

**Transient Numerical Model of
Groundwater Flow for the
Central Carbonate-Rock Province:
Clark, Lincoln, and White Pine Counties
Groundwater Development Project**

November 2009

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PREFACE

This report was prepared by the Southern Nevada Water Authority. The U.S. Geological Survey served as technical advisor to the Bureau of Land Management in the review of this report.

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ACRONYMS

3D	three-dimensional
BARCASS	Basin and Range Carbonate Aquifer System Study
BLM	Bureau of Land Management
CCRP	Central Carbonate-Rock Province
CHD	Time-Variant Specified-Head (package)
CHOB	Specified-Head Flow Observation (package)
CONDFACT	conductance modifier
COV	coefficient of variation
CRP	Carbonate-Rock Province
CSS	composite-scaled sensitivity
CWP	Cooperative Water Project
DEM	digital elevation model
DRN	Drain (package)
DROB	Drain observation module
DTW	depth to water
DVFS	Death Valley Flow System
DVRFS	Death Valley Regional Flow System
EIS	environmental impact statement
ET	evapotranspiration
GIS	geographic information system
GSLDFS	Great Salt Lake Desert Flow System
GVFS	Goshute Valley Flow System
HA	hydrographic area
HFB	Horizontal Flow Barrier (package)
HGU	hydrogeologic unit
HOB	head observation
HUF2	Hydrogeologic-Unit Flow (package)
<i>K</i>	hydraulic conductivity
KDEP	hydraulic-conductivity depth-dependence
LVVWD	Las Vegas Valley Water District
MAE	mean absolute error
MDF	moderate-displacement fault
ME	mean error
MNW	Multi-Node Well
MVFS	Meadow Valley Flow System

ACRONYMS (CONTINUED)

MVWD	Moapa Valley Water District
NA	not applicable
NCDC	National Climatic Data Center
NDWR	Nevada Division of Water Resources
NWIS	National Water Information System
NWS	National Weather Service
PDSI	Palmer Drought Severity Index
PLSS	Public Land Survey System
POD	point of diversion
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RASA	Regional Aquifer-System Analysis
RCH	MODFLOW-2000 recharge (package)
RE	recharge efficiencies
RMSE	root mean square error
RMU	regional modeling unit
SFR2	Streamflow-Routing (package)
SNWA	Southern Nevada Water Authority
SoSWR	sum of squared weighted residual
UDWR	Utah Division of Water Rights
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VANI	vertical anisotropy
WRCC	Western Regional Climate Center
WRFS	White River Flow System

ABBREVIATIONS

af	acre-foot
afy	acre-feet per year
amsl	above mean sea level
bgs	below ground surface
cfs	cubic feet per second
d	day
ft	foot
ft ²	square foot

ABBREVIATIONS (CONTINUED)

in.	inch
km	kilometer
km ²	square kilometer
m	meter
m ²	square meter
m ³	cubic meter
mi	mile
yr	year

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1.0 INTRODUCTION

This report describes the development of a numerical groundwater flow model of the Central Carbonate-Rock Province (CCRP) in Nevada and Utah. The CCRP numerical groundwater flow model supports the Southern Nevada Water Authority's (SNWA) Clark, Lincoln, and White Pine Counties Groundwater Development Project (hereinafter referred to as the Project). The extent of the Project study area (i.e., the regional model area) is shown in [Figure 1-1](#). This numerical model is based on a conceptual model primarily described in a separate report (SNWA, 2009a) and was used as part of the environmental analysis for the Project. Specifically, the numerical model was used to simulate groundwater development scenarios to evaluate the range of potential water-related effects of the Project's groundwater production at the regional scale. Two previous models for this region, the Death Valley Regional Flow System (DVRFS) Model (Belcher, 2004) and the Great Basin Regional Aquifer-System Analysis (RASA) model (Prudic et al., 1995), provided the foundation for much of the modeling approach, methodology, and documentation for the CCRP model. These models are summarized in [Section 1.3](#) and cited throughout this report. Summaries of the Project background, previous models, purpose and scope, general assumptions and model limitations, and Bureau of Land Management (BLM) review process are presented in this section, followed by a description of the contents of this report.

1.1 Background

A brief description of the background of the Project is presented, followed by a summary of the historical background of the study area.

1.1.1 Project Background

To reduce reliance on Colorado River water resources and buffer the impacts of long-term droughts on the Colorado River system, SNWA has identified plans to develop in-state non-Colorado River water resources (SNWA, 2004). These potential additional resources will augment the current water resource portfolio identified in the SNWA Water Resource Plan (SNWA, 2009c). The Project will develop and convey groundwater rights and applications held by SNWA in five basins in eastern Nevada. [Figure 1-2](#) shows the project basins and current points of diversion.

