HYDROGEOLOGY OF SPRING VALLEY AND SURROUNDING AREAS

PART C: IMPACTS OF PUMPING UNDERGROUND WATER RIGHT APPLICATIONS #54003 THROUGH 54021

Presented to the Office of the Nevada State Engineer

On behalf of Great Basin Water Network and the Federated Tribes of the Goshute Indians

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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 Great Basin Water Network, the Confederated Tribes of the Goshute Reservation, and a coalition of protestants to those water right applications. This report assembles evidence supporting the conclusion that pumping the proposed amount of groundwater, or even a substantial portion of that amount, will cause substantial drawdown and detrimental effects to the groundwater levels, spring discharge, wetland evapotranspiration (ET), and water rights in Spring and adjoining valleys.

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. SNWA also filed six water rights applications in Cave Valley, Dry Lake Valley, and Delamar Valley, to which GBWN and the same coalition also are protestants. I have prepared a separate evidence report concerning the effects of pumping in those valleys.

SNWA's Spring Valley applications number from 54003 to 54021. All are considered as "ready for action protested" (RFP).

Figure 1 shows the general layout of Spring, Snake, Tippett and surrounding valleys and SNWA's applications. Applications 54003 through 54018 are for 6 cfs and the remaining three applications are for 10 cfs, also referred to as "underground basin in Spring Valley" or "underground rock aquifer in Spring Valley", respectively. This report analyzes pumping the applications as proposed and at two lower pumping rates, 60,000 and 30,000 af/y to provide a range of impacts for evaluation.

This evidence report presents both overarching and hydrogeologically particularized conclusions about the likely effects of the proposed action. These conclusions are drawn from two sources – the conceptual model (Myers 2011a) and the numerical model of Spring Valley (Myers, 2011b). The first, overarching, conclusion is that the amount of water applied for exceeds the conceptual flow model of Spring Valley, meaning that the request exceeds the perennial yield based on the recharge and discharge within the valley. Pumping SNWA's applications will cause a continuing drawdown of the groundwater table and draw water from or prevent groundwater from reaching adjacent valleys.

The second set of conclusions is presented through the simulation of the impacts caused by actually pumping these applications in the scenarios described using the numerical groundwater model of Spring and Snake Valleys, and adjoining areas, developed over the past few years (Myers, 2011b). I based the numerical model on the conceptual model developed in Myers (2011a).

The remainder of this evidence report refers to Myers (2011a) and Myers (2011b) as Part A and Part B, respectively.

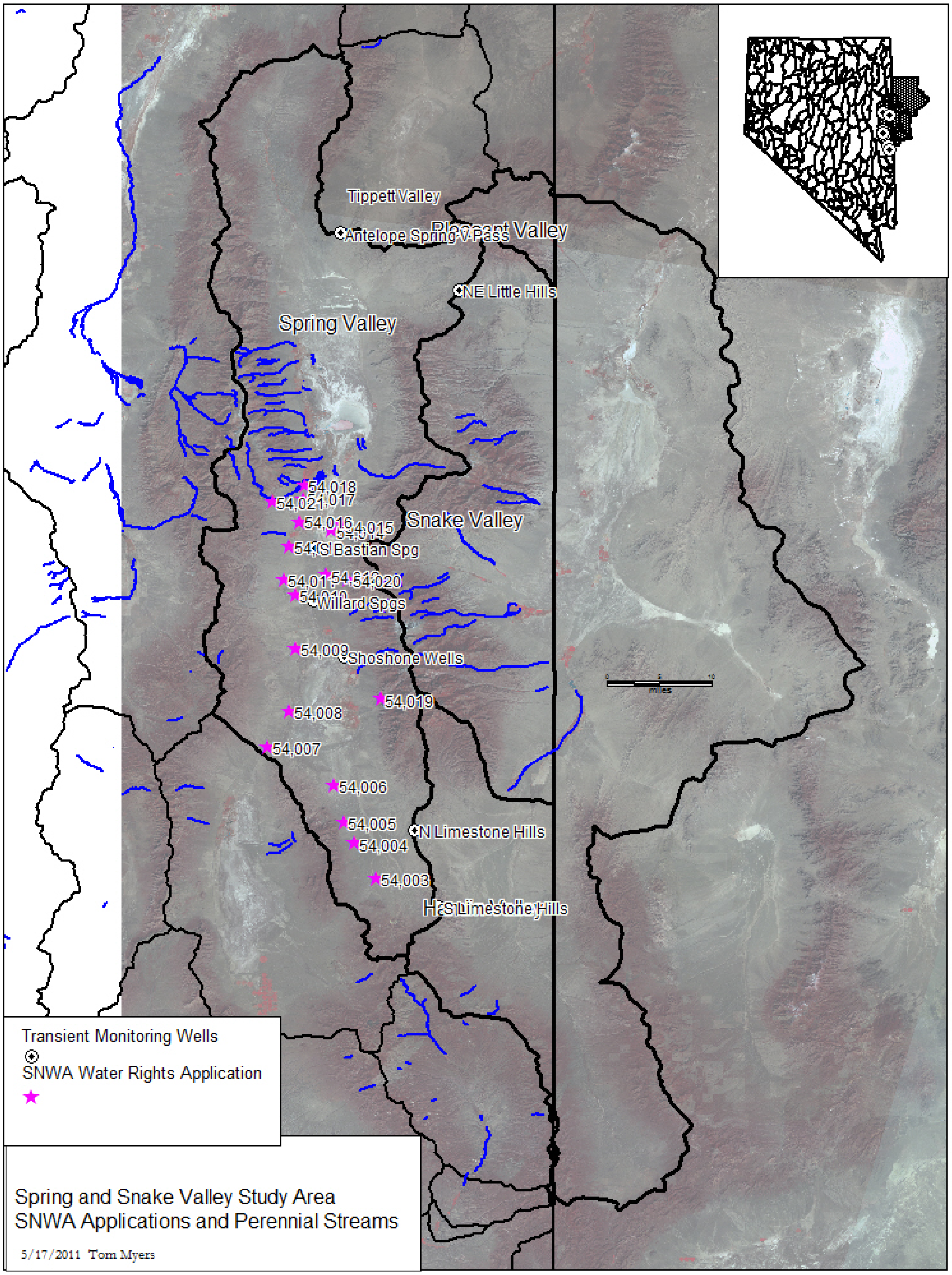

Figure 1: Spring and Snake Valley study area. The stars are the SNWA water right applications and the blue lines are perennial streams.

PERENNIAL YIELD, WATER AVAILABILITY AND SUSTAINABLE GROUNDWATER DEVELOPMENT

Water availability in a Nevada basin depends on the perennial yield of the basin. The Nevada State Engineer (NSE) used the definition of perennial yield from the 1971 Water for Nevada report:

> The perennial yield of a ground-water reservoir may be defined as the maximum amount of ground water that can be salvaged each year over the long term without depleting the ground-water reservoir. Perennial yield is ultimately limited to the maximum amount of natural discharge that can be salvaged for beneficial use. The perennial yield cannot be more than the natural recharge to a ground-water basin and in some cases is less. (Nevada State Engineer, 1971, p. 13)

If the perennial yield is exceeded, groundwater levels will decline in perpetuity and steady-state conditions will not be reached. A situation wherein pumping exceeds the amount of water being naturally restored to a basin is groundwater mining. “The term ‘ground-water mining’ typically refers to a prolonged and progressive decrease in the amount of water stored in a ground-water system, as may occur, for example, in heavily pumped aquifers in arid and semiarid regions” (Alley et al, 1999, p. 4). Additionally, withdrawals of ground water in excess of the perennial yield may contribute to adverse conditions such as water quality degradation, storage depletion, diminishing yield of wells, increased economic pumping lifts, and land subsidence (Nevada State Engineer, 1971). When pumping exceeds the perennial yield, groundwater is being mined from the basin.

Perennial yield is the amount of water that can be pumped consistently from a basin without drawdown continuing in perpetuity. Virtually by definition, this means that pumping must capture discharge within or from the valley. It means that ET and spring discharge must be reduced by an amount equal to the pumping rate, or water will continue to be drawn from storage and drawdown will continue to increase. For this reason, the PY is often considered to equal the total discharge; valleys with little discharge may have only a small PY. If recharge exceeds the discharge, groundwater flows from the valley as interbasin flow and likely discharges from a downgradient valley. Pumping more than the natural discharge from a valley captures interbasin flow that otherwise would discharge further downgradient.

A corollary is that the aquifer system must come to equilibrium within a reasonable time or the amount being pumped exceeds the perennial yield for that pumping regime. In order to come to equilibrium it must capture discharge equal to the pumping rate. A proposed pumping regime may not be able to capture all of the discharge, and therefore could be limited to the amount of discharge that it could feasibly capture within a reasonable time. This time may be known as the “time to full capture” (Bredehoeft and Durbin, 2009) or the system “response time” (Walton, 2011). The amount of water granted to a proposed pumping regime could therefore be limited to the amount of water that can be pumped within a reasonable response time. A corollary to this discussion is that perennial yield may be limited by the ability to place wells to actually capture the discharge.

The NSE currently specifies perennial yield in Spring Valley to be 80,000 af/y (NSE web page, http://water.nv.gov/data/underground/printableSummary.cfm?basin=184&CFID=653613&CFTOKEN=25781569, downloaded 5/17/11, reproduced in Appendix A).

EFFECTS OF SNWA WATER RIGHTS APPLICATIONS ON WATER BALANCE

SNWA's water right applications sum to approximately 91,200 af/y. Any amount granted would be diverted from the valley and is therefore an effective consumptive use to Spring Valley.

Recharge estimates for Spring Valley average about 72,000 af/y (Part A). The ten individual estimates vary around the mean by about plus/minus 30,000 af/y. Three of the most recent estimates, based on the basin characterization method and made by the same hydrologists (Flint et al, 2004; Flint and Flint, 2007), were 56,000, 67,000, and 93,000 af/y. The variation reflected different assumptions of climate record and the model cell size. Considering that the same method yielded such a range of estimates, it is very unlikely that any estimate could be considered as most accurate, especially in light of the effects that climate change may have on groundwater recharge. Even if the historic period could provide a stationary record for recharge, the future will deviate from that record. Because of all the uncertainties in these estimates, the average from Part A, 72,000 af/y, is a good estimate of recharge for comparison.

Discharge from the valley may be more easily estimated, because it is based on phreatophyte areas that can be measured and ET rates that can be estimated. Any given estimate, however, reflects conditions at the time the areas are measured. Wetland and phreatophyte areas, ET rates, and the proportion of ET satisfied by precipitation would vary annually. The point is that estimates of GWET are highly dependent on antecedent conditions, as Myers (2006b) argued in rebuttal for the first Spring Valley hearing. Based on that preamble, the BARCAS estimate of 75,600 af/y for Spring Valley is an acceptable middle-of-the-road estimate (Part A).

The average recharge and discharge for Spring Valley could be considered within measurement error of being the same value. SNWA's total applied-for water rights exceed the average recharge and discharge by 27 and 20 percent, respectively.

BARCAS was the first study to estimate substantial amounts of interbasin inflow to Spring Valley from Steptoe and Lake Valley, about 33,000 af/y, and from Spring Valley to Snake Valley, about 49,000 af/y. These estimates are much higher than any previous estimates, and essentially depend on very high recharge estimates in Steptoe Valley (Welch et al, 2008). They are also higher than simulated in steady state using the groundwater model in Part B.

Irrigation underground rights total 18,908 af/y and mining and milling rights total 1,361 af/y; total underground (UG) permitted and certificated rights total 11,414 and 10,262 af/y, respectively, as of May 17, 2011 (see Appendix A for a summary from the NSE Web page). Total UG certificated and permitted water rights exceed 25 percent of the NSE perennial yield and 28 percent of the BARCAS ET discharge estimate. The basin has significant underground water rights development. The difference between the BARCAS ET estimate and the existing permitted and certificated UG rights, not accounting for spring rights, is approximately 54,800 af/y.

SNWA would not be able to capture sufficient discharge to match its proposed pumpage at their proposed points of diversion. This is because much of the recharge to the basin occurs in the central and northern Schell Creek Range and along the alluvial fan adjacent to the range. As can be seen on BARCAS, Plate 4 (Lazcniak et al, 2008), much of the ET occurs north of Sacramento Pass. SNWA's applications are mostly south of the latitude of Cleve Creek, which is just north of Sacramento Pass. In order to capture ET from north of Cleve Creek, the drawdown in southern Spring Valley would have to be quite high. As will be shown in the next section concerning model predictions, SNWA will not be able to capture the discharge, and the drawdown associated with pumping from the proposed application points will still become quite large.

SIMULATION OF SNWA GROUNDWATER PUMPING IN SPRING VALLEY

SNWA has 19 applications for underground water rights in Spring Valley (Figure 1), with sixteen, numbers 54003 through 54018 for 6 cfs and three, numbers 54019 through 54021, for 10 cfs. The different requested flow rates have long been presumed to mean the well would be completed in fill and carbonate rock (Schaefer and Harrill, 1995), respectively, but in my experience typically a permit grants a water right at a horizontal location in the valley, within a quarter-quarter section, not at a depth. So, if permitted as proposed, SNWA presumably could pump up to the permitted amount from each well, without limit as to pumping depth or aquifer.

I simulated SNWA's proposed pumping with the Spring/Snake Valley Groundwater Model (Part B) with three time periods to simulate three potential stress periods. The first two periods were the same for all scenarios (described below) – 75 and 125 years, specified in days with 110 and 60 time steps. These periods applied SNWA's proposed pumping for 200 years. The second period had fewer time steps because the pumping rate remains constant – there is no new stress to the system. The third period was either 600 years to simulate recovery or 10,000 years to simulate pumping to equilibrium.

SNWA applications were simulated by pumping from multiple model layers using a routine within GWVistas which establishes pumping rates for each layer intersected by a multi-layer well based on transmissivity of the layer. The routine develops MODFLOW well boundaries in each of the specified layers pumping the predetermined amount. It is not an optimization routine, meaning the routine does not attempt to minimize drawdown in other ways as might be accomplished with the MODFLOW multi-node well routine. I initially specified pumping from layers 4 and 5 for all applications, assuming that SNWA would pump from below 400 feet bgs. Effectively, this assumption sets the initial screen length equal to 1600 ft, the sum of the layer 4 and 5 thickness. Boundary reach numbers were the last one or two numbers of the applications - 3 through 21.

Initial conditions were the steady state model solution, as determined in Part B.

The simulation at long time periods has slight convergence problems due to instability in the MODFLOW rewetting routine. During simulation of the larger time steps in stress period three during recovery simulation, a few cells oscillated between wet and dry conditions. The oscillation occurs because the water level in those cells has recovered to within a small fraction of a foot of rewetting. Oscillation does not occur during more rapid recovery. The MODFLOW-2000 output files show (1) that the model almost converges (it is not diverging), the residual values are less than 5 whereas the criteria was set to 1, and (2) that the failure to converge for a few steps does not cause a water balance error.

Three pumping rates were considered, the original application value of 91,200 af/y and two reduced values, 60,000 and 30,000 af/y, respectively.

Pumping Original Applications

The model successfully simulated pumping from the locations and at amounts as requested by SNWA in applications 54003 through 54021 (Figure 1). There were no problems pumping 15 of the applications – those in the valley fill away from the mountain front. However, the 10 cfs applications and application 54010 near Rattlesnake Knoll could not be pumped to their full amount without causing thousands of feet of drawdown. This was due to their location in bedrock with very low conductivity and indicates the SNWA applications as requested cannot actually withdraw the requested amount of water from those locations. I made small adjustments to their location to better accommodate the valley's conceptual model, just as SNWA would do when actually locating the wells if permitted.

Application 54010 located just northeast of Rattlesnake Knoll and layers 4 and 5 were in LCSU with Kh equal to 0.00522 ft/d (Part B) because of the shallow depth to basement (Mankinen et al, 2006). Pumping from this material caused unrealistic drawdown, therefore I moved the well three cells north and east and specified pumping in layers 2 and 3 to increase the amount drawn from fill.

Applications 54019 through 54021 were located near bedrock, either LCSU or low Kh carbonate. Pumping 10 cfs from these formations caused absurdly large drawdowns. Application 54019 was in carbonate rock just north of Swallow Springs, but this carbonate Kh calibrated to 0.018 ft/d (well within published ranges). Moving the well three cells to the west and screening it from layers 2 through 5 allowed it to withdraw the full application amount. Application 54020 plotted near some carbonate outcrops but also next to LCSU which had been interpreted to extend under the fill at shallow depths near this point (Welch et al, 2008; Mankinen et al, 2006). I moved it two cells west and one cell south so that layers 2 through 4 would be in fill. Application 54021was located near Cleve Creek on a boundary between LCSU and LCU. I moved it one cell south and east so that screening it in layers 2 and 3 would be in fill and deeper layers would be in LCU, rather than the LCSU that outcrops at the original application location (Part B).

The problems with pumping the original applications demonstrate it is impossible to actually remove the requested water from some locations. Unless fractured, carbonate rock does not yield substantial amounts of water. The fill will yield the application amounts only if screened over very long lengths.

Scenarios 2 and 3: Pumping Less Water from the Application

The full application amount for Spring Valley totals approximately 91,200 af/y, which exceeds the recharge to and discharge from the valley. As will be discussed in Results below, this pumping rate pulls water from adjoining valleys and causes excessive drawdown. Therefore, I chose two lower pumping rates to consider the effects of pumping less water from Spring Valley. These new scenarios pumped from the same points of diversion and model layers, but the total from the valley was reduced to 60,000 and 30,000 af/y, respectively, or two-thirds and one-third of the original amount. Each well pumping rate was reduced proportionally.

Results

I present the results of simulating the scenarios with drawdown maps, monitoring well hydrographs, and flux hydrographs for boundaries around the model domain below. The drawdown maps present contours at the 1-, 5-, 10-, 20-, 50-, 100-, 500-, 1000-, and 2000-foot levels. The 2000-ft drawdowns occur near two wells and exceed the layer thickness, as described above.

