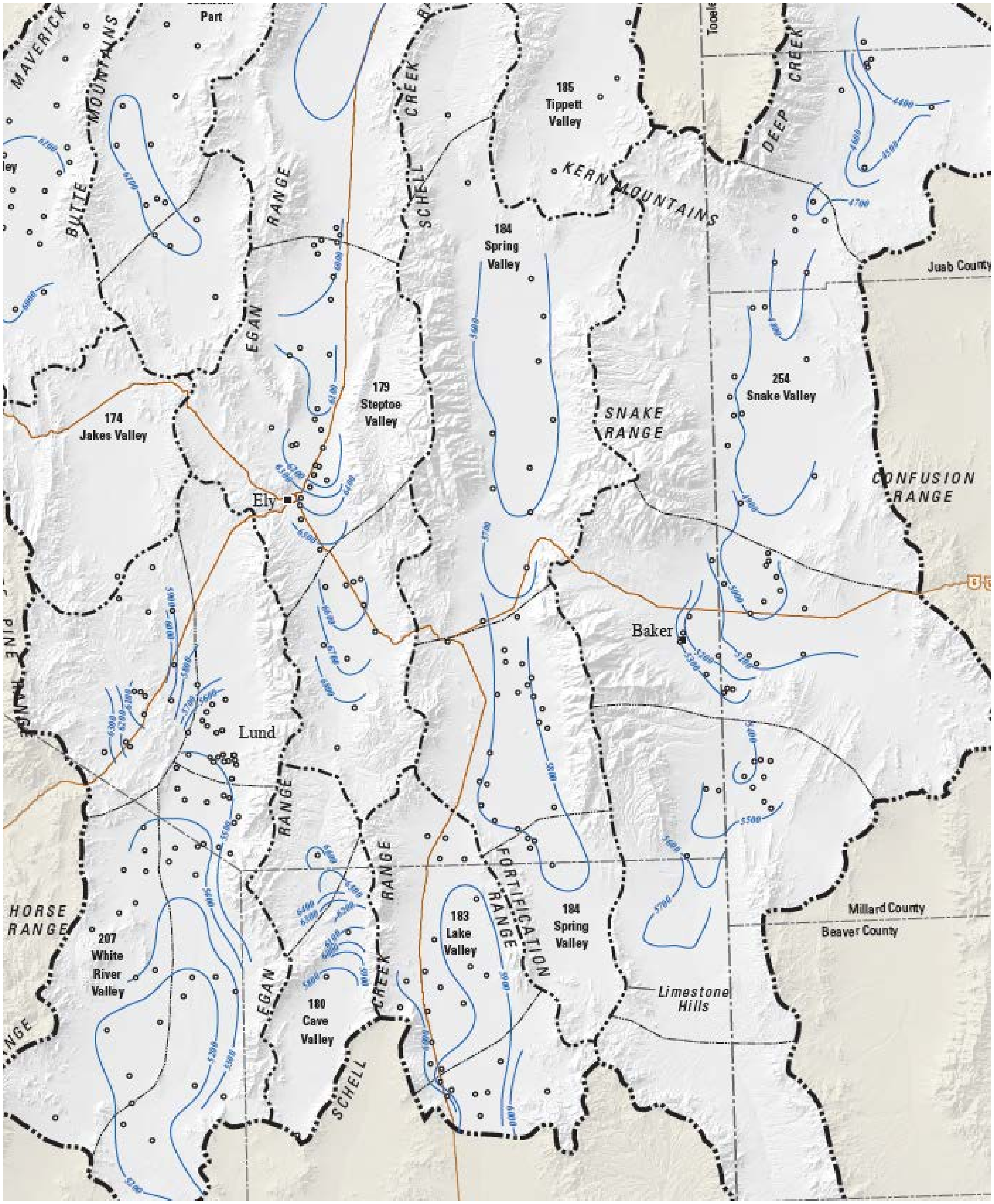


Figure 7: Snapshot of portion of Plate 2 (Welch et al 2008) showing basin fill water levels for Spring and Cave Valleys, and adjoining valleys including Snake Valley and White River Valley.

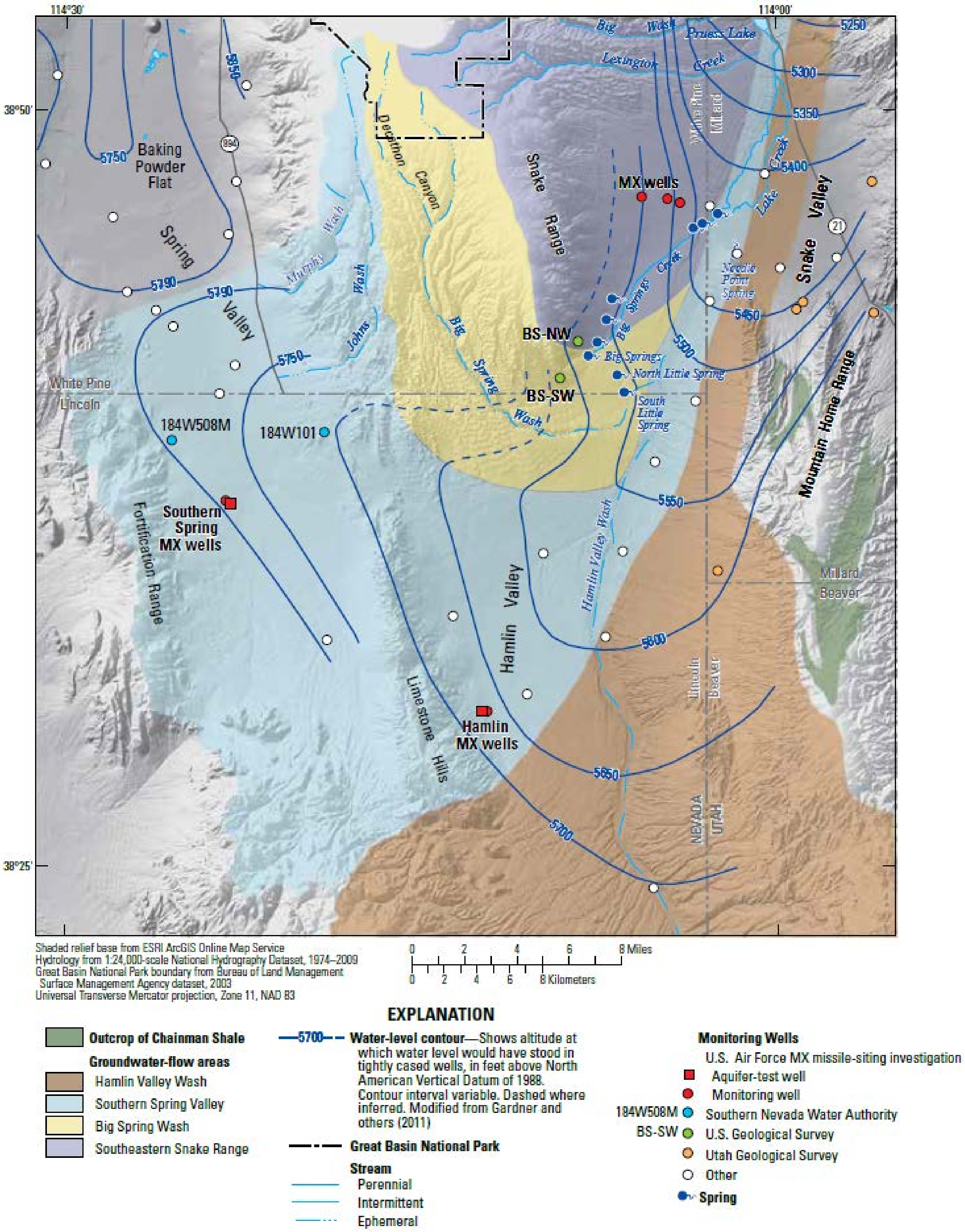


Figure 8: Snapshot of Figure 69 (Prudic et al 2015) showing a groundwater ridge in the southern third of Spring Valley and the conceptualization of groundwater flow from Spring Valley to Snake Valley and from Big Springs.

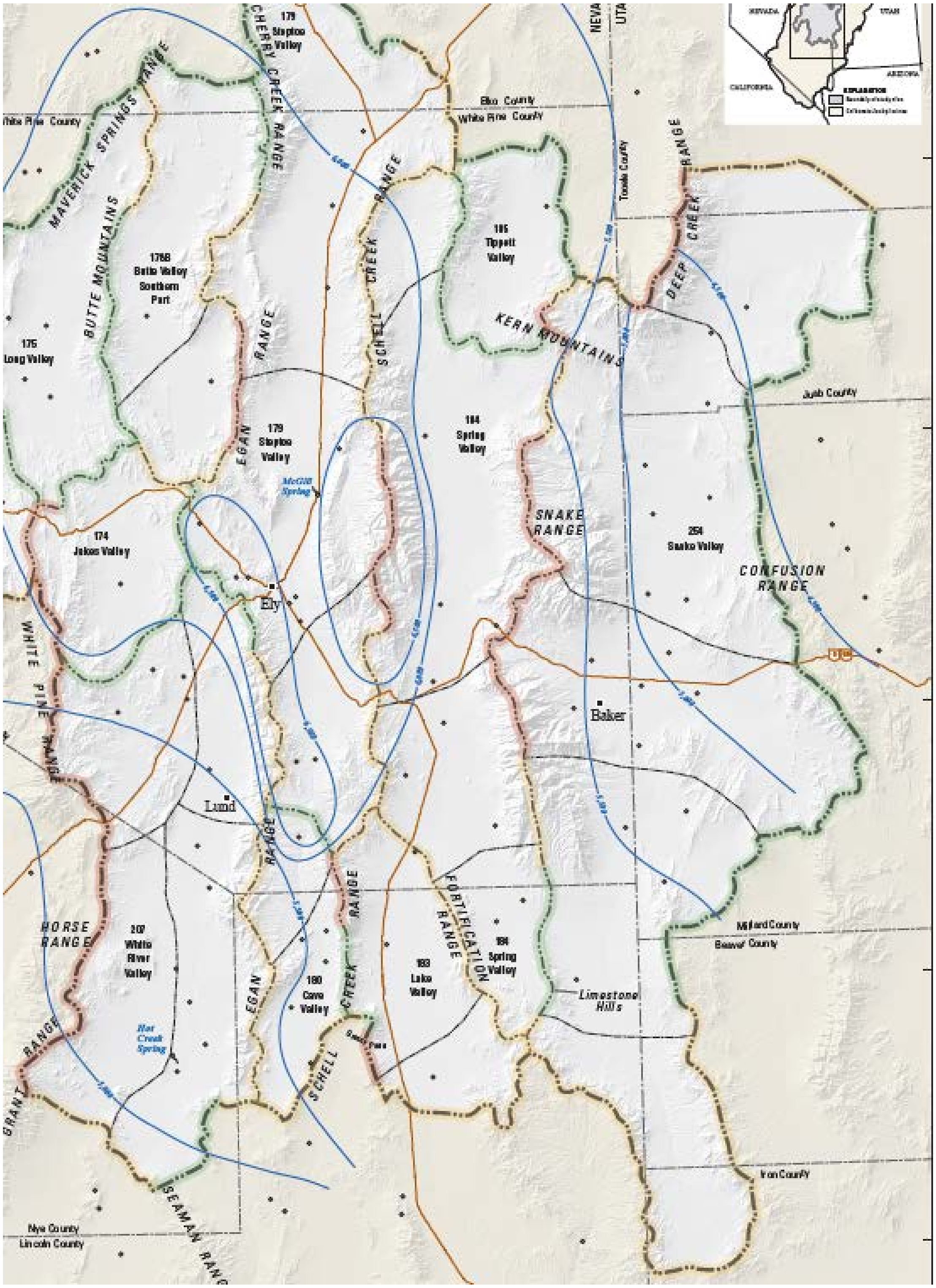
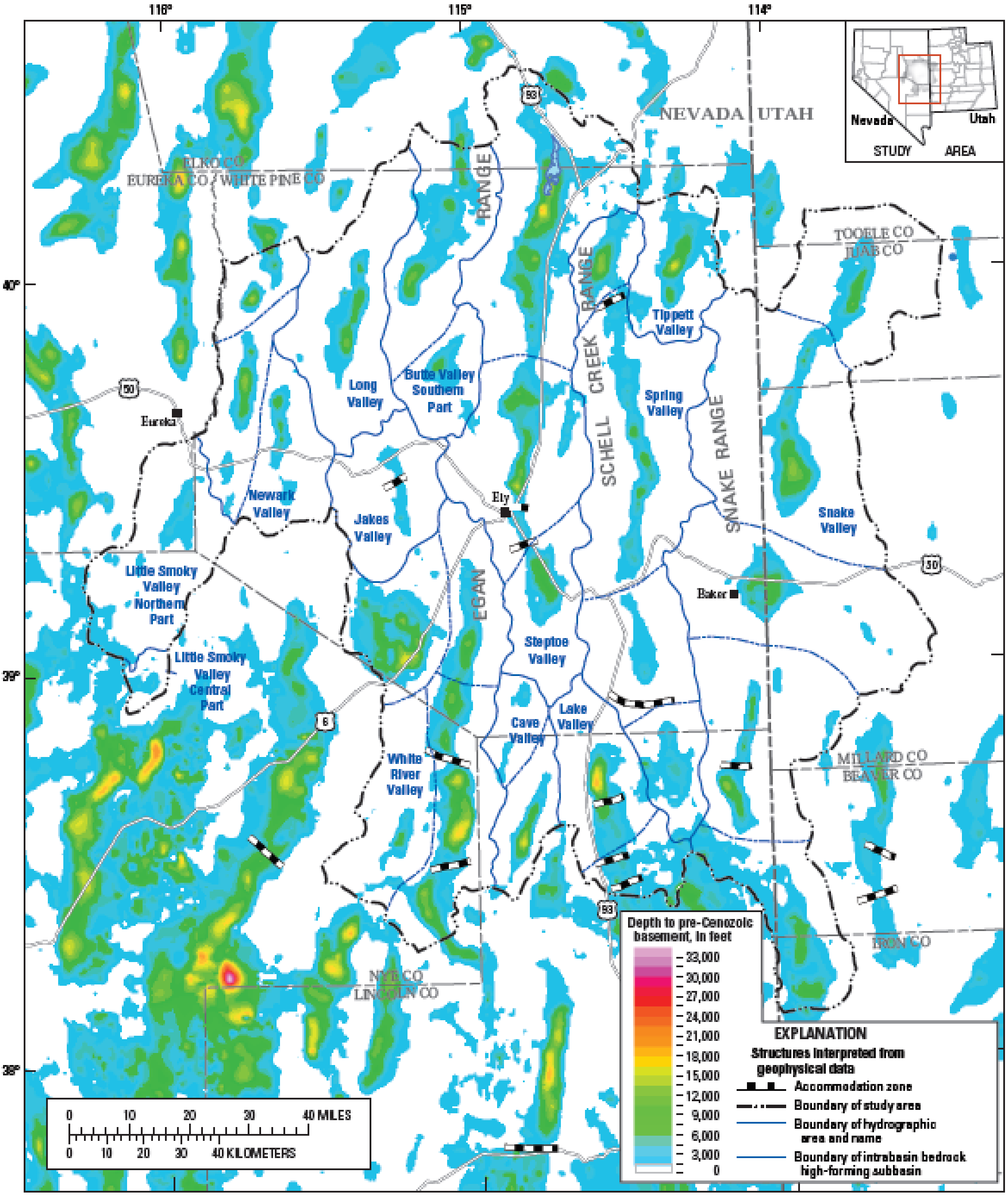


Figure 9: Snapshot of portion of Plate 3 (Welch et al 2008) showing carbonate water levels for Spring and Cave Valleys, and adjoining valleys including Snake Valley and White River Valley.



Base from U.S. Geological Survey 1:100,000-scale digital data, 1979–84.
1:1,000,000 scale watershed boundaries from U.S. Geological Survey digital data.
Universal Transverse Mercator Projection, Zone 11, NAD83.

Caldera boundaries modified after Williams and others (1997), Loucks and others (1989), Raines and others (1996), Workman and others (2002), and Gans and others (1989).

Figure 8. Depth-to-bedrock map of the study area showing interpreted lineaments or features, Basin and Range carbonate-rock aquifer system study area, Nevada and Utah.

Figure 10: Figure 8 from Welch et al (2008) showing the depth to bedrock, or thickness of basin fill, through the valleys of eastern Nevada.

This report does not present an independent estimate of recharge to and discharge from Spring Valley. Recharge is impossible to measure, so it has been estimated using water balance methods (setting recharge equal to discharge), BCM methodology as discussed above, chloride balances method, and isotopes. The water balance methods require an estimate of spring flow, groundwater ET, and interbasin flow from the basin, while assuming steady state (more on that below). The average recharge estimate is about 80,600 af/y, with a coefficient of variation of about 20% (Table 1). The lowest estimate was 56,000 af/y using the BCM method and a long-term climate series (Flint et al 2004); the Flint et al (2004) estimate using an average year was about 10,000 af/y higher which suggests that recharge during dry years is proportionally less than during wetter years. BCM calculations for the entire Great Basin system (Heilweil et al 2011) demonstrated a large year to year variability, as well.

Groundwater discharge occurs in two ways: as evapotranspiration (ET) and/or as spring/stream discharge. Interactions between surface and groundwater complicate the consideration of discharge - spring discharge frequently percolates back into the ground and supports groundwater ET or may form a second spring. Percolation of spring flow is secondary recharge. It is important to avoid double counting spring discharge and ET of the same water. It is likely that estimates which add spring flow and groundwater ET estimates to obtain basin discharge are too high due to double counting in basins such as Spring Valley, which has many springs at the base or the top of fans that discharge into short channels which support phreatophytes downstream.

Welch et al (2008) estimated groundwater discharge by basin based on the ET distribution shown in Figure 11. Their groundwater discharge estimate for Spring, Snake, Steptoe, and Tippett Valleys was 75,600, 132,000, 101,500, and 1700 af/y, respectively. These values are total discharge including spring discharge because the spring flow goes to the various types of discharge and some of the ET discharge is from channels below the springs. The average Spring Valley discharge from various previous studies is 77,600 af/y with a coefficient of variation of about 10% (Table 1). The relatively low variability, compared with recharge estimates, is due to the similarity in methods among studies. Each study estimated a rate for each vegetation type and multiplied it by an area estimated with remote sensing to estimate total groundwater ET, and measured spring flow. Most of the Spring Valley ET occurs in the middle two-thirds of the valley (Figure 11), the section west of the entire length of the Snake Range (Welch et al, 2008).

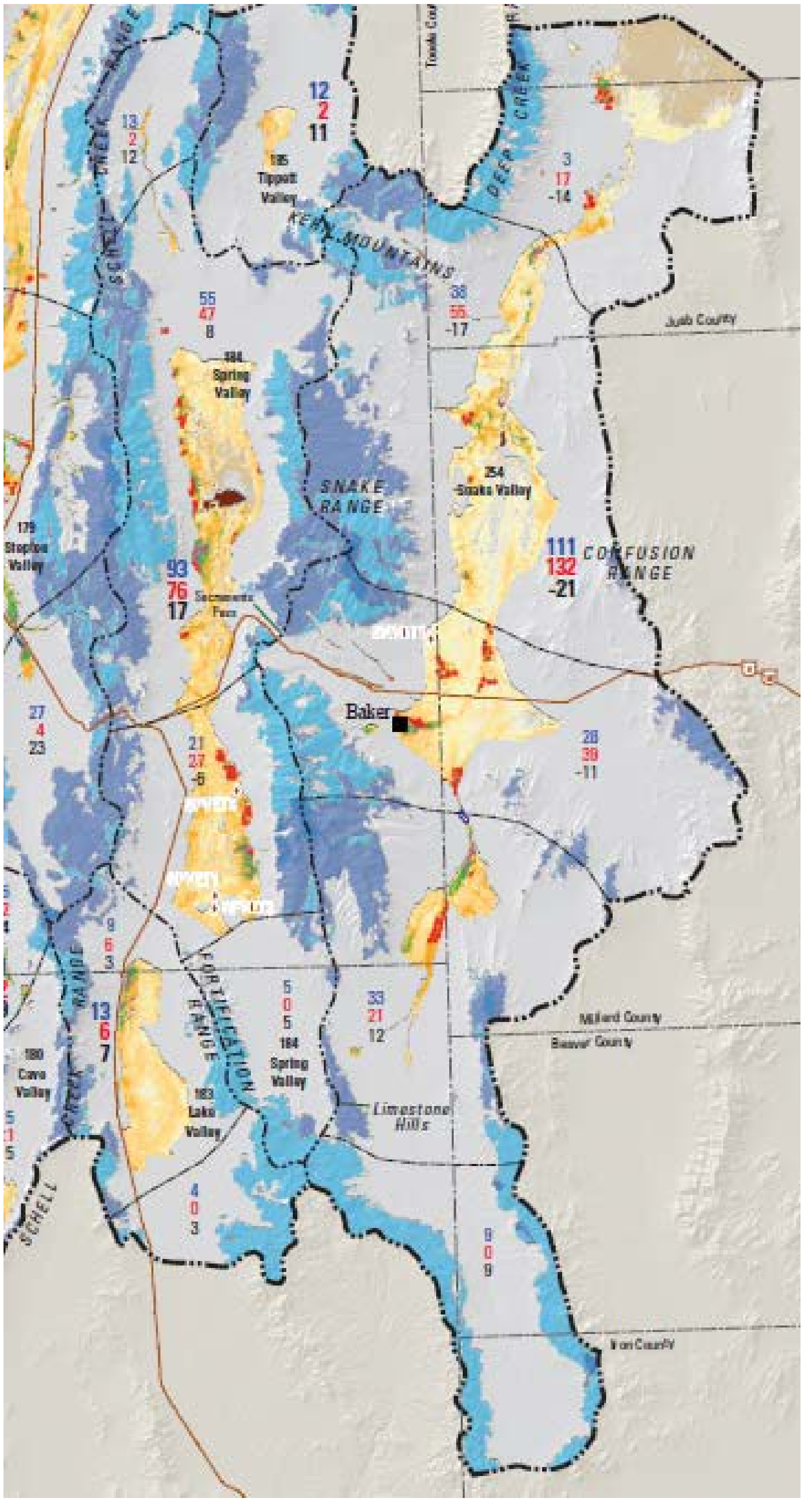


Figure 11: Snapshot of Welch et al (2008), Plate 4, showing distribution of evapotranspiration and locations of in-place recharge or runoff. The ET shading is from about 0.6 ft/y, tan for playa, through yellow (shrubs) to green (marshland) at over 4 ft/y.

Table 1: Various recharge and groundwater evapotranspiration estimates, from the literature. All units acre-feet/year.

	Recharge				GW Evapotranspiration			
Valley	Spring	Cave	Dry Lake	Delamar	Spring	Cave	Dry Lake	Delamar
Heilweil and Brooks 2011	110000	15000	8900	4300	80000	2000	0	0
SNWA 2009a, Table 9-2	81339	15044	16208	6627	72100	1300	3700	not shown
Welch et al 2008	94000	11000			76000	2000		
NV Division of Water Resources, Eakin (1963, 1962)	75000	14000	5000	1000	70000	200	0	0
Nichols	94000				90000			
Brothers et al (1993 and 1994) as referenced in Welch et al 2008	72000							
Dettinger 1989	76000							
Flint et al 2004 (mean year)	67000	10264	10627	7764				
Flint et al 2004 (time series)	56000	9380	11298	6404				
Kirk and Campana (1990)	n/a	11999	6664	1926				
Average	80593	12384	9783	4670	77620	1375		
Standard Deviation	16358	2313	3941	2740	7907	850		
Std Dev/Mean	0.203	0.187	0.403	0.587	0.102	0.618		

Interbasin flow occurs where the geology is conducive and recharge in the mountains between the basins has not created a groundwater divide that coincides with the basin boundaries (Figure 12). BARCASS identified flow from the south portion of Steptoe Valley into northern Lake Valley and then into Spring Valley (Figure 14). The Fortification Range forms the boundary between Lake and Spring Valley. Much of the Fortification Range is volcanic rock as part of the Fortification Range Caldera, but the northern portion, just north of the White Pine/Lincoln County line, is carbonate rock of both the Upper and Lower units (Figure 12). The southern Snake Range is broadly Lower Carbonate with outcrops between both Spring and Hamlin and between Hamlin and Snake Valleys (Figure 12). Carbonate rock also underlies northern Hamlin Valley (Prudic et al 2015). The geology is conducive to interbasin flow, due to carbonate rock in the mountains surrounding the valley, from both Steptoe and Lake Valley upgradient and to Hamlin, Tippet, and Snake Valley downgradient. BARCASS estimated a required transmissivity for flow from Spring to Snake through Hamlin Valleys to be 5800 with an estimated thickness of

2.8 miles and gradient of 40 ft/mi (Welch et al 2008, Figure 42). The corresponding K is 0.4 ft/d (Id.), which is relatively low for carbonate rock (Table 2). Modeling completed by SNWA (2010b) simulated flow from Steptoe to Spring Valley.

The United States Geological Survey (USGS) in BARCASS estimated 33,000 af/y flows from Spring into Snake Valley (Welch et al 2008)[1], which is the highest estimate for interbasin flow at this point (Figure 14). BARCASS estimated that most of the 33,000 af/y flow originated in Steptoe Valley, with only 4000 af/y originating in Spring Valley (Figure 14). In a more locally focused study Prudic et al (2015, p 130) estimated interbasin flow from Spring Valley to Snake Valley to be 6000 to 11,000 af/y based on an understanding that recharge south of the groundwater divide in southern Spring Valley would flow into Snake Valley. This understanding seems reasonable because there is no discharge from Spring Valley south of the groundwater divide, so all the recharge in that area must become interbasin flow to Snake Valley. The authors estimated the necessary transmissivity and found it to be less than the transmissivity estimated by SNWA at one of its wells near the Limestone Hills (between these two valleys, Figure 12).

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[1] BARCASS (Welch et al 2008) estimated interbasin flow using a water balance model to distribute excess recharge among valleys to minimize the difference between simulated and measured deuterium concentrations, which are affected by the distribution of interbasin flow. Recharge and ET discharge were determined independent from the water balance. BARCASS estimated that recharge exceeded groundwater discharge in many of the basins, with Steptoe Valley having the largest surplus at more than 50,000 af/y; natural discharge exceeds recharge in Snake and White River Valleys. Therefore, an accurate water balance would require that these valleys receive substantial interbasin flow to make up the difference.

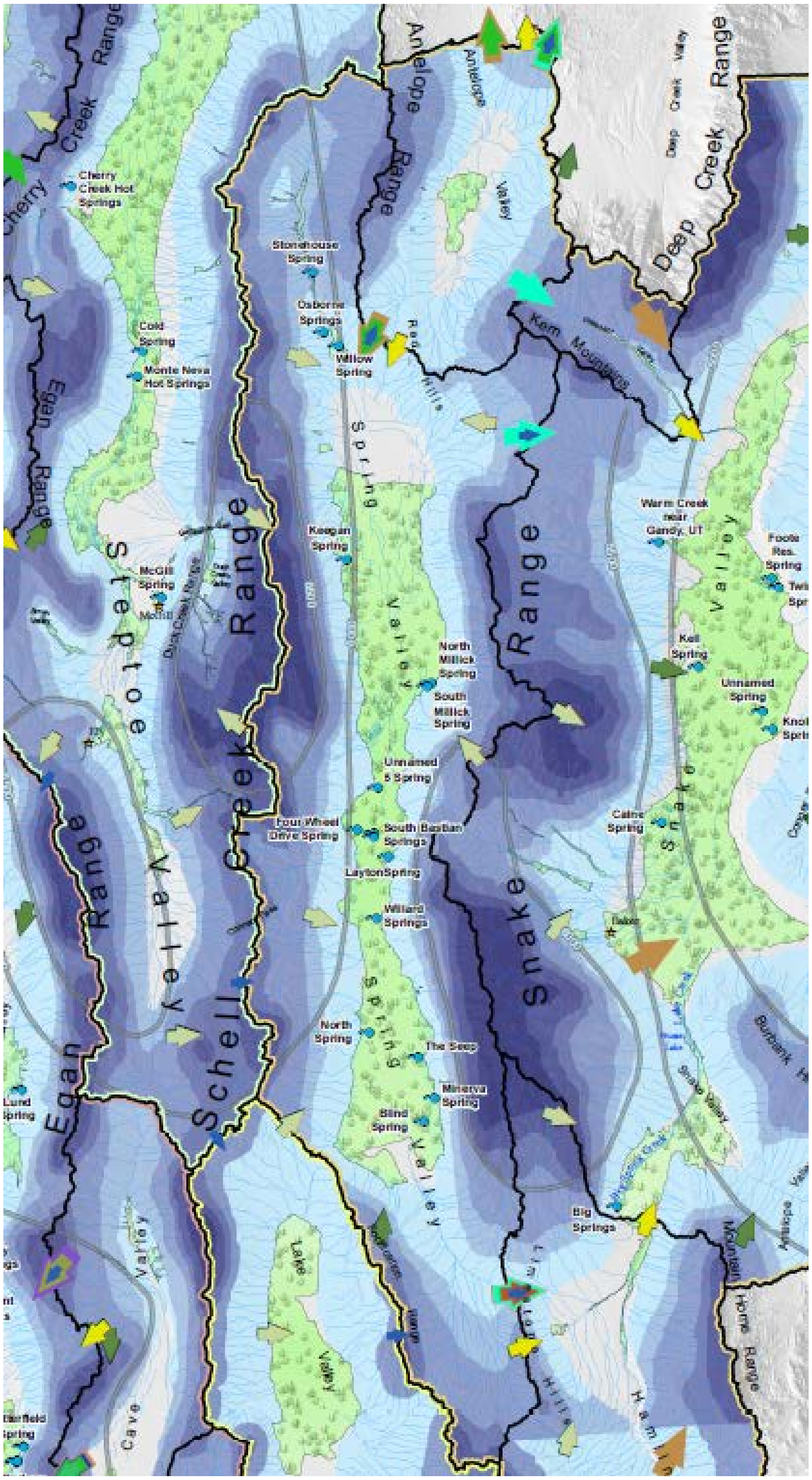


Figure 12: Snapshot of portion of Plate 1 (SNWA 2009a) centered on Spring Valley with portions of surrounding valleys. See Figure 13 for a copy of the legend.

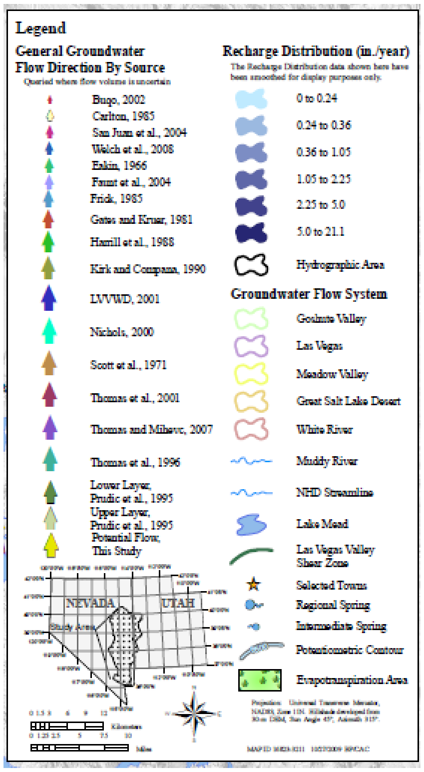
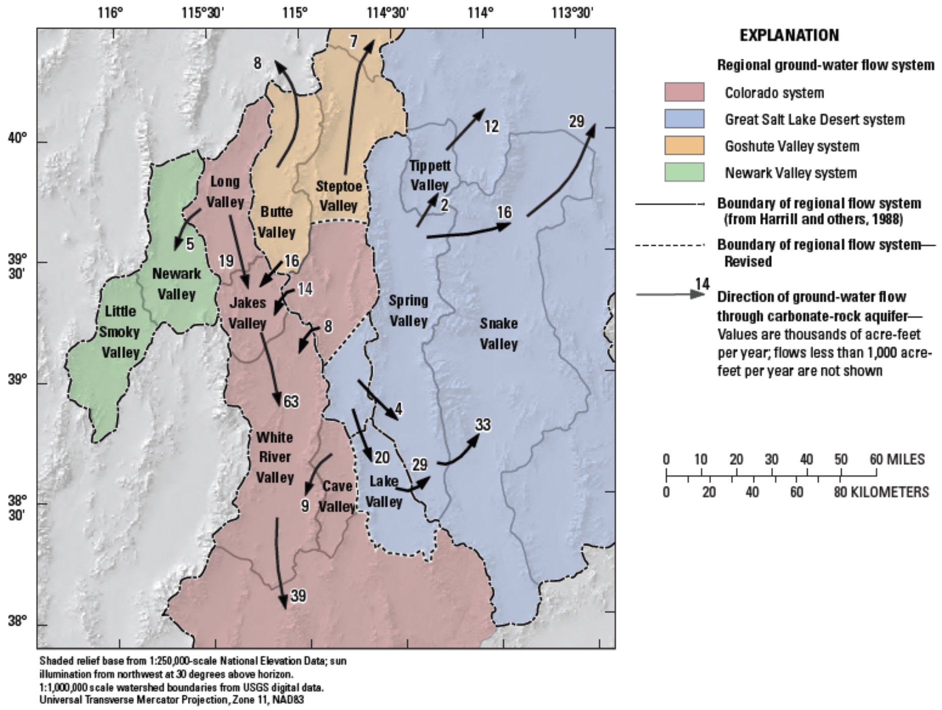


Figure 13: Snapshot of the legend from Plate 1 (SNWA 2009a). Use with Figures 12 and 16.



Shaded relief base from 1:250,000-scale National Elevation Data; sun illumination from northwest at 30 degrees above horizon.
1:1,000,000 scale watershed boundaries from USGS digital data.
Universal Transverse Mercator Projection, Zone 11, NAD83

Figure 14: Snapshot of BARCASS Figure 41 showing estimated interbasin flow for basins in the northern portion of the study area (from Welch et al (2008))

White River Flow System

The WRFS includes thirteen valleys connected by high transmissivity carbonate rock as demonstrated by the presence of high discharge springs in some valleys that have very little recharge (Eakin 1966). Discharge from the Muddy River Springs, the lowest or downgradient-most of three major spring complexes in the WRFS, is highly uniform, which is consistent with the understanding that the springs are supplied by a large groundwater system (Eakin 1966). The targeted basins within the WRFS, Cave, Dry Lake, and Delamar Valleys (CDD Valleys), differ from Spring Valley where much of the recharge is discharged through ET within the valley, in that most recharge within the CDD valleys discharges from springs in downgradient basins, including all the way to Muddy River Springs.

Recharge estimates for these valleys are fraught with uncertainty because the water balance methods require estimates of interbasin flow which in turn require assumptions of where the boundaries could be conducive to interbasin flow and what the relevant transmissivities and gradients could be. There is little discharge within Dry Lake and Delamar Valleys and about 1300 af/y in Cave Valley (SNWA 2009a).

The presence of carbonate rock on the boundaries often indicates the potential for interbasin flow, but the presence of faults and shear zones complicates understanding of flow paths and quantities. Carbonate rock in the Egan Range (Figure 15) is conducive to flow from Cave Valley supporting springs in the White River Valley, but the details are complicated by faults. BARCASS (Welch et al 2008) estimated the interbasin flow to equal 9000 af/y (Figure 14), but the location of interbasin flow may be variable as SNWA (2009a) reported various potential locations for interbasin flow (Figure 12).