The Project consists of groundwater production, conveyance and treatment facilities, and power conveyance facilities, most of which will be located on Federal lands managed by BLM. Consequently, in 2004, SNWA applied to BLM for rights-of-way to construct, operate, and maintain the Project facilities. BLM issuance of these rights-of-way is a Federal action, which must comply with the National Environmental Policy Act of 1969, the Endangered Species Act of 1973, and other Federal regulations. BLM has determined that preparation of an Environmental Impact Statement (EIS) is required to assess the potential effects that may result from permitting the rights-of-way,

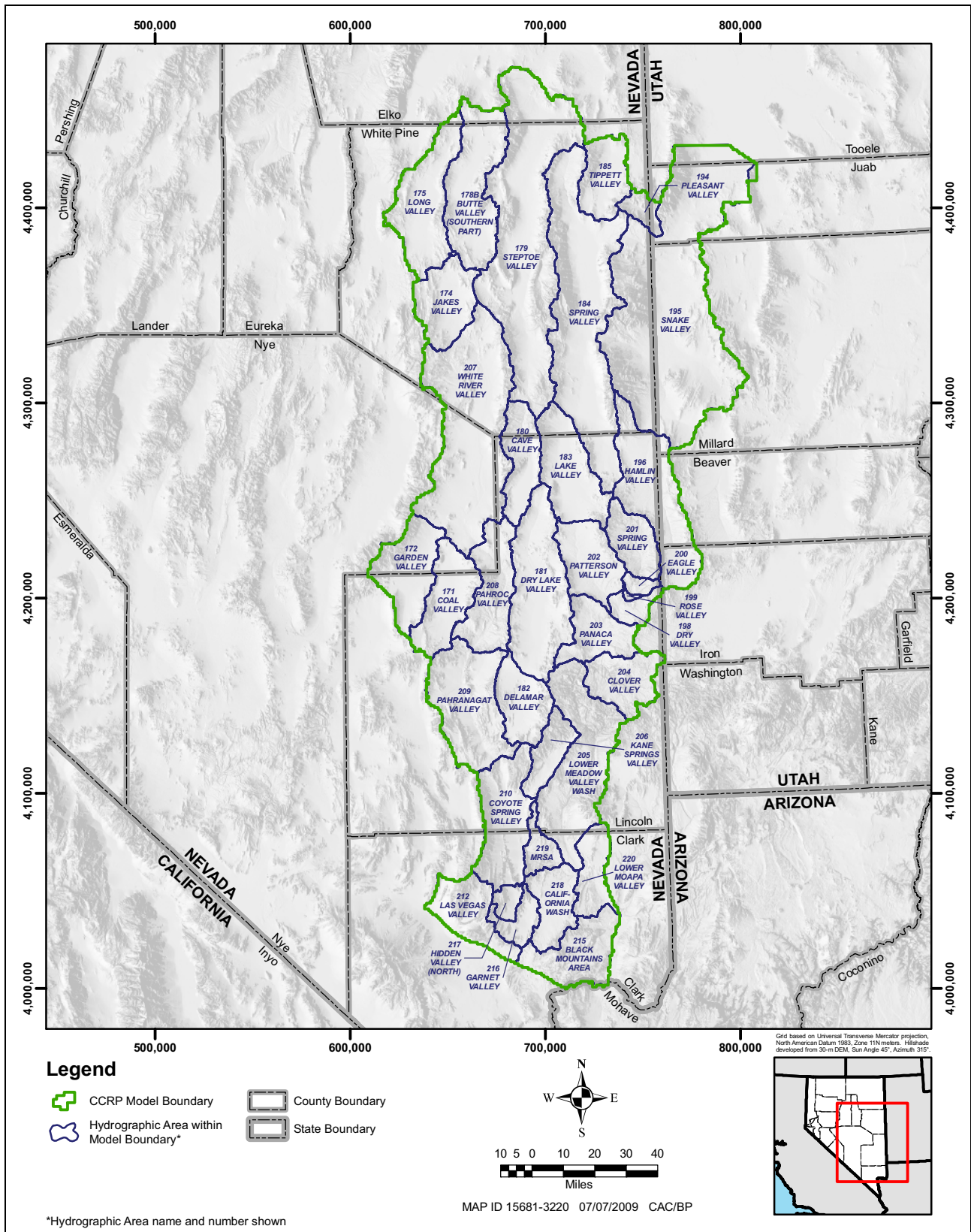


Figure 1-1
Location of Study Area

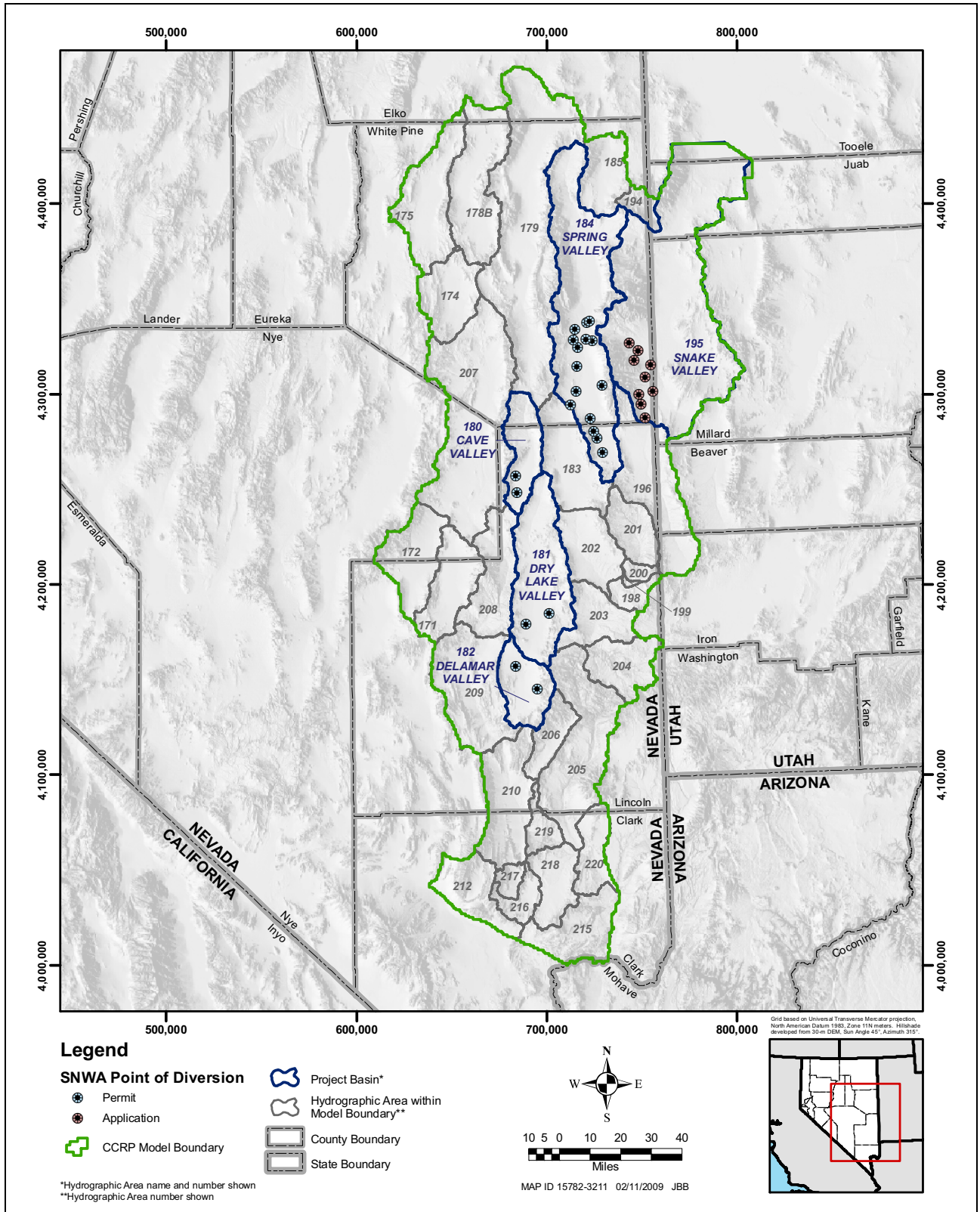


Figure 1-2
**Location of Project Basins and Current SNWA Water Rights/
 Application Points of Diversion**

including the potential indirect effects of the proposed groundwater development. A groundwater flow model was used in the analysis of potential indirect effects for the EIS.

1.1.2 Study Area Background

As described in the Conceptual Model Report (SNWA, 2009a), major historical events include early settlements, the creation of Lake Mead, and increasing historical water use.

According to the Nevada State Engineer (Smales and Harrill, 1971), the first major water use in Nevada coincides with the mining boom starting in 1849. Most of the water was diverted from streams to nearby mills to process the mining ores. Some water was used for irrigation purposes to support the mining community. From 1849 to 1860, the mining community was the main water user in Nevada. The livestock industry began in Nevada around 1870. Irrigation by surface water to produce forage crops started to increase then. Water use continued to expand in Nevada with the building of dams and reservoirs starting in 1903. Major water needs continued to be satisfied by surface water up to the early 1940s when the state began experiencing notable growth. At that time, groundwater use became more significant.

The development history of the basins in the study area is documented in more detail in the Nevada Division of Water Resources (NDWR)/U.S. Geological Survey (USGS) Ground-Water Resources—Reconnaissance Series and the NDWR water-rights database. Boulder Dam, now Hoover Dam, was built in the 1930s during the period when the major source of water in Nevada was surface water. Filling of the reservoir (Lake Mead) was completed in 1937. Spring flow records at the Muddy River Springs Area (Eakin, 1966, p. 264) and Rogers and