CPB Exh 19

Expert Report of Aquaveo, LLC

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Sustainability of the SNWA Pumping Project in Spring Valley, Nevada

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1 Executive Summary

Cleveland Ranch is a cattle ranch situated in the center of Spring Valley, Nevada. The Ranch is owned by Corporation of the Presiding Bishop of The Church of Jesus Christ of Latter-day Saints (CPB) and the ranch has 30,564 AFA of water rights, consisting of surface water (streams, springs, seeps) and groundwater (wells) rights.

The Southern Nevada Water Authority (SNWA) has made a formal application to the Nevada State Engineer to appropriate groundwater from 25 points of diversion (well locations), 19 of which are in Spring Valley. CPB formally protested 12 of these wells, contending that they would conflict with and do harm to the water rights associated with the Ranch. In 2011, CPB experts used the SNWA's own groundwater model to illustrate that the wells would cause substantial dewatering of the aquifer below the ranch and would not be at equilibrium 200 years after pumping began and therefore result in perpetual groundwater mining, which is against Nevada policy.

A set of hearings were conducted in 2011 where arguments for and against the pumping project were made to the Nevada State Engineer. In 2012, the State Engineer approved the project, with the exception of four wells directly adjacent to the Ranch. The State Engineer addressed the CPB objections by stating that there is no requirement for the system to come to equilibrium in a reasonable period of time as long as a balanced flow budget can be demonstrated on paper.

In January of 2013, CPB appealed the State Engineer's decision to the Nevada District Court, contending that the State Engineer's ruling was inconsistent with prior rulings and that the monitor, manage, and mitigate strategy outlined by the SNWA and approved by the State Engineer would not protect existing CPB water rights.

In December of 2013, District Judge Robert Estes issued a ruling on the appeal and reversed and remanded the State Engineer's ruling. Judge Estes agreed with CPB that the monitor, manage, and mitigate strategy would not adequately protect existing water rights holders and that the State Engineer's statements regarding time to equilibrium and groundwater mining were inconsistent with prior rulings and Nevada policy.

A new series of hearings has been scheduled for 2017 to resolve the issues raised by Judge Estes in his ruling. In preparation for these hearings we have conducted a supplemental analysis and prepared new evidence regarding the impact of the project.

The State Engineer determined the perennial yield of Spring Valley on the basis of total estimated recharge. A review of the scientific literature illustrates that groundwater experts have concluded since 1915 that a simple recharge-based water budget should not be used to calculate the perennial yield of an aquifer because the actual yield depends on the spatial distribution of the well field and the hydraulic conditions in the valley. The estimated perennial yield must be validated through long-term computer simulations that take these factors into account.

To determine if the proposed pumping system ever reaches a state of equilibrium, we used the groundwater model developed by the SNWA to conduct long-term simulations. Using the pumping rates approved by the State Engineer in the 2012 ruling, we ran a 2000-yr simulation. In order to reach equilibrium, the well system must lower the water table to a level that captures (terminates) evapotranspiration at a level that balances the amount of water being withdrawn through the wells. Our simulation shows that even after 2000 years of pumping, the system is not balanced and 10,000,000 acre-ft of water is mined from storage. Furthermore, the system results in a net diversion of substantial amounts of water to Spring Valley from adjacent valleys (Lake, Hamlin, and Steptoe).

We also used the groundwater model to perform a rebound analysis. We ran the model with the well system operational for 300 years and then off for 300 years. The simulation illustrated that the drawdown generated during the 300 years of pumping takes 300 years to rebound to pre-pumping conditions.

A review of the scientific literature shows that our computer simulations are consistent with prior studies. Many researchers have demonstrated that with large valleys and improperly distributed well systems, it can take centuries or millennia for a basin to reach an equilibrium state (if ever).

We believe that a monitor, manage, and mitigate strategy will not protect existing water rights. Given the size of the valley and the large distances involved, by the time an impact is observed at the Ranch's water rights locations, reducing the pumping rate at the wells would take an unreasonably long amount of time to rectify the impact. Furthermore, since the system would take many centuries to approach equilibrium, it would be difficult or impossible to differentiate impacts from pumping vs. natural short-term fluctuations caused by natural phenomena such as drought cycles.

2 Introduction

The Southern Nevada Water Authority (SNWA) has proposed to construct a water development project in Southeast Nevada consisting of a series of deep wells, pumping stations, and several hundred miles of pipeline to divert water from selected mountain valleys to the City of Las Vegas for municipal use (SNWA 2015). In support of this project, the SNWA made a formal application to the Nevada State Engineer for water rights to appropriate groundwater from diversion points corresponding to the planned wells. Of these wells, 19 are located in Spring Valley, Nevada.

Corporation of the Presiding Bishop of The Church of Jesus Christ of Latter-day Saints (CPB), a Utah corporation sole, owns and operates a cattle ranch in northern Spring Valley (Figure 2-1). Hereafter we refer to this operation as "Cleveland Ranch" or simply "the Ranch." Cattle from the Ranch are used to support the Church's humanitarian efforts. The Ranch includes several deeded properties totaling 6,400 acres. The Ranch also grazes cattle on three adjacent BLM grazing allotments totaling 39,408 acres. As part of the ranching operation, CPB has 2082 AFA of supplemental groundwater irrigation rights, 26,400 AFA in claims of vested irrigation surface water rights and 5,071 AFA of certified or deeded surface water rights, and numerous stock water rights that allow the Ranch to utilize springs on the BLM allotments as an integral part of cattle grazing.

Because Cleveland Ranch is located near the densest concentration of proposed SNWA wells, it is at "ground zero" in this water rights battle. CPB protested 12 of the points of diversion, because these diversions will impact existing CPB water rights and will have a deleterious impact on the ranching operation. These wells are shown in red and yellow on Figure 2-1. In support of that protest, a study was performed by the authors involving fieldwork and groundwater modeling to determine the long-term impact the proposed SNWA wells will have on the Ranch's water rights (Jones and Mayo 2011). The 2011 report included a detailed listing of the CPB water rights and the geologic setting for Spring Valley and that material will not be repeated here.

2.1 2011 Hearings

The geochemistry and groundwater modeling results of the 2011 study were submitted in writing to the Nevada State Engineer in August 2011 as part of a formal protest filed by CPB relative to the SNWA application for water rights in Spring Valley. In the fall of 2011, CPB and other interested parties, presented testimony before the Nevada State engineer in Carson City, Nevada in opposition to the proposed project and the SNWA presented testimony in support of the project.

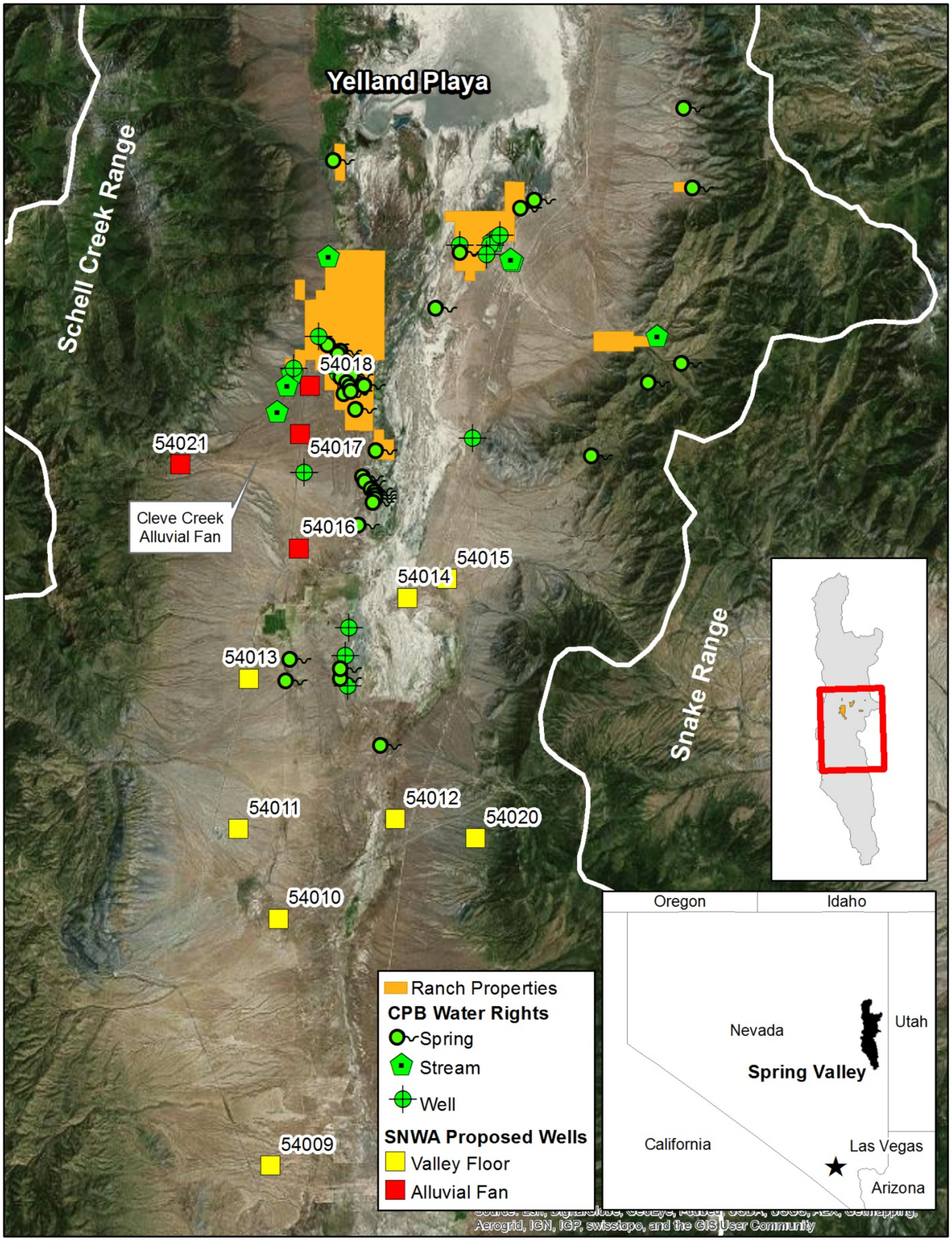


Figure 2-1 **CPB Ranching Properties and Water Rights Locations in Spring Valley, Nevada**

Following the hearings, each of the interested parties was invited to submit a proposed ruling to the Nevada State Engineer summarizing the arguments made by each party. In addition to a number of legal and ecological arguments, the following three points were made by CPB in light of the fieldwork and analysis outlined in the Jones and Mayo (2011) report:

1) The groundwater flow system in the Cleve Creek alluvial fan includes a shallow flow system of young water and a deeper system of older water. The four proposed wells in the fan would pull water from both systems and severely impact the springs and seeps at the downgradient fringe of the fan. These springs and shallow groundwater support 5848 acres of sub irrigated pasture.

2) The 12 protested wells would create a large aggregate cone of depression in the water table in the center of Spring Valley and would have a substantial negative impact on the CPB water rights.

3) The protested wells would result in substantial and perpetual groundwater mining, which is against established Nevada policy.

The information provided at the Fall 2011 hearing and the proposed rulings were considered by the State Engineer and in March 2012 the State Engineer's office issued a formal ruling on the application (King 2012). The State Engineer approved 25 of the 29 wells applied for by the SNWA. The four wells that were denied were part of the twelve wells protested by CPB, and are the four wells (54016, 54017, 54018, 54021) situated near the Cleve Creek alluvial fan directly adjacent to the ranch. The State Engineer agreed with the arguments made by CPB that these four wells would be harmful to CPB water rights. The remaining eight wells protested by CPB were approved.

In response to CPB's concern about excessive drawdown impacting water rights associated with the Cleveland Ranch, the State Engineer responded that this would be addressed through a monitor, manage, and mitigate plan wherein impacts to water rights would be assessed over time and the withdrawals from the wells would be reduced or turned off if it were determined that the water rights were being negatively impacted.

As for the issue of groundwater mining, the State Engineer argued that there is no requirement that the well placement be designed in a manner that would result in evapotranspiration (ET) salvage. From the ruling:

> “The State Engineer finds that there is no requirement that the Applicant must show that the proposed well placement will actually be able to fully capture discharge. Such a requirement is impractical both from a hydrodynamics/aquifer properties perspective and a land ownership perspective. … The State Engineer finds that the applicant is not required to prove capture of ET as a prerequisite to approval of the Applications.” (King 2012)

As for the issue of groundwater mining due to the system not reaching equilibrium, the State Engineer stated:

> "…there is no provision in Nevada water law that addresses time to capture, and no State Engineer has required that ET be captured within a specified period of time." (King 2012)

Taken together, these two statements seem to indicate that the State Engineer does not require applicants to provide evidence that a proposed groundwater development will result in a sustainable groundwater flow system.