One-foot contours show the total reach of these proposals. Some argue that one-foot (anything less than 10 feet) drawdown is within the seasonal variability and measurement accuracy of the wells and therefore should not be considered. Both points are correct, however the smaller drawdowns merely superimpose on top of the natural variability. A phreatic spring by definition is one for which the water table is at the ground surface. Lowering the water table by a foot turns a flowing spring into a mud hole. Lowering the water table by a foot even with natural variability increases the time that the spring is dry. The one-foot drawdown therefore provides a more complete rendition of the springs which could be affected.

Three of the applications caused drawdown to below the layer bottoms. This is due to the relatively low conductivity – calibrated values that are too low to actually pump 6 or 10 cfs on a sustained basis. In the simulation, the cells remain active, and the wells continue to remove water from the model domain, because the layer was simulated as confined. The reality is that SNWA would not be able to pump this amount from these three locations. Although this amount of pumping yields inaccurate predictions at the well, the excessive drawdown would limit the extent of drawdown predicted through the remainder of the valley because the volume of the actual cone simulated within the model is larger near the well than would in reality occur. This release from storage would satisfy pumping requirements that otherwise would be drawn further from the well. Although it is probably not substantial, the model is conservative in favor of SNWA in that it slightly underpredicts the extent of drawdown due to pumping the full application amount.

Drawdown hydrographs show the amount that water levels or potentiometric surfaces drop from the initial water level as a result of pumping without regard to the actual water level. The initial water level is a baseline and drawdown should be considered as a difference from the pre-pumping condition rather than an exact water level prediction. A similar point applies to the flux hydrographs. The starting flux is that resulting from steady state calibration, which accurately but not precisely simulated the steady state flux. The hydrograph should be considered as changes in the flux, not as exact predictions of flows.

Pumping Full Application, Original Locations, for 200 Years

This scenario involves pumping the application amounts at the original locations for 200 years and followed by recovery for 600 years. Drawdown extends about ten miles north of central Spring Valley and 50-ft drawdown covers an area of about 10 by 15 miles in that area after 75 years (Figure 2) and expands about five more miles north and south by 200 years (Figure 3). A large area with 100-ft drawdown becomes apparent in central Spring Valley after 200 years. After 75 years, a large area with 20-ft drawdown has formed in the southern end of Spring Valley; after 200 years the area will have expanded to cover most of the playa with the 50-ft drawdown covering most of the remaining fill in southern Spring Valley (Figure 3). The 20-ft drawdown will extend into Hamlin Valley with the 5-ft drawdown almost reaching Snake Valley proper.

Drawdown at points in the southern end of the valley (Figure 4) is less because the playa is a convergence zone for discharge and more of the wells are located north of the playa. The simulated pumping does not efficiently capture this discharge.

Drawdown extends further to the southeast because of the conductive rock under the Limestone Hills and the limiting poorly conductive rock just east of the pumping in the Snake Range massif. Topography limits drawdown in the north because the ground surface rises about 1000 ft north of the playa towards Tippett Valley and North Spring Valley. That, combined with lower conductivity, slows the expansion of drawdown in that direction.

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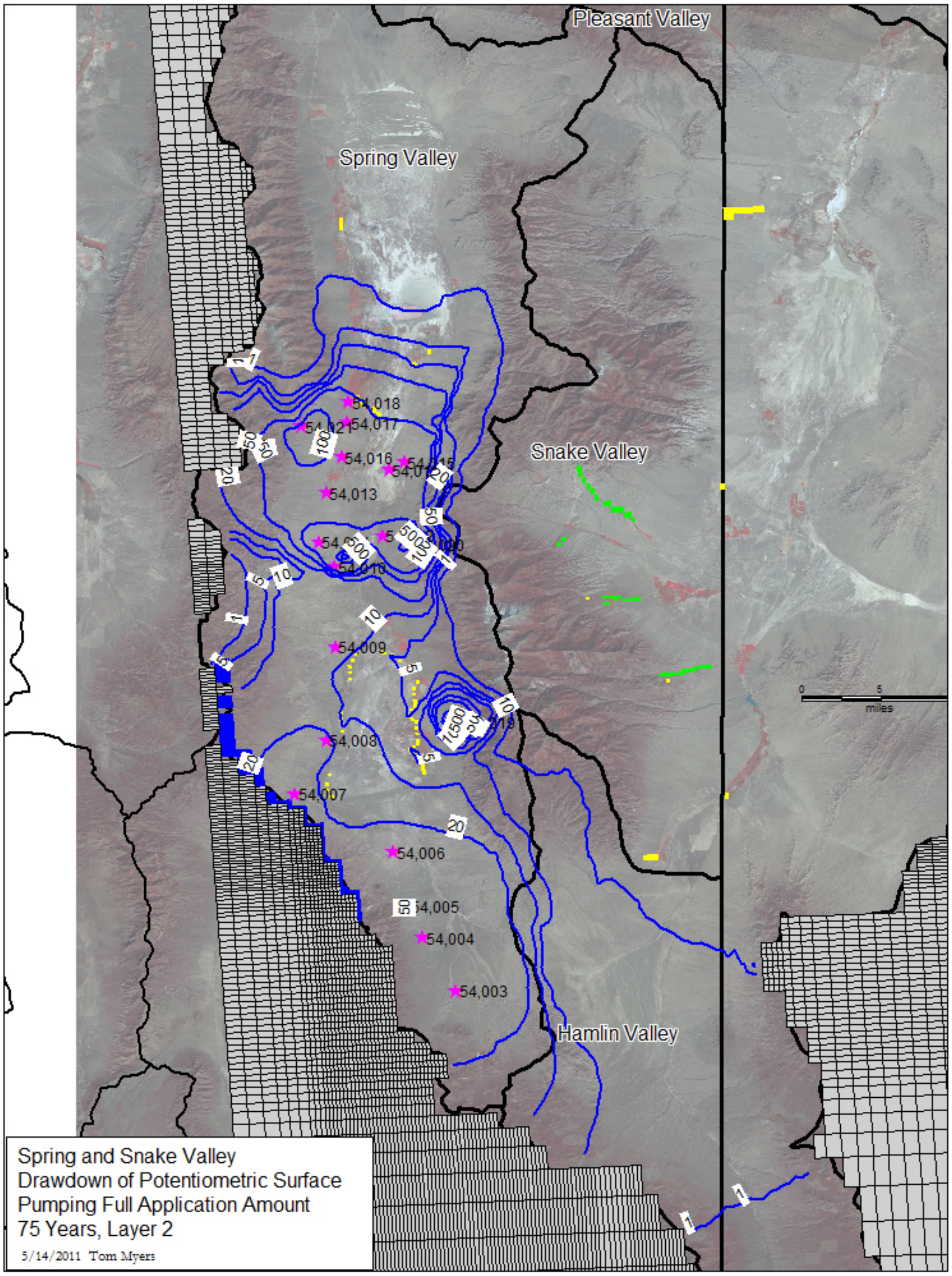

Figure 2: Drawdown contours in layer 2 after pumping the full application amount for 75 years.

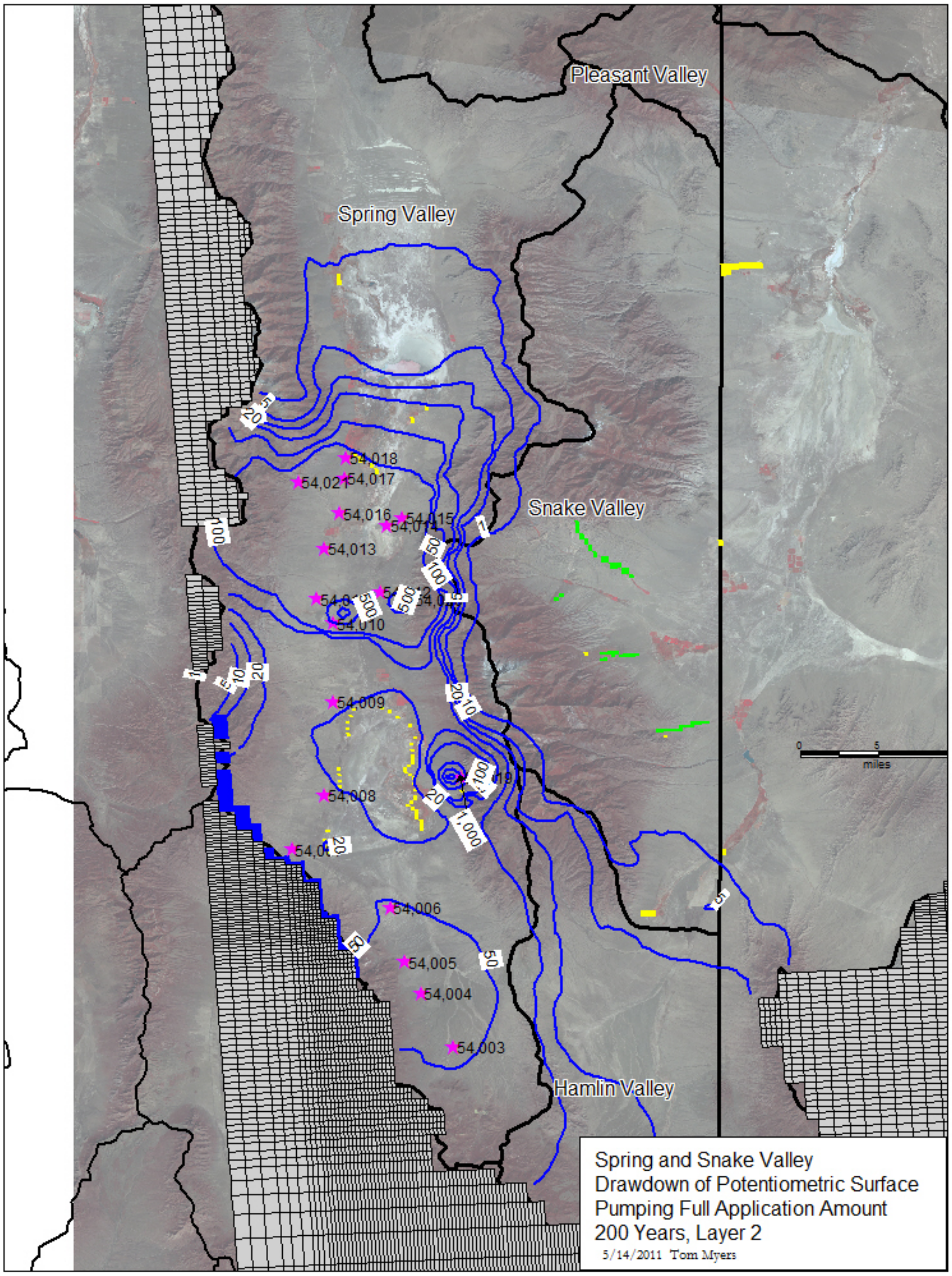

Figure 3: Drawdown contours in layer 2 after pumping the full application amount for 200 years.

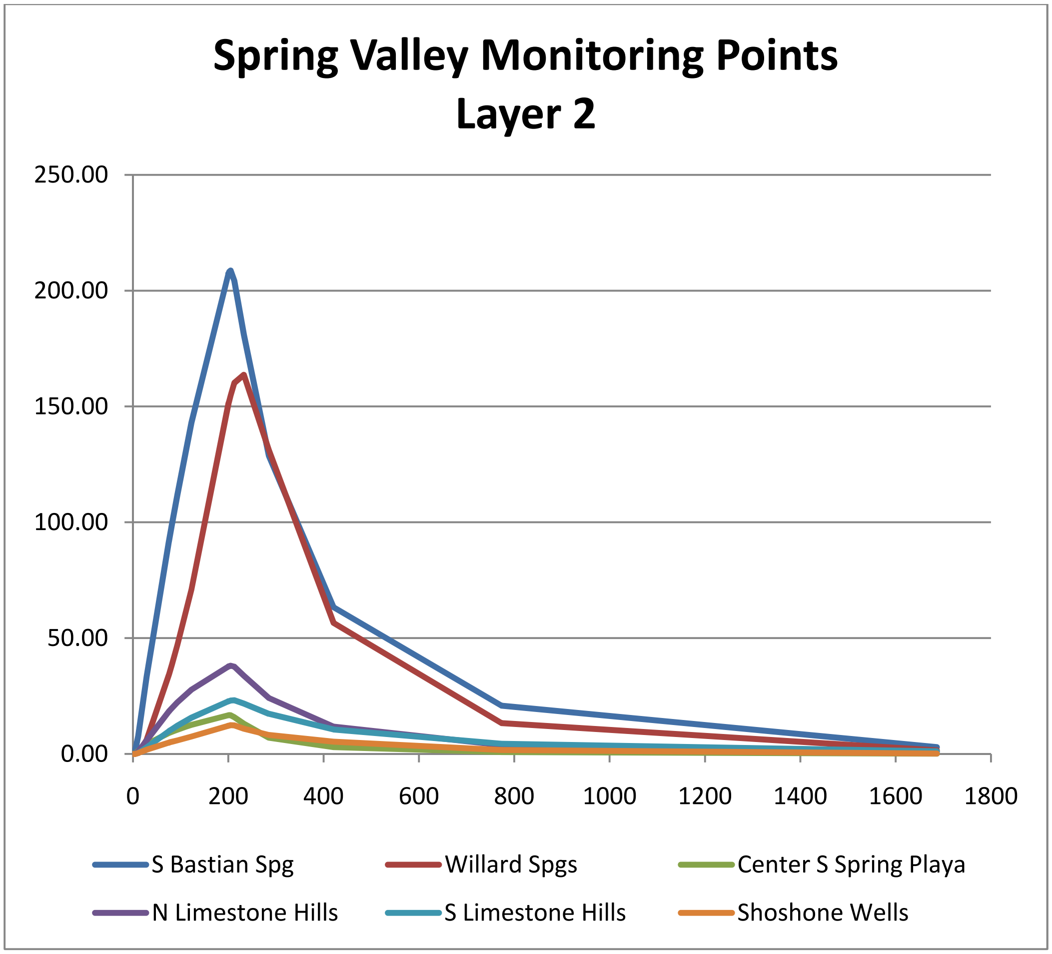

Figure 4: Drawdown hydrograph at various Spring Valley monitoring points in layer 2 for pumping full application amount.

Groundwater level recovery occurs as water flows back into the drawdown cone and fills those voids. When a well stops pumping, flow toward the well and cone replenishes the volume pumped by the well. The top of the cone continues to expand even as the deepest drawdown recovers because a gradient toward the well is still required to drive the flow. Drawdown at the well initially recovers quickly because there is little volume at the tip of the cone but in the long term, the remaining bit of the drawdown recovers slowly because the flow gradient will have decreased so that flux toward the cone decreases. Similar concepts hold for a well field.

Two hundred thirty years after pumping ceases, the 1-, 5-, 10-, and 20-ft drawdown contours have moved north further from the center of pumping but the extent of the 50- and 100-foot drawdown has lessened (Figure 5). These areas have contracted significantly by 600 years after pumping, but extensive 20-ft drawdown remains (Figure 6). The 1- and 5-ft contours remain expanded far to the south and east into Snake Valley.

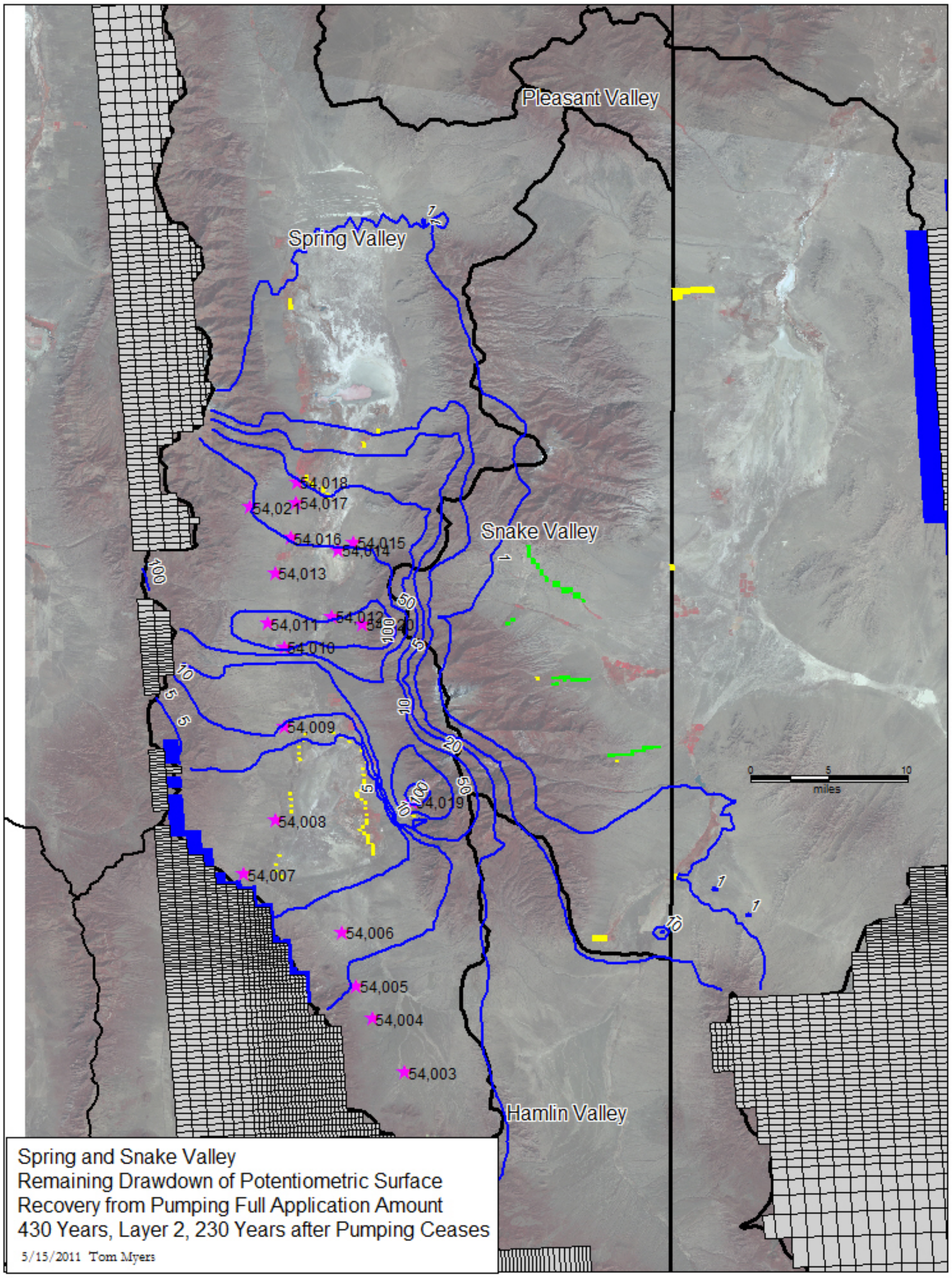

Figure 5: Drawdown contours in layer 2 after 230 years of recovery from pumping full application amount for 200 years.