Blue Point springs (USGS, 2006a and b) indicate that filling the lake has not significantly affected the majority of the flow systems of the study area. Based on the water-rights database, groundwater use by man did not become significant until about 1945 in basins of the study area. Thus, although Lake Mead is man-made, approximate predevelopment groundwater conditions are assumed to prevail up to 1945 and include Lake Mead.

Since the 1940s, groundwater use in the study area has been increasing, as indicated by the water-rights database and the water-use records, although these records are sparse. The rate of increase, however, has slowed down considerably within the last 10 to 15 years. Currently, the main uses of groundwater are irrigation of croplands and rangelands. Other less significant groundwater uses are industrial, mining and milling, municipal, stock watering, and domestic (SNWA, 2008).

1.2 Terminology Used in this Report

The following is a list of definitions for technical terminology used in this report.

Anthropogenic stresses: actions imposed on a flow system by humans. These actions consist of water withdrawals from or additions to a flow system. Water withdrawals may be made directly from wells penetrating the aquifer system, from springs, or from diversion of stream flow of groundwater origin. Water additions to the flow system may result from application of irrigation water to croplands or from artificial recharge.

Anthropogenic effects: the effects that anthropogenic stresses have on the aquifer system. These effects consist of declines or increases in hydraulic heads and flows (discharge by groundwater evapotranspiration [ET], lateral boundary fluxes, and spring and stream flow of groundwater origin).

Predevelopment groundwater conditions: state of a flow system before any anthropogenic stresses occur. When applied to the CCRP model area, this term refers to the state of the flow system when anthropogenic stresses and effects were assumed negligible, i.e., prior to 1945. This term may also be applied to localized areas at any time during the historical period of concern if negligible or no anthropogenic stresses and effects occurred in that area.

Steady-state model or predevelopment steady-state numerical model: numerical groundwater flow model designed to simulate the state of the flow system under equilibrium assuming no anthropogenic stresses. The simulated state represents the average flow system conditions based solely on natural variations caused by natural stresses. This condition is assumed to occur prior to 1945 in this report.

