Simulation of a Groundwater Production Scenario Related to Southern Nevada Water Authority Groundwater Applications in Spring Valley, Nevada

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Pertaining to:
Groundwater Applications 54003 through 54021 in
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ACRONYMS

BLM	Bureau of Land Management
CCRP	Central Carbonate-Rock Province
CLWP GDP	Clark, Lincoln, and White Pine Counties Groundwater Development Project
EIS	Environmental Impact Statement
ET	Evapotranspiration
GSLD	Great Salt Lake Desert
NSE	Nevada State Engineer
POD	Point of Diversion
RMSE	Root Mean Square Error
SNWA	Southern Nevada Water Authority
SoSWR	Sum of Squared Weighted Residuals
USGS	United States Geological Survey
UVF	Upper Valley Fill

ABBREVIATIONS

afa	acre-feet per annum
afy	acre-feet per year
bgs	below ground surface
ft	foot or feet
in.	inch
m	meter(s)
maf	million acre-feet

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EXECUTIVE SUMMARY

This report was prepared to document an analysis conducted to address an issue raised by the Seventh Judicial District Court of Nevada Senior Judge Estes (the Court) regarding Nevada State Engineer (NSE) Ruling No. 6164 in which the NSE granted groundwater rights to the Southern Nevada Water Authority (SNWA) in Spring Valley.

The NSE held an administrative hearing in 2011 to consider permitting SNWA applications to appropriate groundwater in Spring, Cave, Dry Lake, and Delamar valleys. Based on the evidence submitted and expert testimony presented during the hearing, the NSE issued rulings for each of the four basins (No. 6164, 6165, 6166, and 6167) on March 22, 2012. The rulings describe the rationale and evidence relied upon to grant or deny SNWA applications in the four basins, determine the volume of unappropriated groundwater, and define monitoring, management, and mitigation requirements. In the Spring Valley ruling (6164), the NSE found that the average annual groundwater discharge by evapotranspiration (ET) is 84,127 afy and that the perennial yield of the basin is 84,000 afy. Furthermore, the NSE approved 15 of the 19 Spring Valley applications with a maximum combined total duty of 61,127 afy. Permit terms require that development occur in three stages that will allow for a gradual increase in production to observe and, if needed, control the system's response to the groundwater pumping.

Protestants challenged all four rulings before the Court. With the exception of four specific items, the Court accepted all of the findings and conclusions the NSE made in the rulings. The Court then remanded the case to the NSE to resolve the four exceptions. This report will address the Court's instruction for a "recalculation of water available for appropriation from Spring Valley assuring that the basin will reach equilibrium between discharge and recharge in a reasonable time." For Spring Valley, the Court relied on the results of a model simulation presented at the NSE hearing. Unfortunately, the objective of that scenario was not the same as an ET-capture scenario because the project wells were deliberately located outside of the ET-discharge area. In addition, the scenario simulation examined by the Court was based on the ET-discharge estimate and the maximum project pumping values used by SNWA before the NSE ruling for Spring Valley (Ruling 6164) was issued. Based soley on the results of that model simulation, the Court concluded that the aquifer system would not reach equilibrium within a reasonable amount of time.

As recognized in the Court's Decision, no provisions exist in Nevada Water Law that would specifically (1) address the time for full capture of ET discharge, resulting in equilibrium conditions, and (2) dictate that an application be denied for failure to do so. However, if the time to capture ET discharge and reach equilibrium conditions were a valid reason to limit the appropriation as the Court suggests, then the only reasonable approach would be to evaluate the ET capture during and after the NSE-prescribed staged development. During this period of time, the actual effects of groundwater production would be identifiable, and the uncertainties and limitations in the groundwater model would be significantly reduced to a point where the model could more accurately simulate the potential future effects. It is inappropriate to rely upon a groundwater model that has not been calibrated to observed responses to project pumping stresses to quantify the amount of water available for appropriation. Existing models are inherently uncertain and have not been calibrated to these transient conditions because the data do not currently exist.

To satisfy the Court's request to ensure "*... that the basin will reach equilibrium between discharge and recharge in a reasonable time,*" all existing and future groundwater rights would have to be considered, not just SNWA's permits. In other words, development of SNWA's 61,127 afy could never capture the perennial yield of 84,000 afy in any time frame; however, it could effectively capture all of the permitted volume within 75 to 200 years, if the project were configured to achieve that objective. Therefore, the objective of this analysis is to demonstrate that a pumping scenario could be configured and simulated to effectively capture all of the water permitted by the NSE in Ruling 6164, from the ET discharge area of Spring Valley, within a reasonable amount of time and within the uncertainty of the model.

This objective was accomplished using an updated version of the Central Carbonate-Rock Province (CCRP) groundwater flow model. The CCRP model was used by the U.S. Bureau of Land Management to analyze the indirect effects of SNWA's project pumping for the Environmental Impact Statement. Updates to the model focused on Spring Valley. The analysis approach included three steps: (1) update the model to represent an average annual groundwater ET discharge volume in Spring Valley that is consistent with NSE Ruling 6164; (2) configure a groundwater development scenario to effectively capture all of the permitted water from the groundwater-ET discharge area of Spring Valley; (3) perform model simulations; and (4) evaluate the results. ET capture by project pumping was considered to be effectively achieved when the wells captured an annual ET volume within the calibration uncertainty of the updated model.

The CCRP model was updated by changing the estimated volume of groundwater ET discharge for Spring Valley from 75,000 afy to 84,100 afy. The recharge efficiencies in the numerical model associated with Spring Valley were increased to maintain the predevelopment water balance, resulting in a simulated ET discharge value of 84,099 afy that closely matches the estimated ET discharge of 84,100 afy. In the updated CCRP model, simulated recharge in Spring Valley is about 90,000 afy, which falls within the range of 84,000 afy to 96,000 afy estimated by the NSE in Ruling 6164. The fit of the model-simulated quantities to the available data improved slightly. Given that in Ruling 6164, the NSE concluded that the CCRP model "*provides a reliable tool to examine potential effects on the groundwater system...,*" the updated CCRP model does too.

Simulation of two scenarios, Baseline and ET capture, was necessary to achieve the objective of this analysis. The Baseline scenario represents on-going conditions with pumping from existing wells continuing into the future and without any pumping from SNWA project wells. The ET capture scenario includes all of the existing pumping represented in the Baseline scenario, plus a set of SNWA project wells configured to capture ET discharge in Spring Valley. The effects of the ET-capture wells were calculated as the difference between the simulation results of the two scenarios.

The volumes of ET discharge and transitional storage captured by the ET-capture wells computed for the 2005 to 2250 time period are shown in Figure ES-1. As shown on this figure, the temporal progression of ET discharge and transitional storage capture by the ET-capture wells in Spring Valley is typical of well pumping from an aquifer. Initially, the ET-capture wells pump most of their production from groundwater storage. Eventually, the wells begin capturing an increasing amount of their production from groundwater discharge mechanisms, such as ET and boundary flow.

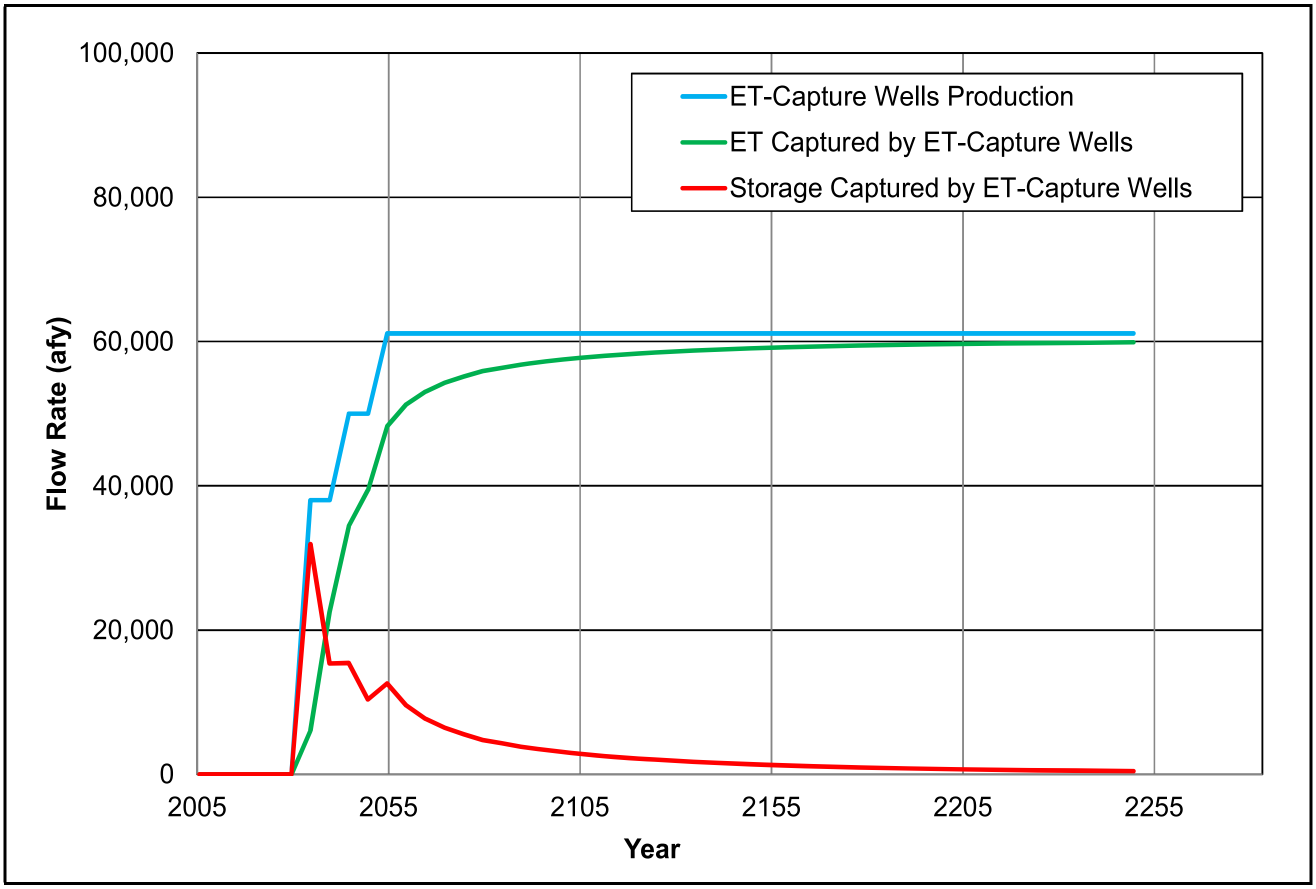

Figure ES-1
ET Discharge and Transitional Storage Captured by ET-Capture Wells as a Function of Time

The volumes of ET discharge and transitional storage captured by the ET-capture wells were also evaluated for years 2125, 2150, and 2250, or 75, 100, and 200 years after the start of full production for the SNWA project. After 75 years of full production, the ET-capture wells capture 96 percent of the permitted volume from ET discharge and 3 percent from transitional storage. After 200 years, in 2250, the wells capture 98 percent of their water from ET discharge and 1 percent from transitional storage. The remaining 1 percent is captured from interbasin flow. In other words, 96 to 98 percent of the ET discharge is captured within the 75- to 200-year time period after the start of full production. Thus, equilibrium between well production and ET capture is considered to effectively occur within this time period, within the level of model uncertainty.

An analysis was completed to calculate the cumulative volume of transitional storage captured as a percentage of the total volume of recoverable storage in the top 100 feet of valley fill in Spring Valley. The recoverable groundwater in storage was estimated to range between 4.79 and 8.57 million acre-feet based on the basin-fill specific yield estimates ranging from 0.1 to 0.18. After 200 years of SNWA pumping at full production, a cumulative volume of 1.8 to 3.3 percent of the recoverable groundwater in storage was captured by the ET-capture wells, or an average of less than 2.5 percent.