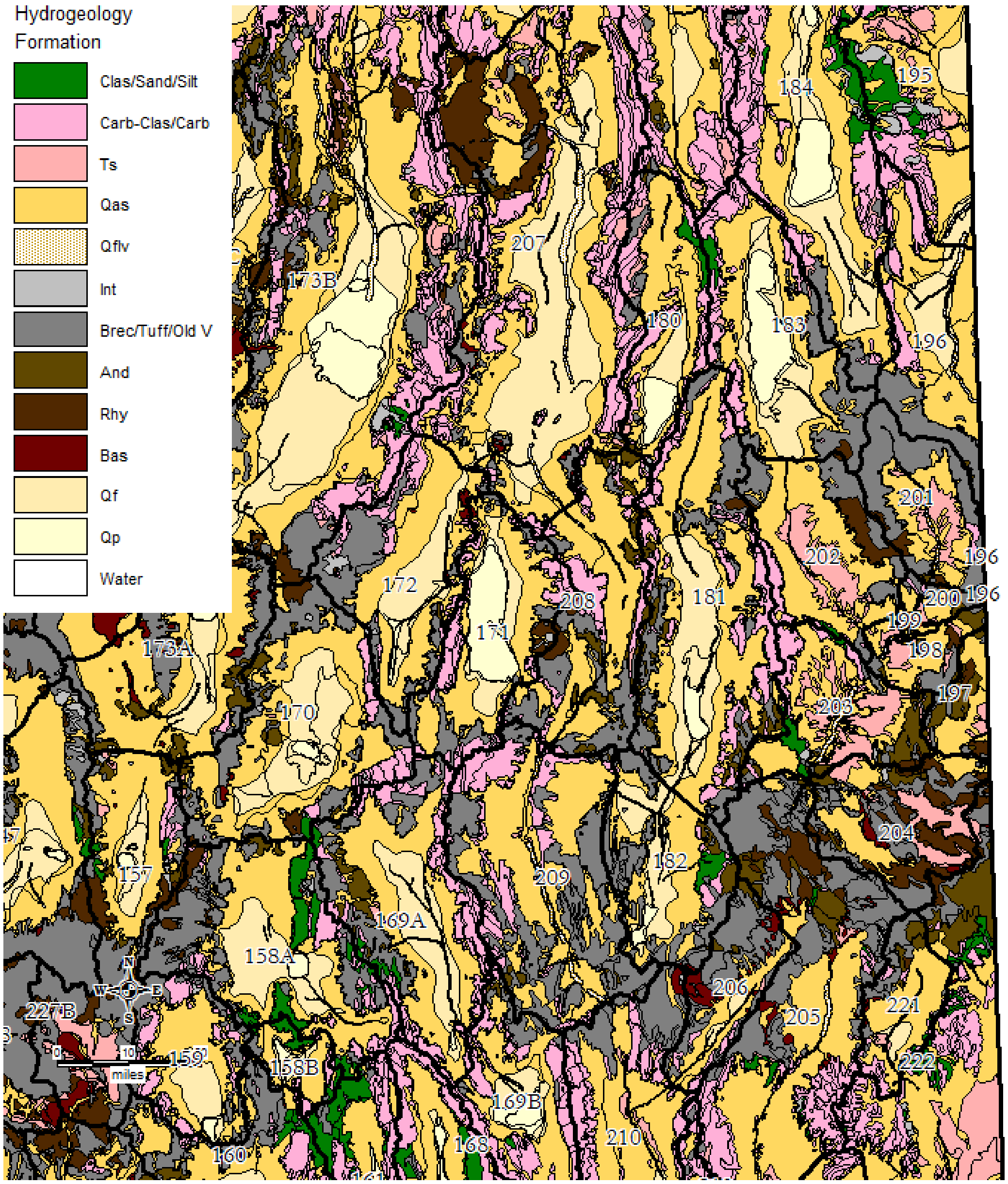
Dry Lake and Delamar Valleys are in a surficially closed trough and are higher than surrounding valleys. There is carbonate rock on the east and northwest bounds of Dry Lake Valley, but volcanic rock bounds the remainder and most of Delamar Valley (Figure 15). The valleys are probably too high for interbasin inflow from the east, and the mountains on the west are low enough with so little recharge that a groundwater divide probably has not formed. Neither topography nor geology would prevent flow from Dry Lake Valley into Panaca Valley to the east. Depth to groundwater in both valleys is substantial (SNWA 2008a, Eakin 1963a). Thus, most interbasin flow is probably from Dry Lake Valley south to Delamar Valley, and there is some possibility for flow into Muleshoe Valley (the northeast portion of Dry Lake Valley) or to the north end of Dry Lake Valley from Cave or the south end of White River Valley (Figure 12). Groundwater in the south end of Delamar Valley most likely discharges through the Pahranagat Shear zone to Pahranagat Valley.

The average recharge estimate for Cave Valley is 12,400 af/y, and the coefficient of variation is 19%, but the SNWA estimate is the highest at greater than 15,000 af/y (Table 1). Groundwater discharge is low, at just 1300 af/y, so most recharge is available for interbasin flow.

Neither Dry Lake Valley nor Delamar Valley has any groundwater discharge, so all of their recharge becomes interbasin flow. Dry Lake Valley recharge averages 9800 af/y with a coefficient of variation of 40% and Delamar Valley recharge averages 4700 af/y with coefficient of variation of 59%. The SNWA estimate for Dry Lake Valley is by far the highest value, at over 6000 af/y higher than the average. SNWA's estimate is the second highest for Delamar Valley, at 7800 af/y.

Interestingly, the BCM model has been used for separate estimates, in 2004 and 2011 (Flint et al 2004; Heilweil and Brooks 2011), but the results were substantially different. For Dry Lake Valley and especially for Delamar Valley, the BCM estimates decreased (Table 1) between the earlier and later BCM estimates. The way the method was applied varied through time, especially the manner in which runoff recharge was estimated, but there may be another reason why the estimate was very high in 2004. The climate driver, PRISM (Daly et al 2008, http://www.prism.oregonstate.edu/) for the area may have yielded precipitation that was too high (Myers 2011e, p 16, 17). PRISM overestimated precipitation for Cave and Dry Lake Valleys by 6 to 15 percent (Jeton et al 2005) and the estimates for Hamlin Valley were so high that Halford and Plume's (2011) methods grossly overestimated recharge. So, the early BCM estimate may have been biased high by an overestimate of precipitation. The same factor, too much precipitation especially in Dry Lake Valley, may have caused the SNWA estimate to be too high. The fact that the SNWA estimate, especially for Dry Lake Valley, is so high is a source of significant uncertainty that could lead to (1) gross overestimates of the available water; (2) underestimates of the drawdown due to pumping in Dry Lake Valley; and (3) underestimates of impacts to downgradient springs.

Interbasin flow leaving Cave Valley would reach White River Valley (Figure 16). White River Valley has a large loss to groundwater discharge, the estimate of which has increased substantially with time. Estimates had been between 34,000 and 37,000 af/y (NV Div of Conservation and Natural Resources 1971), but two recent USGS estimates have been 76,700 af/y (Welch et al 2008) and 80,000 af/y (Heilweil and Brooks 2011). Myers (2011a) attributed the difference to 119,101 acres of phreatophytic shrubs in the southeast portion of the valley and the increase in irrigated agriculture, as shown on the map on Figure 17. Spring flow supports irrigated agriculture and would become secondary recharge, if not diverted, after flowing through the valley, probably supporting the phreatophytes in the southeast portion of the valley. Myers (2011e) presented evidence that static water levels had become shallower probably due to secondary recharge which would support the higher groundwater ET. Thomas et al (2001) also estimated 80,000 af/y groundwater discharge from White River Valley.



Basins: 180 - Cave Valley, 181 - Dry Lake Valley, 182 - Delamar Valley, 207 - White River Valley, 208 - Pahroc V, 209 - Pahranagat V, 206 - Kane Spring V, 210 - Coyote Spring V, 184 - Spring V, 195 - Snake V, 196 - Hamlin V.

Figure 15: Hydrogeology of Cave, Dry Lake, and Delamar Valleys, Basin #s 180, 181, and 182, and surrounding basins.

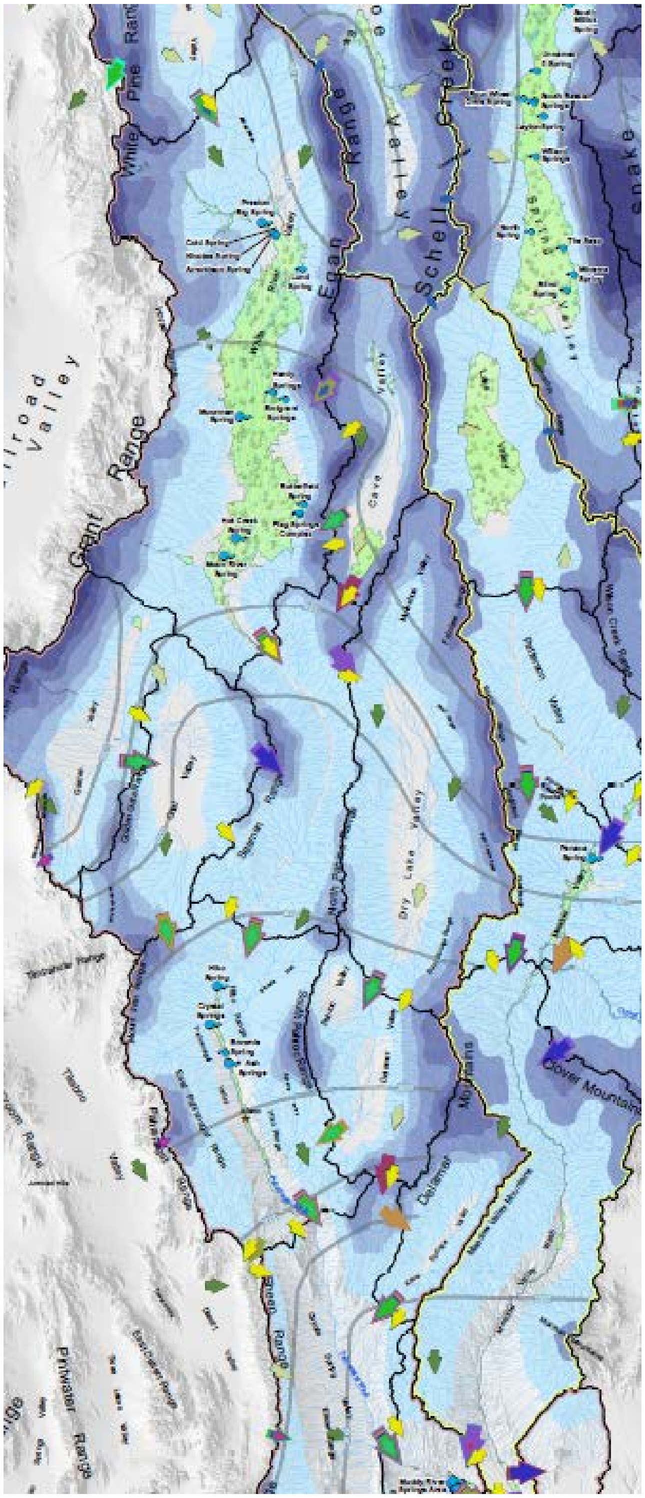


Figure 16: Snapshot of portion of Plate 1 (SNWA 2009a) centered on Cave, Dry Lake and Delamar Valleys with portions of surrounding valleys. See Figure 13 for a copy of the legend.

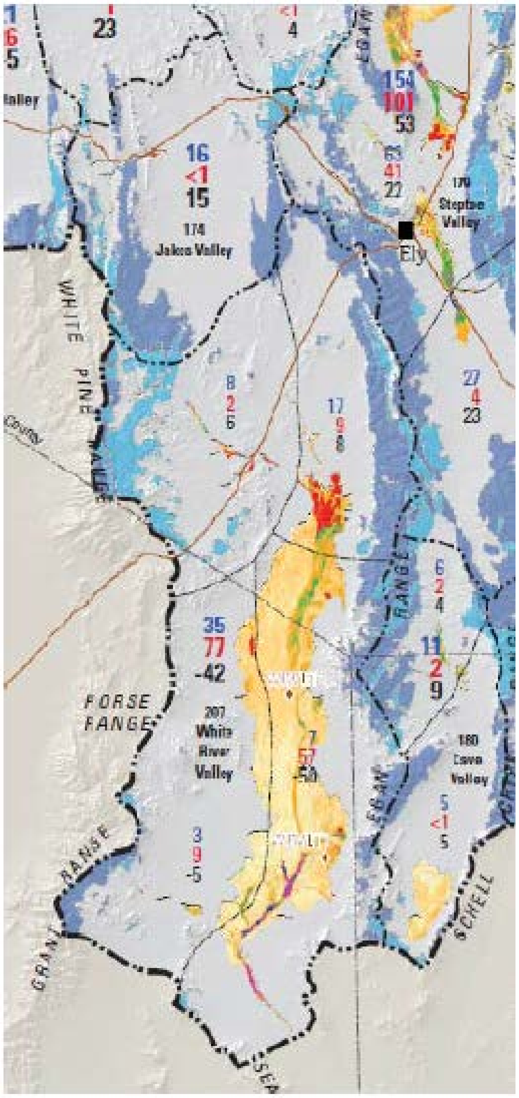


Figure 17: Water balance fluxes for White River Valley snipped from Welch et al (2008) Plate 4

Pahranagat Valley depends almost entirely on interbasin flow to support its total spring discharge, which has been estimated to equal 25,000 af/y or 28,500 af/y, which is 14 times its estimated recharge (SNWA 2009a, Eakin 1963b). The springs support wetlands and lakes on the Pahranagat National Wildlife Refuge (NV State Engineer undated; Kirk and Campana 1990), which indicates that diversion of the interbasin flow that supports these areas would cause them to dry out. The discharge mostly occurs in a narrow band along the middle of the valley (Figure 18).

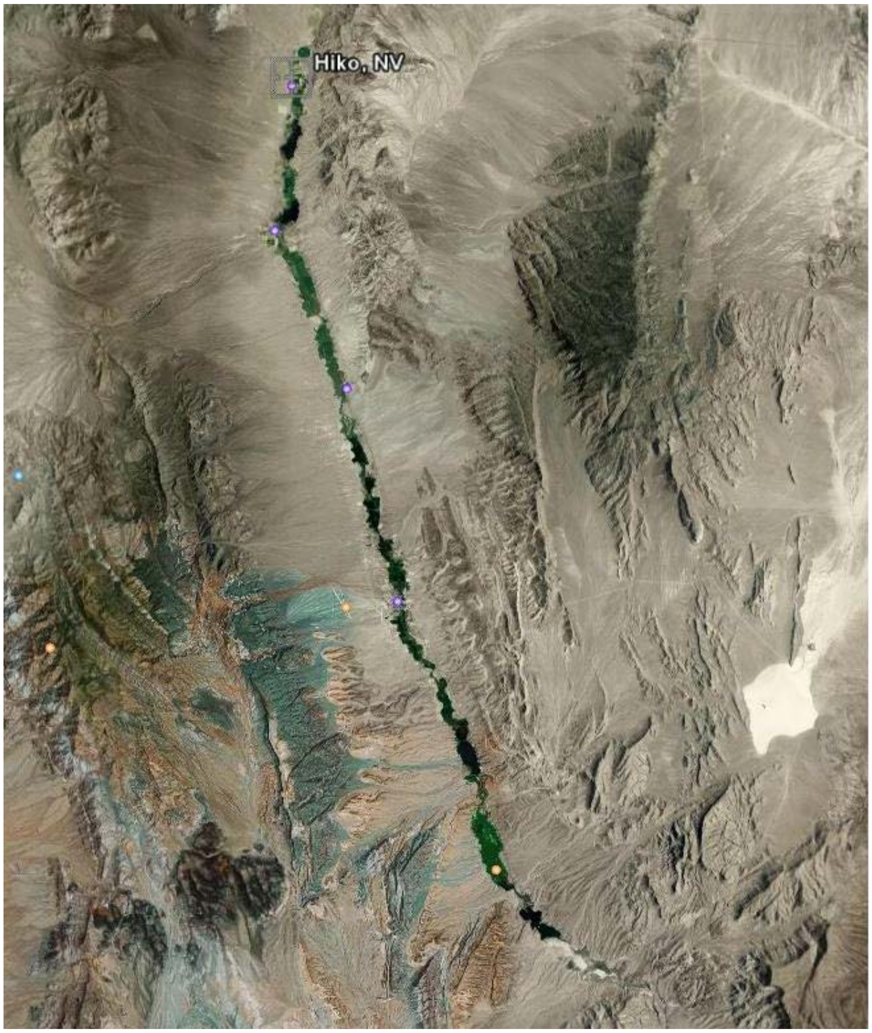


Figure 18: Phreatophytes and narrow riparian zone along the Pahranagat River between Hiko and Pahranagat Lakes.

Eakin (1963b) recognized that water rights development upgradient could affect spring flow, and associated water rights, in Pahranagat Valley.

> 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 of 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 exiting conditions of development in the gross ground-water system, the yield of Pahranagat Valley would be at 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 would be expected to decrease – the magnitude of the decrease would be directly proportional to the magnitude of the water intercepted. (Eakin 1963b, p 22).

Eakin therefore indicated that any development upgradient 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 rights applications within Pahranagat Valley for this reason. Regarding Crystal Springs in 1984, the State Engineer explained:

> 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 dominant role in the economy of Pahranagat Valley. The magnitude of the combined discharge, averaging 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 …. This indicates that **much of the groundwater discharged by the springs is derived from beyond the drainage divide of the valley** (State Engineer Ruling 3225, p 2, emphasis added).

Ruling 3225 denied two applications because they would intercept "source water to Crystal Springs."

Hydrogeologic Properties of Aquifer Systems

There are three broad categories of aquifers in the study area – basin fill, carbonate, and volcanic. Other rock may locally yield small amounts of water, but not sufficiently large to have a substantial effect on regional flow.

Basin fill generally fills the basins between mountains and can extend to thousands of feet below the ground surface (Figure 10). Basin fill aquifers are generally unconfined although confined conditions can occur in localized areas due to clay/silt stringers or other leaky confining units. Bedrock both underlies the basin fill and forms the ridges between the basins. Carbonate rock and volcanic rock forms bedrock aquifers, and siliciclastic rock often forms confining layers among carbonate layers. Intrusive rock forms large non-aquifer units in the mountains. Bedrock aquifers generally have very low primary permeability and higher secondary permeability. Carbonate rock especially has secondary permeability partially formed by dissolution so that small areas can have very high conductivity preferential flow paths. Basin fill, consisting generally of soil particles with varying degrees of compaction and cementation, often is much thicker and has a higher transmissivity than carbonate rock even though the carbonate may be more conductive in small areas.

Hydraulic conductivity for the formations ranges over multiple orders of magnitude based on studies completed throughout the CCFS (Table 2). 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 to represent a thicker aquifer (Fetter 2001). Halford and Plume (2011) refined estimates in Snake Valley with small-scale and large-scale pump tests, finding that K ranged from 0.1 to 3.0 ft/d for fine through coarse-grained basin fill and for intrusive and volcanic rocks would be less than 0.1 ft/d. Halford and Plume also assumed vertical anisotropy equaled 0.1. Hydraulic conductivity also decreases with depth due to the compression caused by the overlying material.

Table 2: Range of observed hydraulic conductivity values for hydrogeologic formations found in the study area (Welch et al 2008, Belcher et al 2001, Heilweil and Brooks 2001, Halford and Plume 2011)

Description	**Abbr**	**Median**	**Min**	**Max**
Fine-grained younger sedimentary	FYSU	19	0.01	111
Coarse-grained younger sedimentary	CYSU	10	0.0002	431
Older sedimentary rock (consolidated Cenozoic rocks, variant of rain sizes and depositional environments	OSU	0.4	0.0001	21
Volcanic flow (basalt, andesite, diorite, and rhyolite lava flows)	VFU	2	0.04	14
Volcanic tuff (ash-flow tuffs)	VTU	37	0.09	179
Mesozoic sed rock (limestones, sandstones, and siltstones)	MSU	0.004	0.0006	0.9
Upper carbonate	UCU	3	0.0003	1045
Upper siliciclastic	USCU	0.1	0.0001	3
Lower carbonate	LCU	4	0.009	2704
Lower siliciclastic	LCSU	3.0E-07	9.0E-08	15
Intrusive	IU	0.01	0.002	5

Bedrock fractures also are usually confined aquifers, if considered locally, therefore they release from two to four orders of magnitude less water for a unit drop in head than does fill based on storativity considerations. 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. Volcanic rocks are less connected by fractures and are therefore much less important as aquifers. Transmissivity may be limited by the thickness of the path. Due to fracturing, it is likely that the horizontal anisotropy in bedrock is not 1, but the only data with which to set horizontal anisotropy different from 1.0 is the fact that major carbonate springs often discharge from a fracture zone with trends reflecting flow from the recharge to discharge point (Dettinger et al 1995). Maps of transmissivity across the entire province (Prudic et al 1995, Figure 20) illustrate the variability as determined by calibrating a regional scale steady state groundwater model for the area. Transmissivity was much higher along columns in Prudic et al’s model from northeast to southwest than transverse to that direction. This direction of higher transmissivity, which resulted from calibration of the model, coincides with the general direction of faulting and likely flow through the WRFS.

Because the effective porosity of fill is higher than bedrock, the basin fill units store much more groundwater than does the bedrock, including carbonate rock. Welch et al (2008, Fig 18) estimated that Cave, Spring, and Tippett Valleys contain about 0.8, 3.5, and 0.8 maf of drainable water in the fill, assuming a uniform 100-foot drop in the water table, respectively. Bedrock would release about 1% as much water for a similar drop in potentiometric surface (Welch et al 2008, p 41).

Perennial yield

The NSE defines perennial yield (PY) on its web page as follows: "Perennial yield is the maximum amount of groundwater that can be salvaged each year over the long term without depleting the groundwater reservoir. The perennial yield cannot be more than the natural recharge of the groundwater reservoir and is usually limited to the maximum amount of natural discharge" (http://dcnr.nv.gov/documents/documents/nevada-water-law-101/, accessed 4/26/17). "Perennial yield is ultimately limited to the maximum amount of natural discharge that can be salvaged for beneficial use." State Engineer Ruling No. 6164.

By "without depleting the groundwater reservoir", the definition requires that extraction from storage cannot continue in perpetuity because eventually the groundwater reservoir would be completely depleted. It requires that the groundwater system return to equilibrium, which in simple terms means the pumping has captured discharge equal to the pumping rate, or that pumping has replaced natural discharge.

Rather than considering PY for each basin within the state, due to interbasin flow, it may be more appropriate to consider PY for a larger system of interconnected basins. A regional groundwater system before pumping begins is usually considered to be in a state of equilibrium, with recharge equaling discharge (Fetter 2001, p 237-246). Recharge occurs generally at higher elevations where conductivity is high enough to allow infiltration and flows to discharge points at lower elevations. This describes the White River Flow System as modeled in the CCFS. Infiltration in the CCFS occurs directly into formations in the mountains as distributed recharge. It may also occur by percolating from streams during high flows or at the point where runoff reaches basin fill as mountain-front recharge. Discharge points from the CCFS include groundwater discharge to wetland systems or phreatophytes and discharge to springs. In the CCFS, most groundwater that becomes streamflow does so by discharging from springs. There are many basins within the WRFS, simulated as part of the CCFS, for which recharge within the basin does not equal discharge within the basin, unless interbasin flow is considered.

Developing groundwater by pumping from wells in an individual basin or in a regional flow system will draw from groundwater storage until the total discharge from the basin or system once again equals the recharge. This occurs either by capturing natural discharge so that it is less than it was under predevelopment conditions or by inducing additional recharge. The CCFS is generally not conducive to inducing recharge because of the lack of connection between rivers or streams in the basins with groundwater. Pumping draws from groundwater storage until the water table or potentiometric surface expands to capture natural discharge equal to the amount of pumping (Fetter 2001, p 247). At that point, the groundwater system will come to equilibrium with total discharge from the flow system equaling the recharge. In many basins, as will be seen below, the capture will affect adjoining basins by either preventing flow into those basins or by drawing flow from those basins.

The CCFS is a combination of unconfined and leaky confined aquifers, with the basin fill being unconfined and the carbonate and other bedrock aquifers being confined. The confined aquifers are leaky because they receive recharge from overlying basin fill aquifers and from the surrounding mountains. A confined aquifer comes to equilibrium with pumping when all the water being pumped comes from leakage across the confining layer and none comes from elastic storage in the confined aquifer (Fetter 2001, p 160). An unconfined aquifer mathematically approaches equilibrium as the water table is drawn further below the bottom of the depth at which ET occurs (Fetter 2001, p 165, 168). Once captured ET equals the pumping rate, the net storage will not change although the water table shape may continue to change.

Lag in Recharge

Perennial yield is based on the concept that recharge equals discharge during steady state conditions. Dettinger (1989) described this method of estimating recharge as the water budget method, which assumes a “natural equilibrium between recharge and discharge exists in each basin” (Dettinger 1989, p 56). However, the concept may be inappropriate for two reasons. First, most recharge occurs during only a few years. Masbruch et al (2016) found that for basins just northeast of Spring Valley, recharge during just five wet periods provided most of the recharge to basins between 1960 and 2013; the 1982-85 period was by far the largest recharge period.

Second, long-term climate has varied so much that Great Basin lakes have formed and dissipated intermittently over the last 35,000 years (Benson et al 1990, 1992, Benson and Thompson 1987). This phenomenon could only occur if there were periods of much higher precipitation and recharge in the past. The component of recharge that occurs in carbonate outcrops in the mountains such as the Snake Range along the east boundary of Spring Valley, especially, could require a very long time to reach the points of discharge in the Spring Valley playa. In this case, the discharge would reflect recharge that occurred in the distant past, and assuming current ET discharge equals current recharge could lead to a PY estimate that is much too high for current or future conditions as the flux reaching the playas from the mountains decreases

Recharge is distributed along the edge of the playas, with the darkest blue shade representing recharge exceeding 50 in/y (Figure 19). The higher rates probably correspond with mountain front recharge near the playas, which is likely into valley fill at the edges of the valley. From these points to discharge points in the playa, the travel times were on the order of decades (Appendix 1). Pumping from the basin fill or the carbonate in the valleys would most probably draw on the mountain front recharge.

Additionally, assessments of climate change scenarios have concluded that most western groundwater aquifers will experience less recharge in the future (Meixner et al 2016). Specifically, the authors reviewed reports showing that recharge will decrease in the Death Valley Flow System and Wasatch Front (Id.). Because the study area lies in between these areas, it is reasonable to conclude that it also will have decreased recharge. Due to climate change, it is likely that basing water rights on current conditions without consideration of likely changes will overallocate water supplies that will be available in the future.

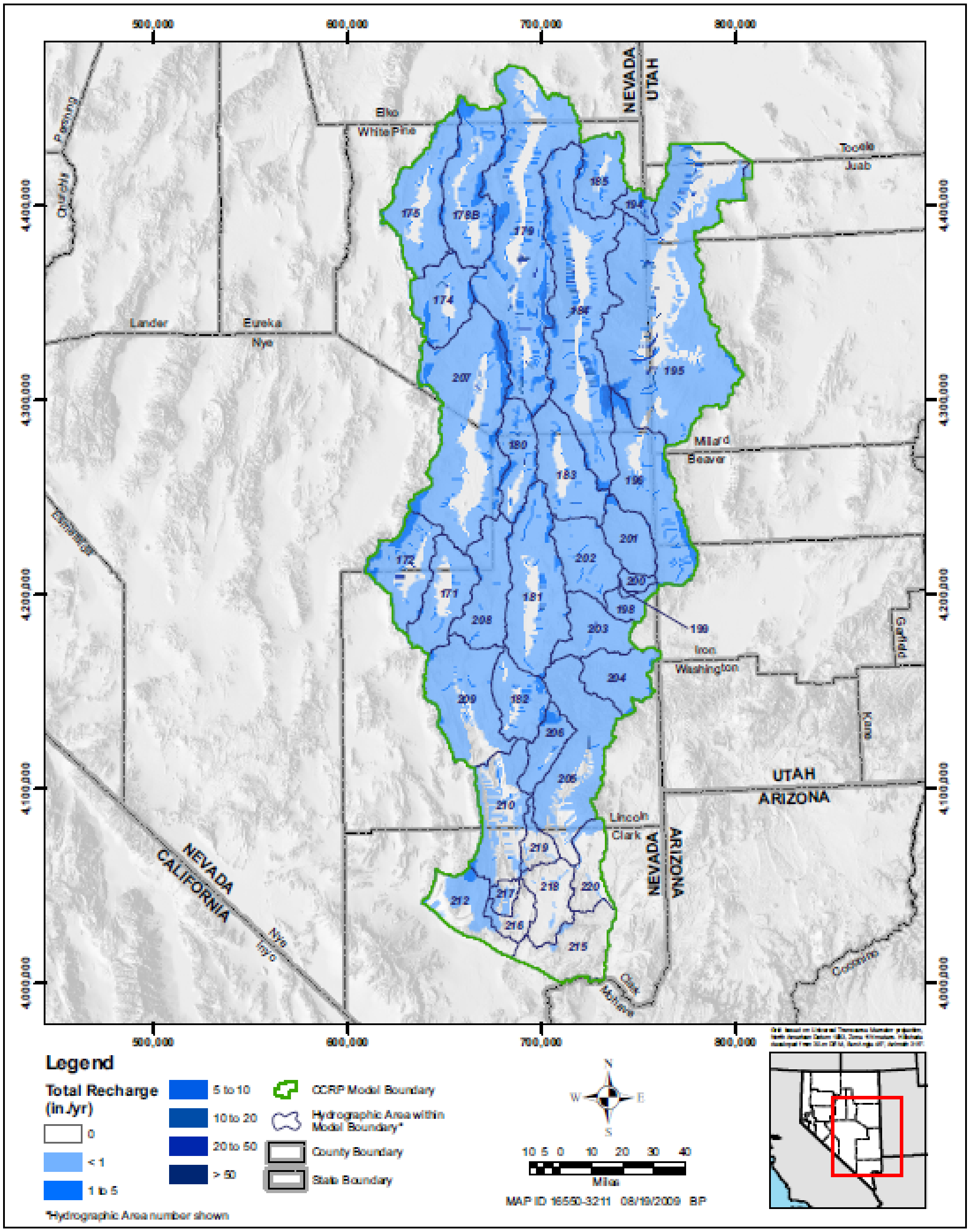


Figure 4-37
Distribution of Total Recharge (Input to MODFLOW-2000)

Figure 19: Snapshot of Figure 4-37 (SNWA 2009d) showing the recharge input to the groundwater model. The light blue is less than 1 in/y.

Central Carbonate Flow System Numerical modeling

The CCFS includes all six flow systems simulated by the model (Figure 2). Spring Valley (#184) is part of the Greater Salt Lake Desert Flow System (Figure 2). Spring Valley is the upper portion of the flow system, with recharge originating in Spring Valley flowing into Snake and Hamlin Valleys (Figure 12). Cave, Dry Lake, and Delamar Valleys (#180, 181, and 182 in Figure 2) are part of the White River Flow System (Figure 14). Cave Valley is generally at the headwaters of the WRFS, generating interbasin flow to the White River Valley and possibly to Dry Lake Valley (Figure 14). There is flow from White River Valley to Pahranagat through Pahroc Valley. Dry Lake Valley discharges to Delamar Valley which discharges to Pahranagat and Coyote Spring Valleys (Figure 14). Coyote Spring Valley discharges to the Muddy River Springs area and from the Muddy River Springs (Figure 20), which are a terminal discharge point of the WRFS.

Total recharge in the CCFS is 580,700 af/y and total pumpage is approximately 1/6th of the recharge, or 100,000 af/y (Table 1)[2]. Existing pumping distributes around the area, with Meadow Valley Wash Flow System having the most for any flow system, although Salt Lake Desert and White River Flow Systems have almost as much (Table 3). The total simulated recharge and pumping results in 40,200 af/y being removed from storage even prior to SNWA development. The No Action alternative simulation is based on 1945 to 2004 with pumping for no action into the future being the average for 2001 to 2004 (SNWA 2010b, p 3-1). Even the no action alternative has the system far from equilibrium at the beginning of FEIS model simulations. Snake Valley has substantially more pumping than the other basins, at 21,600 af/y, with Lake Valley second at 13,400 af/y (Id.). Of the four basins targeted by SNWA for development, only Spring Valley currently has pumping, with total existing pumping at 9000 af/y (Id.).

Table 3: Fluxes for flow systems in the Central Carbonate Flow System (FEIS Appendix F3.3.16)

Flow System Totals	Net IB Flow	Chg Storage	Well	Const Head	ET/Springs	Recharge	Stream Q
Goshute Valley	-44,400	2,500	-12,100	-2,600	-88,400	144,700	0
Meadow Valley Wash	-14,000	23,200	-33,500	0	-36,400	60,600	0
Salt Lake Desert	14,400	5,600	-27,200	-3,390	-179,700	220,800	-100
White River	47,000	8,400	-27,200	-37,300	-120,800	151,800	-22,100
Las Vegas	-3,300	500	0	0	0	2,800	0
Grand Total	-300	40,200	-100,000	-73,800	-425,300	580,700	-22,200

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[2] Flux values reported in this section are as simulated in the FEIS numerical model (SNWA 2009d), not as reported in the previous section regarding conceptual flow models.

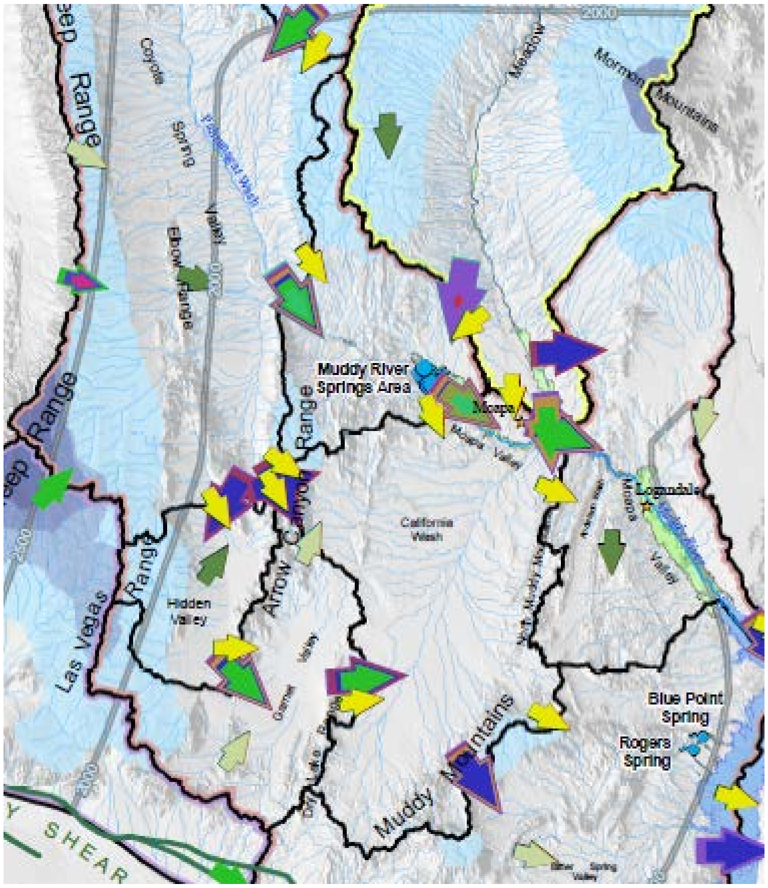

Figure 20: Snapshot of portion of Plate 1 (SNWA 2009a) centered on Cave, Dry Lake, and Delamar Valleys with portions of surrounding valleys. See Figure 13 for a copy of the legend.

Simulated groundwater storage in 2004, at the beginning of pumping for the no action alternative, is declining by 40,200 af/y due to current pumping (Figure 21), as noted above. The existing pumpage in the CCFS does not capture ET discharge by 2250, as demonstrated by storage change equaling about 17,000 af/y (Figure 21). Thus, at the beginning of the project period, existing pumping through the CCFS had not captured about 2/5ths of its water. Initial conditions in 2005 were set equal to the results of simulating pumpage from 1945 to 2004. Almost 250 years, or in about 2250, existing pumpage without any new development was still removing 1/5th of the pumpage from storage. The CCFS remains far from equilibrium under existing conditions. Overall ET/Spring discharge had dropped about 25,000 af/y over the same period, representing amounts that had been captured (Figure 21).