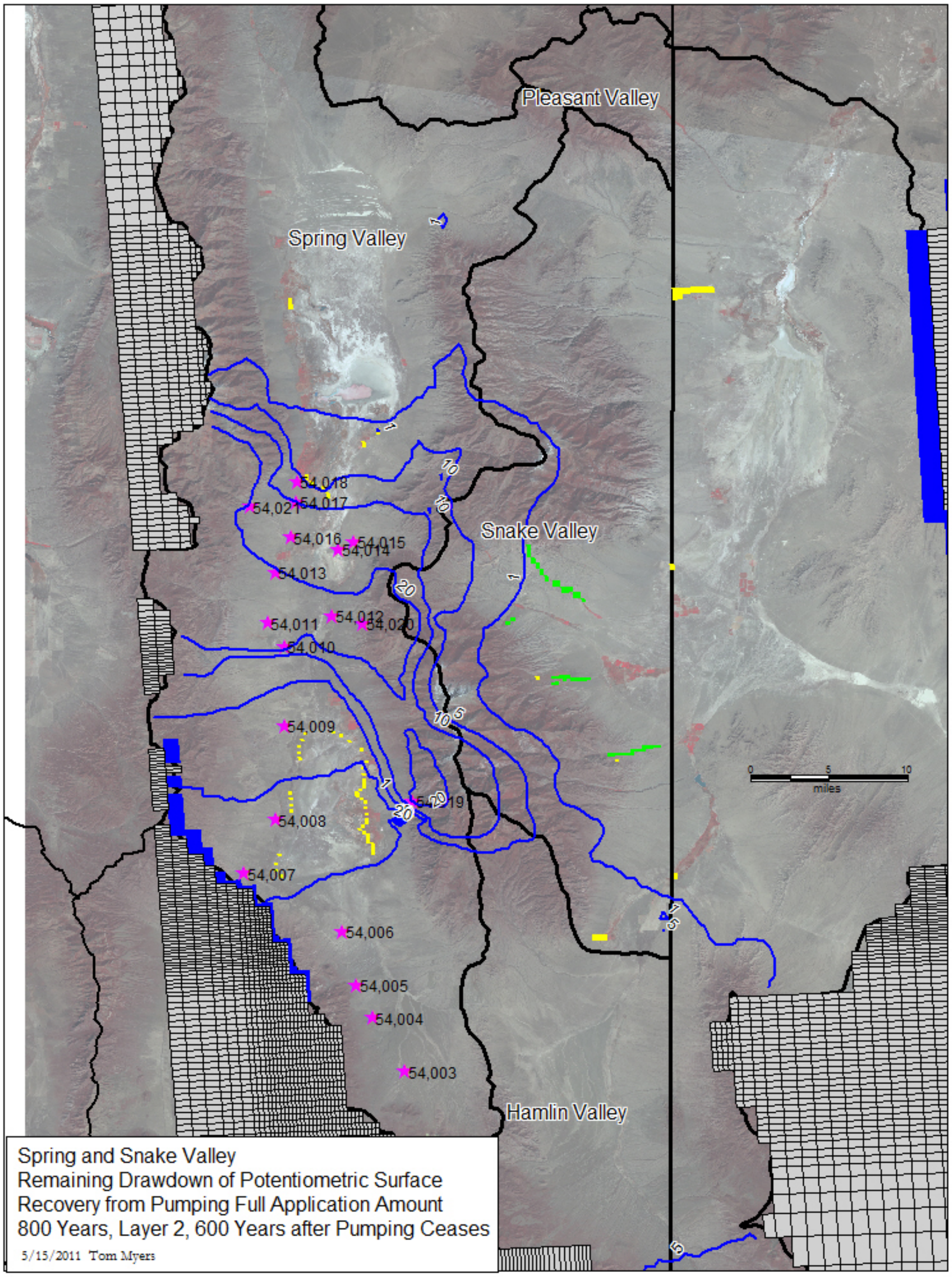

Figure 6: Drawdown contours in layer 2 after 600 years of recovery from pumping full application amount for 200 years.

Drawdown at several monitoring points either continues to increase (especially Willard Spgs) or remains high for substantial periods after peaking (Figure 7). The recovery at both N and S Limestone Hills slows after 400 years (Figure 7), which reflects the fact that discharge from Big Springs continues to decrease after pumping ceases (Figure 8) as the extent of drawdown in that area continues to expand (Figures 5 and 6). Big Springs discharge reaches its minimum about 150 years after pumping ceases.

Millick and Cleve Creek Springs go dry in less than 100 years of pumping the full application amount (Figure 8). Once pumping ceases, over 100 years passes before flow returns to these springs. In contrast, the springs discharging along the S Spring Valley playa begin a rapid recovery (compared to the others) but are still at just 80% of the pre-pumping level 200 years later (Figure 8).

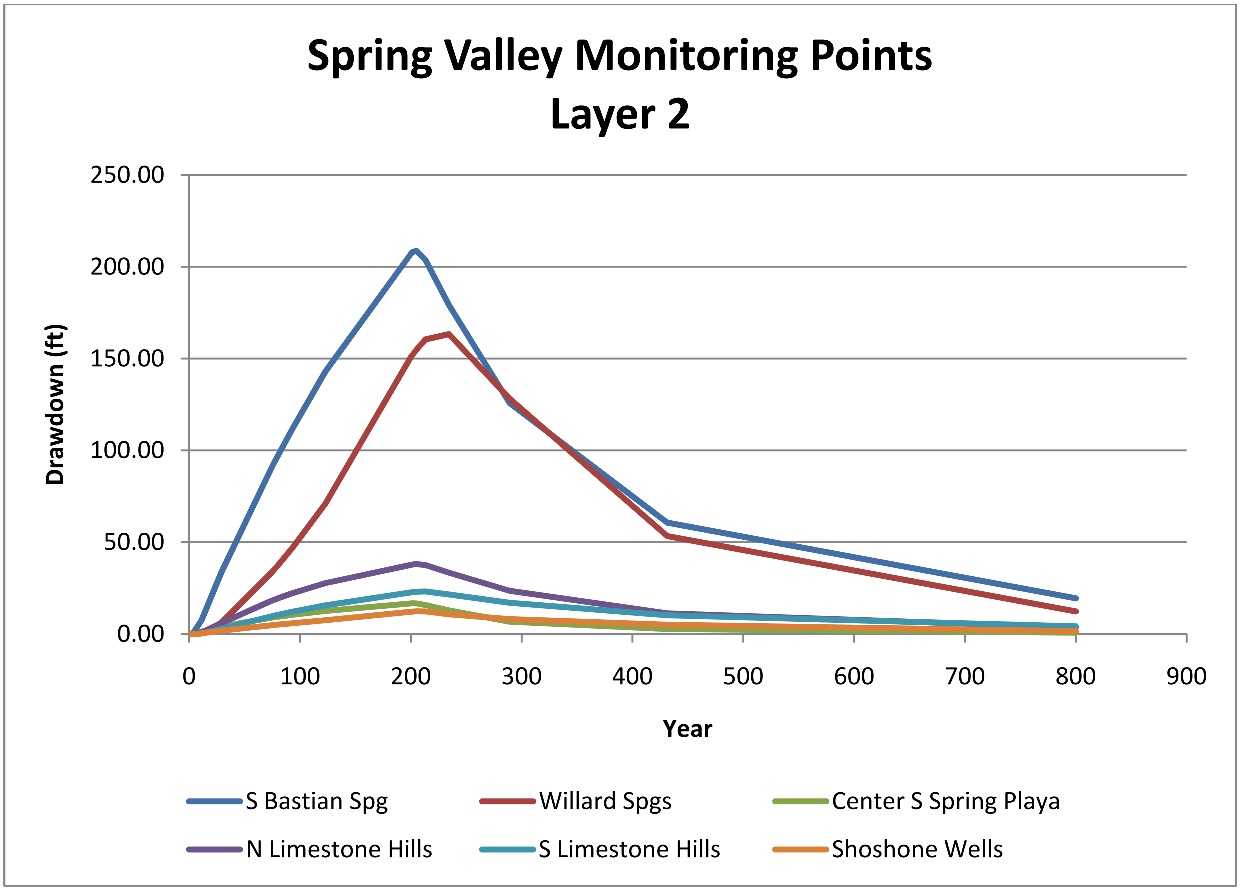

Figure 7: Monitoring well hydrographs for various Spring Valley Monitoring points in layer 2.

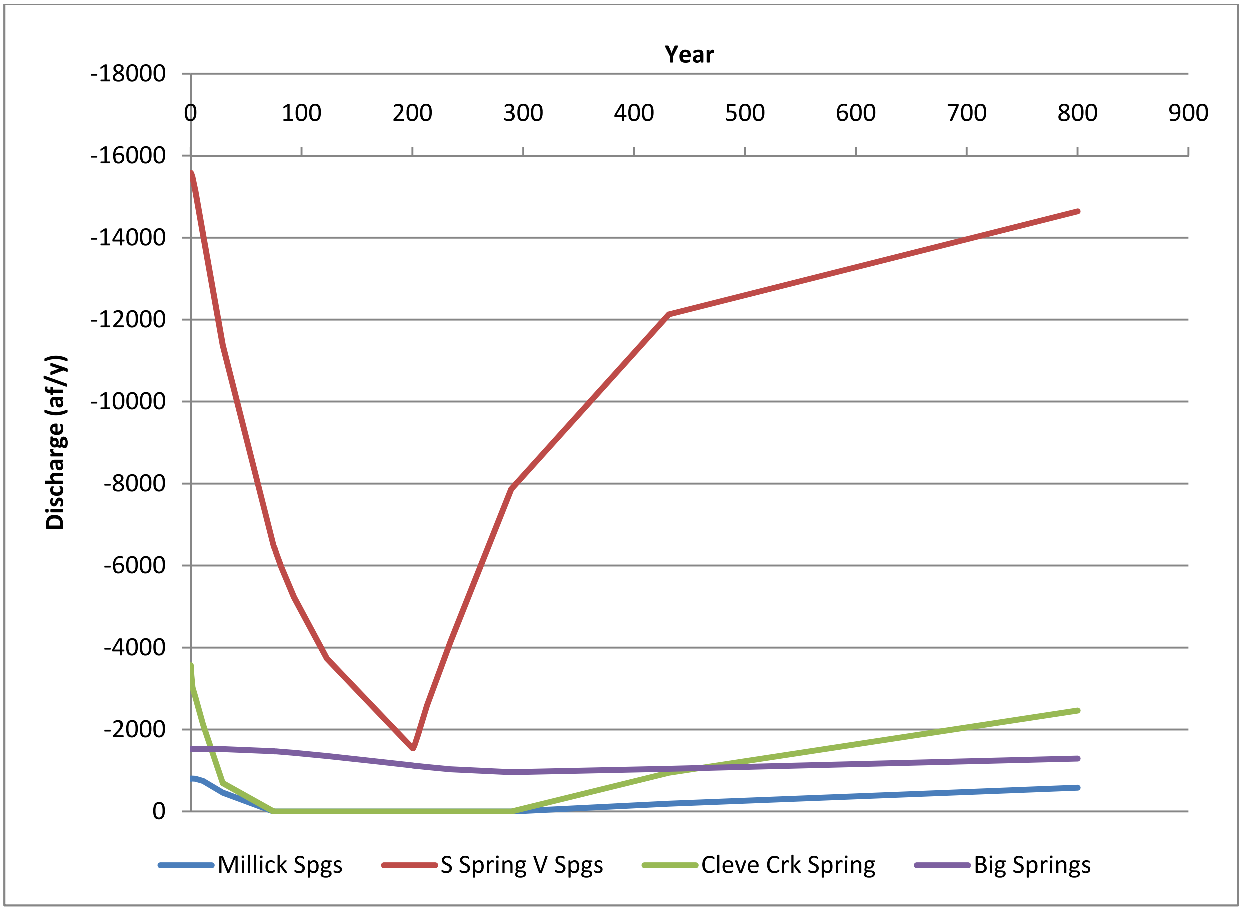

Figure 8: Flux hydrograph for four simulated springs.

Pumping initially pulls water from storage, with change in storage equalling the 91,200 af/y of pumping (Figure 9). After 200 years, when pumping ceases, the amount being removed from storage is still about 50,000 af/y, a rate which reflects how slow the system approaches equilibrium. Six hundred years after pumping ceases, groundwater is slowly being returned to storage. The total volume removed from storage exceeds 12,000,000 af after 200 years of pumping, and has recovered to a deficit of 3,000,000 af after 600 years of recovery. Total ET has not returned to its pre-pumping rate within 600 years because of the continuing 20-ft or so of remaining drawdown. The discharge from springs appears to have mostly recovered, taking the valley as a whole, because of recovery in flow at the South Spring Valley springs.

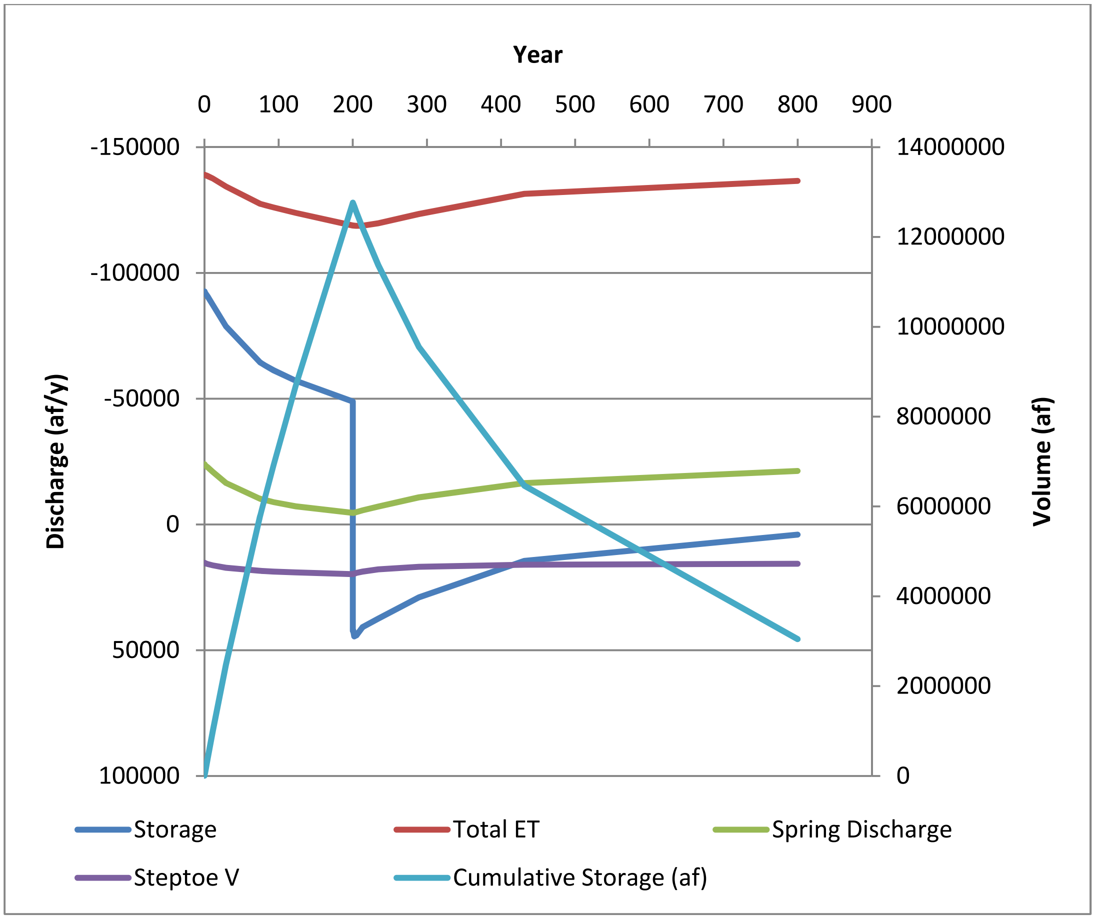

Figure 9: Flux hydrograph for SNWA pumping its full application amount for 200 years.

Alternative Pumping Rates

Pumping almost 92,000 af/y exceeds the natural recharge in Spring Valley and draws water from one valley (Steptoe) and decreases its flow to another (Snake Valley). As has been shown with drawdown maps and hydrographs, its potential impacts to Spring Valley are substantial. This section presents the results of simulating the pumping of two lower alternative amounts of water – 60,000 and 30,000 af/y, the two-thirds and one-thirds pumping scenario – from the original application locations. All other aspects of the simulation, the length of stress periods and time steps remain as in the full pumping scenario. The wells pump for 200 years and the system recovers for 600 years.

Appendix A contains drawdown maps for the two additional pumping rate scenarios for 75, 200, 430, and 800 years. These maps do not differ that much, suggesting that decreasing the pumping rate does not decrease the area affected by the pumping proportionally. Drawdown reaches the semi-impervious barrier of the Snake Range to the east and the topographic barrier to the north in Spring Valley; the differences are only a mile or two when the total extent of drawdown is ten or more miles (to the north). Decreasing pumping significantly changes the location of the drawdown only in the southeast corner of Spring Valley wherein it extends across Hamlin Valley more slowly.