The following conclusions can be drawn from this analysis:

- Due to its limitations and uncertainties, it is inappropriate to use the CCRP model, or any other model, to quantify the water available for appropriations until such time as significant pumping-response data can be represented in the model to improve its predictive capability.

- The time to ET capture is not a valid reason to limit appropriations because the project pumping scenario can be configured to capture ET quickly within a reasonable time frame, or conversely, configured to delay ET capture to minimize impacts within a reasonable time frame.

- Staged development, as prescribed in NSE Ruling 6164, is the most appropriate approach for water development in Spring Valley because observed aquifer responses to pumping stresses can be used to update predictive models so that more informed and accurate decisions on project pumping impacts can be made.

- The ET-capture scenario simulated by the updated CCRP model demonstrates that an ET-capture project could be configured to effectively capture all of the SNWA-permitted groundwater in Spring Valley (61,100 afy) from the ET discharge area of that basin, within 75 to 200 years and the model's level of uncertainty.

- Under the ET-capture scenario, the cumulative volume of water captured from transitional storage during this time period would represent a very small percentage, less than 2.5 percent, of the recoverable groundwater in storage in the top 100 feet of saturated valley fill in Spring Valley.

- The ET-capture scenario simulation demonstrates that the groundwater system converges to a point of equilibrium, where groundwater production is derived from captured ET rather than transitional storage. Therefore, it is reasonable to conclude that an ET-capture pumping configuration would not be a groundwater mining project.

1.0 INTRODUCTION

The purpose of this report is to provide the Nevada State Engineer (NSE) with additional information with which to address the Seventh Judicial District Court's Remand Decision dated December 10, 2013 (hereinafter referred to as the Court's Decision), on the water available for appropriation from Spring Valley. The background leading up to the NSE's ruling, the Court's Decision, the issue to be resolved, and the inappropriate and appropriate uses of the CCRP model are discussed in the following sections.

1.1 Background

In 2011, the NSE held an administrative hearing on Southern Nevada Water Authority (SNWA) groundwater applications 54003 through 54021, inclusive, in Spring Valley, and applications 53987 through 53992, inclusive, in Cave, Dry Lake, and Delamar valleys (Figure 1-1). During the hearing, evidence was presented by SNWA and the protestants on a variety of topics, including hydrology and water resources. After careful consideration of the evidence and expert testimony, the NSE issued Rulings 6164, 6165, 6166, and 6167, which served as the NSE's final determination with respect to the applications in each of the four basins (NDWR, 2012a; b; c and d). The rulings granted some applications, denied others, established the permitted duties for the approved applications, and set the conditions for development of the water resources.

1.2 Nevada State Engineer Ruling 6164

NSE Ruling 6164 regarding SNWA's applications in Spring Valley was issued on March 22, 2012 (NDWR, 2012a). In the ruling, the NSE made certain findings of fact and conclusions of law with respect to the applications and the evidence presented at the hearing. Applications 54003 to 54015, 54019, and 54020 were approved over the objections of the protestants, while applications 54016, 54017, 54018, and 54021 were denied. Ruling 6164 also established the maximum appropriation allowed for Spring Valley as 61,127 afy pending additional review of the observed hydrologic effects associated with development of the water resource during the mandated staged development (NDWR, 2012a, p. 216-217). The most important aspects of the ruling in terms of this report are its discussions regarding the capture of evapotranspiration (ET) and perennial yield.

NSE Ruling 6164 (NDWR, 2012a) generally accepts the methodology SNWA used to develop a predevelopment ET discharge estimate for Spring Valley (Burns and Drici, 2011, pp. 5-1 - 5-10). One protestant witness, Dr. Thomas Myers, testified that the total ET discharge estimates were as accurate as they could be, and the NSE agreed that the total ET discharge estimates were scientifically sound (NDWR, 2012a, p. 64). The NSE differed with SNWA on the method used to convert the total ET estimate to a groundwater ET discharge estimate. The NSE determined that SNWA should have factored in carryover precipitation and tipping bucket undercatch into SNWA's groundwater ET

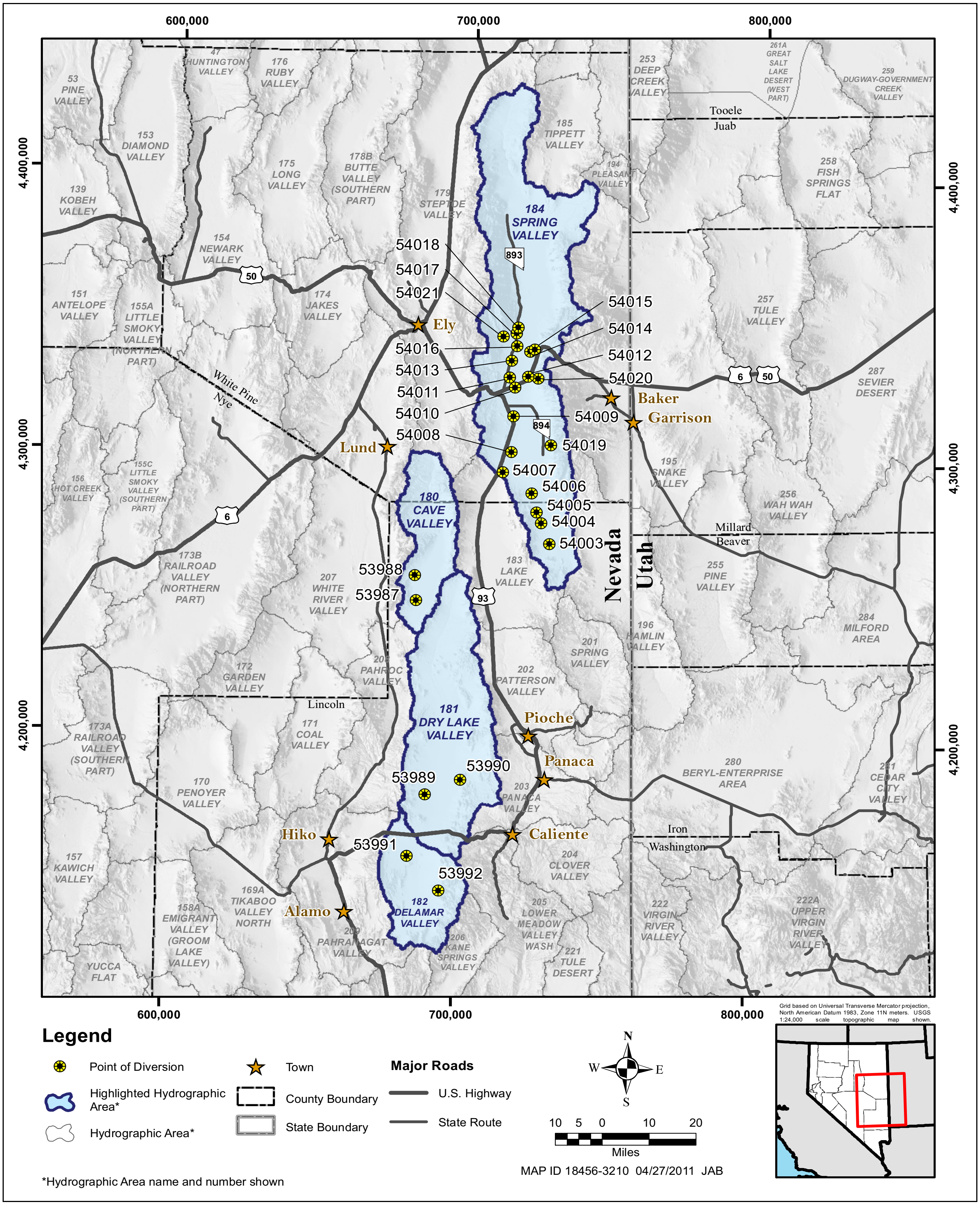

Figure 1-1
Location of the Points of Diversion in Spring, Cave, Dry Lake, and Delamar Valleys for the 2011 NSE Administrative Hearing

discharge estimate. As a result, the NSE reduced the estimated value of groundwater ET discharge for Spring Valley to 84,100 afy and then rounded that to the nearest thousand, resulting in a perennial yield estimate for Spring Valley of 84,000 afy (NDWR, 2012a, p. 76 and p. 214). The NSE estimated the range of recharge (maximum perennial yield) to be between 84,000 and 96,000 afy (NDWR, 2012a, p. 90).

1.3 Seventh Judicial District Court Decision

The four NSE rulings (NDWR, 2012a; b; c; and d) were challenged in the Seventh Judicial District Court of the State of Nevada for White Pine County (White Pine County and Consolidated Cases v. Jason King, 2013). After a review of the NSE hearing record and the legal filings, the Court upheld the vast majority of the findings made by the NSE in the rulings. However, the Court remanded the matter to the NSE for further proceedings related to four specific issues. The four issues are as follows:

1. Add Millard and Juab counties, Utah, in the mitigation plan, so far as water basins in Utah are affected by pumping of water from Spring Valley Basin, Nevada;

2. Recalculate water available for appropriation from Spring Valley ensuring that the basin will reach equilibrium between discharge and recharge in a reasonable time;

3. Define standards, thresholds, or triggers so that mitigation of unreasonable effects from pumping of water is neither arbitrary nor capricious in Spring Valley, Cave Valley, Dry Lake Valley, and Delamar Valley, and;

4. Recalculate the appropriations from Cave Valley, Dry Lake Valley, and Delamar Valley to avoid over appropriations or conflicts with down-gradient, existing water rights (White Pine County and Consolidated Cases v. Jason King, 2013).

1.4 Issue Needing Resolution

This report addresses the second issue raised by the Court, regarding the "*recalculation of water available for appropriation from Spring Valley assuring that the basin will reach equilibrium between discharge and recharge in a reasonable time*" (White Pine County and Consolidated Cases v. Jason King, 2013, p. 23).

The Court's Decision with respect to Ruling 6164 did not reverse the NSE's determination that the perennial yield for Spring Valley is 84,000 afy, existing water rights are 18,873 afy, 4,000 afy are needed for future growth and development, and 61,127 afy are available for appropriation. However, the Court raised concerns about whether SNWA's pumping of the 61,127 afy would actually capture the ET discharge in Spring Valley in a reasonable period of time (White Pine County and Consolidated Cases v. Jason King, 2013, p. 12).

In arriving at its decision, the Court reviewed the modeling results of simulations performed using the Central Carbonate-Rock Province (CCRP) Model developed by the U.S. Bureau of Land

Management (BLM) for the Clark, Lincoln, and White Pine Counties Groundwater Development Project's (CLWP GDP) Environmental Impact Statement (EIS) (White Pine County and Consolidated Cases v. Jason King, 2013, pp. 11-13). The simulations demonstrated that in the particular model scenario used, SNWA was able to capture 84 percent of the ET discharge in Spring Valley within 200 years and the basin would achieve near-equilibrium conditions. This was the only scenario for which simulation results were presented in terms of ET capture at the hearing. The Court relied on the results of this model scenario and concluded that after 200 years "*SNWA pumping and evapotranspiration removes 70,977 afa from the basin with no equilibrium in sight. That is 9,780 afa more than SNWA's grant*" (White Pine County and Consolidated Cases v. Jason King, 2013, p. 11). On this basis, the Court concluded that the NSE lacked sufficient evidence to support the 61,127 afy award of water from Spring Valley. Unfortunately, the scenario simulation the Court relied on was not designed to salvage the ET discharge in Spring Valley.