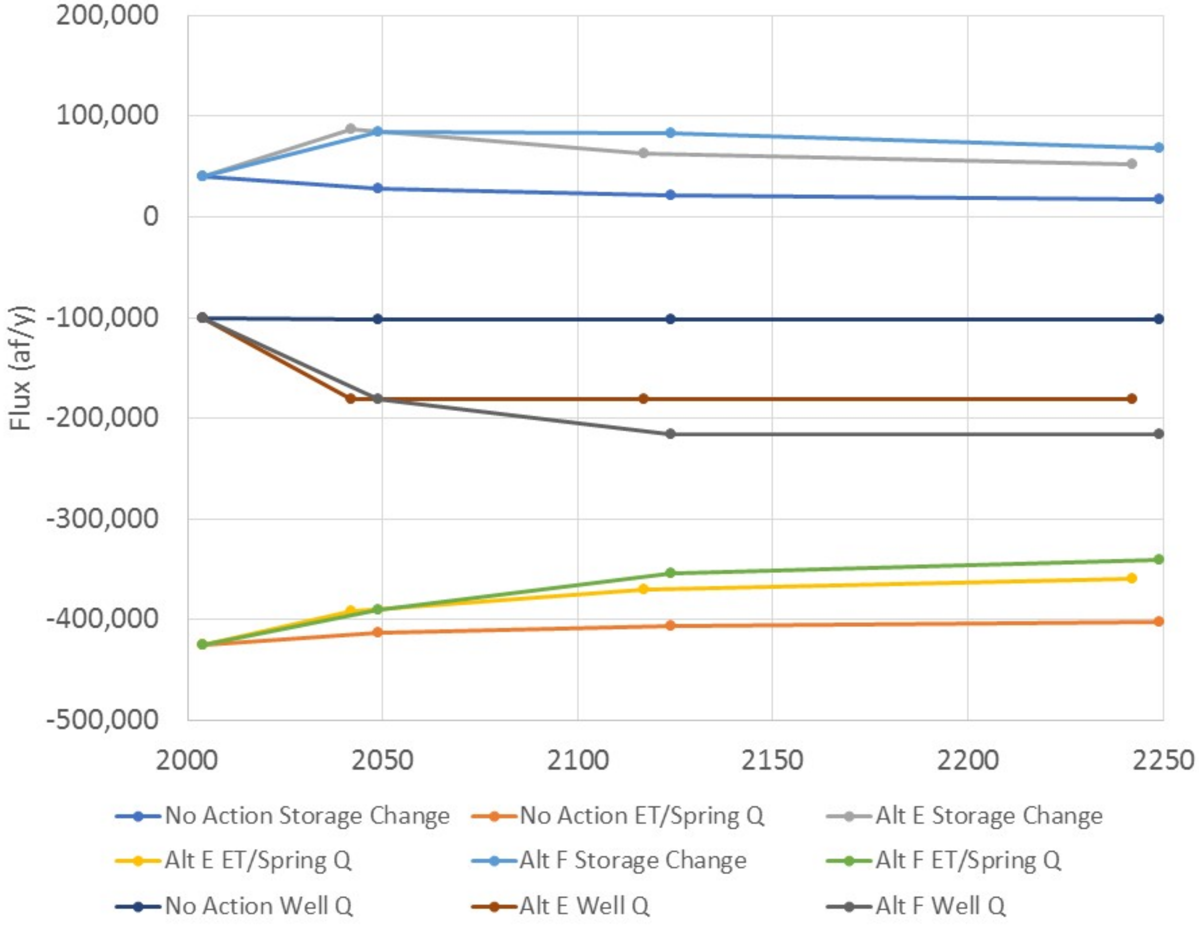

Figure 21: Water budget accounting including storage change, ET/spring discharge (Q), and well pumpage for the Central Carbonate Flow System for the No Action alternative and Alternatives E and F, as simulated for the FEIS (FEIS Appendix F3.3.16).

Alternatives E and F would increase the amounts removed from storage to near 85,000 af/y at full buildout in 2050. By the end of the simulation in 2250, amounts removed from storage were reduced to 51,900 and 68,500 af/y for alternatives E and F, respectively (Figure 21). The difference in captured storage between alternatives is mostly due to the difference in the amount of ET/Spring discharge captured (FEIS Appendix F3.3, Table F3.3.16-8B) with additional small amounts of change in the amount of interbasin flow to or from the CCFS that is captured or the amount of stream discharge captured. To the extent that storage changes or ET/spring discharge within the target basins pumped for Alternatives E or F, discussed below, do not explain the differences in Figure 21, the differences are due to changes in surrounding basins.

Drawdown around the CCFS reflects the simulated storage changes. Figures 22 and 23 depict conditions at 75 and 200 years after full buildout for Alternative E; Figures 24 and 25 do the same for Alternative F. Drawdown in the southwest is in the White River Flow System, including the target basins Cave, Dry Lake, and Delamar Valleys, and drawdown in the northeast is centered on Spring Valley. Drawdown from the target valleys extends into surrounding valleys and affects interbasin flow among the valleys. The drawdown mirrors the shape of the target valleys because the basin boundaries limit interbasin flow regardless of geology because topographic divides correspond with natural groundwater divides.

Drawdown in the target valley due to SNWA's water rights development reaches into surrounding valleys which represents how pumping the target basins would draw water out of or prevent water from flowing to nearby basins. Spring Valley pumping would draw from storage within and capture discharge from parts of Spring Valley, but it also would intercept interbasin flow from reaching Snake Valley or increase the interbasin flow from Steptoe Valley if that is the path of least resistance. Pumping in Cave, Dry Lake, or Delamar Valley must capture interbasin flow because there is little discharge within the basins to capture. Details will be discussed below in the sections regarding individual flow systems or basins.

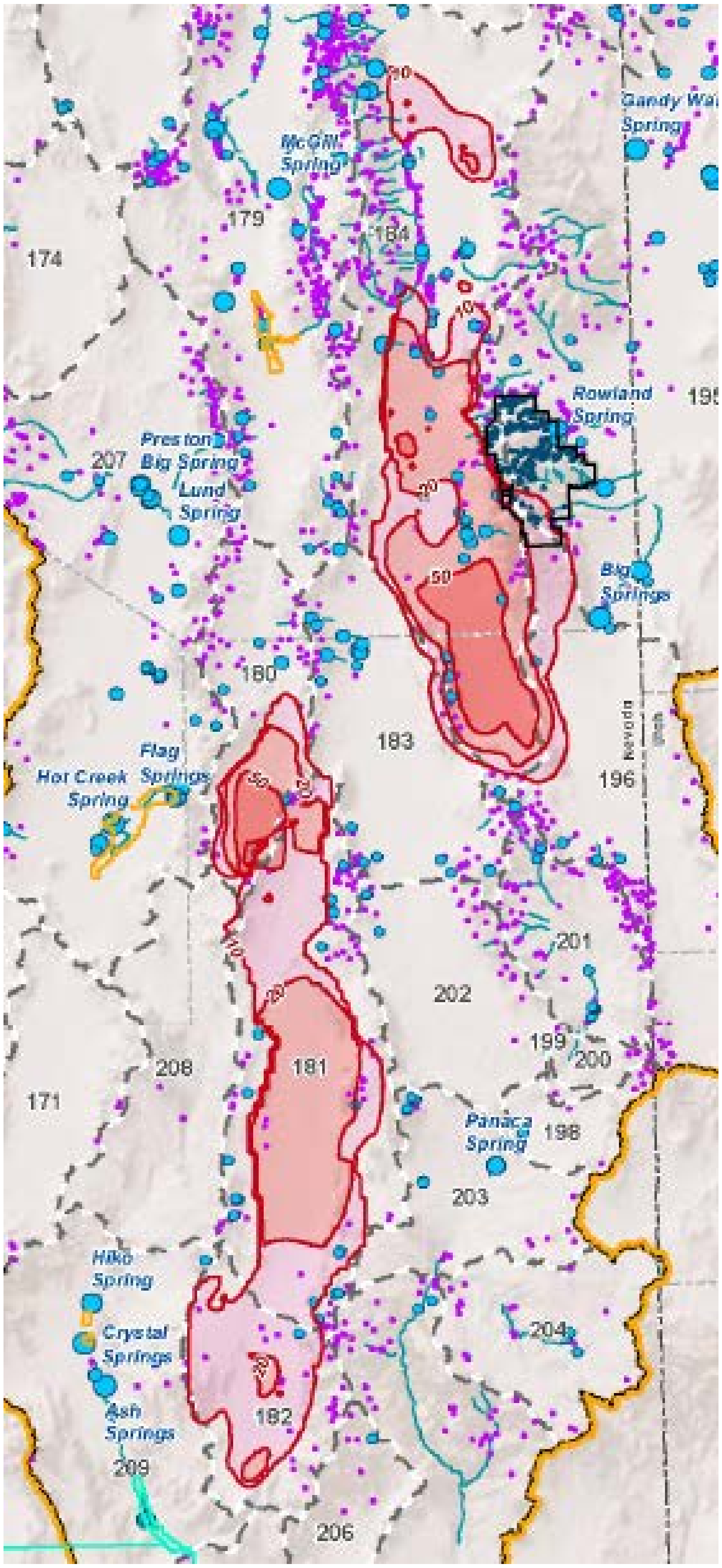

Figure 22: Snapshot of a portion of FEIS Figure 3.2.2.28 showing drawdown in the CCFS for Alternative E at 75 years after full buildout (year 2125).

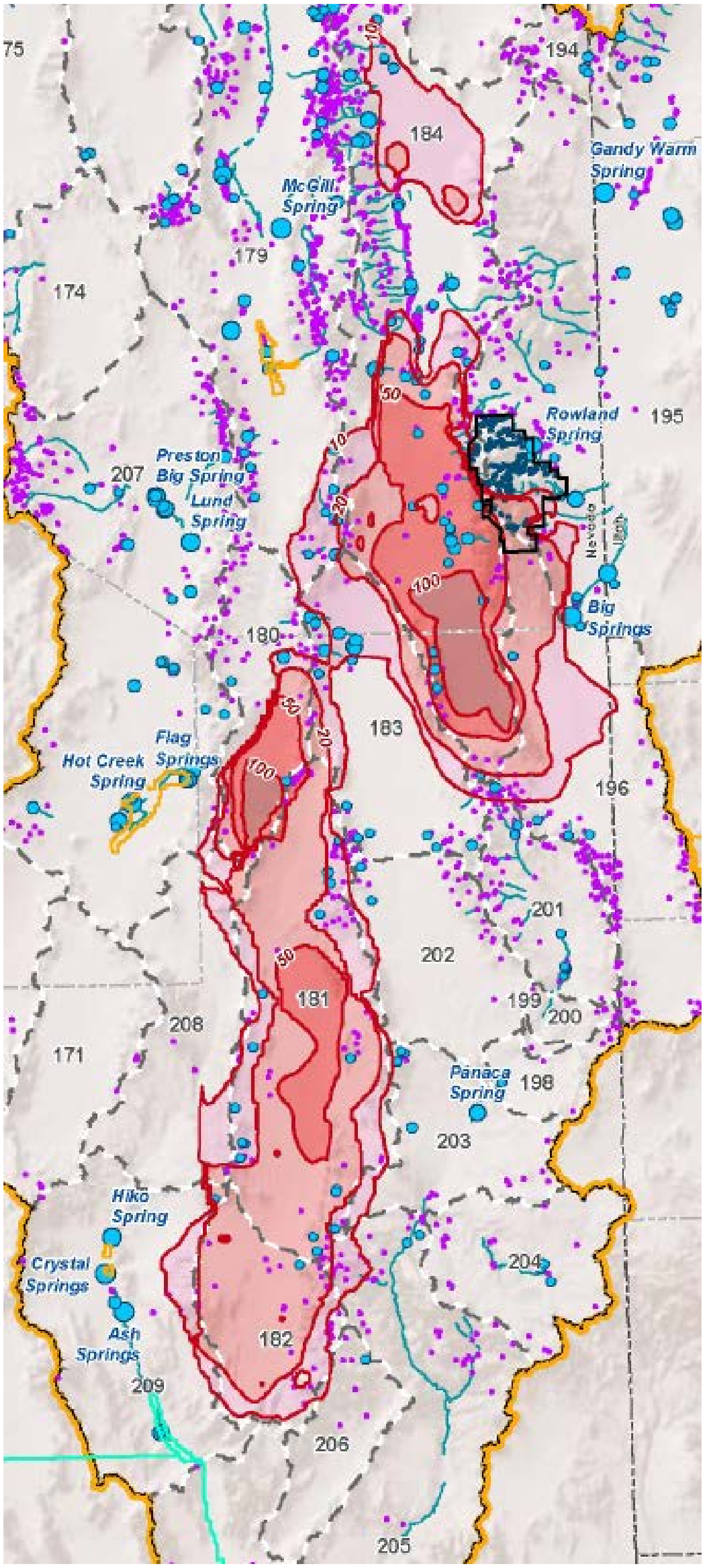

Figure 23: Snapshot of a portion of FEIS Figure 3.2.2.29 showing drawdown in the CCFS for Alternative E at 200 years after full buildout (year 2250).

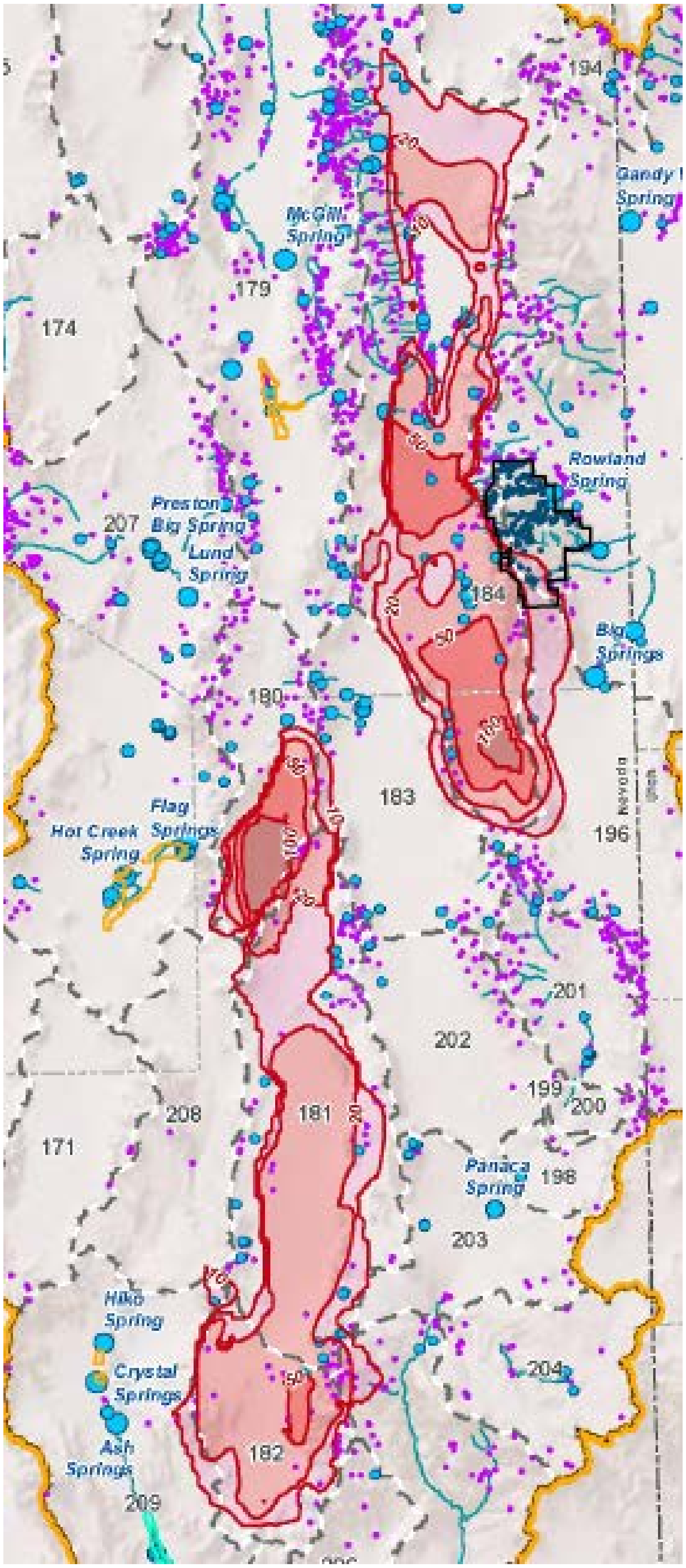

Figure 24: Snapshot of a portion of FEIS Figure 3.2.2.32 showing drawdown in the CCFS for Alternative F at 75 years after full buildout (year 2125).

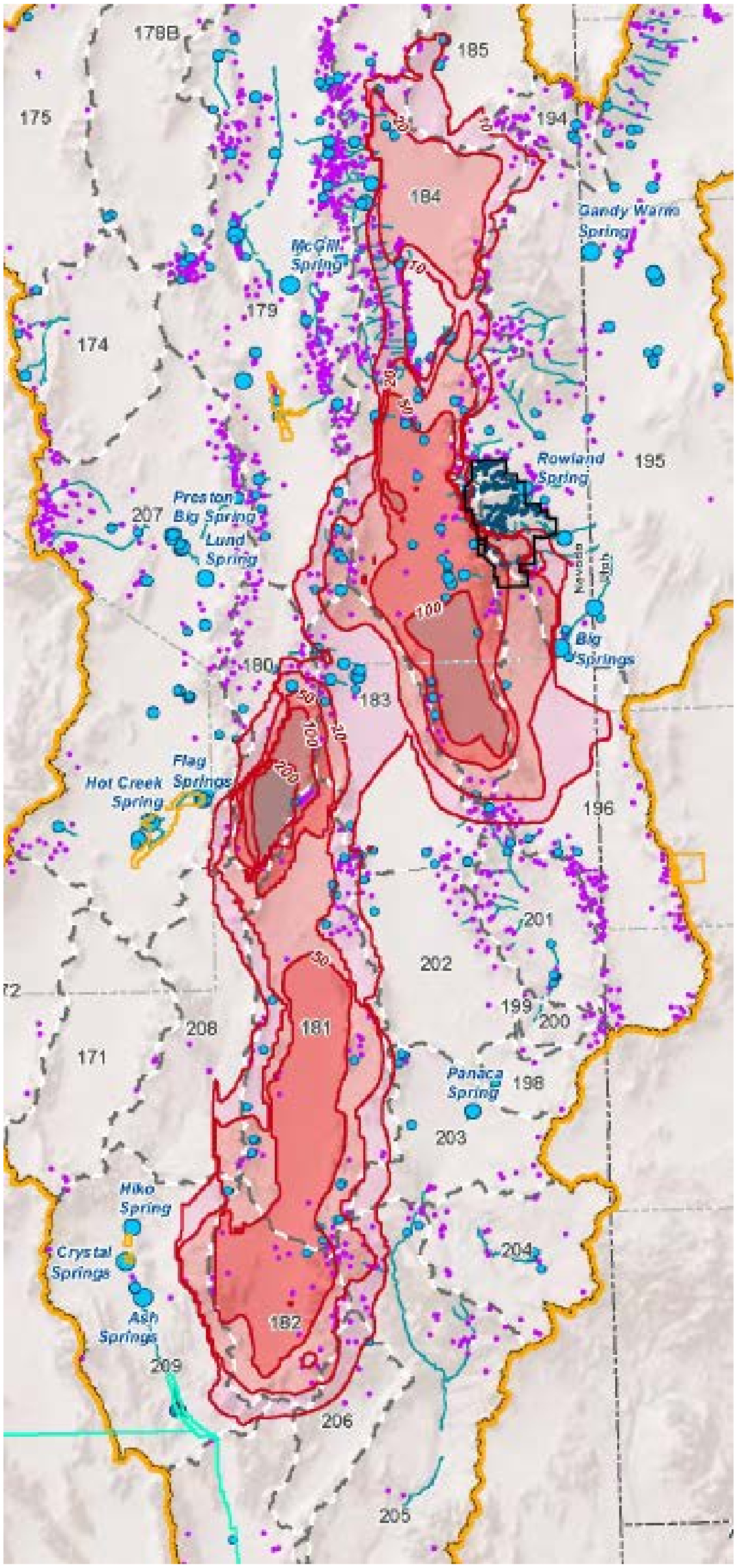

Figure 25: Snapshot of a portion of FEIS Figure 3.2.2.33 showing drawdown in the CCFS for Alternative F at 200 years after full buildout (year 2250).

Spring Valley

Simulated recharge in Spring Valley is 82,600 af/y, so the pumpage for alternatives E and F, at 69,000 and 93,400 af/y, including pre-existing pumpage, are respectively the great majority of or more than the Valley's total recharge. Initially large proportions of the pumpage draw from storage, with drawdown exceeding 50 feet over an extensive portion of Spring Valley 75 years after full buildout for each alternative (Figures 22 and 24). Drawdown exceeds 100 feet 200 years after full buildout over a small portion of the southern part of Spring Valley for alternative E (Figure 23) and over a large portion of the southern part of Spring Valley for Alternative F 200 years after full buildout (Figure 25). Water level graphs for the simulated monitoring well also show that the water level drops up to 70 feet for alternatives E and F and that the downward slope is a straight line (Figure 27), which indicates drawdown will continue at a high rate far into the future. Even 200 years after full buildout, pumpage for alternatives E and F is still removing 18% and 20%, respectively, of the water from storage (Figure 26). Simulated interbasin flow changes from 5300 af/y leaving the basin, to 3800 or 6100 af/y being drawn into the basin for alternatives E and F, respectively (Figure 26), thus 10% of the simulated pumpage in Spring Valley eventually captures interbasin flow. Most of the existing flow is from Spring Valley to Snake Valley before development, while 200 years after full buildout additional amounts of water are drawn from Steptoe, Lake, and Tippet Valleys (FEIS Appendix F3.3.16).

Simulated drawdown in Spring Valley for both alternatives extends over the boundary into Steptoe, Snake, Lake, and Hamlin Valleys for all time periods (Figures 22 through 25), and into Tippet Valley 200 years after full buildout for Alternative F. Drawdown that extends into an adjacent valley primarily is a lowering of the water table at the basin boundary, meaning the groundwater divides which roughly correspond with the topographic boundaries are lower and shifted into the losing basin. This effectively means the boundary of the basin becomes larger so that recharge from the affected hydraulically connected basin will flow into the basin being pumped, regardless of the topography, rather than remaining in the adjacent basin. In this way, pumping in one basin draws water across the basin's existing boundaries. The expansion into Lake Valley occurs through the southwest portion of Spring Valley which is primarily through the volcanic rocks of the Fortitude Range. After 200 years for each alternative the 10-foot drawdown in Spring and Cave Valleys connects within Lake Valley (Figures 23 and 25).

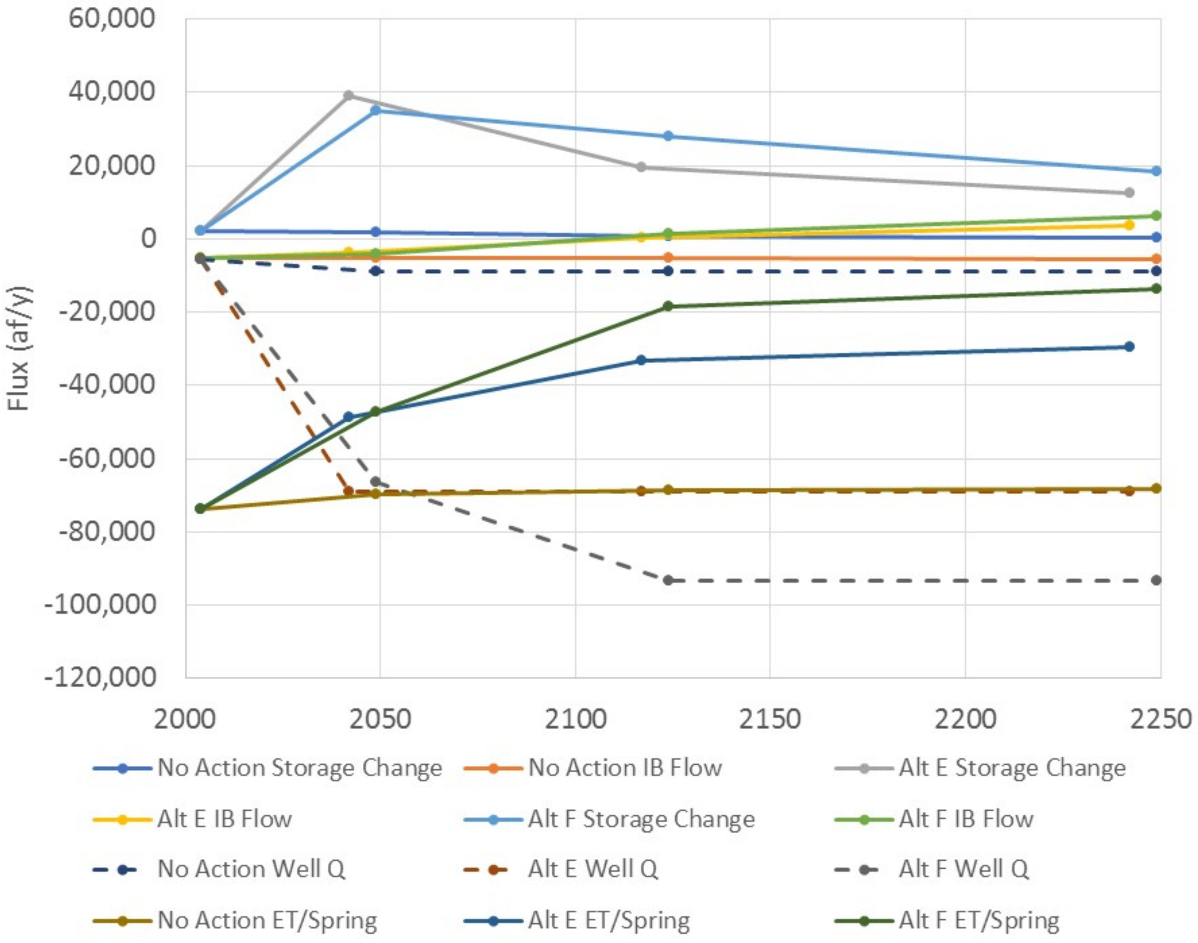

Figure 26: Water budget accounting including storage change, ET/spring discharge (Q), and well pumpage for Spring Valley for the No Action alternative and Alternatives E and F, as simulated for the FEIS (FEIS Appendix F3.3.16).

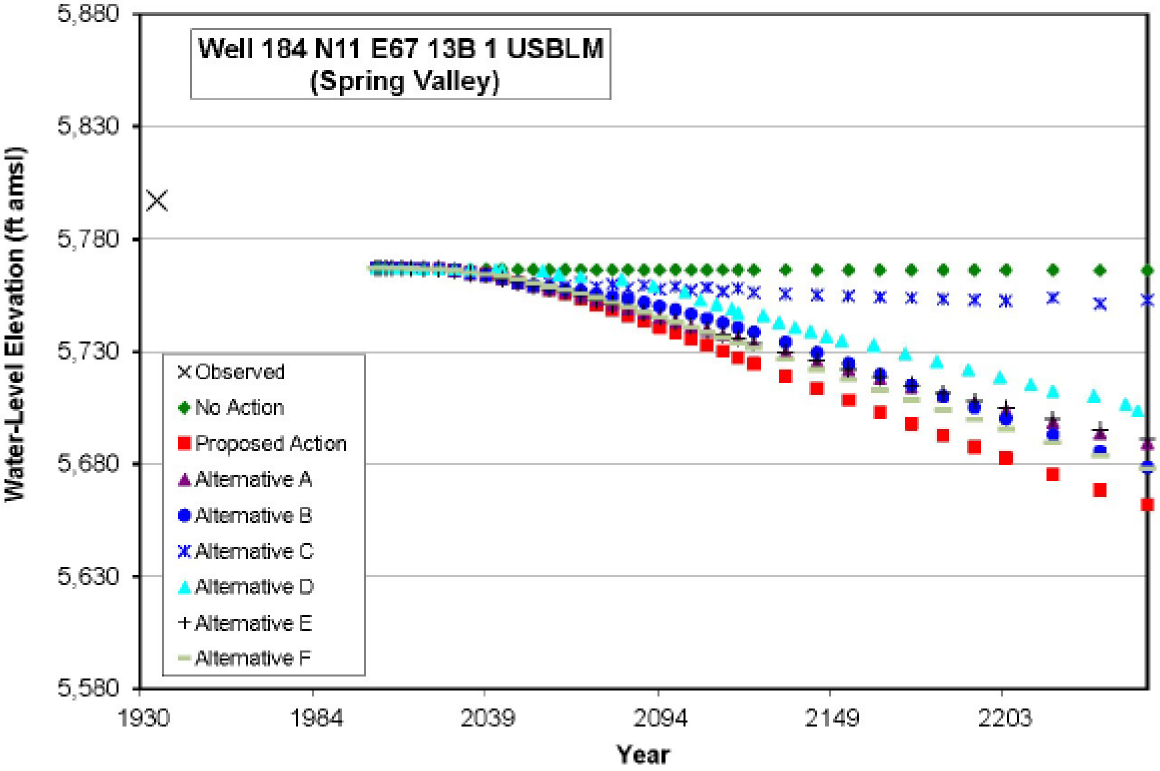

Figure 27: Snapshot of FEIS Figure 3.3.2-7 showing representative water-level hydrograph for Spring Valley.

Simulated drawdown expands into Snake and Hamlin Valleys primarily through carbonate rock in the Snake Range south of Great Basin National Park (Figure 5). The gradient driving interbasin flow, before development, from Spring Valley into Snake Valley is caused by a groundwater divide in the southern portion of Spring Valley that causes water table to slope southeastward toward Hamlin Valley. It effectively adds the southern portion of Spring Valley to Hamlin Valley (Figure 8) because recharge in that area would all flow into Hamlin Valley. Simulated pumping causes drawdown in southern Spring Valley and across the divide into Hamlin Valley (Figures 22 to 25) by effectively capturing the recharge in southern Spring Valley and preventing it from flowing into Hamlin Valley and from there into Snake Valley.

If the higher USGS interbasin flow estimates described above (Prudic et al 2015, Welch et al 2008) prove more accurate than the FEIS simulated estimate, SNWA's pumping would capture substantially more interbasin flow and cause more drawdown and spring flow decreases in Snake Valley than simulated in the FEIS. Because the difference in estimates for interbasin flow depends more on difference in discharge than in estimated recharge, it does not reflect more available water or indicate any real expected difference in the time to pump to equilibrium.

Changed groundwater elevations and gradients at basin boundaries caused by pumping result in the changes in interbasin flow discussed above and in Figure 26. Decreased interbasin flow affects spring flow downgradient in Snake Valley. Pumping according to Alternative E decreased Big Springs flow to about 20% of its 2004 discharge (Figure 28). The other project alternatives have a larger effect because they include pumping in Snake Valley.

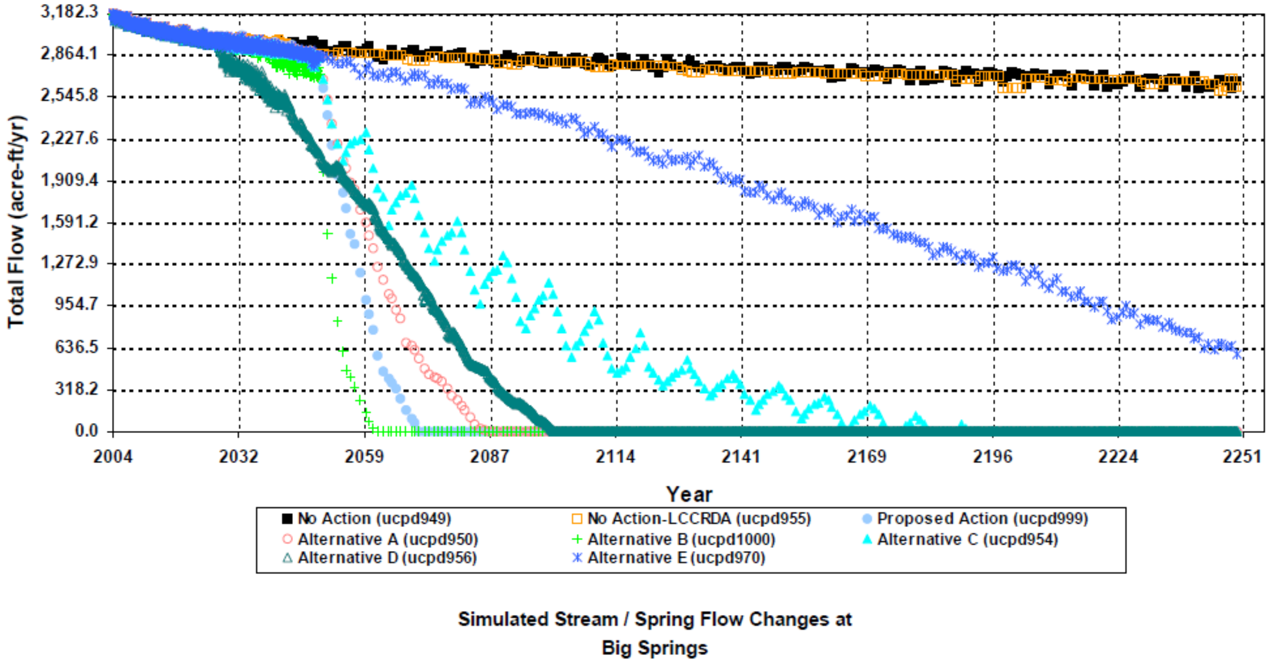

Figure 28: Snapshot of figure from file titled Springs_Hydrograph_Report_2005_2250 (BLM undated e). The graph shows flows at Big Spring for various alternatives. Alternative F was not included and a file with Alternative F was not available. Because it pumps at higher rates, the Big Springs flow would decrease more than for Alternative E.

Prudic et al (2015) found that interbasin flow from Spring Valley did not emerge as discharge from Big Springs. Figure 8 shows the different groundwater flow areas with the yellow area draining Big Springs Wash supporting flow to Big Springs. The light blue area supports groundwater flow east of Big Springs and includes the interbasin flow from Spring Valley, which may support ET along Lake Creek or springs near the state line. This could suggest that Spring Valley pumping which captures interbasin flow will still not capture Big Springs flow, as simulated in the FEIS model. However, if the majority of flow from the light blue zone (Figure 8) is diverted west and north to SNWA pumping, groundwater from the southern portion of Snake Valley would be pulled further south to replace it. Decreasing interbasin flow from Spring Valley will still cause a substantial loss in flow from the springs even if the actual molecules of water flowing from one basin to the other are not diverted from the springs.

White River Flow System: Cave, Dry Lake, and Delamar Valleys

As noted above, Cave, Dry Lake, and Delamar Valleys are part of the White River Flow System and are best considered together due to interbasin flow among them and with adjacent basins. Connectivity among basins within the flow system and in a downgradient direction all the way to the Muddy River make it essential to consider the entire flow system. Simulated recharge in the White River Flow System is 150,800 af/y and pre-development pumpage is 27,200 af/y, resulting in the rate of reduction in storage prior to the beginning of the simulation equaling 8400 af/y, or about a fifth of the existing pumpage (Figure 29). By year 2250, without development existing pumpage would still be removing 3700 af/y from storage (Figure 29). Much of the captured discharge is in White River Valley, but the rate of reduction in storage decreases from 3400 to 600 af/y in WRV because even under the no action alternative losses from storage increase in Dry Lake Valley and Cave Valley from 0 and 100 af/y to 500 and 900 af/y, respectively. So, existing pumping in the White River Flow System does not come to equilibrium and drawdown, as represented by the change in storage, spreads through the flow system.

Pumpage from the WRFS for alternatives E and F, at 45,800 and 56,800 af/y at full build-out, respectively, including pre-existing pumpage (Figure 29), is a little less and a little more than 1/3rd of the recharge for the entire flow system, respectively. At full buildout, alternatives E and F remove 24,000 and 26,700 af/y, respectively, from the WRFS. And after 200 years pumpage still removes 19,400 and 27,100 af/y from storage for alternatives E and F, respectively (Figure 29). This mean that 42% and 47%, respectively, of the amount of water being pumped is water that is being permanently removed from WRFS storage by year 2250. Two hundred years after full buildout, simulations show that a substantial amount of the pumpage is being removed from storage and that the system is not close to coming to equilibrium. The simulations further demonstrate that the removal of water from storage and attendant drawdown spreads outward across the flow system because of the connectivity among the basins in the WRFS.