Transient model or transient numerical model: numerical groundwater flow model designed to simulate the changing behavior of the flow system under anthropogenic stresses. The time continuum is subdivided into stress periods. A transient model may or may not include a steady-state stress period. In the transient model presented in this report, the first stress period represents predevelopment steady-state conditions similarly to a steady-state model and provides the initial conditions for the transient stress periods. During the transient stress periods, average stresses are imposed on the flow system and their effects simulated by the model.

1.3 Previous Numerical Models

Several numerical models have been developed for regions that include the entire CCRP model area or parts of the study area. These models are summarized in this section. Other models developed for neighboring flow systems that may be useful to this study are also mentioned. Relevant details will be cited in the body of the report as appropriate.

Carlton (1985) developed a numerical model for the Fish Springs Flow System as part of the Great Basin RASA study. The purpose of the study was to evaluate groundwater flow in the carbonate-rock province of eastern Nevada and western Utah. Carlton (1985) derived interpretations of major controls on groundwater flow and estimates of groundwater-budget components for the Fish Springs Flow System. However, the recharge distribution used in the model was derived using a method developed by Hood and Waddell (1968) and was not varied during model calibration.

As part of the Great Basin RASA study, Prudic et al. (1995) present a conceptual evaluation of regional groundwater flow in the region based on a numerical model. The two-layer numerical model was used to simulate the concept of numerous shallow-flow regions superimposed upon fewer deep-flow regions (Prudic et al., 1995). The Reconnaissance Series provided the basic estimates of recharge and discharge (Prudic et al., 1995) for this regional flow model. Of particular interest are the interpretations of interbasin flow and flow-system boundaries derived from the modeling results.

Schaefer and Harrill (1995) used the steady-state numerical model developed by Prudic et al. (1995) and made transient simulations of the effects of pumping the points of diversion proposed by SNWA. The simulations were performed without calibration to transient conditions. Instead, storage-property values deemed reasonable were used; therefore, like any model based on this approach, the predictions are even more uncertain than in the case of transient models that are calibrated for transient conditions. No evaluation of the uncertainty associated with the predictions was made.

The Las Vegas Valley Water District (LVVWD, 2001) developed a numerical model in support of the Coyote Spring Valley water-right hearing. The model areas include the southern part of the current model area and compose the White River and Meadow Valley flow systems (LVVWD, 2001). This model was calibrated to predevelopment steady-state and transient conditions using the available data and estimates of historical water use in the area. Using this transient model, LVVWD (2001) evaluated the potential effects of SNWA's proposed groundwater withdrawals in Coyote Spring Valley.

SNWA (2006) developed a numerical model of predevelopment steady-state conditions in support of the Spring Valley water-right hearing. The model area covers much of the northern part of the current model area. The model was developed to serve as a management tool for planning the development of the water resources of Spring Valley (SNWA, 2006). The initial recharge was derived by applying the standard Maxey-Eakin (Maxey and Eakin, 1949) method to an updated spatial precipitation distribution for Spring Valley. Other components of the groundwater budget were based on the Reconnaissance Series of reports.

In the early 1990s, LVVWD developed numerical models for 19 single basins in Nevada, representing predevelopment steady-state conditions. No transient calibration or simulations were performed because the available data were limited. However, analyses were conducted to evaluate the sensitivity of the model to the uncertain parameters. The data and information used in these models are mainly from the Reconnaissance Series and information reported by Harrill et al. (1988). The simulated groundwater budgets were essentially the same as the ones reported in the Reconnaissance reports. The models were documented in the Cooperative Water Project (CWP) Report Series published by LVVWD in support of groundwater applications filed with the Nevada State Engineer's Office in 1989 and as part of its CWP. Brothers et al. (1993, 1994, and 1996) are part of this series of reports and focused on the project basins. The reports were prepared in support of water-rights applications by LVVWD. Other numerical models developed for single basins in the study area include that developed by Frick (1985) for Steptoe Valley and those developed by Leeds, Hill, and Jewett, Inc., (in 1983) for Steptoe and Spring valleys.

Other numerical models of interest were developed for the Death Valley Flow System (DVFS) by D'Agnese et al. (1997, 2002), DOE/NV (1997), and Belcher (2004). The DVFS is contiguous with the CCRP model area, is part of the same region, and has many of the same characteristics. Because of the many similarities between the two study areas, the models developed to represent their flow regimes are very similar, as described throughout this report. For instance, the results derived from these models can be used for comparison purposes in this study.

1.4 Purpose and Scope

This section describes the overall purpose and scope of both the hydrologic evaluation conducted in support of the EIS analysis and the numerical model presented in this report.

1.4.1 Overall Purpose and Scope

The purpose of the hydrologic evaluation was to compile and analyze the available hydrogeologic information to support the EIS analysis. The hydrologic evaluation includes the development of a regional three-dimensional (3D) numerical model of the flow systems underlying the study area. These flow systems consist of three subsystems identified by their depth and the lengths of their flow paths: regional, intermediate, and local, as described by Tóth (1963) and Freeze and Cherry (1979).

The numerical model focuses on the regional flow system. Intermediate systems may also be addressed if they are in contact with the regional flow system. Perched or local flow systems are not modeled. The model will ultimately be used, along with other analyses, to evaluate the potential water-related effects on the environment. As pumping, monitoring, and testing data become available in the future, the model will be improved and used as a management tool.