Plotting the 5- and 50-ft drawdown contours for all pumping scenarios at a time of 75 and 200 years on the same map (Figures 10 and 11) demonstrates where the differences occur. After 75 years, the northern extent of the 5-ft drawdown varies by less than 5 miles for the pumping rates; as noted, the topography limits the expansion to the north. After 200 years, the 5-ft drawdown contours have moved northward only by a mile or so. Significant differences in the 5-ft drawdown after 75 years in the east-central portion of Spring Valley (Figure 10) substantially disappear after 200 years (Figure 11), as the drawdown butts up against the Snake Range massif; at this point the drawdown has reached the Shoshone Wells location. Between 75 and 200 years, the 5-ft drawdown expands across Hamlin Valleys (Figure 10 and 11). Only for pumping 91,200 af/y does the 50-ft drawdown expand across most of southern Spring Valley. That drawdown level has been reached over much of the central Spring Valley playa within 75 years (Figure 10), but expands little up to 200 years.

The differences in the rate that drawdown expands in different directions suggest that the system approaches equilibrium more closely in the north than in the south within 200 years. However, this is limited as can be seen by the continuing growth of the 1-ft drawdown (Appendix A); the apparent equilibrium is due to the relatively steep gradients toward the south (Parts A and B) and the substantial recharge to the north. In the south, there is both less recharge on the west side and pervious rock to the east, so the drawdown expands to the east.

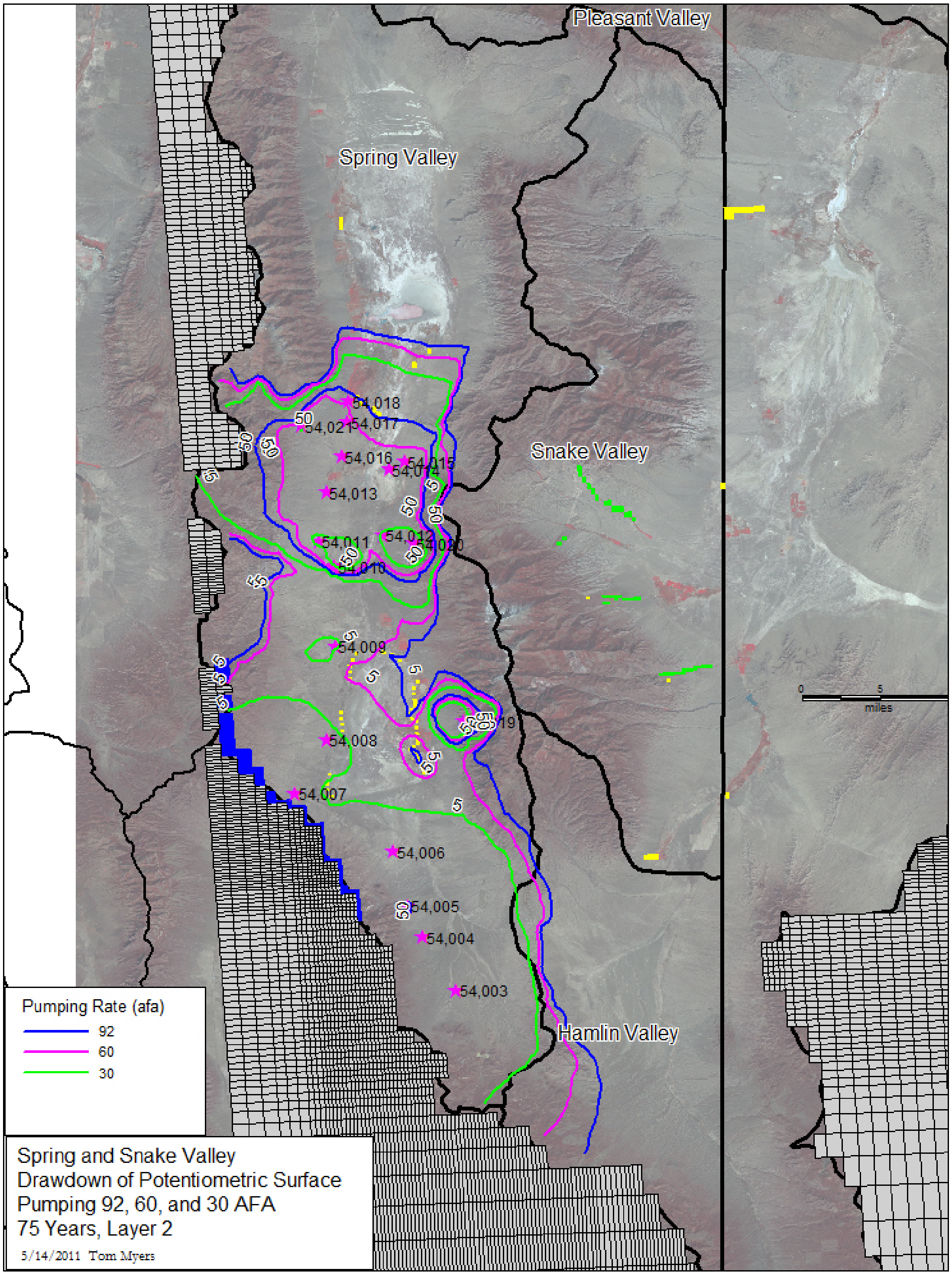

Figure 10: Comparison of the 5- and 50-ft drawdown for pumping 91,200, 60,000, and 30,000 af/y (kaf = 1000 af) for 75 years.

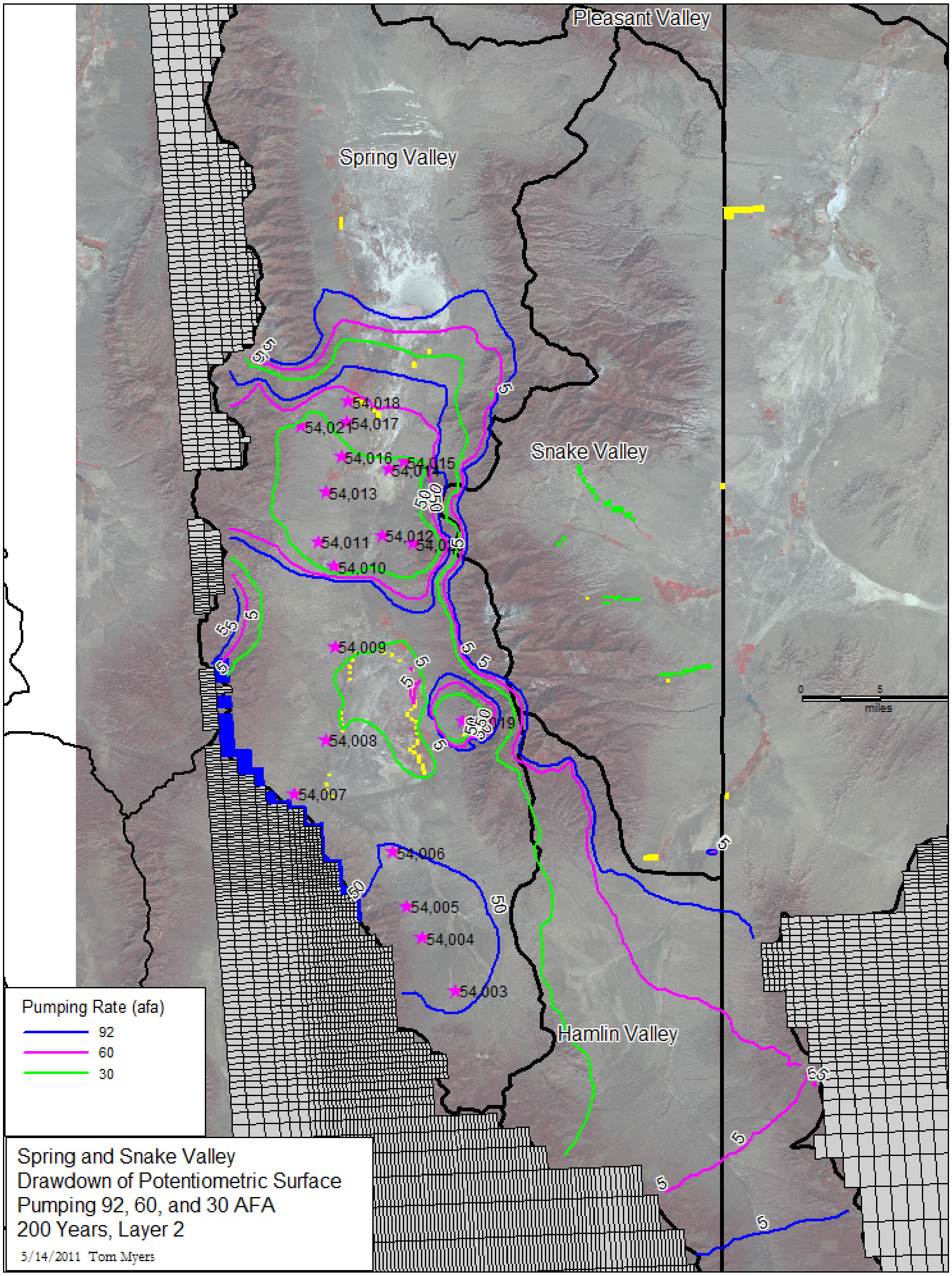

Figure 11: Comparison of the 5- and 50-ft drawdown for pumping 91,200, 60,000, and 30,000 af/y (kaf = 1000 af) for 200 years.

The similarity in drawdown cones belies the difference in the amount of groundwater removed from storage for each pumping rate. Initially pumping removes water strictly from storage (Figure12), causing the initial drawdown. Although the rate that pumping removes water from storage for the first 200 years appears to decrease in a parallel manner for the three pumping rate scenarios, the reality is that the proportion of the initial volume still being removed from storage after 200 years is 0.53, 0.48, and 0.45 for full-, two-, and one-third pumping, respectively (Figure 12). The system is approaching equilibrium much sooner for the lower pumping rate, although it remains far from steady state after 200 years. The proportional recovery is also slower for the lower pumping rate – 600 years after pumping cessation the proportion of the total amount removed from storage is 0.24, 0.27, and 0.38 for full-, two-thirds, and one-third pumping, respectively (Figure 12). Of the total amount withdrawn from storage, the proportion of recovery is less for the lower pumping scenario. Of course, the total volume of groundwater storage deficit is much less at all points of time for the lower pumping scenario.

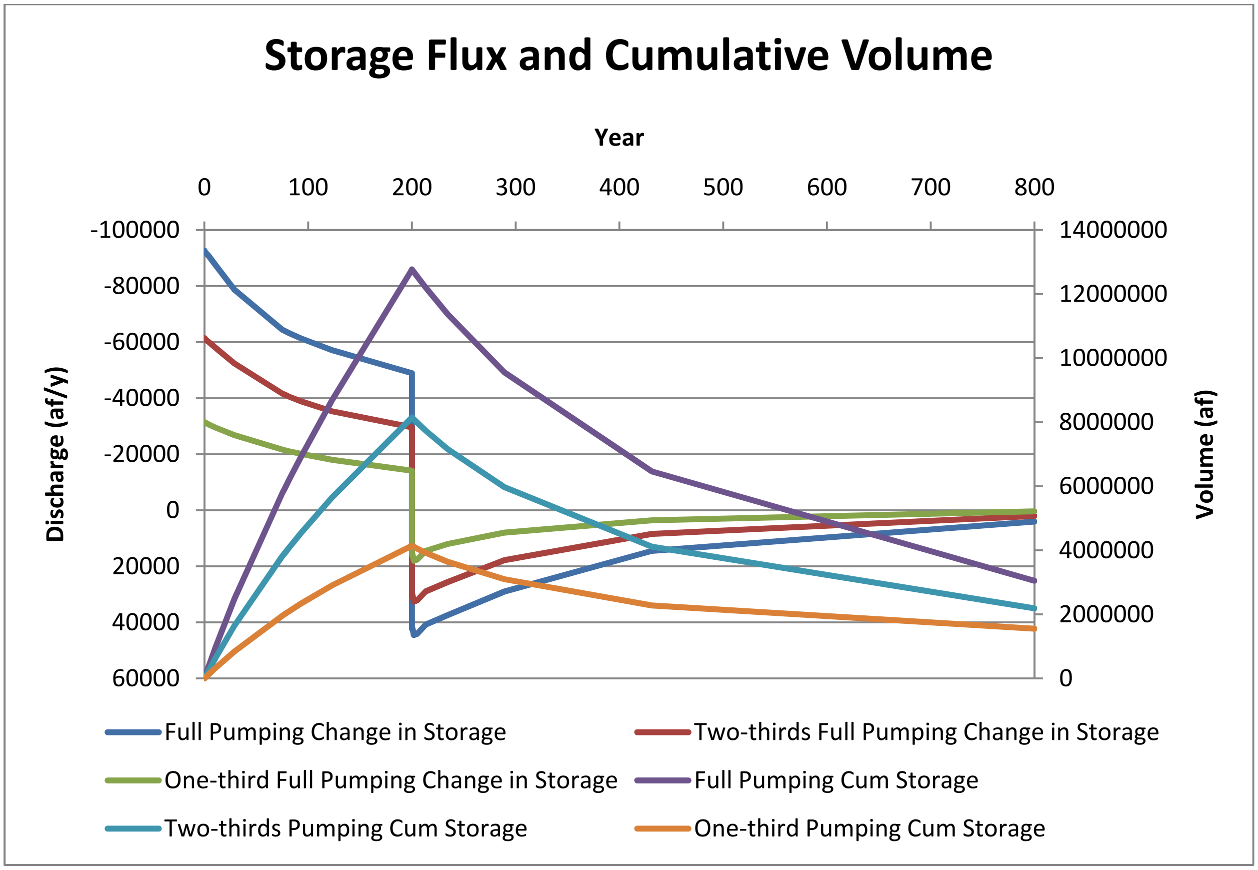

Figure 12: Comparison of change-in-storage hydrographs and cumulative groundwater removed from storage for three pumping rate scenarios.

Capturing natural discharge means capturing groundwater that is lost to phreatophytes. In this study area, especially in Spring Valley, the phreatophyte transpiration is both directly from groundwater and from spring discharge. The total model discharge (ET and springs) and model ET discharge have decreased the most by 200 years and begin to recover only slowly after pumping ceases (Figure 13).

Total discharge for the full pumping scenario remains barely changed for about 13 years; time to recovery starts for the lower pumping rates is about 5 years.

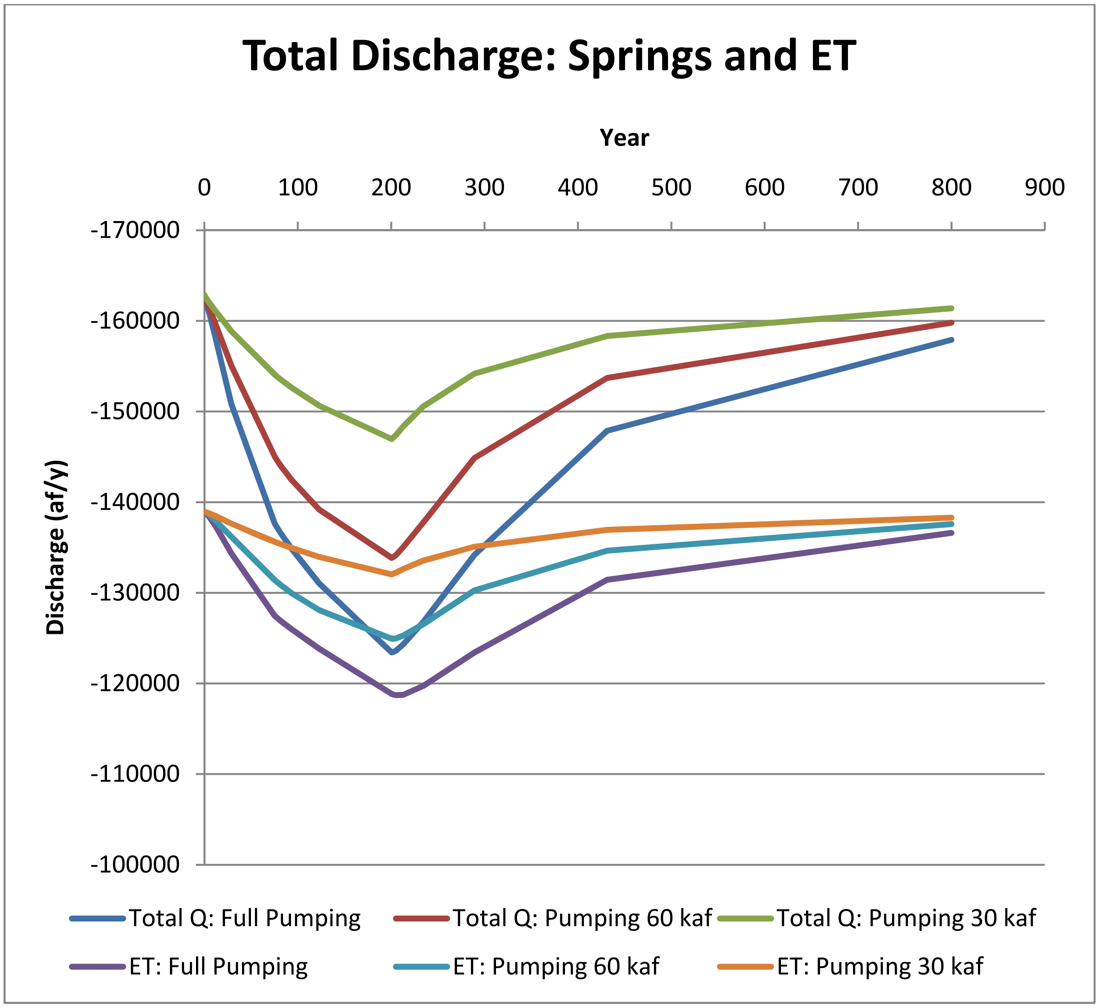

Figure 13: Comparison of discharge hydrographs for pumping the full, two-thirds, and one-third amount from the original SNWA applications.

Some individual springs will be dried completely, and remain dry for tens of years after pumping ceases. Full and two-thirds pumping dried Millick Springs in 75 and 100 years, respectively, with recovery in 230 and 80 years after the cessation of pumping, respectively (Figure 14). One-third pumping has less of an effect, decreasing the discharge after 200 years by 75%; recovery commences immediately (Figure 14). Cleve Creek Springs suffers a similar fate, going dry within 75 years for both full and two-thirds pumping (Figure 15). Recovery to a rate that is just beginning to discharge again takes up to 430 years (Figure 15).