2.2 Appeal to District Court

In January 2013, CPB appealed the decision of the Nevada State Engineer to the Seventh District Court of the State of Nevada on two fronts: First, CPB argued that the state's decision to use a monitor, manage, and mitigate plan to ensure that the wells do not negatively impact the Ranch's water rights was structured in such a way that it offered no protection to the Ranch. They also argued that there were insufficient guidelines and a lack of specificity regarding what level of impact would be deemed sufficient to stop or reduce pumping, and that by the time springs and wells go dry, the damage to the groundwater flow system would be such that it would take many decades for the system to recover after the wells were turned off (Bredehoeft and Durbin 2009b). CPB also argued that it would be highly improbable for the SNWA to invest billions of dollars in a pumping system only to turn it off and shut it down after a few decades of pumping.

Second, in response to the State Engineer's claim that there is no requirement for full ET capture, CPB noted that when addressing the issue of perennial yield in the same ruling, the following definition was provided by the State Engineer:

> "Perennial yield is ultimately limited to the maximum out of natural discharge that can be salvaged for beneficial use. … If the perennial yield is exceeded groundwater levels will decline and steady-state conditions will not be achieved, a situation commonly referred to as groundwater mining."

Furthermore, after providing an estimate of the perennial yield in Spring Valley, the State Engineer stated that:

> "This estimate relies on the capture of ground-water ET as the limit of the perennial yield."

CPB also referred to an April 2007 ruling by the Nevada State Engineer which explains that in most Nevada basins, groundwater discharges primarily through ET and that:

> "…the perennial yield is approximately equal to the estimated ground-water ET; the assumption being that water lost to natural ET can be captured by wells and placed to beneficial use." (Taylor 2007)

These passages clearly link perennial yield to ET capture. It has long been the policy of the State Engineer's office to prohibit groundwater mining and it has regularly denied applications that would result in groundwater mining. For example, in the case of Ruling #3486, an application was denied on the following basis:

> "The capture of groundwater evapotranspiration by pumping will probably not occur in the foreseeable future because some remaining areas of active evapotranspiration are too remote from the concentrated pumping areas. Consequently, the state engineer finds that the maximum amount of natural discharge available for capture and therefore the perennial yield does not exceed 19,000 acre-feet annually." (NSE 1988)

Therefore, the logic used to disregard ET capture in the case of Spring Valley and the SNWA applications is not consistent with prior practice and seems to set a precedent so loosely defined as to remove any burden of demonstrating sustainability from future groundwater use applicants.

2.3 District Court Ruling

In December of 2013, District Judge Robert Estes issued a ruling on the appeal. Judge Estes reversed and remanded the State Engineer's ruling on four key points. Two of these points were directly related to the arguments made by CPB in the appeal. First, Judge Estes agreed that the monitor, manage, and mitigate plan proposed by the SNWA did not provide a reasonable level of protection to the Ranch and he directed the State Engineer to "define standards, thresholds, or triggers so that mitigation of unreasonable effects of pumping of water are neither arbitrary or capricious in Spring Valley…". Second, Judge Estes instructed the State Engineer to recalculate the "water available for appropriation in Spring Valley assuring that the basin will reach equilibrium between discharge and recharge in a reasonable time". In making this ruling, Judge Estes agreed with CPB that the State Engineer's ruling regarding ET capture was self-contradictory and not consistent with Nevada policy.

As to the issue of the time required for the basin to reach a state of equilibrium, Judges Estes stated:

> "The Engineer's finding that equilibrium in Spring Valley water basin will "take a long time" was not based on substantial or reliable evidence, and is incorrect. Indeed, by his own statements - and evidence - equilibrium will never be reached."
>
> "This Court finds that the Engineer's own calculations and findings, show that equilibrium, with SNWA's present award, will never be reached and that after two hundred (200) years, SNWA will likely capture but eighty-four (84%) of the E.T. Further, this court finds that losing 9,780 afa from the basin, over and above E.T. after 200 years is unfair to following generations of Nevadans, and is not in the public interest. In violating the Engineer's own standards, the award of 61,127 afa is arbitrary and capricious."

Judge Estes' ruling was appealed by the SNWA, but the Nevada State Supreme Court declined to hear the appeal.

2.4 2017 Hearings

A new series of hearings has been scheduled for 2017 to resolve the issues raised by Judge Estes in his ruling. In preparation for these hearings we have conducted a supplemental analysis and prepared new evidence regarding the impact of the project. This new analysis includes a set of numerical groundwater simulations. The results of this analysis are summarized in this report.

2.5 Number and Distribution of Wells

The analysis in this report is based on the SNWA wells in the locations specifically defined by the SNWA water rights petition to the Nevada State Engineer. The SNWA has publicly stated that after the application is approved, they will file petitions to redistribute the pumping in Spring Valley to a yet-to-be designed well field consisting of 52 to 65 wells (SNWA 2012). However, if the current application is approved by the State Engineer and the courts, there will be no legal requirement for them to move the well locations or redesign the well field. Therefore, the impact of the proposed system in terms of conflict with existing water rights and groundwater sustainability must be analyzed solely on the well field design as described in the original SNWA applications.

3 Sustainability and Safe Yield

In the ruling by Judge Estes, he instructed the SNWA and the Nevada State Engineer to establish the time required for the pumping system to come to equilibrium and to recalculate the water available for capture. To fully address these issues, we begin with an overview of the concepts of safe yield and sustainability and review the scientific literature associated with these concepts.

A variety of terms (safe yield, sustainable yield, perennial yield) have traditionally been used to denote the amount of groundwater that can be withdrawn from a basin without causing depletion of the groundwater resources over the long term. Simply put, it is the maximum amount of water that can be withdrawn from an aquifer in a state of quasi-equilibrium where the inflows to the system equal the outflows. Typically, the largest form of inflow to an aquifer is recharge resulting from vertical percolation via rainfall, or from lateral inflow through shallow deposits from snowmelt or runoff. Inflow can also include leakage from streams and lakes and lateral inflow through adjacent basins/aquifers. In mountain valleys such as Spring Valley, the outflow is primarily through ET: water lost to evaporation or transpiration to plants in regions where the groundwater table is relatively close to the ground surface. Other forms of outflow include pumping via municipal and agricultural wells and discharge to springs, streams, lakes, and seeps.

3.1 Perennial Yield for Spring Valley

The Nevada Division of Water Resources defines perennial yield as follows (NDWR 2000):

> "The amount of usable water of a ground water reservoir that can be withdrawn and consumed economically each year for an indefinite period of time. It cannot exceed the sum of the Natural Recharge, the Artificial (or Induced) Recharge, and the Incidental Recharge without causing depletion of the groundwater reservoir. Also referred to as Safe Yield."

The logic used by the SNWA and supported by the Nevada State Engineer in determining the perennial yield for Spring Valley is described in the ruling following the 2011 hearings (King 2012). From page 58:

> "Groundwater ET is important because it can be more accurately measured than groundwater recharge or subsurface flow. In hydrologically closed basins, groundwater ET is equal to recharge."

The State Engineer then provided a detailed overview of how ET was estimated in the valleys associated with the project, including Spring Valley, over several years using a variety of field sampling and analytical techniques. This process resulted in an estimate of ET equal to 84,000 acre-feet annually (AFA) for Spring Valley. The Engineer considered interbasin flows and concluded with the following summary for perennial yield (page 90):

> "In hydrographic basins that have relatively little subsurface interbasin flow, such as Spring Valley, the State engineer has consistently determined the perennial yield to be equal to the basin's groundwater ET, rather than estimates of recharge or interbasin flow. Because groundwater ET is a measured value with relatively high confidence, the State Engineer finds that the perennial yield in Spring Valley will be based on the groundwater-ET estimate, rounded to the nearest thousand. Basin boundary flows are not a component of the perennial yield of Spring Valley. Any outflow to Snake Valley and/or Hamlin Valley is reserved for those basins. The State Engineer finds the perennial yield of the Spring Valley Hydrographic Basin is 84,000 acre-feet."

In the subsequent paragraphs, the State Engineer addressed the question of time to reach equilibrium and stated:

> "It will often take a long time to reach near-equilibrium in large basins and flow systems, and this is no reason to deny water right applications. The estimated time a pumping project takes to reach a new equilibrium does not affect the perennial yield."

And then on page 91, in spite of the fact that ET was directly used as the basis for estimating perennial yield, the State Engineer claimed:

> "The State Engineer finds that there is no requirement that the Applicant must show that the proposed well placement will actually be able to fully capture discharge."

As mentioned above, Judge Estes disagreed with this conclusion and remanded the State Engineer's ruling.

On pages 214-215, the State Engineer determined the total amount of unappropriated water in Spring Valley by starting with 84,000 AFA as a basis and then subtracting 18,873 AFA for existing water rights and reserving 4,000 AFA for future growth, resulting in net amount of 61,127 AFA available for appropriation.

3.2 Historical Determination of Safe Yield

At this point, it is useful to review the scientific literature to understand how safe yield has traditionally been determined. One of the earliest systematic and in-depth analyses of safe yield in groundwater basins was published by Charles H. Lee of the United States Geological Survey (USGS) based on his research and observations of groundwater basins in the Western United States (Lee 1915). Lee summarized the typical inflows and outflow to a groundwater basin and indicated that the best way to estimate recharge is typically to estimate the losses, assuming natural steady state conditions. Lee also claimed that in his experience, ET is typically the biggest source of loss for aquifers in the Western United States. Lee defined safe yield as:

> "The net annual supply which may be developed by pumping and artesian flow without persistent lowering of the groundwater plane."

Meinzer (1923) refined this definition to represent the rate at which water can be withdrawn "economically". Other authors have expanded the definition to represent the supply that can be withdrawn without adversely impacting water quality or existing water rights (Alley and Leake 2004; Alley et al. 1999; Banks 1952; Conkling 1946; Devlin and Sophocleous 2004; Kendy 2003; Scanlon et al. 2012; Sophocleous 1997; Sophocleous 2000; Todd 1959).

In his 1915 paper, Lee went on to state that safe yield is typically less than what is indicated by recharge and the actual quantity depends on to what extent ET can be eliminated. He stated that it is rarely possible to fully eliminate ET by pumping and lowering of the groundwater table due to the scale of most basins and the manner in which ET is distributed. One of the commenters to the article stated (page 239):

> "As it is not generally practicable to draw any large part of the ground-water of one segment of a valley to another, a proper distribution of wells is necessary in order to reduce the residual losses to the lowest possible quantity."

In 1935, Charles V. Theis of the USGS published a landmark paper on groundwater hydraulics where he presented a set of mathematical formulas for describing the reaction of a water table surface to pumping by a well (Theis 1935). In 1940, he published another landmark paper addressing safe yield and how aquifers respond to development (Theis 1940). In this paper Theis summarized water balance in aquifers with this highly-cited quote:

> "Under natural conditions ... previous to development by wells, aquifers are in a state of approximate dynamic equilibrium. Discharge by wells is thus a new discharge superimposed upon a previously stable system, and it must be balanced by an increase in the recharge of the aquifer, or by a decrease in the old natural discharge, or by loss of storage in the aquifer, or by a combination of these."

A decrease in discharge represents a decrease in water lost to ET or reduced discharge to seeps, springs, and streams as the water table is lowered (Brown 1963). An increase in recharge can occur when a groundwater table is so high that the ground is saturated and rainfall is unable to infiltrate to the aquifer. This is known as rejected recharge, and under these conditions lowering the water table via pumping results in an increase of recharge. Furthermore, a lowering of the water table may cause a stream to transition from a gaining stream to a losing stream, thus increasing recharge in the underlying aquifer (Figure 3-1). Any net imbalance between recharge and discharge results in a loss of storage to the aquifer.

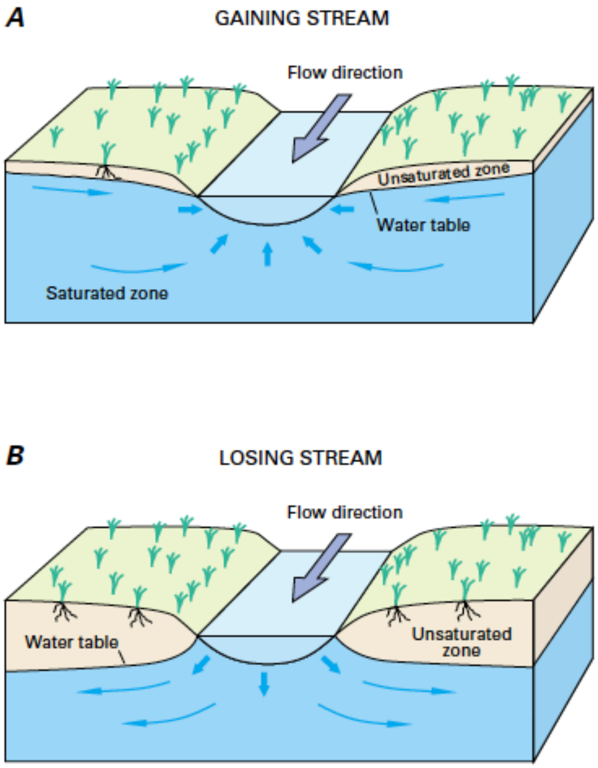


Figure 3-1 Stream-Aquifer Interaction. (a) Gaining Stream, (b) Losing Stream. (Alley et al. 1999)

Theis explains that when a well is pumped, an area of depression in the shape of an inverted cone is created around the well. When multiple wells are pumped, the cones of depression overlap and an aggregate area of depression is created, resulting in a lowering of the water table in the region surrounding the wells. However, the areal extent of the aggregate cone of depression is limited and there is a limit to how much of the theoretically available aquifer yield can actually be captured.