The CCRP model is specifically designed to simulate historical, existing, and reasonably foreseeable, future groundwater withdrawals, including the proposed SNWA pumping and EIS alternatives, to evaluate the potential effects on the following:

- Potential drawdowns in the regional and intermediate portions of the flow system within the model area
- Regional (primarily) and intermediate (secondarily) springs, groundwater ET areas, streams, or wells that are hydraulically connected to regional and intermediate parts of the flow system
- Flow boundaries

The CCRP model is NOT designed for the following uses:

- Simulation of perched (local) portions of the flow system, including perched springs, groundwater ET areas, streams, or wells or the effects that pumping from the regional flow system would have on these features
- Derivation of accurate predevelopment steady-state groundwater budgets for individual basins or flow systems within the study area or estimates of interbasin flow (directions and volumes) across boundaries
- Derivation of new delineations of groundwater basin or flow-system boundaries

The overall scope of work of the hydrologic evaluation includes four major tasks:

1. Preparation of a report documenting the site baseline conditions titled *Baseline Characterization Report for Clark, Lincoln, and White Pine Counties Groundwater Development Project* (SNWA, 2008).
2. Development of a conceptual model of groundwater flow in the flow system underlying the study area. This step is primarily documented in a report titled *Conceptual Model of Groundwater Flow for the Central Carbonate-Rock Province - Clark, Lincoln, and White Pine Counties Groundwater Development Project* (SNWA, 2009a). Additional information supporting this step is included in SNWA (2008) and this report.
3. Analysis of the data necessary to describe the historical behavior of the flow system and development of the transient numerical model calibrated to the available observation data. This step is documented in this report. The data describing the historical behavior of the flow system include additional estimates of aquifer properties, observation data (water levels, spring flow, and stream flow), and anthropogenic stress data (historical well pumping and stream flow diversions). These data analyses are presented in [Appendixes A through C](#), respectively.
4. Use of the resulting transient model to evaluate future water-use scenarios including SNWA's proposed groundwater withdrawals and EIS alternatives as well as the cumulative effects associated with groundwater development in the model area. These evaluations are documented in a report titled *Simulation of Groundwater Development Scenarios Using the Transient Numerical Model of Groundwater Flow for the Central Carbonate-Rock Province: Clark, Lincoln, and White Pine Counties Groundwater Development* (SNWA, 2009b).

The approach followed to conduct each of the tasks listed above and the associated results have been subjected to detailed peer reviews by BLM and a panel assembled by BLM as described in [Section 3.0](#).

The study area extends over parts of Lincoln, White Pine, Elko, Nye, and Clark counties in Nevada and over Tooele, Juab, Millard, Beaver, and Iron counties in Utah, and encompasses the five project basins: Cave Valley (Hydrographic Area [HA] 180), Dry Lake Valley (HA 181), Delamar Valley (HA 182), Spring Valley (HA 184), and Snake Valley (HA 195) ([Figure 1-1](#)). The study area also includes basins where the water-conveyance pipelines and associated facilities will be constructed to move the water from the project basins to the intended places of use in Lincoln County and the Las Vegas Valley. Originally, the eastern boundary of the model area coincided with the boundary of Snake Valley. During the course of this work, the model boundary was extended to include the portion of Fish Springs Flat that comprises Fish Springs.

1.4.2 Purpose and Scope of Numerical Model

The purpose of the work described in this document is the development of a calibrated transient numerical model of the flow systems underlying the study area of the Project ([Figure 1-1](#)).

The scope of work includes model construction, calibration, and evaluation. This work was conducted in two major phases with all of its major aspects subjected to review by the Hydrology Technical Group (discussed in [Section 1.6](#)) throughout the process. The two major numerical model development phases were as follows:

- Phase 1: Testing of a preliminary numerical model
- Phase 2: Calibration of a transient numerical model

The first phase consisted of model construction activities and preliminary simulations to derive a numerical representation of the conceptual model that approximately matched the response of the flow systems under predevelopment conditions. In the preliminary versions of the numerical model, predevelopment conditions were interpreted from data spanning the full period of record to supplement the scarce data available from years prior to 1945. For example, in areas where no significant anthropogenic stress occurred (no major groundwater use), the fluctuations observed in the water levels were interpreted to be caused by natural stresses only. For such a location, the water levels were statistically reduced to a mean and standard deviation to approximate the hydraulic head and hydrograph error at that location. The mean value was then assumed to represent the mean predevelopment hydraulic head at that location. The hydrograph error was added to other sources of error (e.g., land-surface elevation) to represent the error associated with the mean hydraulic-head value. More details are provided in the Baseline Report (SNWA, 2008). Many simulations were conducted using this preliminary numerical model to test and refine the numerical representation of the conceptual model. This preliminary version of the numerical model was then used as the starting point for the development of the transient model.

The transient model was actually designed to simulate the steady-state and transient behaviors of the flow systems. Steady-state conditions were assumed to prevail prior to 1945. Initially, except for a few aspects mostly relating to the simulation of transient conditions, this version of the model is identical to the preliminary version of the numerical model representing predevelopment conditions. The exceptions are as follows: (1) the transient capability is activated and transient stress periods are added, (2) the stress data are added for each stress period, (3) storage parameters for regional modeling units (RMUs) are added, and (4) the observation data (calibration targets) are rearranged to fit the stress periods. The model construction, including the framework, the boundary conditions, recharge from precipitation, and values of all hydraulic parameters other than the storage properties, is initially as in the preliminary numerical model.