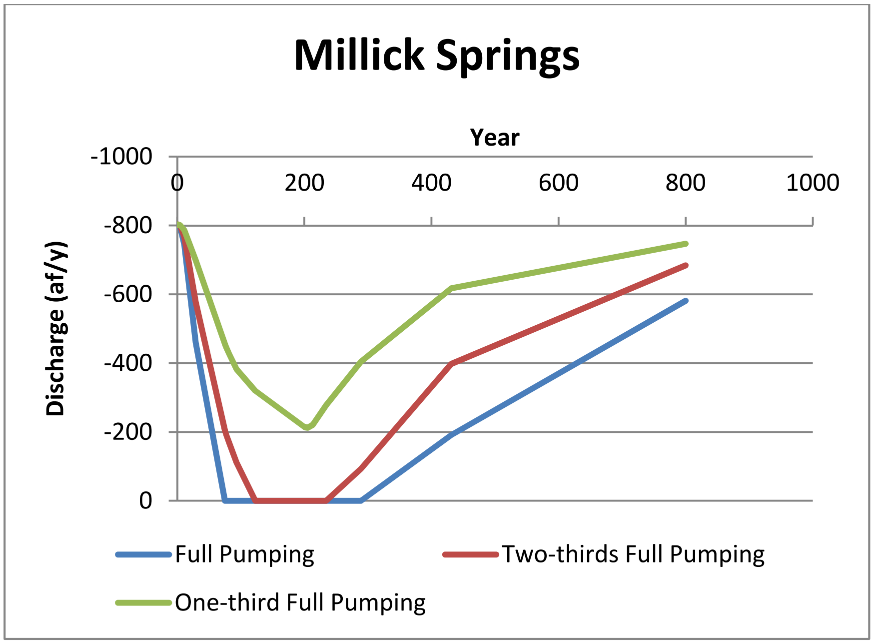

Figure 14: Discharge hydrograph, Millick Springs SNWA Original Apps.

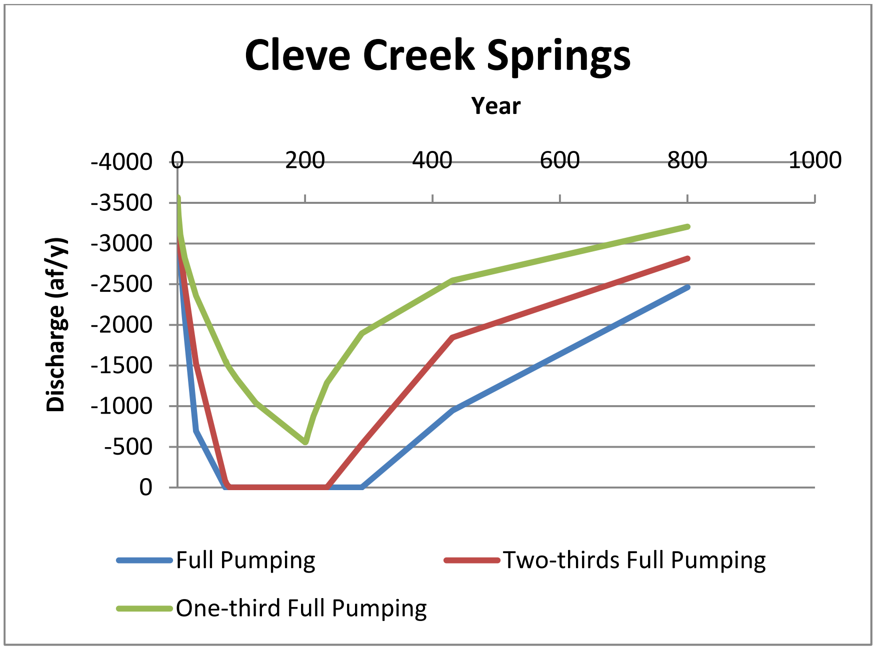

Figure 15: Discharge hydrograph, Cleve Creek Springs, SNWA Original Apps.

Pumping also affects the South Spring Valley spring complex (Figure 16) and its reduced flow is substantially responsible for the overall decreased discharge from the valley (Figure 13). This spring represents seeps around the edge of the playa, so the large recharge both in carbonate rock in the South Snake Range and along the mountain front support these springs and also lead to the relatively rapid recovery (Figure 16).

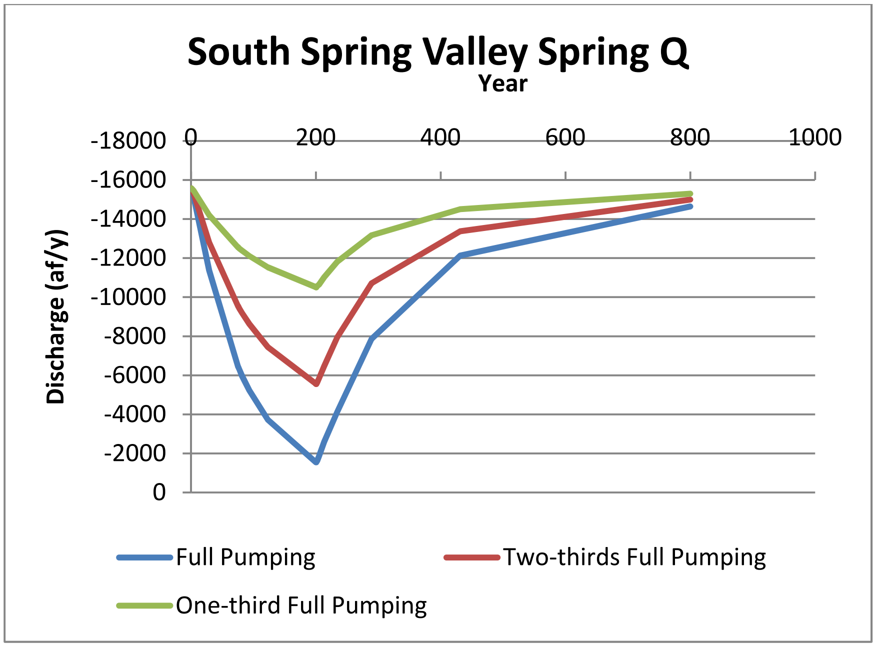

Figure 16: Discharge hydrograph, S Spring Valley Springs.

Pumping also affects discharge from Swallow Springs (Figure 17), although the relatively lower effect reflects both its location east of a fault and proximity to just one SNWA application, #54021. The low conductivity near this well causes a huge drawdown at the well boundary but it decreases rapidly with radial distance from the well.

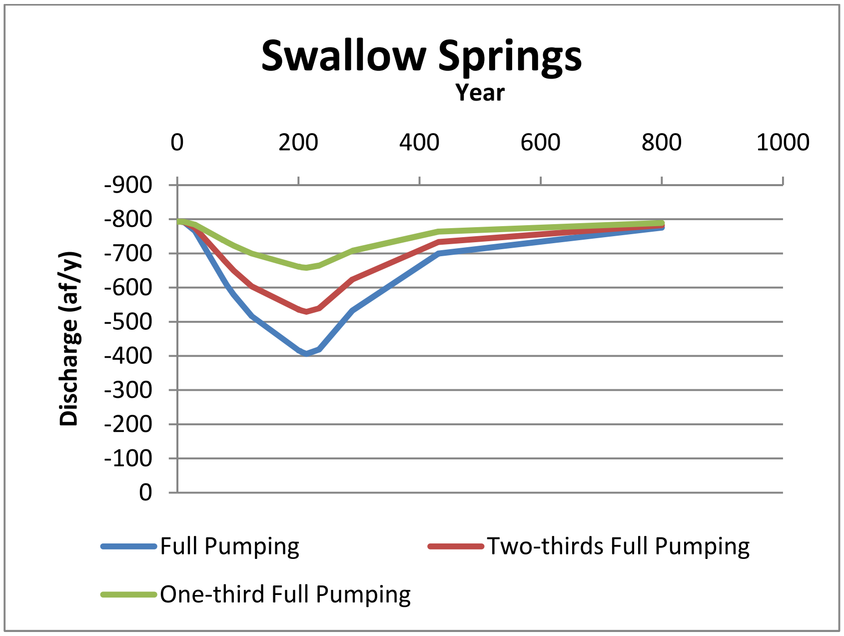

Figure 17: Discharge hydrograph, S Spring Valley Springs, SNWA Original Apps.

Big Springs is a major spring in Snake Valley, but pumping in Spring Valley clearly affects it (Figure 18). The effects continue to worsen up to 80 years after pumping ceases, a factor which demonstrates how the time to full capture can continue long after pumping ceases and demonstrates also the fallacy of monitoring plans (Bredehoeft and Durbin, 2009). Recovery occurs slowly once it begins, with the rate still being less than 85% of the steady state rate a full 600 years after pumping ceases. The broad expansion of drawdown into Hamlin and Snake Valley (Figures 10 and 11 and Appendix A) causes this decreased spring discharge. Spring Valley pumping captures Snake Valley spring discharge by decreasing the interbasin flow which supports Big Springs.

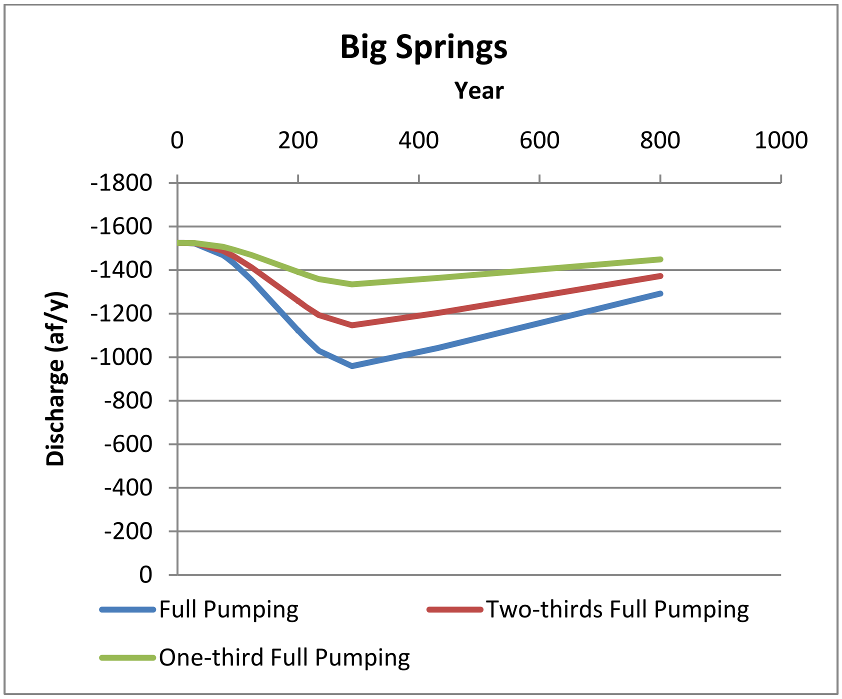

Figure 18: Discharge hydrograph, S Spring Valley Springs, SNWA Original Apps.

Pumping to Equilibrium

None of the scenarios approach equilibrium within 200 years nor recover within 600 years. Because perennial yield is the amount of water that can be pumped such that the system will come to equilibrium within a reasonable time, four scenarios were pumped for 10,200 years to determine the time to equilibrium. All three pumping rates were tested to determine if they would reach equilibrium.

Pumping the full application amount for 10,200 years did not reach equilibrium, as shown clearly on Figure 19. After 10,200 years, the annual release from storage is still 1310 af/y, having started at a rate essentially equivalent to the pumping rate. The total ET from the model domain, which includes Snake Valley, also continues to drop; ET continues at rates higher than 80,000 af/y due to continued discharge from Snake Valley. Springs have essentially dried up, dropping from a simulated discharge in excess of 23,000 af/y to less than 1000 af/y. The total groundwater volume removed in 10,200 years exceeds 90,000,000 af, an amount that reflects hundreds of feet of drawdown in Spring

Valley and up to a couple hundred feet in parts of Snake Valley (Figure 20). The estimates loss from storage does not include releases from storage in Steptoe Valley because inflow from that valley was simulated as a boundary, so the total estimated loss from storage is an underestimate. Pumping for this extended period would have devastating effects around Spring Valley.

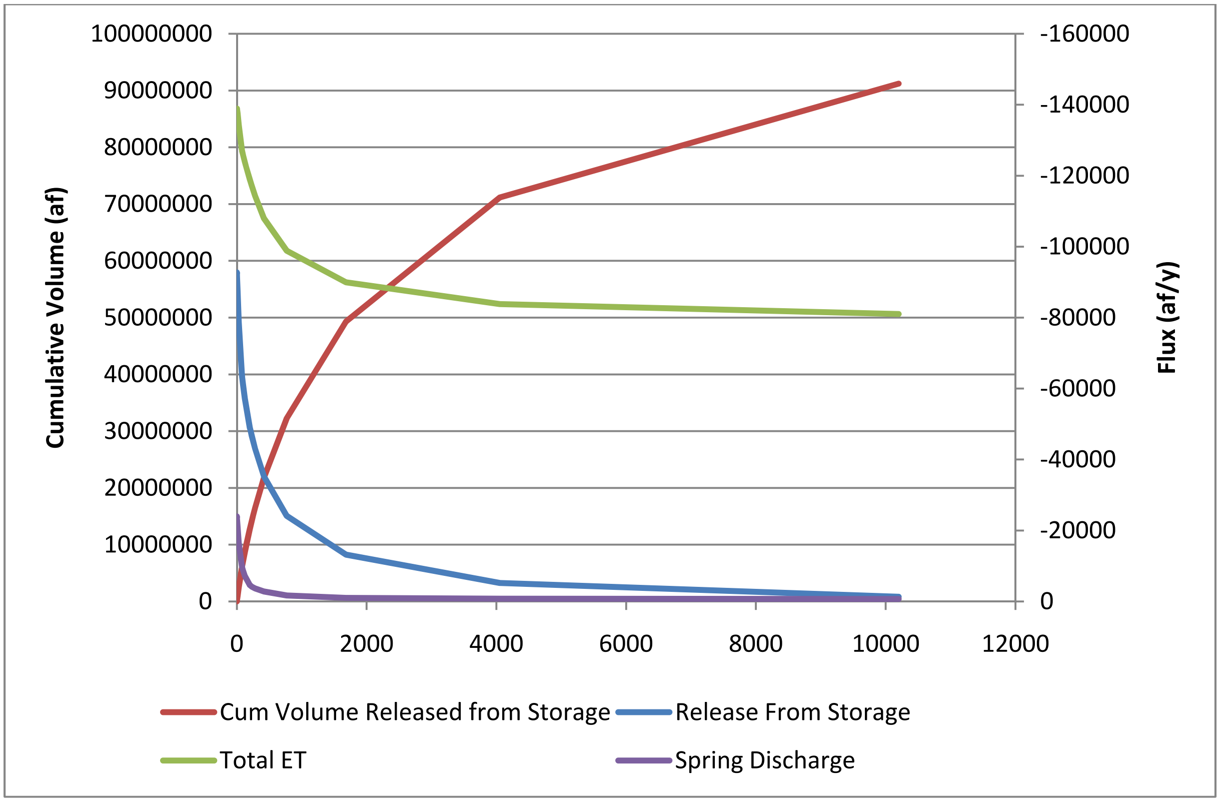

Figure 19: Hydrograph of storage, ET, and spring discharge, and cumulative storage for pumping full application amount at original application locations for 10,200 years.

After 1625 years, drawdown has expanded far into Snake Valley and north to Tippet Valley (Figure 20). Almost all of Hamlin Valley would experience from 20 to 50 feet of drawdown and drawdown up to 20 feet extends far into Snake Valley from the south. This reflects the interception of groundwater that otherwise flows through the Limestone Hills area. Drawdown in Snake Valley of up to 10 feet also occurs in the north, just south of Pleasant Valley.

Drawdown in the pumping wells also continues to increase for 10,200 years (Figure 21). Well 54020 was completed in carbonate rock with relatively low Kh, so its water level had gone below the layer bottoms within 200 years. The other wells on Figure 21 are completed in fill, which has higher Kh and more storativity. The drawdown in those wells remains within reasonable levels, but continues to increase for the entire time period. After 200 years, the wells completed in fill have reached 30 to 50% of the drawdown they reach within 10,200 years; this reflects the large available storage in the fill and the relatively high conductivity.

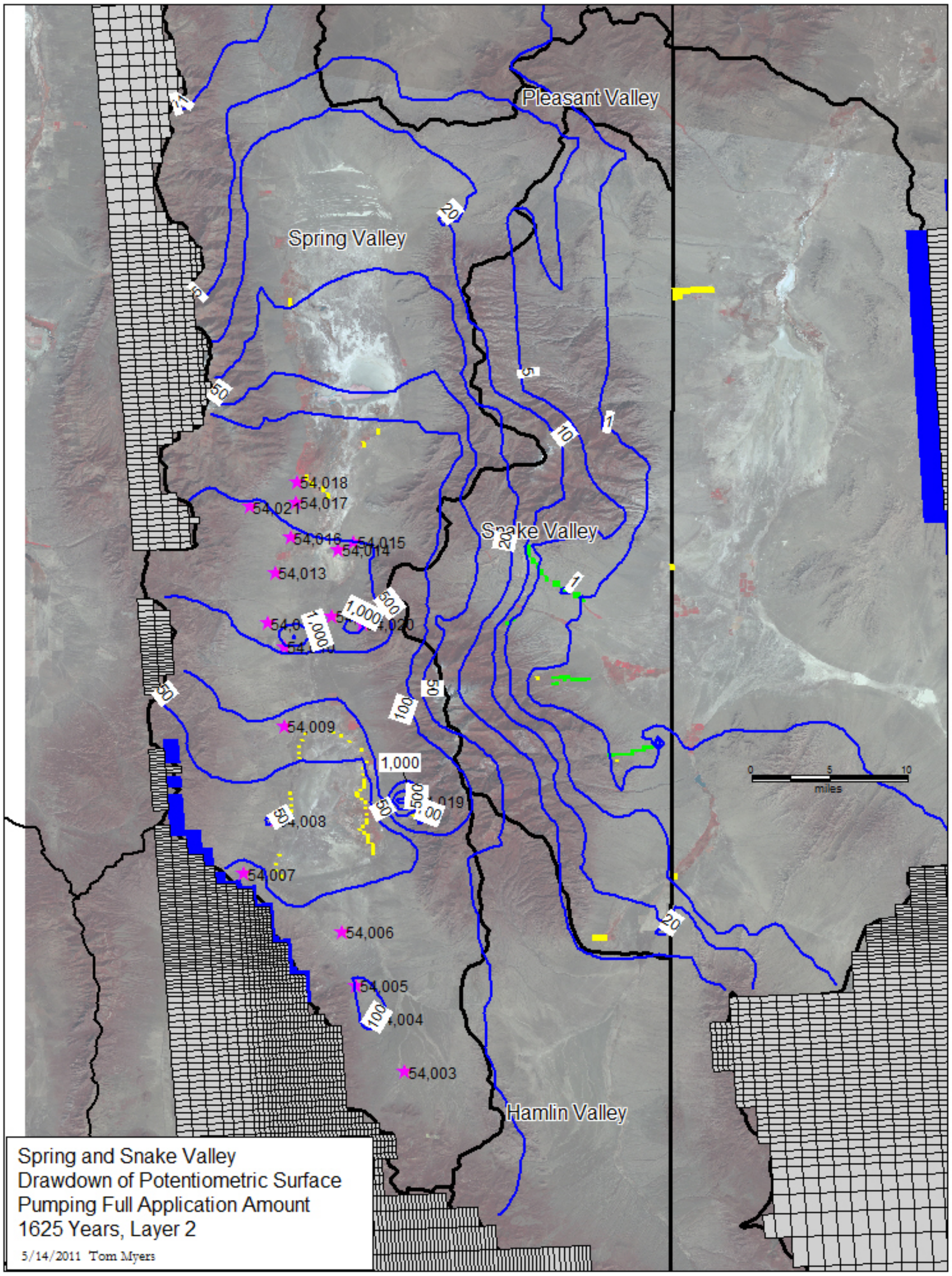

Figure 20: Drawdown contours after pumping full application amount from original application locations for 1625 years in layer 2.