> “The normal recharge of the aquifer is sometimes assumed to be the measure of the possible yield of the aquifer to wells. The theory is that if the wells take the recharge then the natural discharge will be stopped. Under certain conditions, and especially where the wells are located close to the area of natural discharge, this may be at least approximately true, but it is recognized that generally wells are not able to stop all the natural discharge.” (Theis 1940)

The spatial relationship between the wells and natural discharge zones has a significant impact on the time required for a system to come to equilibrium (Bredehoeft 2002; Davids and Mehl 2015; Hubbel et al. 1997).

After describing the mechanics of how pumping creates an aggregate cone of depression, Theis went on to summarize the implications this has for safe yield:

> “The pumps should be placed as close as economically possible to areas of rejected recharge or natural discharge where ground water is being lost by evaporation or transpiration by non-productive vegetation, or where the surface water fed by, or rejected by, the ground water

> cannot be used. By so doing this lost water would be utilized by the pumps with a minimum lowering of the water level in the aquifer."
>
> "In areas remote from zones of natural discharge or rejected recharge, the pumps should be spaced as uniformly as possible throughout the available area. By so doing the lowering of the water level in any one place would be held to a minimum and hence the life of the development would be extended."

If the wells are not placed coincident to the natural discharge zones, Theis warns that equilibrium may never be reached, thus leading to perpetual groundwater mining.

> "In localities developing water from non-artesian aquifers and remote from areas of rejected recharge or natural discharge, the condition of equilibrium connoted by the concept of perennial safe yield may never be reached in the predictable future and the water used may all be taken from storage."

3.3 The Water Budget Myth

The concepts introduced by Lee and Theis have been expanded by other researchers. In another highly-cited article, Bredehoeft et al. (1982) coined the term: "The Water Budget Myth" to describe the notion unfortunately held by many water managers that a simple flow budget can accurately determine the perennial yield of an aquifer.

> "Perhaps the most common misconception in groundwater hydrology is that a water budget of an area determines the magnitude of possible groundwater development. Several well-known hydrologists have addressed this misconception and attempted to dispel it. Somehow, though, it persists and continues to color decisions by the water-management community. The laws governing the development of groundwater in Nevada as well as several other states are based on the idea that pumping within a groundwater basin shall not exceed the recharge."

As noted above, the Nevada State Engineer calculated the perennial yield for Spring Valley using precisely this approach. The total recharge was estimated and then a water budget was used to factor out existing use and a small reservation for future use, leaving a net amount available for extraction. Bredehoeft et al. explain that the amount of water that can be successfully extracted within a reasonable amount of time without severely impacting existing water rights associated with wells, springs, and stream is typically substantially less than the number one would find from a water budget. And in some cases, the groundwater hydraulics are such that the actual safe yield has nothing to do with the water budget safe yield. For example, some wells may go completely dry before they can fully capture the available discharge. Bredehoeft et al. describe a hypothetical island aquifer system where the safe yield is completely unrelated to the original natural recharge, even when such recharge is fully captured. Lowering the water table in this case creates new recharge in the form of lateral inflow. The authors summarize the discussion as follows:

> "The ultimate production of groundwater depends on how much the rate of recharge and (or) discharge can be changed—how much water can be captured. Although knowledge of the virgin rates of recharge and discharge is interesting, such knowledge is almost irrelevant in determining the sustained yield of a particular groundwater reservoir. We recognize that such a statement is contrary to much common doctrine. Somehow, we have lost or misplaced the ideas Theis stated in 1940 and before."

In a book published by the USGS on the topic of groundwater sustainability, Alley et al. (1999) reference the Water Budget Myth and the principles outlined by both Bredehoeft et al and Theis and draw the following conclusions about a pumping system coming to equilibrium:

- The time required for the system to come to equilibrium depends on how quickly the discharge can be captured
- How quickly the discharge can be captured is a function of the distribution (locations) of the pumping wells and the aquifer properties
- It may take a long time for discharge to be captured during this time, large amounts of water will be removed from storage.

Romano and Preziosi (2010) used a MODFLOW model of an aquifer in Italy to illustrate that natural recharge is a necessary but not sufficient factor in determining the safe pumping rate of an aquifer due to various factors such as local dynamics and aquifer geometry that influence equilibrium conditions.

Sophocleous (1997) referenced the Water Budget Myth and lamented the fact that state and local water management agencies continue to define safe yield based on annual recharge, even though this approach has been repeatedly discredited in the scientific literature. Devlin and Sophocleous (2004) note the persistence of the Water Budget Myth and state that while recharge is important, virgin recharge is not indicative of sustainable pumping rates. They argue that one should use a groundwater model to determine the amount of water that can be pumped in a sustainable fashion from wells in a given set of locations. I.e., it should not be assumed that a set of wells will automatically capture the amount of water available according to a water balance calculation.

In 1965, the State of Nevada published a study of Spring Valley and presented the following definition of perennial yield for a groundwater reservoir (Rush and Kazmi 1965):

> ". . . the maximum amount of water of usable chemical quality that can be withdrawn and consumed economically each year for an indefinite period of time..." "Perennial yield cannot exceed the natural recharge to an area indefinitely, <u>and ultimately it is limited to the amount of natural discharge that can be salvaged for beneficial use</u>." (p. 26)

This definition was reaffirmed in a 2006 SNWA water resource assessment of Spring Valley (SNWA 2006) (pg 8-1). The underlined portion supports the concept that perennial yield in Spring Valley is dependent on ET capture.

Kalf and Woolley (2005) argue that a pumping system can only be sustainable if the wells are distributed in a manner that results in the system coming to equilibrium. Stated another way, the sustainable pumping rate for a set of wells in a given configuration may be substantially less than what one would determine from a water budget. In reference to poorly designed well systems that do not come to equilibrium, the authors state:

> "This simply demonstrates that the well field development is not optimal and that the sustainable development of the groundwater resource must include equitable distribution of abstraction. Individuals or groups cannot selfishly appropriate the groundwater resource. Porous media, unlike dam storage, will not allow it."

Balleau (2013) lamented the fact that groundwater availability is still frequently estimated from natural recharge:

> "The idea that pumping an amount equal to natural recharge might cause instant balance with no other problems was dismissed by groundwater specialists long ago. Perhaps it is now time to abandon it from the administrative and planning functions also."

Numerous other groundwater experts have come to the same conclusion (Alley and Leake 2004; Mays 2013; Zhou 2009). Llamas et al. (2006) claim that "pumping the recharge" is "conceptually simplistic, and potentially misleading." South African water experts Seward et al. (2006) argue that policy makers and groundwater managers should focus on capture, and not on recharge when assessing sustainable pumping rates. In 2006, 200 hydrologists from around the world drafted and signed the Alicante Declaration at an international symposium on groundwater sustainability (Ragone and Llamas 2006). The Declaration is a call for action on sustainable groundwater management and includes a number of recommended actions, including a recommendation that long-term hydrologic water balance become the ultimate basis of water management strategy.

3.4 Safe Yield vs. Sustainable Yield

The concepts of safe yield and sustainable yield have evolved over the years as groundwater scientists and researchers have explored various definitions of sustainability (Alley and Leake 2004; Alley et al. 1999; ASCE 1961; Bouwer 1978; Conkling 1946; Domenico 1972; Freeze 1971; Freeze and Cherry 1979; Kalf and Woolley 2005; Kazmann 1956; Scanlon et al. 2012; Snyder 1955; Stuart 1945; Thomas 1951; Williams and Lohman 1949). Both of the terms "safe yield" and "sustainable yield" are used in the scientific literature (Alley and Leake 2004; Gleeson et al. 2012; Kalf and Woolley 2005; Rudestam and Langridge 2014) and some have argued for different meanings for each phrase. Alley and Leake (2004) illustrate how "sustainable yield" tends to incorporate a broad range of impacts where "safe yield" is typically based solely on water budgets. For example, depleting a stream may balance a water budget, but it can be detrimental to fish and other aquatic species.

The state of California recently adopted the Sustainable Groundwater Management Act (SGMA) which establishes standards for groundwater management and provides for sustainable groundwater usage by requiring groundwater sustainability plans for California groundwater basins (California 2014). The SGMA defines "sustainable groundwater management" as the management and use of groundwater that does not cause "undesirable results" over the long term (pg 17). Undesirable results include significant reduction in groundwater storage and chronic lowering of groundwater levels.

Sophocleous (2000) argued that capturing natural discharge - by definition - destroys the discharge of groundwater to seeps and springs. Such an outcome would clearly be detrimental to the CPB water rights in Spring Valley, most of which are related to small springs. Lowering the shallow water table that supports the springs at the distal end of the Cleve Creek alluvial fan will dry up the springs and will stop the sub irrigation that supports an estimated 5,848 acres of pasture land.

Konikow and Leake (2014) studied the transition from storage depletion to capture as a pumping system comes to equilibrium. They indicated that in arid regions with relatively large basins, it is often the case that a massive amount of water must be removed from storage before capture can be complete, and that the amount of storage depletion required for equilibrium may be so significant that pumping from a given set of locations may become economically or physically infeasible.

3.5 Summary

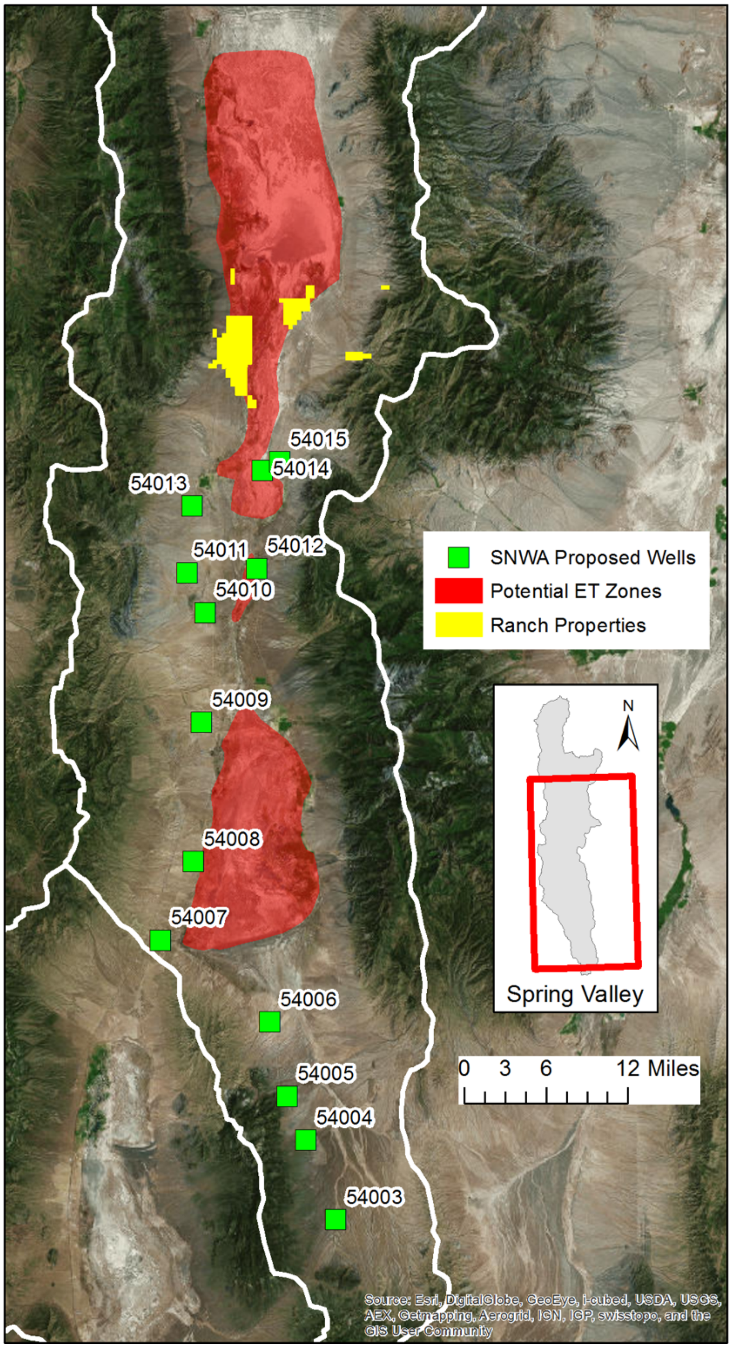
In summary, the following points are firmly established in the scientific literature:

1) Quantifying the safe yield of an aquifer system using a water budget analysis is fundamentally flawed.
2) In large basins, it may take an extraordinarily long period of time for a system to come to equilibrium, and massive amounts of groundwater may be mined in the process.
3) The spatial relationship between the wells and natural discharge regions has a significant impact on the time required for a system to come to equilibrium. If wells are not sufficiently close the natural discharge zones, equilibrium may never be reached, leading to perpetual groundwater mining.
4) In order for a pumping system to come to equilibrium, the aggregate cone of depression caused by pumping must intercept discharge. By definition, this process disrupts discharge to springs and seeps.

