Hydrogeology of Spring Valley and Effects of Groundwater Development Proposed by the Southern Nevada Water Authority

White Pine and Lincoln County, Nevada

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Executive Summary

The Southern Nevada Water Authority (SNWA) proposes to develop approximately 91,200 af/y of groundwater in Spring Valley, Nevada. This report addresses the hydrological impact of these applications, and concludes that the evidence shows that pumping the proposed amount of groundwater will cause substantial drawdown and detrimental effects to the spring flow in the valley.

Spring Valley is a topographically closed basin bounded by mountain bedrock and filled with valley fill. There are two primary aquifers: the valley fill and the carbonate bedrock aquifer although in places the volcanic rock may also transmit sufficient water to be considered an aquifer. Precipitation occurring in the surrounding mountains either runs off into streams, infiltrates into the bedrock, or returns to the atmosphere as evapotranspiration (ET). Most of the run-off infiltrates at some point, either within the streambed or on the alluvial fans surrounding the basin. Infiltrating groundwater replenishes the soil moisture. Additional infiltration either flows through shallow groundwater to reach streams or percolates deeper into the ground and becomes groundwater recharge. Recharge, whether high in the mountains where the precipitation falls, from streambeds in the mountains, or on the upper flanks of alluvial fans, flows toward the center of the valley. The converging groundwater primarily circulates upwards towards the playa where it discharges as ET or from the hundreds of springs that give Spring Valley its name.

A three-dimensional, transient groundwater model using the MODFLOW-2000 code was written to model flows through and groundwater levels within the Spring Valley basin, based on the general conceptual model described in the previous paragraph, for steady state conditions. The model was also used to simulate the proposed groundwater development. All available water level and flow data were used to calibrate the model; calibration statistics were as robust as possible considering the natural variability. The water balance for the steady state model reasonably distributed groundwater flow among springs, evapotranspiration from wetlands, and flow to Hamlin Valley, the only interbasin flow simulated in this model.

Based on results from the transient groundwater model, development of SNWA's water rights applications, if granted as requested, will lower the water table in Spring Valley by more than 200 feet within 100 years and over 300 feet in 1000 years. These estimates are less than the 500 feet found by a U.S. Geological Survey Study. The proposed development will affect all springs in the valley fill and in the bedrock near the mountain front at some point during 1000 years of pumping. At least twenty feet of drawdown will affect 73 percent of the underground water rights within the valley within 100 years. Stresses from Spring Valley could possibly propagate through the southern Snake Range at faults or fractures and affect the flow at Big Springs. Recovery from development is slow as well. The drawdown lingers for more than 1000 years beyond the end of pumping because some of the recharge continues to discharge to natural discharge points rather than replenishing the deficit. The natural discharges continue to be depleted, however, for longer than 1000 years beyond the end of pumping.

Several points of special interest that depend on high groundwater levels will also be affected. The groundwater level will decrease 3 and 8 feet, respectively, within 20 years of

pumping at Shoshone Ponds and Sacramento Pass. At Shoshone Ponds, groundwater drawdown increases to 47 and 87 feet, respectively, after 100 and 200 years. At Sacramento Pass the water levels drop 185 feet in 1000 years. Other targets in the northern half of the valley, will be affected much more slowly. Drawdown affects two points in the northwest extension of the valley but only after 200 years of pumping; water levels at the two targets drop 22 and 8 feet, respectively, between 200 and 1000 years of pumping and continue to drop after pumping ceases as water flows southward to replenish deficits.

The pumping causes such negative impacts and widespread drawdown throughout Spring Valley because the applications request about 22 percent more water than the 75,000 af/y of recharge. Water levels and flows will never reach steady state while pumping at this rate. Accounting for the existing 18,600 af/y of water rights, SNWA's request is for 62 percent more water than recharges within the valley. There probably are vested groundwater rights not accounted for by this total, therefore the actual amount of groundwater available is likely even less. Because spring water rights and the surface water rights to stream baseflow also depend on groundwater discharge, most of the underground water in the basin is not available for appropriation.

Monitoring and mitigation is not likely to prevent unacceptable impacts to the springs and groundwater levels. Water levels recover very slowly from just 100 years of pumping, the length of pumping chosen to represent a possible trigger point for stopping development to allow water levels to recover. The cone will remain near its maximum extent for at least a decade after pumping ceases. Actual ET continues to decrease for 10 years as the drawdown expands, and recovers more slowly than it decreased reflecting the continued broad extent of the drawdown. Only drawdown in the middle of the valley recovers substantially in 100 years. After 1000 years of recovery, the ET is still 2 percent less than before pumping began. Spring flow also continues to decrease for a year after pumping ceases, but recovery is slightly faster than for ET. After 1000 years, the spring discharge is still 1 percent less than prior to pumping.

The current perennial yield estimate for Spring Valley, 100,000 af/y, exceeds the recharge by 25,000 and the ET by 30,000 af/y, respectively. This higher estimate depends on doublecounting recharge by assuming that untested groundwater pumping plans will draw water from streams and prevent it from being wasted to the playas. This assumption does not accommodate the existing surface water or spring flow rights which total substantially more than the estimated surface runoff in the basin. It also does not account for the almost 4000 af/y which flows to Hamlin Valley. Accordingly, the perennial yield should be just the 70,000 af/y of evapotranspiration to be accurate. However, developing even this amount of water would severely affect the existing wetlands and springs. The pumping of any groundwater necessarily takes discharge from the wetlands and springs, therefore the actual perennial yield should be much less than 70,000 af/y.

Introduction

The Southern Nevada Water Authority (SNWA) proposes to develop 91,200 af/y of groundwater in Spring Valley of eastern Nevada. This report was prepared on behalf of the Western Environmental Law Center which represents numerous protestants of these water rights applications. This report assembles evidence supporting and proving the fact that pumping the proposed amount of groundwater will cause substantial drawdown and detrimental effects to the spring flow in the valley.

SNWA filed applications for 19 water rights within Spring Valley (basin 184) in 1989 along with other applications for water rights in many other eastern Nevada basins. The applications were protested by numerous people and organizations. The applications were not acted upon by the State Engineer until 2004 when hearings for applications in four valleys in the Death Valley flow system, Tickapoo North and South and Three Lakes North and South, were held (Nevada State Engineer Ruling 5465). The State Engineer then decided to move forward with hearings on applications in Spring Valley, Snake Valley, Cave Valley, Lake Valley and Delamar Valley. There will be separate hearings for Spring Valley and Snake Valley and a hearing for Cave Valley, Lake Valley and Delamar Valley combined. This report provides evidence for the Spring Valley hearing.

Table 1 lists SNWA's applications as they stand in Spring Valley, basin number 184 (shown in Figure 1).

Table 1: SNWA's Water Rights Applications for Spring Valley

Application Number	Legal Description	Diversion Rate (cfs)
54003	NW ¼ NW ¼ S20, T8N, R68E	6
54004	Spring Valley	6
54005	Spring Valley	6
54006	Spring Valley	6
54007	Spring Valley	6
54008	Spring Valley	6
54009	Spring Valley	6
54010	Spring Valley	6
54011	Spring Valley	6
54012	Spring Valley	6
54013	Spring Valley	6
54014	Spring Valley	6
54015	Spring Valley	6
54016	Spring Valley	6
54017	Spring Valley	6
54018	Spring Valley	6
54019	Spring Valley	10
54020	Spring Valley	10
54021	Spring Valley	10
	Total	**126**

All are considered ready for action protested (RFP). The only indication as to whether the application is for valley fill or carbonate water is the description on the application that says the source is "underground basin in Spring Valley" or "underground rock aquifer in Spring Valley". The assumption is that underground rock aquifer is the carbonate aquifer. Only the last three applications, each for 10 cubic feet per second (cfs), in Table 1 appear to be for carbonate aquifer water. Thus, carbonate applications represent only 23.8 percent of the total water rights applications. The total is 126 cfs which if pumped at this rate for the entire year is 91,200 acre-feet/year (af/y).

This report discusses the hydrogeology, including water rights, of Spring Valley and presents the development of a groundwater model used to predict the impacts of pumping as proposed by SNWA.

Hydrogeology

Structure of Spring Valley

Spring Valley is typical of basin and range valleys albeit with more relief than most (Figure 1). It is topographically closed, bounded by more than six ranges. The Schell Creek and Snake Ranges bound it on the west and east sides, respectively (Figure 1). The Schell Creek range rises to more than 11,000 feet and the Snake Range rises to more than 13,000 feet at the second highest peak in Nevada, Wheeler Peak. The basin is valley fill (Figures 1 and 2) with elevations ranging from more than 6800 feet msl in the north to low points near 5500 feet msl in the central and southern parts of the basin. There are two low points with playas separated by a small rise approximately in the middle of the valley.

Various mountains of complex geology bound the valley (Figure 2). On the northeast, the Antelope Range and a low pass less than 6200 feet msl separate Spring Valley from Antelope Valley. North of the Snake Range lies the Kern Mountains and 6700 foot msl pass. South of the Snake Range lies the Limestone Hills and a pass which drops below 6100 feet msl. The Wilson Creek Range bounds the south end of the valley. The Horse Corral Pass, lying at about 6400 feet msl, separates the Wilson Creek Range from the Fortification Range. Between the Fortification Range and Schell Creek Range lies the Lake Valley Summit at about 6000 feet msl.

The mountain ranges surrounding Spring Valley consist of bedrock but the lower passes are valley fill. The low valley fill passes suggest potential hydraulic connections with surrounding basins if the depth to bedrock at those passes is sufficient. The bedrock forming the core mountains varies from porous and conductive carbonate to impermeable intrusive rocks; the core of the Snake Range is a complex of metamorphic rock, which probably acts as a barrier to deep groundwater flow limiting the hydraulic connection through the mountains between Spring and Snake Valley (Prudic et al 1995, page D11), unless there is a fault system. The Snake Range separates Spring Valley, part of the Central basins, from Snake Valley, part of the Great Salt Lake basin.

Prudic et al (1995) found low transmissivities in model layers associated with the Snake Range and that groundwater flow in this area is radially outward toward the surrounding basins (Prudic et al 1995, page D49). "Estimated transmissivities for the lower layer in the Spring-Steptoe subregion are generally less than 0.006 ft^2/s; as a result most of the simulated flow is in the upper layer" (Prudic et al 1995, page D78). Prudic et al (1995) also found the valley fill of Spring Valley had high transmissivity, possibly reflecting the substantial thickness of deposits which approach 7000 feet on the west side of the valley.

Plume (1996) analyzed the shape of Spring Valley using the results of seismic-reflection data. The Schell Creek Range fault block bounds the valley on the west and the bedrock basin is deepest, about 7000 feet, in this portion. It becomes progressively shallower toward the east side of the valley and the west-dipping fault blocks of the Snake Range.

As indicated by its name, the Limestone Hills on the southeast portion of Spring Valley may connect the Spring Valley with Hamlin and Snake Valley. The modeling of Prudic et al (1995, page D78) simulated flow "through the Snake Range into Hamlin Valley" and their Figure 32 shows this to occur in the south end of the range which corresponds with the Limestone Hills. They reference Rush and Kazmi's (1965) estimate of 4000 af/y of interbasin flow to Hamlin Valley. Elliot et al (2006) have identified a potential for pumping in Spring Valley to affect the flow at Big Springs on the south end of Snake Valley. Figures 31 and 33 in Prudic et al (1995) also show inflow to Spring Valley from Lake and, possibly, Wilson Creek Valley; this flow would be from the Colorado River region in layer 1 corresponding to the valley fill. Table 5 in Prudic et al (1995, page D67) shows the flow from the Colorado River region to the Bonneville region to be 2000 af/y. Other flow arrows on their Figure 33 near Spring Valley correspond to Prudic et al's upper layer flow from adjoining ranges into the Spring Valley basin.

Water Level

The water level contour maps are based on the earliest observed level at the chosen well (Figure 3). Some of the well level hydrographs downloaded from the USGS website had blank levels for the first observation. Because there was little pumpage observed in Spring Valley in the 1970s (Prudic et al 1995, page D16), the water levels approximate steady state conditions. Most well logs specify the aquifer; those that do not but were shallow, less than 300 feet, were assumed to be valley fill unless they were located in an outcrop. This was determined by plotting the monitoring wells on the Spring Valley geology map.

The wells with level observations distributed relatively evenly across the basin, therefore it was possible to contour a groundwater level map. Using the Golden Software Surfer program, water level elevations and UTM coordinates for each well, the static groundwater level contours were determined on a 50 foot interval using an inverse distance squared routine. The contours were manipulated slightly to remove redundant contours. There was no attempt to distinguish among aquifer layers or between aquifer types (valley fill and carbonate) because there were too few in the carbonate to allow for contouring.

Vertical gradients have been observed in regions with sufficient wells. For example, the head in well USGS 3859031142617 is 5811 ft msl at a depth equal to 550 feet while in nearby well USGS 3859151142619, the head is 5776 ft msl at a depth of 272 feet. These wells, developed in the same section, show an upward gradient. Well USGS 3853481142433 has a water level 11.4 feet above ground surface for a depth of 155 feet; well USGS 3855041142408 is just east and has a water level 55 feet higher at elevation 5846 ft msl. The three flowing wells in the data base each lie near the contact of the valley fill and bedrock. The upward gradient is visible at the few paired wells and probably occurs around the valley fill portion of the valley. The presence of springs also indicates where upward gradients occur in the valley.

Conceptual Flow Model

A conceptual model is a basic description of the movement of water throughout a region of interest. One includes a description of the geology and hydrogeology and estimates of fluxes, such as recharge, evapotranspiration or interbasin flow, to or from the region. The conceptual model is essential for predicting changes due to applied stresses. They are a necessary first step in the creation of a detailed flow model (Bredehoeft 2003)

Spring Valley is a topographically closed basin bounded by mountain bedrock and filled with valley fill. Precipitation or snowmelt occurring in the surrounding mountains either runs off into streams, infiltrates into the bedrock, or evapotranspires. Run-off occurs when the rate of precipitation or snowmelt exceeds the capacity of the soil to infiltrate the water. The run-off flows to adjacent downhill land where it either infiltrates or joins with run-off from other areas. If it does not infiltrate, it eventually reaches a stream channel. In the Great Basin, most stream run-off infiltrates at some point, either within the streambed or on the alluvial fans surrounding the basin. Especially during wet years, the run-off may reach a playa in the middle of the basin where it ponds. Infiltrating water replenishes the soil moisture. Excess soil moisture either flows through shallow groundwater to reach streams or percolates deeper into the ground and becomes groundwater recharge. Groundwater recharge therefore is either percolation where the precipitation falls, from streambeds or from the point of discharge onto alluvial fans.

Recharge reaches the saturated soil or bedrock where it becomes groundwater. Recharge causes the water level at the point of recharge to rise, forming a groundwater mound, which causes a gradient for flow away from the mound. In the basins of the Great Basin, the direction of flow is typically towards the center of the valley. Locally, water may flow toward streams where it becomes baseflow. The converging groundwater in the basin bottoms primarily circulates upwards towards the playas and wetlands where it discharges as ET or springs. Some of the basins have connections with surrounding basins through fault zones, conductive bedrock or through low valley fill connections at the passes.

Spring Valley has hundreds of springs surrounding its two central playas. Discharge from these springs flows into the playa, where it ponds and evaporates, mixing with groundwater surfacing from upward flow in some locations. It may be impossible to discern between spring flow and groundwater discharging into the playa when considering the ET from the center of the valley.

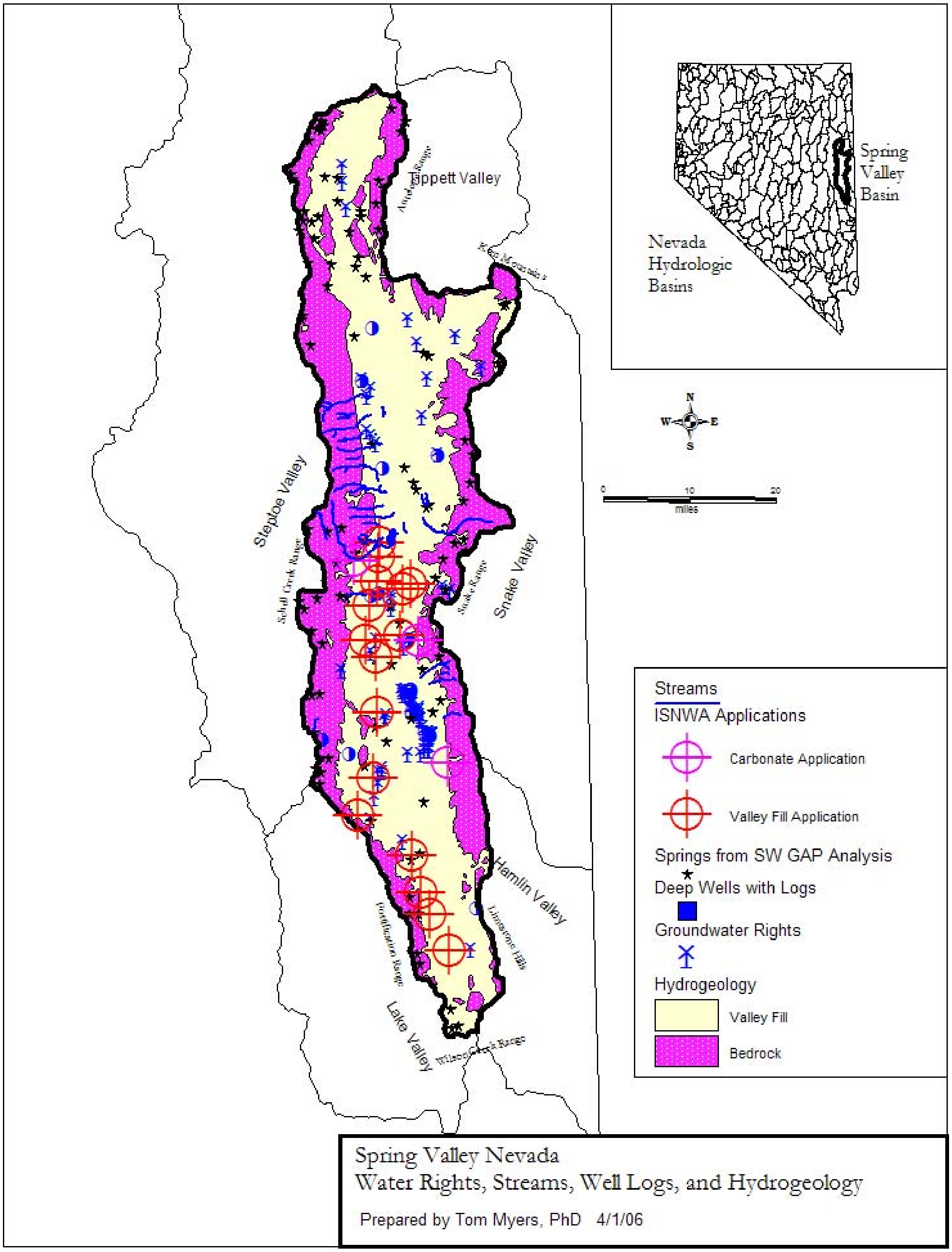

Figure 1: Hydrogeology, groundwater rights, and SNWA water rights applications in Spring Valley.

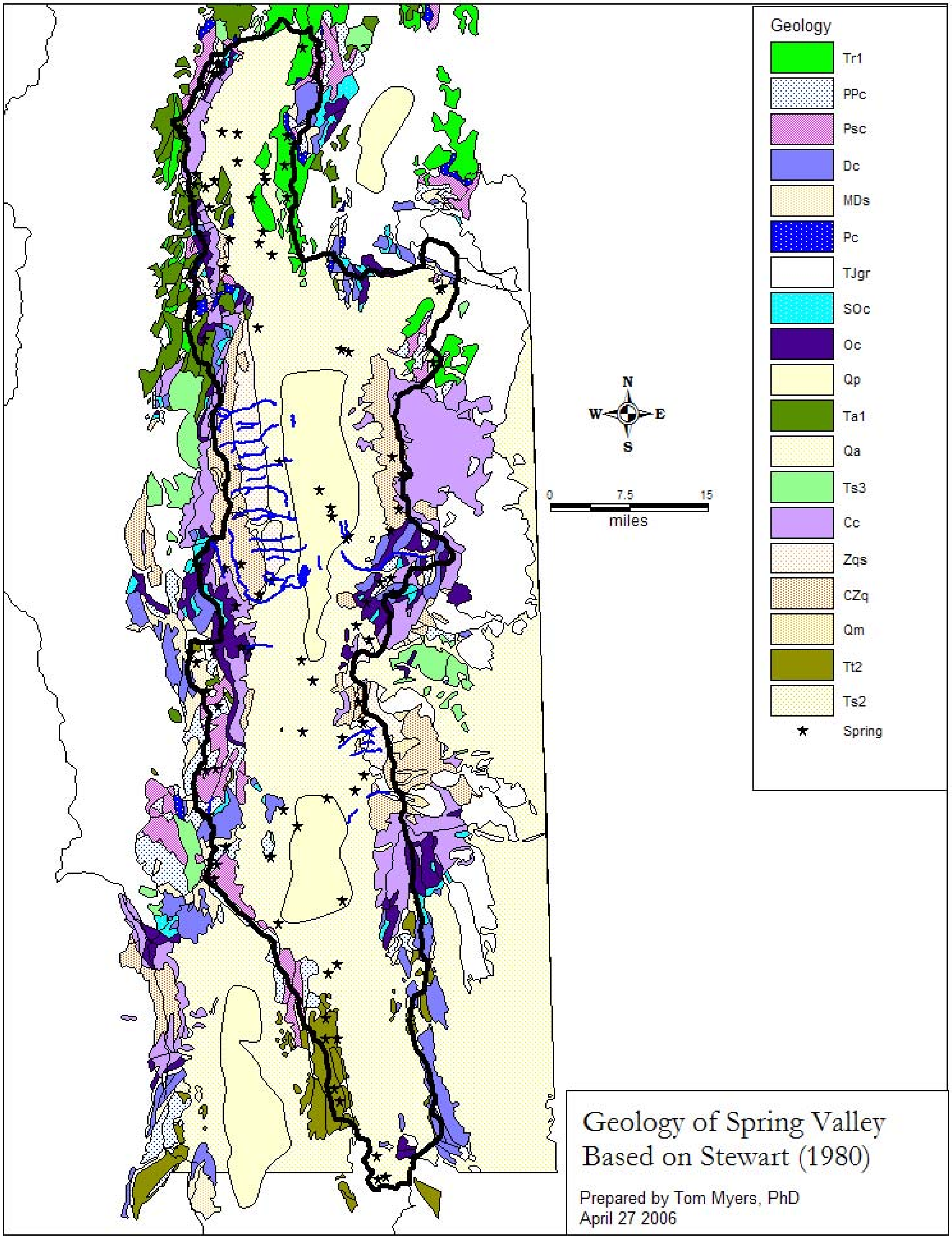

Figure 2: General geology of Spring Valley

Water Budget

The water balance of Spring Valley is conceptually simple because it is topographically and almost structurally closed. During steady state conditions, inflow equals outflow and for Spring Valley that means recharge equals evapotranspiration (ET) and interbasin flow to Hamlin Valley.

Evapotranspiration

Rush and Kazmi (1965) estimated that 70,000 af/y of groundwater discharge from Spring Valley through ET. Prudic et al (1996) simulated ET discharge in Spring Valley to equal 75,000 af/y using a range from 42 to 72 inches/y, from north to south, and a 20 foot extinction depth (Prudic et al 1996, page D21). Nichols (2001) estimated that ET from Spring Valley averages 90,000 af/y. The average was based on estimates made during 1985 and 1989, the wettest decade in 100 years.

Spring Discharge

Many springs discharge on or near the valley floor in Spring Valley, and a fair number discharge in the mountains. Figures 1 and 3 show the springs identified in the GAP analysis performed by the Southwest Regional Gap Analysis Project. USGS topographic maps (1:100,000 scale including Ely NV, Garrison UT, Kern Mtns, and Wilson Canyon Range) show substantially more springs discharging to the valley floor. USGS measurements indicate that spring discharge is at least 28,000 af/y (Table 2, Pupacko et al 1989). This is a minimum estimate because the USGS measured only a few of the hundreds of springs. SNWA measurements (SNWA 2006) show spring discharges are highly variable but show a base flow total about 5400 af/y (Table 3). The studies are simply a random sample of a few springs within the valley.

Water rights associated with springs in the valley provide an alternative estimate of spring discharge. Based on water rights downloaded from the Nevada State Engineer's water rights database (http://water.nv.gov/), there are 3118, 660, 467, and 118,450 for a total 122,695 af/y of certificated, permitted, reserved and vested water rights in Spring Valley, respectively. Most spring water rights are for small amounts of water, although the list contains 12 vested rights, V02817 through V02828 for 9600 af/y each. The point of diversion (POD) is cut with stream channels reflecting the substantial flow that emanates from the spring (Figure 4). Most of the flow discharges to wetlands and the playa northeast of the spring POD. There are also two irrigation pivots shown on Figure 4. A site visit on June 5, 2006, showed that extensive irrigation of fields and meadows occurs in this area. Therefore, while the vested rights almost certainly exceed the actual spring flow, it indicates that substantial flow discharges from the springs in that area.

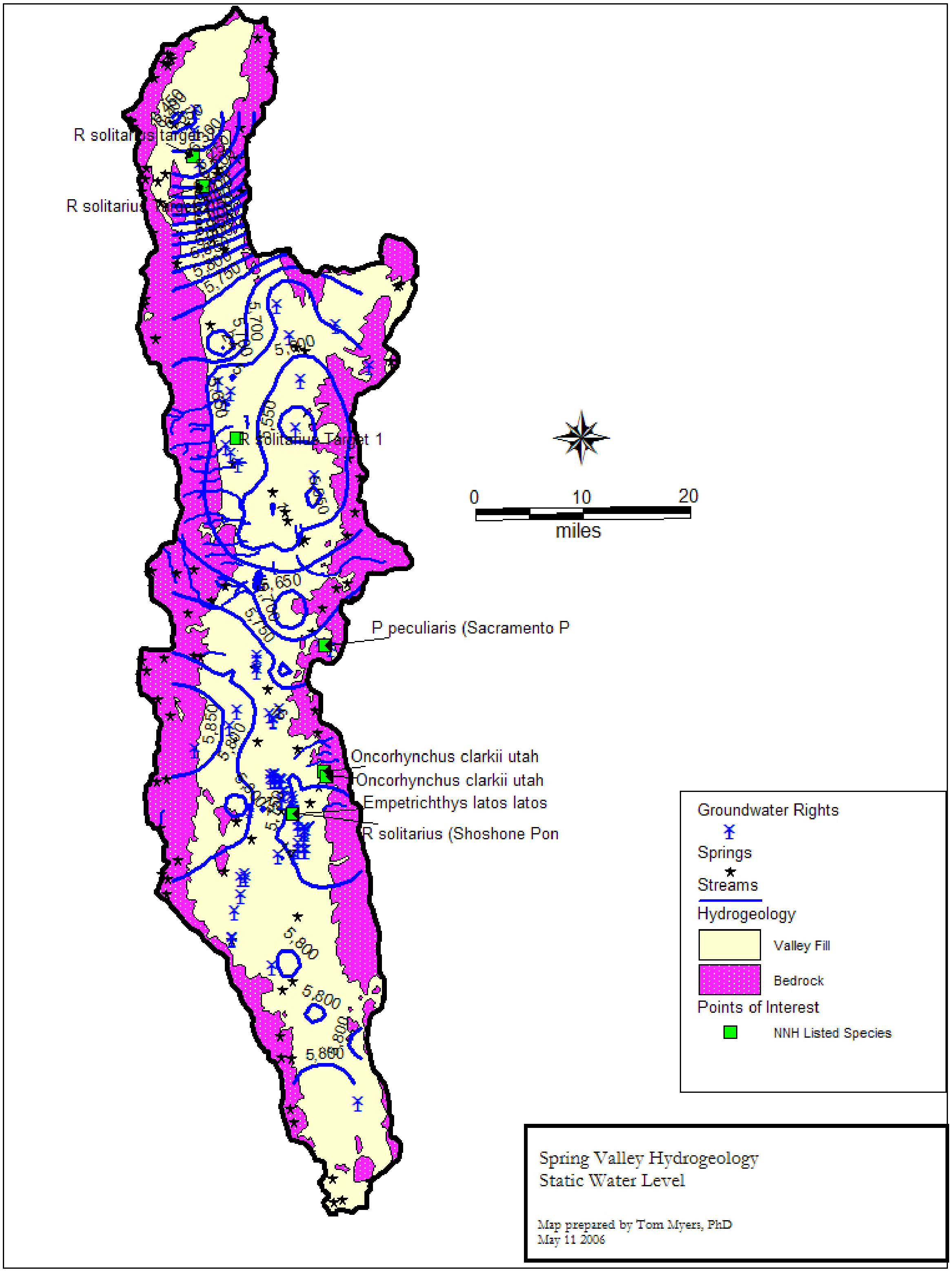

Figure 3: Static water level in Spring Valley based on initial water level reported in driller's logs.