The Court also suggested, by reference to the testimony of an expert, that any uncaptured ET discharge would have to be deducted from the perennial yield. This issue is very similar to the time to ET capture issue, as there is no provision in Nevada water law that specifies ET discharge must be captured. There are many reasons for this, including the fact that the federal government owns more than 80 percent of the land in Nevada, making it difficult for the average water-right owner to site the number of wells needed to capture the volume of ET discharge represented by their water right. Private land holdings in Nevada may be separated by great distances from areas of ET, and would, therefore, be unable to capture any ET discharge. Additionally, a requirement to capture ET discharge would conflict with the processes and intent of staged development, resting of aquifers in times of decreased need, or artificially recharging aquifers when excess water is available. Therefore, the quantification of ET discharge should only be used as a metric for estimating how much water is available for appropriation, not to limit an appropriation.

In arriving at its decision, the Court agreed with the NSE that there is no provision in Nevada water law that addresses time to fully capture ET, nor has the NSE required ET to be captured within specific time frames on other groundwater development projects. Accordingly, the inability to fully capture ET is an insufficient reason, in and of itself, to deny a water-right application. However, the Court also noted that while the time to capture is not a valid reason to deny the granting of an application, "*it may very well be a reason to limit the appropriation below the calculated ET discharge*" (White Pine County and Consolidated Cases v. Jason King, 2013, p. 11).

The Court's analysis was based on a scenario simulation that is not consistent with NSE's ruling 6164 because the scenario simulation did not include the permitted pumping volume or the NSE-adopted ET volume. However, since the Court's Decision provides the basis for the remand proceedings, this report has been prepared to provide additional evidentiary support demonstrating that the full project production of 61,127 afy approved in Ruling 6164 could be simulated to be captured from the ET discharge area of Spring Valley. By extension, a new equilibrium would be established in the basin within a reasonable amount of time.

1.5 Appropriate and Inappropriate Uses of the Model

A groundwater model is a tool designed to represent a simplified version of reality that can be a valuable asset for water resource managers. The value of a model as a predictive tool depends on how well the simplified model represents reality and is largely dependent on both the quantity and quality of the information that is used to construct and calibrate the model (Wang and Anderson, 1982; Anderson and Woessner, 2002; Watrus and Drici, 2011).

The CCRP model contains an up-to-date representation of hydrogeologic data for the Great Basin region. However, the CCRP model covers vast and remote regions of Nevada and Utah where data required for numerical model calibration (most importantly data on aquifer characteristics, water levels, drawdowns, spring flow rates, and stream flow rates) are limited. Of particular interest are aquifer response data collected during prolonged periods of known pumping. Such data, which provide aquifer characteristics for the areas affected by pumping, including the potential presence of barriers to flow, do not currently exist. This lack of data inevitably leads to limitations and uncertainties in values simulated by any currently available models of the area, including the CCRP model.

The CCRP model was specifically designed to evaluate the following:

- Changes in the water levels in the regional and intermediate flow systems within the model area;

- Regional (primarily) and intermediate (secondarily) springs, groundwater ET discharge areas, streams, or wells that are hydraulically connected to regional and intermediate parts of the flow system; and

- Flow system boundaries (D'Agnese, 2011, p. 2).

Given the limitations and the list of appropriate uses, the CCRP model may be used, as it was in the 2011 NSE administrative hearing (Watrus and Drici, 2011), to identify areas of potential conflicts with senior water rights or environmental areas of interest. It is important to understand that, even in the conflicts analysis, the uncertainties of the model were factored into the identification of potential conflicts and that the simulated drawdowns at specific points were not specified because of the uncertainty (Watrus and Drici, 2011, p. 6-1).

The CCRP model was not designed to be used for the following purposes:

- Simulating perched portions of the flow system, including perched springs and ET discharge areas;

- Predicting drawdowns at specific pumping wells due to the resolution of the model cells;

- Deriving accurate predevelopment steady-state groundwater budgets for individual basins or flow systems within the study area or estimating interbasin flow (directions and volumes) across boundaries;

- Deriving new delineations of groundwater basins or new flow-system boundaries (D'Agnese, 2011, p. 2).

The limitations and uncertainties in the CCRP model make it inappropriate to use as a method of quantifying the water available for appropriation. The model is a regional-scale model that cannot represent the change in ET with the precision and accuracy necessary to identify exactly when equilibrium is achieved or to determine exactly how much pumped water would come from captured ET, transitional storage as defined by Scott et al. (1971, p. 13), or interbasin flows.

Modeling limitations and uncertainties are unavoidable but may be reduced with continued monitoring and model updates as additional data are acquired and as groundwater development begins. Therefore, the NSE's approach as specified in Ruling 6164 was appropriate. In granting the applications, the NSE required:

- Additional data collection before the start of the project;
- An update to a groundwater flow model that is approved by the NSE prior to groundwater development and at a minimum every eight years thereafter;
- Predictive results from the groundwater model for 10-year, 25-year, and 100-year periods; and
- Staged development with updated modeling results and hydrologic reporting prior to increasing pumping (NDWR, 2012a, p. 216-217).

As specified in the Court's Decision, no provision exists in Nevada water law that addresses ET capture or the time it takes for a basin to reach a new equilibrium in response to pumping. However, as the Court suggests, if the timeliness of ET capture is a valid reason to limit the quantity approved for appropriation, then the limitation should only be applied during or after the staged development process. During the initial stages of development, the actual effects of groundwater production will be identified, and the uncertainties and limitations in the groundwater model will be reduced to a point where the model can more accurately simulate the potential future effects of full project development. If it is determined that an appropriation must be limited based on ET capture principles, the limitation should be implemented by reducing the amount of water that can be pumped in the last stage of development. In other words, the NSE may reserve a quantity of water for the last stage of development that is equal to the amount of uncaptured ET that is predicted by the model after it has been updated with data gathered during pumping. As the model is refined during the staged-development process, the predictions will become more accurate, and the NSE will be better informed to make a decision on appropriations related to the SNWA permits. Additionally, for basin equilibrium between recharge and discharge to be achieved, all current and future water rights by all water-right holders in Spring Valley would have to be taken into account. SNWA, as a single water user, would only be responsible for equilibrium between its well production and ET capture. SNWA cannot be held responsible for ensuring equilibrium for the whole basin.

The remainder of this report presents an update to the CCRP model and a theoretical project pumping scenario in which production well locations are selected to effectively capture all of their water from the ET discharge area of Spring Valley. It is important to recognize that, as discussed above, the model is not suited to make accurate predictions with respect to capture of specific areas and quantities of ET discharge. Accordingly, it is inappropriate to use this modeling scenario to quantify the amount of water available for appropriation.

2.0 APPROACH

This section presents the purpose and scope, general approach, and details of the analysis included in this document.

The Court utilized the results of the only model simulation addressing ET capture presented during the 2011 hearings on the SNWA permits. Unfortunately, that model simulation did not reflect the subsequently revised values of ET discharge and permitted maximum project pumping for Spring Valley provided in Ruling 6164 (NDWR, 2012a). In addition, in the simulation scenario the Court relied upon, the SNWA wells were located outside of the ET discharge area in Spring Valley to delay ET capture and allow for greater time for the vegetation communities to transition and adapt to changing conditions. Accordingly, the model scenario indicated that pumping may capture only 84 percent of the available ET discharge 200 years after the start of full production. Based on this, the Court concluded that the evidence the NSE relied on demonstrated that a new equilibrium would not be reached in the basin within a reasonable amount of time and ordered the NSE to recalculate the awarded appropriation.

The Court's Decision is based on the results of a pumping scenario that was simulated using the version of the CCRP model that was published before the NSE ruling (6164) was issued. The Court applied these results to the findings of the NSE which were not based on the modeling results used by the Court. Given the same pumping schedule, the simulated effects of a given scenario can be drastically different depending on four factors: (1) the model used, (2) the total volume of pumping, (3) the scenario's objective, and (4) the location of the production wells. The specifics of the pre- and post-ruling factors affecting the simulation results of SNWA project scenario simulations are summarized in Table 2-1 and further described in the following text.

Table 2-1
Comparison of SNWA Project Scenarios Before and After NSE Ruling 6164

Factor	Scenario Before Ruling (Used by Court)	Scenario After Ruling (Scenario Needed)
Model	CCRP Model	Model consistent with NSE Ruling
ET Discharge in Spring Valley	75,000 afy (Estimated) 77,000 afy (Simulated)	84,100 afy (Estimated)
SNWA Maximum Production	91,224 afy	61,127 afy
SNWA Scenario Design Objective	Minimize impact to senior water rights and environment	Capture ET within reasonable time
SNWA Well Locations	Predominantly outside of ET discharge area	Inside of ET discharge area

- The CCRP model used estimated and simulated ET discharge values of 75,000 afy and 77,000 afy, respectively. Those values are much less than the value of 84,100 afy estimated by the NSE (Ruling 6164).

- The pumping scenario used in the CCRP model was designed to simulate the effects of the project application pumping rates totaling 91,000 afy, a value that is much larger than the maximum volume of 61,127 afy permitted by the NSE (Ruling 6164).

- The objective of the scenario used in the CCRP model was to minimize "*...the pumping effects at (1) PODs associated with senior water rights and (2) areas containing sensitive or listed species and/or their groundwater-related habitat*" (SNWA, 2010b, p. 3-4).

- In the scenario used in the CCRP model, the SNWA project wells were deliberately placed outside of the ET discharge area to ensure that the objective stated above would be satisfied. "*This distribution reflects the adaptive management strategies that SNWA plans to utilize in managing the resource by redistributing pumping to minimize effects*" (SNWA, 2010b, p. 3-4).

The permitted maximum volume of project pumping in Spring Valley is limited to 61,127 afy, not the 91,000 afy that was simulated in the CCRP model scenario. This volume is significantly less than the total quantity of ET discharge estimated by the NSE for Spring Valley (84,100 afy). Due to this imbalance, effective capture of the ET discharge by a pumping rate of 61,127 afy in Spring Valley is impossible because the permitted volume of pumping is less than the volume of ET discharge. Also, given the same well locations, reducing the amount of water SNWA is allowed to pump would not ensure that the reduced appropriation would be fully captured from the ET discharge area. To the contrary, ET capture would decrease and be further delayed.

The purpose of this document is to address the issue raised by the Court's Decision, i.e., the "*recalculation of water available for appropriation from Spring Valley assuring that the basin will reach equilibrium between discharge and recharge in a reasonable time*" (White Pine County and Consolidated Cases v. Jason King, 2013, p. 23). However, due to the imbalance between the volume SNWA is authorized to pump and the total quantity of ET discharge in Spring Valley, the objective of the work presented in this document is to develop a modeling scenario designed to demonstrate that ET discharge can be effectively captured by the pumping that was approved in Ruling 6164 within a reasonable time, using a model that is consistent with the NSE's estimate of ET discharge for Spring Valley.

Even though the CCRP regional model will be used, the simulation results will be focused on Spring Valley only and, more specifically, on the amount of ET discharge captured by the simulated pumping from ET-capture wells in Spring Valley. The results will be focused on the capture of ET discharge and transitional storage. The scope of the analysis includes model update activities, pumping scenario configuration, predictive model simulations, and results evaluation.

2.1 General Approach

The steps necessary to achieve the objective of this analysis are as follows:

1. Update the CCRP model used by the BLM for the project EIS to represent annual ET discharge volumes in Spring Valley that are consistent with NSE Ruling 6164 (NDWR, 2012a);

2. Configure a groundwater development scenario, whereby the simulated wells will effectively capture all of the permitted quantity of water from the ET discharge area of Spring Valley within a reasonable amount of time;

3. Perform model simulations of the Baseline scenario and the ET-capture scenario; and

4. Evaluate the simulation results.

2.2 Model Update

As described in Section 1.5, the ET discharge estimate for Spring Valley was established by the NSE in Ruling 6164 after the original CCRP model was published. Therefore, before any new scenario simulation is performed, the CCRP model must be updated and calibrated to simulate an average annual ET discharge volume for Spring Valley that is consistent with NSE Ruling 6164.