Each of these points relate directly to the SNWA project in Spring Valley. A map of ET zones in Spring Valley is displayed in Figure 3-2. These are areas where phreatophytes are present and/or where the effect of ET can be seen on the ground surface. The potential ET zones are shown in red. These zones were determined by the authors through site visits and by examining aerial photos of spring valley. The zones are largely consistent with the discharge zones delineated in Figure 5-2 as part of a water resources assessment for Spring Valley prepared by the SNWA (SNWA 2006). The regions also closely match the discharge zones simulated in the SNWA groundwater model (SNWA 2009b). The length of the ET zone measured from North to South is approximately 66 miles. The entire Spring Valley hydrographic basin measures approximately 144 miles in length, again measured from North to South. From Figure 3-2 it can be seen that the largest section of the ET zone is located entirely north of the SNWA wells.

Creating an aggregate zone of depression large enough to capture the ET in this region would require an extremely long period of time, as will be demonstrated later in this report via numerical groundwater simulations.

Furthermore, the Ranch is situated directly between the proposed wells and the main ET zone to the north. The only way to capture the bulk of the ET is to create a cone of depression south of the Ranch that then extends directly through the Ranch as it expands to the north. This cannot be accomplished without severely impacting the springs, seeps, and wells associated with the CPB water rights.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 3-2 Relationship Between ET Zones, Pumping Wells, and CPB Ranch Properties.

4 Groundwater Model

We performed a series of computer simulations to examine if the proposed SNWA pumping scheme will ever reach an equilibrium state and to determine what impact the aquifer pumping will have on groundwater storage and CPB water rights. The simulations were performed using a MODFLOW model originally developed by the SNWA. The SNWA developed a conceptual model for a large region of Southeastern Nevada that includes a larger number of hydrographic areas in addition to Spring Valley (SNWA 2009a; SNWA 2009b). This conceptual model was used to develop a calibrated MODFLOW model for the entire region and the calibrated model was converted to a transient predictive model (SNWA 2009b). The predictive model was used by the SNWA to analyze the impact of the proposed SNWA wells on the water rights in four valleys, including Spring Valley. The results of this analysis are described in a report by SNWA experts Watrus and Drici (SNWA 2011) and the corresponding MODFLOW model input files were provided by the SNWA as part of a set of exhibits made public on July 1, 2011.

Watrus and Drici used two versions of the SNWA MODFLOW model: one version without any of the SNWA wells representing baseline conditions and one version with the proposed SNWA wells in Spring, Delamar, Cave, and Lake valleys pumping at the full planned pumping rate. Both models cover a period from 2006 through 2254. The SNWA wells are introduced to the model per a three-stage schedule with a preliminary pumping rate beginning in 2029, intermediate pumping rate beginning in 2038, and a full rate beginning in 2043. The wells are pumped at the full rate until 2243 and are turned off for the last nine years of the simulation.

4.1 2011 Model Analysis

In 2011, we analyzed the Watrus and Drici report and the associated conclusions and reported our findings (Jones and Mayo 2011). In our report, we noted that the SNWA model was set up for a 200-yr simulation, but Watrus and Drici only reported the results out to 75 years. To better understand the output from the model, we performed simulations using four different versions of the SNWA model as summarized in Table 4-1. In all cases, no changes were made to the model inputs except for changes to the withdrawal rates for the wells near the Ranch. For the Baseline model, all of the proposed wells were turned off in order to generate a baseline condition that could be used to determine the change in water table elevation and flow conditions from the proposed wells as simulated in the other model instances. The Predictive-Full simulation model represents a model run with all of the wells turned on and corresponds to the same analysis performed by Watrus and Drici. The Predictive-Minus4 simulation represents a condition with all wells pumping except for the four wells (54016, 54017, 54018, 54021) located in the Cleve Creek Alluvial Fan. These wells were selected for removal because they were rejected in the ruling by the State Engineer in an earlier ruling (Taylor 2007). This ruling was set aside and the hearings were re-initiated in 2011, at which point CPB gained standing and filed a formal protest to the application. The four wells were once again rejected in the 2012 ruling by the State Engineer (King 2012). The Predictive-Minus12 simulation represents a condition with all twelve of the wells protested by CPB removed from the simulation (pumping rates set to zero).

Table 4-1 Model Instances Used in the 2011 Analysis.

Name	Description
Baseline	Transient model without any SNWA wells
Predictive-Full	Predictive model with all proposed SNWA wells turned on
Predictive-Minus4	The Predictive-Full model with SNWA wells 54016, 54017, 54018, 54021 removed from the simulation.
Predictive-Minus12	The Predictive-Full model with SNWA wells 54009, 54010, 54011, 54012, 54013, 54014, 54015, 54016, 54017, 54018, 54020, and 54021 removed from the simulation.

We analyzed the model output at various points of time up to the full simulation time of 200 years. We first examined drawdown maps for the region of Spring Valley adjacent to the Ranch properties and enclosing the 12 wells protested by CPB. In this context, "drawdown" is defined as the reduction in water table elevation resulting from the proposed wells, i.e., the difference in elevation between the predictive simulations and the Baseline simulation. The output from the Predictive-Full simulation indicated a large aggregate cone of depression overlapping the CPB water rights locations in the valley floor. In some regions, the drawdown exceeded 200 ft after the full 200-yr simulation time.

We also analyzed time series charts of water table elevation vs time for each of the valley floor water rights locations. A representative chart is shown in Figure 4-1. These charts illustrated that the water levels start to decline when the SNWA wells begin pumping and the water levels continue a steady, linear decline for the full 200 years of the simulation. This indicates that the system is not at equilibrium at the end of the 200-yr period. Similar results were found using the Predictive-Minus4 simulation.

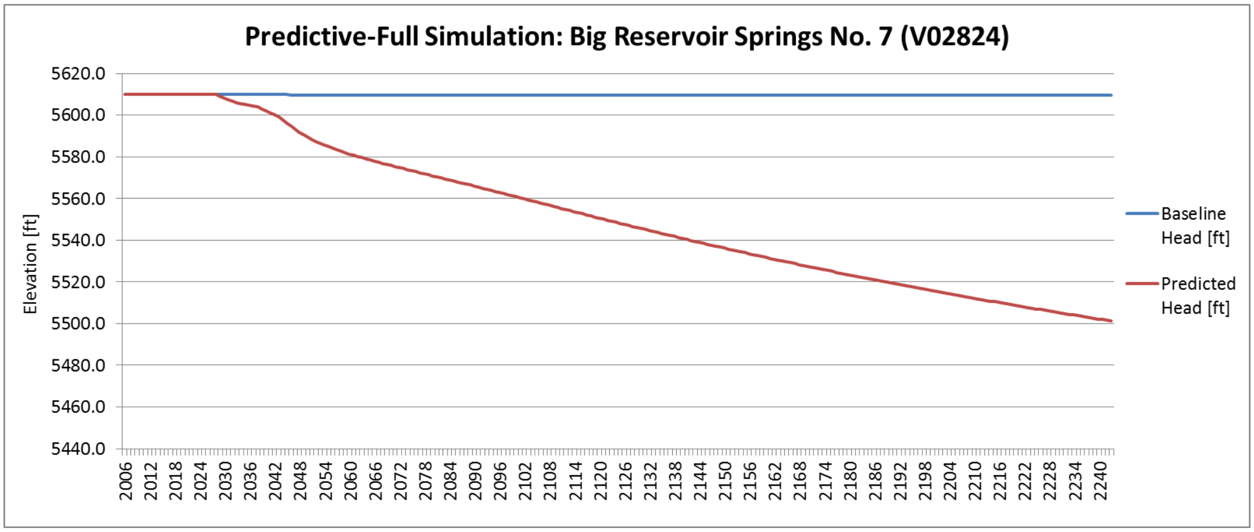


Figure 4-1 Simulated Head vs. Time for Big Reservoir Springs No. 7 (from Jones and Mayo (2011), pg 38).

Finally, we analyzed the flow budget for the predictive simulations and once again illustrated how the system was not at equilibrium after 200 years. The flow budget for the Predictive-Minus4 simulation is shown in Figure 4-2. This chart illustrates the cumulative change in volume for storage, drains (used to simulate ET in the valley floor), and other sources. Typically, when new wells are introduced to an aquifer system there is a transition period where water is drawn from storage as the system comes to equilibrium. This would be indicated in the chart by the storage line becoming flat (horizontal). As shown in the chart, the change in storage is still on a steady upward trend even after 200 years, which means the groundwater system does not reach equilibrium after 200 years and groundwater mining continues.

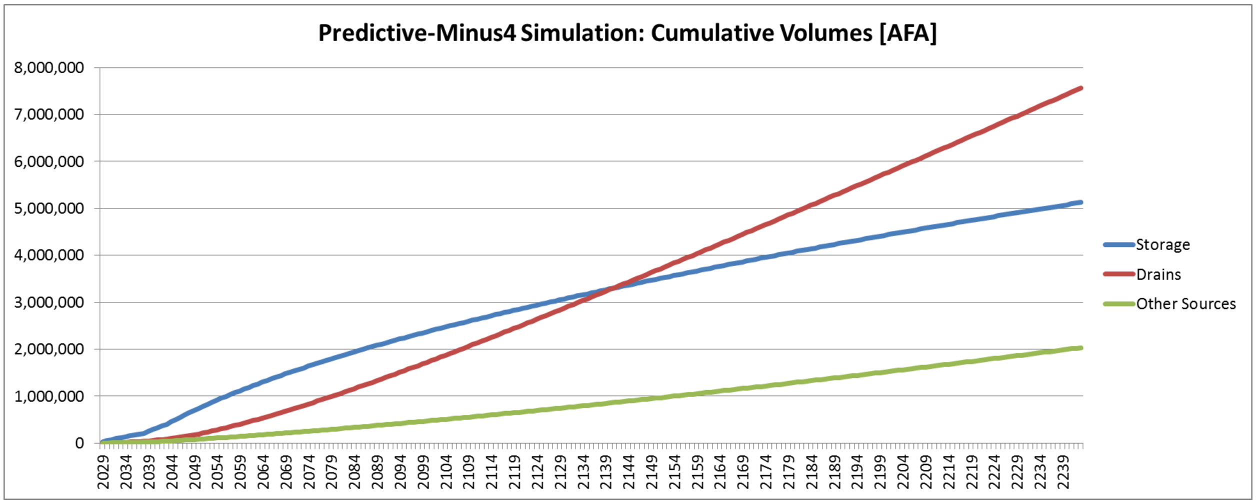


Figure 4-2 Cumulative Net Change in Volume for Source Categories for Predictive-Minus4 Simulation.

4.2 Updated Model Simulations

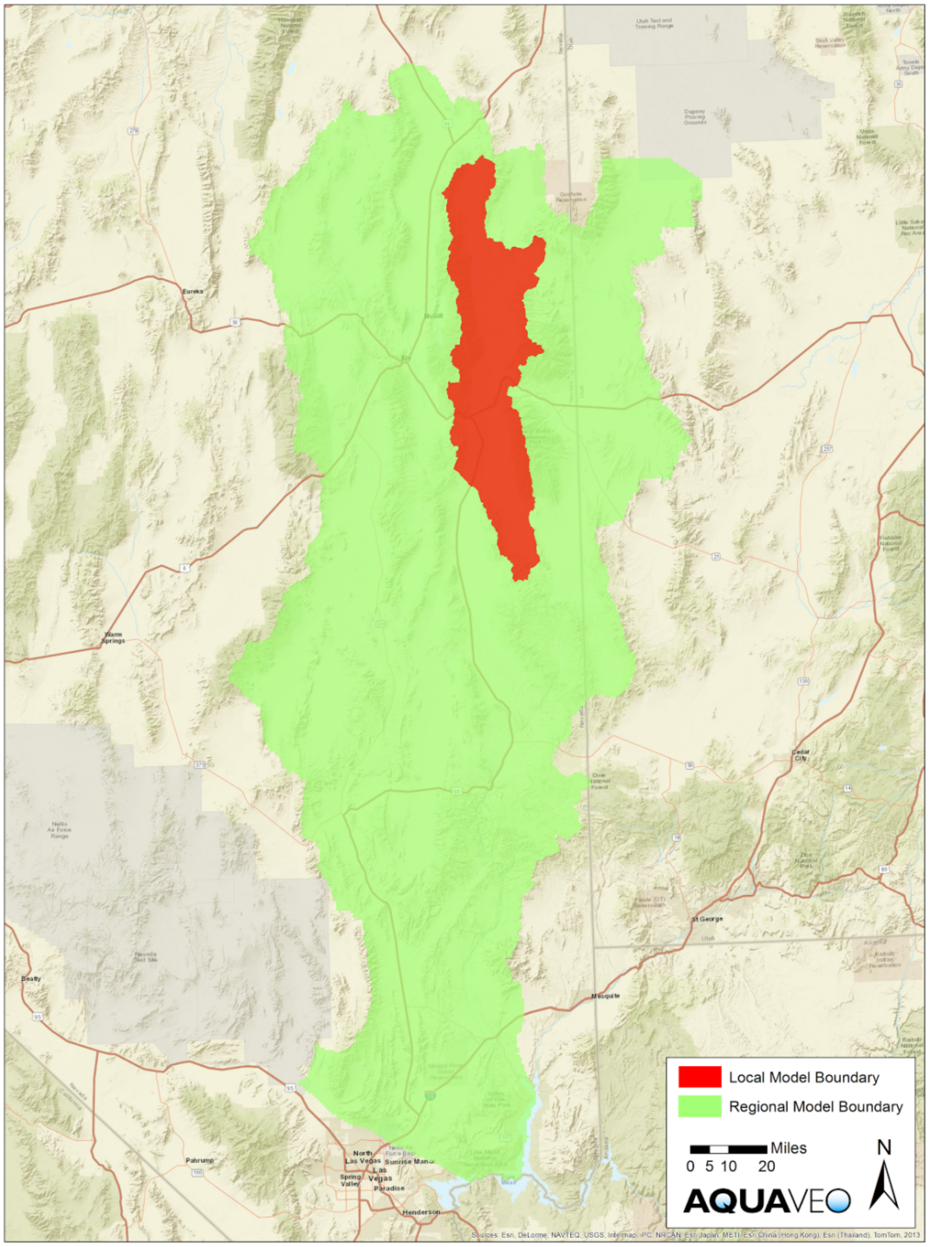
Starting in 2016, we performed a new series of model simulations. The objective of this new round of simulations was to develop a model that can be used to explore the following questions:

a) Does the Spring Valley groundwater system ever come to equilibrium with the proposed wells pumping at the designated rates and locations? If so, how long does it take?
b) As the groundwater system transitions to equilibrium, how much water is removed from storage? What is the impact to interbasin flow?
c) What is the long-term impact to CPB water rights?
d) Is a monitor, manage, and mitigate strategy feasible? When impacts to CPB water rights are observed, can the damage be stopped or reversed? How long does it take for the system to recover under such circumstances?
e) How will the groundwater system respond to various changes in the pumping system design that may be proposed in the future?

Questions (a) and (b) involve a flow budget analysis and could be answered with the original SNWA model. Questions (c), (d), and (e) could also be addressed with the original SNWA model, but may benefit from a simulation using a smaller grid cell size. Accordingly, we took the original SNWA model files and created a “high-resolution” copy of the model, with smaller grid cells. In the following discussion, we refer to this model as the “Local Model” and the original SNWA model as the “Regional Model”.

4.3 Local Model Construction

The boundaries of the Local and Regional models are shown in Figure 4-3. The green region represents the original SNWA model and encompasses several hydrographic units in South-Central Nevada. The Local Model corresponds to the boundary of Spring Valley.



Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

Figure 4-3 Location of the Local and Regional Models.

The objective of the Local Model is to have a higher-resolution model that is better able to represent local-scale variations in water table elevation and impact to springs, streams, and wells. To refine the grid, we took each grid cell from the Regional Model and subdivided it into 49 cells in the horizontal plane as shown in Figure 4-4. This was accomplished by splitting each row of the Regional Model into seven rows in the Local Model, and splitting each column of the Regional Model into seven columns of the Local Model. The grid resolution was not modified in the vertical direction (same number of model layers).

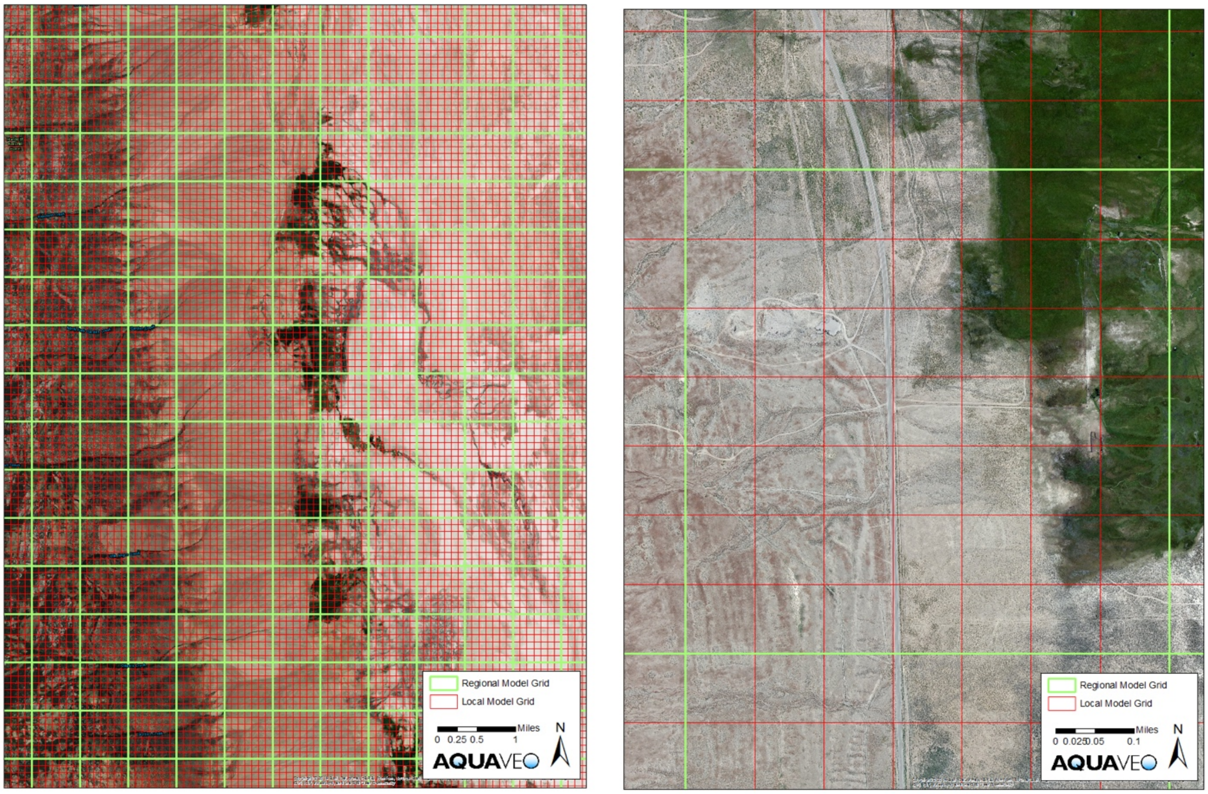


Figure 4-4 Grid Cell Size Comparison for Regional and Local Models.

4.3.1 Scaling of Model Features and Properties

After creating the local model grid with smaller grid cells, we next established the model properties or inputs, including grid elevations, hydraulic conductivities, and storage coefficients. Our objective was to create a model that is consistent with the regional model, but able to take advantage of higher resolution inputs where possible. In some cases, we inherited properties directly from the grid cells of the Regional Model, i.e., each of the 49 cells in the Local Model simply inherited the corresponding value from the Regional Model. In other cases, we linearly interpolated the values from the cells of the Regional Model to the cells of the Local Model. The method used to scale each of the primary input values from the Regional to the Local model is summarized in Table 4-2.

Table 4-2 Method Used to Scale Parameter Values from Regional to Local Model.

MODFLOW Package	Parameter	Method
Constant Head (CHD)	Shead (Head at the start of the stress period)	Linear Interpolation
Constant Head (CHD)	Ehead (Head at the end of the stress period)	Linear Interpolation
Drain (DRN)	Elevation	Linear Interpolation
Drain (DRN)	Conductance	Same as in Regional Model
HUF	TOP	Linear Interpolation
HUF	THCK (Thickness)	Linear Interpolation
KDEP	RS (Reference Surface)	Same as in Regional Model

4.3.2 Boundary and Initial Conditions

A critical part of developing a local model from a regional model is formulating a proper set of boundary conditions at the perimeter of the local model. The boundary conditions should correspond to physical or hydrographic features and allow for a simple means of communication between the regional and local models. As shown in Figure 4-3, we chose the perimeter of the Spring Valley hydrographic unit as the Local Model boundary. While the amount of flow across this boundary is relatively small, it is not zero, and could correspond to a significant amount of flow over a long simulation period. Therefore, we assigned constant head boundary conditions to the entire perimeter of the Local Model and the head values assigned to the boundary are derived from the Regional Model.

One of the issues of using head-based boundary conditions derived from a regional model is that it is possible to add stresses to the local model that impact or alter the heads in the local model in a manner that propagates to the boundary of the local model. This changes the hydraulic conditions at the boundaries and invalidates the head values derived from the regional model. To solve this problem and ensure that the head values from the Regional Model are consistent with changes made to the Local Model, we elected to use the following strategy:

1. For simulations that focus primarily on the flow budget and long-term sustainability and do not involve any changes to the stresses in the Local Model, we use the Regional Model.
2. For simulations that do involve changes to the stresses in the Local Model, we first apply the same stresses to the Regional Model and run the Regional Model over the entire simulation period and then extract the head values from the resulting Regional Model solution to apply to the boundaries of the Local Model. Thus, the head changes at the boundary of the Local Model are always consistent with the Regional Model and cross boundary flow is properly simulated.

All of the simulations in this report involve option (1). We anticipate using the Local Model to simulate yet-to-be-proposed strategies for the monitor, manage, and mitigate programs at a future date.

4.3.3 Model Verification

After creating the Local Model, we performed a series of simulations to verify the linkage between the Regional and Local Models. To begin with, we ran both models using the original model configuration as described by Watrus and Drici (SNWA 2011). This represents a simulation period of approximately 200 years with a staged pumping schedule in the early part of the simulation corresponding to the wells coming online over a multi-year period. At the end of the period the wells are turned off. We analyzed the flow budget from both simulations and plotted the storage loss values for both the Regional and Local Models (Figure 4-5). Although there is a slight deviation in the early years, the models produce essentially the same output.

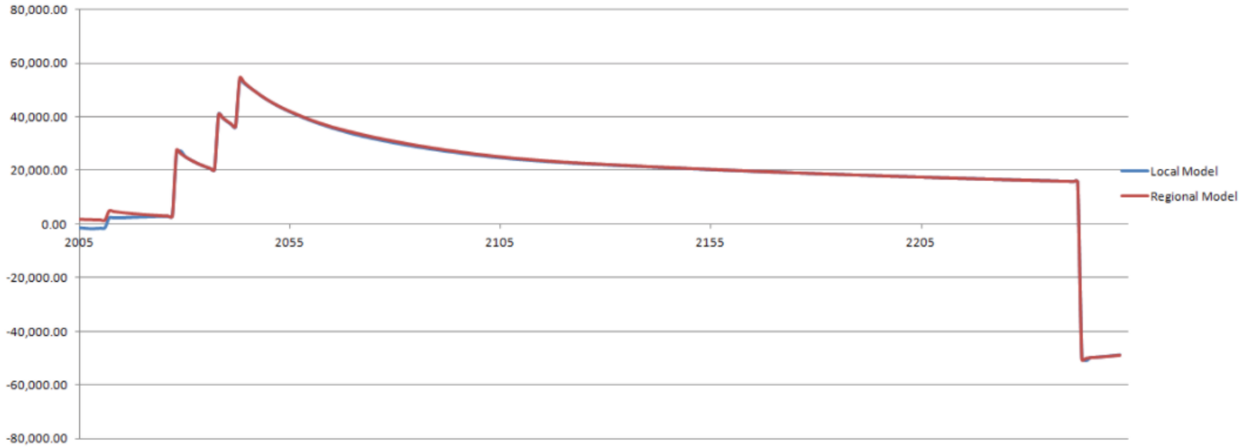


Figure 4-5 Change in Storage Loss (AFA) vs. Time for Regional and Local Models.

5 SIMULATION RESULTS

To answer questions a-c described in Section 4.2, we performed a long-term simulation with the Regional Model. These questions relate to the sustainability of the proposed pumping project and explore whether the system ever reaches equilibrium. The model stresses are identical to the simulations performed by Watrus and Drici (SNWA 2011), except the pumping rates were reduced from the original maximum rate of 91,000 AFA to 61,000 AFA. This reduced rate corresponds to the amount stipulated by the Nevada State Engineer in the 2012 ruling (King 2012). Also, the simulation period was changed from 200 years to 2000 years to determine if and when the system reaches equilibrium. Two simulations were performed: one using baseline conditions without the SNWA wells and one with the SNWA wells.

5.1 Flow Budget Analysis

The model output from the 2000-year simulation was processed using the USGS ZoneBudget utility (USGS 2015). ZoneBudget filters the cell-by-cell flow data produced by MODFLOW to generate a detailed flow budget for all sources and sinks associated with a simulation. The flow budget data for both the baseline and predictive (with the wells turned on) simulations were analyzed and the net flow budget was computed by subtracting the baseline simulation values from the predictive simulation values. The net change in flow budget vs time for the predictive model is illustrated in Figure 5-1.