Simulated recharge in Cave, Dry Lake, and Delamar Valleys is 15,400, 17,300, and 7500 af/y, respectively. Initially large portions of the pumpage draw from storage, and even 200 years after full buildout, pumpage for alternatives E and F are still removing 18% and 20% of pumpage from storage (Figure 29). After 75 years, the 10-ft drawdown for both alternatives extends over the southern half of Cave and all of the Dry Lake and Delamar Valleys (Figures 22 and 24). The depth is mostly less than 50 feet, except for a portion in southern Cave Valley. After 200 years, the drawdown has extended a small distance in each direction, but has mostly deepened so that drawdown depth exceeds 100 feet with some areas exceeding 200 feet for Alternative F (Figures 23 and 25). After 200 years, the 10-foot drawdown extends into

Pahranagat and White River Valleys, and the water table is continuing to decline in a straight line.

The White River Flow System had about 120,000 af/y of ET/spring discharge in 2004 and it decreased by a few thousand af/y during the simulation of buildout and project operations mostly due to reductions in spring flow in the White River and Pahranagat Valleys, as discussed below. The only flow that can be captured therefore is from interbasin flow, which from Cave Valley is into White River Valley, from Dry Lake Valley is into Delamar Valley and from Delamar Valley is to Coyote Spring and Pahranagat Valleys (Figure 16). Most conceptualizations do not show flow into Dry Lake Valley, except for a small amount from Pahroc Valley suggested by two of the studies represented by flow arrows in Figure 16. Flow reductions from Dry Lake Valley eventually would manifest downstream in Coyote Spring Valley and the Muddy River Springs area.

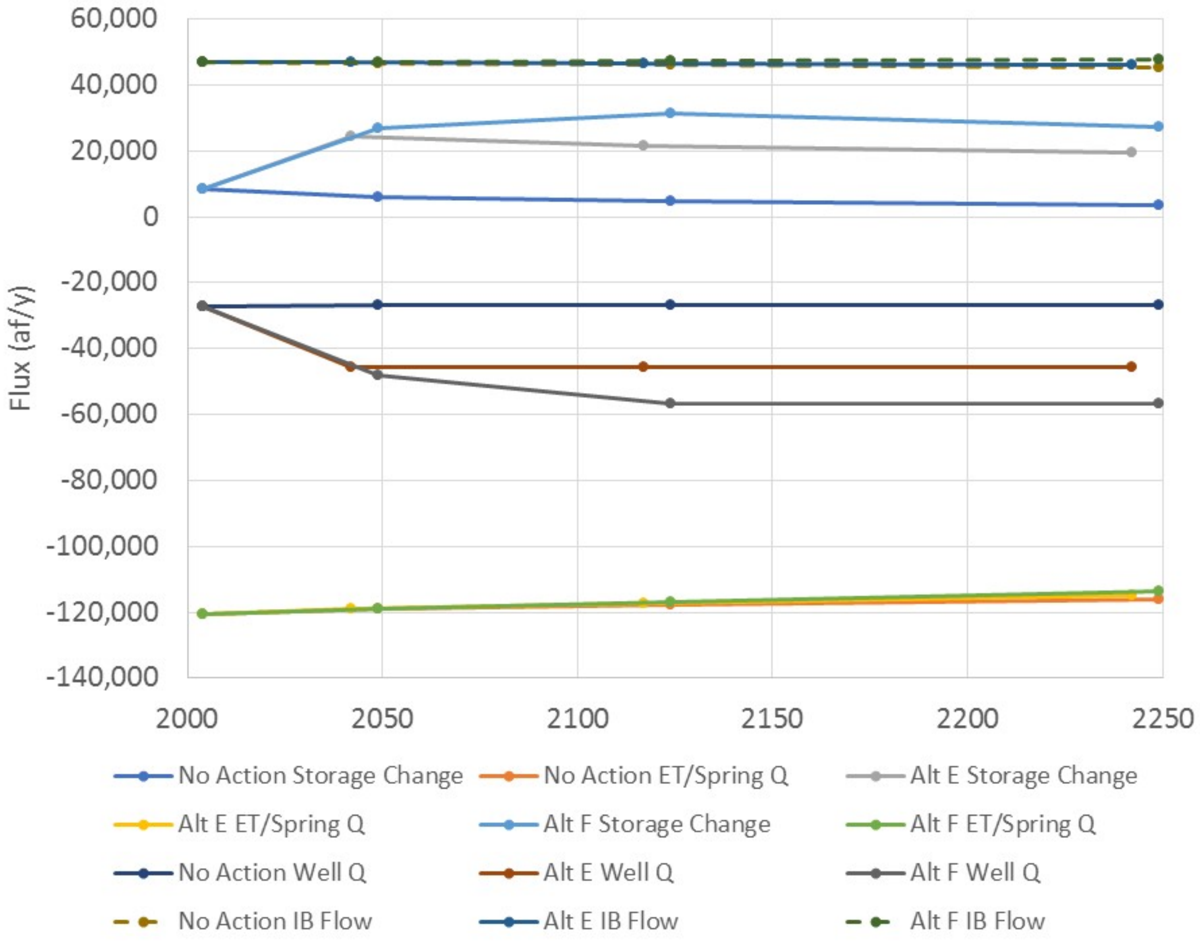

Figure 29: Water budget accounting including storage change, ET/spring discharge (Q), and well pumpage for the White River Flow System for the No Action alternative and Alternatives E and F, as simulated for the FEIS (FEIS Appendix F3.3.16).

Cave Valley

Most of the simulated Cave Valley recharge, 15,400 af/y, becomes interbasin flow and is about a third of the inflow to WRV (Figure 30). Alternatives E and F would pump 4700 and 11,600 af/y, respectively, at full buildout. By 200 years after full buildout, interbasin flow leaving Cave Valley has decreased by about half of the pumpage amount, meaning that after 2250 there still will be a very long period during which SNWA's pumpage in Cave Valley would continue to eliminate interbasin flow to downgradient valleys. The interbasin flow decrease would continue until it finally has eliminated all such interbasin flow permanently (Figure 30). Continued lowering of the water table reflects that much of the pumpage is removed from storage within Cave Valley. By 2250, simulated pumping draws the water table down about 100 and 250 feet for Alternatives E and F, respectively (Figures 23, 25, and 31). The water surface elevation graph in 2250 slopes downward at a constant rate indicating continued linear drawdown would occur well beyond 2250 (Figure 31).

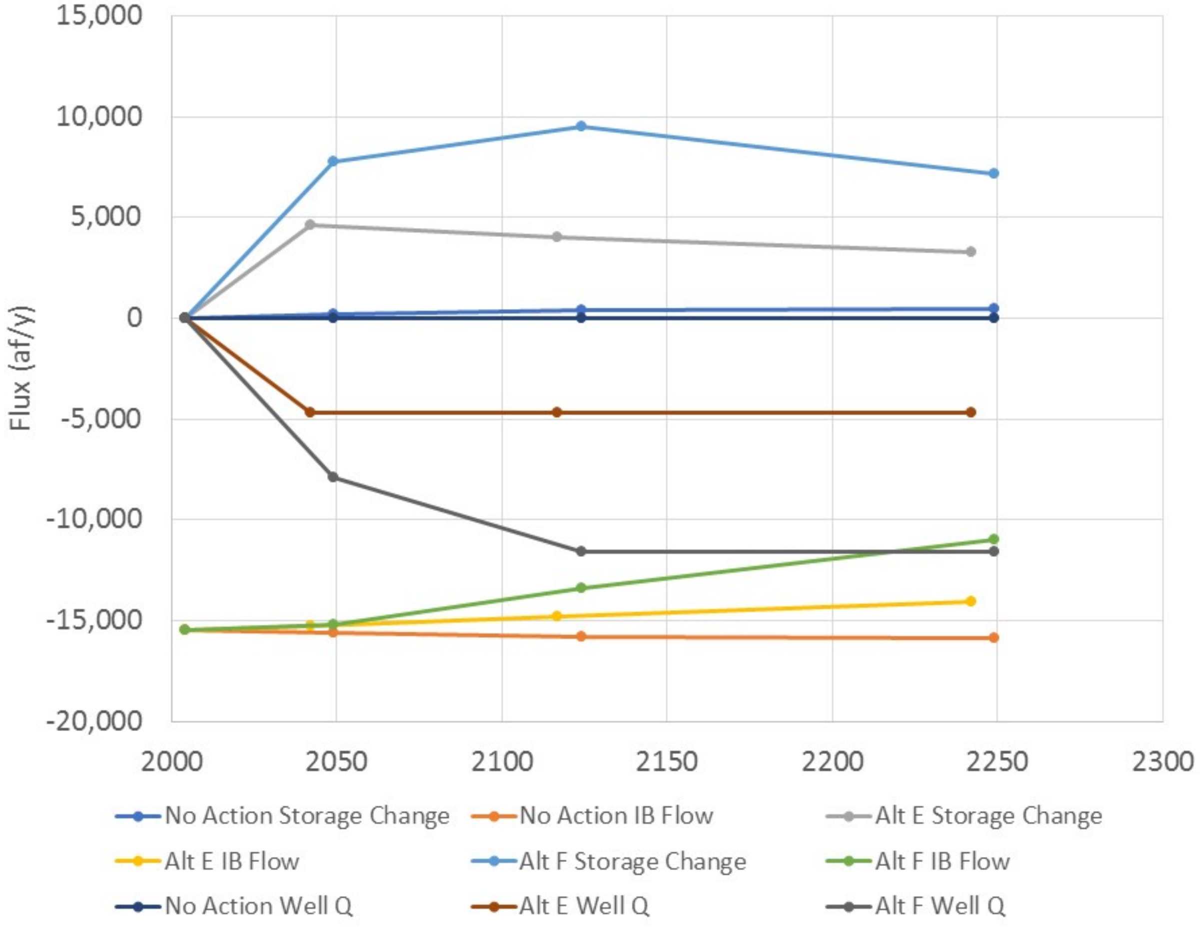

Figure 30: Water budget accounting including storage change, ET/spring discharge (Q), and well pumpage for Cave Valley for the No Action alternative and Alternatives E and F, as simulated for the FEIS (FEIS Appendix F3.3.16).

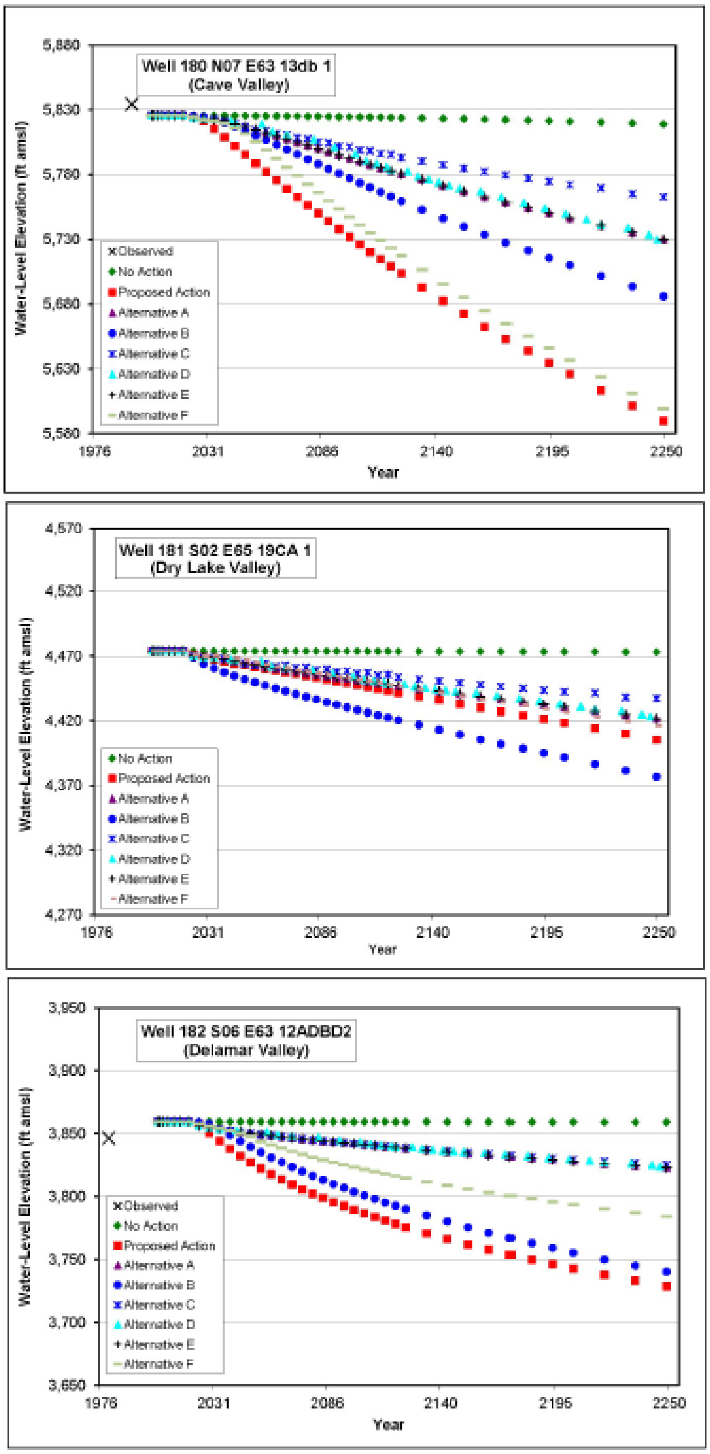

Figure 3.3.2-8 Representative Water-Level Hydrograph for Cave, Dry Lake, and Delamar Valleys

Figure 31: Snapshot of FEIS Figure 3.3.2-8 showing simulated water levels for monitoring points in Cave, Dry Lake and Delamar Valleys for all pumping alternatives.

Springs within the White River Flow System downgradient from Cave Valley lose flow with time due to development of pumping in Cave Valley, with amounts up to several hundred af/y or 5% of their initial flow rates by 200 years after full buildout (BLM undated e). The southernmost springs in White River Valley, Butterfield Springs, Flag Springs #3, Hot Creek Spring, and Moon River Spring, would experience simulated discharge decreases equaling about 70, 100, 170, and 20 af/y, respectively (Id.). In Pahranagat Valley, the four simulated springs, Ash, Crystal, Brownie, and Hiko Springs, would experience simulated flow decreases equaling about 150, 170, 1, and 180 af/y, respectively, for alternative E and all would experience some decreases even for the No Action alternative (Id.). These flow decreases represent up to about 5% of the initial flows from the specific springs. Cumulatively, the flow reductions from springs along the White River Flow System in WRV would total about 860 af/y. The spring flow graphs (Id.) are sloping downward with a straight line meaning that the groundwater would continue to draw down and would not come to equilibrium for a very long time into the future beyond 200 years from full buildout. Because of the connection between Cave Valley and White River Valley and then between WRV and Pahroc and Pahranagat Valleys further downstream, it is likely that much of the pumping in Cave Valley would capture spring discharges in the WRV and that equilibrium would occur only when the spring flow has been reduced by a substantial proportion of the full pumping rate in Cave Valley, whether that rate is as simulated for Alternatives E and F or at a smaller rate.

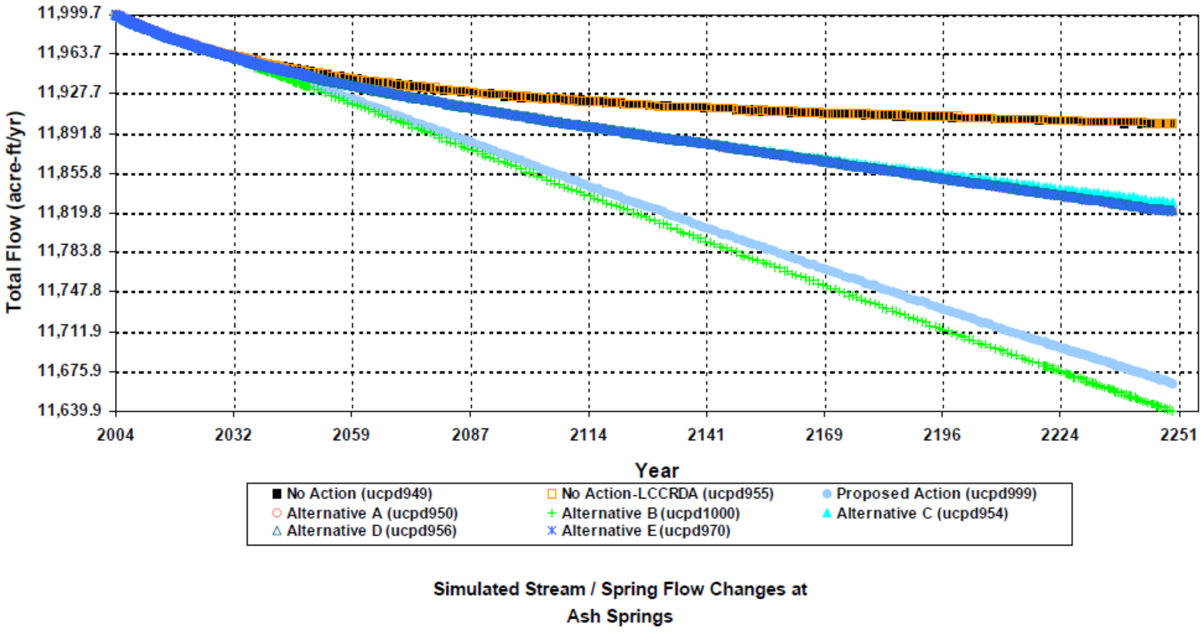

Figure 32: Snapshot of figure from file titled Springs_Hydrograph_Report_2005_2250 (BLM undated e). The graph shows flows at Ash Springs for various alternatives. Alternative F was not included and a file with Alternative F flows was not available. Because it pumps at higher rates, Ash Springs flow would decrease more for Alternative F than for Alternative E.

Dry Lake Valley

Dry Lake Valley has 17,300 af/y of simulated recharge with interbasin discharge to Pahranagat and Delamar Valleys (Figure 33). Both alternatives E and F pump at 11,600 af/y after full buildout, with the only difference being a slower pumpage increase during buildout and to 75 years after full buildout for alternative F (Figure 33); the difference in pumpage during buildout results in less total pumpage during alternative F. The differences in capture of interbasin flow therefore are not substantial. Pumpage for alternative E reduced interbasin flow by 1500 af/y after 2250; pumpage for alternative F resulted in a slight increase in net interbasin flow leaving the valley by year 2250 (Figure 33). This result is counterintuitive but is due to interbasin flow being a net flow. Pumpage in Cave Valley is substantially higher under alternative F, which decreases simulated interbasin flow into Dry Lake Valley resulting in the difference in net interbasin flow.

Storage change accounts for a large proportion of the pumpage in Dry Lake Valley and the rate that the groundwater system releases water from storage has decreased only a small amount by 2250 (Figure 33). The very slow capture of interbasin flow by pumping causes continued substantial releases from storage for each alternative. Dry Lake Valley is unlikely to approach equilibrium for a very long period due to slow capture of interbasin flow even though the valley experiences substantial lost groundwater storage.

However, a model artifact may be limiting drawdown in Dry Lake Valley and preventing the accurate simulated capture of interbasin flow. This is because the model simulates the upper layers of volcanic and carbonate rock aquifers as unconfined. Thus, the model provides water equal to specific yield, or about 0.15 of the volume of the rock. Because the bedrock aquifers likely are confined, the storage coefficient would release water at a rate several orders of magnitude lower than the simulation of an unconfined aquifer suggests. Because the bedrock controls interbasin flow, it is highly likely that treating the upper layer in bedrock aquifers as fully unconfined causes a gross underestimate of the propagation of drawdown into Pahranagat Valley and the extra water release due to draining the pores rather than simple compression (as in confined aquifers) inaccurately supports downgradient spring flow.

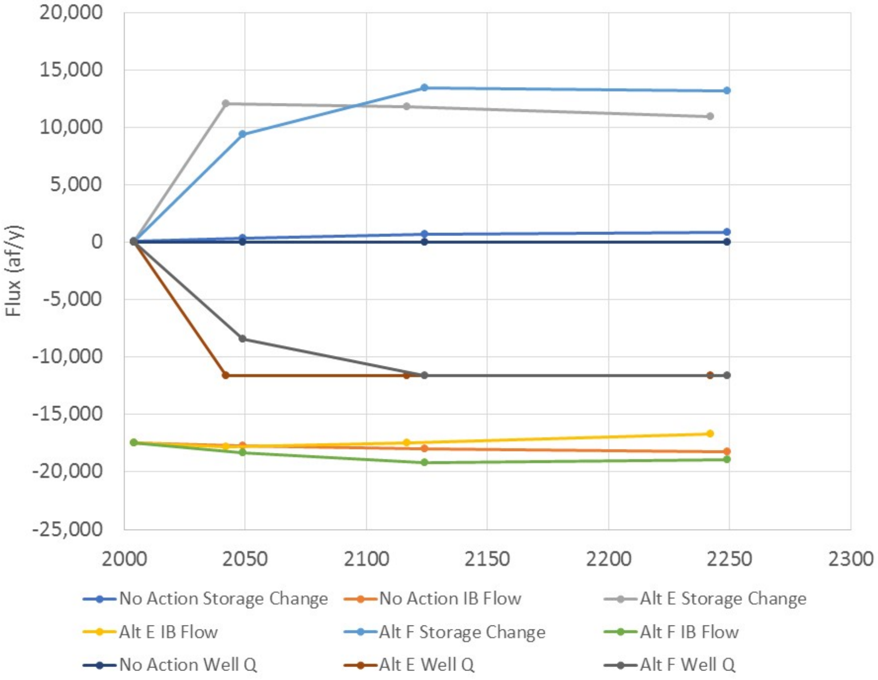

Figure 33: Water budget accounting including storage change, ET/spring discharge (Q), and well pumpage for Dry Lake Valley for the No Action alternative and Alternatives E and F, as simulated for the FEIS (FEIS Appendix F3.3.16).

Delamar Valley

Simulated recharge for Delamar Valley is 7500 af/y which equals interbasin flow out of the basin during pre-project conditions. There is no simulated interbasin flow into the basin. Pumpage for alternatives E and F increases to 2500 and 6600 af/y, respectively, by the end of the simulation (Figure 34). Interbasin flow decreased by half of the pumpage for alternative E and by 2/3rds of the pumpage for alternative F. Storage changes by full buildout are equal to most of the pumpage but then decrease substantially by the end of the simulation (Figure 34). The slope of the groundwater level line for the Delamar monitoring point begins to flatten towards the horizontal (Figure 34), although it would not reach the horizontal for at least a couple hundred more years. Delamar Valley is the only simulated basin in which pumping would capture most of the interbasin flow to downgradient basins (or ET/spring discharge) within a few hundred more years after pumping.

The same issue as for Dry Lake Valley regarding simulation of bedrock aquifers as unconfined applies to Delamar Valley. Delamar Valley pumping would more quickly capture substantial interbasin flow if the upper model layer of bedrock were simulated as confined.

The geology indicates that groundwater could potentially flow from Delamar to Pahranagat Valley at the north through carbonate rock or at the south end through the Pahranagat Shear Zone (Figure 15). Groundwater flow could enter Pahranagat upgradient of all the primary springs, or at the far south end to the springs at the south end of Pahranagat Valley (Figure 16). Ash Springs spring flow decreased about 180 af/y for Alternative E by the end of the simulation, and continues after year 2250 to decrease at the same rate (Figure 32).

Delamar Valley is the furthest south and closest to the downgradient end of the WRFS and therefore reductions in interbasin flow from Delamar Valley would most quickly affect flows through Coyote Spring and Moapa Springs basin. Although Delamar Valley may be, of the four basins considered here, the quickest to approach equilibrium, it does so at the expense of directly drawing flow from the Muddy River Springs, as discussed next.

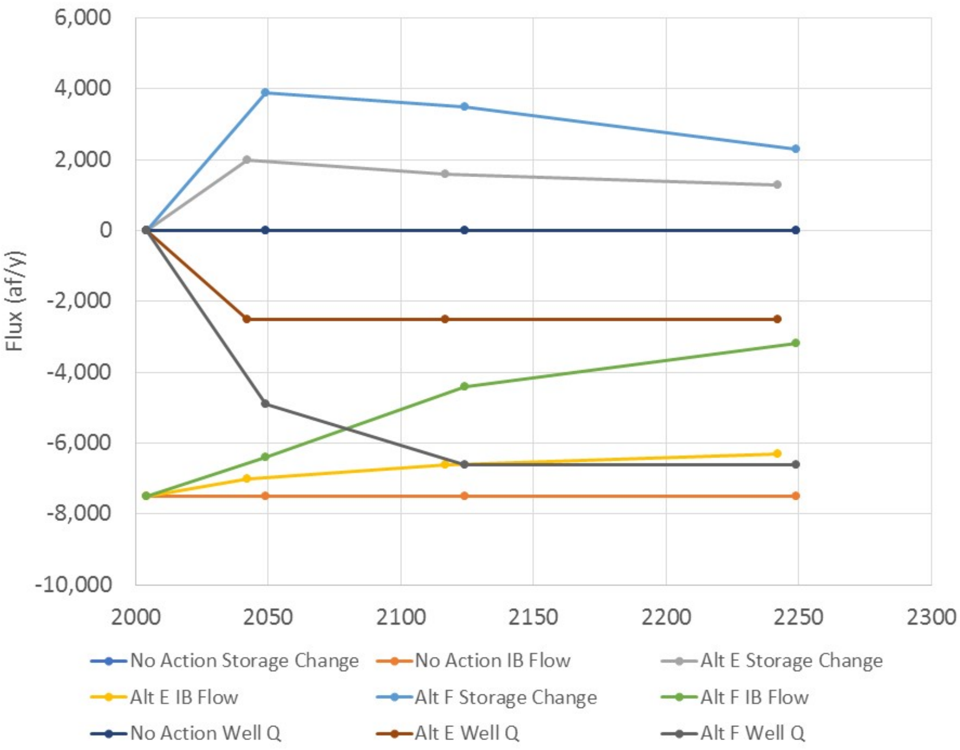

Figure 34: Water budget accounting including storage change, ET/spring discharge (Q), and well pumpage for Delamar Valley for the No Action alternative and Alternatives E and F, as simulated for the FEIS (FEIS Appendix F3.3.16).

Muddy River Springs

Muddy River Springs are a spring system near the downstream end of WRFS. The CCFS model has four discharge points along the Muddy River using the stream package (which allows water to either enter or leave the water balance accounting). Low conductivity model cells and horizontal flow barriers direct groundwater flow toward the discharge boundary. The boundary Muddy River near Moapa is at the upstream end of the Muddy River discharge points and should reflect changes in the groundwater flow system upstream. Simulated discharge decreases almost 2000 af/y from 2004 to 2250 (Figure 35). Because of the decreases in flow from Delamar to Coyote Spring and Kane Springs Valleys (Figure 35), which are upstream of and tributary to the Muddy River system, decreases in discharge from these springs will likely continue far into the future, beyond 200 years. This indicates that the overall system will not approach equilibrium for a very long time beyond end of the simulations period. However, there may be model-based reasons that pumpage stresses have not propagated to the Muddy River springs area, as discussed in the next paragraph.

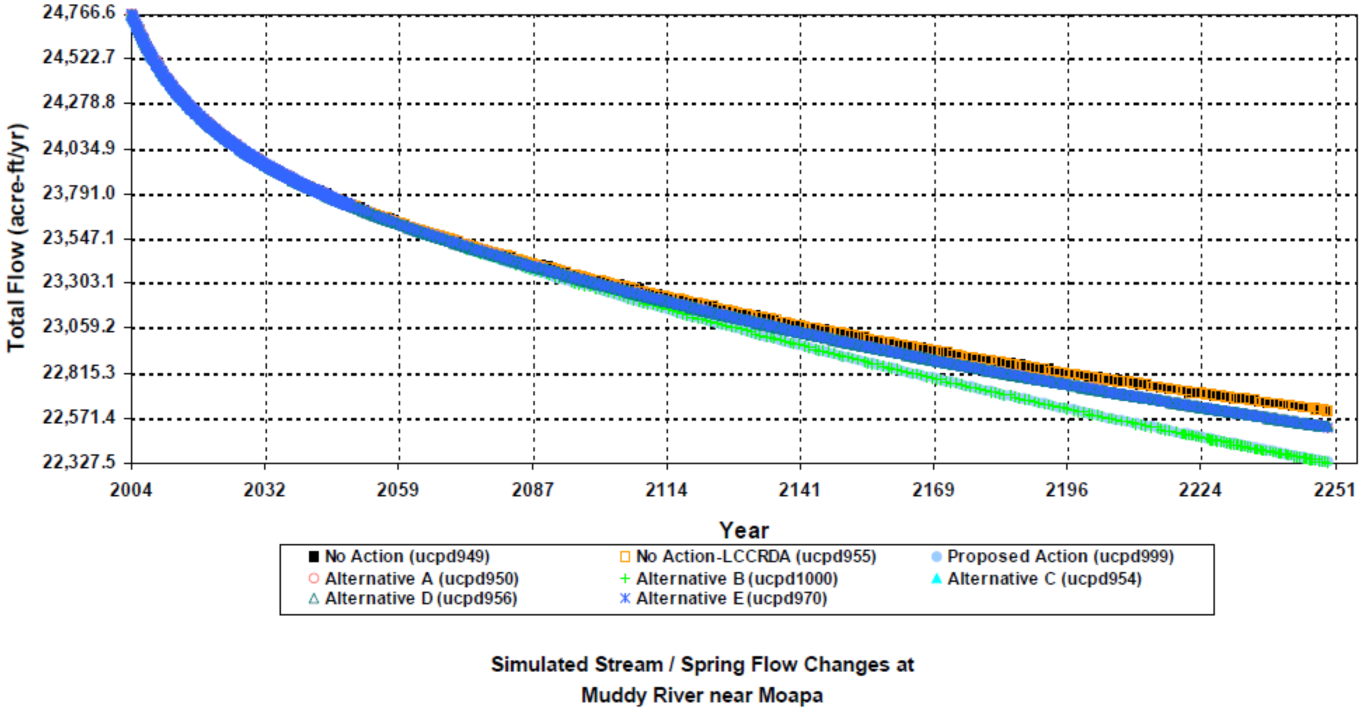

Figure 35: Snapshot of figure from file titled Springs_Hydrograph_Report_2005_2250 (BLM undated e). The graph shows flows at Muddy River Springs for various alternatives. Alternative F was not included and a file with Alternative F was not available. Because it pumps at higher rates, Muddy River Springs flow would decrease more under Alternative F than for Alternative E.

The CCFS model simulated groundwater flow through carbonate formations and fault systems in the southern end of the White River Flow System. The model grid cells are one kilometer square. Most interbasin flow to Coyote Spring Valley emanates from Pahranagat Valley with additional flow from the northeast (Delamar and Kane Springs Valleys) and from the west (Death Valley Flow System) (Figure 16). Some of the flow from Pahranagat Valley entered that valley from Delamar Valley (Figure 16). Most of the interbasin flow, 49,200 af/y, exits Coyote Spring Valley into the Muddy River Springs area (Figure 36). Decreases in the interbasin groundwater flow that supports the spring discharge at the Muddy River near Moapa would manifest at the Muddy River near Moapa gage. However, the modeling minimizes potential flow changes because it does not accurately represent the hydrogeology of the model domain area that allows flow from upstream to reach the Muddy River Springs and that releases water from the aquifer pores spaces in response to pumping. The model cells are far too large and average too much variability in properties to accurately portray preferential flow through carbonate formations which would support the springs.

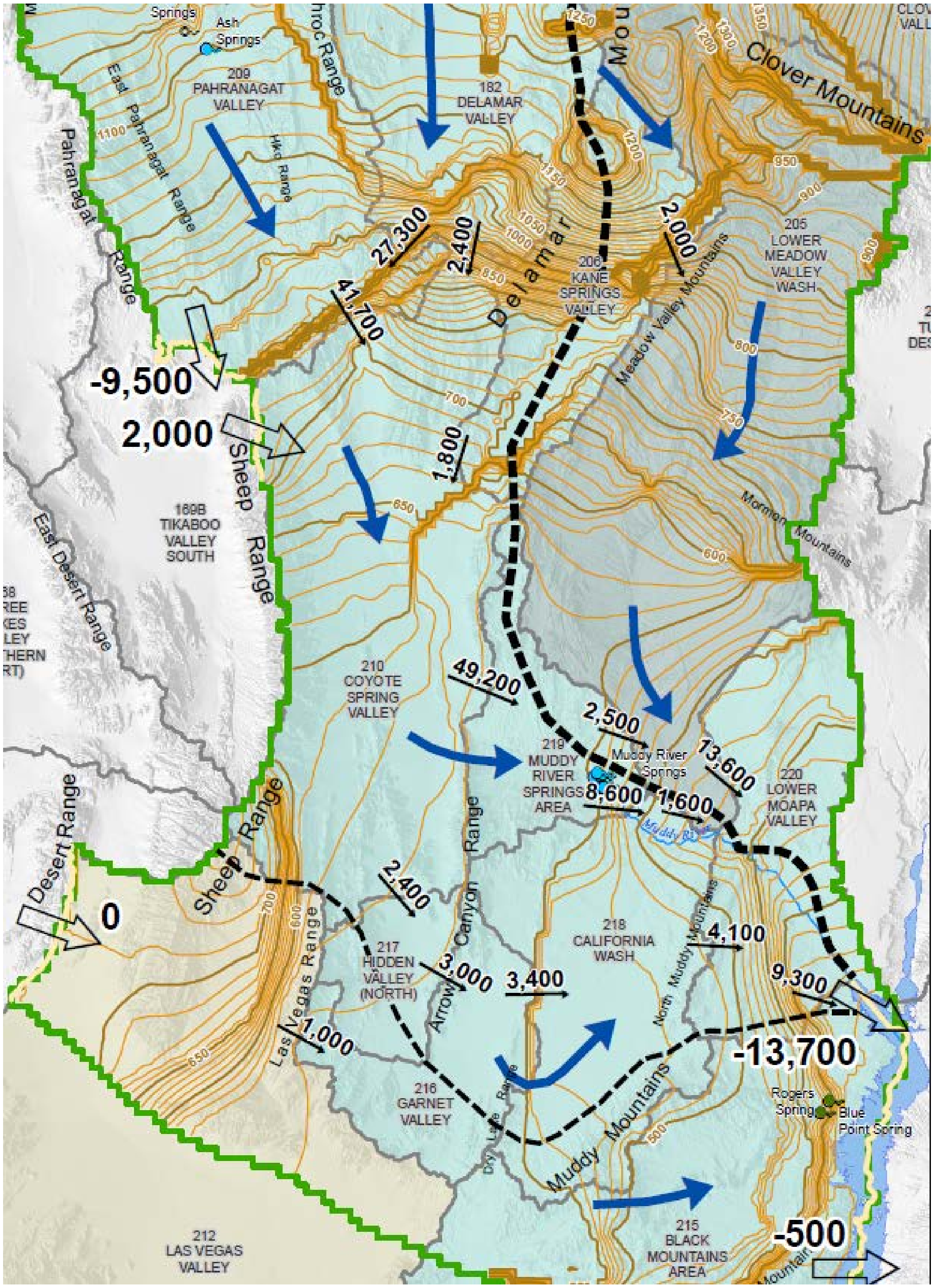

Figure 36: Snapshot of portion of Plate 2 (SNWA 2009a) showing water table contours (10 m), steady state interbasin flow values (af/y) and spring locations.

The surface formations in the southern portion of the area are generally carbonate rock with displacement faults that provide high conductivity pathways (Figure 37). The valleys are basin fill (Figure 37). North of Coyote Spring Valley there is more volcanic rock, although at depth there is some carbonate rock (Figure 37). Displacement faults provide a north-south conduit for flow, but none of the displacement faults, as simulated, connect the northern valleys such as Pahranagat with the Muddy River Springs area (Figure 37). The Pahranagat shear zone across the south end of that valley (Figure 37) causes the substantial drop in the water table across the shear zone (Figure 36). The model simulates the shear zone with horizontal flow barriers with relatively high conductivity carbonate rock.