As described in the Conceptual Model report (SNWA, 2009a, p. 3-4), the annual volumes of recharge for all groundwater basins within the CCRP model domain were estimated using the groundwater balance method. This method equates the annual volume of recharge to the sum of the annual volume of ET discharge and interbasin flow. This method is consistent with the dynamics of real groundwater flow systems and the historic practice of the U.S. Geological Survey (USGS) in Nevada. Therefore, if the estimated annual volume of groundwater ET discharge changes, the estimated annual volume of recharge must also change, assuming that the hydrogeologic framework is the same. However, as ET discharge cannot be measured exactly and varies with precipitation, the long-term average annual volumes of ET discharge and recharge represented in the model were estimated within ranges of uncertainty (SNWA, 2009a, p. 7-6).

The approach used to update the CCRP model consisted of (1) modifying the estimate of ET discharge in the model to be consistent with the Spring Valley NSE Ruling 6164 and (2) adjusting relevant recharge parameters so the Spring Valley recharge volume balanced with the new estimate of ET discharge. All other model parameters were not changed and are the same as in the original CCRP model (SNWA, 2010a). The detailed changes to the model and the results of the new model calibration are described in Section 3.0.

2.3 Scenario Description

In addition to a Baseline scenario representing pumping from existing wells only, a scenario was configured to simulate pumping of the permitted volume approved in NSE Ruling 6164. This scenario incorporates the pumping volumes and stages specified in the ruling. The number, placement, and pumping rates of the simulated ET-capture wells are designed to effectively capture all of their production from the ET-discharge area, within a reasonable period of time of 75 to 200 years. The well locations, pumping volumes, and stages for the simulated scenarios are defined in Section 4.0.

2.4 Scenario Simulation

Simulations of two scenarios are necessary to achieve the objective of the work described in this report. The first scenario is the Baseline scenario in which only existing wells are simulated to continue pumping into the future. The second scenario includes the Baseline scenario pumping and adds the pumping volume of water that was approved in NSE Ruling 6164 from simulated ET-capture wells in Spring Valley, designed to comply with the Court's remand decision. The simulation results are reported and evaluated in terms of ET discharge, storage, and interbasin flow. See Section 5.0 for more details.

2.5 Effects of ET-Capture Wells

The comparison of the two scenarios allows the effects of the ET-capture wells to be isolated. The results of the scenario simulations are evaluated to identify the source of water pumped by the ET-capture wells with respect to the objective of the work described in this report. Effects of the ET-capture well pumping are calculated as the difference between the simulation results of Baseline and the ET-capture scenarios. For instance, water captured from ET discharge by ET-capture wells is calculated as ET discharge that remains uncaptured by existing wells (Baseline scenario) after a given period of time, minus the ET discharge left by existing and ET-capture wells after the same period of time. See Section 6.0 for more details.

3.0 MODEL UPDATE

Before the CCRP model can be used as a tool for evaluating ET discharge, it must first reflect the findings and conclusions of NSE Ruling 6164, regarding ET discharge. This section provides a summary description of the CCRP model and the updates applied to reflect the findings and conclusions contained in NSE Ruling 6164. Details are provided in Appendix A. Note that the units in the CCRP model are metric (meters-days) but have been converted to common English units in this report.

3.1 CCRP Model

The CCRP model was developed for use by the BLM to analyze the indirect effects of the CLWP GDP for the project EIS (BLM, 2012). The model was documented in several reports (SNWA, 2008; 2009a and b; 2010a and b; and 2012) and was used to support the EIS and used as evidence in the 2011 water-right hearing. The CCRP model was developed using a customized version of MODFLOW 2000 (Harbaugh et al., 2000), the data available at the time (SNWA, 2008, 2009a and b), and the model calibration guidelines described by Hill and Tiedeman (2007).

In NSE Ruling 6164, before evaluating the results of the conflicts quantitative analysis conducted by Watrus and Drici (2011) using the CCRP model, the NSE describes the CCRP model, its development, and limitations before concluding that:

> ...the Applicant's model provides a reliable tool to examine potential effects on the groundwater system; however, the model contains many uncertainties that must be kept in mind as it is used to analyze the system (NDWR, 2012a, p. 128).

3.2 Model Changes

This section provides a description of the changes applied to the ET-discharge estimates, the numerical model adjustment process, and the model fit of the updated CCRP model.

3.2.1 Estimated ET Discharge

The estimated ET discharge is part of the conceptualization of a model and represents one of the values that the numerical model is designed to match, as closely as possible, during model calibration.

In the CCRP model (SNWA, 2009b; 2010a), the estimated value of ET discharge for Spring Valley was set to equal approximately 75,000 afy according to estimates documented in the Conceptual Model report (SNWA, 2009a, p. 7-33). This estimated value includes annual discharge volumes from regional and intermediate ET zones and excludes perched ET-discharge areas.

To use the CCRP model for the purpose of demonstrating ET capture by simulated wells, which is consistent with NSE Ruling 6164, it is necessary to adjust the estimate of ET discharge in Spring Valley to the 84,100 afy adopted by the NSE (NDWR, 2012a, p. 76).

3.2.2 CCRP Model Update

The CCRP model was adjusted to match the simulated ET discharge to the new estimate of ET discharge in Spring Valley, 84,100 afy, derived by the NSE. The adjusted model is referred to as the updated CCRP model for the remainder of this document.

The previous estimate of predevelopment ET discharge in Spring Valley was about 75,000 afy. However, the value simulated by the CCRP model was about 77,000 afy. Given that discharge by ET is primarily a function of recharge, recharge had to be increased in Spring Valley to increase the simulated ET discharge. Recharge was the sole variable that was adjusted in the numerical model. No changes were made to any other model parameters.

Spring Valley is located within the Great Salt Lake Desert (GSLD) flow system; therefore, the factor controlling the recharge efficiencies of the GSLD flow system was adjusted. No changes were made to recharge in the other flow systems. In basic terms, recharge in Spring Valley was increased until the simulated annual ET discharge in Spring Valley matched the NSE estimated annual ET discharge in Spring Valley, 84,100 afy, within 100 afy.

3.3 Numerical Model Adjustment Results

To ensure that the updated CCRP model remained a valid representation of the conceptual model, it was compared to the original CCRP model (SNWA, 2010a) in terms of model fit, adjusted recharge parameters, simulated ET discharge, and recharge in Spring Valley.

3.3.1 Model Fit

The fit of the two models may be compared using various statistics as presented in Appendix A. Comparisons may also be made visually in graphic form. The comparison of the two models is shown in graphical form, displaying the simulated versus measured water-level values (Figure 3-1). The comparisons provided in Appendix A and shown in Figure 3-1 show that the fit of the updated model to the available data is essentially the same as the fit of the original CCRP model. Based on the NSE's conclusion described in Section 3.1 that "*the Applicant's model provides a reliable tool to examine potential effects on the groundwater system,*" so does the updated CCRP model.

3.3.2 Adjusted Recharge Parameters

The recharge factor for the GSLD flow system was adjusted from 1 to 1.0947, or an increase of 9.47 percent of the original value. This change led to proportional changes in the GSLD flow system recharge efficiencies. The resulting recharge efficiencies for the updated CCRP model are presented and compared to the efficiencies in the original CCRP model in Appendix A. As expected, all of these parameters changed by the same percentage as the overall recharge factor but stayed within the range

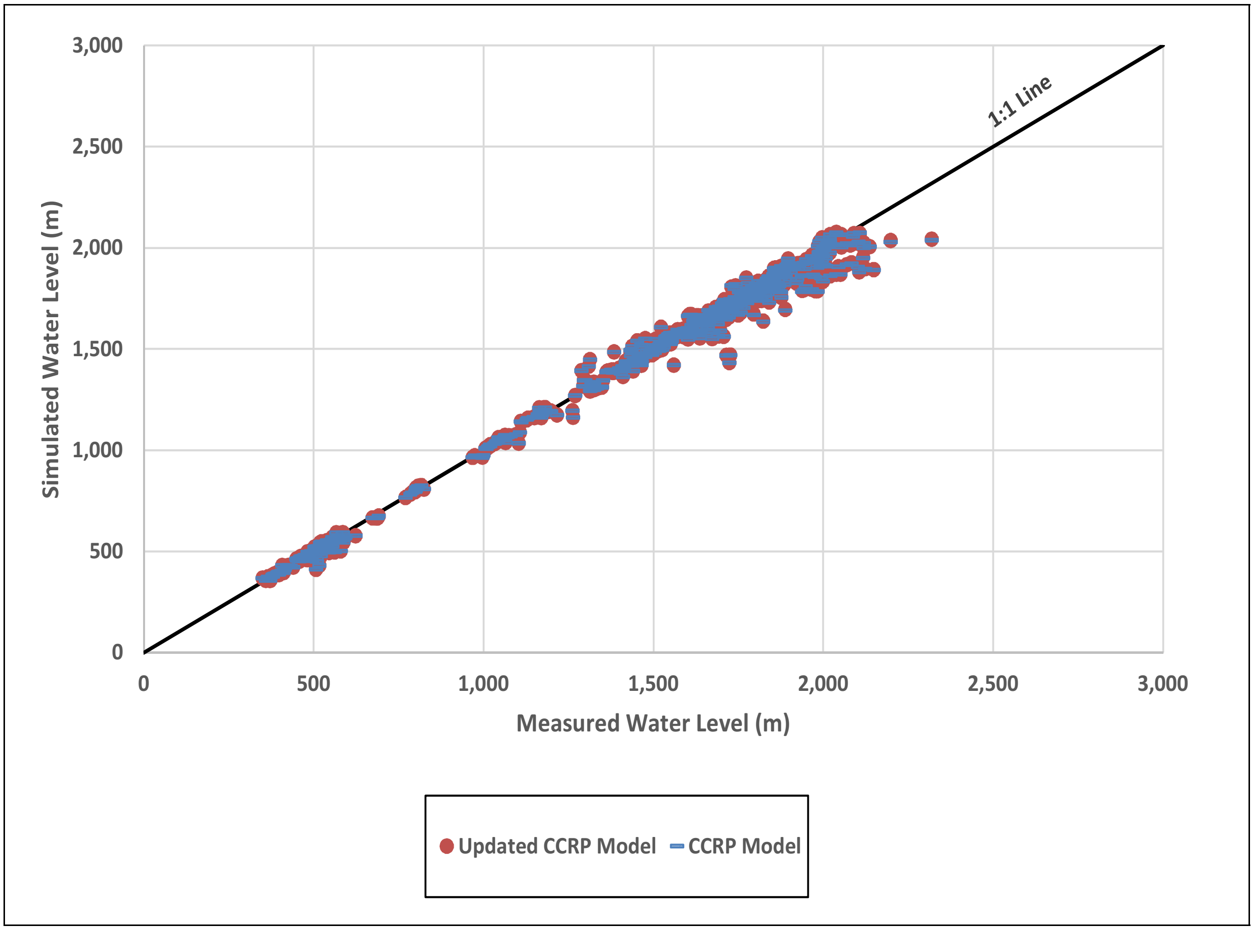

Figure 3-1
Comparison of Water-Level Fit Before and After Model Update

of uncertainty of ± 28 percent documented in the Conceptual Model report (Table 9-6 in SNWA, 2009a, p. 9-18).

3.3.3 Simulated Groundwater Budgets

The components of the groundwater budget, as simulated by the original and updated CCRP models are presented in Table 3-1. As shown on this table, the simulated values after the update are comparable to the values simulated by the original model (SNWA, 2010a). The simulated budget components of the other basins of the GSLD flow system are not presented here, as they do not affect Spring Valley and are not relevant to the objective of this analysis.