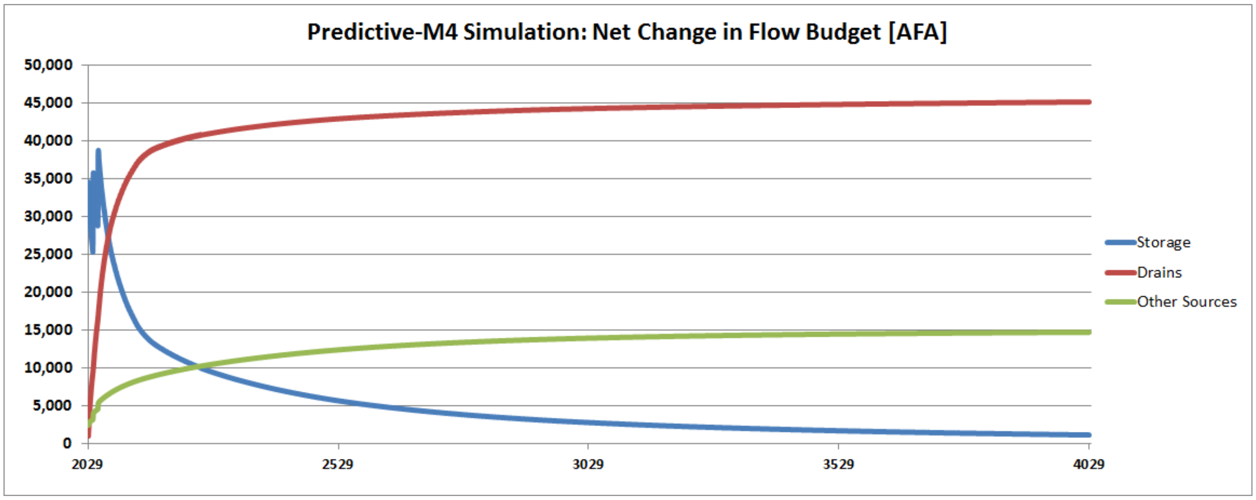


Figure 5-1 Net Change in Flow Budget vs. Time.

Several significant results can be observed in the chart. First, the system reaches equilibrium when the flow budget ceases to change over time. This corresponds to the point in time when the flow budget components become horizontal in the figure. At equilibrium, the net change in storage should also approach zero. As can be seen, there is still a downward slope in the storage curve after 1000 years and even after 2000 years, it has not reached zero. *What this means is that equilibrium between groundwater recharge and pumping is never reached and that groundwater mining occurs during the entire 2,000 year simulation.*

The cumulative amount of water drawn from storage is shown in Figure 5-2. Once again, if the system were to reach equilibrium, this line would become horizontal. After 2000 years, the curve is still trending upwards, indicating perpetual groundwater mining. At the end of 2000 years, a total of 10,000,000 acre-feet of groundwater storage are removed from the valley.

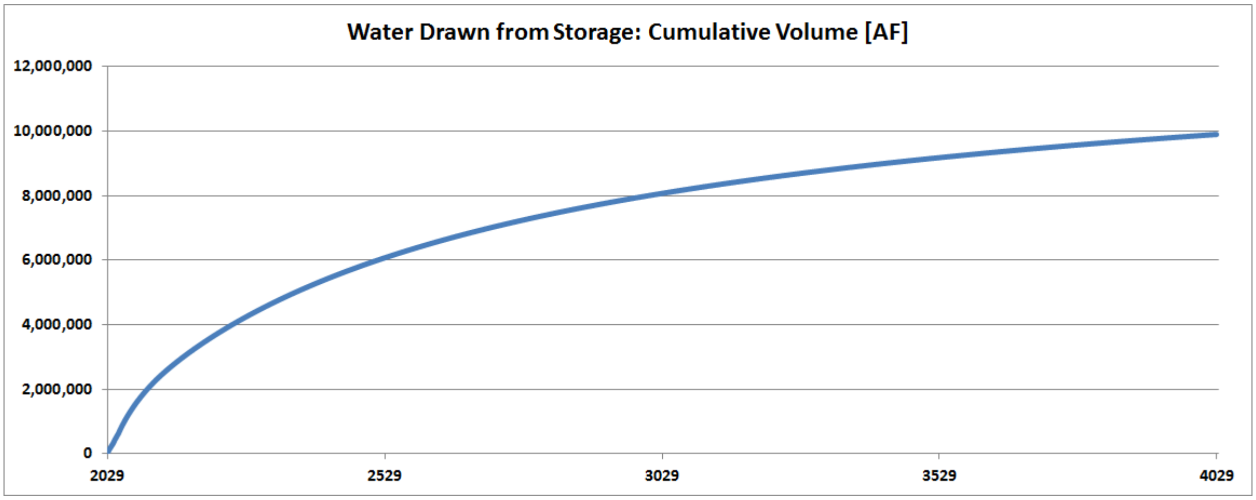


Figure 5-2 Cumulative Change in Storage vs. Time.

Also, as described above, the State Engineer determined the perennial yield of Spring Valley based on estimating uncaptured ET. Using that logic, one would expect that the 61,000 AFA required by the proposed wells would be balanced by a 61,000 AFA net change in discharge to ET. Since ET is simulated in the model using the Drain Package, the change in discharge to ET is represented in Figure 5-1 by the “Drains” curve. This curve stops increasing after approximately 1400 years at a value of 45,000 AFA, well below the 61,000 AFA target. The remaining 16,000 AFA is obtained from “Other Sources”, minus the small deficit still being drawn from storage after 2000 years. The “Others Sources” item represents the net discharge to adjacent valleys. The valleys adjacent to Spring Valley are shown in Figure 5-3.

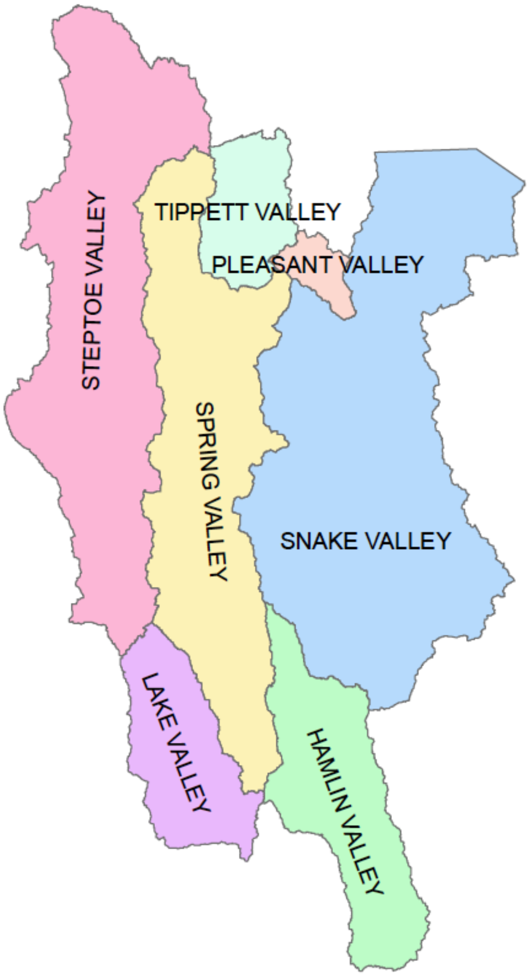


Figure 5-3 Valleys adjacent to Spring Valley.

The net change in discharge from Spring Valley to the adjacent valleys is shown in Figure 5-4. To compile these values, we first calculated the net flow between Spring Valley and each of the adjacent valleys using the sum of the inflows and outflows. For some of the adjacent valleys, there is a net inflow to Spring Valley and for some there is a net outflow. This was done for both the baseline and predictive simulations and finally the net change in interbasin flow is calculated as the predictive net flow minus the baseline net flow. In other words, the curves shown in Figure 5-4 represent the net change in interbasin flow caused by pumping the SNWA wells. A positive value indicates a change in net flow from the adjacent valley to Spring Valley. This could result from a decrease in outflow from Spring Valley, and increase in inflow from an adjacent valley, or a combination of the two. Hamlin, Lake, and Steptoe valleys all experience a net change in discharge to Spring Valley, meaning that less water is available for users in these valleys over time. It is also clear that the system is still not at equilibrium, even at the end of the 2000-yr simulation.

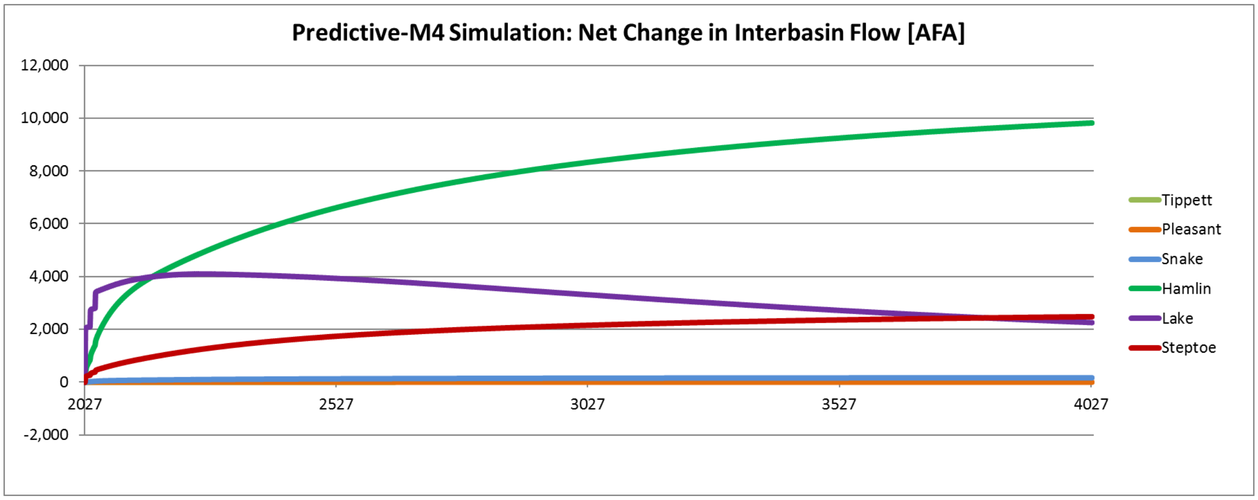


Figure 5-4 Net Change in Interbasin Flow.

The change in discharge to adjacent valleys is especially problematic given that the State Engineer specifically stated the following in the 2012 ruling (King 2012):

> "Basin boundary flows are not a component of the perennial yield of Spring Valley. Any outflow to Snake Valley and/or Hamlin Valley is reserved for those basins."

Why would the model indicate such a large change in interbasin flow when it was expected that the 61,000 AFA in annual pumping would be balanced by ET capture? The answer to this question was discussed in Section 3.3. As Bredehoeft et al. (1982)and many other groundwater scientists have argued, the sustainable yield for groundwater pumping in a basin cannot be determined simply by examining the water budget. The number, spatial location, and pumping rates of the wells are often configured such that an equilibrium condition is not possible. *In this case, the proposed SNWA wells are situated at locations in Spring Valley that make it impossible to achieve equilibrium.* This is illustrated in Figure 5-5. The natural ET discharge zones are in the northern end of Spring Valley, but the wells are situated in the southern and central zones. The ET in the south end of the valley is quickly captured but even after two millennia, the ET in the northern end of the valley remains uncaptured. This is partly due to the large distances involved and partly because the wells in the southern end of the valley are in close proximity to Lake, Hamlin, and Steptoe Valleys and therefore pumping draws a significant amount of water from these valleys, as illustrated in Figure 5-5. *As discussed above, the only way the ET in the northern end of the valley could be captured with the current configuration of wells is by significantly lowering the water table below CPB properties, thus substantially impacting the CPB water rights.*