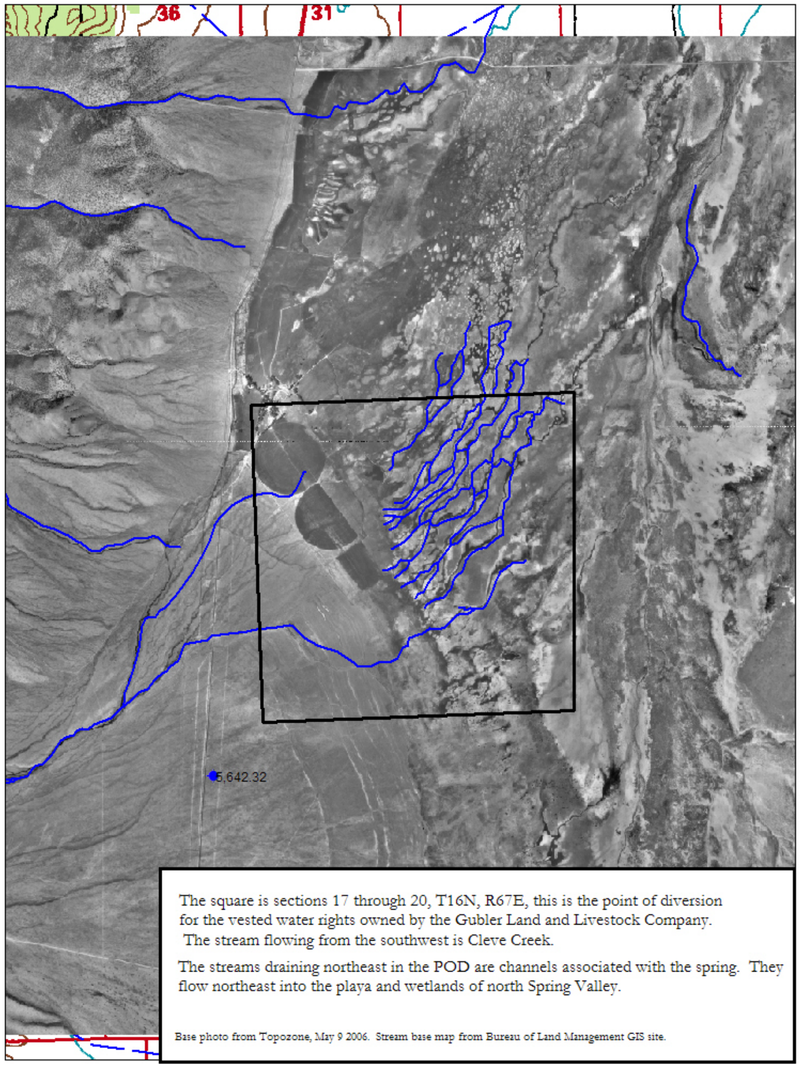

Figure 4: Aerial photograph of springs and point of diversion for vested water rights listed as owned by Gubler Land and Livestock Company near Cleve Creek.

Discussions of regional carbonate springs do not include springs within Spring Valley (Prudic et al 1996, Plume 1996). This suggests that most Spring Valley springs are local meaning that they discharge recharge from within Spring Valley, not flow from adjacent basins. Relatively high water temperatures in some springs in Spring Valley possibly indicate deep circulation (Table 3). The upward gradient driving groundwater to the springs and wetlands also indicates deep circulation. The variability shown in the discharges of the few springs with multiple measurements indicates springs respond quickly to climatic changes; regional springs have much more stable flow regimes because they are not quickly affected by climate fluctuations and seasonal changes.

Table 2: Spring Discharge Measurements in Spring Valley from Pupacko et al (1989)

Local ID	Name or owner	Ground Elev	Geologic Code	Date (initial)	Date	Max (gpm)	Min (gpm)	Max Flow (afa)	Number
184 N11 E67 12DB1	Minerva	5800	374HGPK	Pre 1968		300		483	1
184 N11 E68 04C1	**Swallow**	6400	374HGPK	6/1/1980		4200		6762	1
184 N11 E67 01CD	Shoshone	5800	370PLCN	10/29/1956		300		483	1
184 N11 E68 05CA1	Unknown	6080	110VLFL	Jun-80		360		579.6	1
184 N12 E68 15CBCB1	Mt Wheeler Mine	7960	370LMSN	Pre 1968		36		57.96	1
184 N15 E66 21AC1	Bastian	6693	370SLLK	6/1/1980		1600		2576	1
184 N17 E67 25CH	**S. Mulicck**	5600	110VLFL	7/12/1966		200		322	1
184 N17 E67 03DB1	**S. Mulicck**	5600	110VLFL	Pre 1968	Sep-82	5800	200	**9338**	3
184 N20 E66 30DCC1	Kalamazoo Cr	7200	120VLCC	8/15/1964	9/19/1981	2000	1200	3220	2
184 N20 E66 17A1	Muncy Cr	7000	370SLLK	7/14/1964		1900		3059	1
184 N21 E65 15D1	North Creek	8000	374HGPK	7/14/1964		1000		1610	1
						Total (afa)		28490.56	

The spring in Swallow Canyon is a good example of a local spring (Table 3). The spring is at the mouth of a small canyon on the west side of the Snake Range. The discharge changes quickly and low flows are a small fraction of the high flows (Figure 5). This suggests the residence time in the contributing watershed is short. An aerial photo of the region shows a small vegetated area below the spring and a much larger spring fed wetland area in the playa a short distance to the west (Figure 6 showing springs and wetlands at Swallow Canyon). It appears that discharge from the spring infiltrates and probably recharges the shallow groundwater only to discharge again in a spring further downstream.

The springs near Cleve Creek and in Swallow Canyon suggest that discharge from springs which occur in the lower portions of canyons just above the alluvial fans flows a short distance before it infiltrates and recharges the valley fill. Essentially, the flow from mountain front springs and from many of the streams becomes shallow groundwater. This supports a high water table which also supports springs around the margins of the wetlands in the center of the valley and the playas. Apparently, spring flow may support spring flow further spring flow downstream.

Lithology in the only well in township 16N R67E supports this interpretation. Well log 1452 shows a highly stratified regime with four zones in the top 227 feet bearing mention as aquifer; the highest one was “sand and gravel” from 18 to 21 feet below the ground surface (Table 4). If this reflects the lithology near the point that Cleve Creek exits the mountain range, water infiltrating could easily become perched in this or a similar layer and be forced to discharge.

Table 3: Spring Discharge measurements as collected by SNWA and provided to the Bureau of Land Management. GPM is gallons per minute. The mean is the average of all the flow presented for the specific spring. The baseflow is the lowest flow measured.

Spring		Elevation	Date	Q (gpm)	Mean (gpm)	Base Flow (gpm)	Base Flow (ft3/d)	Temp
Willow Spring		5982	7/14/2004	1.8	1.8	1.8	345.6	22.9
North Millick Spring	184 N17 E67 25DB	5590	6/24/2004	195.7	195.7	195.7	**37674.9**	15.5
South Millick Spring	184 N17 E67 25CD	5592	7/12/1966	200.0				
			7/15/2004	457.8	328.9	200.0	**38502.7**	13.4
South Bastian Spring	184 N15 E67 29	5660	7/15/2004	3.9	3.9	3.9	752.7	12.9
Layton Spring	184 N14 E67 04DB	5698	7/14/2004	0.0	0.0	0.0		
Willard Springs	184 N14 E67 32AC	5755	7/15/2004	0.0	0.0	0.0		
The Cedars	184 N12 E67 02AB	5783	7/28/2004	74.5	74.5	74.5	**14342.2**	
North Spring	184 N12 E67 18AD	5763	6/22/2004	10.0	10.0	10.0	1925.1	22.7
Swallow Springs	184 N11 E68 05CA	6080	7/12/1966	275.0				9.7
			6/15/1980	360.0				
			7/28/2004	340.2	325.1	275.0	**52941.2**	10
Swallow Canyon Spring **	184 N11 E68 04C	6290	7/12/1966	1800.0				9.4
			6/15/1980	42000.0*				
			7/13/1998	23523.0				
			7/14/1998	9650.0				
			7/16/1998	15888.0				
			7/18/1998	14497.0				
			7/14/1999	3478.0				
			7/16/1999	3083.0				
			7/23/2000	435.0				
			7/25/2000	337.0				
			8/7/2001	507.0				
			7/17/2002	1037.0				
			8/7/2003	428.0				
			7/28/2004	295.0	5766.0	295.0	**56791.4**	
Blind Springs	184 N11 E67 23DA	5773	7/28/2004	0.0				
Big Springs ***	195 N10 E70 33B	5568	11/3/1964	3600.0				17.7
			9/30/1965	4000.0				16
			6/22/2004	2302.0				19
			10/28/2004	4802.0	3676.0	2300.0	442780.7	
Caine Springs ***	195 S19 W20 24CB	5028	7/14/2004	5.0	5.0	5.0	962.6	14.4
Warm Springs ***	195 S15 W20 31CBC	5248	11/4/1964	3600.0				27.2
			6/22/2004	3779.0				27
			10/30/2004	6732.0	4703.7	3600.0	693048.1	

* - The 42000 gpm measurement is reported by SNWA to likely be a typographic error in the report which provided it. It is more likely to be 4200 gpm.

** - See the plot of flows for Swallow Canyon Spring on Figure ***.

*** - These springs are in Snake Valley.

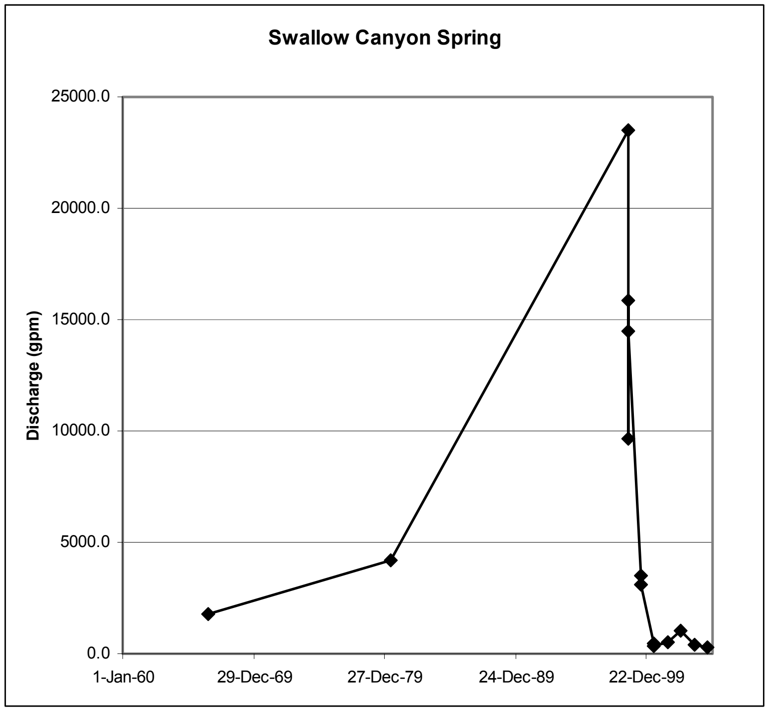

Figure 5: Discharge hydrograph for Swallow Canyon spring. The observation on 6/15/1980 was adjusted to 4200 gpm reflecting Pupacko et al (1989). Average discharge is 5766 gpm and the lowest (baseflow) is 295 gpm.

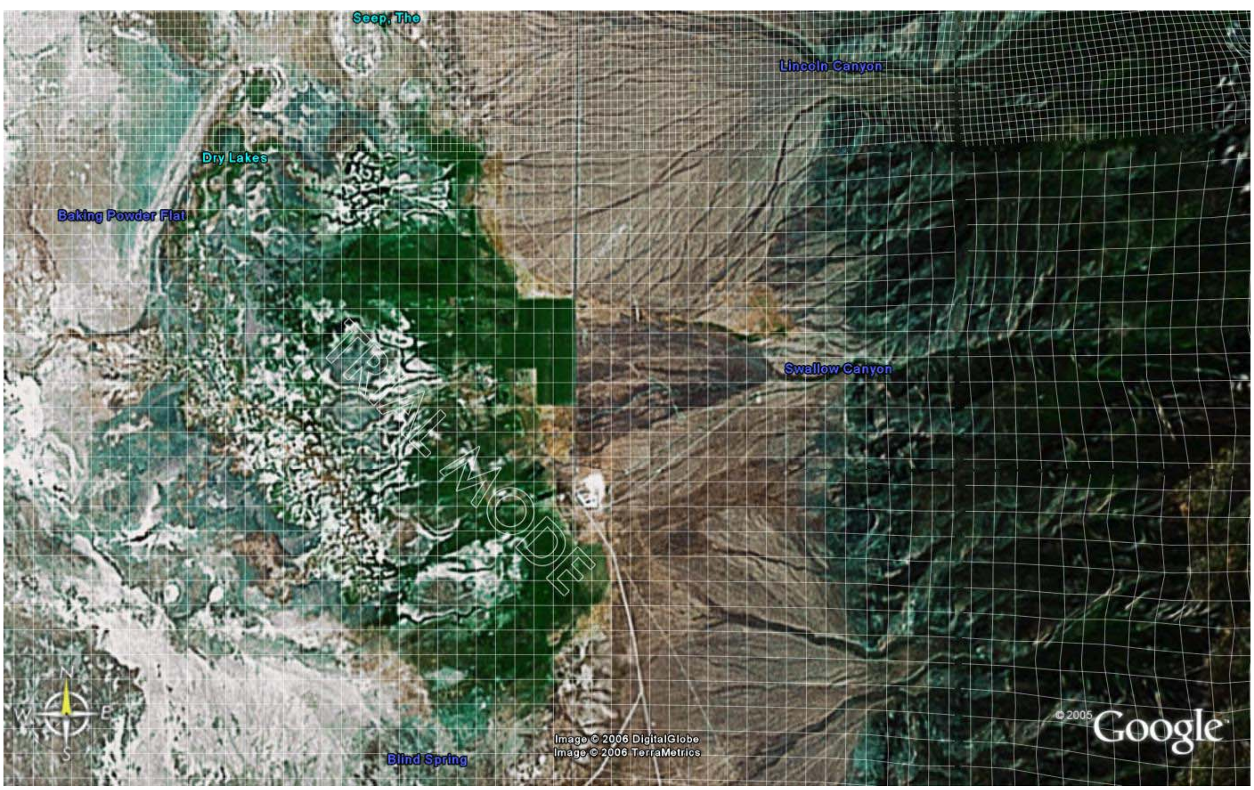

Figure 6: Horizontal grid scale 1 minute, vertical grid scale 18 seconds.

Table 4: Lithology from well log 1452. NE 1/4, S3 T16N, R67E

Top of Layer (Ft below Ground Surface)	Bottom of Layer (Ft below Ground Surface)	Lithology
0	3	Sandy clay
3	4	Hard pan
4	18	Clay
18	21	Sand and gravel (water)
21	47	Sandy clay
47	68	White clay
68	72	Hard pan
72	78	Sandy clay
78	79	Hard pan
79	80	Sand (water)
80	88	Conglomerate
88	105	Gravel (water)
105	145	Sandy clay
145	149	Hard pan
149	173	White clay
173	178	Hard pan
178	223	Sandy clay
223	226	Hard pan
226	227	Sand and gravel (water)
227	308	Sandy clay
308	312	Hard pan
312	317	Sandy clay
The notation "water" in column 3 indicates that water emanated into the well. The static water level was 6 feet below the ground surface.		

Recharge

There have been various estimates of recharge to Spring Valley (Table 5). However, the estimates cluster between 70 and 75,000 af/y. The first published estimate was by Rush and Kazmi (1965). They used the Maxey-Eakin method to estimate that recharge equals about 75,000 af/y; their analysis shows that ET from the basin approximates the estimated recharge. The State Engineer accepted this recharge estimate by using Rush and Kazmi's perennial yield estimate. Katzer and Donovan (2003) used a modified Maxey-Eakin estimate and then made adjustments that resulted in an estimate of 72,000 af/y which is less than Rush and Kazmi. Nichols' estimate of 104,000 af/y was based on an assumption that ET, estimated in 1985 and 1989, added together with interbasin flow equals the recharge. He then used a regression analysis of estimated recharge with precipitation for several other eastern Nevada basins. Based on this regression, he increased the Spring Valley recharge estimate to 104,000 af/y. Dettinger (1989) used a chloride balance method to estimate recharge equals 61,300 af/y. Dettinger acknowledges that if he missed a source of chloride in the valley, his method would yield a low recharge value. Prudic et al (1995) modeled flow through the carbonate province of the eastern Great Basin. Table 5 presents only an estimate of their recharge from the various tables provided in their report. The model cells did not exactly correspond with basin boundaries.

Table 5: Recharge estimates by reference.

Source	Recharge (af/y)	Comment
Nichols	104,000	
Rush and Kazmi (1965)	75,000	
Katzer and Donovan (2003)	72,000	
Dettinger (1989)	61,300	chloride balance
Prudic et al (1995)	75,000	Approximate based on figures in the report

There is not necessarily a best recharge estimate. A steady state recharge estimate is essentially a long-term average of a process that varies substantially from year to year and even from season to season. This report accepts the 75,000 af/y estimate for the estimation of perennial yield and for use in the groundwater model described below.

Perennial Yield

Perennial yield is usually considered the maximum amount of groundwater that can be salvaged each year over the long term without depleting the groundwater reservoir. The Nevada State Engineer publishes in the 1992 Hydrographic Basin Survey the perennial yield for Spring Valley to be 100,000 af/y based on analysis in Rush and Kazmi (1965). Rush and Kazmi (1965) describe the perennial yield to be the:

> maximum amount of water of usable chemical quality that can be withdrawn and consumed economically each year for an indefinite period of time. If the perennial yield is continually exceeded, water levels will decline until the ground-water reservoir is depleted of water of usable quality or until the pumping lifts become uneconomical to maintain. Perannial (sic) yield **cannot exceed the natural recharge to an area indefinitely**, and ultimately it is limited to the amount of natural discharge that can be salvaged for beneficial use. (Rush and Kazmi 1965, page 26, emphasis added)

As noted above, Rush and Kazmi calculated the recharge from precipitation in Spring Valley to be about 75,000 af/y, based on the commonly used Maxey-Eakin method, and also estimated the discharge through ET from phreatophytes to be 70,000 af/y. Combined with the 4000 af/y interbasin flow to Hamlin Valley, Rush and Kazmi (1965) indicates the basin to be relatively in balance. They note that “the natural regimen has been only slightly disturbed” (Rush and Kazmi 1965, page 25). Yet, they estimate perennial yield to be much higher than their estimate of natural flows; their PY exceeds the natural recharge in contravention to the fundamental hydrogeologic constraint they acknowledge in the same report. They acknowledge that the flow to Hamlin Valley probably cannot be salvaged, but that all of the ET discharge, 70,000 af/y, could be salvaged. They also argue that "extensive and well-distributed pumping" might salvage "on the order of one-third of the estimated runoff at the mountain front". Based on an average availability of run-off of 82,000 af/y (90,000 af/y of runoff minus 8000 af/y of irrigation diversions) and taking a rounded-off one-third of this to be salvaged, Rush and Kazmi (1965) suggested that 30,000 af/y could salvaged. They wrote: "[i**f] this assumption is a reasonable** measure of the salvage, then the preliminary estimate of perennial yield of Spring Valley would be on the order of 100,000 acre-feet" (Rush and Kazmi 1965, page 26, emphasis added). Basically, they assumed that one-third of the run-off could be salvaged even though they recognize that "the opportunity for additional recharge by seepage loss from streams is limited by the short distance between the mountain front and the playas" (*Id.*).

This argument that perennial yield should be 100,000 af/y is based on double counting: the water discharged from the phreatophytes and bare playa soil includes flow from springs and streams. Rush and Kazmi (1965) do not estimate spring discharge but indicate that "their discharge is included in estimated average annual discharge by phreatophytes" (Rush and Kazmi 1965, page 22). Water that discharges from springs creates saturated soils and wetlands downgradient from the springs. Recharge also discharges into the lower reaches of streams which could ultimately be water that is "wasted" to the playas. Recharge as determined with the Maxey-Eakin method, used by Rush and Kazmi, not only includes water that recharges where it falls from the sky or melts, but also includes run-off that recharges further downstream, usually on the alluvial fans (Avon and Durbin 1994, Stone et al 2001). Stone et al (2001) applied 200 to 300 percent more recharge, in a groundwater model, to the head of alluvial fans than would occur based strictly on the Maxey-Eakin method reflecting the run-off. This method has been applied to groundwater modeling completed at three major dewatering projects including Barrick's Goldstrike project (McDonald Morrissey Associates 1998), Homestake's Ruby Hills project, and Cortez's Pipeline Deposit project (described by Stone et al (2001)).

In summary, the Rush and Kazmi PY estimate utilizes runoff that naturally recharges at the mouth of the canyons and feeds spring discharge and phreatophytes ET; it is already included in the water balance of the basin. The estimate exceeds the natural recharge to the basin in contravention to common Nevada State Engineer practice. As written in Ruling 5621, "[p]errenial yield is ultimately **limited to the maximum amount of natural discharge** that can be salvage for beneficial use" (Nevada State Engineer, 2006, page 17, emphasis added).

Katzer and Donovan (2003) also creatively assume that all of the ET can be salvaged. Their plan is to lower the water table over the entire valley by 45 feet to dry up all of the phreatophytes. Their assumption is that all of the surface water that combined with the groundwater, discharged to the wetlands can be salvaged. The recharge estimate already includes percolation from the streams at the point they emerge from the mountain front onto the alluvial fans. It is probable that runoff that passes the alluvial fan without recharging the groundwater only occurs during wet years; it is not part of the average or dry year flow regime. There is no evidence that this water can be induced to infiltrate through the stream bottoms by lowering the water table. The soil is much finer downstream of the alluvial fans and there is no evidence the groundwater table intersects the stream. If it does not intersect the stream, drawing it down will not affect the seasonal runoff. The water will still reach the playas. Drying all of the phreatophytes may decrease transpiration but the free water surface evaporation would surely make up a portion of it.

The SNWA water rights applications are spread across the valley and do not appear to include a plan to induce additional recharge to justify a higher PY estimate either. The true perennial yield should be 70,000 af/y or just the estimated ET that could be salvaged if all wetlands and springs could be dried without assuming that surface water can be induced to increase the recharge. As the next section also demonstrates, doing so may well negatively affect surface and spring water rights.

Water Rights

Existing conditions in Spring Valley include the current water rights including surface, spring and groundwater rights. All water rights in the database for Spring Valley, basin 184, were downloaded from the Nevada State Engineer's website on March 9, 2006. It is possible that vested water rights exist that have never been adjudicated. The underground rights are shown on Figure 1.

Table 6 summarizes the existing and proposed water rights in Spring Valley. SNWA's applications total almost 5 times the existing underground water rights. The summation fo existing UG rights have been adjusted to account for supplemental rights. The large duty for vested spring rights was discussed above in the section Spring Discharge.

Table 6: Summary of Water Rights in Spring Valley

	Underground Water Rights	
Basin	**App**	**Annual Duty***
Certificated	58	9434.2
Permitted	14	9140.6
Total		**18574.9**
Ready for Action	66	53857.3
Ready for Action:Protested	67	170667.2
Other	97	
SNWA Aps This Hearing	19	91220
	Spring Water Rights	
Certificated and Permitted	59	3778.8
Vested	57	118449.9
Reserved	25	466.7
Ready for Action, Ready for Action Protested	10	7843.8
Total	151	130539.2
	Stream Water Rights	
Certificated, Permitted	60	46034.9
Vested	32	55434.1
RFA, RFP	8	4960
Total	100	106,429.0

*** - Duty accounts for rights obviously supplemental to another right. They are not double-counted. This information has not been verified by examining the actual water right certificate.**

Spring flow is a discharge of recharge occurring within the basin (Rush and Kazmi 1965). There are 122,228 af/y of certificated, permitted or vested rights to spring water. The summation of spring water rights exceeds by more than 47,000 af/y the estimated recharge. As discussed above, the vested rights total probably overestimates the actual discharge from those springs, but it still indicates a substantial discharge. Spring flow water rights clearly are an additional commitment of underground water resources.

The same logic applies to some of the surface water rights. Certificated, permitted and vested surface water rights total 99,469 af/y. Some of this water is baseflow, which by definition is groundwater discharge to the streams. As defined by the Handbook of Hydrology, baseflow is "return flow from groundwater" (Mosley and McKerchar, 1992, page 8.1). Groundwater that becomes baseflow originated as recharge. Rush and Kazmi (1965) also acknowledge that groundwater discharges sustain stream baseflow. Considering Cleve Creek, they write that "[t]he minimum momentary discharge rates, occurring during the winter months and averaging 3.5 cfs, **represent the base flow from ground-water sources**. In fact, the average flow of 6.5 cfs during the period July through March is also **largely base flow from ground-water sources** within the mountains" (Rush and Kazmi 1965, page 12, emphases added). Water rights that depend on stream baseflow therefore clearly constitute another additional commitment of underground water resources.

Considering water rights to the spring flow and stream baseflow along with the committed underground water rights, it is clear that most of the available water in Spring Valley is previously committed.

The total surface water rights is about twice the amount of surface water runoff, 53,000 af/y, in the valley estimated by Katzer and Donovan (2003, page 23). Any action designed to cause additional surface water to infiltrate to increase PY, as suggested by Rush and Kazmi (1965), would necessarily take water from existing surface water rights. That would apparently violate the existing water rights unless all of the infiltration occurs downstream of the diversion points.

Groundwater Model

Model Structure

This report analyzes the future changes in groundwater level and flux changes potentially cuased by SNWA's proposed development. A transient three-dimensional groundwater model, based on the conceptual model described above, was designed and calibrated for this purpose. The MODFLOW-2000 computer code (Harbaugh et al 2000) was used to solve the conceptual model. The model documentation describes the mathematical design of the code and the input requirements.

Model Domain

The complex geologic structure of the province is the basis for the model design. Model layers correspond to hydrogeologic layers because model cells by design are isotropic and facilitate the simulation of flow between geologic formations. Using a square mile grid, the model cells represent either valley fill or bedrock (Figure 7). The grid spacing was chosen as a compromise between adequate detail around the proposed pumping and the detail with which the geology is known.

The topographic structure, model layers and layer thicknesses of the Spring Valley groundwater model were determined based on observed values, published geology, well logs, and assumptions about the depth of the wells in SNWA's development plans. The model has five layers with the top three corresponding to the valley fill aquifer in the center of the valley. In the mountains, bedrock outcrops occur in layers 1 through 3. The top layer elevation approximates the average elevation of the square mile cells based on USGS 1:100000 scale topographic maps.

Layer 1 has variable thickness depending on the elevation of the top of the layer and the bottom elevation which was set equal to 5400 ft msl. Layer 1 is thinnest in the center of the valley corresponding with the wetlands (and location of most ET). In the mountains, which are a bedrock outcrop where ET is not modeled, the thickness ranges to more than 4000 feet. Layer 2 is 800 feet thick. This thickness was chosen based on SNWA's plans. There are 16 SNWA applications for the valley fill aquifer; the assumption is that wells will not be less than or more than 200 or 1000 feet deep, respectively. Layer 3 is the bottom portion of the valley fill and it extends to 7000 feet below the ground surface near the west side of the domain (Plume 1996). The depth was set at -1000 feet msl two cells east of the bedrock hydraulic conductivity zones (Figure 17 below). It slopes upward to the east so that it is 1000 feet thick next to the Snake Range bedrock outcrop. Based on the presence of outcrops in the middle of the valley fill in the northern part of the valley, it is not likely that this valley fill thickness continues that far north. The layer 3 bottom elevation was set so that the valley fill thickness decreased to 2100 feet at the far north end. The bedrock outcrop for the bounding mountains is one cell wider in layer 3 than in layers 1 and 2 to reflect the fact that the bedrock likely covers more area with depth and to reflect cross-sections shown in Plume (1996). It is in these layer 3 bedrock (carbonate) cells that SNWA's three carbonate applications will be simulated.

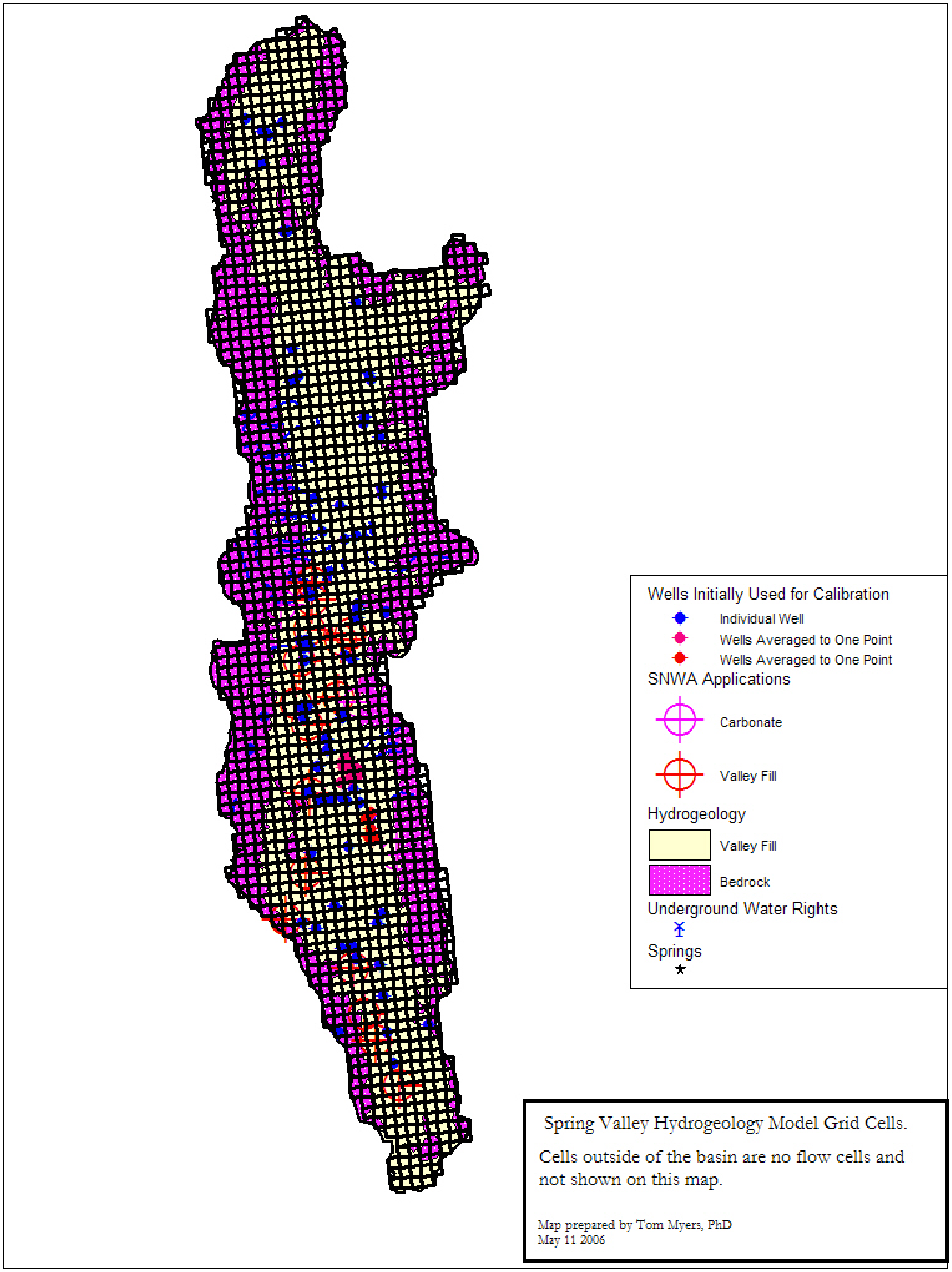

Figure 7: Spring Valley hydrogeology and model grid cells.