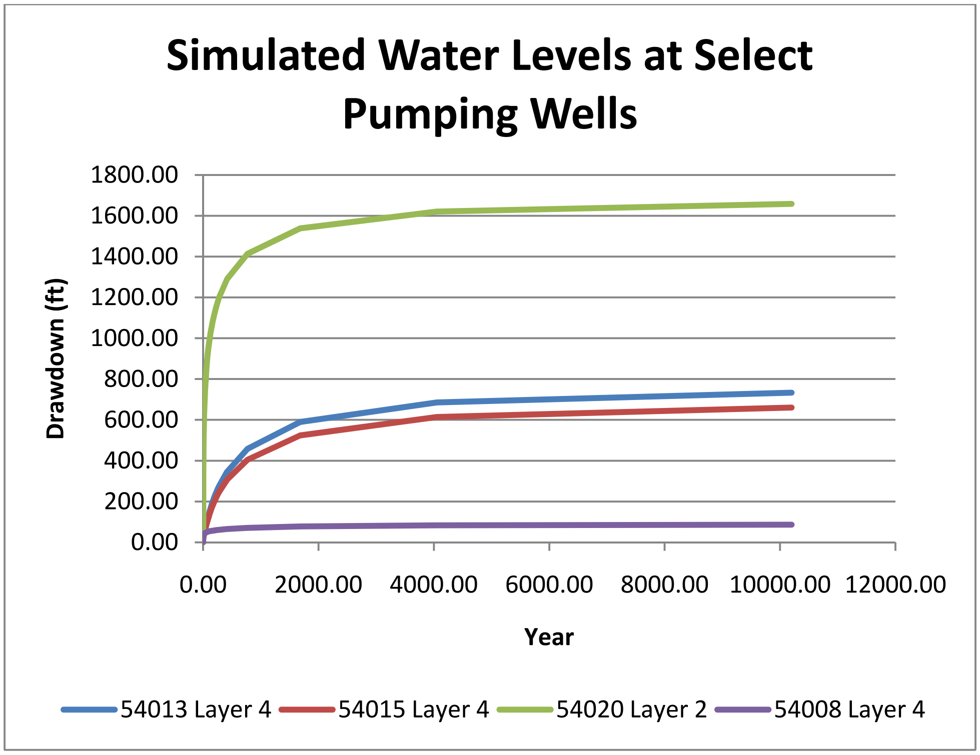

Figure 21: Drawdown hydrograph at various pumping wells pumping full application amount.

An additional test of pumping to equilibrium involved pumping at one-third of the full application rate. This amount is less than half of the recharge and discharge within Spring Valley, so it seemed that the system could approach equilibrium. Change in storage hydrographs varied only marginally for 1000 years. After 10,200 years, pumping had removed 26,500,000 af of groundwater from storage and was continuing to remove about 1200 af/y, about 4% of the pumpage amount. Even at this decreased amount, pumping from Spring Valley will not reach equilibrium within 10,200 years.

In summary, as the system approaches steady state, almost all of the spring and ET discharge within Spring Valley would be eliminated but water would continue to be removed from storage because the discharge is less than the total pumping. For this reason, the pumping removes storage from other valleys by inducing flow from (Steptoe) or reducing flow to (Snake and Tippet Valley) those valleys. At some wells, the predicted drawdown remains within the capacity of pumping to accommodate, but equilibrium is not reached for a very long time, if ever. As Bear (1979) notes, in an infinite aquifer, the drawdown eventually extends to infinity. These aquifers are not infinite, but the reach of drawdown can reach tens to hundreds of miles from the 19 wells.

CONCLUSION

The overarching conclusion of this evidence report regarding SNWA's application to withdraw underground water from Spring Valley is that permitting these applications or even a third of the total amount would dry wetlands and springs throughout the valley, decrease interbasin flow to Snake and Tippet Valley, and increase the amount of water drawn from Steptoe Valley. The groundwater system would not reach equilibrium for over 10,200 years for pumping the original applications as proposed by SNWA; even pumping a much-reduced rate would not come to equilibrium in a similar time frame. The project epitomizes the definition of groundwater mining as outlined by the Nevada State Engineer in Ruling 5726. Specific conclusions are as follows:

- SNWA's applied-for water rights exceed the average recharge and discharge by 27 and 20 percent, respectively.
- All water pumped will eventually take water from the natural discharge – from springs and wetlands within Spring Valley or from surrounding valleys.
- Capturing the discharge means capturing up to all of the spring flow and drying all of the wetlands in Spring Valley. That is the consequence of developing up to the groundwater discharge rate in the valley.
- There are many spring water rights that draw from the groundwater resource. Pumping the SNWA applications will directly take water from these springs, causing them to dry or become much reduced in flow, to the detriment of the environment and spring water rights holders.
- Developing more than the natural groundwater discharge rate would by necessity draw groundwater from discharge locations (springs and wetlands) in adjoining valleys, including Tippett and Snake Valley.
- Developing more than the natural groundwater discharge rate would also cause substantial amounts of water to flow Spring Valley from Steptoe and Lake Valleys.
- Pumping the original applications would causes hundreds of feet of drawdown at the well sites and substantially dry many springs and wetlands.
- Reducing the amount of pumping does not reduce the extent of drawdown much through center of Spring Valley. Springs and wetlands are still detrimentally affected.
- Pumping in Spring Valley would decrease flow in Big Springs by up to a third. The springs require centuries after pumping ceases to recover because shallow drawdown cones continue to expand for decades after 200 years of pumping.
- The Spring Valley groundwater system does not come to equilibrium even after 10,200 years pumping the full application amount from the application location.
- The Spring Valley groundwater system also does not come to equilibrium even after 10,200 years of pumping less than one-third of the applied-for amount of groundwater from the application locations.

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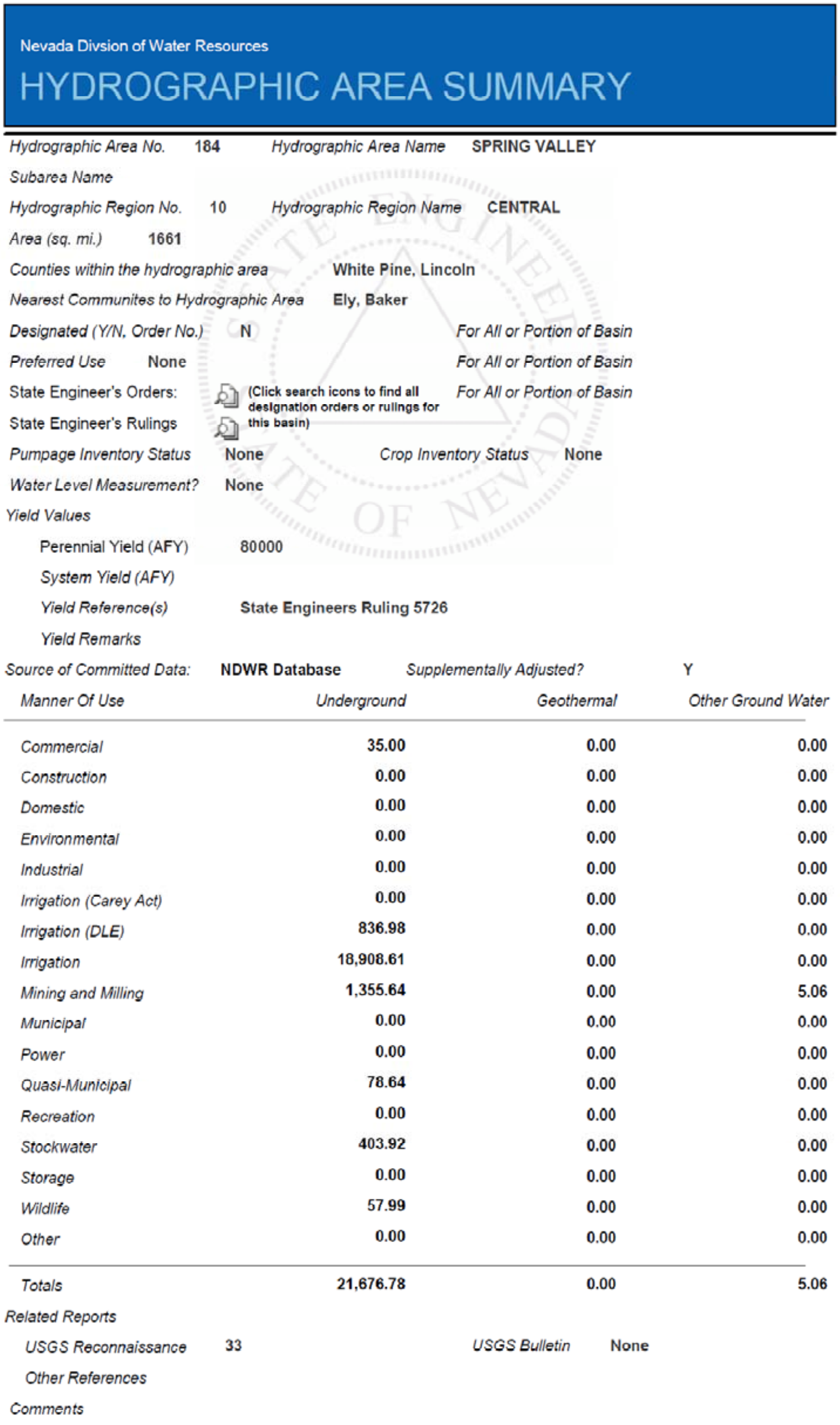
Appendix A: Spring Valley Hydrologic Summaries from Nevada State Engineer Web Page, http://water.nv.gov/data/underground/, downloaded May 17, 2011



Nevada Divsion of Water Resources

HYDROGRAPHIC AREA SUMMARY

Hydrographic Area No. **184** *Hydrographic Area Name* **SPRING VALLEY**

Subarea Name

Hydrographic Region No. **10** *Hydrographic Region Name* **CENTRAL**

Area (sq. mi.) **1661**

Counties within the hydrographic area **White Pine, Lincoln**

Nearest Communites to Hydrographic Area **Ely, Baker**

Designated (Y/N, Order No.) **N** *For All or Portion of Basin*

Preferred Use **None** *For All or Portion of Basin*

State Engineer's Orders: **(Click search icons to find all designation orders or rulings for this basin)** *For All or Portion of Basin*

State Engineer's Rulings

Pumpage Inventory Status **None** *Crop Inventory Status* **None**

Water Level Measurement? **None**

Yield Values

Perennial Yield (AFY) **80000**

System Yield (AFY)

Yield Reference(s) **State Engineers Ruling 5726**

Yield Remarks

Source of Committed Data: **NDWR Database** *Supplementally Adjusted?* **Y**

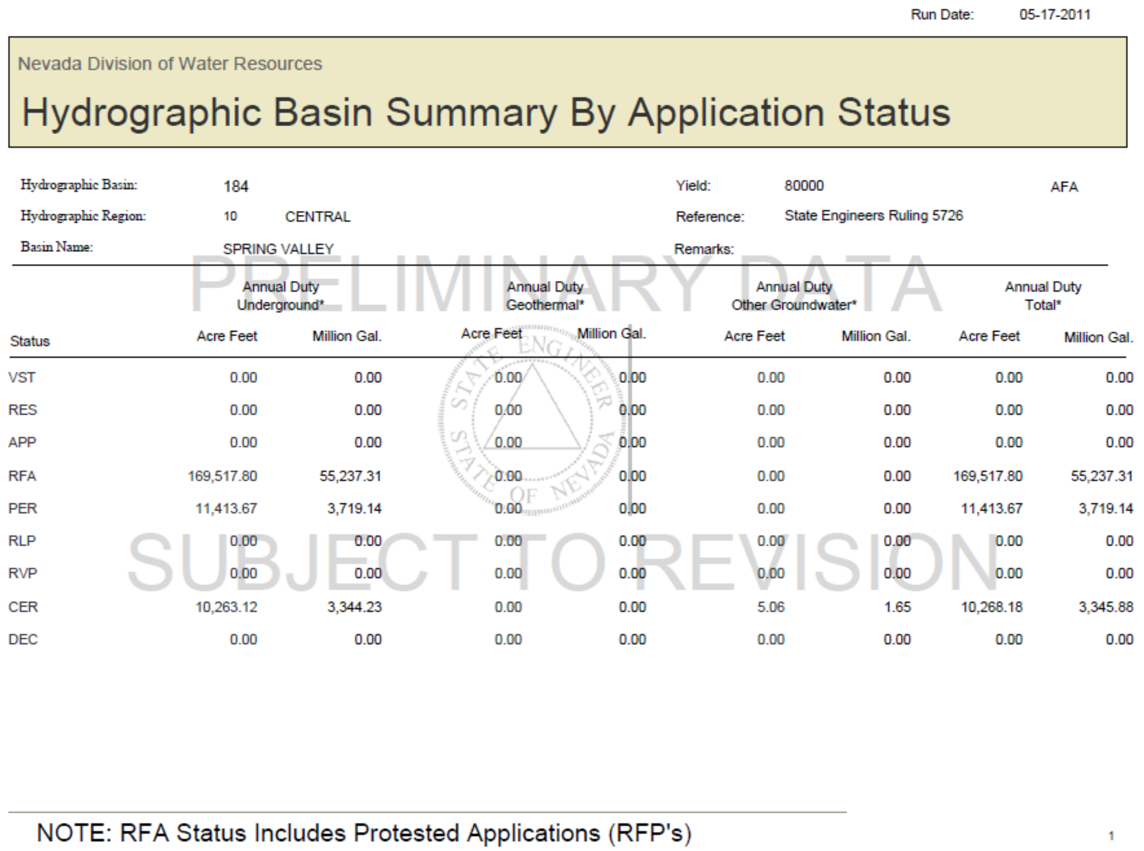
Manner Of Use	*Underground*	*Geothermal*	*Other Ground Water*
Commercial	**35.00**	**0.00**	**0.00**
Construction	**0.00**	**0.00**	**0.00**
Domestic	**0.00**	**0.00**	**0.00**
Environmental	**0.00**	**0.00**	**0.00**
Industrial	**0.00**	**0.00**	**0.00**
Irrigation (Carey Act)	**0.00**	**0.00**	**0.00**
Irrigation (DLE)	**836.98**	**0.00**	**0.00**
Irrigation	**18,908.61**	**0.00**	**0.00**
Mining and Milling	**1,355.64**	**0.00**	**5.06**
Municipal	**0.00**	**0.00**	**0.00**
Power	**0.00**	**0.00**	**0.00**
Quasi-Municipal	**78.64**	**0.00**	**0.00**
Recreation	**0.00**	**0.00**	**0.00**
Stockwater	**403.92**	**0.00**	**0.00**
Storage	**0.00**	**0.00**	**0.00**
Wildlife	**57.99**	**0.00**	**0.00**
Other	**0.00**	**0.00**	**0.00**
Totals	**21,676.78**	**0.00**	**5.06**