Of particular interest to this analysis are the Spring Valley annual recharge and ET discharge volumes of the updated CCRP model and their comparison to values from the original model. The changes in the recharge parameters in the updated model led to changes in the annual recharge volume of Spring Valley. The calibrated annual volume of recharge in the updated model for Spring Valley is 90,237 afy. This value is larger than the value of 82,600 afy simulated by the original CCRP model (SNWA, 2010a, p. 6-80). Both values fall near or within the estimated range of uncertainty of 84,000 afy to 96,000 afy documented in NSE Ruling 6164 (NDWR, 2012a, p. 90). The simulated ET-discharge results are presented for predevelopment steady-state conditions and for the end of the transient historical period. The predevelopment annual ET discharge increased from 77,383 afy to 84,099 afy in the updated model. The annual ET discharge simulated for the end of the transient historical period (2004) increased from 73,705 afy to 80,267 afy (see Appendix A).

Other components of the groundwater budgets, such as net interbasin flow are essentially unchanged, indicating that most of the added recharge discharges from the system in the form of ET. The change in storage in 2004 (the end of the transient historical period) is small and relatively similar, suggesting that pumping from the pre-2005 existing wells (5,645 afy) captures about the same volume of water from storage for both the original and updated models.

Table 3-1
Simulated Groundwater Budget for Spring Valley Before and After Model Update

Budget Component	Before Update Predevelopment (Original CCRP Model)	After Update Predevelopment (Updated CCRP Model)	Before Update Transient on 12/31/2004 (Original CCRP Model)	After Update Transient on 12/31/2004 (Updated CCRP Model)
Recharge (afy)	82,610	90,237	82,610	90,237
Net Interbasin Flow (afy)	(5,224)	(6,139)	(5,308)	(6,226)
Change in Storage (afy)	0	0	2,000	1,861
ET and Springs (afy)	77,383	84,099	73,705	80,267
Groundwater Withdrawals (afy)	0	0	5,645	5,645

4.0 SCENARIO DESCRIPTION

Two groundwater pumping scenarios were developed to accomplish the objective of this analysis: a Baseline scenario and an ET-capture scenario. The Baseline scenario represents pumping conditions that exclude pumping associated with the SNWA permits granted in NSE Ruling 6164. The ET-capture scenario represents the same pumping conditions in the Baseline scenario, plus the SNWA pumping volumes permitted by NSE Ruling 6164. An important element of the scenarios, the period of groundwater production, is discussed first, followed by descriptions of the scenarios.

4.1 Groundwater Production Period

Due to the uncertainties associated with the CCRP model, a time interval, rather than a point in time, was selected to represent the range of possibilities for full production and time to equilibrium. The time interval spanning 75 to 200 years following the start of full production was selected as the range for a reasonable time period to effectively achieve equilibrium conditions within the uncertainty of the model. The 75-year time period after the start of full production was selected for consistency with the conflicts analysis conducted for the 2011 hearing (Watrus and Drici, 2011, p. 4-4). This time period was deemed reasonable because it was designed to match the expected life of the equipment and infrastructure. The 200-year time period after the start of full production was selected to match the Court’s analysis of ET capture at that time.

4.2 Baseline Scenario

The Baseline scenario represents the existing groundwater use over the time period of interest (i.e., 2005 to 2250). Existing groundwater use includes the continuation of groundwater use from existing wells as estimated for the year 2004 for the entire model area (SNWA, 2009b) and permits acquired by SNWA after 2004 for operation of its ranches in Spring Valley. The Baseline scenario pumping must be included in the ET-capture scenario because the flow system does not behave in a linear fashion. The effects of the ET-capture pumping can only be derived from the difference between the Baseline and ET-capture scenario results. For instance, the volume of ET discharge captured by the ET-capture wells is calculated as the difference between the ET discharge remaining under the Baseline scenario and that remaining under the ET-capture scenario for the same point in time. The spatial distribution of the Baseline scenario pumping in Spring Valley is shown in Figure 4-1.

4.3 ET-Capture Scenario

In the ET-capture scenario, SNWA’s pumping that was approved in NSE Ruling 6164 is added to the Baseline scenario’s groundwater production. The spatial distribution and production volumes of wells were selected to present a modeling scenario that demonstrates how the model could be used to identify new well locations to increase the effectiveness of ET capture. Pumping of the permitted

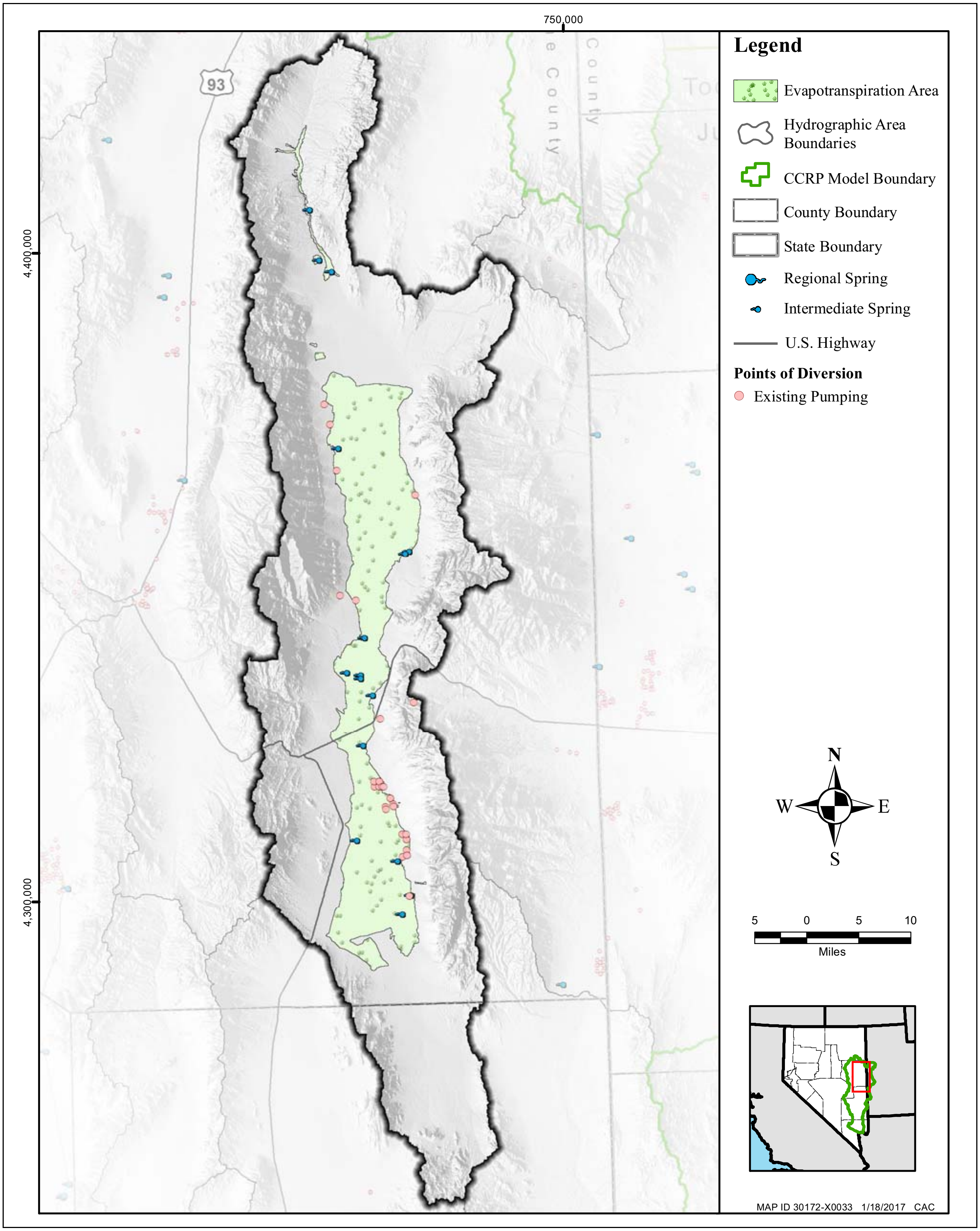

Figure 4-1
Location of Pumping Wells for Baseline Scenario

quantity of 61,127 afy is distributed both spatially and temporally following a pumping schedule as described in the following text.

4.3.1 Groundwater Development Schedule

The groundwater development schedule for the ET-capture wells reflects the staged development required by NSE Ruling 6164. The schedule is consistent with the current SNWA Water Resource Plan (SNWA, 2015, p.27). The schedule for pumping the ET-capture wells in Spring Valley is shown in Table 4-1.

Table 4-1
ET-Capture Scenario Groundwater Development Schedule in Spring Valley

Years[a]	Development Stage	Production Rate (afy)
2005-2033	Before Development Starts	0
2034-2041	1	38,000
2042-2049	2	50,000
2050-2250	3	61,127

[a]Pumping begins on January 1 for the specified year.

4.3.2 Spatial Distribution of ET-Capture Wells

The pumping distribution described below only includes project pumping associated with the ET-capture wells in Spring Valley and does not include SNWA's pumping in Delamar, Dry Lake, or Cave valleys.

The permitted groundwater production of 61,127 afy is distributed among 101 ET-capture wells, including the permitted points of diversion (PODs) and wells placed in the primary ET-discharge area. The scale of such a well field is not unusual for municipal water systems. The ET-capture wells are distributed spatially within the groundwater ET discharge area in locations that (1) avoid privately owned land, (2) avoid playa deposits, and (3) have the potential of capturing ET discharge remaining from the Baseline simulation.

Generally, the annual production volume of a given ET-capture well is based on the location of the well and its proximity to areas of high ET discharge. The spatial distribution of pumping wells in Spring Valley is shown in Figure 4-2.