Layers 4 and 5 are deep carbonate layers. The bottom of layer 4 is flat across the domain at an elevation 500 feet below the deepest point of the valley fill in layer 3. Layer 5 is a 500 foot thick carbonate layer which underlies the model; it is used to aid in measuring vertical flow.

Flux Boundaries

Recharge to the model, based on Rush and Kazmi (1965), was set to equal 75,000 af/y. The distribution by mountain range reflects the distribution in recharge reported by Prudic et al (1995). The Schell Creek, Wilson Creek, Snake and Kern Mountains ranges had 65,000, 4000, 90,000 and 5000 af/y, respectively, as shown on Figure 32 of Prudic et al (1995). These numbers do not reflect which side of the mountain ranges the recharge occurs on. Half of the total, 164,000 af/y, is 82,000 af/y or just 7000 af/y greater than the total for Spring Valley. Because the west side of the Snake Range is steeper and has much less area than the east side, and because there are more perennial streams that emanate from the east side of the range, this model conceptualizes that the difference of 7000 af/y will occur on the Snake Range portion of the model domain. Thus, the specified recharge will be 32,500, 2000, 38,000 and 2500 af/y for the Schell Creek, Wilson Creek, Snake and Kern Mountains ranges, respectively. Along the length of the ranges the recharge distribution depends on elevation with more occurring near the ridges. The recharge distribution also reflected concepts presented by Stone et al (2001) wherein substantial run-off recharges into the alluvial fans. However, alluvial fan recharge occurs only where there are fans at the mouth of drainage basins. The following breakdown shows the five recharge zones and the values initially used to parameterize them.

Elevation Range	Precipitation and Recharge Efficiency	Recharge Rate
>9000 feet	25 inch precip, 25% recharge -	0.52 ft/y
8000-9000	17.5 inch at 15% -	0.22 ft/y
7000-8000	13.5 inch at 7% -	0.079 ft/y
6000-7000	10 inch at 3% -	0.025 ft/y
Top of alluvial fan -		0.07 ft/y

Figure 13 below presents the distribution of recharge by model cell.

ET is modeled with the evapotranspiration package in MODFLOW. This is a head-dependent flux boundary. Based on Prudic et al (1995), a 44 inch/y rate with a 20 foot extinction depth was used initially. The model appeared very sensitive to ET rate, therefore ET was an calibration parameter.

Spring flow is modeled using drain boundaries (Figure 8), although it was not possible to try to match the flux for each spring because the measurements are few and it is difficult to separate spring discharge from ET. The carbonate underlying the Limestone Hills bounding the southeast portion of the valley was modeled using a general head boundary (GHB) in layers 2 and 3 with a target flux of 4000 af/y.

Model Parameter Zones

The geology of Spring Valley is complex having variable thicknesses of permeable carbonate rock and regions of impermeable rhyolitic flows and Precambrian quartzite and siltstone (Figure 2). The complexities of the geology manifest in layers 1 through 3. For layers 1 and 2, an attempt was made to emulate the surface geology using parameter zones. Where carbonate rock predominates, carbonate zones were created. As may be seen in Figure 16, showing the calibrated hydraulic conductivity zones for layer 1, the zones alternate; different carbonate regions were assigned different parameter zones even though the initial conductivity among carbonate zones was constant so that adjustments to the values could be made during calibration. The initial carbonate hydraulic conductivity was set equal to 6 ft/d, following Plume (1996, page 13), with a vertical anisotropy of 10 to reflect the presence of shale and other fine grained lenses. The carbonate zones in layer 3 were set equal to 0.06 ft/d to reflect the barriers discussed by Plume (1996) and modeled by Prudic et al (1995). Additionally, the parameter zone in layer 3 under the Snake Range was set to a lower conductivity, K_h=0.001 ft/d, except for a one model square thick zone on the west side of the range adjacent to the carbonate rock parameterized in layers 1 and 2; this extension of carbonate rock into layer 3 reflects the carbonate rock shown in Plume's (1996) Snake Range cross-section. The Fortification Range bounding the southwest of Spring Valley is tuft (Stewart 1980) and likely relatively permeable with initial conductivity equal to 2 ft/d. Zone boundaries and initial values were the same in layers 1 and 2, but were given different numbers allowing for different parameter values during calibration. All of these zones were allowed to vary during calibration

The valley fill on the valley margins has high conductivity (Plume 1996). In this calibration, the initial conductivity on the margins was the median value found by Plume, 90 ft/d. The lower fans had a median value of 70 ft/d which was used here. For the fans, the initial vertical anisotropy was set at 10. Plume does not provide substantial information about the playa deposits, but the initial values used here are 1 ft/d with a vertical anisotropy of 1000 to represent the expected fine-grained lake deposits.

Prudic et al (1995) found the bedrock underlying the area to have a low transmissivity. Therefore, the basement rock beneath the valley fill, layers 4 and 5, started the calibration with a low conductivity (Kh=Kv=0.001 ft/d). The basement rock, mostly carbonate, under the mountain ranges also started with the same conductivity, following Plume (1996, page 13) but a different zone so that the calibration procedures could adjust the values as necessary.

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Figure 8: Spring Valley groundwater model layer 1 boundary conditions.

Calibration

Steady state calibration is an attempt to adjust the model parameters so that the model results equal the observed conditions in the valley including water levels and fluxes. Because the recharge is set, the flux target is the 4000 af/y that discharges to Hamlin Valley and about 70,000 af/y that discharges through ET or to springs. The other flux condition is the flow rate into deep layers is low (Prudic et al 1995); for calibration the vertical flow from layer 3 into layer 4 and layer 4 into layer 5 will be limited to 20 percent of the recharge or about 15,000 af/y.

Steady state implies that water levels are at an inter-annual steady level and that there is no artificial stress changing the flow. For steady state calibration the initial water levels observed on well logs represent pre-development steady state conditions. During the 1960s, pumpage did not exceed 1000 af/y (Rush and Kazmi 1965). Most of these wells were used to determine the static water level map (Figure 3). All available wells were used if they were acceptable. In two regions of the model domain, the water level from six to ten wells with groundwater levels varying by less than 30 feet spread around a small area were averaged so as not to bias the calibration statistics with many low residuals resulting from the limited area.

Table A-1 (in Appendix A) lists the wells that were initially used in calibration. Some of the wells were not used ultimately for reasons explained in the following paragraphs; wells in Table A-1 with a * at the beginning of the name were not utilized. The map in Figure 10 shows the location of the wells used for calibration. The first eight wells removed were those without a measured well depth.

There are no water level measurements in the mountains useful for calibration. Prudic et al (1995) modeled steady state conditions around the carbonate aquifer zone and accepted water levels in the Schell Creek and Snake Range exceeding 6500 feet. For this analysis, two artificial observation points with a water level equal to 6600 feet were added to layer 1 in both the Snake Range and Schell Creek Range.

The well levels have a high variability even among those completed in similar layers within a close proximity. There were variations up to several hundred feet within just a few miles. In a valley fill aquifer with substantial vertical anisotropy, local vertical gradients or perched aquifers may explain some of this variability. Within a model layer, this local variation cannot be modeled. Seasonal changes may also cause some variability if the wells were developed and measured during different seasons.

Variability among water levels introduces uncertainty to the calibration. To determine an acceptable residual for calibration, a multiple regression of groundwater level with various explanatory variables was used to determine the standard error which represents the variability around the expected water level value. If the regression explains a high amount of variance (R^2 is close to 1.0), then the standard error represents a lower limit to the standard deviation of residuals that may be obtained from model calibration and is therefore a reasonable target for constraining the residuals.

A regression of groundwater elevation with ground surface elevation and well depth yielded an equation that explained 92 percent of the variance and had a standard error equal to about 60. The regression used all groundwater levels in Table A-1 except for those with depth equal to 0. Using just the northing and easting explained less than 30 percent of the variance. Adding the northing and easting to the regression with depth and ground surface elevation explained little additional variance and the coordinate variables had insignificant coefficients, therefore there does not appear to a significant variation of water level with direction. Based on these results, the desired target for the calibration residuals was set to have 95 percent of the residuals within + or – 121 to reflect the regression results.

Horizontal and vertical hydraulic conductivity were the primary parameters adjusted to obtain a calibrated model. Matching modeled groundwater levels with observed levels was done initially by trial and error with some precision added by the use of the calibration routine in MODFLOW 2000. It was found that the model had to be closely calibrated before the calibration routine functioned properly. Varying more than three of the parameters caused the model to not converge. After obtaining a successful calibration by trial and error, some parameter values were fine-tuned using sensitivity analysis as described below.

During calibration, several wells were found to have errors in their measured data. Because the correct groundwater elevation was impossible to determine for these wells, they were removed from the calibration analysis. Table 7 lists and provides explanations for removing several wells.

Table 7 : Wells removed from the calibration.

Well Number	Reason for Removal
USGS3913271142559	Groundwater level was more than 100 feet above the ground surface based on map elevations.
USGS3943331143110	Ground surface elevation off by more than 200 feet.
USGS3932111143207	Ground surface elevation off by more than 200 feet. The water level in this and the previous well differed by more than 300 feet.
USGS3909521142144	Screened in bedrock; water level much higher than nearby wells and appears to be perched.
USGS3911231142450	Water level 200 feet above the ground surface.
USGS3913271142559	The well is 14 foot deep with ground surface elevation reported at least 100 feet above the mapped surface and therefore the reported water level was likely incorrect.
USGS3909521142144	Well located just south of Sacramento Pass hundreds of feet above the valley floor, it had an observation very close to the ground surface which is presumably perched. Appears to be perched.
USGS3842161142600	The ground surface elevation for is about 90 feet off; the well level is much too high.

After manually reaching a satisfactory point in the calibration, auto sensitivity analysis was used to fine-tune the hydraulic conductivity of the parameter zones which represent the valley fill and the conductivity of the drains representing the spring discharge. This fine-tuning was limited to the valley fill zones because there were few targets in the bedrock zones. The process involved adjusting the calibrated value, one zone at a time, by the factors 0.5, 0.7, 0.9, 0.95, 0.99, 1.01, 1.05, 1.1, 1.3, and 1.5 and re-running the steady state model. The sum of squared residuals was compared among model runs; if there was a significant change in the value, the parameter value was changed to that which yielded the minimum sum of squares and the sensitivity analysis was run again. If the minimum sum of squares occurred on the model run with the parameter value equal to either 0.5 or 1.5, determining the final parameter required several sets of model runs. Table 8 summarizes the results; the most significant change was in horizontal hydraulic conductivity for parameter zone 9, layer 3, which changed from 1 to 25 ft/d.

Table 8: Sensitivity of select calibration parameters

Parameter	Zone	Sensitive	Comments
Kv	2	No	
Kh	2	Yes	Kh changed from 0.2 to 0.18 ft/d
Kh	7	Yes	0.29 to 0.276 ft/d; this parameter primarily controls heads in the northern arm of the valley
Kh	1	Yes	Kh changed from 100 to 70 ft/d
Kh	5	Yes	Kh changed from 20 to 18 ft/d
Kv	5	Yes	Kh changed from 0.002 to 0.0039 ft/d
Kh	6	Yes	Kh changed from 2 to 0.95 ft/d
Kh	9	Yes	Kh changed from 1 to 25 ft/d. The sum of squared residuals dropped from 175,021 to 172,313.
Kv	9	No	
Kh	41	No	
Kv	41	Yes	Kv changed from 0.02 to 0.014 ft/d
Kh, Kv	42	No	Almost no effect on sum of squared residuals.
Drain conductance	1, 3	No	Changing the drain conductance affected the discharge substantially but the change in head values was insignificant.

The final calibration resulted in residuals that mostly lie within the acceptable ranges based on the regression analysis presented above with 97 percent of the residuals within the desired range of -121 to 121; only the ends of the calibrated range exceeded the desired ranged. The mean of the residual is just less than 0 and the standard deviation is substantially less than the standard error of the regression (49 < 60) (Table 9). The residuals have no obvious differences among layers or spatial variation (Figures 9 and 10). The calibration statistics are better than expected based on the standard deviation being substantially less than the regression standard error. Also, the water level contours for layers 1 and 2 (Figures 11 and 12) resemble the static water level contours.

Table 9: Descriptive statistics for calibration residuals.

Mean	-3.51
Standard Error	5.79
Median	0.73
Mode	#N/A
Standard Deviation	49.14
Sample Variance	2414.37
Kurtosis	1.33
Skewness	0.23
Range	282.40
Minimum	-126.30
Maximum	156.10
Sum	-253.03
Count	72.00
Largest(1)	156.10
Smallest(1)	-126.30
Confidence Level (95.0%)	11.55

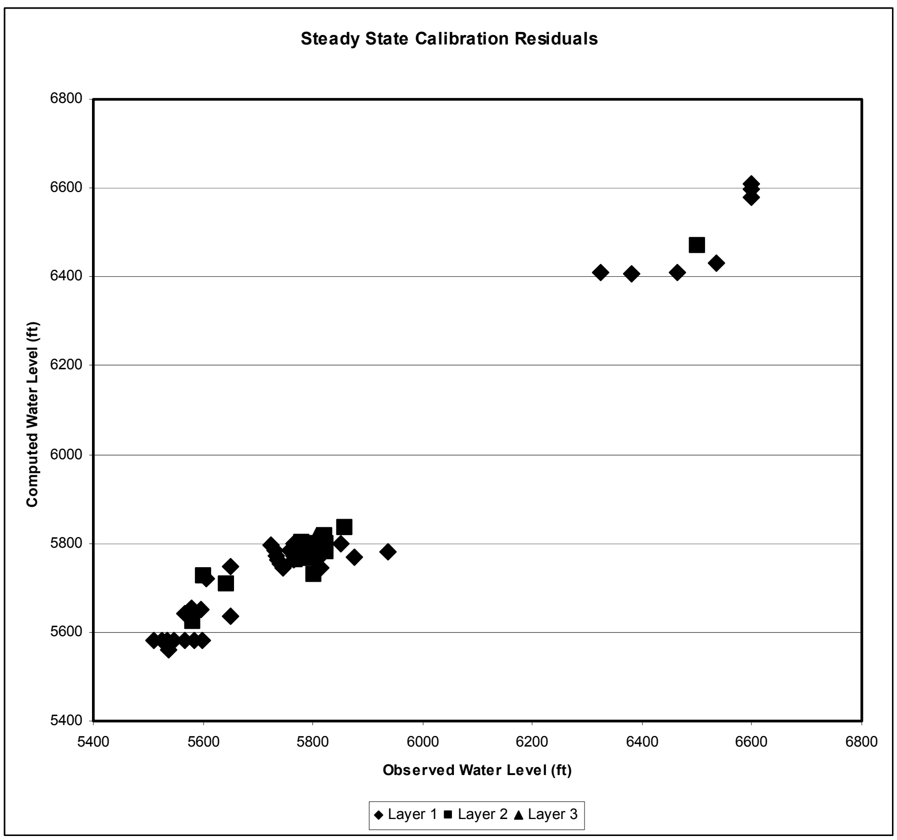

Figure 9: Scatter plot of groundwater model residuals.

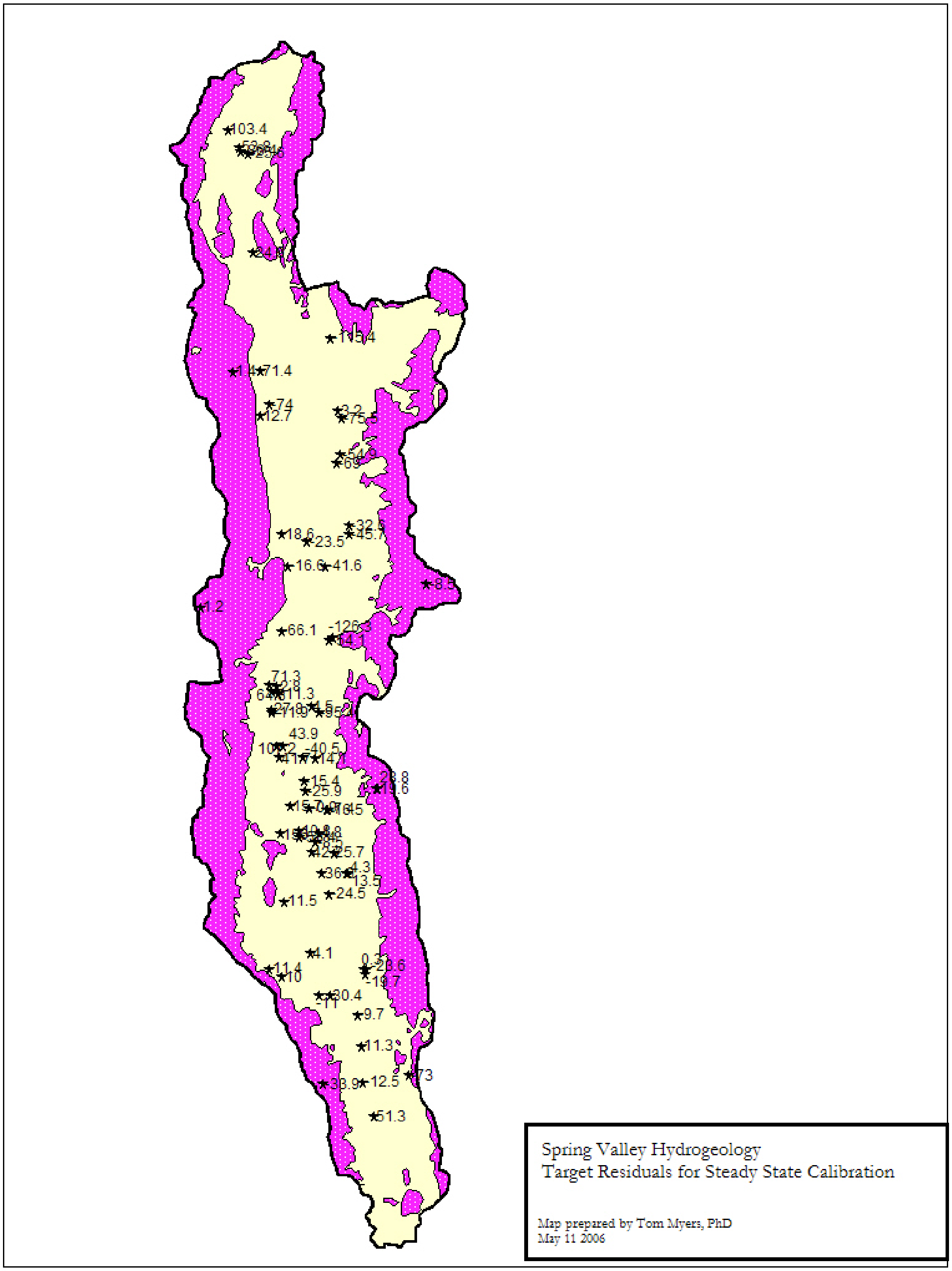

Figure 10: Map of residuals from groundwater model calibration in Spring Valley.

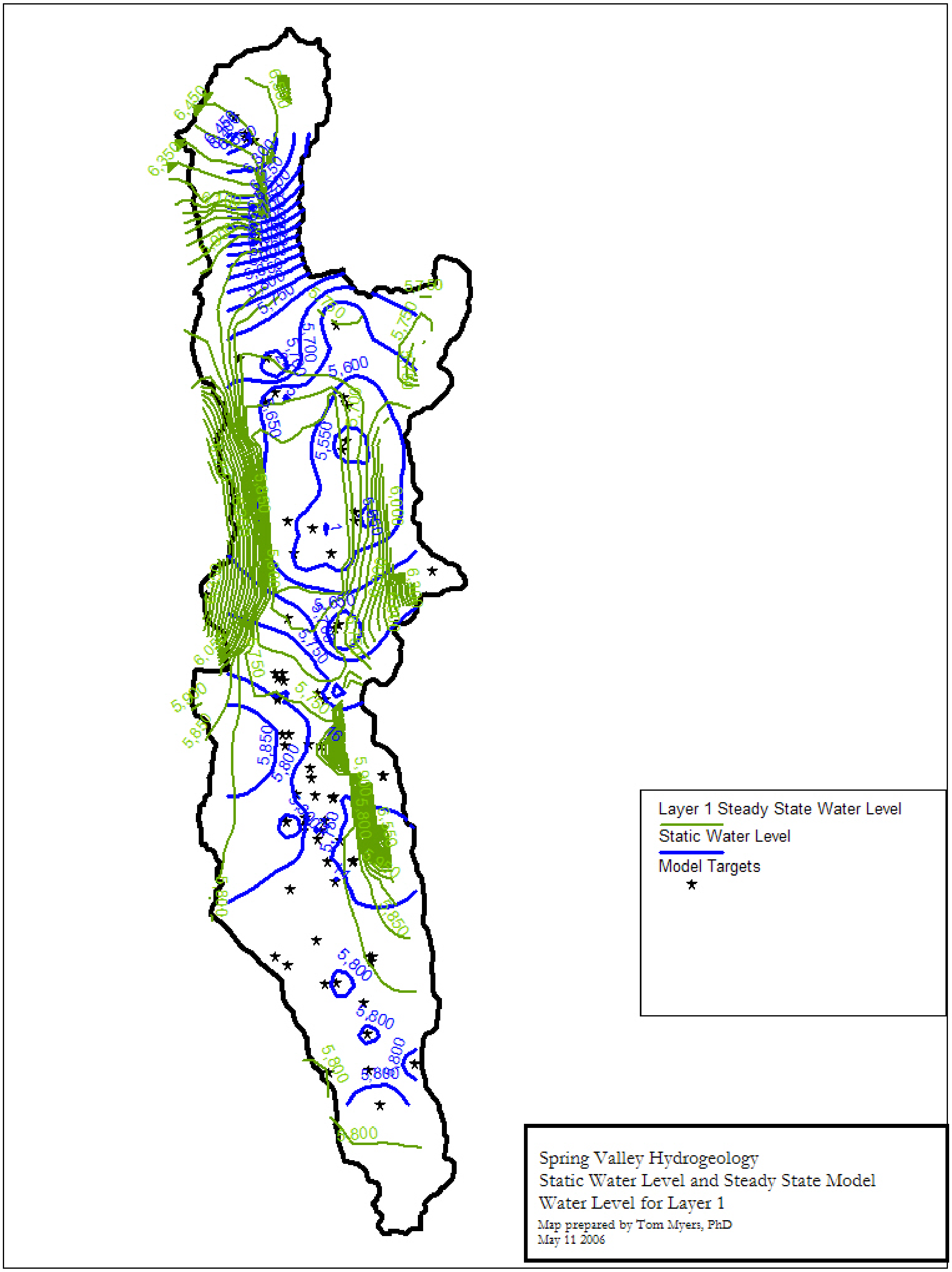

Figure 11: Static water level and simulated layer 1 water level.

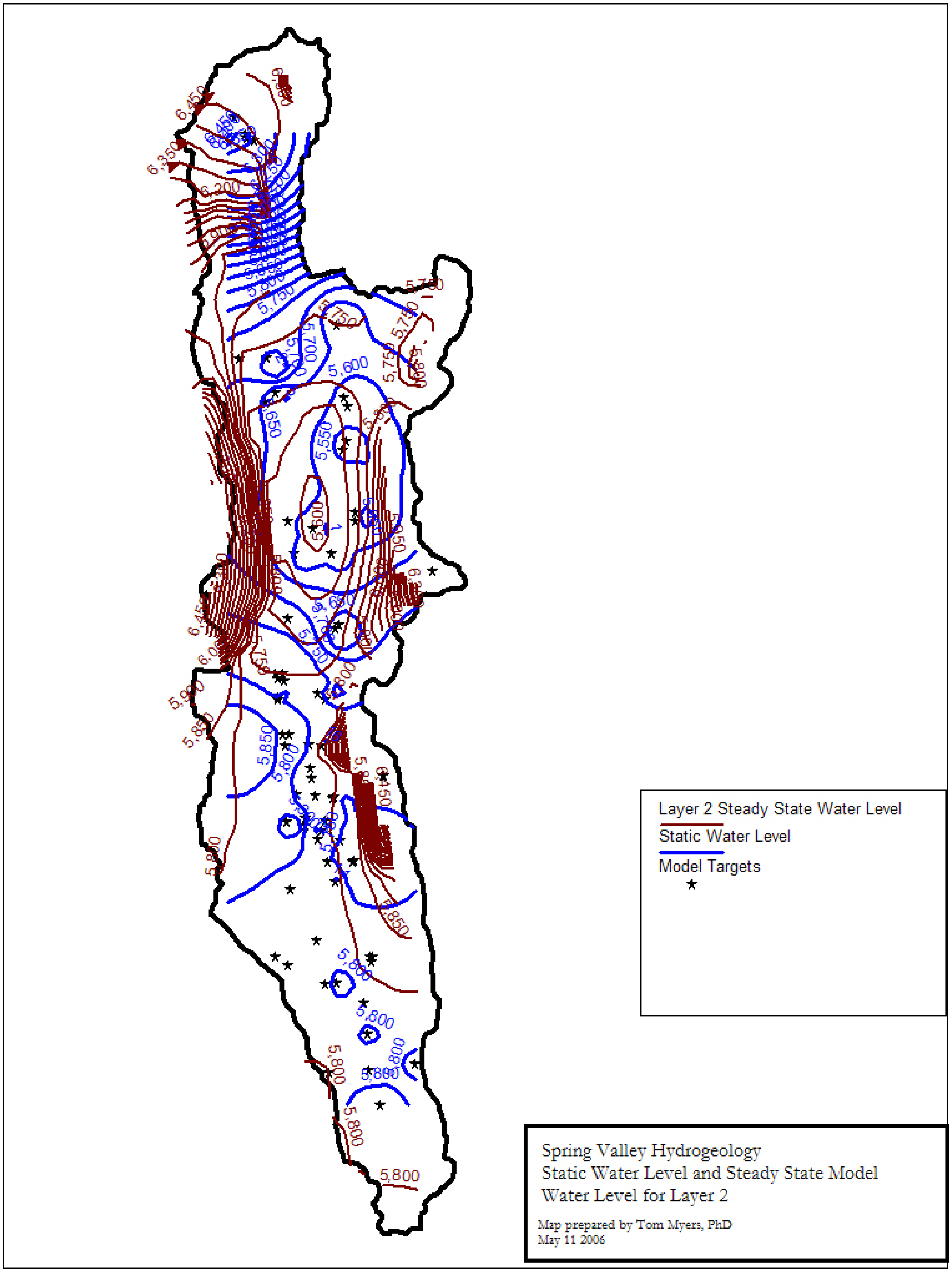

Figure 12: Static water level and simulated layer 2 water level.

Water balance is the second calibration constraint. The water balance error was just 0.09 percent. More importantly, the fluxes resemble those observed or estimated in the field. The approximately 75,000 af/y recharge in Spring Valley (Figure 13) was balanced by ET (35 percent), spring flow (59 percent), and out of basin flow (6 percent) (Table 10). As has been discussed above, it is difficult to distinguish between spring flow and ET because spring flow supports the wetlands and phreatophyte ET. Over all the model ET cells, the average ET rate was about 1 inch/y. This rate however includes cells that may have had no flux because the water level was below the extinction depth. Considering just the active ET cells would result in a higher effective ET rate.

Table 10: Water balance for the steady state calibration. Flows in ft^3/day.

Feature	Boundary Reach	Inflow	Outflow
Recharge		8948130	
Evapotranspiration			3110457
Interbasin Discharge	GHB Total		551057
Springs along the west side of the north end of Snake Range	Drain 1		1141460
Springs along the west side of south end of Snake Range	Drain 2		183721
Springs along the east side of the Schell Creek Range	Drain 3		2764065
Springs on south side of playa north half of valley	Drain 4		1205649
Total		8948130	8956409

ET discharges from layer 1 mostly between the cells that have drains (springs) (Figure 14). The water balance for the cells in layer 1 lying between the drain cells for reaches 1, 3, and 4 shows that ET equals 1,238,705 ft^3/d. Inflow from layer 2, upward flow, equaled 1,308,579 ft^3/d. The excess upward inflow discharged into the drains. The model circulates water downward in the recharge zones in the mountains. Vertical groundwater flow circulates through layers 2, 3, 4 and 5 but decreases substantially with depth (Figure 15). The total flux in and out of layer 1 exceeds the total amount of inflow to the model because it includes all of the recharge and all of the flow discharging from layer 2 into layer 1. The total flux in layers 4 and 5 is less than 10 percent of the flux in layer 1 and less than 20 percent of the total inflow to the model.

Vertical mixing, recharge in the mountains and at the top of alluvial fans, discharge from springs and ET are exactly as postulated in the conceptual model for groundwater flow in Spring Valley. The breakdown of flux between ET and spring flow is reasonable. The distribution of model spring flow appears reasonable considering the field locations of larger springs, substantial wetlands and higher recharge areas.