Related Reports

USGS Reconnaissance **33** *USGS Bulletin* **None**

Other References

Comments



Run Date: 05-17-2011

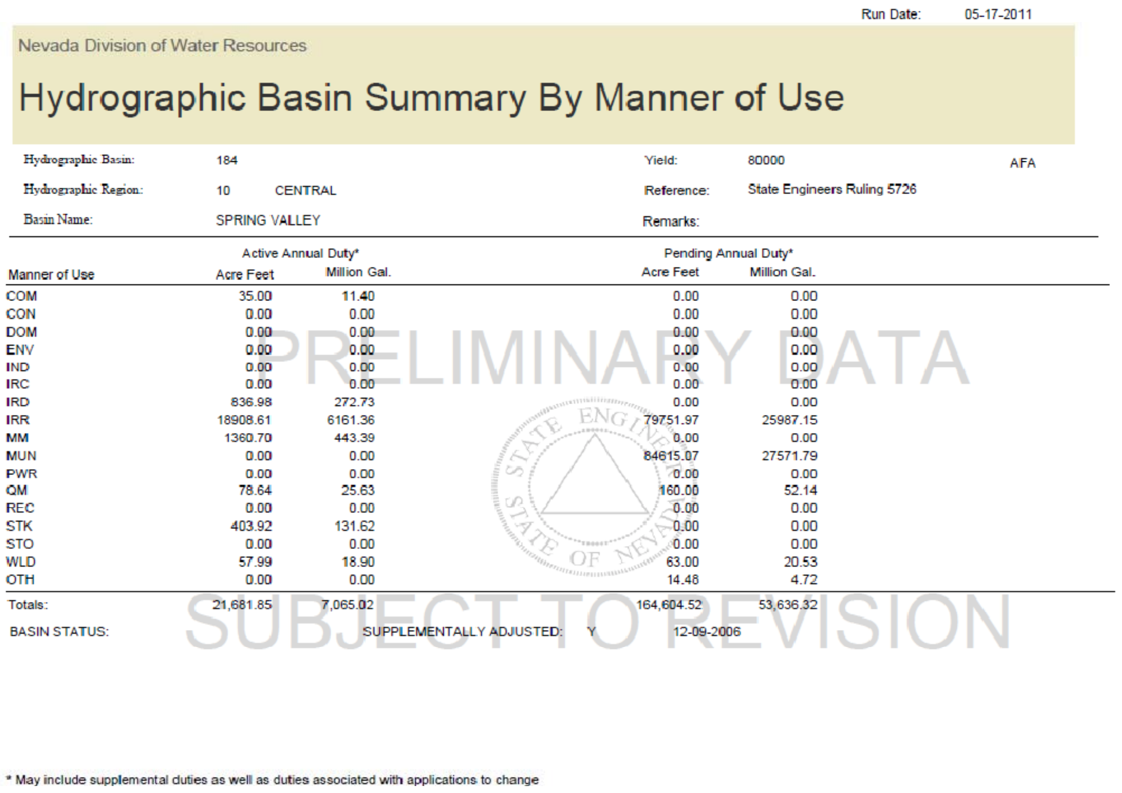
Nevada Division of Water Resources

Hydrographic Basin Summary By Application Status

Hydrographic Basin:	184	Yield:	80000	AFA
Hydrographic Region:	10 CENTRAL	Reference:	State Engineers Ruling 5726	
Basin Name:	SPRING VALLEY	Remarks:		

	Annual Duty Underground*		Annual Duty Geothermal*		Annual Duty Other Groundwater*		Annual Duty Total*	
Status	Acre Feet	Million Gal.	Acre Feet	Million Gal.	Acre Feet	Million Gal.	Acre Feet	Million Gal.
VST	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
APP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RFA	169,517.80	55,237.31	0.00	0.00	0.00	0.00	169,517.80	55,237.31
PER	11,413.67	3,719.14	0.00	0.00	0.00	0.00	11,413.67	3,719.14
RLP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RVP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CER	10,263.12	3,344.23	0.00	0.00	5.06	1.65	10,268.18	3,345.88
DEC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

NOTE: RFA Status Includes Protested Applications (RFP's)



Run Date: 05-17-2011

Nevada Division of Water Resources

Hydrographic Basin Summary By Manner of Use

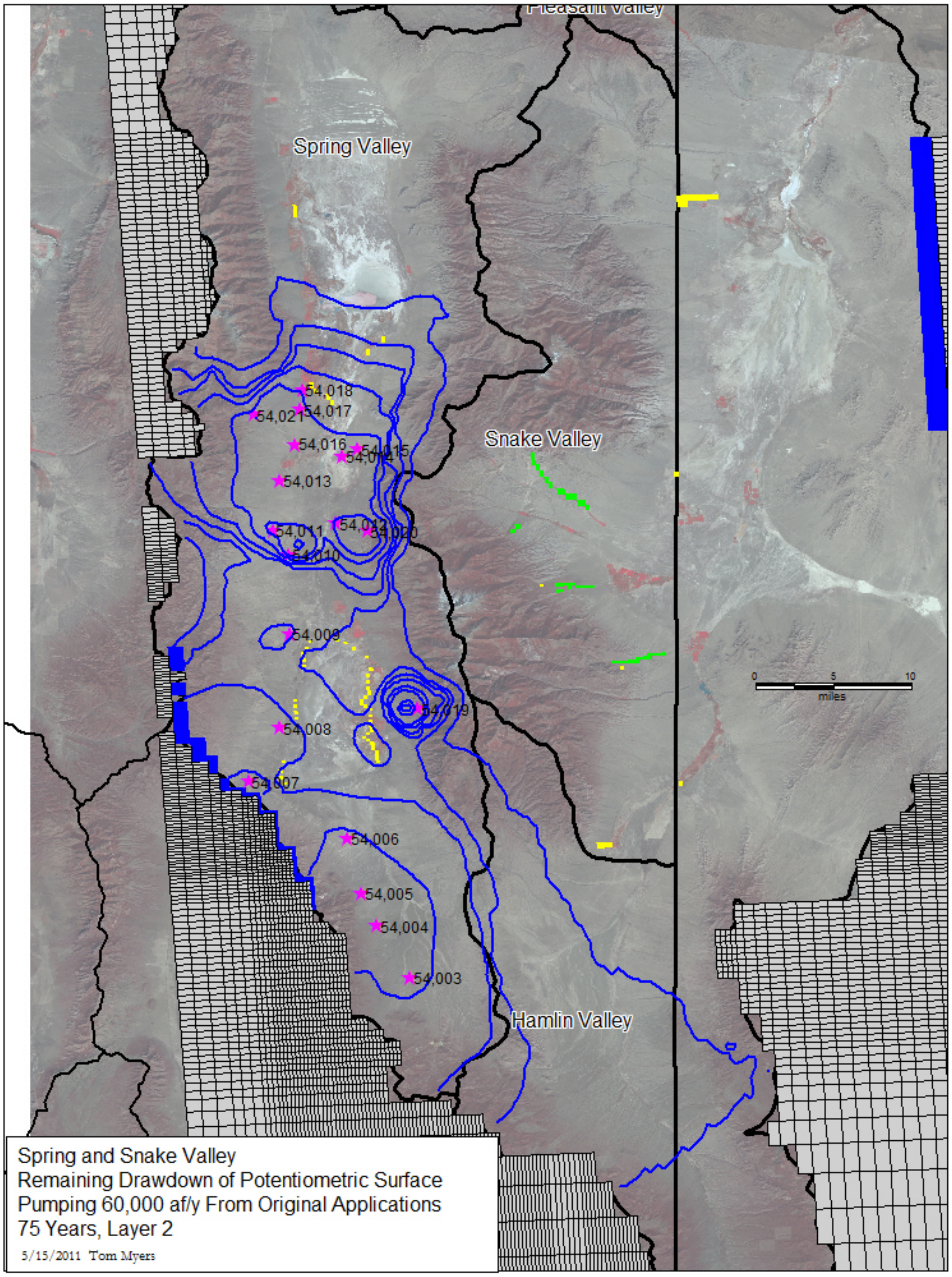
Hydrographic Basin:	184	Yield:	80000	AFA
Hydrographic Region:	10 CENTRAL	Reference:	State Engineers Ruling 5726	
Basin Name:	SPRING VALLEY	Remarks:		

	Active Annual Duty*		Pending Annual Duty*	
Manner of Use	Acre Feet	Million Gal.	Acre Feet	Million Gal.
COM	35.00	11.40	0.00	0.00
CON	0.00	0.00	0.00	0.00
DOM	0.00	0.00	0.00	0.00
ENV	0.00	0.00	0.00	0.00
IND	0.00	0.00	0.00	0.00
IRC	0.00	0.00	0.00	0.00
IRD	836.98	272.73	0.00	0.00
IRR	18908.61	6161.36	79751.97	25987.15
MM	1360.70	443.39	0.00	0.00
MUN	0.00	0.00	84615.07	27571.79
PWR	0.00	0.00	0.00	0.00
QM	78.64	25.63	160.00	52.14
REC	0.00	0.00	0.00	0.00
STK	403.92	131.62	0.00	0.00
STO	0.00	0.00	0.00	0.00
WLD	57.99	18.90	63.00	20.53
OTH	0.00	0.00	14.48	4.72
Totals:	21,681.85	7,065.02	164,604.52	53,636.32

BASIN STATUS: SUPPLEMENTALLY ADJUSTED: Y 12-09-2006

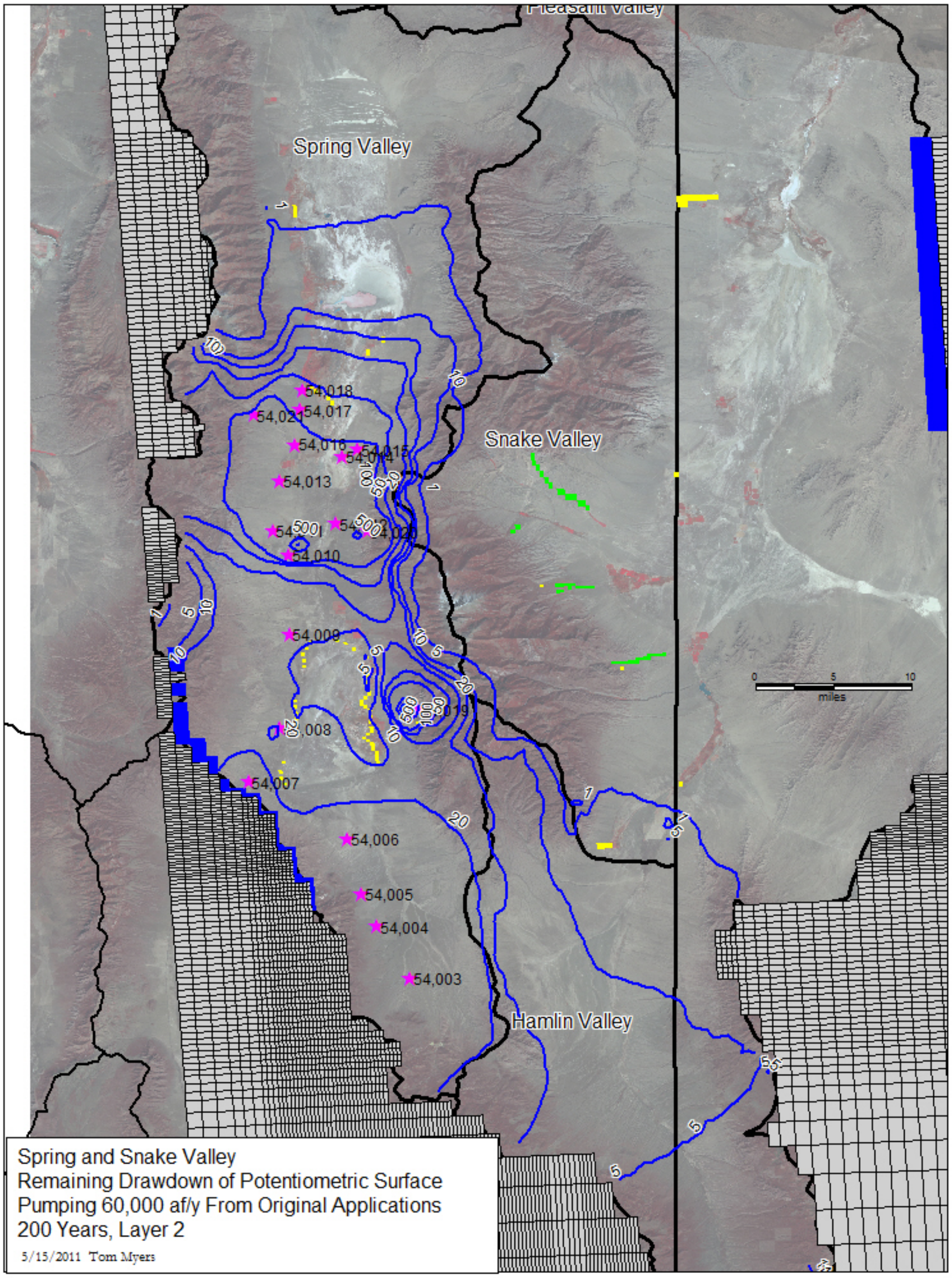
* May include supplemental duties as well as duties associated with applications to change

Appendix B: Drawdown Contour Maps for Various Pumping Scenarios

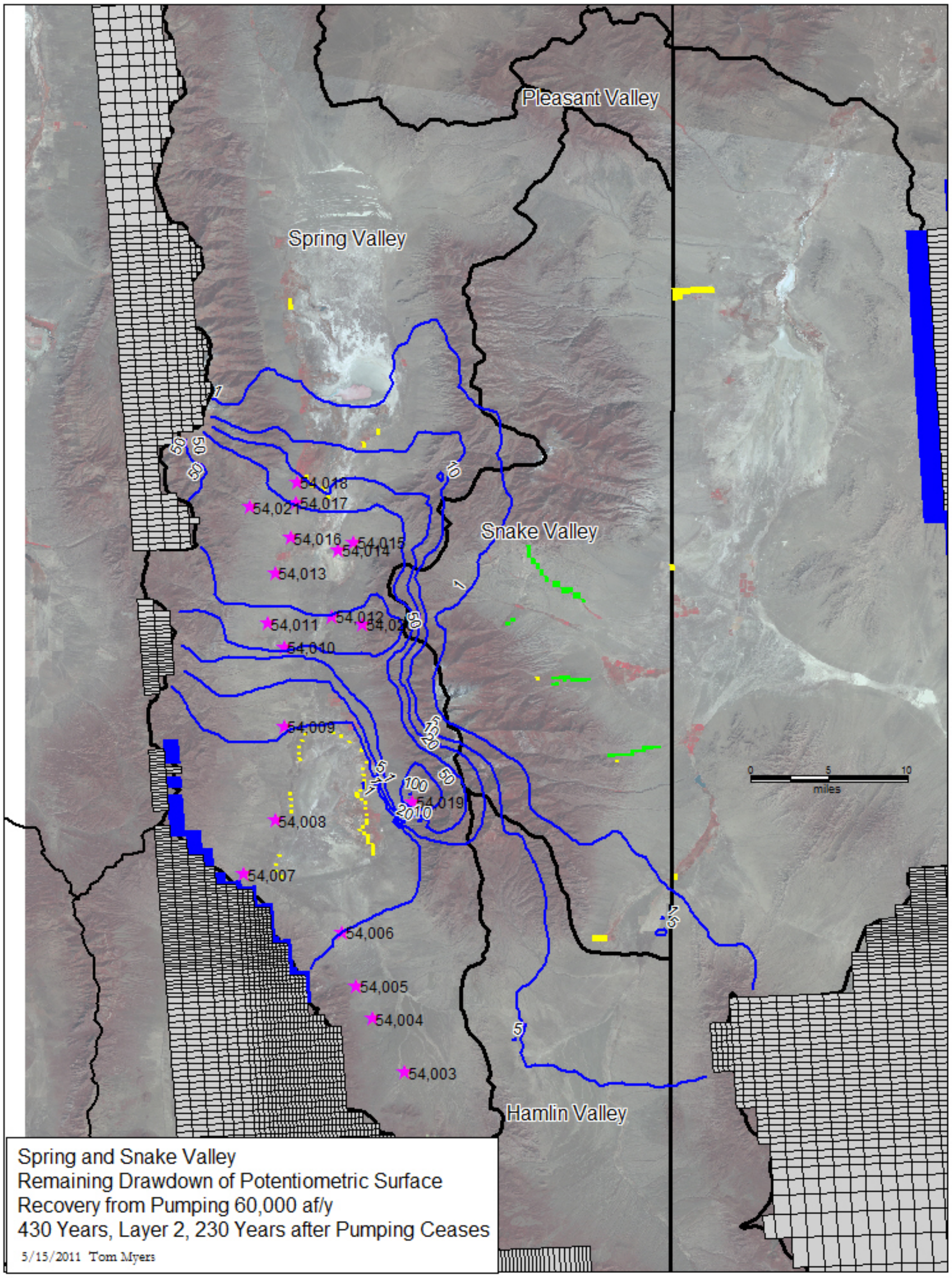


Spring and Snake Valley
Remaining Drawdown of Potentiometric Surface
Pumping 60,000 af/y From Original Applications
75 Years, Layer 2