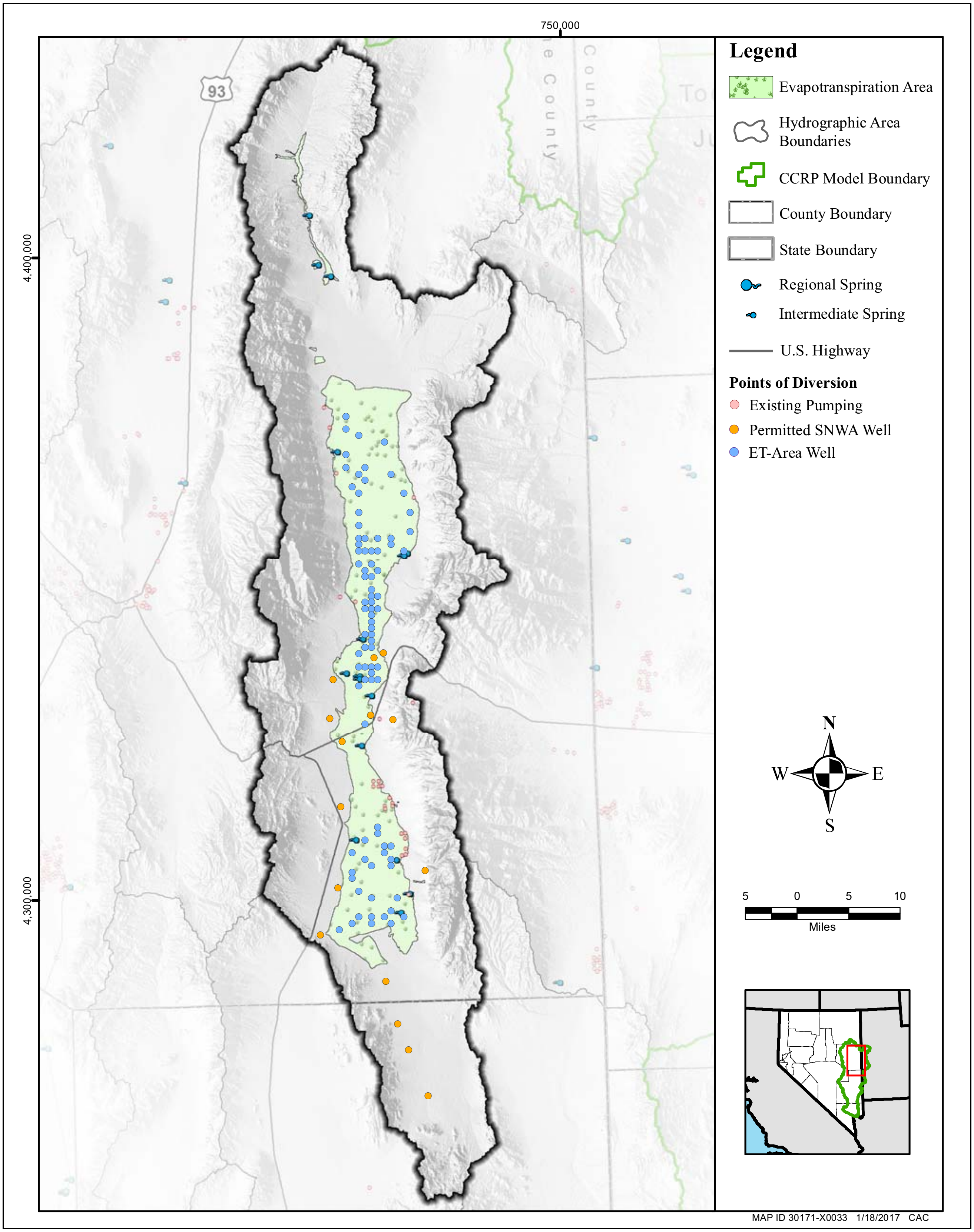

Figure 4-2
Locations of Pumping Wells for ET-Capture Scenario

5.0 SCENARIO SIMULATIONS AND RESULTS

The simulations of the Baseline and ET-capture scenarios and their results are summarized in this section. The simulation results of the ET-capture scenario presented in this section include the effects of existing and ET-capture wells. The simulated effects of pumping the ET-capture wells are presented in Section 6.0.

5.1 Scenario Modeling

The Baseline and ET-capture scenarios were simulated for the time period spanning from 2005 to 2250, using the updated CCRP model described in Section 3.0 and provided in electronic form on attached DVD. Descriptions of the initial conditions and the points in time of interest are provided in the following subsections.

5.1.1 Initial Conditions

Initial conditions (January 1, 2005) were set to be the same as the conditions simulated by the updated transient CCRP model for the end of 2004 (Section 3.0). Initial conditions are represented in the model by the water-level distribution in the model on December 31, 2004. This initial distribution, together with the distributions of all model parameters, produces initial values for all other simulated variables, such as groundwater ET-discharge rates, spring flow, and boundary flow.

5.1.2 Points in Time of Interest

The simulation starts on January 1, 2005. For the ET-capture scenario, the ET-capture wells begin production on January 1, 2034 (Stage 1). The start of full production (Stage 3) begins on January 1, 2050, and continues until December 31, 2249. The simulation results presented in this section are summarized for selected points in time over the 200-year time period following the start of full production, or full build-out of the permitted pumping volumes (2050 to 2250). Model simulation results were evaluated for the following points in time:

- December 31, 2049: the start of full production
- December 31, 2124: 75 years after the start of full production
- December 31, 2149: 100 years after the start of full production
- December 31, 2249: 200 years after the start of full production

5.2 Effects of Baseline Scenario

The simulated effects of pumping under the Baseline scenario are summarized in this section in terms of changes in ET discharge and groundwater storage. The simulation results represented by this scenario provide estimates of the hydrologic conditions that would occur without the implementation of the SNWA project.

5.2.1 Effects on ET Discharge

The simulated effects of the Baseline scenario on ET discharge are summarized in Table 5-1. The table shows that the ET discharge values in Spring Valley are very consistent for the Baseline scenario for the four time periods of interest. The simulated ET discharge values range from approximately 76,418 afy in 2050 to 74,982 afy 200 years later (2250). These values suggest that ET discharge in Spring Valley is not greatly influenced by existing pumping in the Baseline scenario.

Table 5-1
Simulated ET Discharge for Baseline Scenario in Spring Valley

Year	Time	Simulated ET (afy)
2005	0	80,193
2050	Full Build-Out	76,418
2125	+75 Years	75,370
2150	+100 Years	75,257
2250	+200 Years	74,982

5.2.2 Effects on Groundwater Storage

The simulated effects of the Baseline scenario on groundwater storage are summarized in Table 5-2. The table shows that the change in storage values in Spring Valley are relatively small, which is consistent with the small annual groundwater withdrawals from the existing wells. These simulated changes in storage values suggest that groundwater storage in Spring Valley is not greatly influenced by existing pumping under the Baseline scenario.

Table 5-2
Simulated Change in Storage for Baseline Scenario in Spring Valley

Year	Time	Change in Storage (afy)
2005	0	0
2050	Full Build-Out	1,457
2125	+75 years	508
2150	+100 Years	434
2250	+200 Years	306

Note: Change is from January 1, 2005

5.3 Effects of ET-Capture Scenario

The simulated effects of pumping under the ET-capture scenario are summarized in this section in terms of groundwater ET discharge and change in storage. The ET-capture scenario represents the addition of SNWA's permitted groundwater production to the Baseline scenario's groundwater production. Groundwater production associated with the SNWA permits under this scenario begins in 2034, reaches full production in 2050, and ends in 2250.

5.3.1 Effects on ET Discharge

The simulated effects of the ET-capture scenario on ET discharge are summarized in this section and presented in Table 5-3.

Table 5-3
Simulated ET Discharge for ET-Capture Scenario in Spring Valley

Year	Time	Project Scenario Simulated ET (afy)
2005	0	80,193
2050	Full Build-Out	37,026
2125	+75 years	16,890
2150	+100 Years	16,197
2250	+200 Years	15,087

Table 5-3 contains the simulated ET discharge values for the ET-capture scenario for the time periods of interest. Table 5-3 shows that pumping in the ET-capture scenario greatly affects the simulated ET discharge. For example, at the four different time periods of interest, the simulated ET discharge is substantially lower than the simulated ET discharge from the Baseline scenario (Table 5-1). The annual volume of ET discharge simulated under the ET-capture scenario is approximately 15,087 afy after 200 years of full production.

5.3.2 Effects on Groundwater Storage

The simulated effects of the ET-capture scenario on groundwater storage in Spring Valley are summarized in this section and presented in Table 5-4.

Table 5-4 shows that, early in the simulation period, the pumping wells are mostly capturing transitional storage. However, by the year 2125, 75 years after the start of full production, the ET-capture wells capture a negligible volume from transitional groundwater storage, as the aquifer system of Spring Valley nears equilibrium conditions.

Table 5-4
Simulated Change in Storage for ET-Capture Scenario in Spring Valley

Year	Time	Change in Storage (afy)
2005	0	0
2050	Full Build-Out	11,849
2125	+75 years	2,539
2150	+100 Years	1,825
2250	+200 Years	751

Note: Change is from January 1, 2005

6.0 Simulated Effects of ET-Capture Wells

The results of the model simulations described in Section 5.0 are discussed in terms of the volumes of ET discharge and transitional storage captured by the ET-capture wells. The volumes were calculated as the difference between the ET discharge and transitional storage values simulated by the Baseline and ET-capture scenarios.

6.1 ET Discharge and Transitional Storage Capture

The capture of ET discharge and transitional storage by the ET-capture wells in Spring Valley is best illustrated as a graph of their change as a function of time (Figure 6-1). Table 6-1 provides a summary of ET discharge and transitional storage captured by the ET-capture wells at selected points in time.

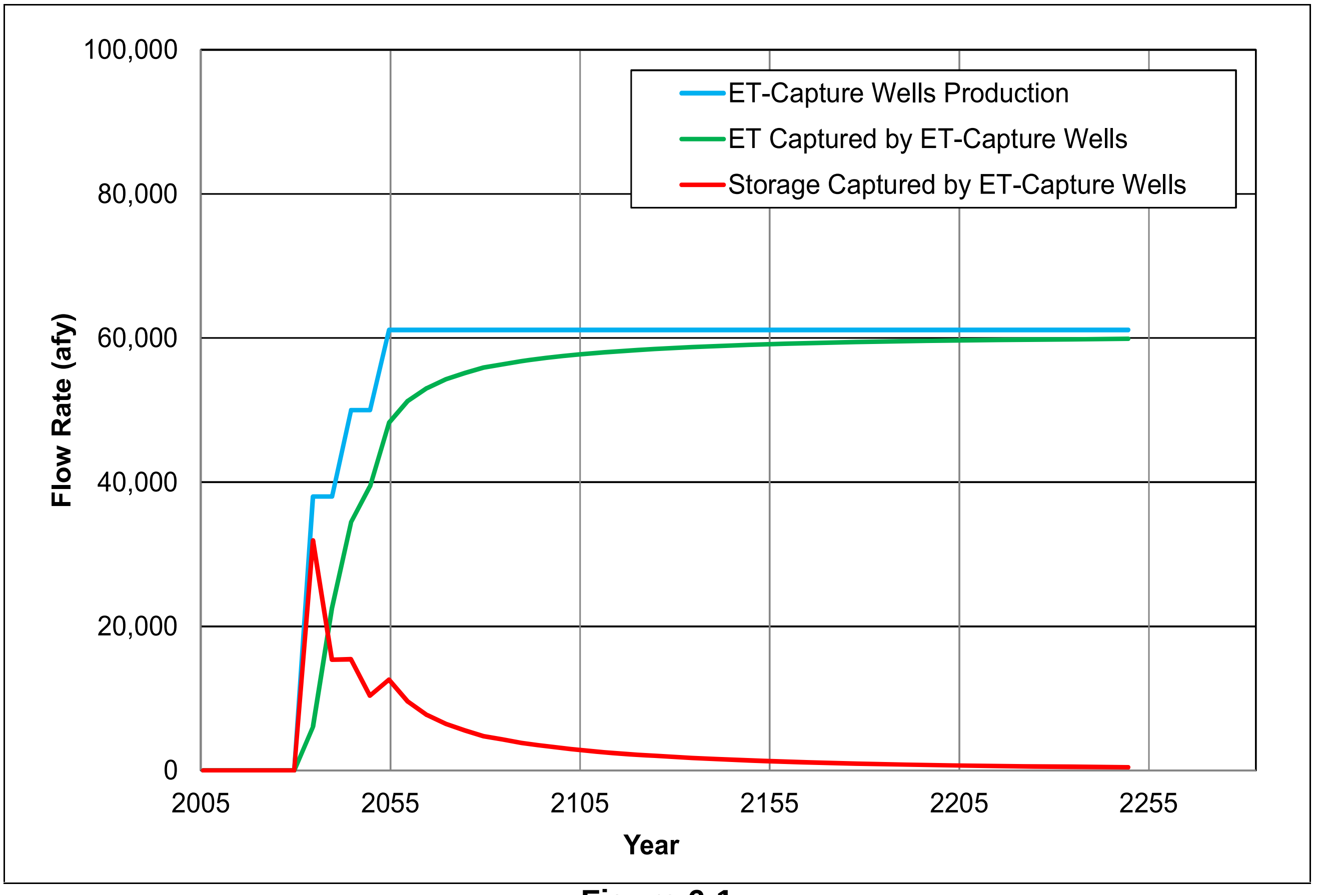

Figure 6-1
ET Discharge and Transitional Storage Capture by ET-Capture Wells as a Function of Time

Table 6-1
ET Discharge and Transitional Storage Captured by ET-Capture Wells at Selected Points in Time in Spring Valley

Item	Description	2125 (+75 years)	2150 (+100 years)	2250 (+200 years)
a	ET-Capture Well Maximum Pumping Rate (afy)	61,127	61,127	61,127
b	Remaining ET under Baseline Scenario (afy)	75,370	75,257	74,982
c	Remaining ET under ET-capture Scenario (afy) [Existing + ET-Capture Wells]	16,890	16,197	15,087
d	ET Captured by ET-Capture Wells (afy)	58,480	59,060	59,894
e	Groundwater Captured by ET-Capture Wells from ET Area (% Maximum Pumping Rate)	96%	97%	98%
f	Storage Captured under Baseline Scenario (afy)	508	434	306
g	Storage Captured under ET-Capture Scenario (afy) [Existing + ET-Capture Wells]	2,539	1,825	751
h	Storage Captured by ET-Capture Wells (afy)	2,031	1,392	445
i	Groundwater Captured by ET-Capture Wells from Transitional Storage (% Maximum Pumping Rate)	3%	2%	1%

Calculations:
d = b – c
e = d / a x 100
h = g – f
i = h / a x 100
Note: For the three times of interest, 1 percent of the well production is captured from boundary flow.