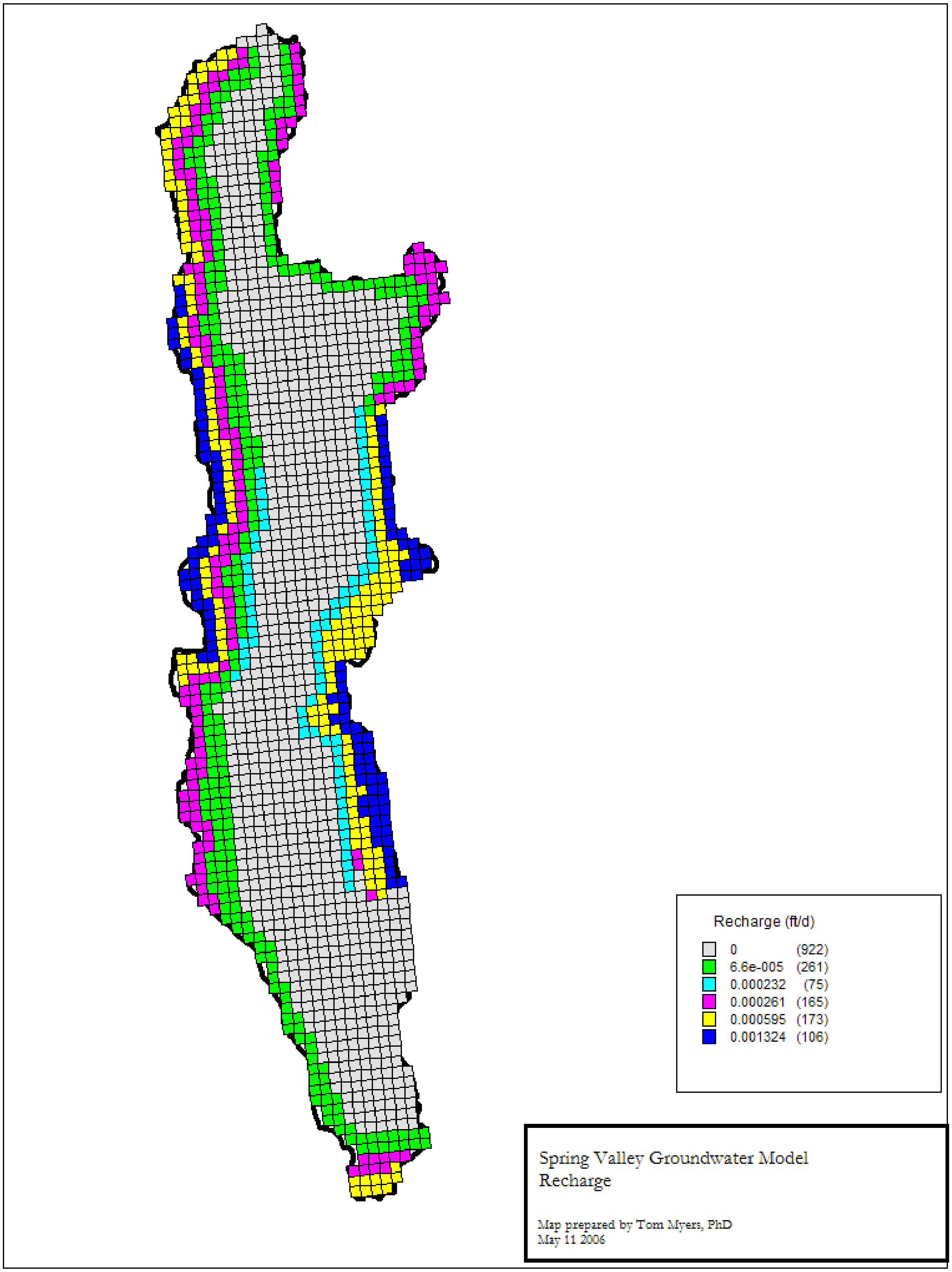

Figure 13: Recharge values in Spring Valley groundwater model.

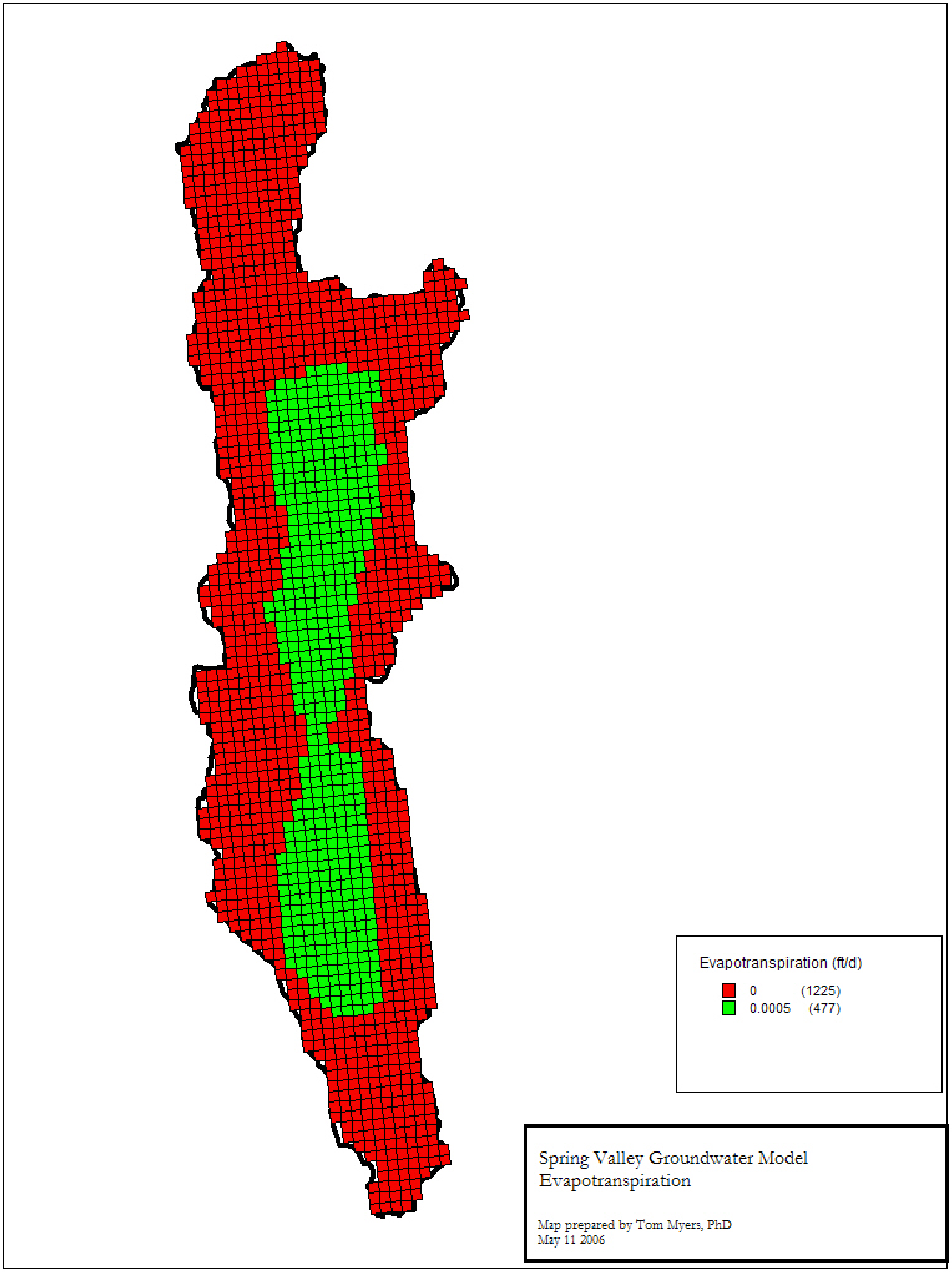

Figure 14: Evapotranspiration values in Spring Valley groundwater model.

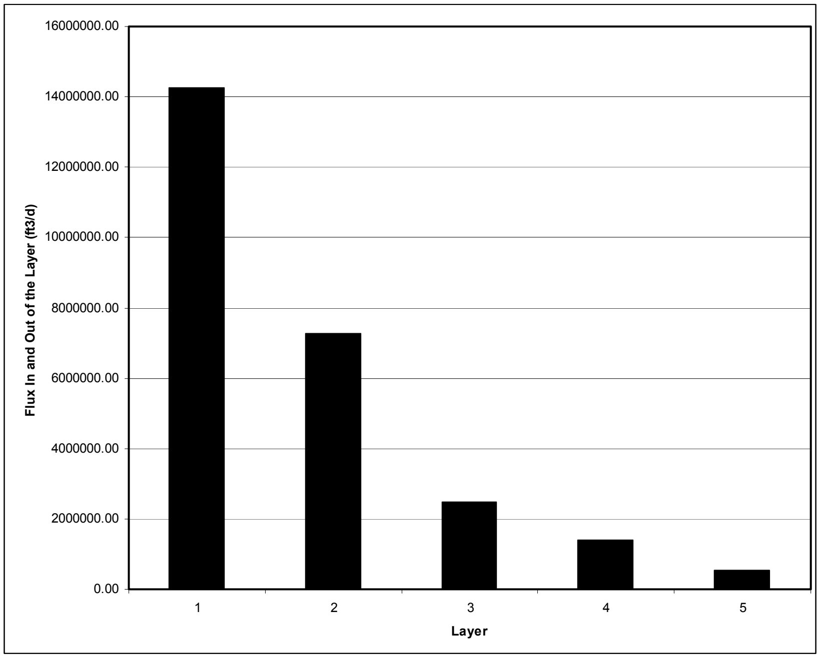

Figure 15: Steady state vertical flow among model layers.

Calibrated Parameters

As described above, horizontal and vertical hydraulic conductivity was the primary calibration parameter. The parameter zones reflect the geology of the basin (Figures 16 through 22 and Figure 2). The final calibrated values also resemble within an order of magnitude the initial values which were set based on Plume (1996) and Prudic et al (1995).

The calibrated values generally correspond with the basin hydrogeology. The valley fill conductivity values are generally higher than the bedrock, but some of the carbonate bedrock has values of 6 ft/d. The primary control on horizontal conductivity in the mountain bedrock is the desired water level monitoring points in layer 1 in the mountains. The valley fill conductivity is lowest in the top layer at 1 ft/d and highest in layer 3 at 25 ft/d. The presence of wetlands and the fine material that settles from terminal dry lakes causes the lower valley fill conductivity in layer 1.

Vertical conductivity is low in the valley fill as well (Figures 19 to 21). The lowest vertical conductivity occurred in layer 3 in the same zones that had the highest horizontal conductivity. This reflects the layering of larger soil particles found at depth in the valley and the high gradient, and high head drop, from 6500 feet msl in the mountains to the valley floor level near 5600 feet msl. The model was sensitive to vertical conductivity because it controlled the gradient which drives vertical flow.

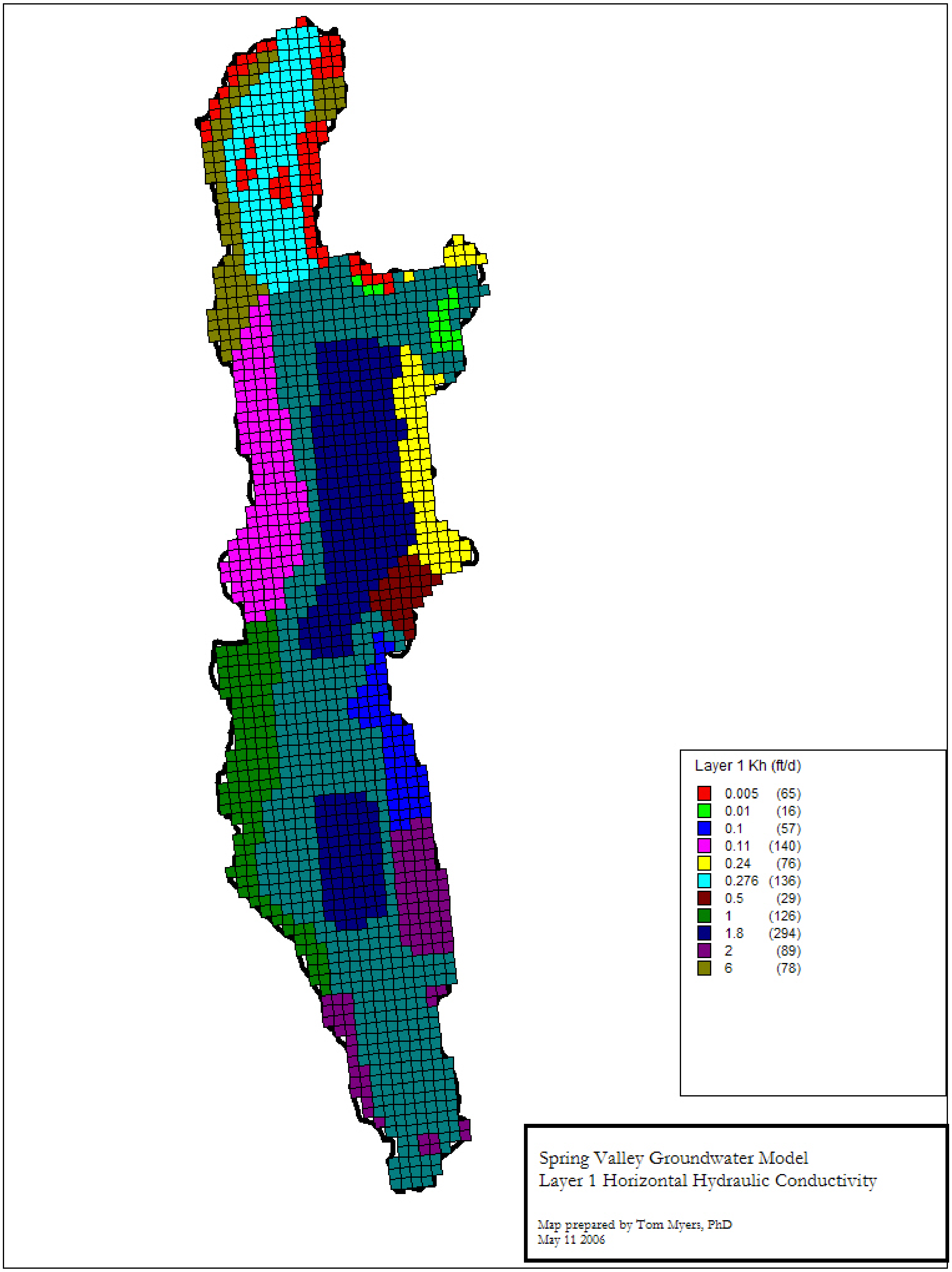

Figure 16: Calibrated layer 1 horizontal hydraulic conductivity.

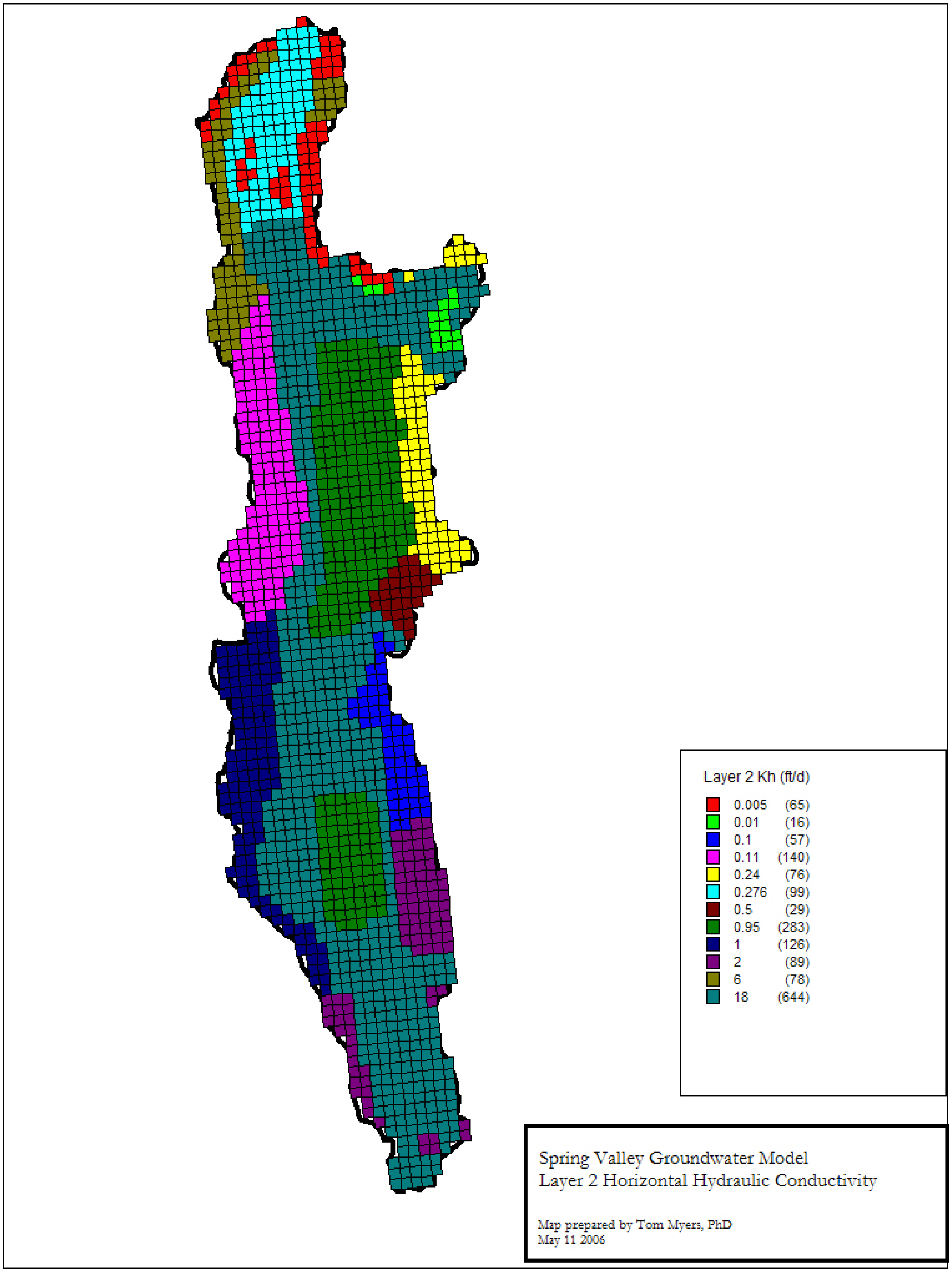

Figure 17: Calibrated layer 2 horizontal hydraulic conductivity.

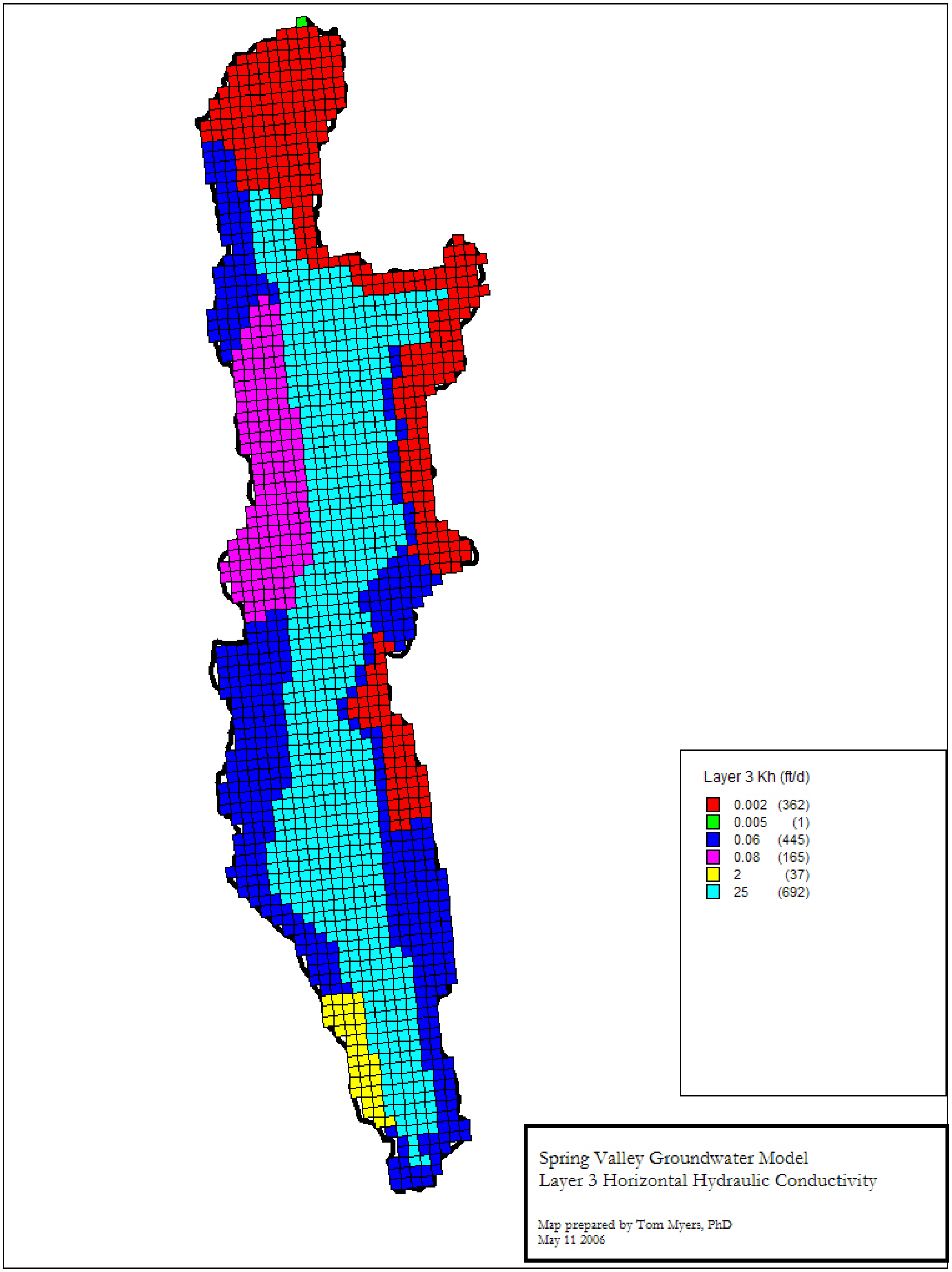

Figure 18: Calibrated layer 3 horizontal hydraulic conductivity.

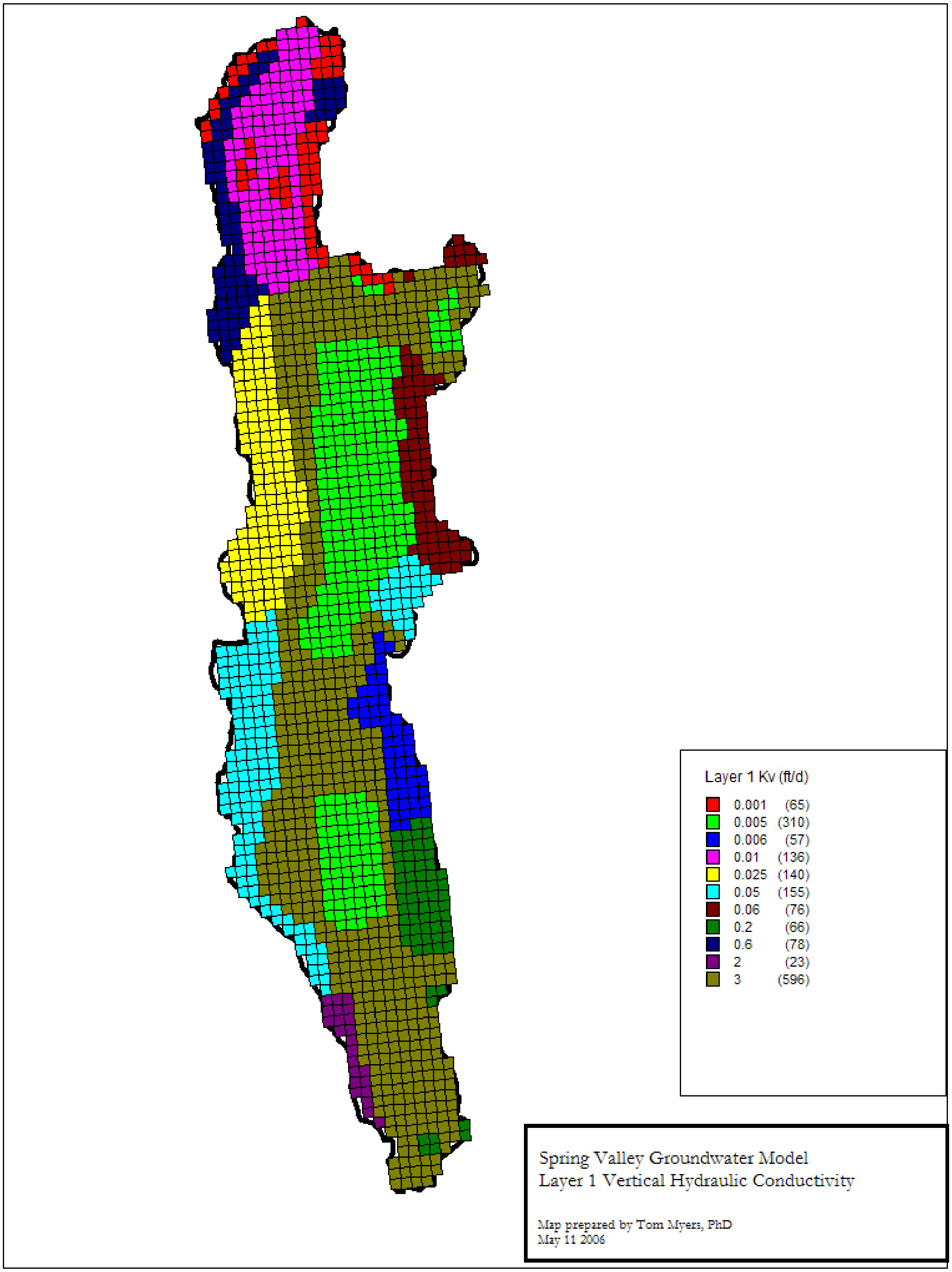

Figure 19: Calibrated layer 1 vertical hydraulic conductivity

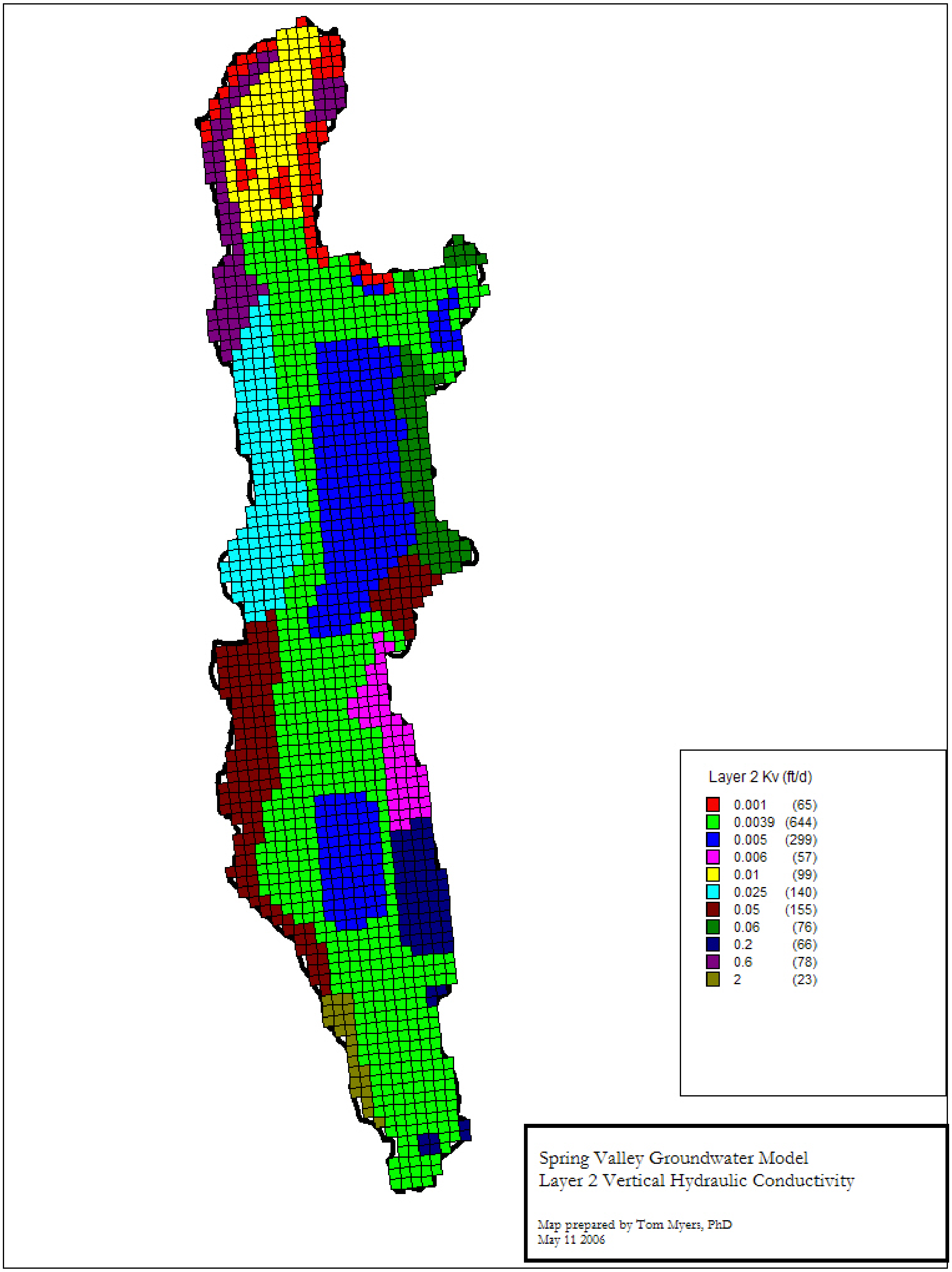

Figure 20: Calibrated layer 2 vertical hydraulic conductivity

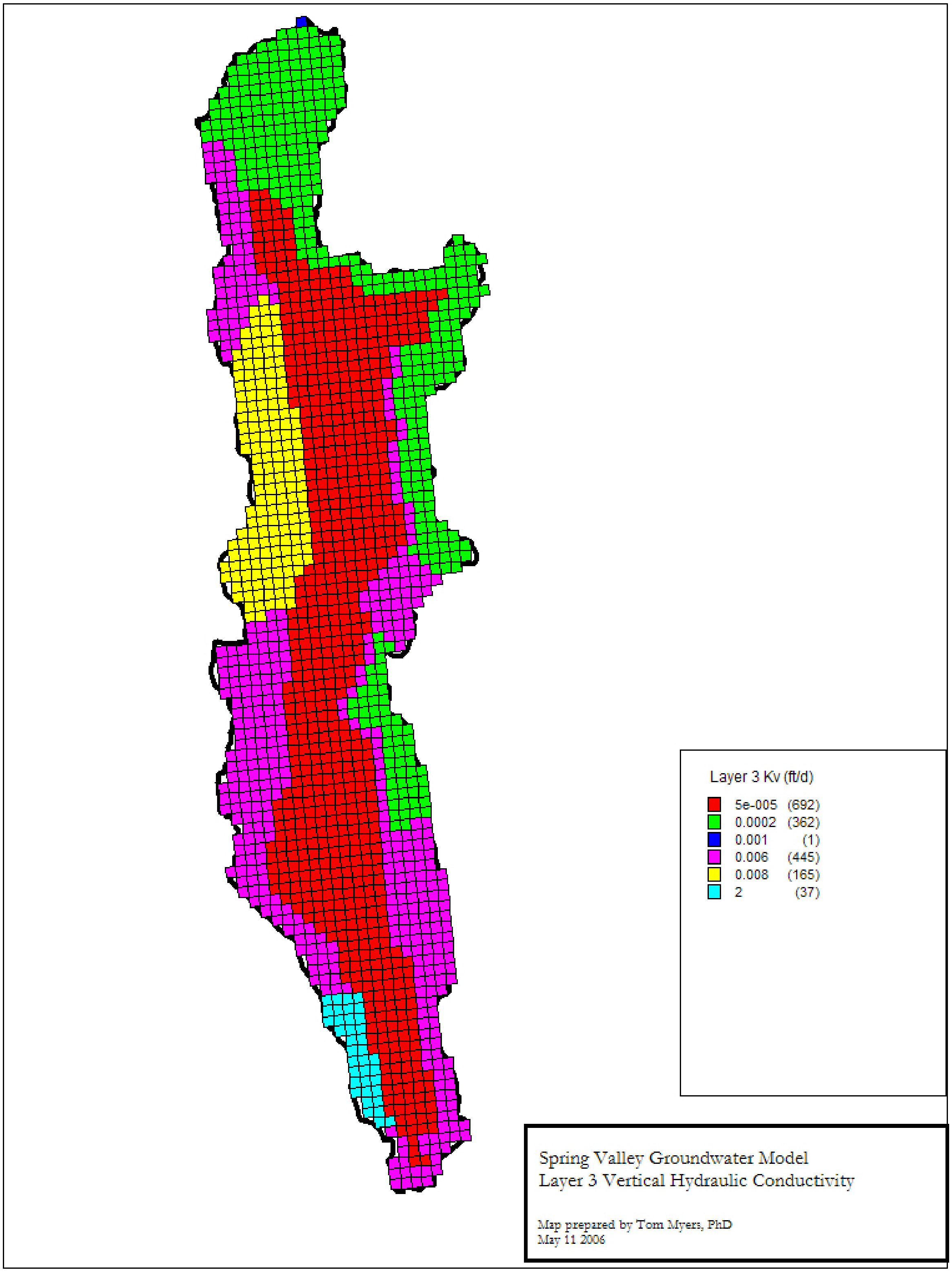

Figure 21: Calibrated layer 3 vertical hydraulic conductivity.