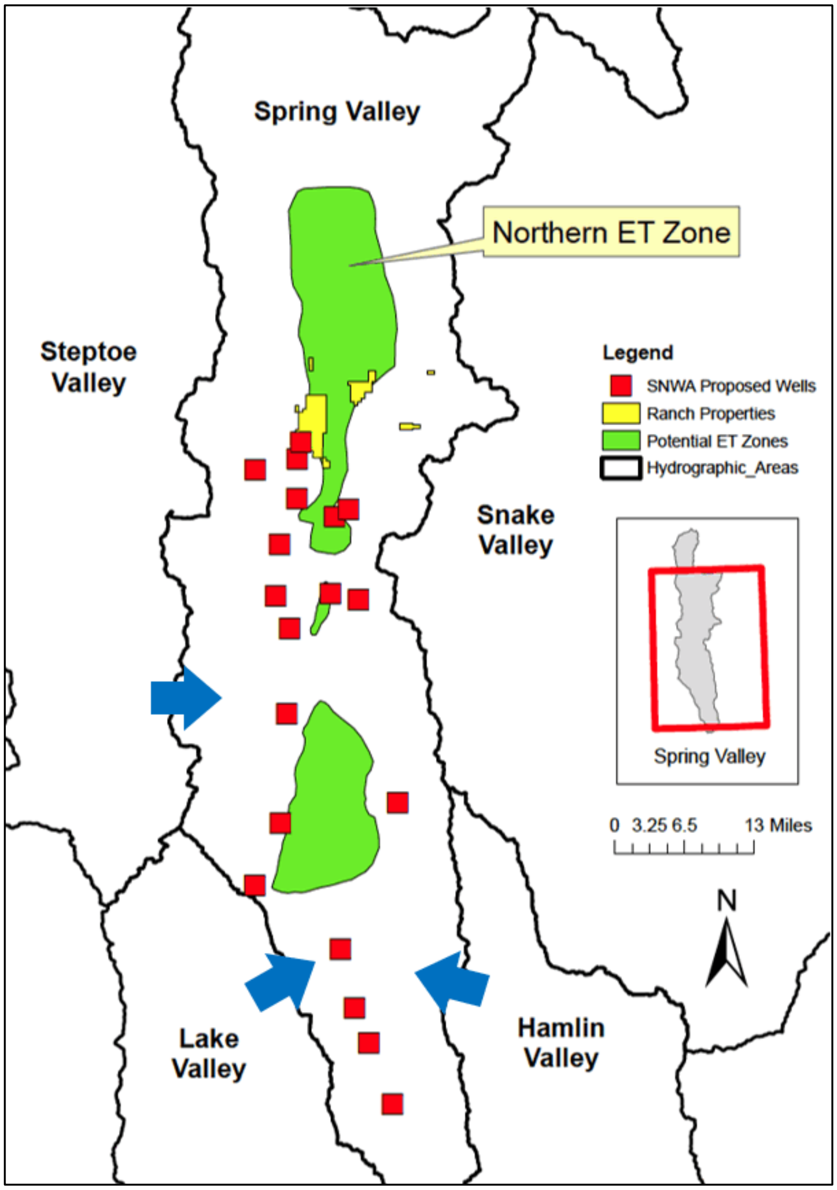


Figure 5-5 Spatial Distribution of Proposed Wells Relative to Ranch Properties and ET Zones. Net Change in Interbasin Flow Indicated by Block Arrows.

5.2 Rebound Analysis

A second set of simulations was performed to analyze how the aquifers in Spring Valley would rebound if the pumps were turned off after a long period of pumping. We allowed the proposed wells to pump for 300 years and then turned the wells off and then continued the simulation for another 300-yr period to examine how the water levels and flow budget would recover. Again, we analyzed the flow budget by comparing the model predicted values to the baseline simulation values. The net change in flow budget vs time is illustrated in Figure 5-6. When the wells are turned off, the net change in storage flips from a positive to a negative value meaning that water is being returned to storage and storage becomes a sink rather than a source of water. It takes more than 200 years for the flows to return to near pre-pumping conditions.

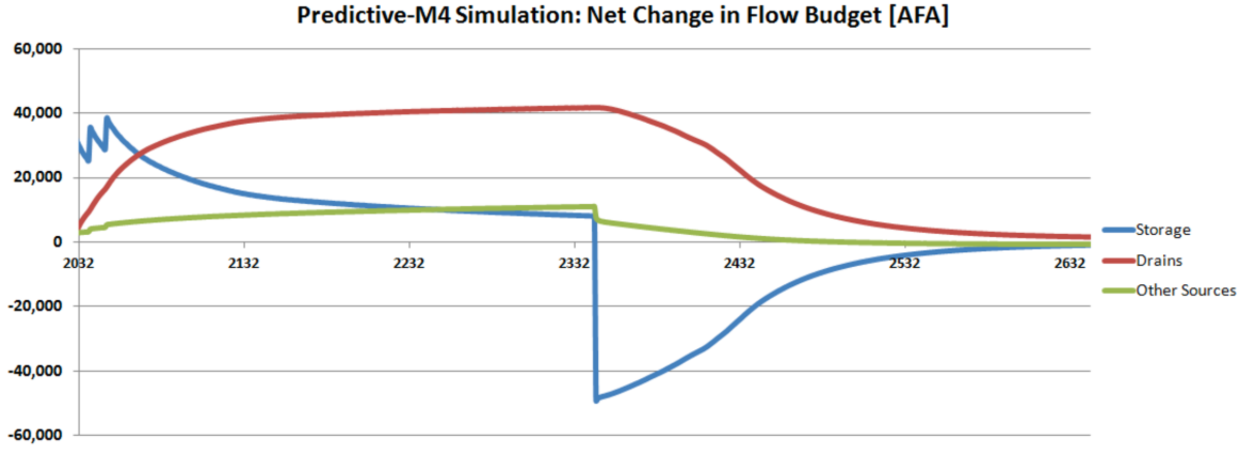


Figure 5-6 **Net Change in Flow Budget vs. Time for the Rebound Analysis Simulation.**

The total flow to drains (ET) vs. time is shown in Figure 5-7. Again, most of the ET is restored after 200 years, but it takes 300 years for a full rebound. *What this means is that the water levels beneath the CPB property will continue to be in a state of drawdown for 300 years after the wells have been turned off. Thus, the proposed SNWA pumping will impact the CPB water rights for hundreds of years and that simply turning off wells because impacts to the CPB water rights have been observed will not result in the restoration of the water rights.*

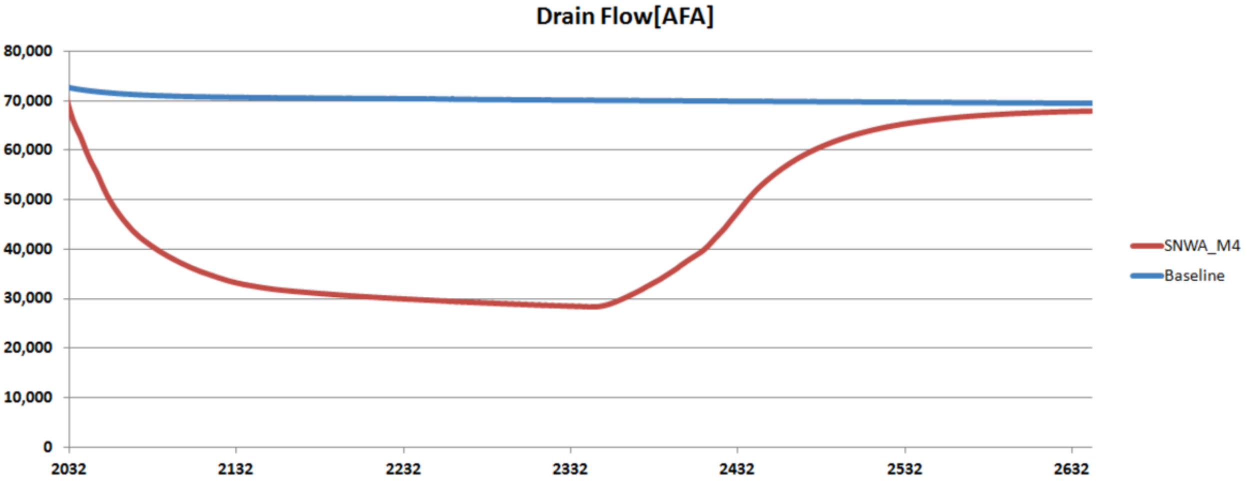


Figure 5-7 **Drain Flow (Discharge to ET) vs. Time for the Rebound Simulation.**

We also plotted water levels vs. time at selected water rights locations for the rebound analysis. The results shown in Figure 5-8 are typical.

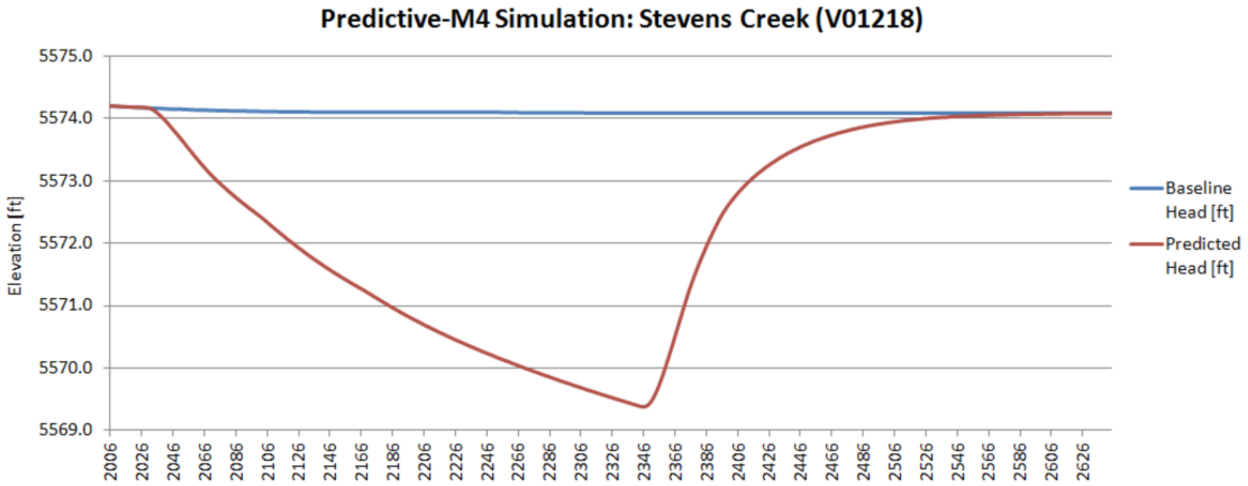


Figure 5-8 **Water Level vs. Time for Stevens Creek for the Rebound Simulation.**

5.3 Validity of Long-Term Simulations

When analyzing the impact of the proposed wells on existing water rights, the SNWA performed a 200-yr simulation, but only reported model results out to 75-yr simulation time (SNWA 2011). In the fall 2011 hearings in Carson City, the SNWA repeatedly argued that longer model simulations are unreliable due to uncertainty in long-term conditions. While this is a valid argument for critiquing a long-term water level prediction at a specific location, long-term simulations are routinely used and are widely regarded as the best available method for analyzing questions related to flow budget and sustainability.

After a comprehensive review of groundwater sustainability studies and literature, Zhou (2009) argues that a numerical groundwater model is the best available tool to simulate the long-term impacts of proposed groundwater development scenarios. Konikow and Leake (2014) examine the interplay between storage and capture and conclude that response times in aquifers can range from days to millennia. In reviewing the process of determining aquifer response times, Walton (2011) states:

> “Response time can be based on water level and budget data for a production well with constant discharge generated by a numerical model such as MODFLOW (Harbaugh 2005) and an idealized conceptual model with uniform aquifer system properties and boundaries, multiple stress periods, and usually a 10-, 100-, or 1000-year simulation time.”

Groundwater studies involving simulation periods of multiple centuries or millennia are common in the literature.

5.4 Comparison with Prior Studies

Not only are long-term simulations routinely used, the results of our simulations mirror the results found in a variety of other groundwater studies looking at similar basins with similar pumping systems and conditions. Numerous researchers have shown that with large basins and poorly configured well systems, it can take centuries or millennia to approach a state of equilibrium and in many cases, hydraulic conditions prohibit the system from ever reaching equilibrium.

5.4.1 Smith Valley - Thomas et al. 1989

In the late 1980's, the USGS performed a Regional Aquifer-System Analysis (RASA) study of Smith Creek Valley in Lander County, Nevada (Thomas et al. 1989). Like Spring Valley, Smith Valley is a long hydrologically closed valley with a playa at the center and a significant amount of groundwater discharged to ET. The objective of the study was to use a MODFLOW model to simulate the long-term impact resulting from groundwater withdrawals associated with development. The model was used to simulate response to various hypothetical development scenarios. As was the case with the Rebound Analysis described above, the model used a 600-yr simulation with 300 years of pumping and 300 years of recovery. Five scenarios (A-E) were analyzed with wells placed in various locations. The pumping rate in most scenarios was equal to recharge. In Scenario A, the wells were strategically placed around the perimeter of the playa to optimize ET capture and there was 75% capture after 25 years, but the system never reached full ET capture even after 300 years. The water table mostly but not completely recovered after the next 300 years. In Scenario B, the pumping wells were situated between the recharge and discharge zones and 80-85% of ET was captured after 300 years with a slow recovery over the next 300 years. In Scenario C, the pumping was concentrated in the north - away from ET zones and there was less than 75% ET capture after 300 years and slow and incomplete recovery 300 years after pumping stopped. Scenarios B and C are most similar to the proposed pumping in Spring Valley and the results are similar: the system does not reach equilibrium even centuries after pumping is initiated.