Both phases of numerical model development were implemented following the modeling approach described in [Section 2.0](#). Phase 1 is summarized in [Section 3.0](#), and Phase 2 is discussed in the remainder of this report. Most of the information used to develop the numerical model is contained in the Conceptual Model Report (SNWA, 2009a). Many of the interpretations derived by the Basin and Range Carbonate Aquifer System Study (BARCASS) (Welch et al., 2008) for the northern part of the model area were incorporated in the conceptual model. Some of the information used in the numerical model was obtained from SNWA (2008). Some of the information needed (aquifer properties derived from inverse analytical solutions, aquifer response data, and aquifer stress data) is provided in [Appendixes A through C](#). Specific references to these documents, along with additional information used for the development of the CCRP numerical model, are provided throughout this report.

1.5 General Assumptions

As stated by Prudic et al. (1995), it is difficult to use computer models to describe groundwater flow in an area as geographically large and geologically complicated as the Carbonate-Rock Province of Nevada and western Utah. However, as has been demonstrated by previous investigators who conducted groundwater modeling studies of the Great Basin or portions of it (Prudic et al., 1993, 1995; D'Agnesse et al., 1997, 2002; and Faunt et al., 2004), it is possible and useful to develop such models. As reiterated by these investigators, many arguments can be invoked concerning the validity of the assumptions and hydrologic values used in simulating groundwater flow when such complex geology and hydrology are involved. Inevitably, simplifying assumptions must be used to adapt the complex conceptual model for numerical simulation. Three major assumptions were used in the development of the CCRP numerical groundwater flow model:

- Groundwater in the region flows through fractures and solution openings of consolidated rocks, as well as in porous basin-fill deposits. Fracture-flow simulation is, however, impractical at a regional scale; therefore, a porous medium model is used. This assumption is reasonable as long as the grid-cell size is selected to be within the range of representative elementary volumes of the media (Bear, 1979). Representative elementary volumes occur over the range of volumes for which media properties do not change with volume.
- The flow system is assumed to have been under predevelopment steady-state conditions before 1945, prior to large-scale groundwater development, but after the construction of Hoover Dam in the 1930s. As a result, estimates of groundwater recharge are assumed to equal estimates of natural groundwater discharge prior to 1945. That is, no groundwater withdrawals are simulated for that period. Several conditions exist, however, that may violate this assumption:
 - Regional flow systems of the Great Basin Region may be undergoing a drying-out sequence following a wetter climate cycle related to the late Pleistocene period (Prudic et al., 1993). As a result, groundwater levels and groundwater discharges being used as calibration targets for pre-1945 in this model may not be in equilibrium with present-day groundwater recharge and interbasin flow estimates.
 - Flow systems are subject to natural seasonal or annual fluctuations that are reflected in the uncertainty of pre-1945 target hydraulic heads and groundwater discharge estimates but are not explicitly represented in the simulation. As a result, pre-1945 conditions are represented by average pre-1945 conditions.
 - Lake Mead is historically a significant new regional hydrologic feature in the region, and flows in the CCRP model area may not have come into equilibrium with its presence. Well observations taken over the years since its construction may also have some temporal bias.
 - Some irrigation and municipal pumping did occur prior to 1945, on a localized basis, in the study area. This may bias the pre-1945 hydraulic heads and flow observations assumed to be subject to only natural stresses at that time.

- For the post-1945 time period, the flow systems were assumed to be under transient conditions due to stresses imposed by man through well pumping and diversion of spring and stream flow originating from groundwater. The stresses and effects of natural fluctuations on the flow systems, namely those associated with variations in precipitation, were not simulated.

1.6 BLM Review Process

A Hydrology Technical Group was assembled by BLM in the early stages of the technical work conducted in support of the EIS. The primary objective of this group was to provide technical advice and recommendations to BLM, so they could ensure that the hydrologic data analysis and numerical model development satisfy the analysis requirements of the EIS.

The BLM Hydrology Technical Group members are as follows:

- BLM (Nevada, Utah, and Denver regional offices)
- USGS
- ENSR/AECOM (BLM EIS consultant)
- Nevada State Engineer's Office (Observing)

The Hydrology Technical Group review process included meetings and conference calls to discuss and resolve technical issues. It also included formal reviews of preliminary reports and work products, including data compilation and analysis and modeling files or results. This group conducted the report reviews and provided review comments to SNWA and Earth Knowledge, Inc., a consultant to SNWA. ENSR/AECOM was selected by BLM as a third-party contractor to assist in the preparation of the EIS. The Nevada State Engineer's Office participated in the technical meetings but in an observation capacity only.

Major comments provided by the Hydrology Technical Group throughout the development of the CCRP model and their resolution are summarized in [Section 3.0](#) of this report.

1.7 Document Contents

This document consists of nine sections and three appendixes. A brief description of the contents of each is provided:

- [Section 1.0](#) is this introduction.
- [Section 2.0](#) describes the approach followed to develop the numerical model. This section includes descriptions of the general modeling approach, code selection, model construction, and the methods used in the model calibration and evaluation processes.
- [Section 3.0](#) provides a summary of the preliminary testing of the CCRP model before the start of transient calibration, including descriptions of the major issues identified by the Hydrology Technical Group and their resolution. All previous work was essentially focused on refining the conceptual model and numerical model construction and identifying appropriate initial

parameter estimates through preliminary simulations and review. The resulting model serves as the initial configuration for the transient model described in this report.