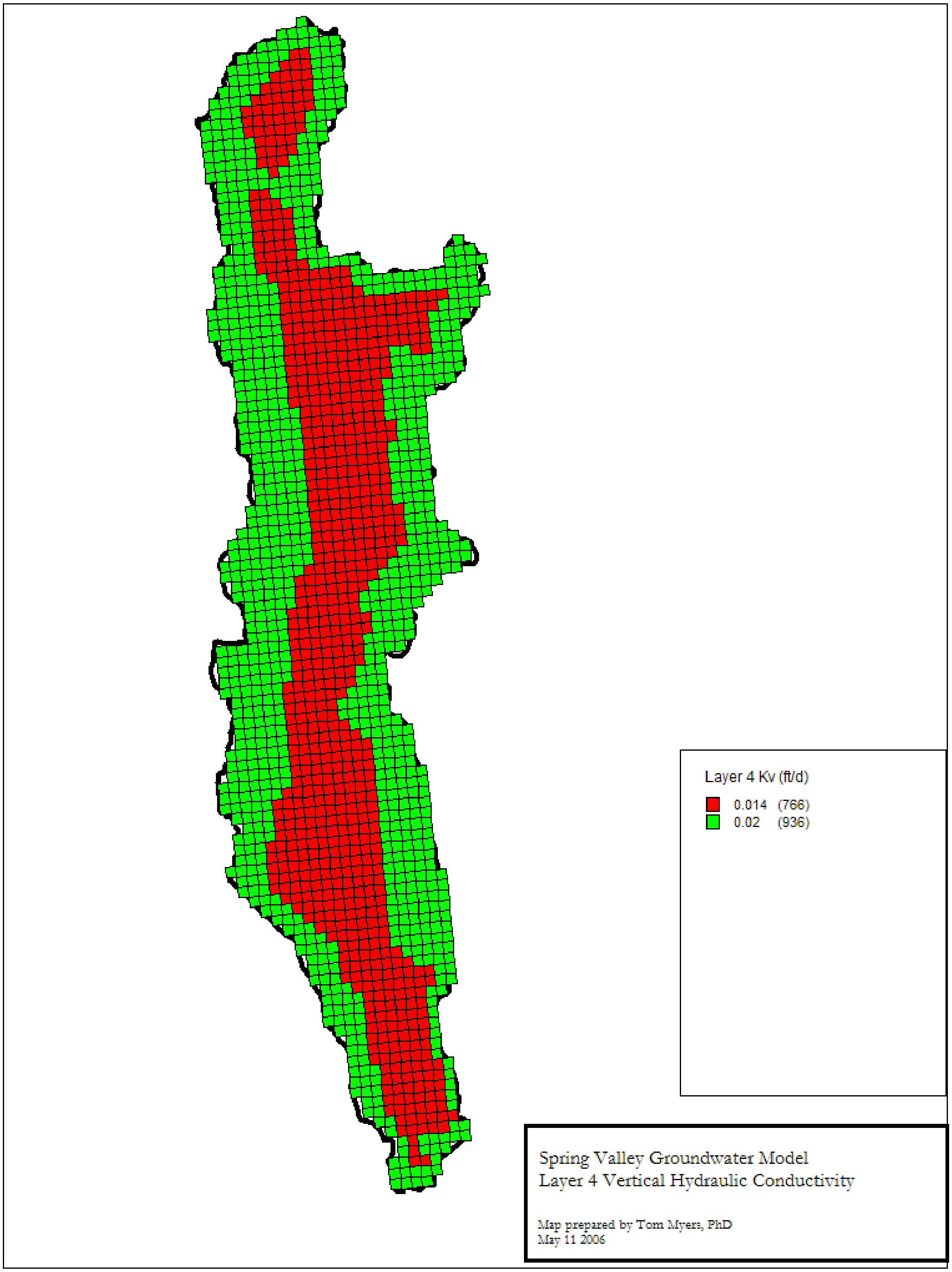

Figure 22: Calibrated layer 4 vertical hydraulic conductivity

The calibrated ET rate was 0.0005 ft/d (2.2 inches/y) (Figure 14). This relatively low rate compensates for the low cover found in the phreatophytic regions of the area (Rush and Kazmi 1965). It also compensates for the amount of water removed from the model by the drains (springs) that would have been available in the field to evapotranspire.

Transient Calibration

Transient calibration is used to set the storage parameters so that the model responds to stress correctly. In addition to hydraulic conductivity, the storage parameters, specific storage and specific yield, control the water level changes due to stress. Transient calibration involves setting the storage parameters so that water levels change due to stress according to observed values.

SNWA proposes to pump from both valley fill and carbonate rock aquifers. The valley fill is unconsolidated and consists of varying mixtures of silt, sand and gravel. Reasonable values of specific yield would be 0.05 to 0.25 (Anderson and Woessner, 1992). The specific storage to use for the bedrock, carbonate and intrusive rock, zones is more complicated. Storage depends on the location, size, density and interconnection of fractures. In the marine carbonate rocks, storage is enhanced by dissolution features. The primary storage of these rocks is near zero, but the secondary storage may be quite high due to the fractures and solution channels. Schaeffer and Harrill (1995) used Prudic et al's (1995) model to predict the effects of SNWA's proposed pumping and estimated storage coefficient based on aquifer properties. For the carbonate layers, Schaeffer and Harrill (1995) used a dimensionless storage coefficient equal to $6e^{-4}$ based on an equation which includes aquifer thickness but MODFLOW-2000 requires the input of specific storage which has the units of ft^{-1}. Schaeffer and Harrill calculated a range but chose the middle of the range. Converting their value based on a 5000 foot thick aquifer, their assumed aquifer thickness, yields a value equal to $1.2e^{-7}$ ft^{-1}, or $3.75e^{-8}$ m^{-1}. This is at the low end of the range, $1.5e^{-8}$ to $6.3e^{-2}$ m^{-1}, reported by Faunt et al (2004, page 323) in their study of the carbonate aquifer in the Death Valley flow system (DVFS); the range in that report includes confining units and carbonate aquifers. Faunt et al (2004) ultimately used very low specific storage values. McDonald Morrissey Associates (1998) used 0.000003 ft^{-1} for carbonate aquifers in the Carlin Trend and assumed that water levels would not be sensitive to the value.

The valley fill, carbonate and intrusive rock specific yield was initially set to equal 0.1, 0.05 and 0.01, respectively, based on Schaeffer and Harrill (1995). During initial runs of SNWA's pumping regime (described in the next section), excessive drawdown, greater than 1000 feet in one year, occurred in the cells with the well boundaries using values reported in the preceding paragraph. However, the location of the SNWA pumping was in carbonate with Kh approximating 0.06 ft/d resulting from the steady state calibration. Changing the conductivity in the steady state model was attempted but yielded significantly poorer calibration. Both storage and conductivity values are likely accurate for the bulk material represented by the cell. The values used by Faunt et al (2004) were not in cells that were pumped, therefore they did not encounter this potential issue in their model (the Death Valley Flow System model).

SNWA will however screen its' wells in fracture zones where the effective storage and conductivity is much greater. For this reason, the specific storage for the carbonate was set equal to 0.00003 ft^{-1}, an order of magnitude greater than that used by McDonald Morrissey Associates (1998) in a region similar to that expected at depth in Spring Valley (Boulder Valley basin located on the Carlin Trend 150 miles to the northwest of Spring Valley).

Verification consisted of changing recharge and ET rates to semiannual values to reflect seasonal changes. This seasonal recharge and ET was simulated for ten years long with each year into two equal length periods. During one half of a year, recharge was twice the steady state value while ET was zero. During the other half of the year, the ET rate was twice the steady state value while recharge was zero. Because valley fill wells have been observed to fluctuate four to eight feet annually, presumably due primarily to natural seasonal stresses, the goal was to observe similar changes in the layer 1 water level due to seasonally changing recharge and ET. During the 20 stress periods, the drawdown (both positive and negative) consistently increased suggesting that seasonal steady state had not been achieved after ten years. However, the absolute value of the drawdown reached a maximum of about 3 feet after 10 years reflecting a six foot fluctuation. ET and fluxes to the springs reflect the seasonal changes (Figure 23). The storage coefficients are therefore the right order of magnitude. The fluxes also reflect that ET and drain flows are sensitive to the change in head in layer 1. Water levels in the mountain zones (both types of bedrock) fluctuated about three times the magnitude observed in the valley; drawdown reached about 10 feet after ten years.

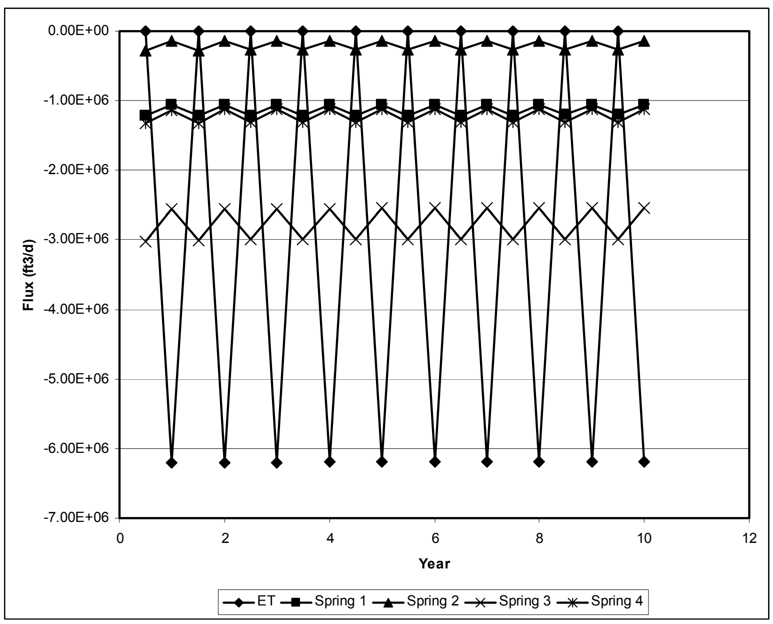

Figure 23: Flux to ET and to the drains (springs) as a result of seasonal changes in recharge and ET rates.

Simulation of SNWA Groundwater Pumping

SNWA proposes to develop 91,200 af/y of groundwater from 19 wells in Spring Valley (Table 1 and Figure 1). The model developed and calibrated herein was used to determine groundwater drawdown and flux changes to ET, the springs, and to interbasin flow caused by 1000 years of SNWA's groundwater pumping and an additional 1000 years of recovery. Intermediate drawdown at 20 and 100 years and continuous hydrographs were also considered.

A second model run considering the recovery from just 100 years of pumping was used to consider the effectiveness of potential mitigation.

Initial head values were from the steady state modeling. There were 14 stress periods used to simulate the pumping and recovery (Table 11). Flow and head data were written to a file at the end of each stress period for tracking the head and flux with time during the pumping and recovery.

The model grid overlay was matched to the points of diversion (Figure 1) to determine the cell row and column numbers (Table 12). The valley fill diversions were taken from layer 2 and the carbonate diversions were taken from layer 3. Layer 2 elevations range from 4600 to 5400 feet msl. Layer 3 elevations range from 2800 to 4600 feet msl. Based on the layer elevations, the water will be withdrawn from valley fill from 200 to 1000 feet below the valley surface and from the carbonate from 800 to 2800 below the valley floor.

Table 11: Stress periods for simulation modeling of SNWA's development plans.

Stress Period	Length (days)	Length (years)	Time Since Beginning of Pumping (years)
1	365	1	1
2	1460	4	5
3	5475	15	20
4	10950	30	50
5	18250	50	100
6	36500	100	200
7	292000	800	1000
8	365	1	1001
9	1460	4	1005
10	5475	15	1020
11	10950	30	1050
12	18250	50	1100
13	36500	100	1200
14	292000	800	2000

Table 12: SNWA water rights applications and model cells for diversion.

Application	Reach	Row	Column	Layer
54003	3	105	15	2
54004	4	100	13	2
54005	5	98	12	2
54006	6	93	12	2
54007	7	88	6	2
54008	8	84	2	2
54009	9	76	9	2
54010	10	70	10	2
54011	11	68	9	2
54012	12	67	13	2
54013	13	64	9	2
54014	14	62	13	2
54015	15	62	14	2
54016	16	61	11	2
54017	17	58	11	2
54018	18	56	11	2
54019	19	83	17	3
54020	20	68	15	3
54021	21	58	8	3
Reaches 19 through 21 were carbonate wells and pump At 864,000 ft^3/d. The valley fill wells pump 518,400 ft^3/d.				

Figures 24 through 34 provide drawdown contours for various layers after 20, 100, and 1000 years of pumping and after 100 and 1000 years of recovery from 1000 years of pumping. Most figures include only layers 1 and 2 because water levels in those features control changes to the wetlands and springs. Figures 35 and 36 provide flux hydrographs through various valley features. Figures 37 through 39 are layer 1 and 2 water level hydrographs for three points in the valley.

Drawdown in layer 1, the valley surface, is just a few feet until period 3, 20 years after pumping commences. By year 20, drawdown has expanded across the southern two-thirds of Spring Valley and reached 30 and 90 feet in layers 1 and 2 respectively (Figures 24 and 25). Drawdown at the carbonate wells in layer 3 is high but localized after 20 years (Figure 26). The steep local drawdown in the carbonate affects the overlying layers, as can be seen from the drawdown in layer 2 corresponding to the carbonate wells (Figure 25).

Drawdown expands for the entire pumping period because the pumping rate exceeds the recharge. Pumping to steady state is only a theoretical concept, but in this situation steady state will not even be approached because pumping exceeds recharge by 22 percent. This proposal as shown by this series of maps clearly pumps more than perennial yield because the groundwater continues to lower. The continued lowering of the groundwater level indicates that the proposal violates groundwater sustainable development concepts (Bredehoeft 2002).

Very little drawdown occurs in the northern portion of the valley through the first 100 years (Figures 24 through 28). Most of SNWA's proposed development is in the south and much of the recharge occurs in the north. Of the total 75,000 af/y recharge, approximately 36,500 af/y, or almost half, occurs north of model row 55 which coincides with the northernmost SNWA well. This recharge off the Schell Creek Range and the north end of the Snake Range, near Mt. Moriah, slows the drawdown expansion to the north.

After 1000 years, however, significant drawdown extends north of this line, especially on the west side of the valley (Figures 29 and 30). The drawdown under the mountains exceeds that in the valley; at the point where drawdown is 90 feet in the valley, the contour directly west in the Schell Creek Range is 140 feet. That is not the case everywhere in the valley. During the first 100 years of pumping, drawdown under the mountains is less than that in the valley, usually by more than 25 percent (Figures 22 through 26). However after 1000 years the drawdown under the mountains approaches that seen under the valleys, except as noted in the Schell Creek Range. The higher drawdown in the Schell Creek Range after a long time period is due to the proximity of SNWA pumping wells on the west side of the valley and to the slightly higher hydraulic conductivity in the bedrock in layer 2.

Ten-foot drawdown reaches the north end of the valley after 1000 years of pumping (Figures 29 and 30) as drawdown propagates from the south and from lower layers. Propagation of the effects upgradient into the north part of Spring Valley is slow because of the steepness of the valley. Drawdown in lower layers creates a vertical gradient which pulls water from the upper layers causing this drawdown. If the pumping had not exceeded recharge, the effects would not likely be observed in the north end of Spring Valley.

The drawdown determined in this study is very substantial, but is actually less than predicted by the U.S. Geological Survey. Schaeffer and Harrill (1995) found that pumping an earlier SNWA development proposal would result in 500 foot drawdown in both the valley fill and carbonate aquifers in southern Spring Valley.

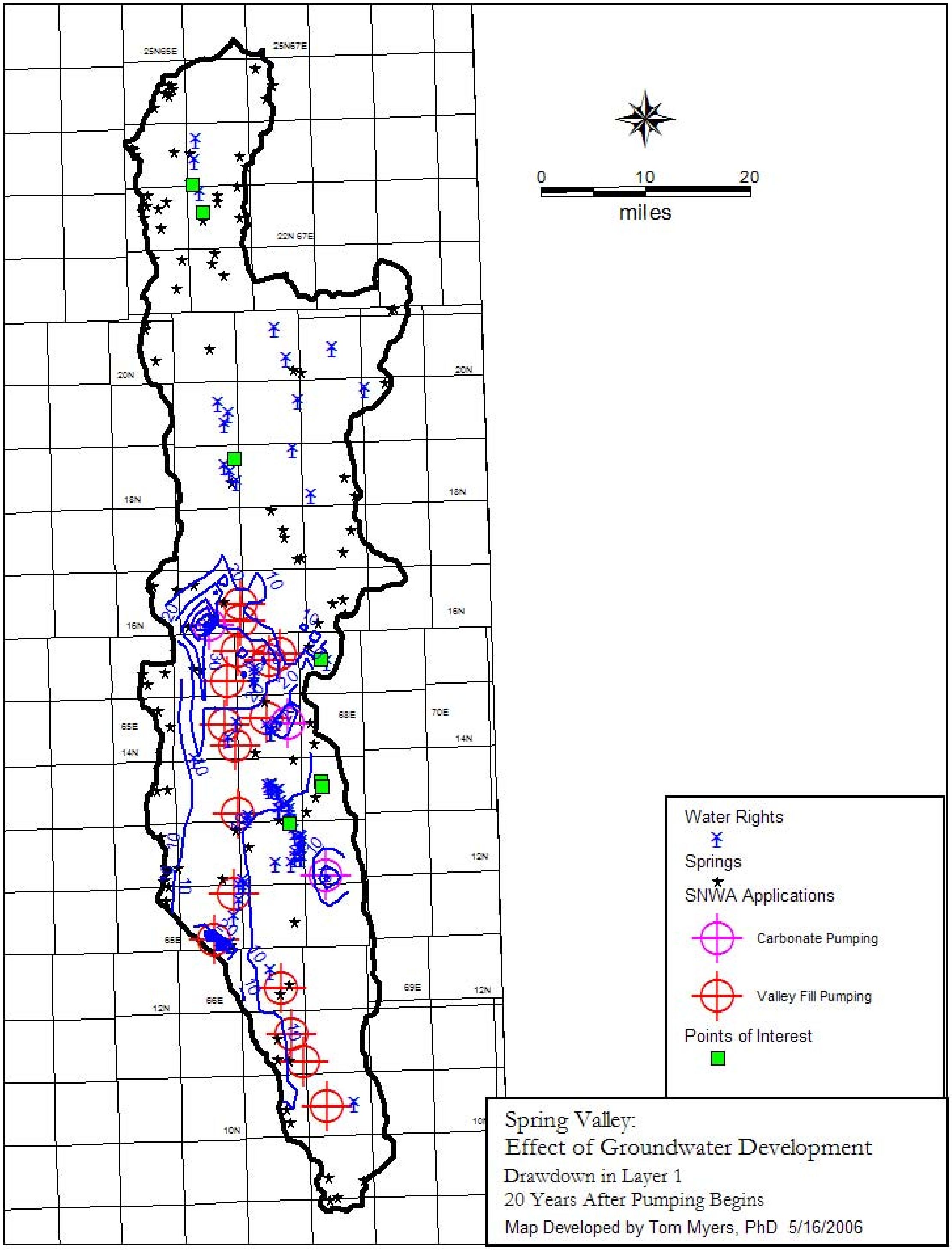

Figure 24: Effect of groundwater development in layer 1 after 20 years of pumping. See Figure 3 for Point of Interest labels.

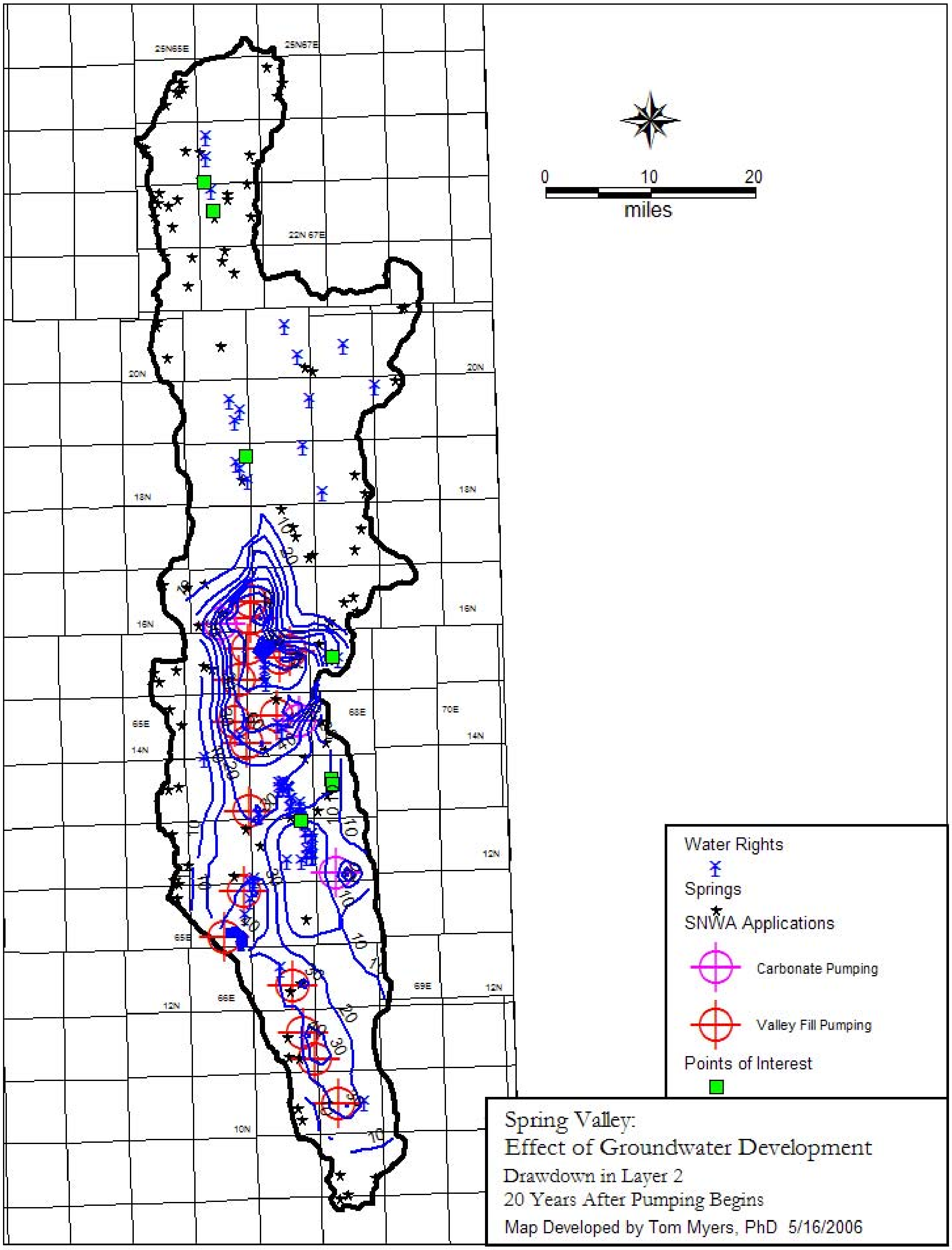

Figure 25: Effect of groundwater development in layer 2 after 20 years of pumping. See Figure 3 for Point of Interest labels.

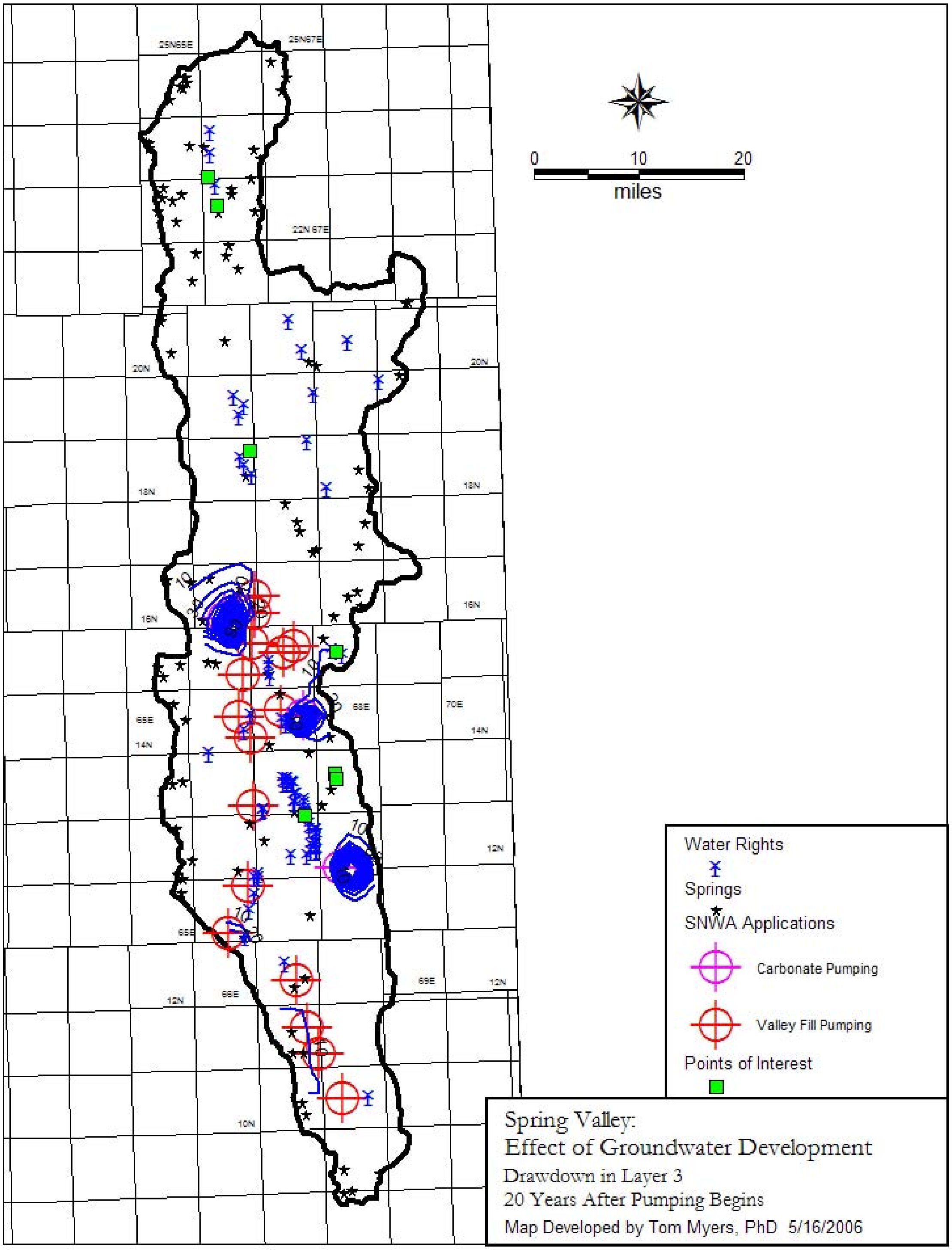

Figure 26: Effect of groundwater development in layer 3 after 20 years of pumping. See Figure 3 for Point of Interest labels.