Simulation of flow depends on the conductivity of the formations, with high conductivity zones along fault lines simulating flow along the fault. Parameterization for the area reflects carbonate rock hydrogeology with much higher conductivity for the fault zones, which the model simulates as 3280 feet or 1000 m wide (Figure 38). There is no evidence that faults affect flow over such a wide zone with conductivity two orders of magnitude higher than outside the fault. Caine et al (1996) describes how faults can be a barrier or a conduit, but provides nine examples of faults that are mostly less than 100 m wide, which is much less than the 1000 m wide cells in this model. SNWA (2008b), the geology study that forms the basis for the groundwater flow model, does not document the width of any faults nor show the importance of fault flow. The document notes that fault damage zones in carbonate rock may undergo dissolution to create large flow zones, but does not present any examples or references. Studies have shown that most flow through faults is concentrated in a very small portion of the fault, which would be a factor of the formation of the flow path. For example, for a geothermal fault system in the Great Basin northwest of this study area, Fairly and Hinds (2005) found that, based on detailed mapping of conductivity in an 800 by 100 m fault zone, the truly high permeability pathways conduct a very small proportion of the flow. “On the basis of our findings, we conclude that the flux transmitted by an individual fast-flow path is significantly greater than that of an average flow path, but the total flux transported in fast-flow paths is a negligible fraction of the total flux transmitted by the fault” (Fairly and Hinds 2005, abstract).

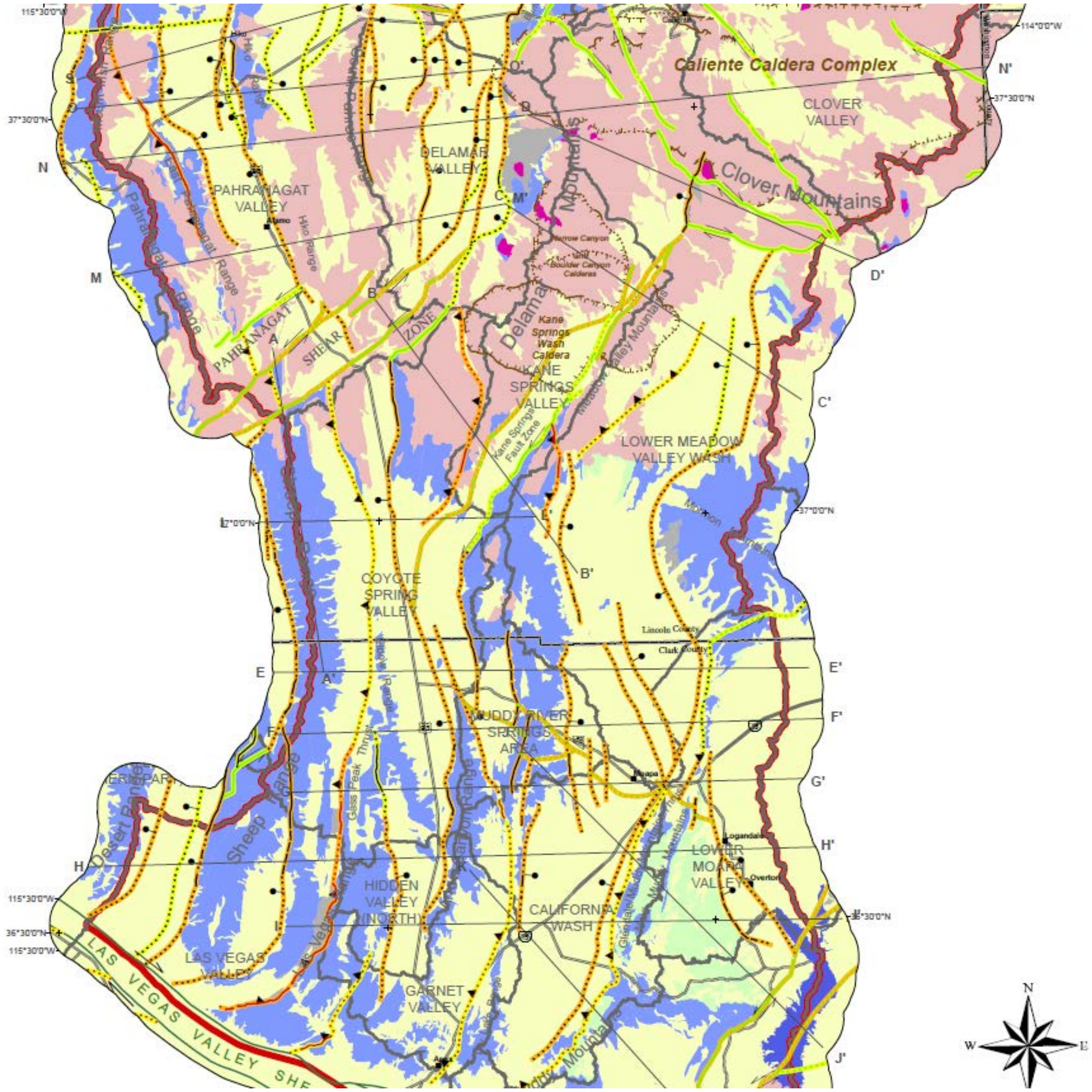

Figure 37: Snapshot of portion of Plate 2 (SNWA 2009a) showing surface geology and structure centered on Coyote Spring Valley with portions of surrounding valleys.

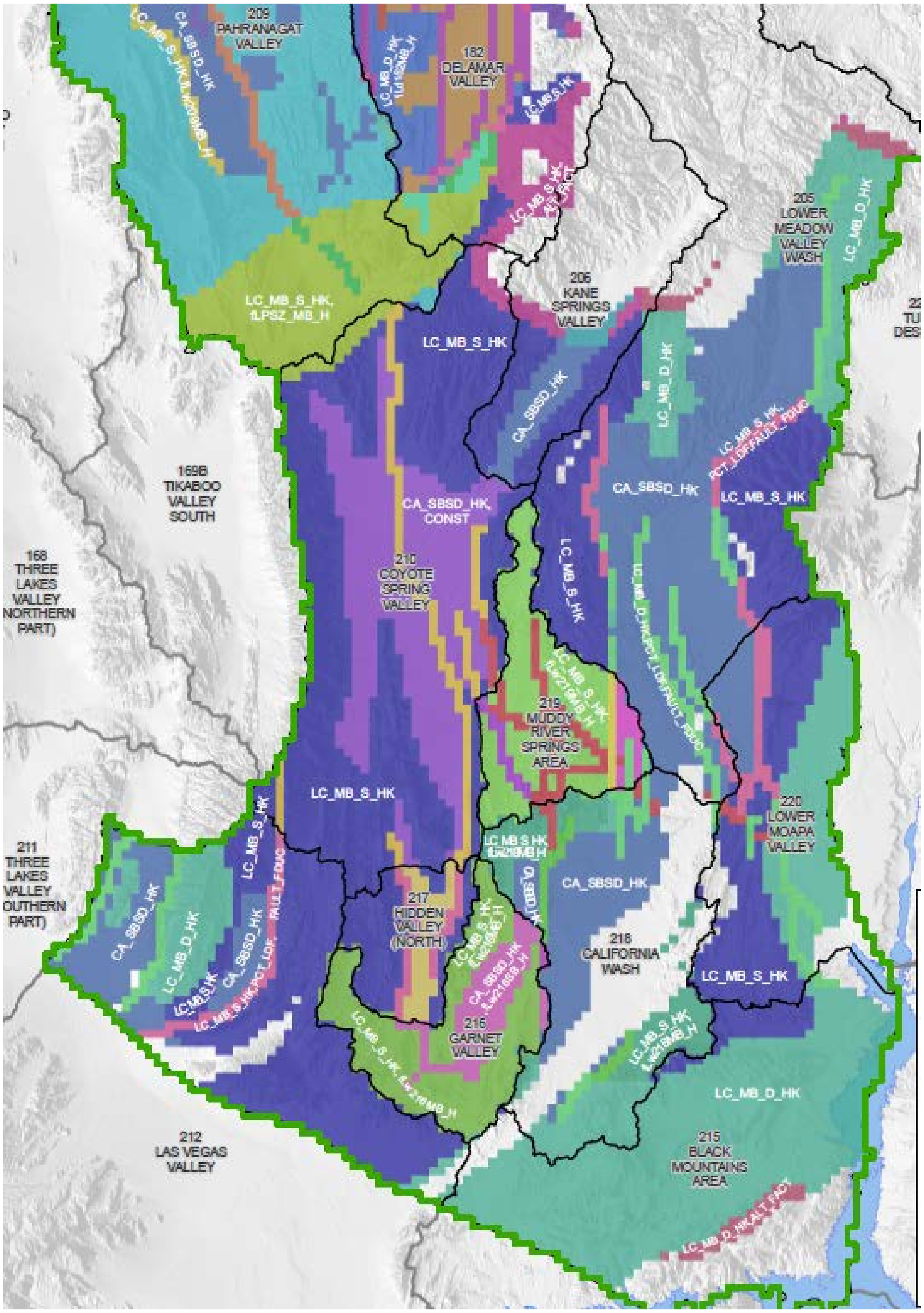

Figure 38: Snapshot of southern portion of the CCFS from Plate 1 (SNWA 2009d) showing parameter zones for carbonate rock formations.

SNWA in previous reports discussed broad fault zones but provided no evidence that can be verified. Burns and Ricci (2011) noted that the orientation of major faults influences the direction and rate of flow and suggested that some faults are as wide as 3 miles. “An examination of some geologic maps provides examples of widths of large fault zones ranging between 0.5 to greater than 3 mi. Additional details regarding groundwater flow in faults are provided in Rowley et al. (2011)" (Burns and Ricci 2011, p 2-9). The Rowley et al report cites several geologic maps that label several areas as fault zones with only one being from the study area[3]. None of those maps describe the fault zone in a way that would indicate the zone differs from that described by Fairly and Hinds (2005) or that would justify the conductivity over a 1000 m wide cell being two orders of magnitude higher than the surrounding rock. Rowley et al (2011, p 2-11) stated that in Section 5 of the that report that "[D]etailed, high-quality geophysics, including seismic and audiomagnetotellurics (AMT) profiles and also gravity and aeromagnetic anomalies, provides even better estimates of fault widths." That section presents substantial geophysics but at no point provides width or thickness of fault zones nor does it discuss the hydrogeology of faults.

Even though a fault affects flow over a few tens of meters of width (Caine et al 1996) and significantly increases the conductivity over a much smaller proportion of the fault thickness, the CCFS model parameterizes faults over a 1-km width cell. With very high conductivity for pathways at least 1-km in width and up to 12,000 feet in thickness (up to seven model layers), the model transmits a very large flow rate to the Muddy River springs even with a very flat gradient, as described in the next paragraph.

Conductivity in the seven layers in the conduit shown in Coyote Spring Valley from layers 1 through 7 is 0.0278, 22.1, 61.4, 51.8, 40.2, 27.7, and 17.7 ft/d (Figure 39). Figure 39 does not specify layer thickness but the bottom is at -10,000 feet and the upper layer is at about 2000 feet; the upper layer with low conductivity is very thin. The average conductivity of the lower six layers is 36.8 ft/d, not weighted for layer thickness because the thicknesses are not provided. Gradient across a cell is quite variable, but the contours suggest about 20 feet over 3280 feet, or about 0.0061 ft/ft. Applying Darcy's law, the flow through just one north-south column of cells would be about 67,900 af/y. There would be flow exchange between the high K and surrounding lower K cells due to the surface not being perfectly flat. Figure 39 shows groundwater contours, in the upper cross-section showing conductivity by model cell and in the lower plan view, that converge on the high conductivity flow path that represents a fault zone.

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[3] Ekren EB, Hinrichs EN, Quinlivan WD, Hoover DL (1973) Geologic map of the Moores Station quadrangle, Nye County, Nevada: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-756, scale 1:48,000. Swadley WC, Page WR, Scott RB, Pampeyan EH (1994) Geologic map of the Delamar 3 SE quadrangle, Lincoln County, Nevada: U.S. Geological Survey Geologic Quadrangle MapGQ-1754, scale 1:24,000. Billingsley GH, Workman JB (2000) Geologic map of the Littlefield 30' × 60' quadrangle, Mohave County, northwestern Arizona: U.S. Geological Survey Geologic Investigations Series Map I-2628, scale 1:100,000. Dixon GL, Hedlund DC, Ekren EB (1972) Geologic map of the Pritchards Station quadrangle, Nye County, Nevada: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-728, scale 1:48,000.

Exchange of flow across the cell walls would cause the actual flow to vary along the north-south profile of the high-K flow pathway.

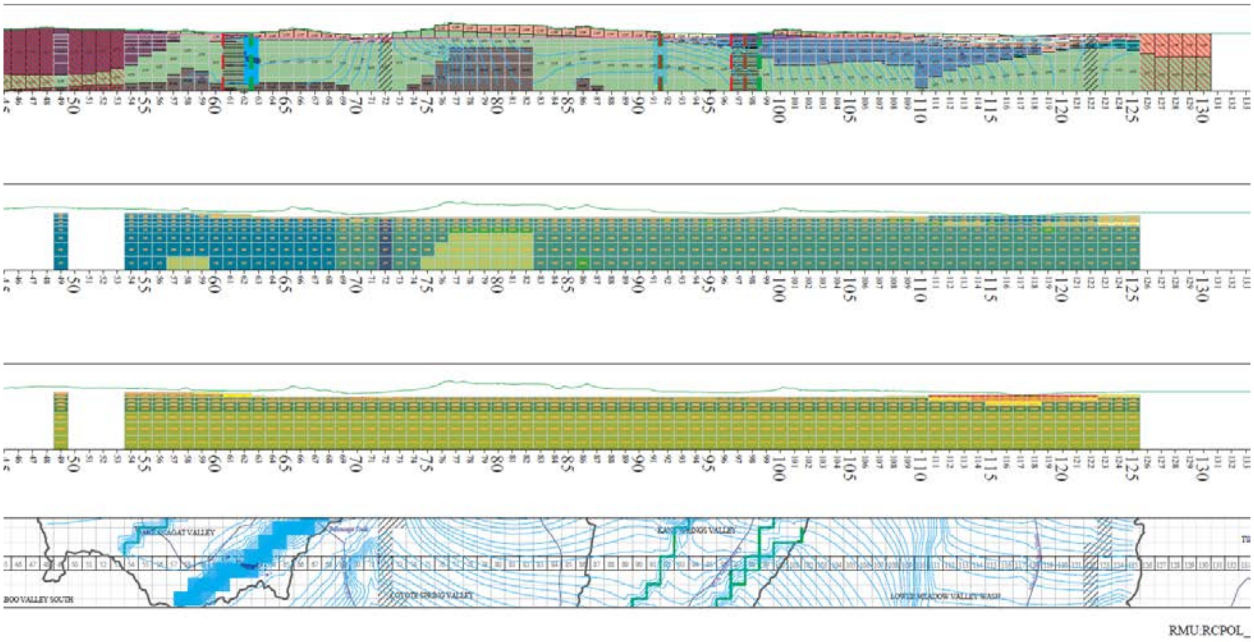

Figure 39: Snapshot of part of model row 359 from file xs>rmu>rows>rev2-7o-map-hd-kh-s-11lay-ucth813-1-474B showing the modeled formations (top row), conductivity (2nd row), specific storage (specific yield uppermost layer) (3rd row), and plan of 7 rows showing steady state water table contours and simulated faults. This section crosses the southern Pahranagat Valley (left), northern Coyote Springs Valley, central Kane Springs Valley, and Lower Meadow Valley Wash on the right. The green, blue, and purple in the upper row is carbonate rock with the cross-hatched column being a significant displacement fault. The second row is conductivity with the green ranging from 0.1 to 0.5 ft/d, the blue on the left being from 1.5 to 4.0 ft/d, and the vertical dark blue column ranging from 61.4 ft/d to 17.7 ft/d (3rd layer to bottom layer) to model the displacement fault. The third row is specific storage which ranges from 0.000196 ft-1 in the lower layer to .00006 in layer 3; there is no difference in the displacement fault. Water surface contours are 10-foot with the dense cluster on the southeast Pahranagat Valley being a 700 foot drop from about 3100 to 2400 feet, from NW to SE.

The specific storage values for the carbonate rock specified in the conceptual model report (SNWA 2009a) averaged 8.26×10^{-6} ft^{-1} with a maximum and minimum value equal to 1.24×10^{-5} and 4.67×10^{-7} ft^{-1}. The calibrated values used for the numerical model for carbonate rock near Coyote Spring were 1.95×10^{-4}, 1.35×10^{-4}, 9×10^{-5} or 6×10^{-5} ft^{-1} (Figure 39). Thus, the calibrated values are one to two orders of magnitude higher than the range identified in the conceptual model. This same trend occurred throughout the CCFS model domain. Also, the larger specific storage values were near the bottom of the section. This does not comport with expected specific storage which should be smaller as the pores become more compact with depth.

Specific storage values set higher than they should be would cause the model to release one to two orders of magnitude more water for a given change in head. Simulated pumpage would cause substantially less drawdown because more water would be pumped for each foot of drawdown. In Coyote Spring Valley and the Muddy Springs area, the simulated water level lowering caused by decreased inflow to the valley would be substantially less. The large area with high storativity effectively creates a very large reservoir of water within the model that the model releases to support the springs.

Summarizing, the CCFS model developed by SNWA allows far too much water to flow to the Muddy River Springs much easier than would naturally occur. This is because the fault flow paths have a much too high transmissivity because of very large model cell sizes with very high conductivity values over very thick sections of aquifer, and because the storage coefficients within these model cells are set much higher than observed so that the model releases unrealistically high amounts of water for every decrease in water level. The model artificially suppresses the likely effects of proposed pumping on Muddy River Springs in the alternative.

Concerns about the potential effect that development of SNWA water rights would have on interbasin flow and downgradient spring flow and water rights is critical in light of the State Engineer's Carbonate Order 1169. That order recognized testimony in the Kane Springs hearing that 50,000 af/y enters Coyote Spring Valley from northern groundwater basins, that 37,000 af/y discharges from the Muddy River Springs area, that the Muddy River Springs discharge is fully appropriated pursuant to the Muddy River Decree and that approximately 16,000 to 17,000 af/y flows to basins further south (State Engineer Order 1169, page 5). In the Kane Springs Ruling 5712, the State Engineer referred to 37,000 af/y entering Coyote Spring Valley from Pahranagat Valley. The two basins with the largest amount of spring flow and groundwater ET, White River Valley and Pahranagat Valley, are close to fully appropriated. SNWA water rights development will either take flow from those basins, thereby harming water rights holders within those basins, take flow from the fully appropriated Muddy River Springs, thereby taking water rights from those water rights holders, or do both.

Further Pumping to Equilibrium Considerations

Two different models have considered pumping to equilibrium in parts of the CCFS, and both found that it would require far more than 2000 years to approach equilibrium.

Bredehoeft and Durbin (2009) simulated pumping the WRFS portion of the CCFS, and found that after 2000 years, the system was not close to reaching steady state. "The storage should level out and reach a stable level as the system reaches a new equilibrium …, but this system is not close to reaching a new equilibrium state after 2000 years of projected pumping. A plot of the predicted ET vs. time … shows that the system has not reached a new equilibrium in 2000 years." (Bredehoeft and Durbin 2009, p 6).

Myers (2011c, d) simulated pumping the Spring Valley applications, for the full application rate and for one third of the full application rate, for 10,200 years. Myers' (2011c) model included Spring and Snake Valleys with adjoining valleys simulated using various boundary conditions. At the full application rate, the simulations showed more than 90,000,000 af of water being removed from storage after 10,200 years, with that water coming from Spring and Snake Valleys, with additional flow drawn from Steptoe Valley (indicating lost groundwater storage in that basin as well) (Myers 2011d, p 24-27). Pumping at one-third of the full application rate removed 26,500,000 af of groundwater from storage and was continuing to remove an amount equal to about 1200 af/y, or 4% of the pumpage amount, after 10,200 years (Id.). Even with substantially decreased pumping rates the Spring/Snake Valley system did not approach equilibrium in more than 10,000 years (Id.), and the drawdown and lost groundwater storage was immense.

Monitoring, Management and Mitigation Plans

The primary function of groundwater monitoring in the study area must be to protect the groundwater resource, as it supports private water rights to groundwater and springs and streams and groundwater dependent ecosystems (GDEs), such as springs and wetlands. Monitoring would not be done for its own sake, but to protect existing water rights and valuable GDEs and to obtain data to improve future models of the area. Monitoring can be of water levels, for which either drawdown or actual water level elevation is determined, or of flow rates, such as discharge to a spring. Either the water level, drawdown, or flow rate should be compared to trigger levels which have been determined to represent a threshold beyond which further reduction will result in deleterious changes to a GDEs or water right. Trigger levels must be designed to provide a warning that such a threshold is being approached with sufficient lead time to allow for prevention of harm.

Once thresholds are reached, management comes into play meaning that the pumping regime must be changed to prevent further damage. Trigger points must allow sufficient time for the implementation of management changes that will protect the resource. Bredehoeft and Durbin (2009) illustrate the problem with this aspect of management – there is a delayed response between the observation of an impact and its maximum effect and there is a long lag time between implementing a management change, typically changing the pumping stress, and observing the effect of that change at the point of interest. Bredehoeft and Durbin used a simplified pumping situation to show how difficult it is over the long term to protect a spring, even when the spring is the only discharge from the system and when the management prescription is complete shutdown of pumping. Most 3M plans envision changing the location of pumping stresses with some small reductions, but in a large complex system, complete cessation of pumping requires an extremely long time to work through the system to the GDE or water right being protected.

If management fails to protect the resource, mitigation may be implemented. Mitigation usually means replacing the lost water, and sometimes is broadened to encompass measures ostensibly designed to replace a potentially lost ecosystem or ecosystem function with something similar elsewhere. The latter type of approach to mitigation would not be acceptable in this study area because it would allow the degradation and destruction of resources in the project area that are required to be protected. Therefore, this report does not consider that less accepted approach further. Replacing lost water at a GDE or water right usually means moving water from one place to another within the same region, so it usually means transferring the problem to a different area and possibly creating a greater cumulative problem. Mitigation can only be acceptable if it involves providing water from a basin or groundwater flow system that is not connected to the one in which mitigation is required.

A monitoring, management, and mitigation (or 3M) plan must include a plan to monitor groundwater levels and flow rates that represent GDEs and water rights with a plan to implement management if various triggers are reached. Mitigation occurs when management fails. This section first describes GDEs in more detail, followed by a general description of what should be considered in a 3M plan, based on a broad consideration of relevant literature.

Groundwater Dependent Ecosystems

Capturing groundwater discharge requires that groundwater be taken from wetlands and springs. These features may not have appropriative water rights associated with them, but they often are in themselves, or they are necessary to support, important environmental resources that should be protected as part of the public interest. They are GDEs because taking their groundwater will cause them to cease to exist (Brown et al 2011; Howard and Merrifield 2010). The concept of a GDE is important because protecting groundwater for human uses often does not suffice to protect it for environmental needs. A private appropriative spring water right can be replaced by a shallow well, but the functionality of the spring in the ecosystem is lost, causing a significant environmental impact. As described in Howard and Merrifield (2010):

> Groundwater plays an integral role in sustaining certain types of aquatic, terrestrial and coastal ecosystems, and their associated landscapes, by providing inflow which maintains water levels, water temperature and chemistry required by the plants and animals they support. Groundwater provides late-summer flow for many river and can create cool water upwelling

> critical for aquatic species during high temperatures, and groundwater is the only water source for springs and subterranean ecosystems which harbor a distinct and poorly understood fauna.

Howard and Merrifield (2010) also recognize the differences among GDEs based on the groundwater flow mechanism that supports the ecosystem. Distinctive springs are often discharge from relatively deep groundwater flow systems. Many examples occur throughout the CCFS. Discharge also supports dry-weather flow in rivers and streams. In the CCFS, this is most important in springs in the WRFS and lower-elevation streams in the Snake Range. Wetlands are often discharge of shallow groundwater flow, although in the CCFS deep groundwater may circulate to shallow aquifers that support wetlands from below. Phreatophytic vegetation extracts moisture from the water table, with their roots at least seasonally in the water table. This vegetation occurs most often in the CCFS in the lower elevations of the basins and near the playas. Not mentioned by Howard and Merrifield (2010) would be the playas, some of which exfiltrate groundwater which supports ecosystems on the playa and contributes to cohesion in the soil which prevents it from blowing away. Additional GDEs that groundwater development could affect include subterranean ecosystems (Brown et al 2011).

Extensive groundwater development in the CCFS would affect these GDEs. Development would be of both basin fill aquifers and carbonate aquifers. The basin fill aquifers provide water to wetlands and phreatophytic vegetation. Carbonate aquifers provide water to the large regional springs and rivers in the WRFS. The aquifers are connected, so drawdown in the carbonate aquifer could lower the water table by decreasing upward flow into the basin fill thereby affecting wetlands and phreatophytic vegetation.

Monitoring, Management, and Mitigation Plan Basics

While there is no simple, uniform boilerplate format for a 3M plan that must be implemented in all cases, and each plan must be specifically designed for the area being monitored, there are widely recognized standards and minimum requirements that must be included in a 3M plan for that plan to be considered effective. At a national scale, groundwater monitoring is necessary to make nationwide decision about large-scale water management questions (Subcommittee on Ground Water of the Advisory Committee on Water Information 2013, Committee on USGS Water Resources Research et al 2000). The National Groundwater Monitoring Network, run by the US Geological Survey, is an example of such a scale. States may have similar monitoring networks (such as Montana at http://mbmggwic.mtech.edu/ or Nevada at http://water.nv.gov/WaterLevelData.aspx), not focused on a specific problem but rather providing large-scale data to identify problems that could result from development or possibly climate change (Subcommittee on Ground Water of the Advisory Committee on Water Information 2013, Committee on USGS Water Resources Research et al 2000).

Smaller scale 3M plans usually are site specific with a focused intent. For the dispersed water rights applications and large-scale groundwater development proposed here, it is necessary to protect other water rights and GDEs within both the target basins and hydrologically connected basins within the study area. Because they are interconnected, groundwater and surface water behave as if they are one source of water (Winter et al. 1998), and so taking from one affects the other. For that reason, monitoring a complex system requires monitoring of both surface and groundwater.

Four steps emerge as being necessary for the establishment of an adequate monitoring plan.

1. Identify the GDEs and water rights that should be protected. Determine what is necessary to protect them. Groundwater rights and wetlands may require a minimum depth to water whereas a spring may require minimum flow rates.
2. Develop a localized conceptual flow model that describes the hydrologic system that supports each GDE and water right. This would be more detailed than a CFM used for the entire region because broad-scale flows do not describe small features well. For example, some springs may be perched but could be affected by long-term drawdown beneath a confining layer.
3. Implement the more refined CFM to determine the level of drawdown or other measurable effect that would signal impending impacts to the GDE and water right. This may require numerical modeling or data collection to do correlation analysis of the relationship between the data and the protected feature. These levels are the triggers that monitoring would be designed to detect and prompt management changes. A regional model used for the overall project probably would not be sufficiently detailed to understand flow at individual sites.
4. Determine the type and location of monitoring that would allow the prediction of changes at the GDE or water right. Where does drawdown occur in advance of problematic changes in the flow rate or prior to reaching the GDE or water right being protected? Uncertainty should inform these decisions, with more monitoring required and more conservative trigger levels applied where impacts are less certain.

SNWA's monitoring approach relies on a broad scale conceptual model (SNWA 2009a), which renders SNWA's existing 3M approach worthless. The details of a connection between groundwater and spring flow are likely too complicated to be accurately described by the CFM used for a basinwide model, which is why detailed CFMs are needed for each GDE and water right. Large-scale models (SNWA 2009a, d) simulate an entire aquifer's response, whereas layering would probably cause variation in head throughout the aquifer. Model-simulated drawdown for a large aquifer may not represent accurately the portion of the aquifer that controls the spring flow of an individual spring or GDE. Each spring may require its own specific

CFM. Even if the correct portion of the aquifer is identified for monitoring by a large scale CFM, setting triggers based on the larger scale model will not be reliably accurate.

Springs require monitoring of both discharge and groundwater levels at a location appropriate for predicting the discharge. Groundwater level would correlate with discharge, and could provide a warning if properly sited. Monitoring perched springs could require paired piezometers to monitor gradient between shallow and deeper aquifers. SNWA's modeling to date either was not accurate for many springs or did not attempt to simulate some of them. Many of the springs are either perched or a combination of flow from deep and shallow aquifers. The models do not distinguish among the contribution of different aquifers very well. At a reasonable distance from the GDE or water right, monitoring should be of shallow as well as deeper groundwater to understand the vertical gradient controlling the flows to the spring. It is essential to monitor groundwater far enough from the point of discharge to detect a difference that will cause a flow change because spring flow can decrease without there being a drawdown at the site but only a change in gradient (Currell 2016).

Monitoring within an area should commence prior to development to establish a baseline against which impacts can be compared. Baseline monitoring for spring flow must include groundwater level, or levels in the case of perched springs, and flow, so that statistics can be used to estimate flows based on groundwater level.

Triggers must be determined based on what will affect the features, not on whether the decline in monitored water levels exceeds what was predicted in the FEIS. For example, in Inyo County, the 3M plan for Owens Valley (Geosyntac and Ganda 2014) uses triggers approximately an order of magnitude more sensitive than the general trigger levels proposed by SNWA. This is a striking contrast, because the model relied on in Inyo County predicted only small impacts whereas the model here predicts more significant drawdown over a broader area, which strongly suggests that more conservative triggers are required. Observed natural fluctuations that exceed the predicted drawdown or the predicted trigger should be considered, because the modeling often does not consider seasonal changes.

Protection of areas dependent on shallow groundwater, but not surface discharges, presents additional difficulties. Shallow groundwater levels in wetland areas support surface vegetation through exfiltration to soil or occasional groundwater level rises into the root zone. Identifying triggers in these areas requires consideration of the difference between survival and growth. The healthiest systems may require the groundwater level to rise sufficiently into the root zone, but alternatively the system may survive at minimal levels. Monitoring shallow groundwater levels in wetland areas requires shallow piezometers and frequent measurement to establish the frequency and duration during which the groundwater levels are high enough for the system to thrive.

Because 3M plans are intended to protect important features, the action triggers must be designed to establish groundwater levels that, if reached, will signal an impending impact to those features. If the data and localized modeling indicates that those triggers must be established at levels that are less than the drawdown predicted in the FEIS and discussed in the previous section, then SNWA's groundwater development project may not be feasible as designed, because the proposed pumping levels simply may not allow for effective mitigation.

A 3M plan must include management and mitigation strategies supported by adequate proof that the plans will effectively protect the resource. In order to enable its effectiveness to be evaluated, a management plan must be supported with modeling that shows the management has a good chance of preventing the impact to the GDE. The plan should also include the development of data over a sufficient baseline period to establish correlation to verify the models or reconceptualize and redo the plan.

Mitigation plans should assess whether it is possible to replace water, including the source of the replacement water. The plan should consider the impacts of obtaining that replacement water. Further, a mitigation plan should recognize that environmental amenities cannot be mitigated with replacement water, because the ecosystem function that the plan is supposed to protect cannot be maintained in that way.

The following subsections consider the 3M approach proposed by SNWA for Spring Valley and Cave, Dry Lake and Delamar Valleys in the previous hearings and included in the FEIS. Full implementation of SNWA's water rights development proposal would dry up springs and important ecosystems, including GDEs, and would lower the water table at wells with water rights. The approach to 3M planning proposed by SNWA, which has yet to produce any actual 3M plan, will not protect these resources unless they include a process to effectively stop pumping for long time periods when that appears to be the only management measure that will avoid or mitigate harmful impacts.

Spring Valley

Under its proposal, SNWA would use ten quarterly-sampled and 15 continuously-monitored wells in Spring Valley and Hamlin Valley. That is 25 monitor wells in two aquifers over a 1700 mi^2 basin, just in Spring Valley, or one monitoring well for every 43,520 acres. There would be four carbonate and two basin-fill monitor wells completed in the zone between Spring, Hamlin, and Snake Valleys to characterize interbasin flow.

The wells were selected to "serve as monitoring points between SNWA's future production wells and existing water-right holders as well as Federal Water Rights and Federal Resources" (SNWA 2009c, p 10), but neither the production wells nor resources being protected are specified. SNWA claims the monitoring well locations were chosen "with consideration of hydrogeologic conditions at each location" (SNWA 2009c, p 9), including "[g]eologic reconnaissance, including stratigraphic and structure field mapping and aerial photo analysis, surface geophysics, and review of existing hydrogeologic data" (Id.). However, SNWA did not prepare a CFM or provide any other support for their choices of location.

The Spring Valley monitoring plan provides a table showing existing monitor wells (SNWA 2009c, Table 1). It specifies the perforated intervals for the wells[4], showing wells with very broad intervals that would monitor large thicknesses of the formation. The water level in a monitor well represents the portion of aquifer intersected by the screened interval. Each productive, or flow, zone in the aquifer has its own pressure, or head, value. Head differences among aquifer levels create a vertical gradient among those levels. If the screened interval intersects more than one aquifer level, the water level in the well represents an average of the varying water levels. The average, however, would be weighted according to the transmissivity of the different levels, which means that the water level would represent the most transmissive aquifer layer. If a given aquifer layer undergoes more drawdown, water from other aquifer layers would enter the well causing the well water level to reflect the water level from the unaffected layers. Water levels from monitor wells that span more than one aquifer level will equal the highest water level rather than the level experiencing drawdown. In Spring Valley, this is especially problematic in the carbonate and volcanic wells, which have perforated intervals over hundreds of feet. The monitor wells' design therefore will provide little information about drawdown happening in differing carbonate aquifer levels if those aquifer levels are separate. Actual drawdown that could warn that downgradient spring flows will be affected would be dampened by the unaffected aquifer levels, which would mask actual drawdown.

Many of the basin fill wells are relatively shallow and have open intervals only to 200 feet (Table 1, SNWA 2009c) (most are existing MX wells; they do not have perforated intervals specified). These would monitor the water table initially with a proper perforated interval width, but would also go dry with substantial drawdown. Monitoring wells would be lost due to large drawdown.

SNWA's proposed approach to Spring Valley monitoring proposes to "effectively characterize the hydraulic gradient between Spring, Hamlin, and Snake Valleys" (SNWA 2009c, p 10). The proposed approach to monitoring provides for just four carbonate and two basin-fill monitor wells to be added to the existing four basin-fill wells within the zone including southern Spring

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[4] The table shows both "perforated interval" and "open interval", but does not specify the difference. A well open to the aquifer with a perforated casing is usually considered to have a "perforated interval". An "open interval" usually means there is a thickness of well that is not cased, or simply open to the aquifer without a casing. This table shows a "perforated interval" within an "open interval" that is not simply the full thickness of the well, but provides no explanation of their meaning. Throughout this review, I consider the "perforated interval" as being the aquifer interval that is being monitored.

Valley, Hamlin Valley, and Snake Valley near Big Springs. This approach would not be effective because the wells would be so spread out, both spatially and among aquifers, as to estimate just one gradient over an area ranging about 12 miles east-west and 18 miles north-south (Figure 40). The bedrock geology is primarily carbonate rock with interspersed volcanic rock and with various faults. The bedrock is highly heterogenous so monitor wells that span multiple flow paths would at best provide a single, cursory estimate of gradient.

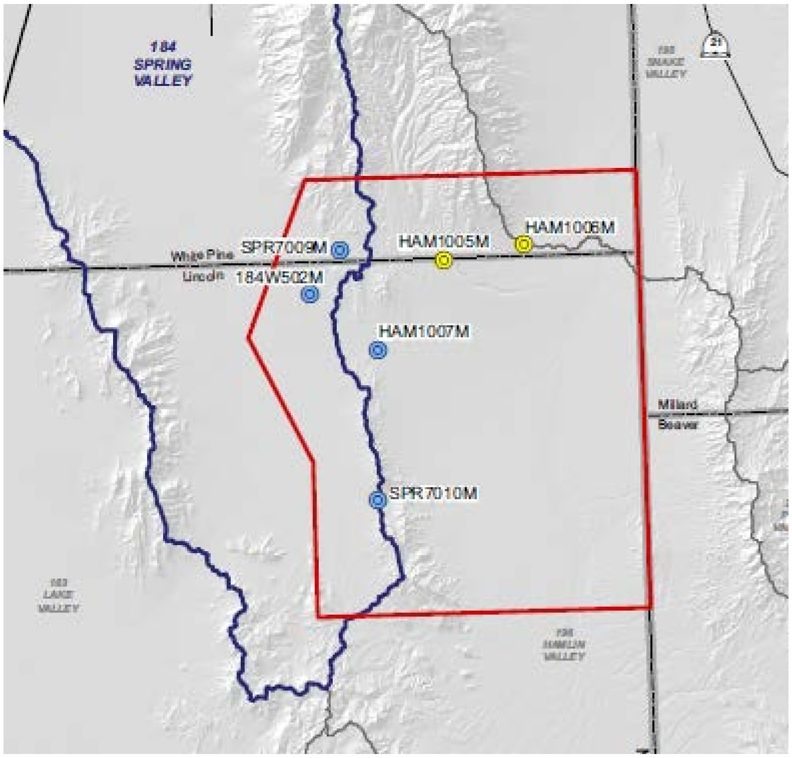

Figure 40: Snapshot of a portion of Figure 3 (SNWA 2009c) showing the zone between Spring Valley and Big Springs to be characterized by the monitoring plan.