- [Section 4.0](#) describes the construction of the transient model, which includes grid definition, external boundary conditions, representation of the hydrogeologic system, and observation data.
- [Section 5.0](#) describes the model-calibration process and the refinements of the conceptual model during calibration.
- [Section 6.0](#) describes the model-evaluation process in detail, along with the final parameter-estimation simulations. The evaluation process includes the assessment of the model fit, the estimated parameters, and the simulated flow systems.
- [Section 7.0](#) describes model limitations and uncertainties.
- [Section 8.0](#) provides a summary of this report.
- [Section 9.0](#) provides a list of references cited in this report.
- [Appendix A](#) describes local analytical and numerical models developed independently to analyze local site-specific irrigation data to derive estimates of aquifer properties at scales larger than aquifer tests.
- [Appendix B](#) describes the analysis of transient observation data (water levels and spring and stream flow). The data sets are provided on the DVD.
- [Appendix C](#) describes the analysis of the available water-use data to derive estimates of historical groundwater use in the study area. The data set is provided on the DVD.

2.0 CCRP MODEL DEVELOPMENT APPROACH

The general approach followed to develop the CCRP model is presented in this section, followed by a description of the numerical model construction and calibration approach. The specific computer codes and processes of model construction and calibration are then presented, followed by a description of the process of model fit evaluation.

2.1 General Approach

The general approach for the development of the CCRP model consisted of the following steps:

1. Development of a three-dimensional conceptual model for the flow systems of the study area, including estimates of groundwater-budget components (e.g., precipitation, recharge, groundwater discharge by ET, and interbasin inflow and outflow).
2. Development of a numerical model for the flow systems of the study area, including:
 - Construction of the numerical model based on the conceptual model.
 - Preliminary testing of the numerical model.
 - Calibration of the numerical model to transient conditions.
3. Simulation of development scenarios using the transient numerical model to evaluate:
 - Effects of proposed pumping and alternatives.
 - Cumulative effects of historical groundwater use and proposed pumping.

The approach followed to develop the conceptual model (Step 1) is described in SNWA (2009a). Additional information relating to the conceptualization of the flow systems, including the specific approaches followed, is presented in [Appendixes A through C](#) of this document. The approach followed to complete Step 2 is described in the remainder of this section. The approach to Step 3 is described in the corresponding report (SNWA, 2009b).

2.2 Numerical Model Calibration Approach

The numerical model was developed by approximately following the 14 guidelines for effective model calibration advanced by Hill (1998) and recently updated by Hill and Tiedeman (2007). Relevant guidelines were applied to all stages of development of the numerical model.

The 14 guidelines were organized into four major modeling stages—model development, model testing, potential new data, and prediction uncertainty—by Hill and Tiedeman (2007, Table 1.3) and are as follows:

- Stage 1 - Model Development
 1. Apply the principle of parsimony (start very simply; build complexity slowly).
 2. Use a broad range of system information (soft data) to constrain the problem.
 3. Maintain a well-posed, comprehensive regression problem.
 4. Include many kinds of observations (hard data) in the regression.
 5. Use prior information carefully.
 6. Assign weights that reflect errors.
 7. Encourage convergence by making the model more accurate and evaluating the observations.
 8. Consider alternative models.
- Stage 2 - Model Testing
 9. Evaluate model fit.
 10. Evaluate optimized parameter values.
- Stage 3 - Potential New Data
 11. Identify new data to improve simulated processes, features, and properties.
 12. Identify new data to improve predictions.
- Stage 4 - Prediction Uncertainty
 13. Evaluate prediction uncertainty and accuracy using deterministic methods.
 14. Quantify prediction uncertainty using statistical methods.

This general modeling approach is applicable to any process model, not just groundwater models. It is consistent with the iterative nature of the development of groundwater flow models as described by Bredehoeft (2003).

2.3 Description of Selected Codes and Supporting Software

The finite-difference modeling code, MODFLOW-2000 (Harbaugh et al., 2000), was selected as the platform for construction of the numerical model. More specifically, a customized version of MODFLOW-2000, Version 1.18.01, was used to construct the CCRP model. Given that MODFLOW-2000 has several limitations for sensitivity analysis and parameter-estimation capabilities, a customized version of UCODE_2005 (Poeter et al., 2005), a parameter-estimation code, was selected for these purposes. UCODE_2005 adds significant flexibility in parameter definition, allowing application of formulas to create derived parameters that may be dependent on a function or multiplier. This feature was used specifically for the recharge runoff parameters. Two other programs, SIM_ADJUST (Poeter and Hill, 2008) and a customized version of ZONBUD, were also used in calculating intermediate statistics for UCODE_2005 processing. The codes were executed in the Cygwin environment. Several utility codes were also developed to pre- and post-process the input and output data. The code changes made to MODFLOW-2000, UCODE_2005, and ZONBUD are provided electronically on the DVD accompanying this report. The installation and execution of modeling codes and supporting software as well as a description of the model files are also provided on the DVD. Summary descriptions of the main computer codes that were used follow.

2.3.1 MODFLOW-2000

MODFLOW-2000 (Harbaugh et al., 2000) was selected because of its ability to simulate a wide variety of flow systems, its publicly available source code and documentation, and its rigorous USGS peer review. MODFLOW-2000 and earlier versions of MODFLOW have also been used extensively in this region of the United States for regional modeling (Prudic et al., 1995; Schaefer and Harrill, 1995; D'Agnese et al., 1997, 2002).