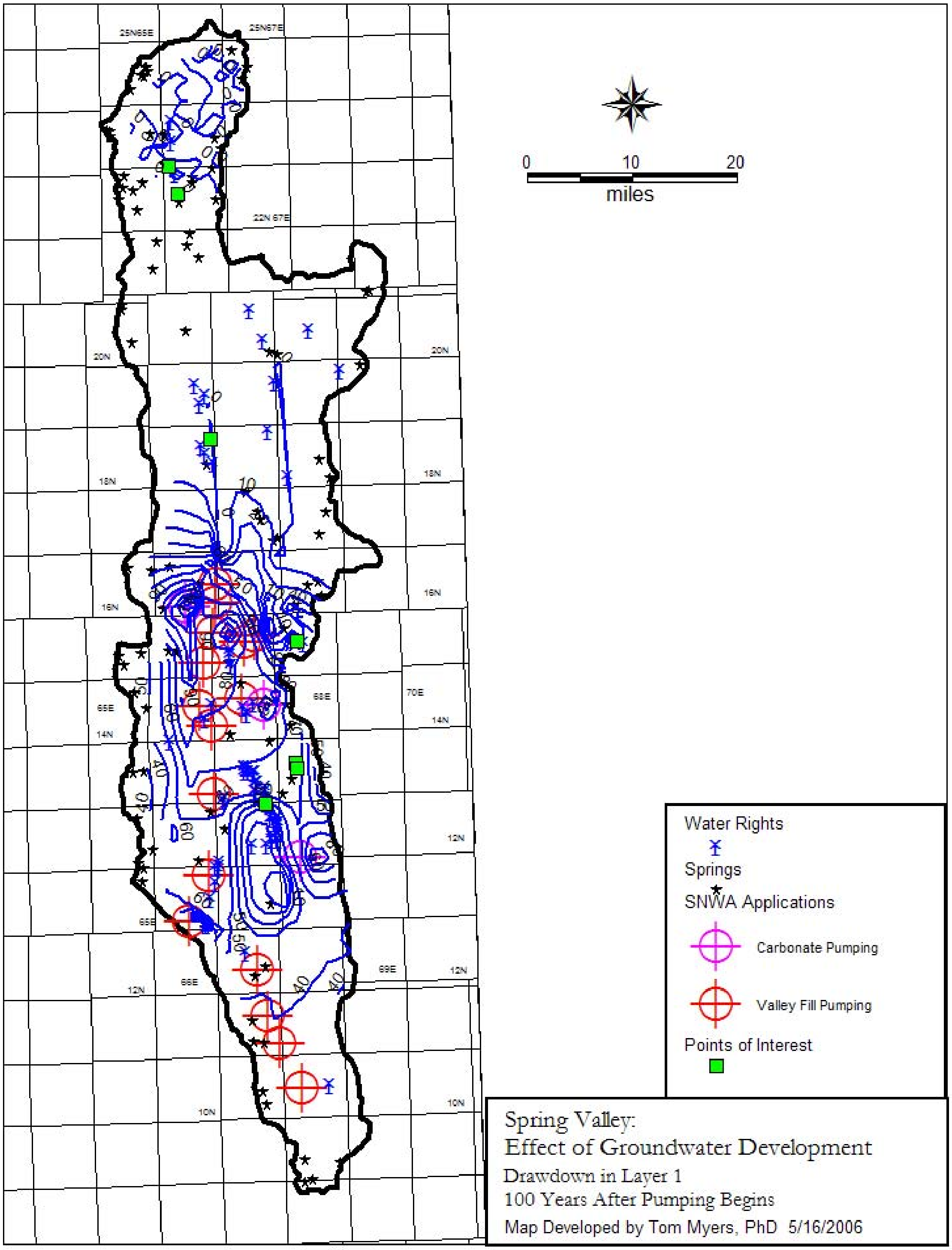

Figure 27: Effect of groundwater development in layer 1 after 100 years of pumping. See Figure 3 for Point of Interest labels.

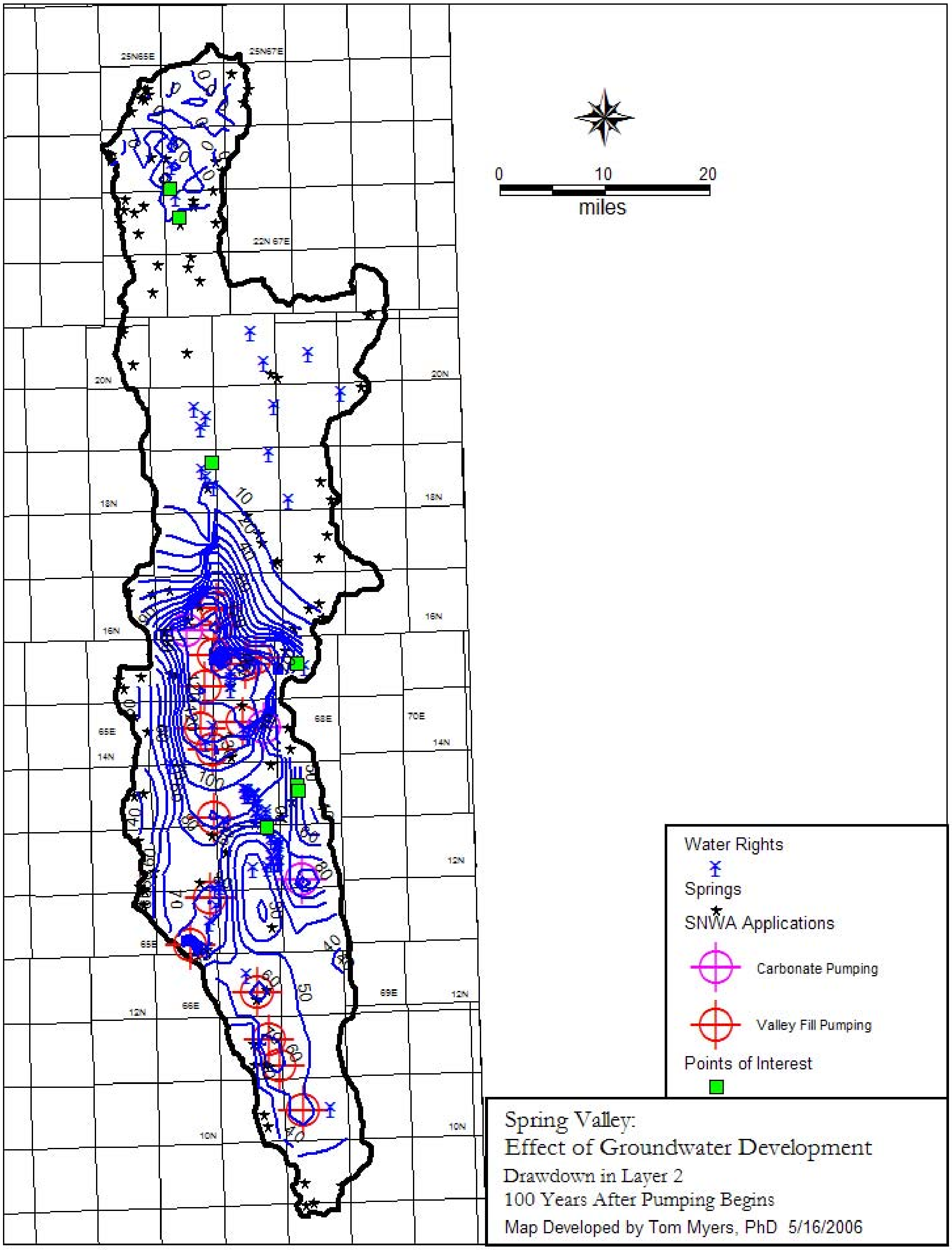

Figure 28: Effect of groundwater development in layer 2 after 100 years of pumping. See Figure 3 for Point of Interest labels.

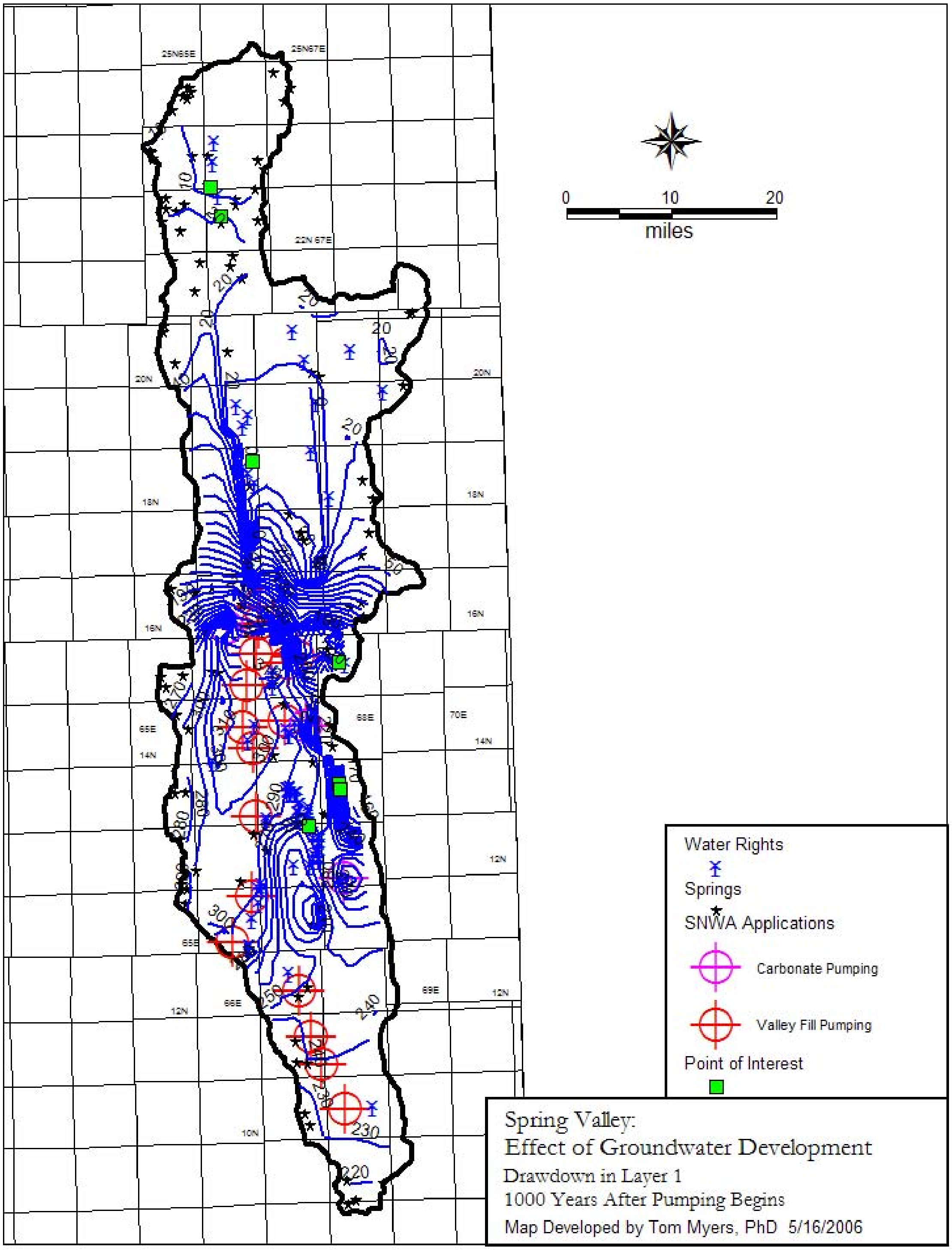

Figure 29: Effect of groundwater development in layer 1 after 1000 years of pumping. See Figure 3 for Point of Interest labels.

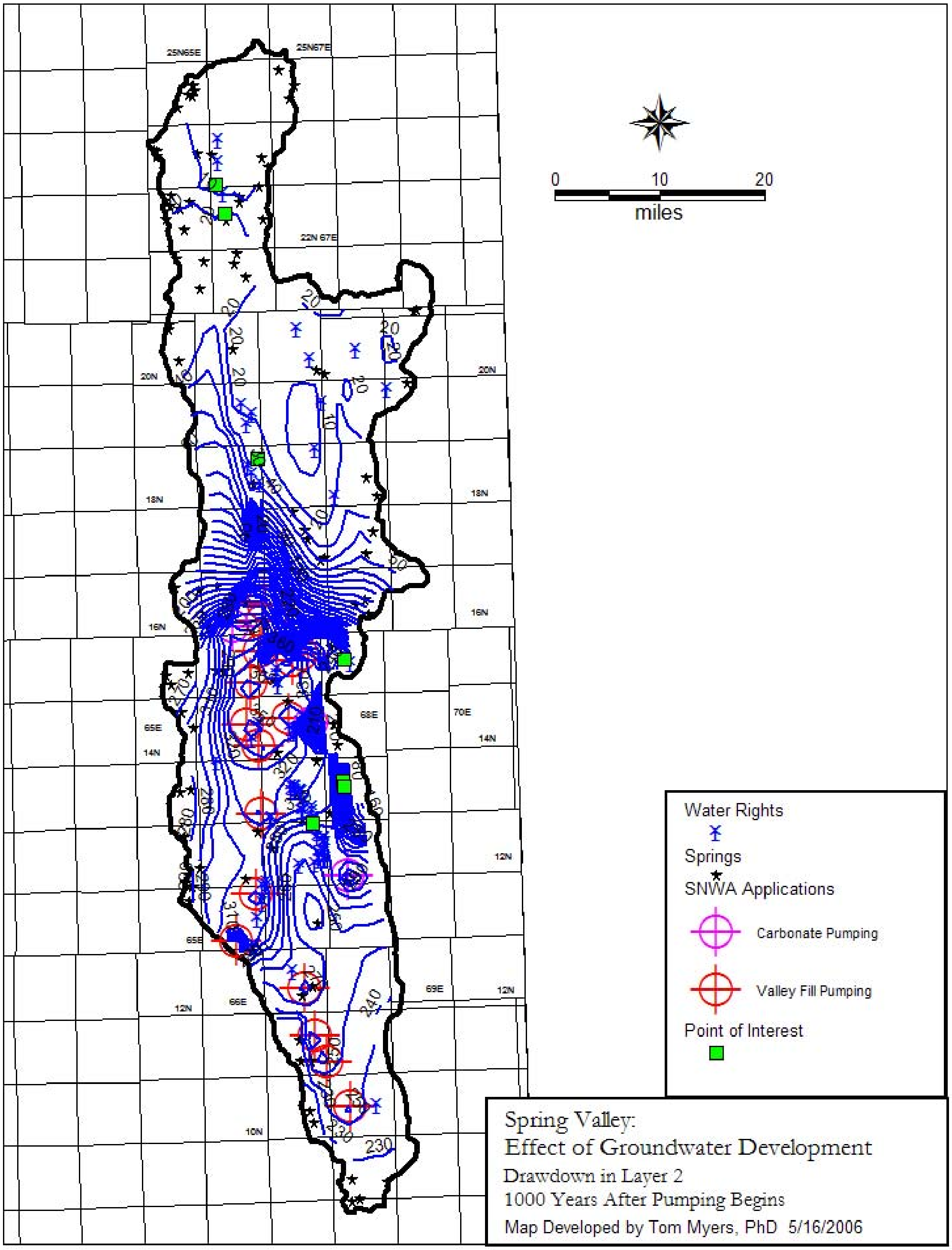

Figure 30: Effect of groundwater development in layer 2 after 1000 years of pumping. See Figure 3 for Point of Interest labels.

Recovery of the deficit created by 1000 years of pumping also is slow (Figures 31 through 34). One hundred years after pumping ceases, drawdown in the central part of the valley still exceeds 200 feet primarily because of the extent of the drawdown after 1000 years of pumping. There was a large area with 300 feet or more drawdown which indicates a huge deficit exists after 1000 years of pumping. Drawdown under the northern mountains recovers little but water levels in the valley fill have largely recovered. As the level recovers in the north, which occurs quicker than further south in the valley because there is less deficit and higher recharge, the discharge to ET and spring flows prevents recharge in the north from reaching the deficit in the south. This reflects the general flow path from the mountain tops to the center of the valley; the ET boundary discharges the flow and can only do so once the water level recovers to within 20 feet of the ground surface.

The drawdown significantly affects the flux within the valley as well. ET drops by over two-thirds in 1000 years of pumping, but about 80 percent of that decrease occurs within the first 100 years (Figure 35). Once water level falls below the extinction depth, as it does over parts of the valley, ET cannot continue to decrease. Flow to the spring boundaries decreased by about three-fifths as well with most of the decrease occurring within the first 100 years (Figure 35). Two of the four spring boundaries go completely dry within 100 years (Figure 36). Very significant decreases, exceeding 20 percent, occur within 20 years.

Flow to the southeast to Hamlin Valley drops to zero and reverses so that the pumping draws water from another valley (Figure 35). Due to the location of pumping wells in southeast Spring Valley, the pumping reverses the minor interbasin flow from Spring Valley and draws from Hamlin Valley. The point of interbasin flow lies where there is little recharge to quickly replenish the water level. The flow to Hamlin Valley recovers slowly, reaching just 64 percent of its pre-development value after 1000 years of recovery (Figure 35). Over the 2000 year simulation period, approximately 2,470,000 af less water flows to Hamlin Valley. After just 20 years, the cumulative flow has reduced by 1878 af. This shows that the pumping proposed by SNWA will cause a significant deficit in two or more valleys including Hamlin Valley and potentially Snake Valley. Elliot et al (2006) indicate that pumping in Spring Valley may affect Big Springs in Snake Valley, therefore their study supports the results of the modeling presented herein.

A difference in groundwater level between layer 1 and 2 of up to 50 feet develops with time as shown in the water level hydrographs in the central and southern part of Spring Valley (Figures 37 and 38). In the central part of Spring Valley, the head in layer 2 began the simulation higher than in layer 1 by about 10 feet. This reflects the upward gradient observed in the steady state gradient. The gradient direction reversed over the 1000 years of pumping due to the groundwater being withdrawn from layer 2 which establishes a gradient. The relatively high vertical anisotropy slows the propagation of drawdown to the surface. In the north part of the valley, the gradient began the simulation in an upward direction, but the magnitude was only a few feet. Because there was no pumping that far north, the gradient does not reverse. Because of the lack of pumping and high recharge in the north, the head drops in both layers by only about 30 feet (Figure 39). However the flux values, as shown above, decrease because a 30 foot head drop still lowers the head below bottom of the extinction depth. The extinction depth is the maximum depth from which water may be drawn for discharge as ET.

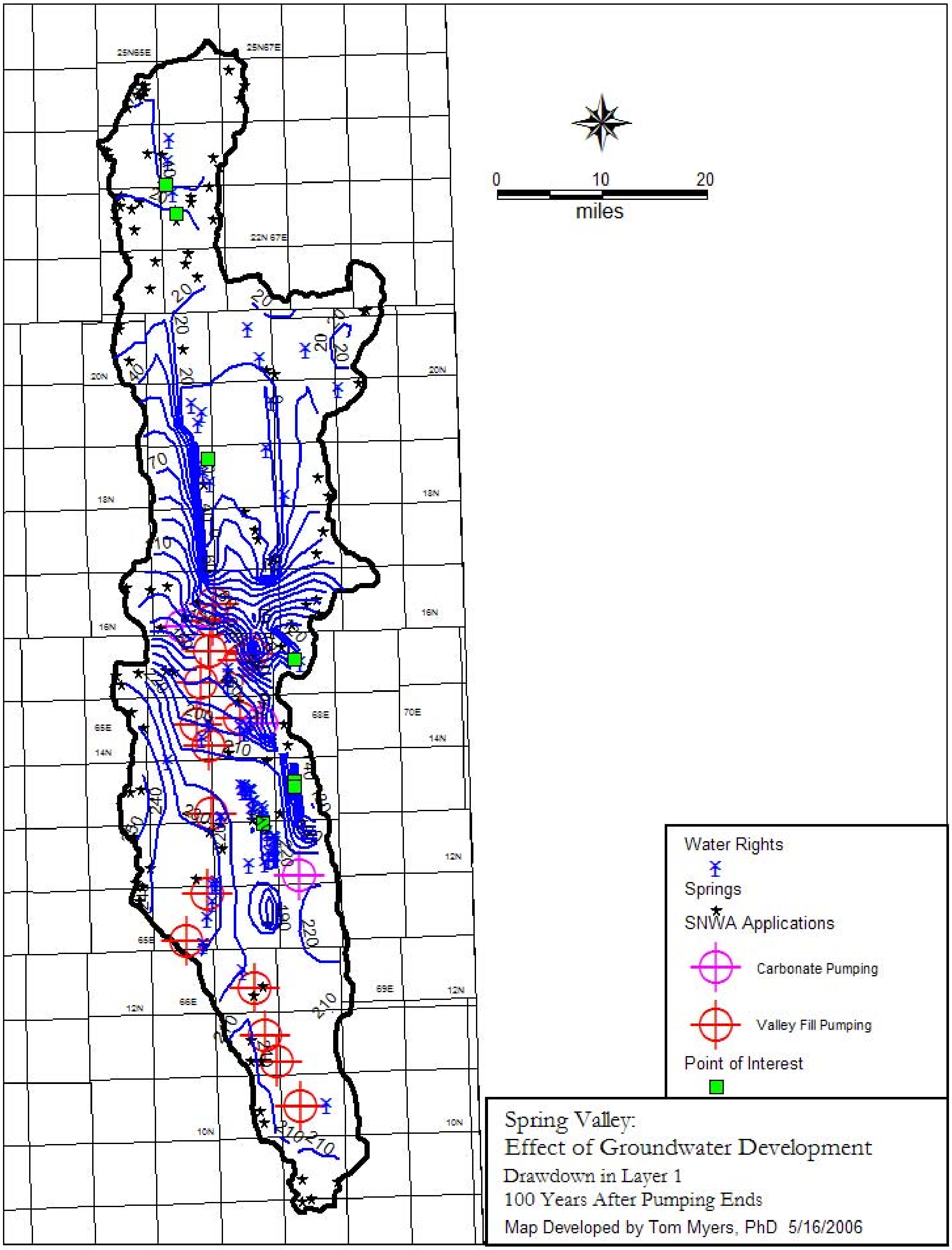

Figure 31: Effect of groundwater development in layer 1 100 years after pumping ceases. See Figure 3 for Point of Interest labels.

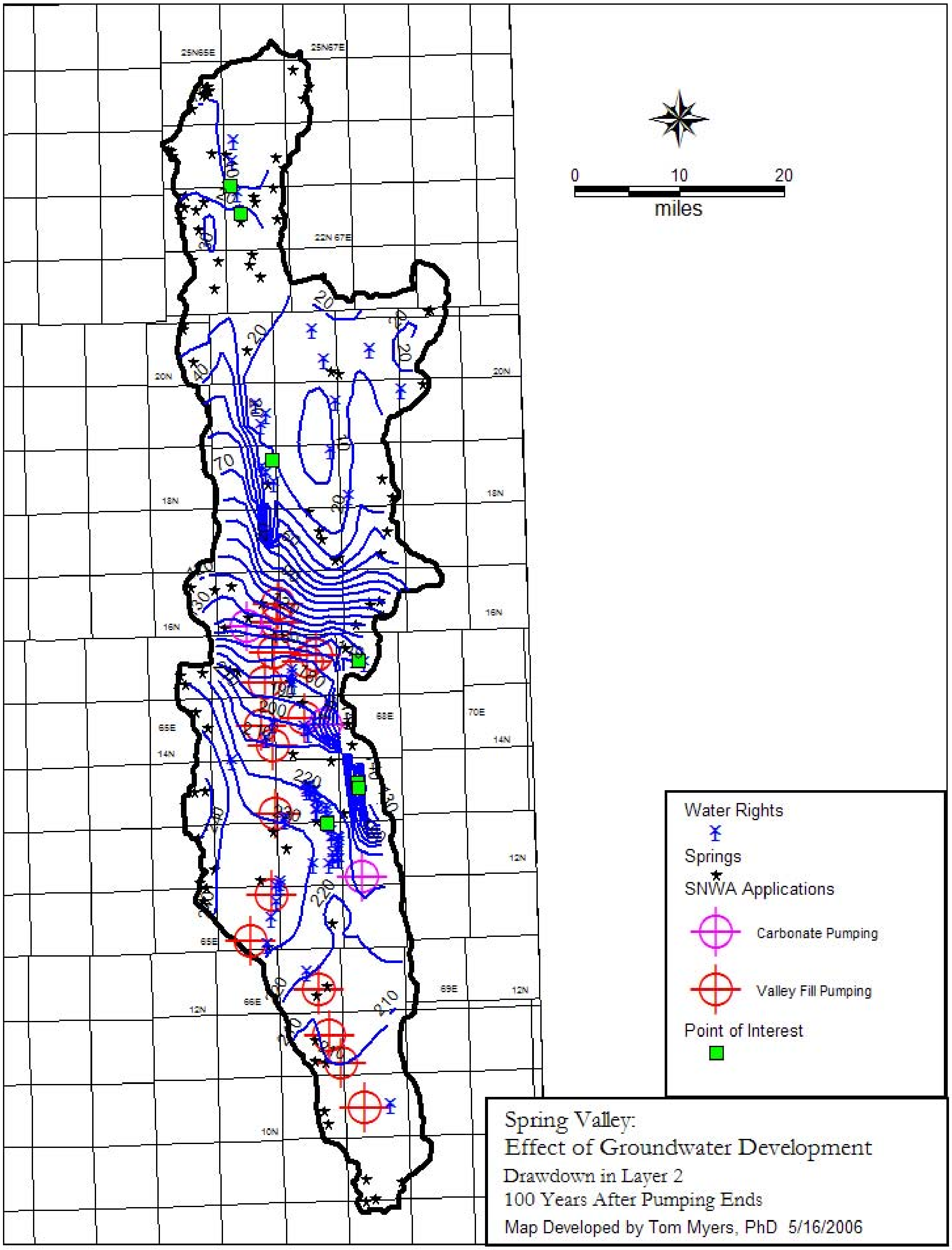

Figure 32: Effect of groundwater development in layer 2 100 years after pumping ceases. See Figure 3 for Point of Interest labels.

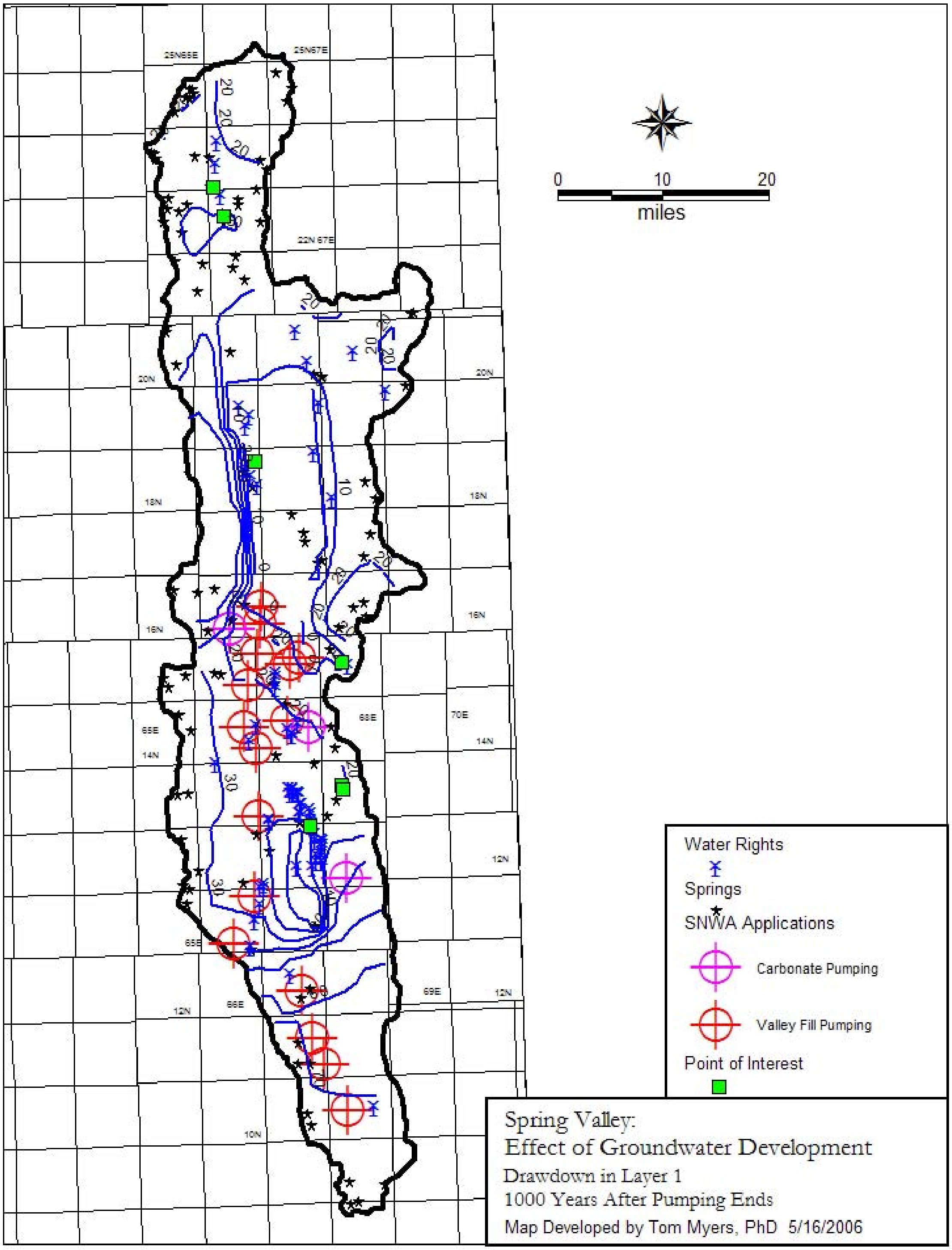

Figure 33: Effect of groundwater development in layer 1 1000 years after pumping ceases. See Figure 3 for Point of Interest labels.