Bedrock also outcrops through most of the divide between Spring and Hamlin Valleys, so interbasin flow would have crossed the bedrock. Basin-fill groundwater, especially in Hamlin Valley downgradient of the bedrock outcrops, would mix water that passed through the bedrock and water flowing north through Hamlin Valley. While a groundwater level in the basin-fill near the carbonate would represent the head just downgradient of the bedrock, the mixing of waters in Hamlin Valley would cause the groundwater level at a point to be affected by both sources. Wells further from the bedrock would provide a less accurate measured head and therefore a less accurate measure of the gradient through the bedrock.

Water level data also would be distributed "in order to analyze and produce annual groundwater-level contour and water-level drawdown maps" (SNWA 2009c, p 10). The maps would be inaccurate because they would not account for vertical gradients within formations.

Also, the limited proposed aquifer tests (SNWA 2009c, p 16-19) only would provide data for an aquifer average rather than information regarding the actual flow paths.

Thirteen springs would be monitored as representative of the entire 1700 mi^2 Spring Valley basin. SNWA did not complete a CFM to provide a rationale for the choices, although some of the springs in the middle of the valley are obvious choices. SNWA did not justify any choice based on the value of the spring. Only Rock Spring would be monitored continuously. Periodic measurements at the other springs would provide no information regarding the mix of water sources. Except for deep carbonate springs, the discharge would likely be a mix of basin fill and carbonate water due to mixing of shallow groundwater from local recharge with deeper groundwater. All the springs should be continuously monitored to separate natural variability from project-caused changes.

Piezometers would be installed at the spring locations, although neither distance from the spring nor screened-interval depth is described, which prevents an evaluation of the effectiveness of those piezometers. Regional springs would be controlled by the head in the aquifer level representative of the pathway that provides flow to the spring. Piezometers completed in the wrong layer or spanning many layers would provide a water level that may not correspond to flow from the spring, for the same reasons that a well screened over multiple aquifer layers would not provide layer-specific readings.

Under its proposed 3M approach for Spring Valley, SNWA would complete a synoptic survey of Big Springs Creek and Lake Creek to Pruess Lake. Irrigation and non-irrigation season synoptic surveys would be completed within one year prior to the start of SNWA pumping and would be repeated every five years thereafter. The goals of this synoptic monitoring are not stated, and itis not clear how this would be useful as a monitoring tool. SNWA fails to describe a CFM for flow in this area, which is necessary to determine where to conduct measurements.

This section has outlined that SNWA's 2009 3M proposal falls far short of providing monitoring that would signal when management changes would be necessary to protect GDEs or water rights. SNWA's proposal did not even identify the GDEs or water rights that should be protected. The monitoring proposed for interbasin flow to Snake Valley also would not characterize the variable flow conditions within the flow pathway.

Cave, Dry Lake, and Delamar Valleys

SNWA (2009b) describes the monitoring approach proposed for the CDD Valleys, which was originally based on NSE Ruling 5875. The document defines its objectives as identifying and assessing potential impacts to existing water-rights and GDEs capable of sustaining endangered and/or threatened species (SNWA 2009b, p 1).

According to SNWA, a hydrologic monitoring and mitigation program would be approved by the NSE (SNWA 2009b, p 5). A baseline period would be a minimum of two years prior to proposed pumping, and results would be filed annually (Id.). The plan would collect quarterly data from nine existing monitor wells in the CDDC Valleys and adjacent basins and continuous water-level data from six existing monitor wells (SNWA 2009b, p 6). Thus, SNWA's approach to monitoring in the CDD Valleys and the WRFS mostly relies on preexisting monitoring wells that have not been designed or evaluated with a view toward effectiveness for 3M purposes. It does provide for "up to four new monitor wells" (Id.), but does not specify what would trigger their construction.

The wells would be monitored to "help characterize groundwater movement within DDC and the adjacent HAs of White River, Pahroc, and Pahranagat valleys" (Id.). That means there will be, at most, nineteen wells to monitor flow over at least six valleys and two types of aquifers.

Also, eight spring locations in downgradient Pahranagat and White River Valleys would be monitored on a biannual basis (SNWA 2009b, p 6). These valleys and the spring and stream features within them have substantial water rights associated with them. Table 4 shows the total water rights, either certificated, permitted, vested, or decreed, for each valley, and Appendix 1 lists those rights. By the time drawdown decreases flow at these springs in downgradient basins, it will have propagated a significant distance and will therefore continue to propagate regardless of any changes in pumping (Bredehoeft and Durbin 2009). Unless monitoring wells detect the propagation for drawdown sufficiently in advance, the springs will not be protected. The following paragraphs discuss the inadequacy of currently installed monitor wells and those proposed to be installed between the target valleys and springs in downgradient basins.

Table 4: Total number and amount of spring and stream water rights by valley downgradient from Cave, Dry Lake, and Delamar Valleys.

Source	**Spring**		**Stream**	
	Number rights	**Duty (afa)**	**Number**	**Duty (afa)**
White River Valley	132	18876	36	38837
Pahroc Valley	8	85		
Pahranagat Valley	45	23792	4	946
This table includes only those rights with a duty and does not account for rights with just a diversion rate. Therefore, the table may underestimate the full water rights amount within each valley.				
Not supplementally adjusted				

Monitor wells have been or would be completed in three different aquifers over five valleys: basin-fill, carbonate, or volcanic rock aquifers. SNWA claims that these wells would provide "representative data spatially across the program area" (SNWA 2009b, p 9). The reality, however, is that no more than a couple of wells would serve as the sole monitor wells for dozens of square miles, and these wells would be screened so that the monitoring is of broad aquifer thicknesses without consideration of individual productive layers that could be the primary source for given springs. The locations were based on a variety of surveying and reconnaissance (Id.), but the document does not describe or discuss how or whether this information was or will be used to develop a conceptual model for flow to any of the springs, or how any monitor well would be most likely to intercept a flow path. Myers (2011a, p 29-43) described CFMs, for various springs in the CDD Valleys and the affected downgradient region, that could be used in designing an actual monitoring plan. The wells would "provide spatially distributed hydrologic data … in order to analyze and produce annual groundwater-level contour and water-level drawdown maps …" (Id.).

Monitor wells that screen thick sequences of an aquifer would neither provide information about the individual zones that support given resources, primarily the springs in downgradient basins, nor provide any information about vertical gradients within the aquifers. SNWA's proposed approach to monitoring for the CDD Valleys and WRFS provides a table showing existing monitor wells (Table 1, SNWA 2009b). It specifies the screened interval for the wells[5],

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[5] The table shows both "screened interval" and "open interval", but does not specify the difference. A well open to the aquifer with a screened casing is usually considered to have a "screened interval". An "open interval" usually means there is a thickness of well that is not cased, or simply open to the aquifer without a casing. This

and with one exception, the well screens span at least several hundred feet. Two wells, 382807114521001 and 372639114520901, have two screened intervals. The water level in a monitor well is a level that represents the portion of aquifer intersected by the screened interval. Each productive, or flow, zone in the aquifer has its own pressure, or head, value. If the head differs among aquifer levels, there is a vertical gradient among those levels. If the screened interval intersects more than one aquifer level with a different head, the water level in the well represents an average of the varying water levels. The average, however, would be weighted according to the transmissivity of the different levels, which means that the water level would represent the most transmissive aquifer layer. If a given aquifer layer undergoes more drawdown, water from other aquifer layers will be able to rise to their level. A monitor well that spans more than one aquifer level will provide data based on the highest water level rather than the level experiencing drawdown. The monitor wells' design therefore will provide little information about drawdown happening in differing aquifer levels if those aquifer levels are separate. Actual drawdown that could be a warning that downgradient spring flows will be affected would be dampened by the unaffected aquifer levels. Also, the proposed aquifer tests (SNWA 2009b, p 13) would provide data only for an aquifer average rather than information regarding the actual flow paths.

SNWA (2009b) Figure 2 shows proposed monitor well 3 between Cave Valley and White River Valley, a carbonate well and the only monitor well between the valleys. Carbonate rock is highly heterogeneous with multiple primary flow paths. If the placement is not perfect, it will not be monitoring a primary flow zone between the valleys and will miss the drawdown signal. A transect of wells would be necessary to improve the chances of detecting drawdown propagation. Additionally, as noted, carbonate rock is highly heterogenous so the critical flow path supporting one or more springs could occur at one depth in the aquifer while at another depth flow may not be affected. A monitor well that is screened over two or more productive layers will report a water level equal to that in the pathway with the highest head, not the level in the pathway being affected by pumping. Thus, even if a well does intersect the critical zone, it may not provide a warning due to its water level being affected by other flow paths. The only way to prevent this is for each well to have multiple completions, with a completion over each productive layer. This is called multiport monitoring, and is easy to accomplish in the field (Einarson 2006).

SNWA (2009b) Figure 2 shows proposed monitor well 2 generally about four miles east of Hiko Springs in Pahranagat Valley to be installed in carbonate rock. This is not an interbasin flow path identified in the CFM (Figure 16) (SNWA 2009b), although there is no geologic reason

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table shows a "screened interval" within an "open interval" that is not simply the full thickness of the well, but no explanation of their meaning. Throughout this review, I consider the "screened interval" as being the aquifer interval that is being monitored.

there would be no flow from Delamar Valley at this point. There is an existing monitor well, 209M-1, on the divide between the valleys, also in carbonate rock. It is about eight miles further east of the proposed well. If there is an impact propagating to Hiko Springs, there will be just two wells over more than twelve miles between the pumping wells and the springs in which to detect the drawdown. The same issues with heterogeneity that applied to Monitor Well 3, described in the preceding paragraph, apply to these wells.

SNWA (2009a) shows a pathway from Delamar into the very southern end of Pahranagat Valley, and SNWA (2009b) Figure 2 shows Maynard and Cottonwood Springs in that end of Pahranagat Valley. New monitor well 1 would be installed at one of two locations in this area in volcanic rock – the locations are a little more than two miles northeast of Maynard Spring in Pahranagat Valley or about six miles northeast of Maynard Spring on the basin divide (Id.). There are two volcanic monitor wells north of these proposed locations in Delamar Valley, thus there would be three volcanic monitor wells over an area of about 12 by 5 miles in the southwest portion of Delamar Valley. This area generally is the Pahranagat Shear Zone which would have various potential pathways; there is no indication that the existing wells are, or the proposed wells would be, located along one of the fault paths. The screened interval on the existing wells exceeds 200 and 400 feet for 182M-1 and 182W9D6M, respectively. In a highly fractured shear zone, if a well intersects any flow paths it is likely to intersect multiple flow paths, and this presents the same problems as discussed for the other wells with large screened intervals.

Downgradient spring monitoring would occur quarterly, biannually, or continuously (Table 4, SNWA 2009b). Frequency should be increased for the springs if upgradient monitor wells begin to show propagating drawdown, in addition to the management changes discussed below.

This section has outlined that SNWA's 2009 3M proposal for the CDD valleys and WRFS falls far short of providing monitoring that would signal when management changes would be necessary to protect GDEs or water rights. This is especially true for springs, with water rights, in basins downgradient from the basins proposed to be developed. The monitoring proposed for interbasin flow would not characterize the variable flow conditions within the flow pathway or provide adequate warning of impending impacts.

Management and Mitigation

The 3M approach proposed for both Spring Valley and the CDD Valleys includes five mitigation options that could be applied if monitoring indicated that the resource, a water right, spring, or valuable wetland area, would be impacted by continued pumping. However, there is little evidence that these options would protect the resources, as described in this section.

Management options include the geographic redistribution of or reduction or cessation of groundwater withdrawals. As demonstrated by Bredehoeft and Durbin (2009), in general, the lag between potential changes and the manifestation of those changes at the resource would result in the propagation of impacts over a very long period. "If the monitoring point is some distance removed from the pumping, there will be (1) a time lag between the maximum impact and the stopping of pumping and (2) the maximum impact will be greater than what is observed when pumping is stopped" (Bredehoeft and Durbin 2009, p 7). This is especially true for monitoring wells spaced as sparsely as proposed by SNWA (2009b, c) for the large valleys targeted here.

SNWA (2009b, c) presented no analysis demonstrating that redistribution or changing pumping rates would prevent degradation. It presented no analysis estimating the lag time between invoking the changes in pumping and the time when the impacts would be mitigated. It presented no triggers that would cause changes to be implemented. So, SNWA's proposed approach merely presented some potential management and mitigation options with no strategy for implementing them and no method for assessing their likely effectiveness.

The only other mitigation option proposed is the provision of consumptive water-supply requirements at the resources being protected (GDEs or water rights) using surface and groundwater resources, presumably from other sources not permitted as part of the project pumping.

SNWA has not provided any details related to where such replacement water could be obtained. Without a plan in place, this mitigation option is meaningless. SNWA owns other water rights in Spring Valley (SNWA 2009c), but those rights are associated with a ranch, so moving the water to replacement consumptive use or to augment environmental flows would require a change in place of use of the rights which takes time to implement, time during with the protected resource would be harmed. Additionally, moving a surface water right has ramifications such as impacts to other rights that might depend on secondary recharge of the primary right.

Therefore, the mitigation alternatives proposed in SNWA (2009b, c) are not feasible unless the water source is identified along with precise plans to move it to where it is needed and plans to minimize impacts where it is currently used.

CCFS Model Updates

SNWA's Spring Valley proposal calls for collected data to be used to update a groundwater flow model every five years after proposed pumping begins and to provide "predictive results under pumping conditions of 10-, 25-, and 100-year periods" (SNWA 2009c, p 5). The document does not specify what those "predictive results" will be used for. SNWA's CDD proposal similarly calls for the model to be updated with predictions for the same time periods (SNWA 2009c, p 5). A difference is that the CDD proposal does not include a section describing the updates, whereas the Spring Valley one does, which will be considered in the next paragraph.

Groundwater modeling would be “one component of the adaptive management program developed for the basin-fill and regional carbonate-rock aquifer systems” (SNWA 2009c, p 33). SNWA would be responsible for the model, which presumably would be the CCFS model, the results and faults of which I described above. As discussed above, one major problem with the monitoring and modeling approach proposed by SNWA is that the monitoring wells are not screened according to the layer thicknesses used in the model. The layers are vastly too thick to accurately simulate local flow patterns in the area, especially through preferential flow paths. However, the monitoring wells screen a much smaller thickness than the model considers. So, the monitor wells cover much too wide an aquifer thickness to accurately describe those flowpaths, while also being designed to intersect much too thin a portion of the aquifers to provide an accurate simulation of flow through the model layers.

The solution, which SNWA has not proposed, is for the wells to be screened, as recommended above, over the productive aquifer layers, but to use an average for each model layer for calibration. Observing water levels in each productive zone would provide a measure of head for each productive zone which would allow an assessment of which layers support, and provide warning of potential impacts to, each aquifer layer. Such monitoring would also provide useful head values for calibration of the model, and also help demonstrate whether the model layering is sufficient. The current proposal would not adequately monitor productive zones or provide useful water levels to verify the CFM or accurately calibrate the current layers.

Numerical Model

The numerical model described in SNWA (2009d) implements the conceptual model described in SNWA (2009a). This section provides a thorough review of the numerical model implementation, based on the review I completed on behalf of White Pine County in 2010. Through this section, I use NMR as an acronym for SNWA (2009d).

Model Domain and Discretization

SNWA laid the model out on a north-south east-west grid, claiming that this “would approximately match the general direction of regional groundwater flow” (NMR, p. 4-1). Because the mountains trend slightly to the east of south to north, it would have been more accurate to rotate the grid about 10 degrees, as was done by Prudic et al (1995). Doing so would allow a more accurate use of horizontal anisotropy, with the direction of the grid more accurately coinciding with general layout of the mountains.

All cells are the same size - 3281 feet (1000 m) square. This is common for a regional model, but it limits the precision of drawdown estimates near the pumping wells. Over a large area, the average drawdown estimated may be accurate but the averaging over a large cell size decreases the estimates near the wells.

Vertical Layers and Layer Manipulation

SNWA used eleven layers for vertical discretization, which would be an appropriate number of layers if the thicknesses were more appropriately chosen, as will be discussed in this section.

SNWA set all model layers to be confined, which is a common trick to aid steady state calibration especially if there are convergence problems, as occurred with this model (NMR, p. 4-2). Convergence problems during steady state solutions are typically caused by an inaccurate representation of the flow system. In this case, the model cell size may be too big to accurately simulate the details of flow in the upper layers. The model very precisely inputs the perceived geology (depths to formations and thicknesses) over a coarse grid. This requires detailed calculations in the HUF2 package and elsewhere to set the parameter values for each cell; this could cause steep gradients or large differences in the parameters among cells, as formations pinch out, which also causes instability in the water balance calculations for these cells. Either the use of smaller grid cells or specifying the model layers with hydrogeologic units could eliminate this problem.

For steady state simulations used for calibration, treating all layers as confined is possible because the top of the top active layer can be set close to the water level so that the unconfined top layer is simulated as a confined layer with constant thickness. To do this, SNWA simplified the model by removing the four uppermost layers (NMR, page 3-4).

This simplification is not appropriate for transient simulations because pumping causes drawdown which decreases the saturated thickness in the upper layer (and in lower layers if the upper layer desaturates) and changes the layer transmissivity. By assuming the upper layer is confined, the model assumes away the transmissivity changes which could cause errors due to changing transmissivity, as SNWA acknowledges. “Except in places of large drawdown, this approach maintains a large saturated thickness, **minimizing numerical inaccuracies** of the confined assumption” (NMR, page 4-4, emphasis added). “Minimizing numerical inaccuracies” simply means the model simulation reached convergence. Also, SNWA’s statement that “this assumption greatly affects the results simulated under transient conditions when anthropogenic stresses are imposed on the flow system: well yields are underestimated, and drawdowns are overestimated” (NMR, page 4-25), is incorrect, as discussed in the next paragraph.

Setting all layers as confined introduces significant errors because the layers fail to model the changes in transmissivity if the water table, in the topmost layer, or potentiometric surface in a confined layer, falls below the top of the layer. The response to pumping would therefore be different and would bias the calibrated storage coefficients. SNWA attempts to remedy the problem by setting storage coefficients to represent specific yields as if the aquifer layer is unconfined, but this approach allows transmissivity to remain the same throughout the simulation even as the water level changes. Contrary to SNWA's claim in the NMR, this will **tend to underestimate the drawdowns** because the constant transmissivity would remain higher than it would if simulated properly, thereby transmitting more groundwater through the layer than would be the case if the decreased transmissivity were actually simulated. This will dampen the effect of pumping and decrease the predicted drawdown.

Layers 2 through 6 are specified as 328 to 984 feet in thickness (100 to 300 m) (NMR, p. 4-2) with layers 7 through 11 being thick and extending to as far as 10,000 feet below sea level. The upper layers are too thick and the lower layers are discretized too deeply, even for a regional model. The most active region for this simulation is the upper 1500 feet and it would be sensible and accurate to divide this thickness, at least in the basin fill, into from seven to nine layers; this is justifiable because most wells and well logs occur within this zone. Most of the flow and vertical flow circulation occurs within the upper thickness, especially if the assumptions for depth/decay of conductivity are accurate. There may be deep circulation, but the deep layers could be simulated with at most two layers, representing the carbonate and siliclastic units. It may be justifiable to simulate the bottom layer as being so thick as to reach 10,000 ft below mean sea level, but there is no accuracy gained from dividing the bottom 10,000 feet into more than one layer (no accuracy because there really is no data to parameterize the unit and the proportion of the water balance circulating through this layer would be very small).

***Summary**: Simulating all layers as confined even with massive drawdown sets the transmissivity artificially high and decreases the amount of drawdown simulated by the model. There are no advantages gained by discretizing many layers more than about 1500 feet below the ground surface. Although 11 layers seems like a large number of layers, in this model about half of them add no improvement to the model.*

SNWA set vertical anisotropy lower than it should have based on the thickness of the layers – using a value of between 10 and 100 (NMR, page 3-2). Vertical anisotropy is a ratio of horizontal to vertical conductivity. When a layer of sandstone is laid down by settling sediments, the platelets tend to orient horizontally so that the vertical pores and pathways are much more tortuous than those in the horizontal direction. Horizontal conductivity in each formation is significantly higher than vertical. Layers in this model agglomerate numerous actual formation layers which, if accurately accounted for, would make the vertical anisotropy in a layer higher than in an individual formation (Anderson and Woessner, 1992, pages 69-70).

***Summary**: SNWA should have included vertical anisotropy in transient model calibration. The value should be biased to the higher end of the potential range because the large screen length in the pumping well will draw from a much larger thickness of aquifer than any of the existing wells do. Failure to accurately model vertical anisotropy allows the wells to draw water from a* *wider effective aquifer than would be appropriate. This assumption minimizes drawdown by effectively increasing transmissivity.*

SNWA used the HUF2 package (Anderman and Hill, 2003, 2000) which allows the user to combine hydrogeologic units, such as lower carbonate or upper valley fill, into one cell or one model layer (Figure 41). It sums the transmissivity for each layer within a cell, which effectively is a weighted average of the conductivity for each of the formation layers within a model layer. The weighting is based on thickness. Weighting property values is a good method of combining similar formations that are too thin to represent as an entire model layer, but it must be used cautiously. “Although the HUF Package allows model layers to be defined independently of hydrogeologic units, **careful definition of the model layers** is important to represent properly the flow through the simulated area. Specifying model-layer boundaries that coincide with or are parallel to hydrogeologic-unit boundaries is helpful” (Anderman and Hill, 2000, emphasis added).

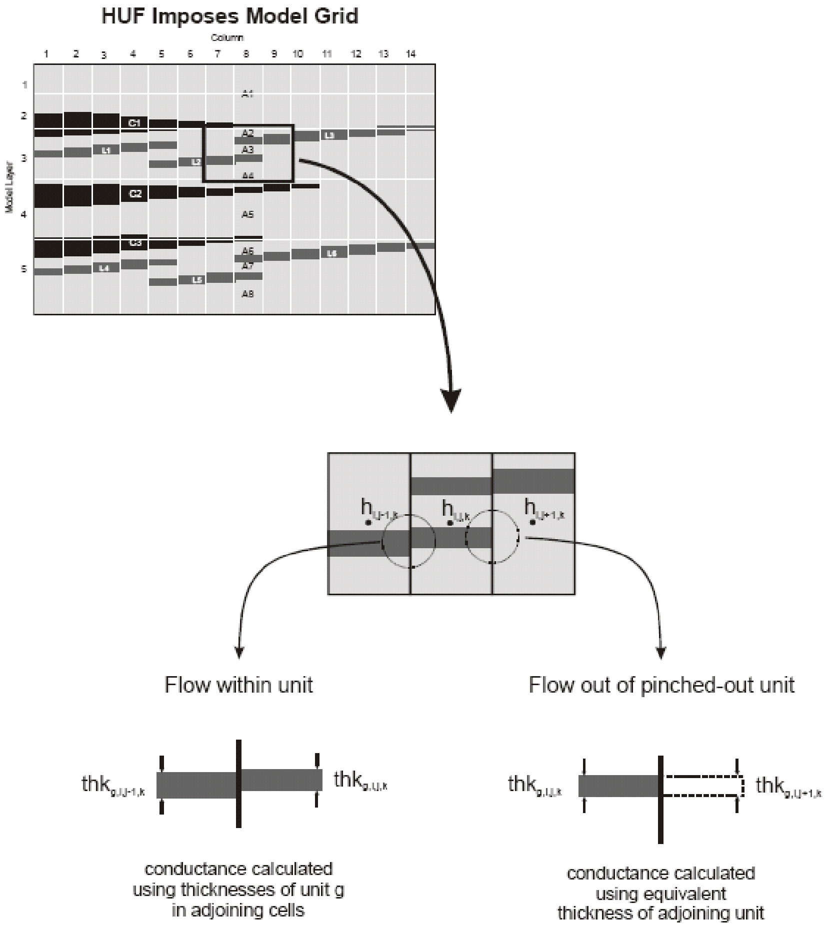

Figure 41: Figure 4 from Anderman and Hill, 2003.

If the HUF or HUF2 package combines significantly different hydrogeologic units, the cell properties may be an average of significantly different flow types. For example, it may be inappropriate to combine rock and fill formations in one cell because they have different flow types - fracture and media flow. Additionally, averaging two units with significantly different conductivity values results in a value representative of flow through neither formation, and is therefore meaningless. Drawdown propagates at much different rates in the two formations and the average represents neither. Averaging makes sense within basin fill units or different carbonate units, but not between fill and carbonate or any other bedrock type.

The east front of the Snake Range, near Baker, is a great example of the inappropriate averaging of formations in one cell by SNWA's model. As may be seen in Figure 42, in column 149, the model averages UVF and LC3 properties. In column 150, the model averages LVF and LC3 properties. Considering the conductivity values by cell, the model combined values that differ by more than an order of magnitude (Figure 43). Also, the model would not allow continuous flow along the LC3 unit under Snake Valley because the unit does not match in adjacent cells (Figure 42). This forces the groundwater to follow unrealistic pathways. It would essentially force water in the LC3 unit in column 149 to flow into the LVF unit in column 150.

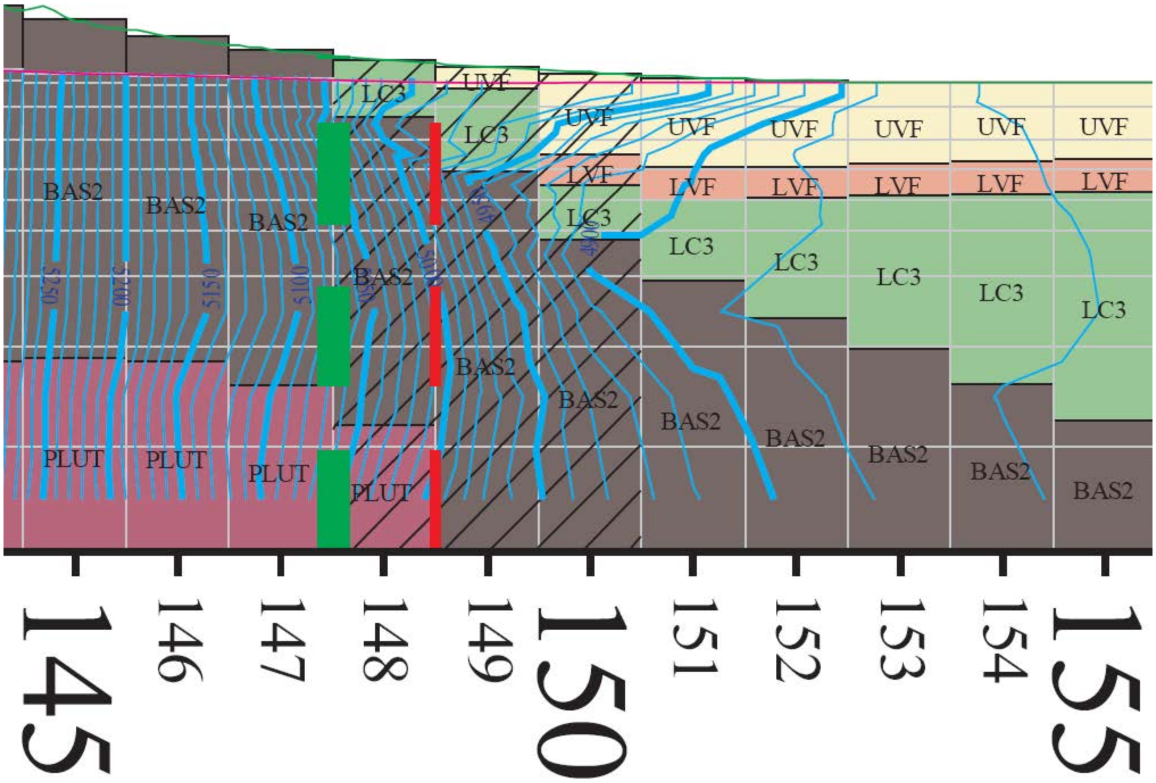

Figure 42: Portion of model row 126 near the east side of the Snake Range near Baker. White lines are cells, blue lines are groundwater head contours. Other colors represent hydrogeologic units as labeled.

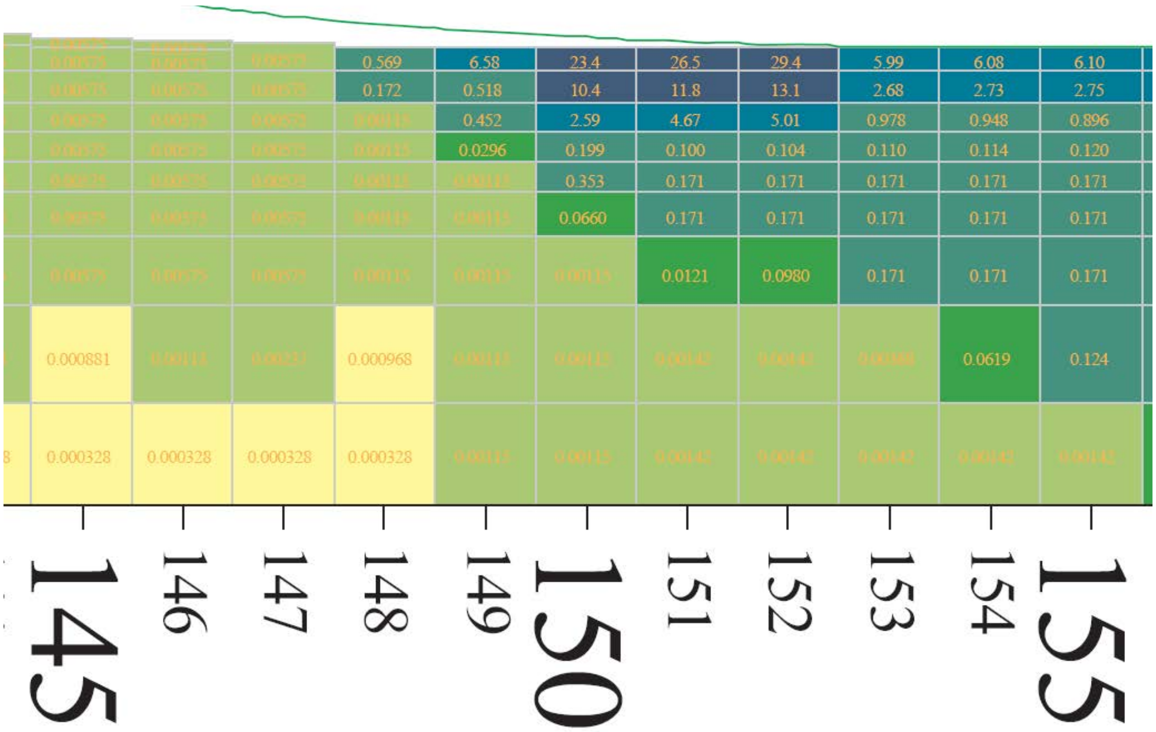

Figure 43: Portion of model row 126 near the east side of the Snake Range near Baker showing the average horizontal hydraulic conductivity values.

Forcing the flow into the valley fill, as just described, would **minimize predicted drawdowns from the model**. This is because the model pumps primarily from the valley fill units (see discussion in Simulations section below) where the storage coefficient is much higher than in the carbonate units. Less drawdown is predicted for a given amount of pumping in the fill than in the carbonate. Because the carbonate plunges beneath valley fill in many areas, this type of inappropriate averaging and the artificial disconnections it creates among the LC cells may significantly bias the model to underestimate drawdown in these locations.

Summary: *SNWA has implemented a numerical structure that does not reflect the conceptual flow model. The model inappropriately combines certain formations in a way that would cause it to simulate flow not representative of either formation. Layers should represent hydrogeologic units rather than weighted averages of significantly different units if the units are vastly different.*

SNWA used the HFB package to simulate the 50 various normal faults it perceived across the domain. While this seems like a high number, it mostly represents basin-bounding normal faults and a few other major faults. SNWA included the faults it perceived to be flow barriers, but SNWA treated each fault as an equal barrier, with the conductance calibration for the majority simulated across the entire domain (NMR, Table 4-5).

The HFB hydraulic conductivity was a simulation parameter and had one of the highest CSS (composite sensitivity[6]) values of the different parameter zones. The modelers started with HFB_KH equal to 10^{-6} m/d, or 3.3×10^{-6} ft/d (NMR. P. 4-16), which means the modelers started with the assumption the faults are significant barriers. The faults would be highly sensitive because they are spread across the model domain – few areas exist that are not affected by these barriers. It would be much more appropriate to consider the conductivity of each fault separately.

Summary: SNWA set HFB boundaries to have very low conductance, without data that requires them to be set that way. This would lead to artificial control of drawdown at the faults. A sensitivity analysis of the faults, each with separately adjustable Kh values, would help determine which faults should be focused on in calibration. This analysis should commence with different initial Kh values, not just a uniform assumed value of 10^{-6} *m/d, to determine whether the faults can be considered unique.*

Model Calibration

Calibration of a model is the process of adjusting parameters so that the model reproduces the observations on which the conceptual model was based. In steady state, pre-development conditions, the calibration is intended to match the water levels and steady state fluxes (flows) through the boundaries. SNWA did not accurately match the observed water level data throughout the domain and particularly within White Pine County, as shown by the residuals mapped on Figure 44. A residual is the difference between observed and simulated water level, with a positive value indicating an underestimated water level.

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[6] Composite sensitivity shows the sensitivity of a specific parameters as related to the other parameters in the model. Sensitivity for a specific parameter is how the model changes as a result of changes in that parameter.

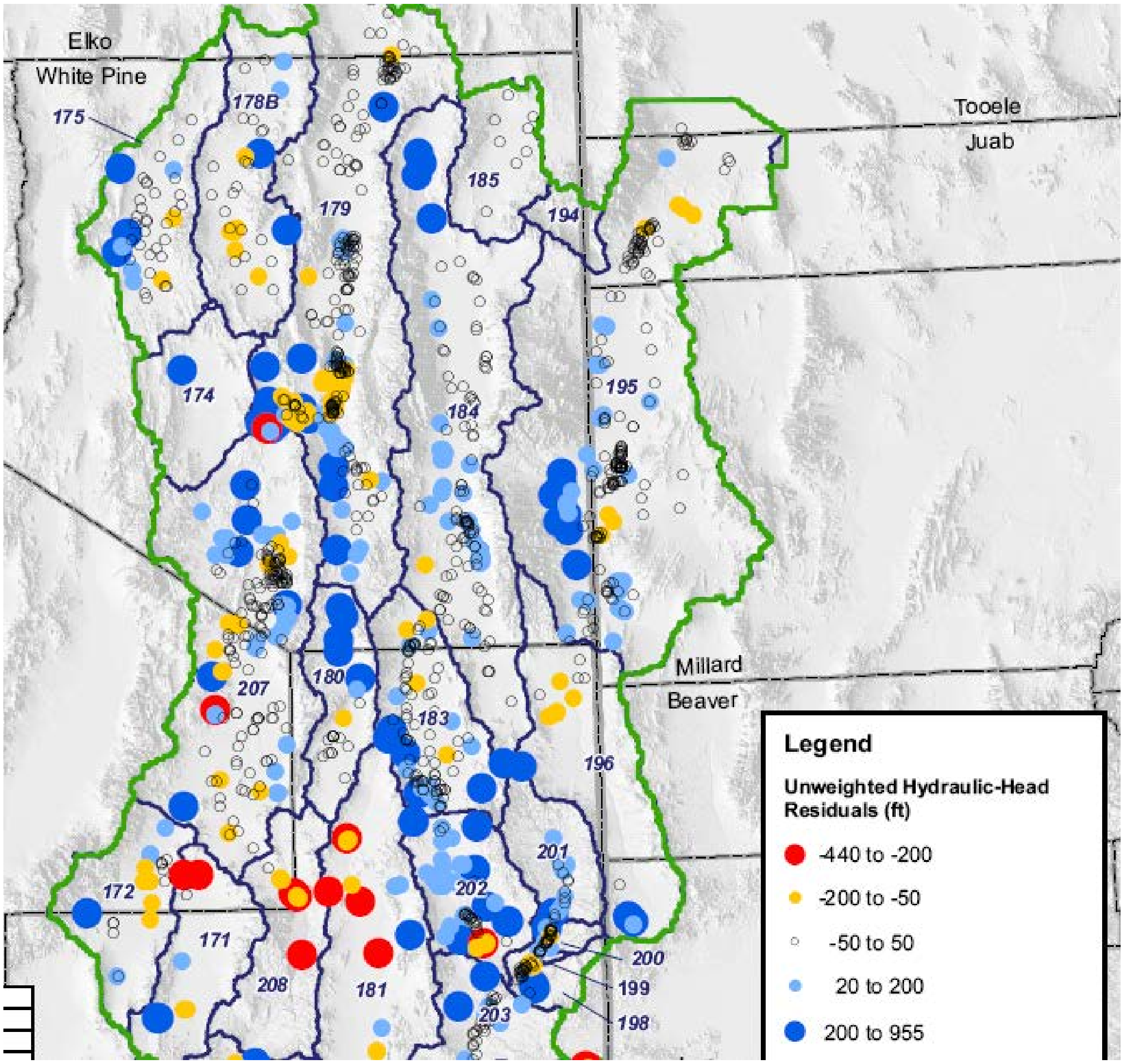

Figure 44: Portion of NMR Figure 6-9 showing the unweighted residual for the northern two-thirds of the model domain.