The temporal progression of ET discharge and transitional storage capture by the ET-capture wells in Spring Valley (Figure 6-1) exhibits the typical behavior of well pumping from an aquifer. Initially, pumping produces water mostly from transitional groundwater storage and eventually captures water from discharge mechanisms in the aquifer system. In Spring Valley, the primary discharge mechanisms are ET and springs, which are both simulated as ET in the model, and boundary flow.

As shown in Figure 6-1, when the ET-capture wells are activated in 2034, they initially capture most of their production from transitional storage and the rest from ET discharge. After this point, the responses reflect NSE-prescribed staged development. During periods when production is not increased, capture from ET discharge increases as capture from transitional storage decreases. When well production is increased, capture of transitional storage increases briefly before resuming its downward trend. After 75 years of pumping at full production rates (61,127 afy), the ET-capture wells have captured 96 percent of their water production from the ET discharge, 3 percent from transitional storage, and 1 percent from interbasin flow. After 100 years of pumping at full production rates, the ET-capture wells have captured 97 percent of their water production from the ET discharge, 2 percent from transitional storage, and 1 percent from interbasin flow. After 200 years of full production, the ET-capture wells have captured 98 percent of their water production from the ET discharge. The remainder of the well production is captured from transitional storage (1 percent) and from interbasin flow (1 percent). Therefore, it is reasonable to conclude that the permitted pumping, as represented and simulated in the ET-capture scenario, effectively captures the entire volume of water from ET discharge, within a reasonable period of time of 75 to 200 years, and within the model's level of uncertainty.

As shown in Figure 6-1, after 75 years of pumping at full production rates, both the ET discharge and transitional storage capture curves begin to stabilize. The ET-capture curve approaches the total production curve for the ET-capture wells, which reach their maximum production rate of 61,127 afy in 2050 and remain at that level until 2250. During the same time period, the transitional storage capture curve exhibits a continuing downward trend toward zero. The rate of change of the two curves decreases with time as their behavior stabilizes and converges to equilibrium conditions.

6.2 Cumulative Transitional Storage Capture

The calculations described in this section were performed to evaluate the relative magnitude of the cumulative volume of transitional storage captured under the ET-capture scenario as a percentage of the total volume of recoverable storage of Spring Valley. The volume of recoverable storage, as defined in the USGS's Water Resources Reconnaissance Series reports, is the groundwater in storage in the top 100 ft of the valley fill aquifer of a given basin (Rush and Kazmi, 1965, p.27).

Estimates of the recoverable groundwater in storage for Spring Valley, Nevada, were made using data compiled for the CCRP model and documented in SNWA (2009b) and SNWA (2010a). Details are presented in Appendix B.

The estimated volume of recoverable storage in the top 100 ft of saturated material varies from 4.79 maf to 8.57 maf in Spring Valley. The large range in storage values is dependent on the range of specific yield values. The majority of model cells in the valley bottom had a specific yield value of 0.18 in the calibrated model and a low value of 0.1 used in the uncertainty analysis (Appendix B). Note that the specific yield values are the same in both the original and updated CCRP models.

The lower estimate of recoverable storage in Spring Valley compares favorably with the estimate of recoverable storage provided by Rush and Kazmi (1965, p. 27). Rush and Kazmi (1965, p. 27) stated that the estimated volume of recoverable water stored in the top 100 ft of saturated alluvium was at least 4.2 maf, using a specific yield value of 0.1 in their calculations.

The cumulative volume of transitional storage captured by the ET-capture wells is presented as a function of time in Figure 6-2. Three curves representing the cumulative transitional storage captured as a percentage of minimum, average, and maximum estimates of recoverable storage, are presented. The maximum range is between 1.8 percent and 3.3 percent in 2250.

The very small percentage of recoverable storage captured by the ET-capture wells indicates that the SNWA project is not a groundwater mining project. After 200 years of production, 97 percent to 98 percent of the recoverable storage remains in the aquifer system of Spring Valley.

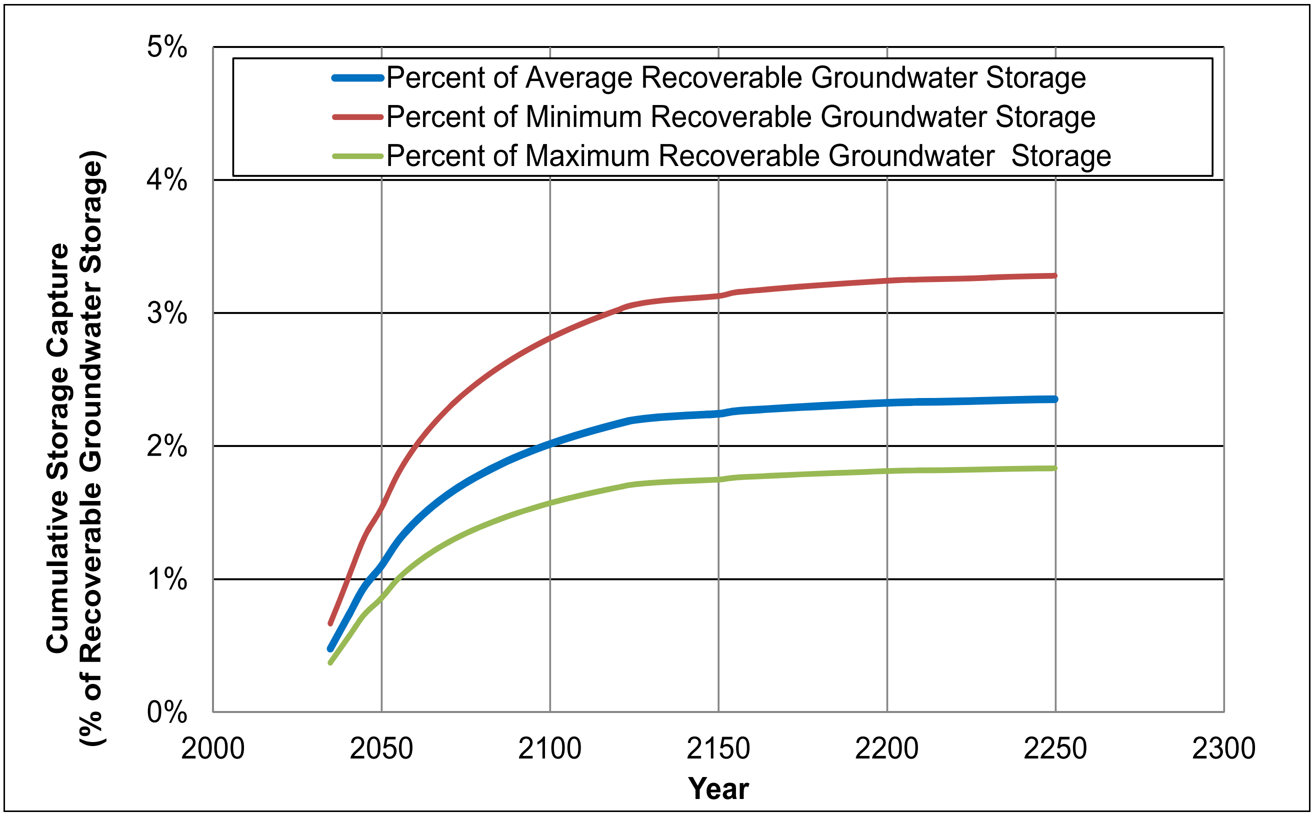

Figure 6-2
Cumulative Transitional Storage Capture by ET-Capture Wells as Percentage of Recoverable Storage in Spring Valley

7.0 NUMERICAL MODEL LIMITATIONS AND UNCERTAINTIES

Numerical modeling limitations and uncertainties are very common for regional-scale models developed for very large expanses of the geologically and tectonically complex Great Basin, as described in modeling studies in this region (D'Agnese et al., 1997; Belcher and Sweetkind, 2010). The limitations and uncertainties of the CCRP model, as well as its development and utilization in the NSE's water-rights hearing in 2011 are described in Watrus and Drici (2011).

As stated in Section 1.0, the predictive capabilities of a numerical model depends mostly on both the quantity and quality of the data used to construct and calibrate the model (Wang and Anderson, 1982; Anderson and Woessner, 2002; Watrus and Drici, 2011). The limitations and uncertainties of the CCRP model stem from the scarcity of spatial and temporal data, particularly hydrologic response data of the aquifer system under pumping conditions.

Modeling uncertainties are unavoidable but can be reduced through time with continued data collection and iterative model updates as development and monitoring occur in Spring Valley. An example of this type of refinement would include updates to the ET-discharge estimates for Spring Valley. At the time of model construction, the best estimate of ET discharge in Spring Valley was 75,400 afy (SNWA, 2009a, p. 7-29). However, with additional years of data collection, the estimate was revised to 84,100 afy as described in NSE Ruling 6164 (NDWR, 2012a, p. 73).

The limitations and uncertainties in the model apply both directly and indirectly to the simulation of ET capture. The land-surface elevations assigned to numerical model cells that contain ET discharge also affect the ability to simulate groundwater conditions more accurately. The elevations in ET-discharge cells were set to values of land-surface elevation reduced by one of two values of extinction depth depending on location. Extinction depth is defined as the depth below the land surface at which ET ceases. Extinction depths depend on the type of plants and their rooting depths, which greatly vary and depend on the depth to water across the valley floor (SNWA, 2009a, p. 7-6). "*The rooting depths of phreatophytic plants extend from just below the ground surface to depths greater than 100 ft*" (SNWA, 2009a, p. A-1). The values of land-surface elevation were based on a 1:24,000-scale digital elevation model. For simplification consistent with a regional-scale model, the extinction depth values were set to only two values, either 16.4 ft bgs (5 m bgs) or 32.8 ft bgs (10 m bgs) (SNWA, 2009b, p. 4-38). This simplified method of representing ET-cell elevations does not provide the necessary resolution to accurately represent extinction depth for all discharge areas.

Additionally, the limited data on water levels create uncertainties between the simulated rate at which the water table lowers and the actual rate at which it will lower in response to pumping. The rate at which the water table lowers will impact the ability of vegetation to adapt to the lowering and will therefore have an effect on the magnitude and timing of ET capture. This is another reason that ET capture is unlikely to occur in reality exactly as the model simulates.

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8.0 CONCLUSIONS

The following conclusions were drawn from the analysis described in this document.

- Due to its limitations and uncertainties, it is inappropriate to use the CCRP model, or any other model, to quantify the water available for appropriations until such time as significant pumping-response data can be represented in the model to improve its predictive capability.

- The time to ET capture is not a valid reason to limit appropriations because the project-pumping configurations can be designed to capture ET quickly within a reasonable time frame, or conversely, designed to delay ET capture to minimize impacts within a reasonable time frame.