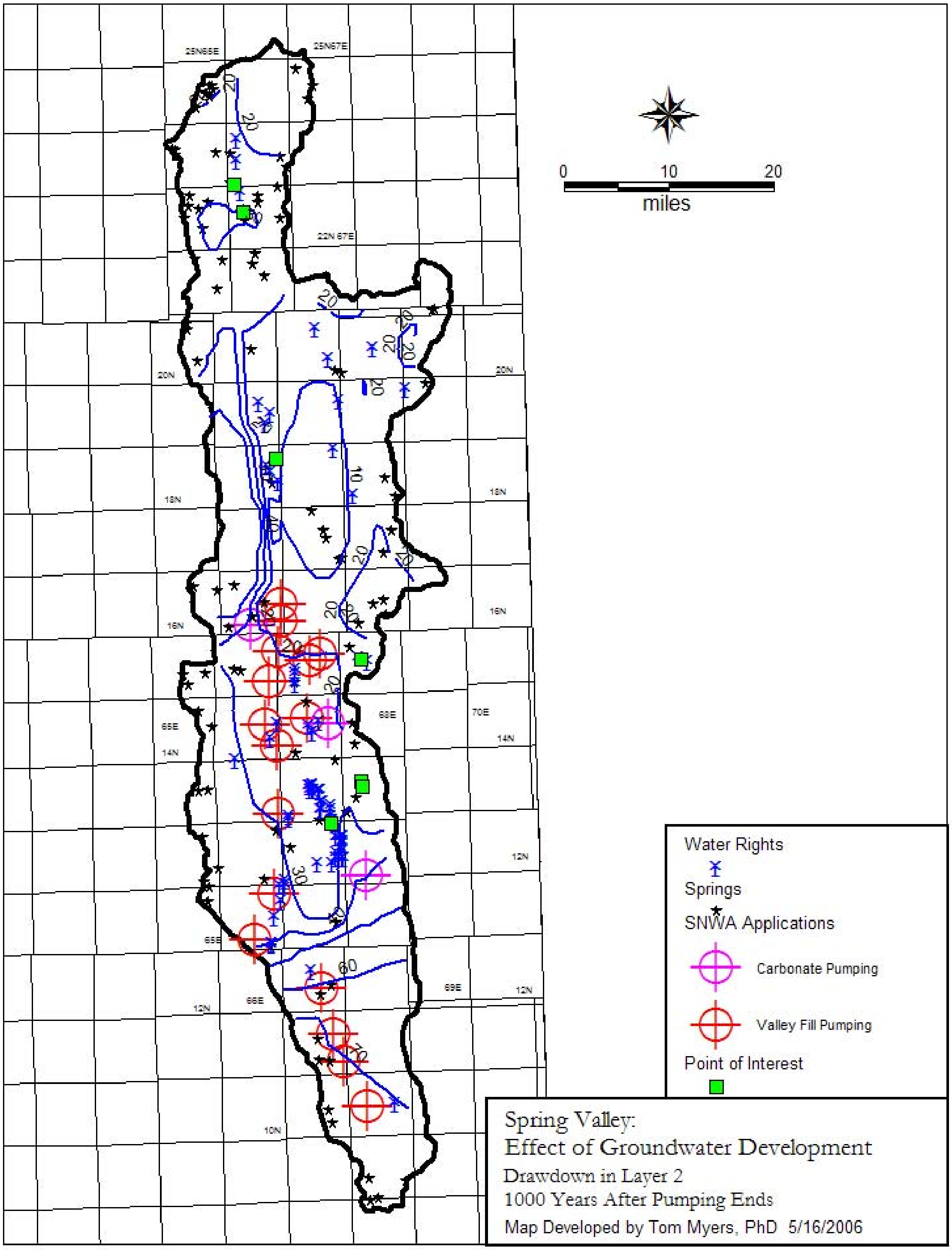

Figure 34: Effect of groundwater development in layer 2 1000 years after pumping ceases. See Figure 3 for Point of Interest labels.

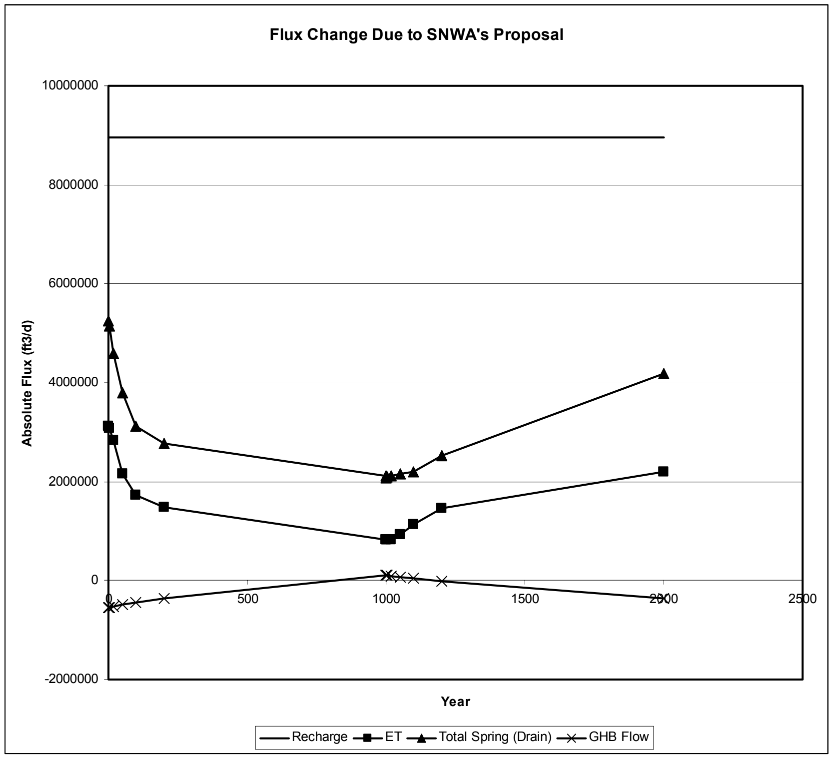

Figure 35: Changes in flux due to groundwater development in Spring Valley.

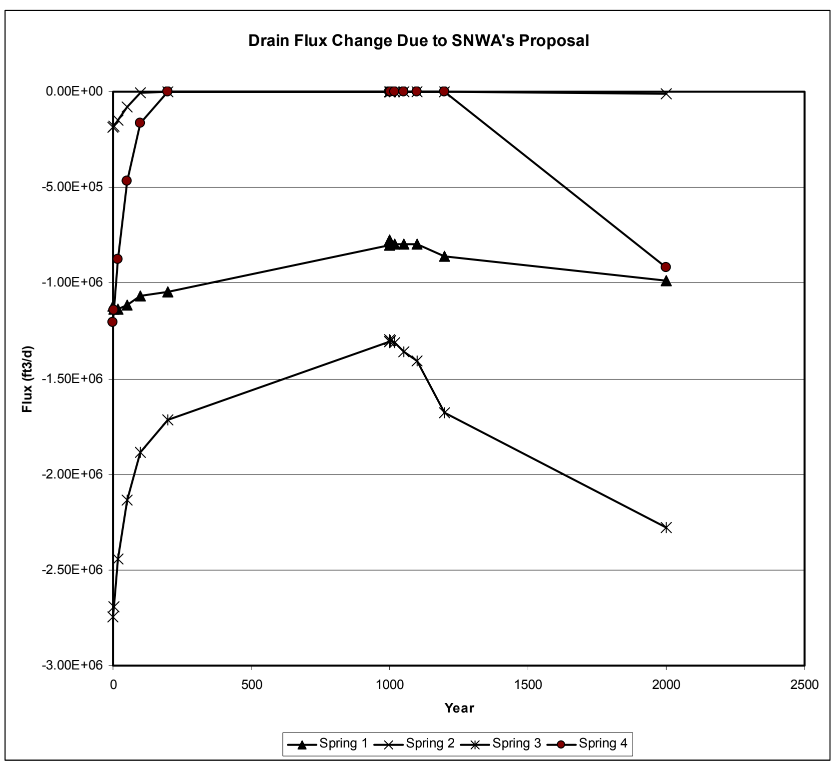

Figure 36: Change in spring flux due to groundwater development in Spring Valley. The numbers refer to the model reach number.

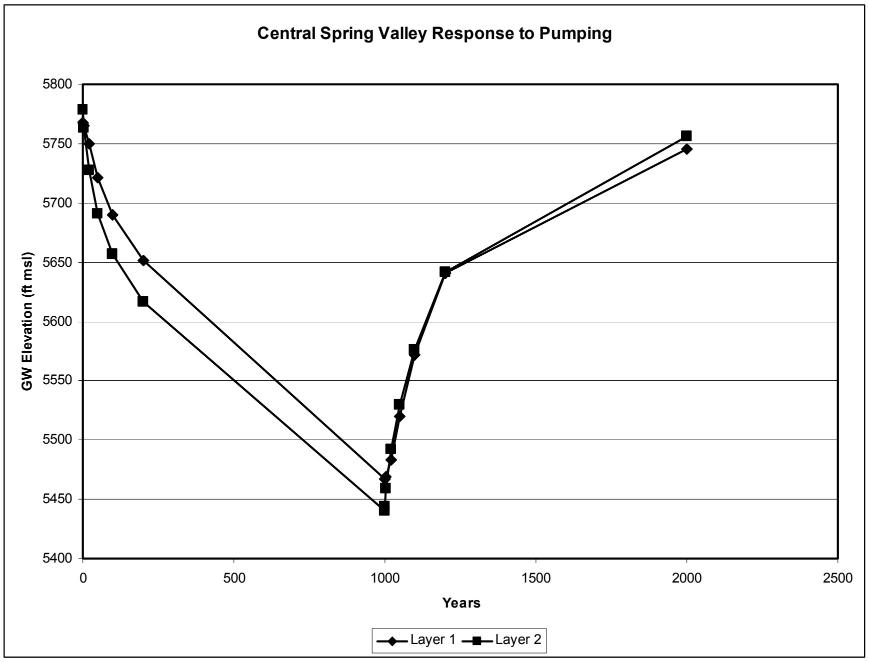

Figure 37: Groundwater surface elevation in layers 1 and 2 at a point in the center of Spring Valley.

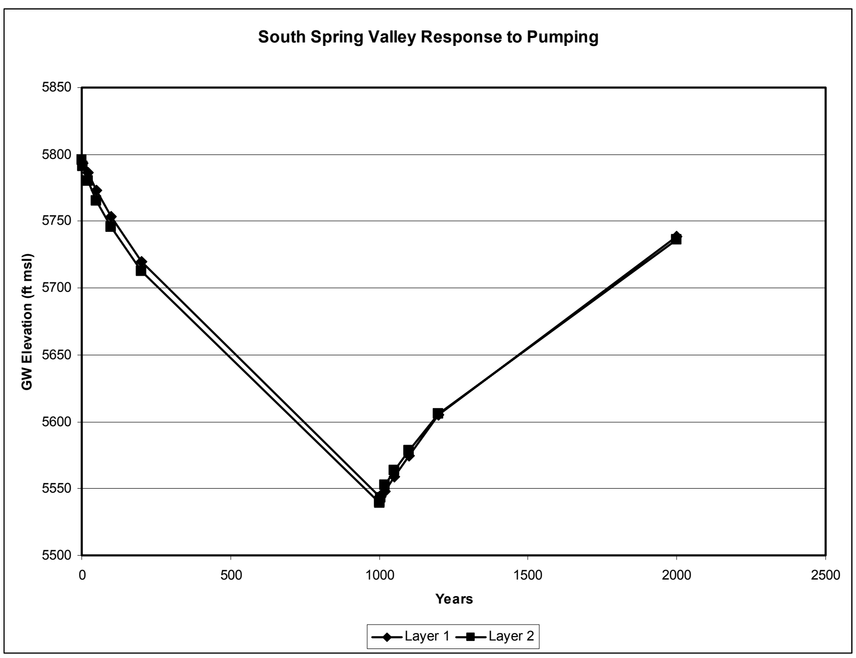

Figure 38: Groundwater surface elevation in layers 1 and 2 at a point in the south part of Spring Valley.

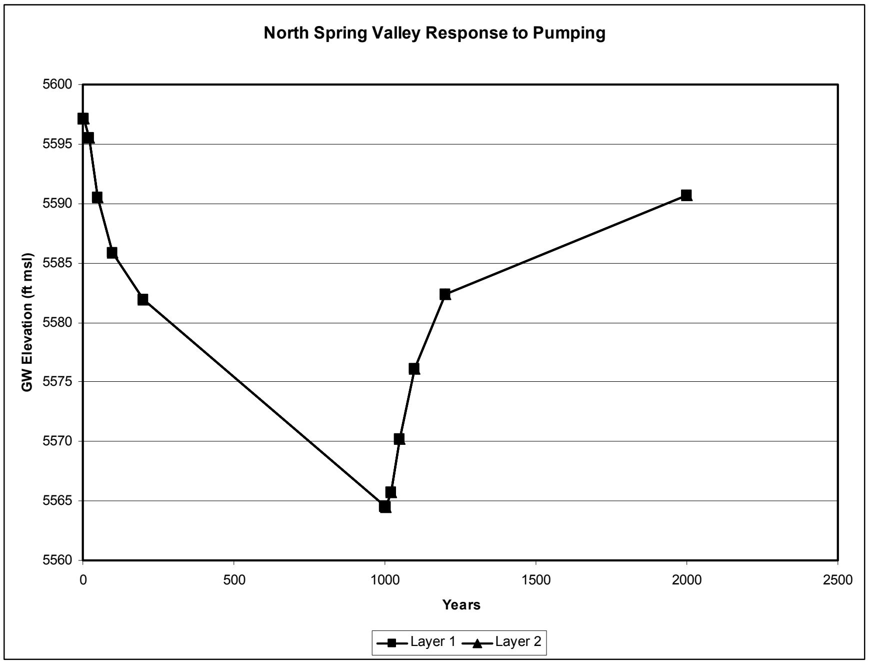

Figure 39: Groundwater surface elevation in layers 1 and 2 at a point in the north part of Spring Valley.

An alternative means to consider the growing effect of the pumping is to plot on a map a time series of a specific drawdown contour. After 20 years, 20-foot drawdown affects just a couple of townships within the center of the valley (Figure 40). After 100 years the 20-foot drawdown covers most of the south part of the valley. The small circular 100-year 20-foot contour in the southern portion of the valley actually is a region where the drawdown becomes less than 20 feet due to the area being an ET discharge point. That zone disappears after 1000 years, but the 20-foot drawdown expands only about 2 more miles north in the valley. The 20-foot drawdown expands north under the mountains as discussed above.

Affected Underground Water Rights

Lowering the water table near a well will increase the pumping head necessary to use water from that well. Most of the wells in Spring Valley are relatively shallow, although some are as much as 1000 feet deep. A 20 foot water level drop in a shallow well may cause it to go dry or at least have a pumping lift that proportionally is much higher than experienced before the level dropped. For this analysis, all wells that have a 20 foot water level drop have been identified because drawdown exceeding this amount significantly affects the use of the well. Of the 73 UG water rights mapped in Figure 41, 53, or 73 percent of the total, lie within the 20-foot drawdown projected after 100 years of pumping. Table 13 lists the affected wells.

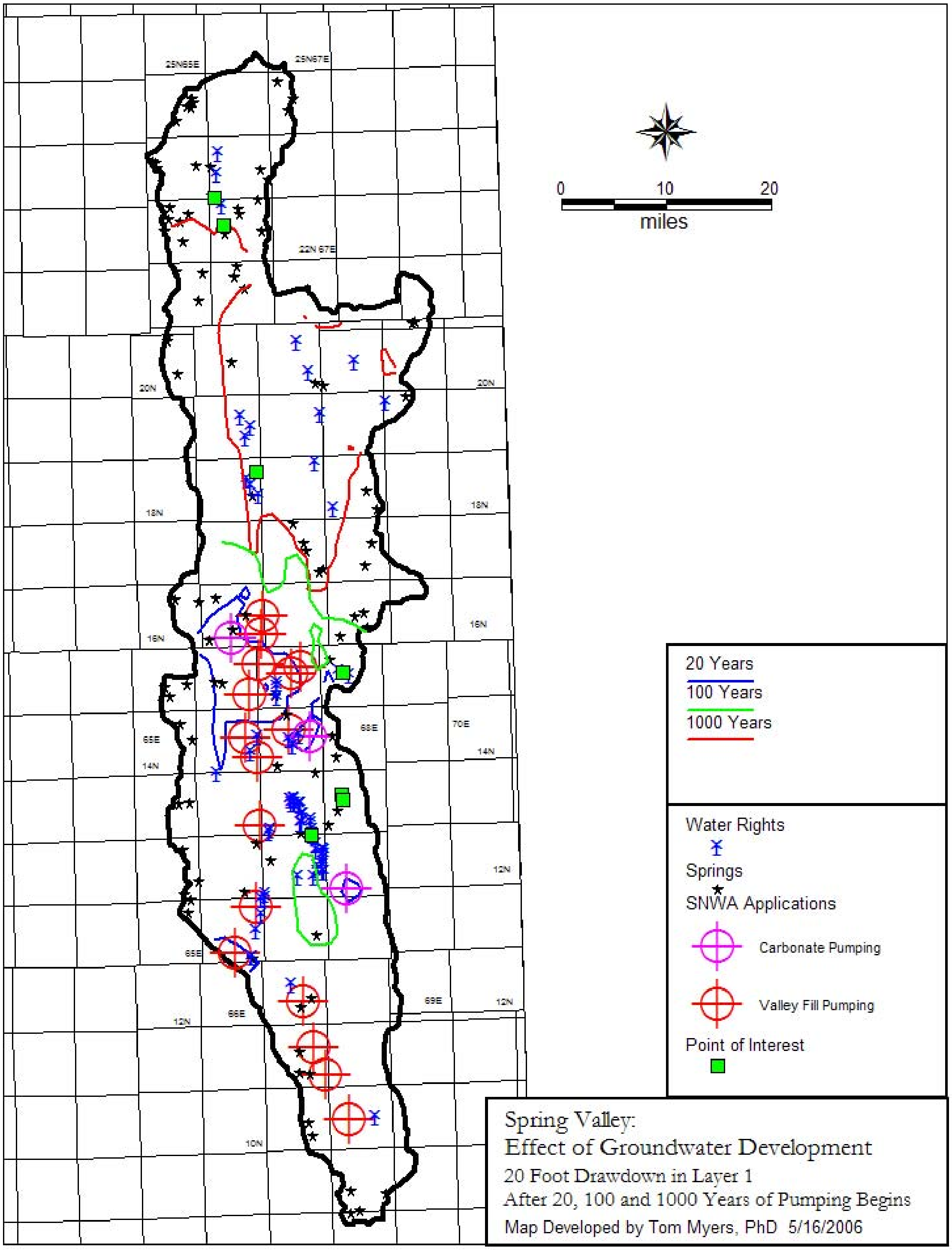

Figure 40: The expansion of the 20-foot layer 1 drawdown cone with time. See Figure 3 for Point of Interest labels.

Table 13 : Underground water rights affect by a 20 foot drawdown after 100 years of pumping.

Application	Status	Irrigated Acres	Annual Duty	Unit	Water Use	Owner of Record
1367	CER	0	8.88	MGS	STK	NV Land and Resource
7446	CER	0	4.38	MGA	STK	Production Credit Corp of Berkeley
7497	CER	0	1.75	MGA	STK	Huntsman Ranch Limited liability
8074	CER	0	8.7	MGS	STK	NV Land and Resource
8075	CER	0	5.84	MGS	STK	Adams McGill Co.
8077	CER	0	8.8	MGS	STK	Robison, Doyle G.
8713	CER	0	3.07	MGA	STK	Swallow, George M.
10020	CER	0.3	1.2	AFA	IRR	Swallow, Richard
12467	CER	0	23.58	MGA	MM	Minerva Scheelite
16890	CER	0	23.58	MGA	QM	Pierce, L.L
18043	CER	0	1.46	MGA	IRR	NV Land and Resource
18044	CER	0	1.46	MGA	STK	NV Land and Resource
18045	CER	0	2.92	MGA	STK	NV Land and Resource
18525	CER	14.46	57.84	AFS	IRR	Phillips, Anita
18827	CER	448	544.33	AFS	IRR	Huntsman Ranch Limited Liability
18828	CER	0	1.46	MGA	STK	Huntsman Ranch Limited Liability
18829	CER	0	1.46	MGA	STK	Huntsman Ranch Limited Liability
18841	CER	0	2.92	MGA	STK	NV Land and Resource
18842	CER	0	2.92	MGA	STK	NV Land and Resource Co.
18843	CER	0	2.92	MGA	STK	NV Land and Resource
19654	CER	143.96	575.83	AFA	IRR	Rhodes, Ursel C.
20817	CER	160	640	AFA	IRR	Harbecke, Fern A.
22645	CER	15	60	AFA	IRR	Bransford, Robert M.
25439	CER	60	240	AFA	IRR	Rhodes, Ursel
25679	CER	157.56	630.24	AFA	IRR	Phillips, Anita
25680	CER	157.56	630.24	AFA	IRR	Phillips, Anita
26228	CER	59.75	239	AFA	IRR	Harbecke, Fern A.
26229	CER	39.42	157.68	AFA	IRR	Harbecke, Robert L.
26502	CER	18.37	73.48	AFA	IRR	Rasmussen, James B.
26546	CER	39.42	157.68	AFA	IRR	Harbecke, Fern A.
26952	CER	59.75	239	AFA	IRR	Harbecke, Fern A.
27768	CER	0	6.52	MGA	WLD	NDOW
29219	CER	390.28	1561.12	AFA	IRR	Cache Valley Syndicate Trust
29220	CER	390.28	1367.97	AFA	IRR	Cache Valley Syndicate Trust
29221	CER	390.28	1049.76	AFA	IRR	Cache Valley Syndicate Trust
29371	CER	0	261.7	MGA	MM	Golden Eagle Mining
29567	CER	0	228.07	MGA	MM	Golden Eagle Mining
30319	CER	211.7	730.73	AFS	IRR	Phillips, Anita D.
31239	CER	0	57.816	MGA	MM	Mitchell, Richard
34727	CER	201.19	804.78	AFA	IRR	Harbecke, Fern A.
38972	CER	192.12	768.48	AFA	IRR	El Tejon Cattle Co.
39455	CER	0	4.72	MGA	STK	Huntsman Ranch Limited Liability
45287	CER	78.2	318.2	AFA	IRR	Bransford, Robert M.
45496	CER	0	28.1	MGA	STK	Okelberry, Ray
58134	PER	0	2.47	MGA	STK	BLM
58302	PER	0	98.55	MGA	MM	Minel, Inc.

Table 13 continued

60104	CER	0	0.73	MGA	STK	Harbecke, R.L. and Fern
63531	PER	0	544.33	AFS	IRR	Huntsman Ranch
65641	PER	0	0.73	MGA	QM	Fava, Paul D.
67886	PER	0	0	AFA	IRR	Huntsman Ranch
67887	PER	0	0	AFA	IRR	Huntsman Ranch
69316	PER	0	1080	AFA	IRR	Harbecke, Robert L. and Fern
72643	PER	0	4.04	AFA	QM	Gianoli, John and Julie

Affected Springs and Surface Water Flows

Groundwater supports the springs and the baseflow in streams in Spring Valley. Springs in valley fill occur where the water table intersects the ground surface. If the water table drops below the ground surface, the spring will no longer discharge. A drawdown of as little as 1 foot will cause discharge to a spring to cease.

As shown above, drawdown eventually covers the entire valley. After 100 years only the far northern portion of the valley is unaffected. The baseflow of all of the springs will be eliminated within 1000 years and will be almost eliminated within 100 years. During wet seasons and years, because of fluctuations in the water level and local effects, it is possible that discharge will still occur. Most springs and their associated wetlands will eventually go dry if this proposal goes forward as proposed. Elliot et al (2006) confirm this conclusion. "Large-scale ground-water withdrawals in the valleys likely would affect the discharge of the springs on the southeast and west sides of the southern Snake Range, and streamflow along Big Springs Creek and Lake Creek" (Elliot et al 2006, page 44).

Baseflow in streams between the mountain front and the playa could also be affected by the drawdown because it extends to and under the mountain front. Elliot et al (2006) reported the same potential impacts by identifying Shingle Creek, draining from the Snake Range, as potentially being affected by pumping in Spring Valley. Essentially all of the surface water rights that are for season-long or year-long pumping periods would also be affected.

Several points of special interest occur in Spring Valley due to special status species or stands of rare Rocky Mountain junipers. Dr. Jim Deacon provided Table A-2 which lists the special status species and provides their coordinates which are plotted in Figure 3. Groundwater development will lower the groundwater level at all of the points, but the shape of the hydrograph depends on the distance from the pumping wells (Figure 41). Most affected will be wells at Shoshone Ponds, cedars near Shoshone ponds, and springs on Sacramento Pass. The groundwater level drops 3 and 8 feet, respectively, within 20 years of pumping at Shoshone Ponds and Sacramento Pass. At Shoshone Ponds, groundwater drawdown increases to 47 and 87 feet, respectively, after 100 and 200 years. At Sacramento Pass the water levels drop 185 feet in 1000 years. These sites will likely be affected within 20 years. The flowing well at Shoshone Ponds may experience more drawdown than shown because the pressure is from a relatively deep well and the drawdown is due to pumping in model layer 2 propagating to layer 1 (Figure 41).

Other targets for R solitarius (targets 1, 2 or 3) lie in the north part of the valley (Figure 3). Drawdown affects targets 2 and 3, but much more slowly because of the slow expansion of drawdown north. Water levels at those two targets do not drop within 200 years, but between 200 and 1000 years of pumping drop 22 and 8 feet, respectively. The end of pumping does allow the water levels to begin recovering at these targets in the north end of the valley because water flows southward to replenish deficits. The water level at target 3 drops an additional 15 feet during the 1000 year recovery level; the water level at target 3 has not yet begun to recover after 1000 years. Target 1 is barely affected because it is near a recharge point.

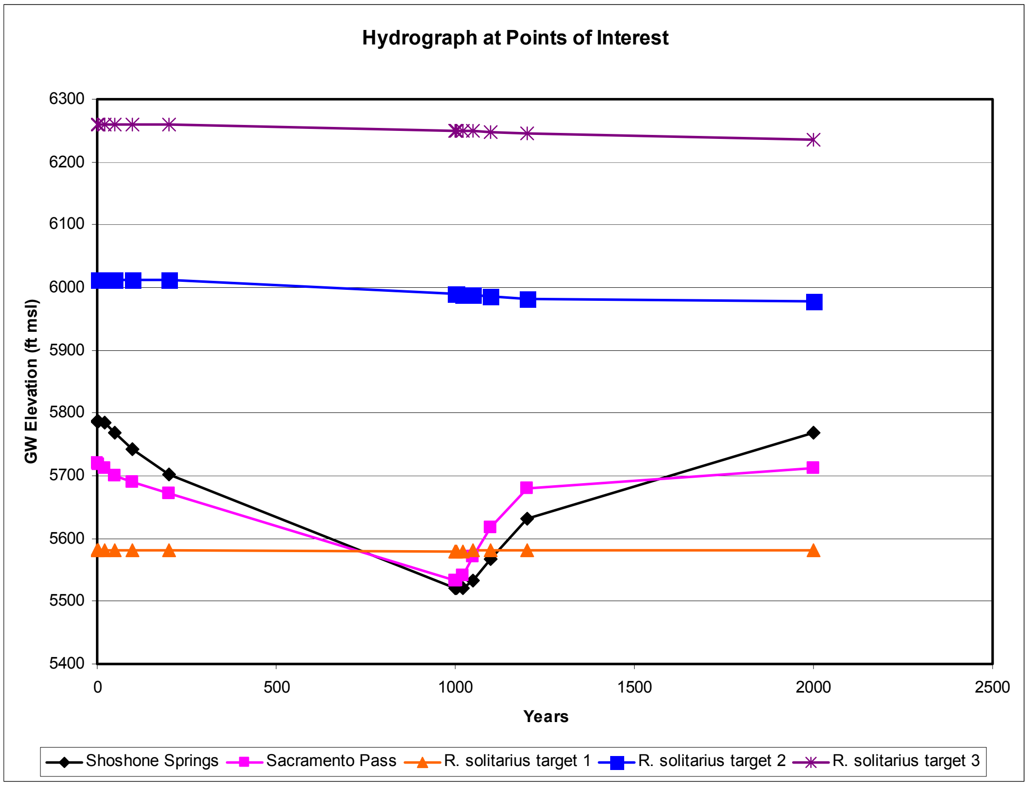

Figure 41: Water levels in layer 1 at Shoshone Springs and the Cedars. The drawdown maps all show the drawdown contours near the points of interest.

Hydrographs for sites represented by O clarkia utah have not been presented because these sites lie above the water level modeled in the bedrock aquifer in the Snake Range (Prudic et al 1995). The model developed herein does not specifically include a connection with the groundwater supporting these sites but it also does not rule out an impact. It should be noted that Elliot et al (2006) indicate that several streams draining the west side of the Snake Range. "On the west side of the southern Snake Range, likely susceptible areas also are outside of the park boundary, and limited to streams on the alluvial slopes between the mountain front and where water is diverted into pipelines including Shingle, Pine, and Ridge Creeks and Williams Canyon (Elliot et al 2006, page 43). The points referred to by Elliot et al are within the drawdown cones found in this report within valley fill near the Snake Range (layers 1 and 2 on the east side of the model domain).

Valuable spring resources outside of Spring Valley could also be affected. Although the groundwater modeling conducted herein used the crest of the Snake Range as a boundary because the intrusive core of the range is considered to be impermeable, it is possible that substantial stresses induced by massive pumping could propagate into Snake Valley due to faulting and the mixture of geology at the south end of Snake Range. The USGS concluded that pumping in the Spring and Snake Valley could affect the flow at Big Springs which is thought to be substantially derived from the carbonate aquifer (Elliot et al 2006). Stresses from Spring Valley could possibly propagate through the southern Snake Range at faults or fractures and affect the flow at Big Springs.

Monitoring and Mitigation

SNWA may propose a monitoring and mitigation plan (M&M) to support its applications. Without seeing the details of this plan, it is not possible to model it. However, the model developed in this report can be used to examine how long would be required to recover from a shorter pumping period. This is useful because the idea behind an M&M plan is that once negative impacts are seen, the pumping will stop to allow recovery to begin and avoid further negative impacts. This study considers the time for recovery if SNWA pumped for 100 years and then turned off the wells.

A time series of drawdown maps (Figures 43 through 45) shows that recovery is slow. The extent of drawdown after 10 to 65 years of recovery changes very little from that existing at the end of 100 years of pumping (Figures 42-44 and Figures 27 and 28). Only the drawdown magnitude in the middle of the valley near the middle of the well field decreases. Drawdown magnitude continues to expand to the north for a while after pumping ceases.

The fluxes also recover slowly (Figure 45). ET recovery reflects the recovery of groundwater levels around the valley; ET flux recovers more slowly than it decreased. The ET continues to drop for up to ten years after pumping stops as the drawdown expands slightly. The recovery after this time is slow because ET does not change due to recovery of water levels drawn below the extinction depth. Even after 1000 years, the ET remains 2 percent less than before pumping began. Spring flow also continues to decrease for a year after pumping ceases and the lower magnitude continues for at least 10 years. Spring flow recovery is slightly faster than for ET because just a small recovery on the margin of the drawdown cone allows discharge to the drain cells. After 1000 years, the spring discharge is still 1 percent less than prior to pumping. Flow to Hamlin Valley also remains almost 3 percent less than that before pumping.

It is also likely that recovery from even shorter pumping periods would also be slow and there would be a continued expansion of drawdown for a period while groundwater flows toward the area of deficit from points further away in the valley.

The conclusion from modeling recovery from a short time period is that M&M plans would not likely work unless they are designed that mitigation begins immediately at the onset of drawdown a long distance from the resources intended to be protected.