The average error, or residual, is 15 feet (NMR Table 6-2) showing a considerable bias toward the model simulating water levels in the model domain lower than the observed values. The mean absolute error (45) and standard deviation (90) shows just how poorly the model fits the observed head values in steady state. The table shows the ratio of RMSE/range is just 1% which allows the SNWA to claim a good fit, but the range is misleading – it is the total difference between the highest and lowest well levels or 6461 feet but the high value is due to the model domain being so large; the topographic elevation ranges from about 1000 feet to greater than 10,000 feet from south to north. The RMSE/range ratio would be more meaningful if it could be presented for specific model areas. In Spring Valley, the water levels likely range from more than 5000 to less than 7000 feet, a range of less than 2000 feet, and a significant number of residuals exceed 200. This suggests that for Spring Valley, the RMSE/range would be much larger than 1%.

The distribution of residuals shows clearly that the water levels are underestimated in Snake Valley, Lake Valley, Spring Valley, and the north and south ends of Steptoe Valley (there is a prevalence of blue markers (Figure 45)). Large residuals appear in the mountain blocks which reflect the significant topographic gradients there. The cause for this is unclear, but could be due to the lower weights given to mountain block observations. Wherever the residuals are positive, as in the listed basins, the model clearly underestimates the flow gradient between the valley and mountain block which would bias the conductance between the mountain and valley to higher values, meaning the transmissivity could be too high. **This would allow the pumping to draw water from mountain block with less drawdown more quickly, a clear bias to underpredicting drawdown near the mountain front.**

Recommendation: *Steady state model calibration resulted in large residuals that are geographically biased around the model domain. The steady state calibration resulted in especially large residuals within mountain blocks. Before it can be considered reasonably reliable, the model should be recalibrated giving the mountain block observations more weight.*

Transient Calibration

Transient calibration involved modeling the drawdown and observed changes to flow in the springs or streams from 1944 through 2004, based on observed or assumed pumping rates during that time (NMR, Section 6.0). **The proposed future pumping would stress the aquifers much more than they were calibrated for herein, and therefore, while it is better than no calibration, the model remains effectively uncalibrated for transient conditions.**

The initial conditions were set at the steady state solution which is appropriate especially since, as evidenced by the residuals (Figure 44), the simulated steady state head varies significantly from the observed values. SNWA adjusted the storage coefficients to attempt to calibrate these values because the coefficients control the rate that the model releases groundwater from storage. Drawdown residuals are much less than steady state values (Figure 45) because the actual drawdowns due to existing development are relatively small; sixty years of drawdown was about 5 feet and up to 25 feet in Spring and Snake Valleys, respectively. SNWA claims that:

> In general, simulated transient drawdowns match observed drawdowns. Seasonal and larger-term climatic cycles are not simulated, but the overall trends also generally match well. Wells (C-11-17) 1bdc 2 and (C-20-20)12acc 1 are distributed across Snake Valley and represent how the numerical model matches the general trend of hydraulic-head observations (Figures 6-3 and 6-4). Similarly, wells Behmer-MW and 219 S14 E65 21AC 1 EH-4 illustrate the response of wells in the Muddy River Springs Area (Figures 6-5 and 6-

6). In some instances, the numerical model may simulate one well poorly and one well adequately in the same model cell. Wells 219 S14 E65 23BB 1 and 219 S14 E65 23ABBB 1 are examples (Figures 6-7 and 6-8). (NMR, page 6-3).

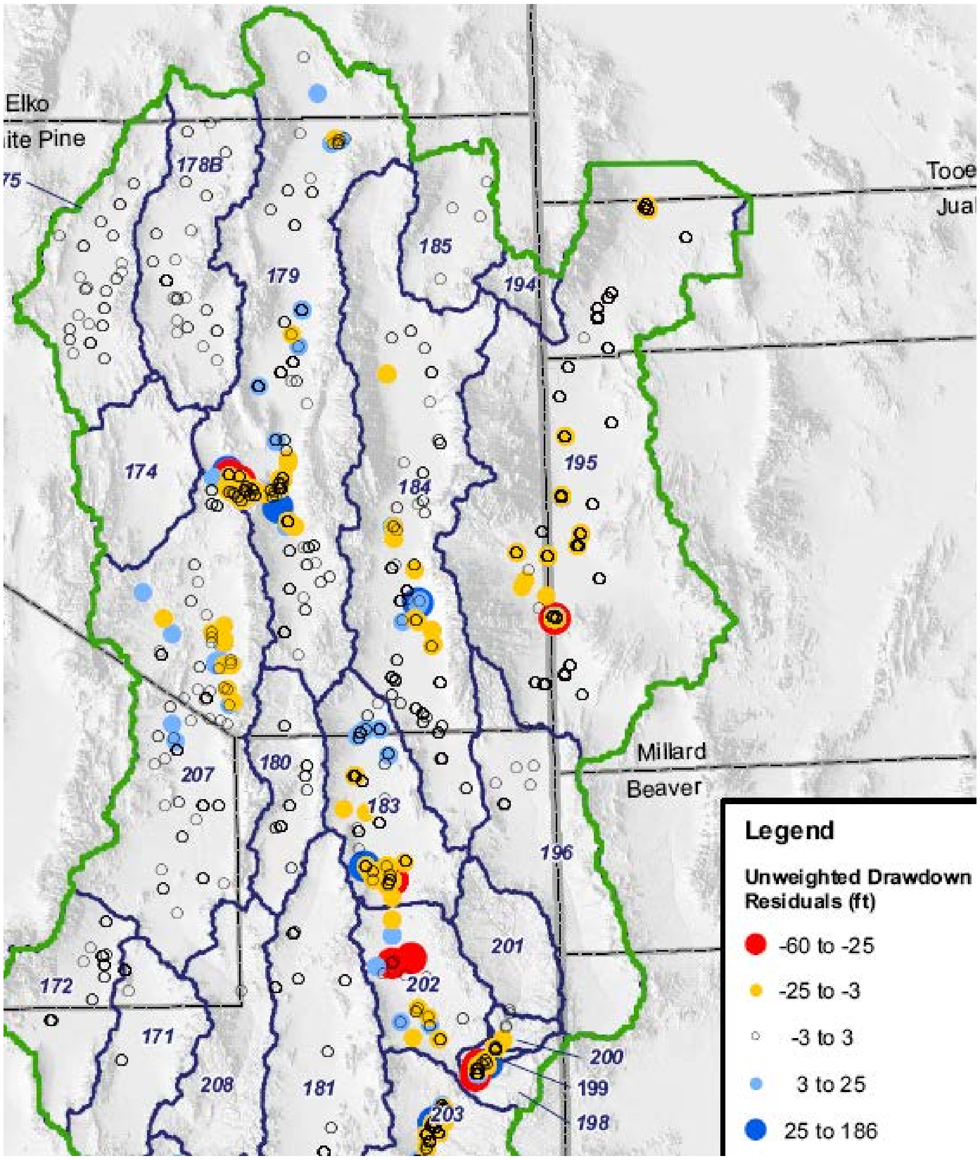

Figure 45: Portion of NMR Figure 6-10 showing the unweighted drawdown residuals. These values are from the transient calibration.

The statement regarding Snake Valley is not correct, as shown on Figure 46. The well in NMR Figure 6-3 fluctuated plus or minus 3 feet and the model simulated no changes; the well in NMR Figure 6-4 fluctuated plus or minus 5 feet while the model simulated a 4-foot drawdown (Figure 46). Failure to consider seasonal and annual recharge variations likely caused the observed changes, thus the model is only considering a partial representation of the stresses. The calibrated storage coefficients could be substantially wrong because they are based on an implicit assumption that pumping causes all drawdown. The simulated flat drawdown on NMR Figure 6-3 could be caused by a fault or other effective barrier preventing communication between the pumping and observation wells in the model. If a modeled barrier limits the propagation of stress inappropriately, the model is likely to underestimate impacts in portions of the valley - Snake Valley in this example but this type of problem would likely occur elsewhere.

NMR Figures 6-7 and 6-8 show a different response in different wells in the same cell (Figure 47). The NMR should discuss whether the wells are developed in different formations, noting that as discussed above, a cell may agglomerate several formations. These figures illustrate a potential error caused by combining formations in one layer or cell and indicates that the layer thickness for the uppermost model layers may be too thick.

Summary: *Failure to represent seasonal recharge changes in the transient calibration causes an inaccurate calibration. One way to correct this distortion would be to distribute the recharge seasonally using the long-term observed data as was done by Flint et al (2007) for the BARCASS. Another method would be to use a model such as HELP to distribute the annual recharge seasonally.*

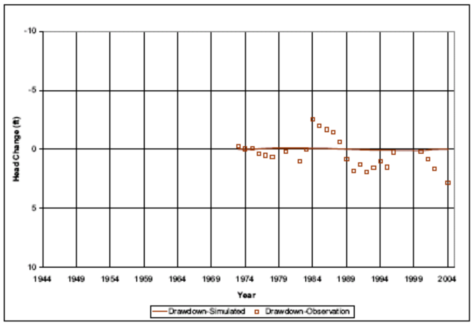

Figure 6-3
Simulated and Observed Drawdowns for Well (C-11-17) 1bdc 2

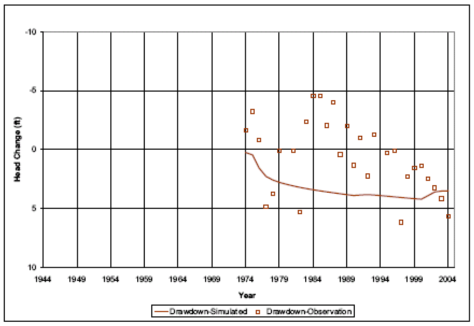

Figure 6-4
Simulated and Observed Drawdowns for Well (C-20-20) 12acc 1

Figure 46: Figures 6-3 and 6-4 from the NMR report showing two Snake Valley wells.

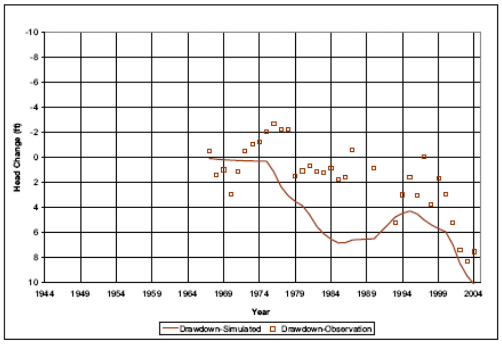

Figure 6-7
Simulated and Observed Drawdowns for Well 219 S14 E65 23BB 1

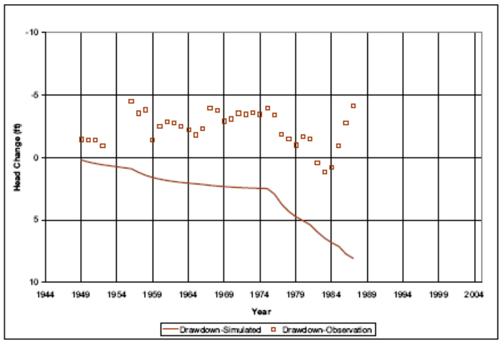

Figure 6-8
Simulated and Observed Drawdowns for Well 219 S14 E65 23ABBB 1

Figure 47: Figures 6-7 and 6-8 from the NMR report.

Water Balance in the Numerical Model

Groundwater fluxes for the entire model domain, in steady state, will be in balance because inflow is specified, as recharge, and outflow must equal inflow if the model solution converges. It is critical to consider water budgets basin-by-basin to determine whether the flow system recharge, discussed above, is properly distributed among basins. Too much recharge in a basin would cause the model to underestimate the effects of pumpage within that basin.

BLM provided a DVD with the NMR that contained four summary files for water budgets. These are zb_ucth814_2004, zb_ucth814_1944ss, ibf_ucth814_2004, and ibf_ucth1944ss (BLM undated a, b, c, d). The zb* files are interbasin flows by flow system, the ibf* files are interbasin flow by basin, and the dates represent the time for each summary. The year 1944 is considered to predate all well development in the study area and represent steady state (Table 3). The year 2004 is the end of the transient calibration period.

SNWA estimated recharge by basin and flow system as part of SNWA (2009a). The numerical model then distributed the values throughout the basin. Simulated recharge by basin (Table 3) is close to the targeted values with four exceptions. The conceptual values for Butte Valley South and Steptoe Valley were 24,688 and 91,685 af/y (CMR, Table 9-2), respectively, or significantly less than the simulated steady state values (Table 3). Because the simulated recharge exceeds the GWET by more than the amount predicted in the CMR, the numerical model has excess groundwater in Steptoe Valley, which becomes available to downstream basins, such as Spring Valley, which likely leads the model to underestimate the predicted impacts due to pumping as compared to the values reported in the CMR. The second two exceptions are Panaca and Clover Valleys, for which the conceptual model recharge is 2381 and 15,110 af/y, respectively. This exception appears to be the result of the model's inaccurate allocation of recharge from Clover Valley to Panaca Valley.

The simulated discharge measurements (Table 5) approximate the estimates from SNWA (2009a) on a basinwide basis, although the NMR estimates combine ET and spring discharge. Simulated GW discharge from both Butte Valley South and Steptoe Valleys in the NMR is less than the SNWA (2009a) ET estimates by more than 10%. This underestimated discharge increases the simulated amount of water available in Steptoe Valley.

Two water budget components in Steptoe Valley combine to provide more water to downgradient basins, Spring Valley and Lake Valley, than SNWA (2009a) had estimated independent from the numerical model. The numerical model estimated 22,800 af/y of interbasin flow to adjacent basins from Steptoe Valley. SNWA (2009a) estimated recharge in Steptoe Valley to be about 10,000 af/y less than GWET and did not estimate interbasin flow; the recharge estimate for Steptoe Valley is more than 50,000 af/y less than the estimate in BARCASS (Welch et al, 2008), which had been made using a different method. The ***numerical model therefore provides more interbasin flow to Spring Valley than the conceptual model (SNWA 2009a) which biases the results to underestimate the impacts of pumping to Spring Valley***.

Table 5: Simulated Water Budget Values from the Steady State Numerical Model: File ibf_ucth814_1944

Steady State: 1944 Conditions					
Hydrographic Area	**Net IB Flow**	**CH Bdry**	**GW Discharge**	**Recharge**	**Stream Flow**
Goshute V					
Butte V South	-21700	-500	-8900	31700	
Steptoe V	-22800	-2100	-88700	113600	
Total	-44500	-2600	-97600	145300	
Las Vegas Valley					
Las Vegas V	-2800	0	0	2800	
Total	-2800	0	0	2800	
Meadow Valley Wash					
Lake V	-7900	0	-2400	10400	
Dry V	3200	0	-4800	1600	
Rse V	300	0	-400	100	
Eagle V	-700	0	-400	1100	
Spring V	-6700	0	-700	7400	
Patterson V	-6900	0	0	6900	
Panaca V	12800	0	-20800	8000	
Clover V	-7400	0	-1900	9400	
Lower Meadow V	-1100	0	-14600	15700	
Total	-14400	0	-46000	60600	
Salt Lake Desert					
Spring V	-4900	0	-77700	82600	
Tippett V	-1500	-4200	0	5700	
Pleasant V	-4400	0	0	4400	
Snake V	47900	-31900	-122600	106900	-200
Hamlin V	-20300	0	-800	21100	
Fish Spring Flat	-2300	2200	0	100	
Total	14500	-33900	-201100	220800	-200
White River					
Coal V	-4900	0	0	4900	
Garden V	-22100	-2300	0	24300	
Jakes V	-10700	0	0	10700	
Long V	3600	-13500	-800	10700	
Cave V	-15400	0	0	15400	
Dry Lake V	-17300	0	0	17300	
Delamar V	-7500	0	0	7500	
Kane Springs V	-4000	0	0	4000	
White R V	32000	0	-73100	41100	
Pahroc V	-5500	0	0	5500	
Pahranagat V	40600	-9500	-23000	6100	-14200
Coyote Spr v	-5700	2000	0	3700	
Black Mtns Area	11600	-7500	-2100	0	-2000
Garnet V	-200	0	0	200	
Hidden V N	-200	0	0	200	
California Wash	6400	0	-7500	0	1200
Muddy R Sprigs	38000	0	-4200	100	-33900
Lower Moapa V	8400	-6700	-21300	100	19500
Total	47100	-37500	-132000	151800	-29400
GW Discharge equals the sum of GWET and Springflow discharge.					

Gandy Warm Springs

The simulated flow from Gandy Warm Spring is approximately one-third of the targeted flow (NMR, page 5-5), which is likely an error in the implementation of the conceptual flow model. However, the simulated discharge from Snake Valley is within 4% of the targeted value, so SNWA accepts the tradeoff after it did not succeed in balancing the spring flow (NMR, page 5-6). As a result, groundwater that discharges from the spring will be simulated as discharging from elsewhere in the valley, where it can be captured by the proposed pumping *while decreasing the predicted impacts of pumping*. The error in simulating the spring is likely because SNWA treats the spring as intermediate rather than regional (CMR page 7-41), and describes it as follows:

> Gandy Warm Springs is located on the western edge of Snake Valley in the northern portion of the study area (Plate 1). It discharges water from alluvial materials approximately 1.6 mi west of a normal fault. The spring was selected for inclusion in the conceptual model because of its large discharge. The average spring discharge is approximately 17 cfs. (CMR, page 7-41)

The fact that this description of Gandy Warm Springs is incorrect is reflected in the fact that the spring discharges from the base of a carbonate outcrop, with numerous side springs discharging from 20 to 40 feet above the main channel on the outcrop. This would not occur if the flow conduit to the spring was through fill material. SNWA simulated the spring as a deep drain (Table 4-28, NMR), but information on which model layer was used (a significant consideration) does not appear to have been included. SNWA apparently does not attempt to simulate the carbonate outcrop because the upper model layer in that area does not show LC, although SNWA implied it did (NMR, page 5-5). SNWA changed the model in an attempt to improve the simulation of the springs, as follows.

- Increasing the heads on the east side of Snake Valley should be verified by comparison with the springs near the Gandy Salt Marshes and with the GWET in that area (NMR, page 5-5).
- Increasing the amount of runoff that recharges just west of the spring (*Id.*) may increase flows from the springs, but that would ***not account*** for the temperature in the springs. To justify this scenario, SNWA should complete a particle tracking analysis for flow from the recharge to discharge zone to show that it circulates deeply.
- Increasing recharge efficiencies also may increase the simulated spring flow, but is ***partly wrong*** for the same reason as the runoff recharge in the previous bullet (NMR, page 5-6).

SNWA misses the two most likely sources of water to the spring: (1) the substantial carbonate rock on the northeast side of the Snake Range southwest of the spring; and (2) interbasin flow from Spring Valley. It is apparent that SNWA does not consider the carbonate outcrops because contours on NMR, Plate 2, indicate the flow path to the spring from this source may be diverted by a fault – flow passes south of the Gandy Warm Spring to flow further north in the valley. Flow arrows on NMR, Plate 2, suggest that most flow to the spring is from the northwest which explains why increasing recharge in that area would increase spring flow. The connection between Spring Valley and the springs is apparent on the 2008 SNWA geology report (SNWA 2008b), but a model cross-section indicates the carbonate rock is not simulated as an outcrop in that area (Figure 48).

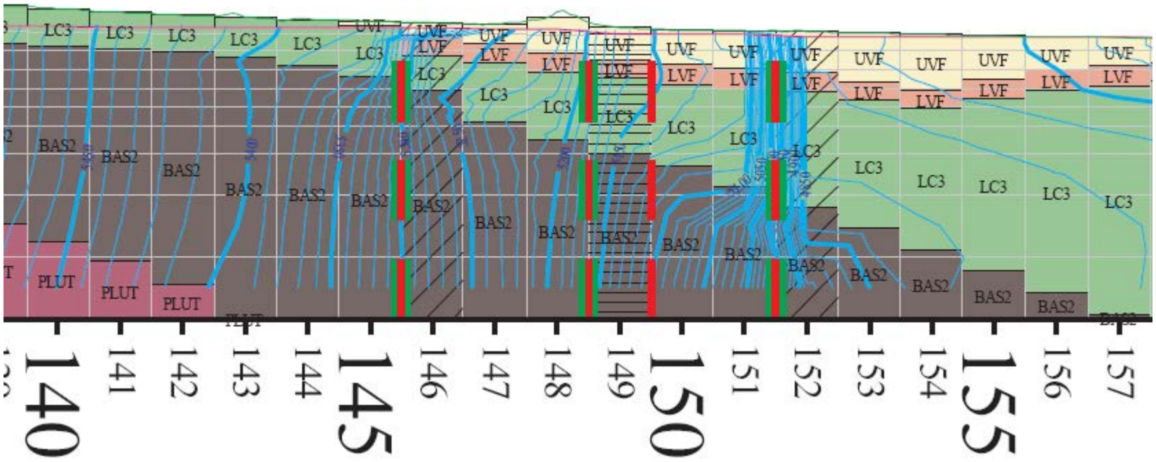

Figure 48: Snapshot for Row 100 showing groundwater contours and hydrogeologic formations near Gandy Warm Springs, near column 148.

SNWA discounts the likelihood that interbasin flow from Spring Valley could support the spring (NMR, page 5-6). This is curious because the model simulates 11,800 af/y of interbasin flow to Snake Valley just to the north of Gandy Warm Springs, which is of the same order of magnitude as the approximately 16,000 af/y estimated for this region in BARCASS (Welch et al, 2008, Figure 41). While there is uncertainty and disagreement around the BARCASS estimate, the model simulation shows it is credible. If even a third of that amount combined with carbonate recharge in the northeast portion of the Snake Range, the Gandy Warm Springs flow could be accurately reproduced.

Summary: SNWA simulations underestimated Gandy Warm Springs flow because an incorrect conceptualization was used. They failed to provide a carbonate pathway through the north Snake Range, which limited the effect that simulated pumping in Spring Valley had on the spring flow.

Lack of Verification

SNWA did no verification of this model, which means SNWA has not assessed the predictive accuracy of the model.

Specific Comments on the Numerical Model and Report

GWET Simulated as DRAIN Cells: SNWA modeled GWET within the numerical model using DRAIN boundaries with the DRAIN head set to represent the extinction depth and the conductance set to represent the ET rate (NMR p. 4-38 to 4-41). This method would have biased the model to simulate GWET at rates lower than would actually occur. The model cell is assumed to be covered by the dominant wetland type within the cells. In other words, if a cell is a mixture of wetland and shrubland, but there is more shrubland, the model simulates the entire cell as shrubland which has a smaller GWET rate. The report notes that open water was never the dominant type even though 2700 acres of White River Valley is open water. This method has the effect of spreading low GWET phreatophytes across the model which would decrease the rate of groundwater discharge simulated from the model.

Distribution of Recharge: The method for estimating recharge for each basin was addressed in the CMR section; it yielded estimates for each basin and “new” Maxey-Eakin recharge efficiencies for each flow system in the model domain. The basinwide recharge estimates were distributed around the basin by combining a statistical estimate of potential recharge based on the new recharge efficiencies with a deterministic assessment, based on geology, of the amount of potential recharge that will actually become in-place recharge.

Recharge efficiencies do not have a physical basis – they are tantamount to regression coefficients. They simply represent the proportion of basinwide precipitation falling in certain precipitation depth bands that must recharge for the sum to equal the estimated discharge from the basin. For example, the efficiencies for the above-20-inch precipitation zone vary from about 0.23 in the Meadow Valley Flow System to more than 0.37 in the White River Flow System (NMR, Table 4-21). To the extent there is a causal or physical explanation for the efficiencies, they would include topographic effects of relief and aspect, seasonal effects such as distribution and type of precipitation, and geologic effects.

Applying the recharge efficiencies to the estimated precipitation yields a potential recharge which either recharges onsite or runs off. If it runs off, it will recharge at the first point with geology conducive to infiltration. The model does not simulate the runoff but forces the recharge into the groundwater at the point the precipitation falls. Forcing too much water into the ground would cause the conductivity to be set too high during calibration because the model cell must simulate more groundwater flow that actually would occur if some of the recharge runs off.

Sensitivity of Recharge Coefficients: SNWA altered the recharge efficiencies as part of the calibration process (NMR, sec. 6.3.3). The purpose for doing this, however, was unclear. The parameters are so sensitive (NMR, p. 6-59) that the U_CODE calibration routine sometimes yielded recharge efficiencies that would have made recharge exceed precipitation, or produced other impossible results. Therefore, SNWA completed a manual calibration to determine scaling factors to adjust the recharge efficiencies (NMR, Table 6-10). All scaling factors exceeded 1.0, which means the recharge estimates were scaled upward. This explains why the simulated recharge exceeded the target (NMR, p. 6-59).

If recharge efficiencies are to vary within the numerical model, they should do so within a basin so that total recharge within a basin equals targeted recharge. This could be done by adding a flux target to the calibration. Physically it is feasible that the distribution of recharge around a basin controls the simulated head and that changing that distribution might improve the fit of simulated to observed heads. Once the recharge has been distributed using the recharge efficiency and the geologic factors, the known physical parameters controlling recharge have been controlled for. The factors used to control the distribution of recharge among distributed and runoff recharge, which is to say the geologic factors, should be the primary distribution control. It follows that conductivity parameters should control the remaining head distribution across the basin; only if substantial variance remains should the recharge parameters be added to the regression analysis and then only with conductivity parameters considered simultaneously during the automated calibration routine.

Pahranagat Valley Flows: The model simulated too much ET from cells within Pahranagat Valley (NMR, p. 5-13), so the modeler chose to allow flow from that valley into Tikaboo Valley and then back into Coyote Spring Valley. There is both support and opposition in the literature for such flow. SNWA should consider whether there is too much inflow to Pahranagat Valley or whether the residual in that valley indicates that simulated water levels are too high. Inflow could be reduced by increasing discharge from White River Valley or allowing more flow from Delamar Valley to Coyote Springs Valley. Heads could be decreased by altering, probably by small amounts, the Pahranagat Shear Zone conductivity. This would allow more flow from Pahranagat Valley to Coyote Springs Valley, and beyond. Estimates of flow between those valleys have a wide range therefore there would be some leeway to allow more flow across the shear zone.

Observed Data Weighting for Calibration: The number of flux and head observations, combined with the weighting of these observations, probably causes the model to be non-unique. As noted (NMR, section 5.2), head observations were given the same weight as flux observations, but there were 2700 head and 4300 transient drawdown observations but there were just over 220 spring and streamflow measurements (NMR, Table 5-1). The several spring discharge measurements that were given higher weight (NMR, Table 5-2) are correlated, which decreases their value for calibration because two observations of essentially the same phenomena does not increase the information content of the observations. This bias toward head observations (NMR, p. 5-3) would cause the model to be non-unique, which means that different parameters could match the observations equally as well, as long as they were altered proportionally. That is the case here because the model simulates fluxes so poorly, and different parameter distributions may match the head observations just as well as it does now while they do just as poorly with the flux. SNWA also used over 2400 ground surface elevations to compare with the water level in places where the model simulated ponding (NMR, Table 5-1). Even though SNWA used low weights for these observations, using ground surface as a target in locations the model was simulating head above the ground surface does not constrain the model simulations to the observed water levels.

Conclusion

As the analysis in this report explains, SNWA's proposed groundwater development project in Spring, Cave, Dry Lake, and Delamar Valleys would constitute groundwater mining on a massive scale and cannot be developed without taking water from valuable groundwater dependent ecosystems and existing water rights. Pumping for this project would not bring the groundwater systems, whether the CCFS, WRFS, GSLFS, or the individual project basins, into equilibrium for at least many centuries and most likely for millennia. Modeling completed by SNWA and confirmed by at least two other independent models confirms this conclusion. Because pumping would not bring the subject groundwater systems into equilibrium, the impacted groundwater systems would continue to lose groundwater in storage and would experience continuing increased drawdown for centuries and beyond.

Developing this groundwater mining project will cause irreversible environmental damage to springs and wetlands in Spring Valley and downgradient from the CDD basins in White River Valley, Pahranagat Valley, and Muddy River basin. Developing a perennial yield in its entirety is not possible without drying groundwater discharge points within a basin, and if those are valuable resources, they will be lost. Moreover, the springs in these basins and in downgradient basins are highly, and in many cases fully, appropriated. The NSE has acknowledged the importance of interbasin flow in supporting those springs, and has previously denied applications to protect the flows and water rights in those springs.

Additionally, the groundwater model used to estimate the impacts and times to equilibrium has many shortcomings that bias the simulations to underestimate the impacts. Of the numerous deficiencies outlined above, two factors stand out as likely to cause the most significant bias. First, the simulations of carbonate rock in the uppermost active model layer as unconfined would allow far too much water to be released in response to SNWA's proposed pumping. Second, the model simulates pathways supporting springs in the CDD area as being far too transmissive. The conductivity is far too high over far too wide an area and allows far too much water to flow to the springs under pre-development conditions. Thus, even though SNWA's own model predicts devastating impacts from SNWA's proposed pumping, those devastating impacts are an underestimate of the actual likely impacts of developing the proposed project.

Finally, a monitoring, management, and mitigation plan for SNWA's project cannot protect the environment or other water rights, whether within the target basins or in adjacent downgradient basins, without an improved understanding of flowpaths and a commitment to more monitoring points. Analysis of simple monitoring examples show that monitoring points must be far upgradient of the point to be protected to have any chance of protecting it. Due to complexities of the flow systems that SNWA's project would affect, identifying the horizontal and vertical critical pathways for groundwater flow to each water right or environmental resource to be protected is an essential prerequisite for the design of an effective 3M plan. Yet in its 3M proposals SNWA has not even attempted to identify these pathways, as demonstrated by the lack of consideration of more locally focused conceptual flow models. Any reasonable management plan would need to be designed to change or stop pumping when drawdown or flows drop below a specified trigger and must account for the fact that drawdown will continue for substantial periods after the changes to pumping are implemented. The fact that effective monitoring points and triggers may constrain SNWA's freedom to pump as much water from this project as it would like does not lessen the scientific necessity to establish such monitoring points and triggers in order for a 3M plan to do its job. But SNWA has not attempted to identify monitoring points properly or establish effective triggers. Because of these fundamental deficiencies in the vague 3M approach that SNWA has proposed, there simply is not sufficient information or assurance on which to base a decision that SNWA's proposed groundwater development project can be developed at any level without causing unreasonable harm to important environmental resources or existing water rights.

References

Anderman ER, Hill MC (2003) MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model – Three Additions to the Hydrogeologic-Unit Flow (HUF) Package: Alternative Storage for the Uppermost Active Cells (SYTP Parameter Type), Flows in Hydrogeologic Units, and The Hydraulic-Conductivity Depth-Dependence (KDEP) Capability. US Geological Survey Open File Report 03-347.

Anderman ER, Hill MC (2000) MODFLOW-2000, The U.S. Geological Survey Modular Ground-water Model _ Documentation of the Hydrogeologic-Unit Flow (HUF) Package. US Geological Survey Open-File Report 00-342.

Anderson MP, Woessner WW (1992) Applied Groundwater Modeling: Simulation of Flow and Advective Transport. Academic Press

Belcher, W.R., Elliott, P.E., and Geldon, A.L., 2001, Hydraulic-property estimates for use with a transient ground-water flow model for the Death Valley regional ground-water flow system, Nevada and California: U.S. Geological Survey Water-Resources Investigations Report 01–4210, 25 p.

Benson LV, Currey DR, Dorn RI, Lajoie KR, Oviatt CG, Robinson SW, Smith GI, Stine S (1990) Chronology of expansion and contraction of four Great Basin lake sytems during the past 35,000 years. Palaeogeography, Palaeoclimatology, Palaeoecology 78:241-286.

Benson LV, Currey DR, Lao Y, Hostetler S (1992) Lake-size variations in the Lahontan and Bonneville basins between 13,000 and 9000 ^{14}C yr B.P. Palaeogeography, Palaeoclimatology, Palaeoecology 95:19-32.

Benson LV, Thompson RS (1987) Lake-level variation in the Lahontan Basin for the past 50,000 years. Quaternary Research 28:69=85.

BLM (Bureau of Land Management) (undated a) Net Groundwater Flow Between Hydrographic Areas, file ibf_ucth814_1944ss (provided to White Pine County by BLM with Numerical Model Report).

BLM (Bureau of Land Management) (undated b) Net Groundwater Flow Between Hydrographic Areas, file ibf_ucth814_2004 (provided to White Pine County by BLM with Numerical Model Report).

BLM (Bureau of Land Management) (undated c) Simulated Groundwater Budgets, file zb_ucth814_1944ss (provided to White Pine County by BLM with Numerical Model Report).

BLM (Bureau of Land Management) (undated d) Simulated Groundwater Budgets, file zb_ucth814_2004 (provided to White Pine County by BLM with Numerical Model Report).

BLM (Bureau of Land Management) (undated e) Springs_Hydrograph_Report_2005_2250 (provided to White Pine County by BLM with Numerical Model Report).

Bredehoeft J, Durbin T (2009) Ground Water Development – The Time to Full Capture Problem. Ground Water doi:10.111/j.1745-6584.00538.x

Brown J, Bach L, Aldous, A, Wyers A, DeGagne J (2011) Groundwater-dependent ecosystems in Oregon: an assessment of their distribution and associate threats. Font Ecol Environ 9(2):97-102, doi:10.1890/090108.

Brothers, K., Buqo, T.S., Bernholtz, A.J., and Tracy, J.V., 1994, Hydrology and steady state ground-water model of Spring Valley, Lincoln and White Pine Counties, Nevada: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 13, 69 p.

Brothers, K., Buqo, T.S., and Tracy, J., 1993, Hydrology and steady state ground-water model of Snake Valley, east-central Nevada, and west-central Utah: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 9, 66 p.

Burns, A.G., and Drici, W., 2011, Hydrology and water resources of Spring, Cave, Dry Lake, and Delamar valleys, Nevada and vicinity: Presentation to the Office of the Nevada State Engineer: Southern Nevada Water Authority, Las Vegas, Nevada.

Caine JS, Evans JP, Forster CB (1996) Fault zone architecture and permeability structure. Geology 24(11):1025-1028.

Committee on USGS Water Resources Research, Water Science and Technology Board, National Research Council (2000) Investigating Groundwater Systems on Regional and National Scales. National Academy Press, Washington

Currell MJ (2016) Drawdown "Triggers": A misguided strategy for protecting groundwater-fed streams and springs. Groundwater 54:619-233, doi:10.1111/gwat.12425

Daly C, Halbleib M, Smith JI, Gibson WP, Doggett MK, Taylor GH, Curtis J, Pasteris PP (2008) Phydiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. Int J Climatol DOI: 10.1002/joc.1688.

Dettinger MD (1989) Reconnaissance estimates of natural recharge to desert basins in Nevada, U.S.A., by using chloride-balance calculations. J. Hydrol. 106:55-78.