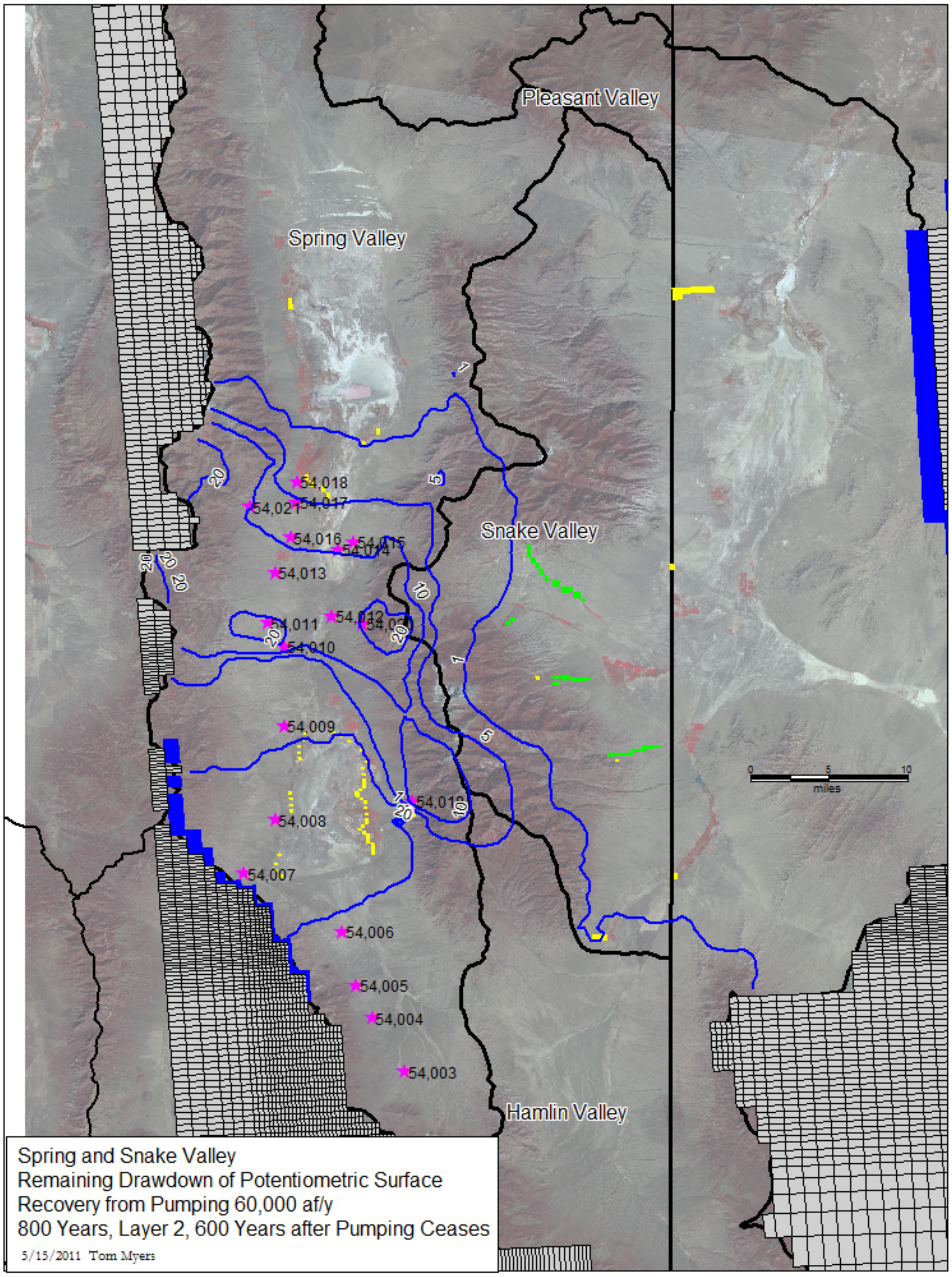
5/15/2011 Tom Myers



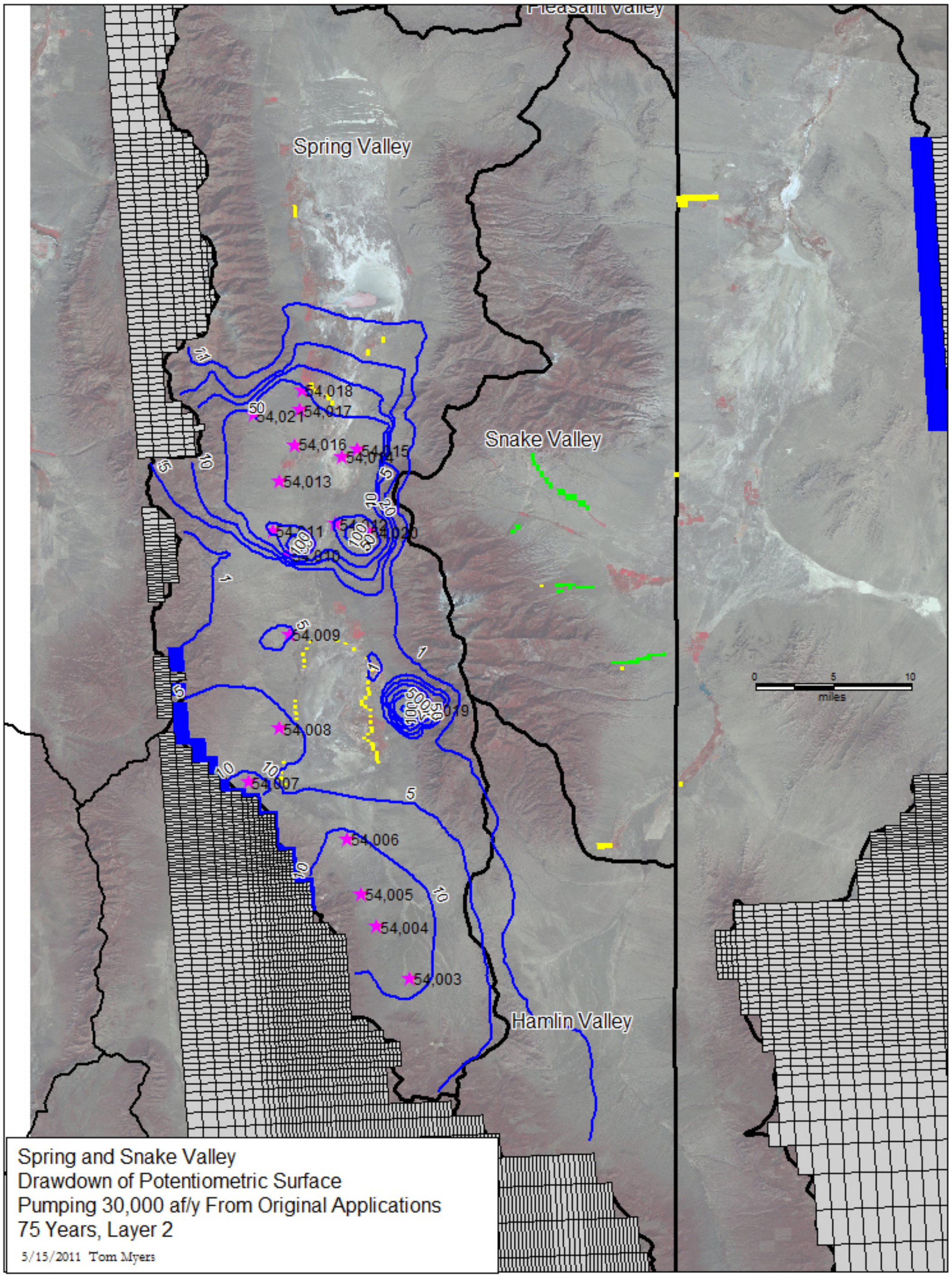
Spring and Snake Valley
Remaining Drawdown of Potentiometric Surface
Pumping 60,000 af/y From Original Applications
200 Years, Layer 2
5/15/2011 Tom Myers



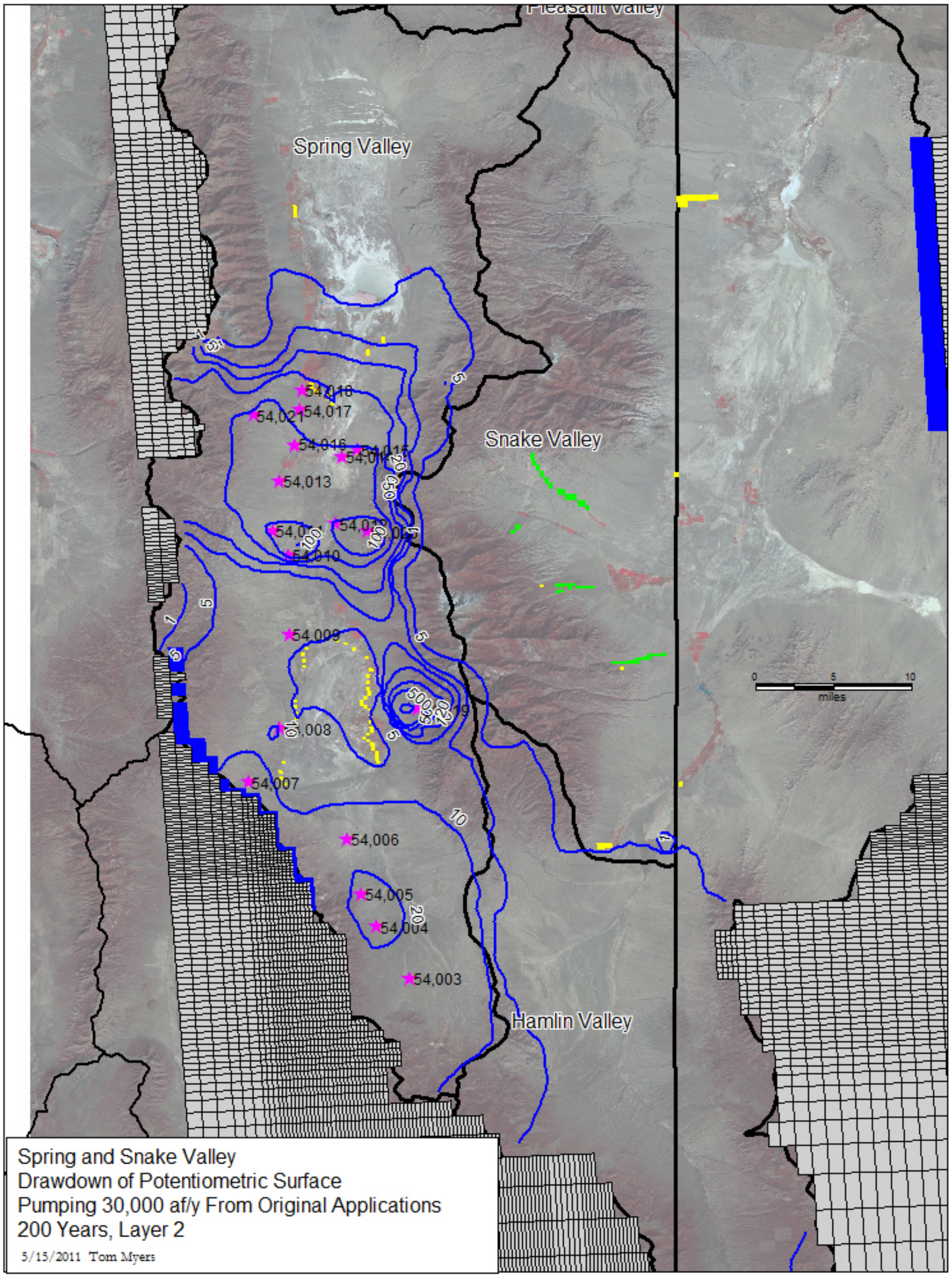
Spring and Snake Valley
Remaining Drawdown of Potentiometric Surface
Recovery from Pumping 60,000 af/y
430 Years, Layer 2, 230 Years after Pumping Ceases
5/15/2011 Tom Myers



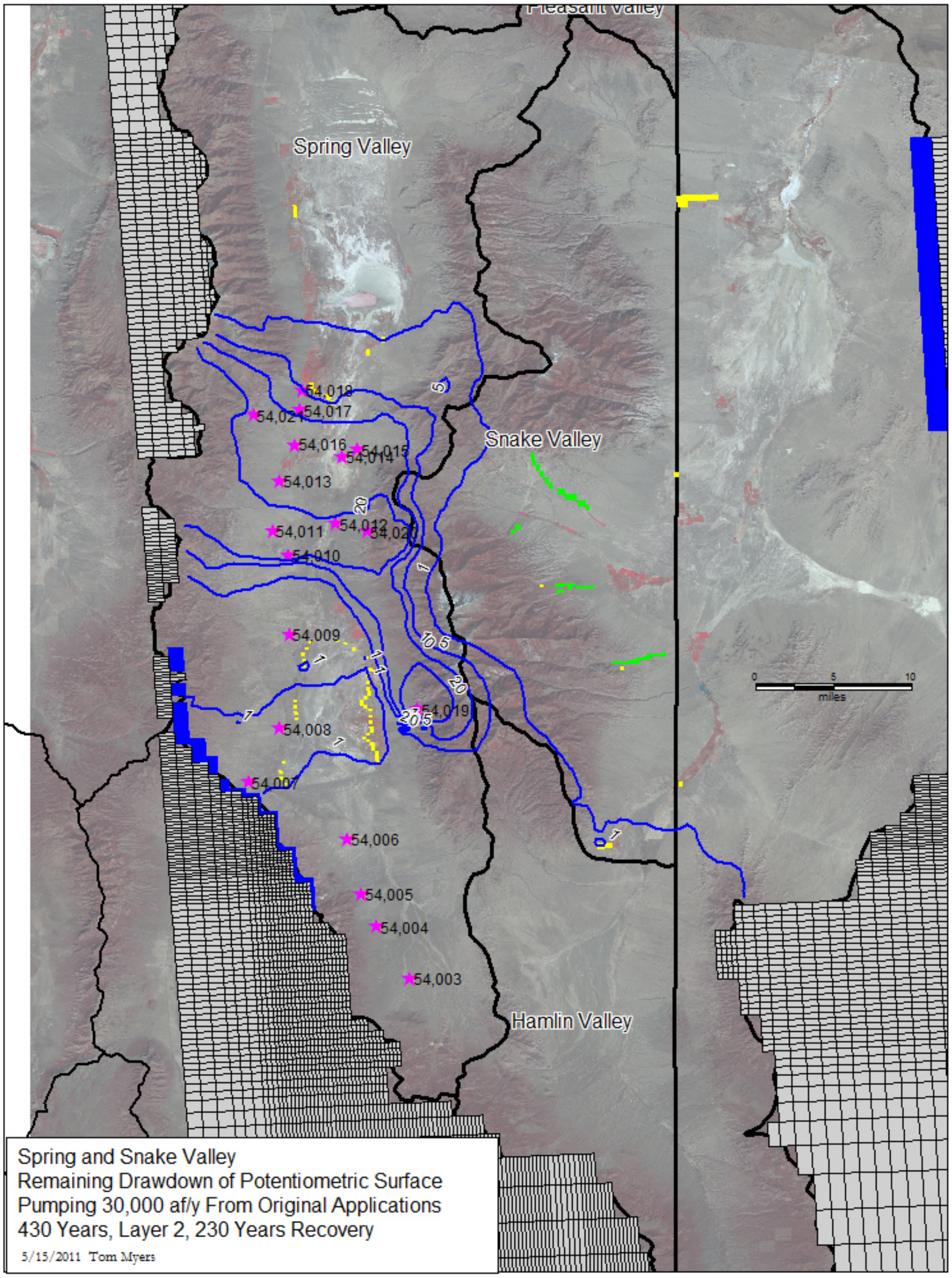
Spring and Snake Valley
Remaining Drawdown of Potentiometric Surface
Recovery from Pumping 60,000 af/y
800 Years, Layer 2, 600 Years after Pumping Ceases
5/15/2011 Tom Myers



Spring and Snake Valley
Drawdown of Potentiometric Surface
Pumping 30,000 af/y From Original Applications
75 Years, Layer 2
5/15/2011 Tom Myers

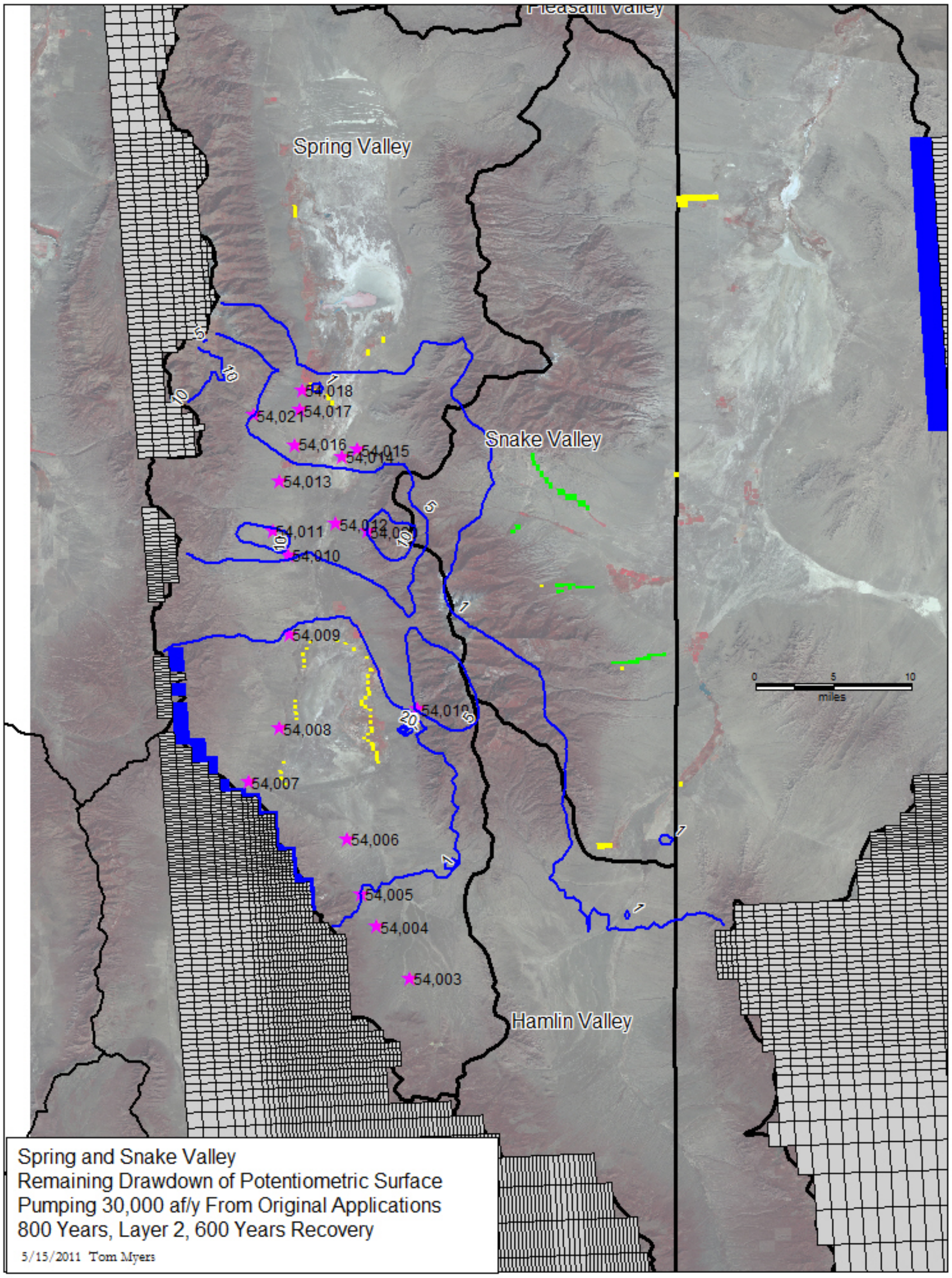


Spring and Snake Valley
Drawdown of Potentiometric Surface
Pumping 30,000 af/y From Original Applications
200 Years, Layer 2
5/15/2011 Tom Myers



Spring and Snake Valley
Remaining Drawdown of Potentiometric Surface
Pumping 30,000 af/y From Original Applications
430 Years, Layer 2, 230 Years Recovery

5/15/2011 Tom Myers



Spring and Snake Valley
Remaining Drawdown of Potentiometric Surface
Pumping 30,000 af/y From Original Applications
800 Years, Layer 2, 600 Years Recovery
5/15/2011 Tom Myers