5.4.2 Nevada Basins, Schaefer and Harrill, 1995

In 1989, the Las Vegas Valley Water District filed 149 applications to pump groundwater from several basins in Central and Southeastern Nevada. They applications were later reduced in number and the proposed SNWA system analyzed in this report represents the continuation of these applications. In the early 1990's, the USGS performed a modeling study to determine the impact of this proposed project (Schaefer and Harrill 1995). They built a MODFLOW model and simulated the impact of 180,000 AFA of pumping spread across 17 basins. The simulation used a staged pumping schedule, ramped up over 18 years, with a maximum simulation time of 200 years. The simulations indicated water level declines, decreased flow to springs, and decreased discharge to ET. Groundwater levels drop several hundred feet in some basins. The simulated pumping rate for Spring Valley was 50,000 AFA and after 100 yrs, there was as much as 350 ft of drawdown and a maximum of 450 ft at 200 years. However, the systems did not approach steady state, even after 200 years. At that point, 40% of the water was coming from storage, 10% from reduction in spring discharge, and 50% from reduction to ET.

5.4.3 Great Basin Aquifers – Harrill and Prudic, 1998

In the late 1990's, the USGS published the results of a RASA study of the Great Basin region covering most of Nevada and portions of adjacent states (Harrill and Prudic 1998). The region included 39 major flow systems, many of which include multiple hydrographic areas. Spring Valley was included in the study. The authors used a MODFLOW model to simulate the long-term impacts of pumping in one valley in Utah (Milford) and five valleys in Nevada (Carson, Paradise, Smith Creek, and Stagecoach). Pumping was turned on for 300 years and then off for 300 years of recovery for a total simulation time of 600 years. For each model, the location of the wells and the pumping rates (equal to recharge or double recharge) was varied using a strategy like that used in the Smith Creek study described in Section 5.4.1 and the conclusions were similar. It was determined that sustained yield is only possible if wells are strategically located with respect to areas of ET discharge. If the pumping is not strategically located, or is highly concentrated, sustained yield is not viable. The well locations can be as important as pumping rates.

5.4.4 Simulation with SNWA Model – Bredehoeft and Durbin 2009

Bredehoeft and Durbin (2009a) published an issue paper in Groundwater Journal focused specifically on the time to capture problem in Nevada groundwater basins. Bredehoeft and Durbin are groundwater experts with substantial experience on groundwater hydrology in Nevada. They used a simple model set up to mimic a typical Nevada valley aquifer to illustrate ET capture vs time and showed that it takes up to 1,000 years to fully equilibrate even when the wells are close to the phreatophytes. They then performed a second set of computations with an early version of the regional SNWA MODFLOW model and showed that after 2000 years it still is not at equilibrium. The authors conclude by saying that equilibrium is not possible or meaningful in these cases.

5.4.5 Other Studies

Many other studies illustrate that sustainable large-scale pumping systems are only possible under carefully designed conditions. When dealing with the radial flow of groundwater to wells, the time it takes for a selected point in the aquifer to respond to a change in pumping is proportional to the square of the distance between the point and the well. Increasing the distance by a factor of ten results in a one-hundred-fold increase in the response time (Sophocleous 2000). For long valleys like Spring Valley, several centuries of response time are to be expected. Balleau and Mayer (1988) describe a hypothetical MODFLOW model meant to represent a basin in an arid region 32 km in length with a set of well fields distributed throughout the valley. In the simulation, the wells are turned on and the water table is gradually lowered. Initially, the water withdrawn comes mostly from storage, but eventually the water table is lowered sufficiently that 98% of the water comes from induced recharge. This transition takes 375 years.

In the paper that introduced the Water Budget Myth referenced in Section 3.3, Bredehoeft et al. (1982) used a simple groundwater model shown in Figure 5-9. The model represents a typical groundwater basin one would find in the intermountain western United States. Under virgin conditions, the inflow to the basin consists of two streams discharging at the upper (left) end of the basin. As a result, the recharge to the basin is not impacted by pumping. The basin discharges entirely via ET to a set of phreatophytes in the lower (right) end of the basin. The extinction depth for the phreatophytes (the groundwater depth at which ET is terminated) is assumed to be 5 ft. The authors then do two simulations to determine the impact of a set of wells where the total pumping rate for the wells is equal to the virgin recharge. In Case I, the wells are roughly halfway between the streams and the center of the phreatophytes. In Case II, the wells are adjacent to the phreatophytes. The system is assumed to reach equilibrium when the zone of groundwater depression caused by pumping completely terminates discharge to the phreatophytes.

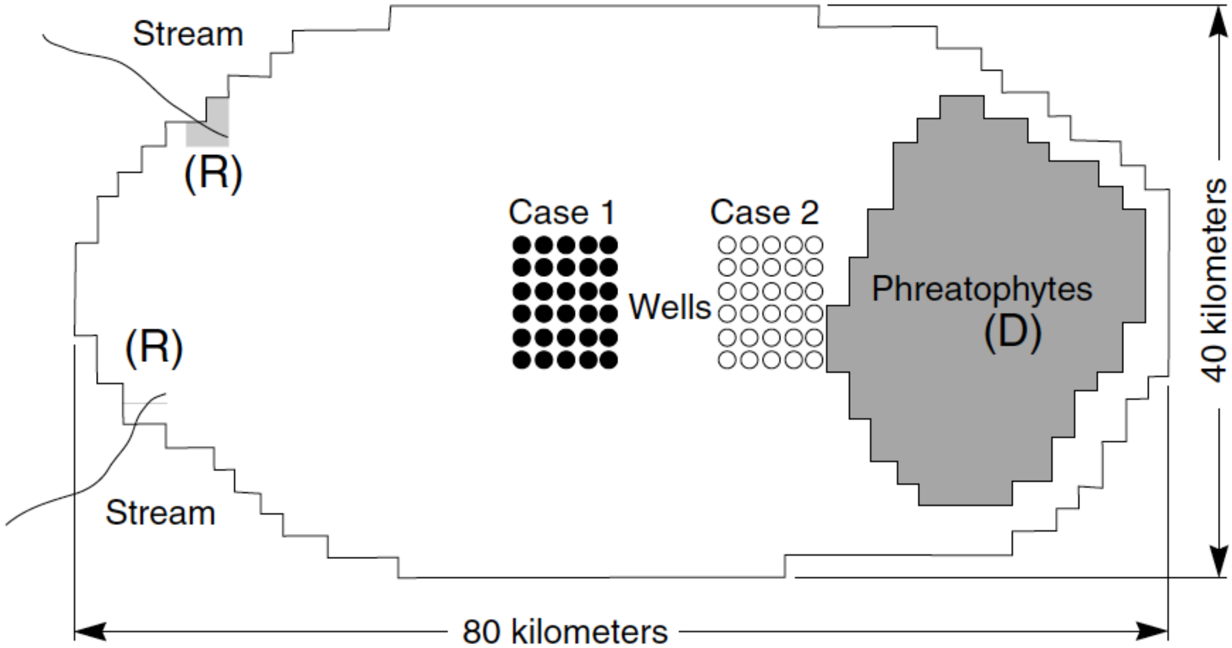


Figure 5-9 Hypothetical Groundwater Basin Model. Adapted from (Bredehoeft et al. 1982; Sophocleous 2000).

The simulations were allowed to run for a 1000-year period. For both cases, a substantial amount of the water pumped by the wells comes from storage during the initial period of pumping. For Case I, it takes 300 years to capture 60% of the ET and even after 1000 years, the ET is not fully captured. For Case II, it takes 500 years for complete capture.

The time to capture is dependent on the transmissivity of the aquifer (transmissivity is a combination of the permeability and thickness of the aquifer). Bredehoeft revisited the water budget myth in 2002 and using the same basin model, showed that the time to reach equilibrium can vary from 400 to 1000 years depending on the basin transmissivity (Bredehoeft 2002).

6 Monitor, Manage, and Mitigate

As part of the application for approval of the proposed pumping system, the SNWA has promised to implement a monitor, manage, and mitigate program to deal with impacts to senior water rights in Spring Valley, including those owned by CPB. We will not attempt here to address the legal and management difficulties with such a proposal, but we will make a few brief observations from a groundwater hydrology point of view. When the SNWA proposes a specific monitor, manage, and mitigate strategy that addresses the concerns outlined by Judge Estes, the proposed action will be analyzed.

There are three fundamental problems with this approach from a hydraulic point of view: spatial distribution of wells, long-term response, and time to rebound.

6.1 Spatial Distribution of Wells

As we have illustrated above, the spatial location of the SNWA wells guarantees that the wells will impact the CPB water rights locations associated with Cleveland Ranch for the duration of pumping and for an indefinite period of time thereafter. The only way the pumping system can possibly reach equilibrium is by developing a massive cone of depression that starts south of the Ranch and then slowly progresses northward until it lowers the water table in the large ET zone north of the Ranch to a point that that the flow budget is balanced. In theory, the SNWA will monitor impacts at the Ranch and take steps to mitigate these impacts by reducing pumping or other measures. But these two goals are contradictory – there is no way the system can achieve a balance and function as designed without dramatically dewatering the aquifer beneath the Ranch.

6.2 Long-Term Response

The model simulations described herein conclusively demonstrate that it will take centuries, perhaps even millennia for the proposed system to approach a state of equilibrium. This is due to the spatial distribution of the wells, the hydraulic properties of the aquifer, and the size of the basin. However, operating a monitor, manage, and mitigate strategy over such a time scale presents significant logistical challenges. The drawdown generated by the pumping system will result in small changes when observed from year to year. At the same time, there will be additional stresses on the system resulting from drought cycles and natural hydrologic fluctuations. For example, when drawdown is observed at a well, how could one definitively conclude that the drawdown is caused by the SNWA wells or by natural fluctuations? This problem becomes more challenging as the distance between the pumping wells and the monitoring locations increases.

This issue was described in detail by Bredehoeft (2011) in a paper addressing the difficulties associated with the monitor, manage, and mitigate strategy proposed by the SNWA for the project specifically analyzed in this report. Bredehoeft uses a groundwater model to illustrate the long times it takes for drawdown to propagate from a pumping well to a monitoring location and how the signal at the monitoring well is impacted by many other stresses and influences.

> "I cannot imagine an observer, with the best present monitoring techniques, discriminating the impact of the SNWA pumping from other pumping in the area or from other long-term impacts on the groundwater system such as changes in recharge associated with climate change."

We agree that this would be a near-impossible task.

6.3 Time to Rebound

Another issue with a monitor, manage, and mitigate strategy is that once an impact from pumping reaches a distant monitoring well or water rights location, it is too late to stop the impact, the impact may get worse even if the pumping is curtailed, and the time required to recover from the impact may take centuries because drawdown continues long after the well has been turned off. In the model simulation related to rebound analysis described in Section 5.2, we simulated 300 years of pumping and 300 years of rebound and illustrated that it takes most of the 300 years to fully recover from the impacts of pumping.

Bredehoeft (2011) performed a sophisticated analysis of this phenomenon and showed that in many cases, once a well is turned off, the impact from the pumping at distant locations may in fact continue to get worse for many years before it starts to rebound.

> "This hypothetical model illustrates the monitoring problem. If the monitoring point is some distance removed from the pumping, there will be (1) a time lag between the maximum impact and the stopping of pumping and (2) the maximum impact will be greater than what is observed when pumping is stopped (unless one has reached a new equilibrium state during the pumping period). The time for full recovery of the system will be long, even in the case where one has not reached the new equilibrium."

Furthermore, completely shutting off pumping is likely to be the last resort considered due to the tremendous cost associated with constructing the system in the first place (Bredehoeft and Durbin 2009a).

> "The real world is more complex. Those that advocate monitoring seldom envision totally stopping the pumping; rather, they imagine changes in the development that minimize damages. Stopping the pumping is a management action of last resort and we showed that it has problems. Less stringent management actions have a correspondingly lesser beneficial impact and even more problems."

Developing a monitor, manage, and mitigate program for a basin the size of Spring Valley with the large distances and time scales involved that adequately protects existing water rights holders is difficult, if not impossible.

7 Conclusions

Based on our analysis, we offer the following conclusions:

1. The safe yield of Spring Valley should not be determined solely on the basis of current recharge and volumetric water balance, as this is a classic case of the “Water Budget Myth” problem. The actual safe or sustainable yield is dependent on the design of the well field and can only be properly assessed through long-term computer simulations.
2. A long-term simulation using the SNWA’s own computer model shows that the system does not reach equilibrium after 2000 years of pumping, removing 10,000,000 acre-ft of water from basin storage in the process and pulling water from adjacent valleys. This is a classic case of perpetual groundwater mining.
3. The only way the system could possibly come to equilibrium is by lowering the groundwater table over a large section of Spring Valley to capture a volume of water currently being lost to evapotranspiration at an amount equal to the total pumping rate. Given that the Ranch’s water rights locations are situated between the wells and a large evapotranspiration zone in the north end of the valley, this cannot be accomplished without a significant lowering of the water table below the Ranch, thus dewatering the Ranch’s seeps, springs, and wells.
4. A monitor, manage, and mitigate strategy would not adequately protect the Ranch’s water rights. Due to the large size of the valley, by the time the impacts of pumping are detected at the water rights locations, it would take as long as centuries for the system to rebound, assuming the wells were turned off, which is highly unlikely. Also, since the system would take many centuries to approach equilibrium, it would be difficult or impossible to differentiate impacts from pumping vs. natural short-term fluctuations caused by drought cycles, climate change, and other natural phenomena.

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