Durbin T, Bredehoeft J (2009) Ground water development – The time to full capture problem. Ground Water 47:1-9, doi: 10.1111/j.:174506584.2008.00538.x

Eakin, T.E., 1962, Ground-water appraisal of Cave Valley in Lincoln and White Pine Counties, Nevada: Nevada Department of Conservation and Natural Resources, Ground-Water Resources–Reconnaissance Series Report 13, 19 p.

Eakin, T.E., 1963a, Ground-water appraisal of Dry Lake and Delamar Valleys, Lincoln County, Nevada: Nevada Department of Conservation and Natural Resources, Ground-Water Resources–Reconnaissance Series Report 16, 25 p.

Eakin, T.E., 1963b, Ground-water appraisal of Pahranagat and Pahroc Valleys, Lincoln and Nye Counties, Nevada: Nevada Department of Conservation and Natural Resources, Ground-Water Resources - Reconnaissance Report 21, 36 p

Eakin, T.E., 1966, A regional interbasin groundwater system in the White River area, southeastern Nevada: Water Resources Research, Vol. 2, No. 2, p. 251–271.

Einarson M (2006) Multilevel ground-water monitoring. In Nielsen DM (ed.) Practical Handbook of Environmental Site Characterization and Ground-water Monitoring, 2nd. Ed. CRC -Taylor and Francis

Fairley JP, Hinds JJ (2004) Rapid transport pathways for geothermal fluids in an active Great Basin fault zone. Geology 32(9):825-828.

Fetter CW (2001) Applied Hydrogeology, Fourth Edition. Prentice-Hall

Flint, A.L., L.E. Flint, J.A. Hevesi, and J.B. Blainey, 2004. Fundamental Concepts of Recharge in the Desert Southwest: A Regional Modeling Perspective. Pages 159-184 in Hogan, J.F., 46

F.M. Phillips and B.R. Scanlon (eds.), Groundwater Recharge in a Desert Environment: The Southwestern United States, Water Science and Application 9. American Geophysical Union, Washington.

Geosyntac Consultants, Inc, Garcia and Associates (GANDA) (2014) Groundwater Monitoring, Mitigation, and Reporting Plan, Cabin Bar Ranch, U.S. Highway 395, Olancha, California. June 18, 2014.

Halford, K.J., and Plume, R.W., 2011, Potential effects of groundwater pumping on water levels, phreatophytes, and spring discharges in Spring and Snake Valleys, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2011-5032, 52 p.

Howard J, Merrifield M (2010) Mapping groundwater dependent ecosystems in California. PLoS One 5(6):e11249. Doi:10.1371/journal.pone.0011249.

Jeton, A.E., S.A. Watkins, T.J. Lopes, and J. Huntington, 2006. Evaluation of Precipitation Estimates from PRISM for the 1961–90 and 1971–2000 Data Sets, Nevada. Scientific Investigations Report 2005-5291. U.S. Geological Survey, Carson City, NV.

Kirk ST, Campana ME (1990) A deuterium-calibrated groundwater flow model of a regional carbonate-alluvial system. J Hydrol 119:357-388.

Masbruch MD, Rumsey CA, Gangopadhyay S, Susong DD, Pruitt T (2016) Analyses of infrequent (quasi-decada) large groundwater recharge events in the northern Great Basin: Their importance for groundwater availability, use, and management. Water Resources Research, 52:7819-7836, doi:10.1002/2016WR019060.

Meixner T, et al. (2016) Implications of projected climate change for groundwater recharge in the western United State. J Hydrology 534:1124-138, http://dx.doi.org/10.1016/j.jhydrol.2015.112.027

Myers T (2011a) Hydrogeology of Cave, Dry Lake and Delamar, Impacts of Pumping Underground Water Right Applications #53987 Through 53092. Presented to the Office of the Nevada State Engineer on Behalf of Great Basin Water Network, June 2011.

Myers T (2011b) Hydrogeology of Spring Valley and Surrounding Areas, Part A: Conceptual Flow Model. Presented to the Office of the Nevada State Engineer On behalf of Great Basin Water Network and Federated Tribes of the Goshute Indians, June 2011.

Myers T (2011c) Hydrogeology of Spring Valley and Surrounding Areas, Part B: Groundwater Model of Snake and Spring Valleys, and Surrounding Areas. Presented to the Office of the Nevada State Engineer On behalf of Great Basin Water Network and Federated Tribes of the Goshute Indians, June 2011.

Myers T (2011d) Hydrogeology of Spring Valley and Surrounding Areas, Part C: Impacts of Pumping Underground Water Right Applications #54003 Through 54021. Presented to the Office of the Nevada State Engineer On behalf of Great Basin Water Network and Federated Tribes of the Goshute Indians, June 2011.

Myers T (2011e) Rebuttal Report: Part 1, Review of Evidence Reports Submitted by southern Nevada Water Authority in Support of Water rights Applications for Spring, Cave, Dry Lake, and Delamar Valleys, Presented to the Office of the Nevada State Engineer, On Behalf f Great Basin Water Network and the Confederated Tribes of the Goshute Reservations. August 2011

Myers T (2011f) Rebuttal Report: Part 3, Prediction of Impacts Caused by Southern Nevada Water Authority Pumping Groundwater from Distributed Pumping Options for Spring Valley, Presented to the Office of the Nevada State Engineer on Behalf of Great Basin Water Network and the Confederated Tribes of the Goshute Reservation.

Nevada State Engineer (undated) Pahranagat Valley Hydrographic Basin 13-209, Groundwater Pumpage Inventory, Water Year 2015. State of Nevada, Dept of Conservation and Natural Resources.

Nichols WD (2000) Chapter C. Regional Ground-water Budgets and Ground-water Flow, Eastern Nevada. In Nichols WD, Regional Ground-water Evapotranspiration and Ground-water Budgets, Great Basin, Nevada, US Geological Survey Professional Paper 1628.

Page, W.R., Scheirer, D.S., Langenheim, V.E., and Berger, M.A., 2011, Revised geologic cross sections of parts of the Colorado, White River, and Death Valley regional groundwater flow systems, Nevada, Utah, and Arizona: U.S. Geological Survey Open-File Report 2006–1040.

Prudic, D.E, Sweetkind, D.S., Jackson, T.R., Dotson, K.E., Plume, R.W., Hatch, C.E., and Halford, K.J. 2015, Evaluating connection of aquifers to springs and streams, Great Basin National Park and vicinity, Nevada: U.S. Geological Survey Professional Paper 1819, 188 p., *http://dx.doi.org/10.3133/pp1819*.

Prudic DE, Harrill JR, Burbey TJ (1995) Conceptual evaluation of regional ground-water flow in the carbonate-rock province of the Great Basin, Nevada, Utah, and adjacent states. US Geological Survey Professional Paper 1409-D.

Rowley, P.D., Dixon, G.L., Burns, A.G., Pari, K.T., Watrus, J.M., and Ekren, E.B., 2011, Geology and geophysics of Spring, Cave, Dry Lake, and Delamar valleys, White Pine and Lincoln Counties and adjacent areas, Nevada and Utah: The geologic framework of regional groundwater flow systems: Presentation to the Office of the Nevada State Engineer: Southern Nevada Water Authority, Las Vegas, Nevada.

SNWA (Southern Nevada Water Authority) (2012). Addendum to the simulation of groundwater development scenarios using the transient numerical model of groundwater flow for the Central Carbonate-Rock Province-Clark, Lincoln, and White Pine Counties Groundwater Development Project. Las Vegas NV 49 p.

SNWA (Southern Nevada Water Authority) (2010a) Addendum to the groundwater flow model for the Central Carbonate-Rock Province, - Clark, Lincoln, and White Pine Counties Groundwater Development Project. Las Vegas NV 48 p.

SNWA (Southern Nevada Water Authority) (2010b) Simulation of groundwater development scenarios using the transient numerical model of groundwater flow for the Central Carbonate-Rock Province: Clark, Lincoln, and White Pine Counties Groundwater Development Project, September 2010. Las Vegas NV, 97 p.

SNWA (Southern Nevada Water Authority) (2009a) Conceptual model of groundwater flow for the Central Carbonate-Rock Province – Clark, Lincoln, and White Pine Counties groundwater development project. Las Vegas NV 418 p.

SNWA (Southern Nevada Water Authority) (2009b) Hydrologic Monitoring and Mitigation Plan for Delamar, Dry Lake, and Cave Valleys. Las Vegas NV 38 p.

SNWA (Southern Nevada Water Authority) (2009c) Spring Valley Hydrologic Monitoring and Mitigation Plan (Hydrographic Area 184). Las Vegas NV 49 p.

SNWA (Southern Nevada Water Authority) (2009d) Transient numerical model of groundwater flow for the central Carbonate-Rock Province – Clark, Lincoln, and White Pine Counties groundwater development project. Las Vegas NV 394 p.

SNWA (Southern Nevada Water Authority) (2008a) Baseline characterization report for Clark, Lincoln and White Pine Counties Groundwater Development Project, January 2008. Las Vegas NV.

SNWA (Southern Nevada Water Authority) (2008) Volume 1, Geology of White Pine and Lincoln counties and adjacent areas, Nevada and Utah: The geologic framework of regional groundwater flow systems, January 2008. Las Vegas NV, 158 p.

State of Nevada (undated) Water Planning Report. Dept of Conservation and Natural Resources, Division of Water Resources.

Subcommittee on Ground Water of the Advisory Committee on Water Information (2013) A National Framework for Ground-water Monitoring in the United States, Revised 2013. https://cida.usgs.gov/ngwmn/

Thomas, J.M., Calhoun, S.C., and Apambire, W.B., 2001, A deuterium mass-balance interpretation of groundwater sources and flows in southeastern Nevada: Desert Research Institute, Las Vegas, Nevada, Publication No. 41169, 46 p.

Welch AH, Bright DJ, Knochenmus LA, eds. (2008) Water resources of the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2007–5261, 96 p.

Winter TC, Harvey JW, Franke OL, Alley WM (1998) Ground Water and Surface Water, A Single Resource. US Geological Survey Circular 1139.

Appendix 1: Table of spring and stream water rights for White River Valley (207), Pahroc Valley (208), and Pahranagat Valley (209)

Basin	App	Change Of App	Cert	Filing Dt	Stat	Src	Source Name	Div Rate (CFS)	Type of Use	Priority Dt	Sup	Ann Duty	Unit
207	10176		3022	10/15/1937	CER	SPR	Arnoldson	3.82	IRR	10/15/1937		507.53	AFS
207	5977		680	2/6/1920	CER	SPR	Badger Hole	0.02	STK	2/6/1920	Y	14.49	AFA
207	V01415			9/10/1915	VST	SPR	Barrel	0.125	STK	1/1/1888		90.47	AFS
207	V09874			1/27/2010	VST	SPR	Barrel	0.0203	STK	1/1/1900		0	AFA
207	5976		679	2/6/1920	CER	SPR	Black Jack Spgs 1 and 2	0.018	STK	2/6/1920	Y	13.01	AFA
207	46426		18685	12/10/1982	CER	SPR	Blue	0.0062	STK	12/10/1982		1.5	AFA
207	28209		9425	3/25/1974	CER	SPR	Butterfield	2.15	IRR	3/25/1974		1556.54	AFA
207	V01333			10/17/1914	VST	SPR	Camp	1	STK	1/1/1902		723.95	AFS
207	3934		1279	4/26/1916	CER	SPR	Cottonwood	0.001	DOM	4/26/1916	Y	1.1	AFA
207	66360		16734	5/10/2000	CER	SPR	Dee Gee	0.038	STK	5/10/2000		26.88	AFA
207	4324	V01501	1968	2/20/1917	CER	SPR	Douglas	0.19	STK	1/1/1885	Y	134.42	AFA
207	699		354	9/26/1907	CER	SPR	Douglas	0.105	IRR	9/26/1907	Y	42.04	AFA
207	V01501			2/26/1917	VST	SPR	Douglas	0.5	STK	1/1/1885		0	AFA
207	10219		2603	4/4/1938	CER	SPR	Easter	0.011	DOM	4/4/1938		7.98	AFA
207	20329		5898	3/1/1962	CER	SPR	Egan	0.015	STK	3/1/1962		11.42	AFA
207	28208		9417	3/25/1974	CER	SPR	Emigrant	1.279	IRR	3/25/1974		824	AFA
207	49476		13043	10/23/1985	CER	SPR	Flag	0.022	QM	10/23/1985		1.81	AFA
207	408		195	3/21/1907	CER	SPR	Forest Home	0.706	IRR	3/21/1907	Y	282.44	AFA
207	V01151			7/26/1912	VST	SPR	Forest Home	0	IRR	1/1/1881		0	AFA
207	13423		3632	6/19/1950	CER	SPR	Gardner	0.003	STK	6/19/1950		2.15	AFA
207	5336		1524	12/19/1918	CER	SPR	Goodman	0.15	IRR	12/19/1918	Y	0	AFA
207	5174		2006	7/29/1918	CER	SPR	Granite	0.001	STK	7/29/1918	Y	0.89	AFA

207	7390			6/7/1925	PER	SPR	Greek	0.003	STK	6/7/1925	Y	2.24	AFS
207	11665		3557	7/26/1946	CER	SPR	Green	0.128	IRR	7/26/1946		69.98	AFA
207	19294		5897	10/24/1960	CER	SPR	Gurley Irrigation	0.096	IRR	10/24/1960		52.97	AFA
207	19471		5833	1/23/1961	CER	SPR	Gurley Stockwatering Spring	0.015	STK	1/23/1961		11.29	AFA
207	28206		9416	3/25/1974	CER	SPR	Hardy	0.671	IRR	3/25/1974		268	AFA
207	V02126			10/18/1927	VST	SPR	head of sawmill	0.025	STK	1/1/1900		1.41	AFS
207	43451	3459	13025	4/2/1981	CER	SPR	High	0.06	IND	6/26/1915		43.42	AFA
207	V09908			2/8/2010	VST	SPR	High	0.0637	STK	1/1/1905		0	AFA
207	43452	300	13026	4/2/1981	CER	SPR	Holt Creek	0.619	IND	11/30/1906		0	AFA
207	43453	299	13027	4/2/1981	CER	SPR	Holt Creek	0.45	IND	11/30/1906		325.79	AFA
207	V03026			5/31/1978	VST	SPR	Horsely	0.01	IRR	3/1/1904		20	AFS
207	V03027			5/31/1978	VST	SPR	Horsely	0.01	STK	3/1/1904		22.59	AFA
207	5851		970	11/8/1919	CER	SPR	Indian	0.07	IRR	11/8/1919	Y	21	AFA
207	8424		1794	1/5/1928	CER	SPR	Irwin Canyon	0.005	STK	1/5/1928	Y	0.83	AFA
207	V11181			1/13/2017	VST	SPR	Jagger	0.025	STK	1/1/1873		0	AFA
207	V09819			8/25/2009	VST	SPR	Lion	0.0071125	STK	1/1/1900		0	AFA
207	1945		297	2/8/1911	CER	SPR	Little	0.12	IRR	2/8/1911	Y	48	AFA
207	V01791			4/5/1922	VST	SPR	Logan	0.1	STK	1/1/1892		8.87	AFS
207	V02195			7/26/1928	VST	SPR	Lone Pine	0.025	STK	1/1/1902		0	AFA
207	V09898			2/1/2010	VST	SPR	Lone Pine	0.0223	STK	1/1/1905		0	AFA
207	V02088			3/27/1927	VST	SPR	Lower Parish	0.01	STK	12/31/1885		0.55	AFA
207	10108		3002	4/12/1937	CER	SPR	Lund	6	IRR	4/12/1937		784	AFS
207	12499		5336	6/14/1948	CER	SPR	Lund	2.031	IRR	6/14/1948		942.43	AFS
207	12677		5308	10/5/1948	CER	SPR	Lund	0.47	IRR	10/5/1948		218.09	AFA
207	V09909			2/8/2010	VST	SPR	Mahogany Hotel	0.0462	STK	1/1/1905		0	AFA

207	7389		1584	6/7/1925	CER	SPR	Mill	0.001	STK	6/7/1925	Y	0.86	AFS
207	7322		2086	3/13/1925	CER	SPR	Millard	0.01	STK	3/13/1925	Y	3.38	AFA
207	V09899			2/1/2010	VST	SPR	Millard	0.00329	STK	1/1/1905		0	AFA
207	13760	11247	4173	6/29/1951	CER	SPR	Moon River	5	IRR	2/23/1945		1513	AFA
207	22882		8668	12/7/1965	CER	SPR	Moorman	0.015	STK	12/7/1965		10.83	AFA
207	28207		9401	3/25/1974	CER	SPR	Moorman	0.41	IRR	3/25/1974		132.6	AFA
207	V02091			3/25/1927	VST	SPR	Moorman Spg	0.25	STK	1/1/1893		7.4	AFA
207	V02092			3/25/1927	VST	SPR	Moorman Spg	1	IRR	1/1/1902		24.4	AFS
207	7979		1969	1/15/1927	CER	SPR	Moorman Spring Slough	0.156	STK	1/15/1927	Y	65.06	AFS
207	43450	3659	13024	4/2/1981	CER	SPR	Mountain	0.09	IND	10/27/1915		65.15	AFA
207	8421		1791	1/5/1928	CER	SPR	Mud	0.004	STK	1/5/1928	Y	2.79	AFA
207	V01365			4/9/1915	VST	SPR	Mud	2	STK	1/1/1903		1447.94	AFA
207	V02322			7/12/1943	VST	SPR	Mud	0.1	STK	1/1/1900		1.96	AFS
207	V03287			12/4/1979	VST	SPR	Mud	0.02	STK	1/1/1899		14.49	AFA
207	43756	2087	13030	5/18/1981	CER	SPR	New	0.1	IND	6/3/1911		72.4	AFA
207	7216		1469	9/19/1924	CER	SPR	Nicholas	3	PWR	9/19/1924		2171.89	AFA
207	9805		2422	9/26/1934	CER	SPR	Nicholas	0.005	STK	9/26/1934	Y	3.35	AFA
207	5337		972	12/19/1918	CER	SPR	North	0.25	IRR	12/19/1918	Y	0	AFA
207	4163		495	9/23/1916	CER	SPR	Oxborrow	0.237	IRR	9/23/1916	Y	94.8	AFA
207	V02100			6/24/1927	VST	SPR	Parker	0.025	STK	1/1/1887		3.35	AFA
207	2420		438	5/3/1912	CER	SPR	Parker Range	2.93	IRR	5/3/1912	Y	1170.32	AFA
207	V01962			1/11/1926	VST	SPR	Perry	0.002	STK	3/1/1905		1.44	AFA
207	43449	3660	13023	4/2/1981	CER	SPR	Pine	0.01	IND	10/27/1915		7.24	AFA
207	3298	1860	2211	3/10/1915	CER	SPR	Preston Big	0.402	IRR	10/29/1910	Y	171	AFS
207	8306		2158	8/29/1927	CER	SPR	Preston Big	0.011	STK	8/29/1927	Y	7.95	AFA

207	10177		3023	10/15/1937	CER	SPR	Preston Big	4.57	IRR	10/15/1937		607.17	AFA
207	10107		3001	4/12/1937	CER	SPR	Preston Big, Cold, Nicholas	7.5	IRR	4/12/1937		980	AFA
207	67441		18859	4/23/2001	CER	SPR	Rollins	0.5	IRR	4/23/2001		60	AFA
207	19631		6185	3/3/1961	CER	SPR	Ruppe	0.047	IRR	3/3/1961		13.12	AFA
207	19930		6186	6/21/1961	CER	SPR	Ruppe No 2 and 3	0.097	IRR	6/21/1961		27.09	AFA
207	22284		7004	10/19/1964	CER	SPR	Ruppe No 4	0.022	IRR	10/19/1964		15.92	AFA
207	V02067			1/15/1927	VST	SPR	Sam	0.025	STK	1/1/1898		6.63	AFA
207	10483		2567	3/23/1940	CER	SPR	Secret	0.005	STK	3/23/1940		0.46	AFS
207	11649		3556	7/26/1946	CER	SPR	Sheep Ranch	0.61	IRR	7/26/1946		331.78	AFA
207	V09237			3/8/2000	VST	SPR	Silver	0.01	STK	5/1/1887		0	
207	69363			12/4/2002	PER	SPR	Silver	0.7	IRR	1/31/1995		480	AFA
207	58162		17241	10/2/1992	CER	SPR	South Horse	0.0022	WLD	12/19/2007		1.61	AFA
207	V09917			2/8/2010	VST	SPR	Spring	0.0637	STK	1/1/1905		0	AFA
207	V09921			2/10/2010	VST	SPR	Spring	0.0637	STK	1/1/1905		0	AFA
207	V09922			2/10/2010	VST	SPR	Spring	0.0637	STK	1/1/1905		0	AFA
207	V09923			2/10/2010	VST	SPR	Spring	0.0637	STK	1/1/1905		0	AFA
207	V09924			2/10/2010	VST	SPR	Spring	0.0637	STK	1/1/1905		0	AFA
207	V09927			2/10/2010	VST	SPR	Spring	0.0637	STK	1/1/1905		0	AFA
207	V09929			2/10/2010	VST	SPR	Spring	0.0637	STK	1/1/1905		0	AFA
207	V09930			2/10/2010	VST	SPR	Spring	0.0637	STK	1/1/1905		0	AFA
207	V09931			2/10/2010	VST	SPR	Spring	0.0637	STK	1/1/1905		0	AFA
207	V09932			2/10/2010	VST	SPR	Spring	0.0637	STK	1/1/1905		0	AFA
207	V09933			2/10/2010	VST	SPR	Spring	0.0637	STK	1/1/1905		0	AFA
207	V09934			2/10/2010	VST	SPR	Spring	0.0637	STK	1/1/1905		0	AFA
207	4819		702	1/4/1918	CER	SPR	Trough	0.025	STK	1/4/1918	Y	18.11	AFA

207	V01963			1/11/1926	VST	SPR	Trough	0.002	STK	1/1/1905		13.44	AFA
207	13272		4132	2/20/1950	CER	SPR	Turner	0.266	IRR	2/20/1950		74	AFA
207	28771		9486	10/4/1974	CER	SPR	unnamed	0.045	IRR	10/4/1974		8.2	AFA
207	28819		9487	10/22/1974	CER	SPR	unnamed	0.112	IRR	10/22/1974		67.24	AFA
207	3141		2333	10/23/1914	CER	SPR	unnamed	0.005	STK	10/23/1914	Y	1.78	AFS
207	36649		14238	2/7/1979	CER	SPR	unnamed	0.002	STK	2/7/1979		1.14	AFA
207	46427		18686	12/10/1982	CER	SPR	unnamed	0.0062	STK	12/10/1982		1.5	AFA
207	47729		12331	2/27/1984	CER	SPR	unnamed	0.001	STK	2/27/1984		0.37	AFA
207	52867		13894	1/18/1989	CER	SPR	unnamed	0.001	STK	1/18/1989		0.18	AFA
207	58164		17242	10/2/1992	CER	SPR	unnamed	0.0022	STK	12/19/2007		1.61	AFA
207	V02848			1/30/1975	VST	SPR	unnamed	0.13	STK	3/13/1901		6.72	AFA
207	V02849			1/30/1975	VST	SPR	unnamed	0.13	STK	3/13/1901		6.72	AFA
207	44090		11567	6/29/1981	CER	SPR	Upper New Spring 1	0.5	QM	6/29/1981		362.01	AFA
207	43391		11566	3/25/1981	CER	SPR	Upper New Spring 2	0.5	QM	3/25/1981		362.01	AFA
207	V02089			3/25/1927	VST	SPR	Upper Parish spg 2	0.01	STK	1/1/1985		4.48	AFA
207	V02090			3/25/1927	VST	SPR	Upper Parish spg 2	0.01	STK	1/1/1985		4.48	AFA
207	2193		1203	9/5/1911	CER	SPR	Ward Mountain	0.1	MM	9/5/1911	Y	72.4	AFA
207	13273		4136	2/20/1950	CER	SPR	Warm	0.25	IRR	2/20/1950		270.64	AFA
207	29856		10313	12/12/1975	CER	SPR	Warm Spring	3.67	IRR	12/12/1975		887.6	AFA
207	V09928			2/10/2010	VST	SPR	Water Canyon spg	0.0462	STK	1/1/1905		0	AFA
207	V02087			3/25/1927	VST	SPR	West Parker Range	0.025	STK	1/1/1973		1.87	AFA
207	15453		4587	12/28/1953	CER	SPR	White Knoll	0.005	STK	12/28/1953		3.31	AFA
207	V09812			8/13/2009	VST	SPR	Willow	0.0022	STK	8/13/2009		0	AFA
207	V10802			11/16/2015	VST	SPR	Zebulon	0.025	STK	6/1/1873		0	AFA
207	V01161			1/1/1875	DEC	SPR		0	DEC	1/1/1875			

207	V01162			1/1/1898	DEC	SPR		0	DEC	1/1/1898		0	AFA
207	V01163			1/1/1870	DEC	SPR		0	DEC	1/1/1870		0	AFA
207	V01164			1/1/1898	DEC	SPR		0	IRR	1/1/1898		0	AFA
207	V01165			1/1/1890	DEC	SPR		0.282	DEC	1/1/1890		102	AFA
207	V01166			1/1/1869	DEC	SPR		0	DEC	1/1/1869		0	AFA
207	V01167			1/1/1880	DEC	SPR		0	DEC	1/1/1880		0	AFA
207	V01168			1/1/1898	DEC	SPR		0	DEC	1/1/1898		0	AFA
207	V01169				DEC	SPR		0	DEC				
207	V01170			1/1/1869	DEC	SPR		0	DEC	1/1/1869		0	AFA
207	V01171			1/1/1881	DEC	SPR		0	DEC	1/1/1881		0	AFA
207	V00715			4/1/1910	VST	STR	Cottonwood	0	IRR	3/15/1880		800	AFA
207	2896		773	2/27/1914	CER	STR	East and West	0.995	IRR	2/27/1914	Y	398	AFA
207	V01889			4/18/1925	VST	STR	East Water	0	STK			0	AFA
207	7328		1919	3/18/1925	CER	STR	Ellison	0	IRR	3/18/1925	Y	775	AFA
207	V02224			3/5/1930	VST	STR	Ellison	1	IRR	1/1/1886		0	AFA
207	3235		1872	1/11/1915	CER	STR	Hot Creek	1.222	IRR	1/11/1915	Y	443	AFS
207	V00801			1/1/1915	VST	STR	Hot Creek	0	IRR	1/1/1891		0	AFA
207	V01351			1/11/1915	VST	STR	Hot Creek	0	IRR	1/1/1885		11600	AFA
207	V10515			4/28/2014	VST	STR	Hot Creek, White River	12.9	IRR	1/1/1874		0	AFA
207	20465		6662	5/14/1962	CER	STR	Moorman Springs Wash	0	IRR	5/14/1962		680	AFA
207	20466		6663	5/14/1962	CER	STR	Moorman Springs Wash	0	WLD	5/14/1962		3040	AFA
207	10174		2836	10/4/1937	CER	STR	Rowe Creek	1	IRR	10/4/1937		544	AFA
207	21294		6606	5/22/1963	CER	STR	Rowe Creek Drainage	0.0094	STK	5/22/1963		5.06	AFA

207	22354		7716	12/7/1964	CER	STR	Rowe Creek Drainage	0	IRR	12/7/1964		9	AFA
207	9378		3555	11/21/1930	CER	STR	Sheep	0.2	IRR	11/21/1930	Y	72.78	AFS
207	70969			3/22/2004	PER	STR	Smith	0.34	IRR	3/22/2004		152.1	AFA
207	7251		1330	11/19/1924	CER	STR	Smith	1.2	IRR	11/19/1924		0	AFA
207	38205		12850	5/17/1979	CER	STR	Sunnyside, Hot Cr and WR	80	WLD	5/17/1979		1230	AFA
207	20819		7451	10/30/1962	CER	STR	Tule Field Reservoir	0	IRR	10/30/1962		507	AFA
207	V01519			10/5/1917	VST	STR	Water Canyon	0	IRR	1/1/1902		1200	AFA
207	10118		3021	5/17/1937	CER	STR	White River	8.206	IRR	5/17/1937		3482.36	AFA
207	15763	12518	4588	8/11/1954	CER	STR	White River	1	IRR	6/28/1948		300	AFA
207	23624		7468	1/20/1967	CER	STR	White River	2.403	WLD	1/20/1967		1120	AFS
207	V00776			6/2/1910	VST	STR	White River	0.68999999	IRR	1/1/1871		500	AFA
207	2384		444	3/25/1912	CER	STR	White River	3.29	IRR	3/29/1912	Y	1316	AFA
207	11076		3351	3/4/1944	CER	STR	White River Slough	1.461	IRR	3/4/1944		260.35	AFS
207	11078		3352	3/6/1944	CER	STR	White River Slough	1.024	IRR	3/6/1944		182.51	AFA
207	2661		1868	3/14/1913	CER	STR	White River Slough	0	IRR	3/14/1913		3330	AFS
207	3232		1869	1/11/1915	CER	STR	White River Slough	1.929	IRR	1/11/1915		817.36	AFA
207	78946	11076		10/7/2009	PER	STR	White River Slough	0.731	IRR	3/4/1944		130.26	AFA
207	2334		220	2/7/1912	CER	STR	White River West Branch	2	IRR	2/7/1912	Y	800	AFA
207	12517		4130	6/28/1948	CER	STR	White River, Hot Creek	10	IRR	6/28/1948		1853	AFA
207	13031		4550	8/26/1949	CER	STR	White River, Williams Crek	1.66	IRR	8/26/1949		292	AFA
207	349		128	1/25/1907	CER	STR		9	IRR	1/25/1907	Y	2700	AFA
207	4818		1371	1/4/1918	CER	STR		0.81599999	IRR	1/4/1918	Y	297.29	AFA
207	V04605			7/16/1987	VST	STR		7.69	IRR	1/1/1880		0	

208	52774			12/13/1988	PER	SPR	Black Horse Well	0.003125	STK	12/13/1988		2.24	AFA
208	5970		932	2/2/1920	CER	SPR	Brinkerhoff	0.01	STK	2/2/1920	Y	0.55	AFA
208	6497		1020	6/22/1921	CER	SPR	Mustang	0.015	STK	6/22/1921	Y	4.48	AFS
208	12511		4390	6/18/1948	CER	SPR	Pine Spring	0.003	STK	6/18/1948		1.87	AFA
208	12510		4389	6/18/1948	CER	SPR	Red Rock	0.001	STK	6/18/1948		0.95	AFA
208	4666		1575	11/1/1917	CER	SPR	Weepah	0.001	STK	11/1/1917		0.55	AFA
208	2822		213	11/10/1913	CER	SPR	White Rock	0.1	STK	11/10/1913	Y	72.4	AFA
208	11308		3187	6/6/1945	CER	SPR		0.002	STK	6/6/1945		1.63	AFA
209	23730A01	V01793	13662	3/6/1967	CER	SPR	Ash	0.015	QM	1/1/1885		8.2	AFA
209	23730A02	V01793	13663	3/6/1967	CER	SPR	Ash	0.005	QM	1/1/1885		2.98	AFA
209	26007	V01394	9039	3/16/1971	CER	SPR	Ash	0.382	IRR	3/16/1971		152.8	AFA
209	3755		935	12/24/1915	CER	SPR	Ash	0.091	IRR	12/24/1915	Y	43.68	AFS
209	45452	V01793	12537	3/16/1982	CER	SPR	Ash	0	QM	3/16/1982		3	AFA
209	62434	V01793		9/4/1996	PER	SPR	Ash and Crystal Spgs	6.634	WLD	2/6/1970		1514.38	AFA
209	62436	8715		9/4/1996	PER	SPR	Big (Lonetree Springs)	1.1	WLD	10/7/1928		795	AFA
209	3517		1932	7/19/1915	CER	SPR	Bluff	0.002	STK	7/19/1915	Y	1.34	AFA
209	62431			9/4/1996	PER	SPR	Cottonwood Spring	0.75	WLD	9/4/1996		543	AFA
209	6913		1550	6/13/1923	CER	SPR	Divala	0.001	STK	6/13/1923	Y	0.43	AFA
209	3516		1931	7/19/1915	CER	SPR	Foxtail	0.001	STK	7/19/1915	Y	1.32	AFA
209	3515		270	7/19/1915	CER	SPR	Granite	0.025	STK	7/19/1915	Y	18.08	AFA
209	4718		1578	11/19/1917	CER	SPR	Henry	0.002	STK	11/19/1917	Y	1.1	AFA
209	12882		6566	4/21/1929	CER	SPR	Hiko	6.72	IRR	4/21/1929		2400	AFS
209	20544		6859	6/27/1962	CER	SPR	Hiko	3	IRR	6/27/1962		2171.39	AFA

209	4719		1579	11/19/1917	CER	SPR	Little Cut	0.001	STK	11/19/1917	Y	0.74	AFA
209	62433			9/4/1996	PER	SPR	N Maynard	0.2	WLD	9/4/1996		144.8	AFA
209	V08965			6/3/1997	VST	SPR	Pasture	0.022	IRR			16.14	AFA
209	3853		2331	4/1/1916	CER	SPR	Reed	0.001	STK	4/1/1916	Y	0.64	AFA
209	62432			9/4/1996	PER	SPR	S Maynard	0.2	WLD	9/4/1996		144.8	AFA
209	6114		777	5/12/1920	CER	SPR	Springer	0.003	STK	5/12/1920	Y	2.18	AFA
209	3806		271	2/19/1916	CER	SPR	Willow	0.025	STK	2/19/1916	Y	18.05	AFA
209	10214		2602	3/3/1938	CER	SPR		0.004	STK	3/3/1938		2.58	AFA
209	14510	11718	3938	9/1/1952	CER	SPR		0.012	STK	11/14/1946		8.96	AFA
209	20234			1/10/1962	PER	SPR		18.14	IRR	1/10/1962		0	AFA
209	V01354			6/25/1922	DEC	SPR		1.659	IRR	1/1/1894		663.6	AFA
209	V01362			6/25/1922	DEC	SPR		0.82	DEC	1/1/1882		304	AFA
209	V01363			6/25/1922	DEC	SPR		0.82	DEC	1/1/1866		328	AFA
209	V01393			6/25/1922	DEC	SPR		1.09	DEC	1/1/1868		436	AFA
209	V01394			6/25/1922	DEC	SPR		4.594	DEC	1/1/1875		1837.6	AFA
209	V01490			6/25/1922	DEC	SPR		0.595	DEC	1/1/1882		238	AFA
209	V01548			6/25/1922	DEC	SPR		3.387	DEC	1/1/1872		1259.8	AFA
209	V01765			6/25/1922	DEC	SPR		1.368	DEC	1/1/1884		392.8	AFA
209	V01788			6/25/1922	DEC	SPR		0.171	DEC	1/1/1872		68.36	AFA
209	V01789			6/25/1922	DEC	SPR		1	DEC	1/1/1867		400	AFA
209	V01793			6/25/1922	DEC	SPR		11.866	DEC	1/1/1880		2708.62	AFA
209	V01794			6/25/1922	DEC	SPR		6.75	DEC	1/1/1867		2295.4	AFA
209	V01796			6/25/1922	DEC	SPR		1.347	DEC	1/1/1888		390.36	AFA
209	V01797			6/25/1922	DEC	SPR		0.1	DEC	1/1/1872		40	AFA
209	V01798			6/25/1922	DEC	SPR		2.715	DEC	1/1/1873		972	AFA

209	V01799			6/25/1922	DEC	SPR		0.114	DEC	1/1/1877		45.6	AFA
209	V01802			6/25/1922	DEC	SPR		5.015	DEC	1/1/1868		1873.2	AFA
209	V01825			6/25/1922	DEC	SPR		5.795	DEC	1/1/1866		1541.6	AFA
209	V01567			4/16/1918	VST	SPR		0.025	STK	1/1/1889		2.18	AFA
209	V01705			6/2/1920	VST	SPR		4	IRR	12/31/1979		0	
209	28599	V01394	9091	8/13/1974	CER	STR	Ash Springs Creek	1.898	IRR	8/13/1974		759.2	AFA
209	3387		460	5/8/1915	CER	STR	Ash Springs Creek	0.2	IRR	5/8/1915			
209	11159		3144	8/24/1944	CER	STR		0.005	STK	8/24/1944		2.23	AFA
209	V01630			1/1/1872	DEC	STR		0.513	DEC	1/1/1872		184.4	AFA