- Staged development, as prescribed in NSE Ruling 6164, is the most appropriate approach for water development in Spring Valley because observed aquifer responses to pumping stresses can be used to update predictive models so that more informed and accurate decisions on project pumping impacts can be made.

- The ET-capture scenario simulated by the updated CCRP model demonstrates that an ET-capture project could be designed to capture nearly all of the SNWA-permitted groundwater in Spring Valley (61,100 afy) from the ET-discharge area of that basin, within a reasonable amount of time and within the model’s level of uncertainty.

- Under the ET-capture scenario, the cumulative volume of water captured from transitional storage during this time period would represent a very small percentage, about 2 percent, of the recoverable groundwater in storage in the top 100 ft of saturated valley fill in Spring Valley.

- The ET-capture scenario simulation demonstrates that the groundwater system converges to a point of equilibrium, where groundwater production is derived from captured ET rather than transitional storage. Therefore, it is reasonable to conclude that the ET-capture pumping configuration used in this scenario would not be a groundwater mining project. However, this scenario should not be used to conclude that it represents the only pumping configuration that can avoid groundwater mining.

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Appendix A

Updated CCRP Model Fit and Recharge Parameters

A.1.0 INTRODUCTION

This appendix provides details regarding the changes made to the CCRP model to ensure that it is consistent with the findings specified in NSE Ruling 6164 for Spring Valley (NDWR, 2012a). The results of the update include comparisons between the original and updated CCRP models in terms of model fit and adjusted parameters.

A.2.0 MODEL FIT

The two models were compared in terms of the overall fit of the two calibrated transient models and the statistics of their unweighted residuals.

The overall fit to the observed data is represented by the sum of squared weighted residuals (SoSWR), a dimensionless quantity. In a model, observed data can be actual measurements, like historical water levels, or estimated values like ET discharge. The SoSWR is an expression of the residuals or differences between the simulated and observed values of variables calculated by the model, such as water levels and flow rates. The residuals are assigned weights between 0 and 1, representing the level of accuracy of the observed values. The most accurate values are assigned the highest weights. During model calibration, parameters, such as hydraulic properties and recharge, are adjusted while trying to reduce the SoSWR value. As the SoSWR value decreases, the simulated values get closer to the observed values and the model fit improves. The SoSWR decreased from 41,464 for the original CCRP model (SNWA, 2010) to 38,251 for the updated CCRP model, or a decrease of about 8 percent, that indicates a better fit to the observed data. See the detailed definition of the SoSWR in the Numerical Model report (SNWA, 2009, p. 2-8).

Detailed statistics for the unweighted observations are presented in Table A-1 for the original model and Table A-2 for the updated model. A comparison of the statistics of the unweighted residuals calculated as the difference between the original and updated model is presented in Table A-3. As shown in this table, the two models are very similar in terms of fit to the observed (or measured) data. Important statistics listed in these tables are the root mean square error (RMSE), the range, and their ratio (RMSE/Range). The RMSE is the square root of the sum of the squared residuals divided by the number of observations of a given target variable (ET discharge for example). It is a measure of how well the model simulates the observed values of that variable, which are usually measured or estimated. The range is the difference between the maximum and the minimum observed values of that variable. The ratio of RMSE to Range is a measure of the average model error in simulating the target variable, expressed as a percentage. This error is the minimum error associated with values simulated by the model. It does not include the errors associated with measurements or estimates, and the errors associated with the conceptualization of the real system.

A.3.0 ADJUSTED RECHARGE EFFICIENCIES

The change in the total recharge factor made during the model update led to changes in the recharge efficiencies of the GSLD flow system. The resulting efficiencies are presented in Table A-4. The table also includes comparisons with the flow system's efficiencies before the model update. As expected, all of these parameters changed by the same percentage as the overall recharge factor (i.e., 9.47 percent of their original values).

Table A-1
Unweighted Observation Statistics for Original CCRP Numerical Model

Observation Type	Units	Number of Samples	Mean Error	Mean Absolute Error	Root Mean Square Error (RMSE)	Standard Deviation	Target Data Range	RMSE/Range (%)
Boundary Flux	afy	16	1,173	1,707	2,275	2,013	20,000	11
Gage Flow	afy	140	255	1,211	1,687	1,674	35,672	5
Ground Surface[a]	ft	2,145	0	0	5	5	0	NA
Regional ET Discharge	afy	108	-250	1,765	2,908	2,910	69,431	4.2
Spring Flow	afy	29	-1,146	1,293	2,208	1,921	12,833	17
Well Drawdown	ft	4,301	-1	4	9	9	238	4
Well Head	ft	2,707	15	45	92	90	6,461	1

[a]Because all ground surface measurements were expected to be 0.0 (no mounding), the target data range is 0.0, and RMSE/Range cannot be calculated.
NA - Not Applicable

Table A-2
Unweighted Observation Statistics for Updated CCRP Numerical Model

Observation Type	Units	Number of Samples	Mean Error	Mean Absolute Error	Root Mean Square Error (RMSE)	Standard Deviation	Target Data Range	RMSE/Range (%)
Boundary Flux	afy	16	1,268	1,797	2,331	2,020	20,000	12
Gage Flow	afy	140	278	1,214	1,691	1,674	35,672	5
Ground Surface[a]	ft	2145	0	0	5	5	0	NA
Regional ET Discharge	afy	108	-165	1,831	3,126	3,136	69,431	4.5
Spring Flow	afy	29	-1,103	1,252	2,114	1,836	12,833	16
Well Drawdown	ft	4301	-1	4	9	9	238	4
Well Head	ft	2707	15	45	91	90	6,461	1

[a]Because all ground surface measurements were expected to be 0.0 (no mounding), the target data range is 0.0, and RMSE/Range cannot be calculated.
NA - Not Applicable

Table A-3
Comparison of Unweighted Observation Statistics for the Updated CCRP Models to the Original Model

Observation Type	Units	Number of Samples	Mean Error	Mean Absolute Error	Root Mean Square Error (RMSE)	Standard Deviation	Target Data Range	RMSE/ Range
Boundary Flux	afy	16	95	90	56	7	0	0
Gage Flow	afy	140	23	3	4	0	0	0
Ground Surface[a]	ft	2,145	0	0	0	0	0	NA
Regional ET Discharge	afy	108	85	66	218	226	0	0.3
Spring Flow	afy	29	43	-41	-94	-85	0	-1
Well Drawdown	ft	4,301	0	0	0	0	0	0
Well Head	ft	2,707	0	0	-1	0	0	0

[a]Because all ground surface measurements were expected to be 0.0 (no mounding), the target data range is 0.0, and RMSE/Range cannot be calculated.
NA - Not Applicable

Table A-4
Comparison of Recharge Parameters Before and After Model Update

Parameter	Description	Precipitation Rate[a] (in./yr)	Original CCRP Model (Before)	Updated CCRP Model (After)	Difference (Updated - Original)
RSC_ME_GSL[b]	Factor controlling all recharge efficiency factors of Great Salt Lake Desert flow system	All	1.000	1.095	0.095
rtme2_gsld	Recharge efficiency factor for all of Great Salt Lake Desert flow system	8 - 12	0.011	0.011	0
rtme3_gsld	Recharge efficiency factor for all of Great Salt Lake Desert flow system	12 - 15	0.050	0.054	0.004
rtme4_gsld	Recharge efficiency factor for all of Great Salt Lake Desert flow system	15 - 20	0.120	0.132	0.012
rtme5_gsld	Recharge efficiency factor for all of Great Salt Lake Desert flow system	> 20	0.328	0.359	0.031

[a] For precipitation rates less than 8 inches per year, the recharge efficiency factor is assumed to equal zero.
[b] The total recharge factor affects all recharge efficiency factors in the Great Salt Lake Desert flow system.

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Appendix B

Calculation of Volume of Recoverable Groundwater in Storage in Spring Valley

B.1.0 INTRODUCTION

Estimates of the recoverable groundwater in storage in Spring Valley, Nevada, were made using data compiled for the CCRP model and documented in SNWA (2009a and b) and SNWA (2010).

The method used is the same as the one described in the Reconnaissance Report series, including the one prepared by Rush and Kazmi (1965, p. 27) for Spring Valley. In this method, a conservative range of recoverable groundwater volumes in storage is calculated as the product of the area of the valley fill in the basin multiplied by a saturated valley-fill thickness of 100 ft, multiplied by the specific yield of the valley fill. A range of specific yield values is used to derive the range of recoverable groundwater in storage. The estimates provided in this document are considered conservative because only 100 ft of the much thicker valley fill aquifer are considered in the calculations. In other words, the actual volume of recoverable groundwater in storage in the valley fill of Spring Valley may be larger.

This method was used to calculate the recoverable volume of groundwater in storage in the valley fill of Spring Valley, based on data utilized in the CCRP model (SNWA, 2009a and b; SNWA, 2010).

B.2.0 DATA

Data needed for the calculation are the area of the valley fill and estimates of its specific yield in Spring Valley. The area was derived from the geologic framework of the CCRP model (SNWA, 2009 a and b; SNWA, 2010).

From the geologic framework model, the area of the upper valley fill (UVF) regional modeling unit was derived from the available geographic information system data. In Spring Valley, the area of the UVF is 511,261 acres. This area compares favorably to previous estimates of the area of the alluvium in Spring Valley. For comparison, Rush and Kazmi (1965, p. 27) reported 548,000 acres mapped as alluvium.

The SYTP parameter is an alternative specification of storage properties for the uppermost active cells of a model constructed using MODFLOW 2000 (Harbaugh et al., 2000) and is specified for each hydrogeologic unit (Anderman and Hill, 2003). For the CCRP model, the MODFLOW code was modified to generate a grid of specific yield (SNWA, 2009b, p. 4-25). The estimates of specific yield for the valley fill used in the storage calculations were extracted from the MODFLOW SYTP grids used as input to the transient simulations of the calibrated model documented in SNWA (2010) (simulations ucth935). The upper estimates of the specific yield were obtained from the MODFLOW SYTP grid used in the sensitivity simulation (ucth971).

From the SYTP model outputs, the specific yield values for each model cell in Spring Valley were obtained. The SYTP values from simulation ucth935 correspond to the historical transient forward model, while the SYTP values from simulation ucth971 correspond to the historical transient forward calibration uncertainty model. The specific yield values for the original simulation ranged from 0.01 to 0.18 (dimensionless). For the uncertainty simulation, the specific yield values range from 0.01 to 0.10 (dimensionless). SNWA (2009a) presented an analysis of the transmissivity and specific yield for sites within the CCRP model area based on a local numerical model using MODFLOW-96 (Harbaugh and McDonald, 1996) and MODOPTIM (Halford, 2006). From that analysis, a representative range of specific yield for alluvial deposits was reported as 0.12 to 0.18 (dimensionless) (SNWA 2009a).

B.3.0 CALCULATIONS

The groundwater storage in the valley fill of Spring Valley for each model cell was computed as the product of the model cell acreage, the specific yield of the model cell, and an assumed aquifer thickness of 100 ft. The cumulative groundwater storage in Spring Valley is the summation of the storage from the individual model cells. The overall storage for the two different model simulations is presented in Table B-1 and ranges from 4.79 maf to 8.57 maf. The large range is entirely dependent on the specific yield values. For the ucth935 simulation, the majority of model cells in the valley bottom had a specific yield value of 0.18 (dimensionless). In the ucth971 simulation, the majority of model cells in the valley bottom had a specific yield value of 0.10 (dimensionless).

Table B-1
Summary of Recoverable Groundwater in Storage in Spring Valley

Simulation	Specific Yield Range (-)	Storage (maf)
ucth935	0.01 to 0.18	8.57
ucth971	0.01 to 0.10	4.79

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