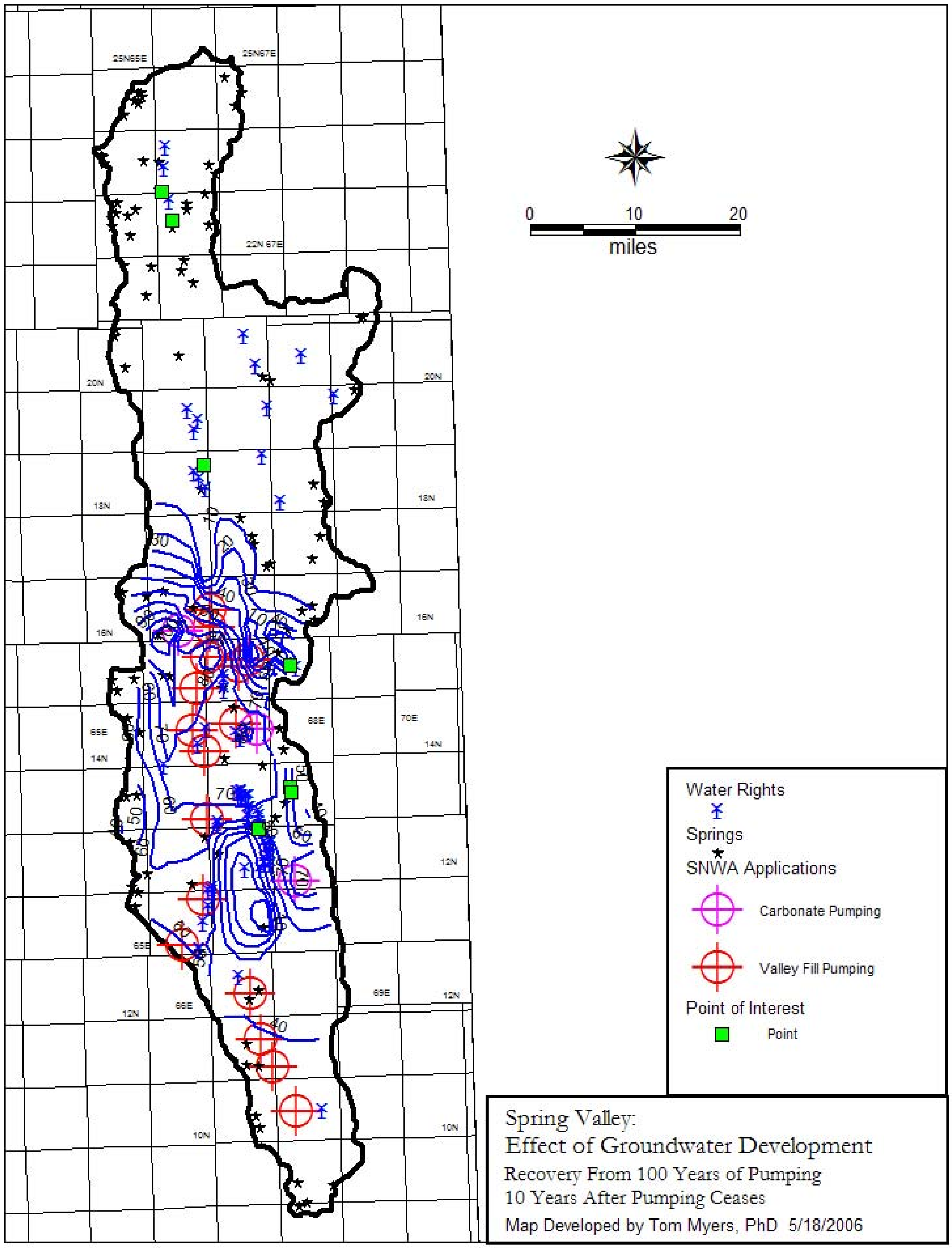

Figure 42: Drawdown contours 10 years after the cessation of 100 years of pumping. See Figure 3 for Point of Interest labels.

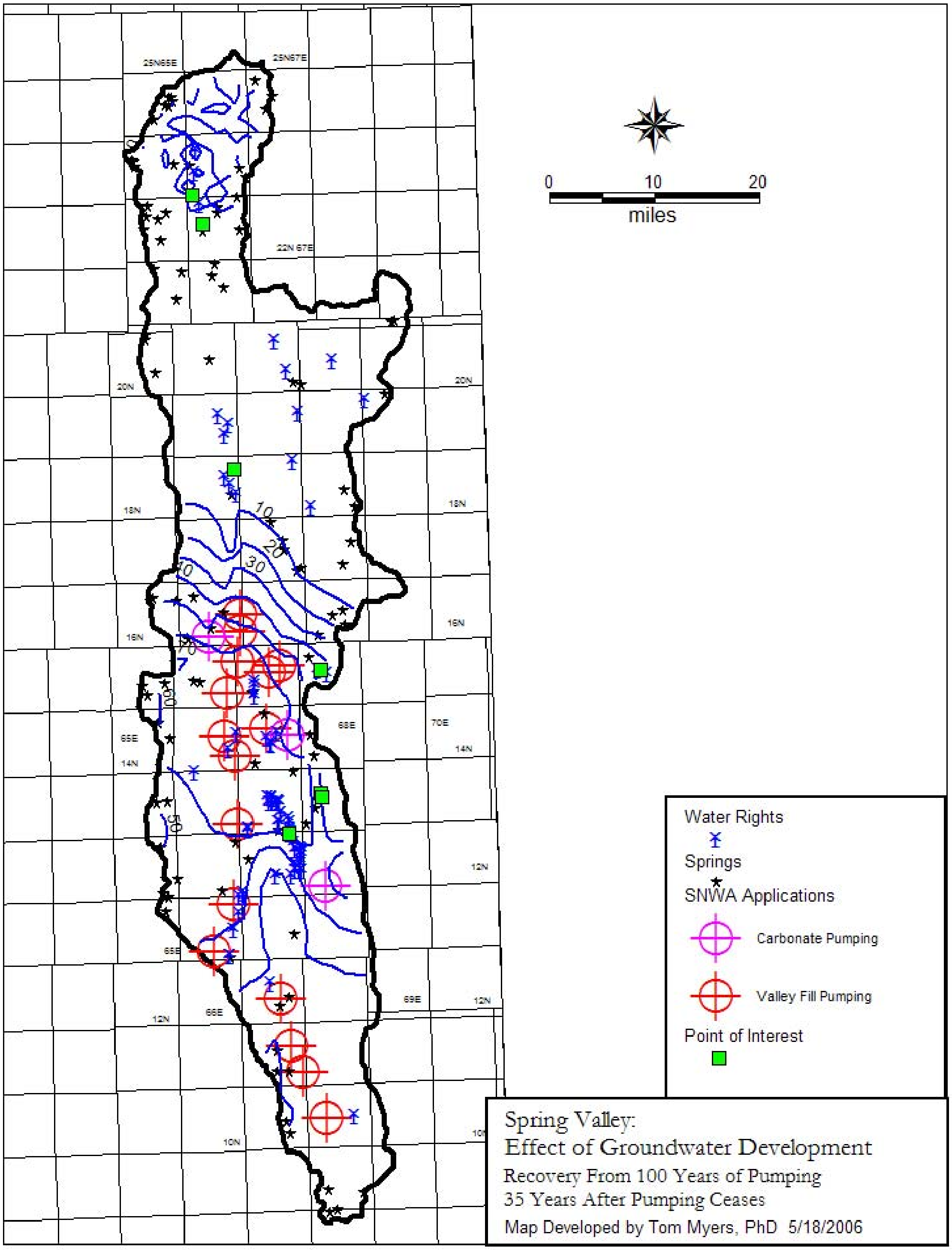

Figure 43: Drawdown contours 35 years after the cessation of 100 years of pumping. See Figure 3 for Point of Interest labels.

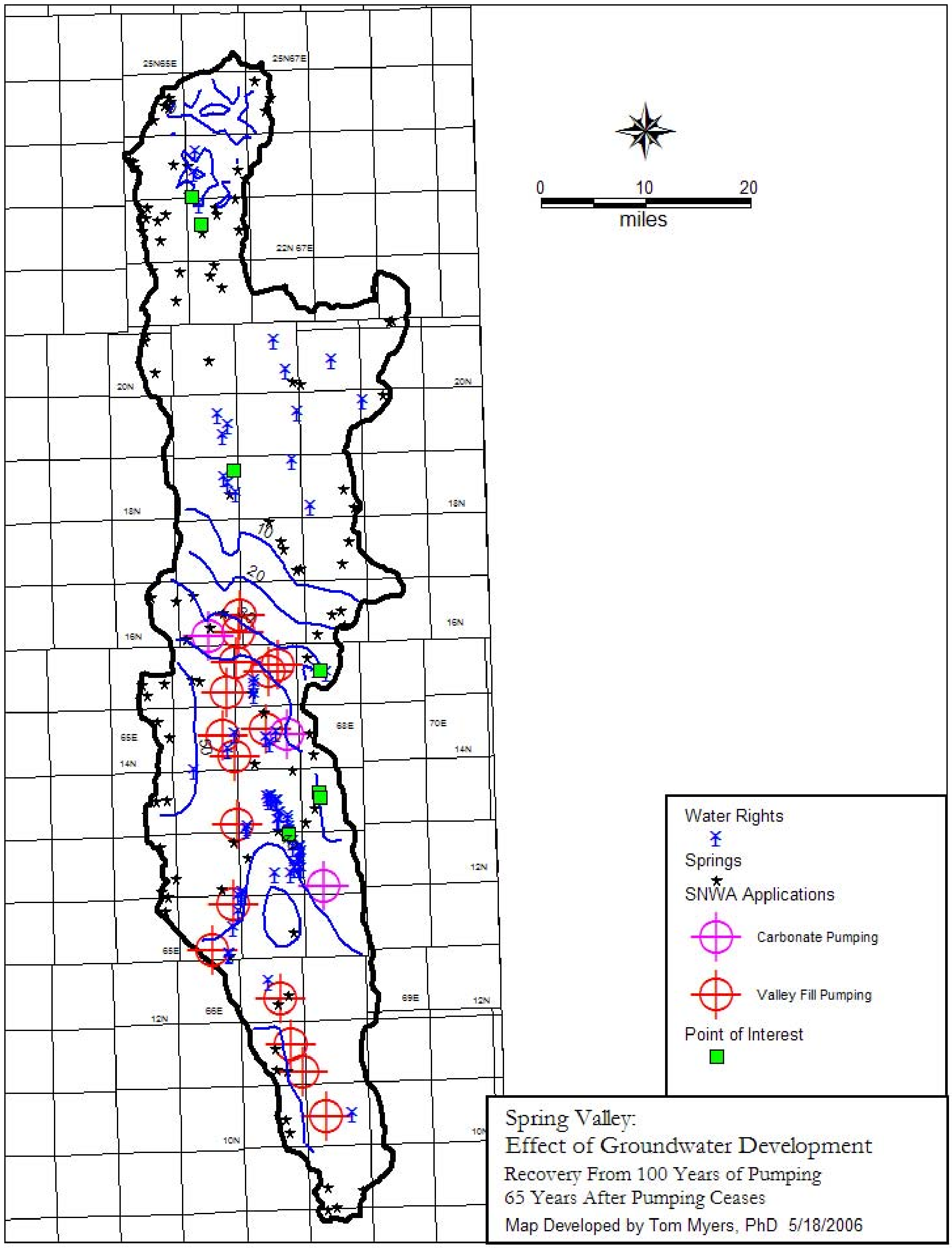

Figure 44: Drawdown contours 65 years after the cessation of 100 years of pumping. See Figure 3 for Point of Interest labels.

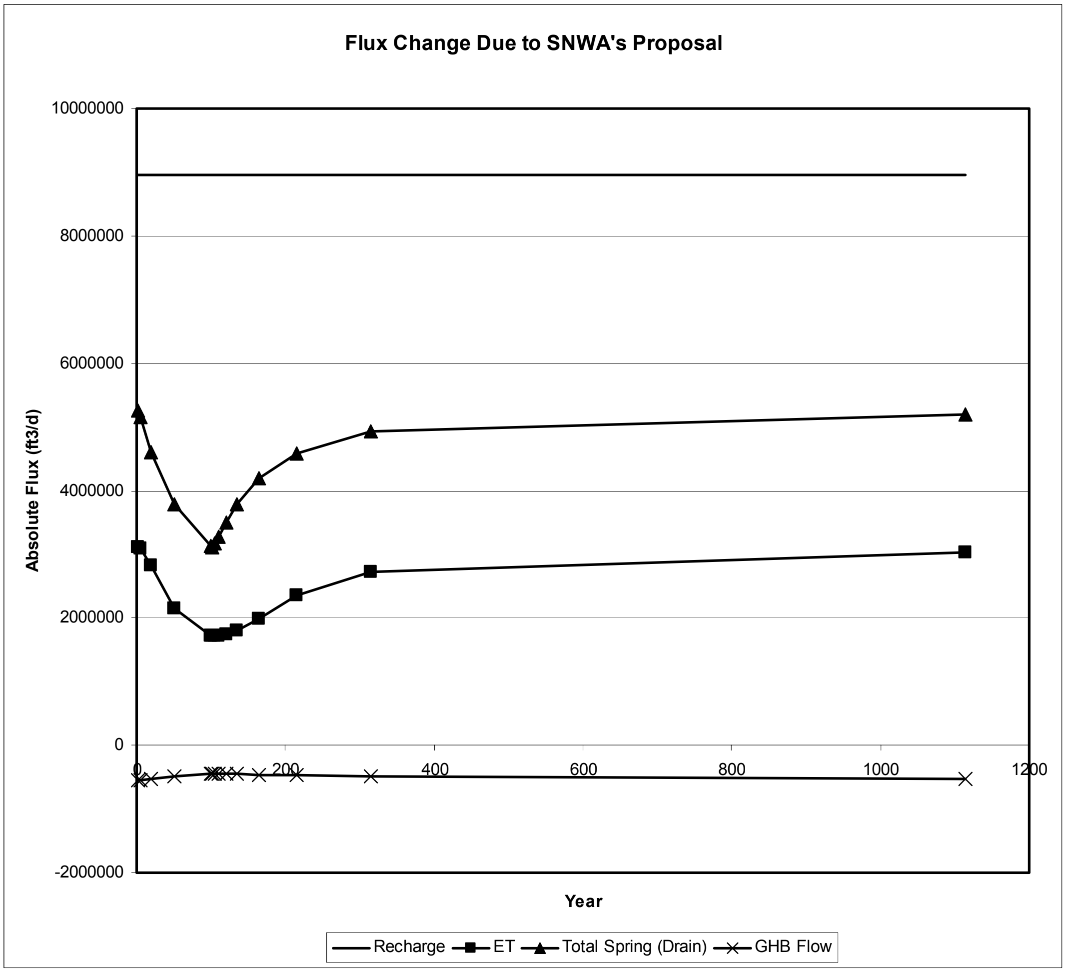

Figure 45: Hydrograph of flux for 100 years of pumping and 1000 years of recovery.

Conclusion

The water rights applications of the Southern Nevada Water Authority in Spring Valley will, if granted as requested, lower the water table in Spring Valley by more than 200 feet within 100 years and 300 feet within 1000 years. The proposed development will affect all springs in the valley fill and near the mountain front within the valley at some point during 1000 years of pumping. The proposed development will affect all springs in the valley fill and in the bedrock near the mountain front at some point during 1000 years of pumping. At least twenty feet of drawdown will affect 73 percent of the underground water rights within the valley within the first 100 years of pumping. Discharge to springs and wetlands will drop by a third within 100 years. Points of interest defined for protecting sensitive species will also be affected. Shoshone Ponds and springs on Sacramento Pass will be affected significantly in less than 20 years. Further north drawdown will reach the critical springs after 200 years of pumping but will continue to expand for a thousand years after pumping ceases. Stresses from Spring Valley could also possibly propagate through the southern Snake Range at faults or fractures and affect the flow at Big Springs in Snake Valley.

The pumping causes such negative impacts and widespread drawdown throughout Spring Valley because the applications request about 22 percent more water than the 75,000 af/y of recharge. Water levels and flows will never reach steady state while pumping at this rate. Accounting for the existing 18,600 af/y of water rights, SNWA's request is for 62 percent more water than recharges within the valley. There probably are vested groundwater rights not accounted for by this total, therefore the actual amount of groundwater available is likely even less. Because spring water rights and the surface water rights to stream baseflow also depend on groundwater discharge, most of the underground water in the basin is not available for appropriation.

Developing water rights up to the total 75,000 af/y recharge will negatively affect the natural springs within the valley. At steady state, inflow equals outflow, and the outflow in Spring Valley is to springs and wetlands. Even current development takes some of that discharge. The development of much additional underground water from Spring Valley will, based on simple water balance accounting, eventually dry most of the springs. The groundwater model developed for Spring Valley shows that SNWA's applications if granted effectively dry all of the springs, at least on an annual average, within the 1000-year analysis time period.

Monitoring and mitigation is not likely to prevent unacceptable impacts to the springs and groundwater levels. Water levels recover very slowly from just 100 years of pumping, the length of pumping chosen to represent a possible trigger point for stopping development to allow water levels to recover. The drawdown cone will remain near its maximum extent for at least a decade after pumping ceases. Actual ET continues to decrease for 10 years as the drawdown expands, and recovers more slowly than it decreased reflecting the continued broad extent of the drawdown. Only drawdown in the middle of the valley recovers substantially in 100 years. After 1000 years of recovery, the ET is 2 percent less than before pumping began. Spring flow also continues to decrease for a year after pumping ceases, but recovery is slightly faster than for ET. After 1000 years, the spring discharge is still 1 percent less than prior to pumping.

Recovery from development is slow as well. The drawdown lingers for more than 1000 years beyond the end of pumping because some of the recharge continues to discharge to natural discharge points rather than replenishing the deficit. The natural discharges continue to be depleted, however, for longer than 1000 years beyond the end of pumping.

The current perennial yield estimate for Spring Valley, 100,000 af/y, exceeds the recharge by 25,000 and the ET by 30,000 af/y, respectively. This higher estimate depends on doublecounting recharge by assuming that untested groundwater pumping plans will draw water from streams and prevent it from being wasted to the playas. This assumption does not accommodate the existing surface water or spring flow rights which total substantially more than the estimated surface runoff in the basin. It also does not account for the almost 4000 af/y which flows to Hamlin Valley. The perennial yield should be just the 70,000 af/y of evapotranspiration. However, developing this amount of water would severely affect the existing wetlands and springs. The pumping of any groundwater necessarily takes discharge from the wetlands and springs, therefore the actual perennial yield should be much less than 70,000 af/y.

Tom Myers

6/27/06

Date

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Appendix

Table A-1: Wells utilized for calibration of the groundwater model.

Well	GSEL	Depth			Water Level	GWEL
*USGS 385315114233501 184 N12 E67 24DAD 1	5920	0		4/19/1983	57.3	5862.7
*USGS 385627114292101 184 N13 E67 31DDCC1	5788	0		4/22/1960	23	5765
*USGS 385902114264801 184 N13 E67 22BBBB1	5840	0		4/20/1983	58.89	5781.11
*USGS 385911114264901 184 N13 E67 22A 1	5850	0		4/22/1960	70	5780
*USGS 385928114264901 184 N13 E67 15CBBB1	5860	0		4/20/1983	83.64	5776.36
*USGS 391224114293601 184 N16 E66 36DBAD1 USBLM - CLEVE CREEK WELL	5858	0	110VLFL	3/7/1990	215.68	5642.32
*USGS 394407114320401 184 N21 E66 04B 1	6070	0		7/16/1964	21.4	6048.6
*USGS 395314114373101 184 N23 E65 10D 1	6922	0		4/22/1960	65	6857
USGS 385636114265501 184 N13 E67 33DDA 1	5770	6		4/19/1983	1.4	5768.6
USGS 384620114313602 184 N11 E66 35DBAC2 CMP at S. Fox flowing well	5785	12	110VLFL	4/22/1960	4.6	5780.4
USGS 391308114245101 184 N16 E67 27DADD1 USBLM	5608	13		8/5/1948	12.12	5595.88
USGS 391835114282001 184 N17 E67 30AC 1	5575	15		8/18/1949	9	5566
USGS 390336114272701 184 N14 E67 27B 1	5800	16		8/22/1949	12.2	5787.8
USGS 391327114255901 184 N16 E67 27D 1	5700	16		7/15/1964	7	5693
USGS 384709114280101 184 N11 E67 28CBBC1 SPVET2W	5773	19		8/23/2005	6.98	5766.02
USGS 395321114344001 184 N23 E66 07C 1	6480	23		8/19/1949	15.8	6464.2
USGS 384640114280101 184 N11 E67 32AADA1 SPET1W	5776	25	110VLFL	8/23/2005	9.57	5766.43
USGS 390417114302701 184 N14 E66 24AABB1 USBLM	5838	27		8/15/1949	25.26	5812.74
USGS 390420114313901 184 N14 E66 24A 1 USBLM	5850	27		8/25/1949	25.3	5824.7
USGS 392234114222801 184 N17 E68 06D 1 USGS	5570	28		8/5/1948	22.6	5547.4
USGS 391908114270801 184 N17 E67 28A 1 USBLM	5560	29		2/18/1949	22.1	5537.9
USGS 394333114311001 184 N21 E66 04B 2	6150	29		4/21/1983	16.68	6133.32
USGS 395200114341201 184 N23 E66 19A 1	6400	30		8/19/1949	20	6380
USGS 385108114302602 184 N11 E66 01AABB2	5790	30		4/20/1983	2	5788
USGS 385251114272701 184 N12 E67 27B 1	5750	30		10/13/1955	13	5737
USGS 385623114272501 184 N12 E67 03B 1 USGS	5770	30		8/17/1953	5.3	5764.7
USGS 385659114280301 184	5770	30		4/22/1960	8.3	5761.7

N13 E67 33D 1 USBLM						
USGS 392137114222801 184 N17 E68 07AB 1	5558	30		8/16/1949	23.7	5534.3
USGS 392238114222801 184 N17 E68 06A 1 USBLM	5570	31		8/16/1949	23.7	5546.3
USGS 392703114230501 184 N18 E67 01CCAA1	5587	42		7/16/1964	61.9	5525.1
USGS 385526114290701 184 N12 E67 08A 1	5750	45		1/1/1935	20	5730
USGS 390032114281901 184 N13 E67 08ACAB1	5770	45	110VLFL	12/29/1947	13.13	5756.87
USGS 390052114291001 184 N13 E67 08A 1 USGS	5780	45		11/11/1964	14.1	5765.9
USGS 390127114350101 184 N13 E66 05ACAB1	6474	45		10/5/1955	15	6459
USGS 392729114241101 184 N18 E67 01C 1	5570	45		7/16/1964	58.9	5511.1
USGS 393059114221501 184 N19 E67 13AAAC1	5614	53		8/16/1949	47.85	5566.15
USGS 393128114233201 184 N19 E67 13A 1	5630	53		8/16/1949	46.8	5583.2
USGS 384403114272301 184 N10 E67 16AABA1 USBLM (South Well)	5825	54	110VLFL	4/22/1960	45.5	5779.5
USGS 390315114304701 184 N14 E66 25BADD1 USBLM	5838	61		8/15/1944	24	5814
USGS 390336114320701 184 N14 E66 25B 1	5900	61		8/15/1944	24	5876
USGS 392750114310601 184 N18 E66 01B 1	5600	68		7/11/1953	20	5580
USGS 384604114234301 184 N11 E68 31C 1 USBLM	5870	80		7/15/1964	71.2	5798.8
USGS 385433114242501 184 N12 E67 13A 1	5900	80		10/10/1955	8	5892
USGS 390940114302001 184 N15 E66 13D 1	5760	82		9/10/1952	13.68	5746.32
USGS 390940114314801 184 N15 E66 24B 1 USGS	5830	82		9/14/1947	15.1	5814.9
USGS 390936114305801 184 N15 E67 19B 1	5750	83		9/30/1947	9	5741
USGS 384310114261401 184 N10 E67 22AA 1 USGS-MX (Spring V Central)	5889	100	110VLFL	7/1/1980	67	5822
USGS 394942114342001 184 N23 E66 31C 1	6370	104		6/4/1953	26	6344
USGS 394949114331801 184 N23 E66 31AB 1	6350	104		6/4/1953	26	6324
USGS 385756114314801 184 N13 E66 25A 1 USBLM	5950	120		12/29/1947	13.1	5936.9
USGS 385920114294001 184 N13 E67 18DCAB1 Majorwoods Windmill	5850	120		4/22/1960	53.3	5796.7
USGS 392028114290301 184 N17 E67 18BCAA1	5620	125		6/3/1996	21	5599
USGS 393442114231801 184 N20 E67 26ABBD1 USBLM	5705	130		6/21/1950	100	5605
USGS 395234114363601 184 N23 E65 14C 1	6660	140		5/31/1977	124	6536
USGS 384039114232701 184 N10 E68 31CD 1 USGS-MX	5906	150		7/1/1980	121	5785

USGS 385348114243301 184 N12 E67 24BBB 1	5780	155		4/20/1983	-11.4	5791.4
USGS 390352114305401 184 N14 E66 24BDDD1 USGS-MX (Spring Valley N.)	5840	160	110VLFL	1/1/1981	39	5801
USGS 385906114260501 184 N13 E67 15DCDC1 USGS-MX	5886	160		7/1/1980	90.9	5795.1
USGS 390952114214401 184 N15 E66 14DBBD1	6548	168		6/29/1999	24	6524
USGS 385504114240801 184 N12 E67 12CAAD1	5882	182		7/8/1976	36	5846
USGS 391123114245001 184 N15 E67 02DA 1 USGS-MX	6090	185		7/1/1980	150	5940
USGS 391135114244701 184 N15 E67 02DACB1 USAF	5780	185		7/1/1980	180	5600
USGS 384216114260001 184 N10 E67 26BB 1 USGS-MX	5944	200		7/1/1980	12	5932
USGS 384448114300901 184 N10 E67 07BA 1 USGS	5880	200	300CRBN	7/1/1980	85	5795
USGS 390803114251001 184 N15 E67 26CA 1 USGS-MX	5676	200		1/1/1981	25	5651
USGS 390807114304101 184 N15 E66 25DBCB1 White Pine Power Project	5855	210		4/21/1983	46.67	5808.33
USGS 390330114264401 184 N14 E67 22CCCA1	5790	238		4/21/1983	57.76	5732.24
USGS 384620114313601 184 N11 E66 35DBAC1 (S. Fox flowing well)	5785	240	110VLFL	4/20/1983	-5.2	5790.2
USGS 384558114230501 184 N11 E68 31CDCD1 USBLM	5849	260		3/8/1990	70.14	5778.86
USGS 385259114240701 184 N12 E67 24CDDD1	5843	260		7/15/1960	23	5820
USGS 385915114261901 184 N13 E67 15CDAA1	5880	272		4/20/1983	103.37	5776.63
USGS 385259114234901 184 N12 E67 24DCD 1	5900	300		7/15/1976	78	5822
USGS 385314114250901 184 N12 E67 24C 1	5850	300		7/15/1960	23	5827
USGS 385723114250801 184 N13 E67 26DCCB1	5850	300		6/4/1962	48	5802
USGS 385757114251601 184 N13 E67 26BADC1	5860	300		6/4/1967	48	5812
USGS 385849114255901 184 N13 E67 22ADBB1	5865	300		4/20/1983	72.21	5792.79
USGS 391713114244701 184 N16 E67 03AAAA1	5586	300		8/28/1950	5	5581
USGS 384731114224501 184 N11 E68 29B 1	6100	353		11/7/1953	250	5850
USGS 393211114320701 184 N19 E66 11B 1	5900	400		4/22/1960	40.8	5859.2
USGS 385613114250401 184 N12 E67 02ACBA1 USBLM (Shoshone pond well)	5777	441		10/24/1971	-48	5825
USGS 390802114303001 184 N15 E66 25DADC1 White Pine Power Project	5845	470		8/17/1982	51	5794
USGS 385915114261902 184 N13 E67 15CDAA2	5880	487		4/20/1983	102.3	5777.7
USGS 383351114180201 184	6142	495		7/15/1964	418.5	5723.5

N08 E68 14A 1 USBLM						
USGS 385852114261701 184 N13 E67 22BADD1	5855	500		10/20/1980	78	5777
USGS 385903114261701 184 N13 E67 15CDDD1	5865	550		1/23/1968	54	5811
USGS 390448114274401 184 N14 E67 15C 1	5780	600		4/22/1960	12	5768
USGS 383704114225001 184 N09 E68 30AAAB1 USGS-MX (Spring Valley S.)	6010	679	110VLFL	8/7/1980	227	5783
USGS 383707114231202 184 N09 E68 30AB 2 USGS-MX	6025	700		9/22/1980	219	5806
USGS 393055114310001 184 N19 E66 14AB 1	5700	815		10/22/1972	50	5650
USGS 385715114254501 184 N13 E67 34AAAA1	5805	916		4/19/1983	2.54	5802.46
USGS 390802114303901 184 N15 E66 25DBCC1 White Pine Power Project	5858	1005		9/2/1982	50.78	5807.22

Table A-2

Aquatic At Risk Taxa Recorded in the Spring Valley Area
Compiled by the Nevada Natural Heritage Program
31 May 2006

Scientific name	Common name	Usfws	Blm	Usfs	State	Srank	Grank	Lat	Long	Prec	Last observed
Invertebrates											
Cercyonis pegala pluvialis	White River Wood Nymph	xC2	N			S2	G5T2	394723N	1144214W	G	1993-07-27
Gastropods											
Pyrgulopsis peculiaris	bifid duct pyrg		N			S1	G2	390943N	1142107W	S	1998-PRE
Fishes											
Empetrichthys latos latos	Pahrump poolfish	LEPT	S		YES	S1	G1T1	385615N	1142454W	S	2001-06-27
Oncorhynchus clarkii utah	Bonneville cutthroat trout	xC2	N	S	YES	S1	G4T2	385937N	1142132W	S	1978-PRE
Oncorhynchus clarkii utah	Bonneville cutthroat trout	xC2	N	S	YES	S1	G4T2	390057N	1141644W	G	1970-PRE
Oncorhynchus clarkii utah	Bonneville cutthroat trout	xC2	N	S	YES	S1	G4T2	385912N	1142125W	S	1984
Relictus solitarius	Relict Dace	xC2	N		YES	S2S3	G2G3	394919N	1143322W	M	1983
Relictus solitarius	Relict Dace	xC2	N		YES	S2S3	G2G3	394657N	1143224W	S	1983
Relictus solitarius	Relict Dace	xC2	N		YES	S2S3	G2G3	392633N	1142942W	M	1983
Relictus solitarius	Relict Dace	xC2	N		YES	S2S3	G2G3	385615N	1142454W	S	2001-06-27