The numerical modeling code MODFLOW-2000 (Harbaugh et al., 2000; Hill et al., 2000) is a 3D, block-centered, finite-difference code of groundwater flow. MODFLOW-2000 is an enhanced version of the USGS 3D, finite-difference, modular groundwater flow modeling code MODFLOW (McDonald and Harbaugh, 1988; Hill, 1992) and MODFLOW-96 (Harbaugh and McDonald, 1996). Enhancements include:

- Restructuring of the code to add processes to packages, procedures, and modules used in previous versions of MODFLOW. This facilitates the solution of additional equations, such as transport equations or automatic parameter-estimation equations.
- Addition of automatic parameter estimation using nonlinear regression.

Code capabilities in the latest version of MODFLOW-2000 (Version 1.18.01) are as follows:

- Steady and nonsteady flow simulation in a layered 3D and irregularly shaped flow system
- Confined, unconfined, or a combination of confined and unconfined model layers
- Heterogeneous aquifer properties
- Anisotropy of hydraulic conductivities (principal directions restricted to grid axes)
- Depth-decay of hydraulic conductivity

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- Specification of hydraulic properties by hydrogeologic unit
 - Barriers to groundwater flow
 - Several types of lateral boundary conditions:
 - Specified-head boundaries (steady-state and transient)
 - Specified-flux boundaries (steady-state and transient)
 - Head-dependent flux (general head)
 - Simulation of flow from external stresses (wells, areal recharge, ET, and drains)
 - Simulation of streams, including unsaturated flow beneath streams
 - Simulation of lakes and reservoirs
 - Time-varying parameters
 - Observation, sensitivity, and parameter-estimation processes
 - Compatible post-processors, such as RESAN-2000, YCINT-2000, and BEALE-2000

This version of MODFLOW (MODFLOW-2000) includes the following processes:

- GWF1: Ground-Water Flow Process
- SEN1: Sensitivity Process
- OBS1: Observation Process
- PES1: Parameter-Estimation Process

This version of MODFLOW (MODFLOW-2000) includes the following packages:

- BAS6: Basic Package
- BCF6: Block-Centered Flow Package
- LPF1: Layer-Property Flow Package
- RIV6: River Package
- DRN6: Drain Package
- WEL6: Well Package
- GHB6: General Head Boundary Package
- RCH6: Recharge Package
- EVT6: Evapotranspiration Package
- CHD6: Time-Variant Specified-Head Package
- HFB6: Horizontal Flow Barrier Package
- SIP5: Strongly Implicit Procedure Package
- SOR5: Slice Successive Over-Relaxation Package
- PCG2: Version 2 of Preconditioned Conjugate Gradient Package
- DE45: Direct solver
- LMG1: Multigrid solver (for USGS use only)
- STR6: Streamflow-Routing Package
- ADV2: Advective-Transport Observation Package
- RES1: Reservoir Package (RES is the file type in the name file)
- FHB1: Flow and Head Boundary Package (FHB is file type in the name file)
- IBS6: Interbed Storage (subsidence) Package (IBS is the file type in the name file)
- HUF2: Hydrogeologic-Unit Flow Package

- LAK3: Lake Package
- ETS1: Evapotranspiration with a Segmented Function Package
- DRT1: Drains with Return Flow Package
- LMT6: Link to MT3DMS contaminant-transport model
- MNW1: Multi-Node Well Package
- DAF1: Diffusion Analogy Surface-Water Flow Package
- SUB1: Subsidence and Aquifer-System Compaction Package
- SFR2: Stream-Flow Routing Package, version 2
- GMG1: Geometric MultiGrid Solver Package
- SWT1: Subsidence and Aquifer-System Compaction Package for Water-Table Aquifers

Additional capabilities are as follows:

- HYDMOD: Hydrograph option
- GAGE: Hydrograph option for lakes (LAK3 Package) and streams (SFR Package)

2.3.2 UCODE_2005

Although MODFLOW-2000 has built-in parameter-estimation capabilities, UCODE_2005 (Poeter et al., 2005) provides additional flexibility and, therefore, was used in this study. UCODE_2005 (Poeter et al., 2005) is a universal-analysis code and represents updates of the methods implemented in MODFLOW-2000 (Harbaugh et al., 2000) and UCODE (Poeter and Hill, 1998). The methods implemented in these codes follow the guidelines for effective model calibration (Hill, 1998; Hill and Tiedeman, 2007) (see [Section 2.2](#)).

UCODE_2005 and associated codes (Poeter et al., 2005) were developed by the USGS, in cooperation with the U.S. Environmental Protection Agency and the International Ground Water Modeling Center of the Colorado School of Mines. The objective was to enhance inverse modeling by expanding the functionality of UCODE (Poeter and Hill, 1998). The resulting software package not only performs parameter estimation but can also be used to conduct residual analysis, linear uncertainty, and a test for model linearity. UCODE_2005 also may be run under two additional modes (advanced-test-model linearity and nonlinear uncertainty). The two additional modes are based on the methods of Christensen and Cooley (2006). The two modes allow for advanced residual analysis and model-linearity testing and adjustment of confidence intervals for nonlinearity. UCODE_2005 also allows for the calculation of linear and nonlinear uncertainties on model predictions.

UCODE_2005 solves parameter-estimation problems using nonlinear regression. It can be used with any process model that has ASCII or text input and output files, and it can be executed in batch mode. The parameters being estimated can primarily be identified in the input files of the application model(s). However, parameters can also be used in conjunction with user-defined functions to calculate a quantity defined in the input files. Quantities simulated by the application model(s) are compared to observations in the regression process. Observations may be selected to correspond to values simulated by the process model or simulated-equivalent values calculated by UCODE_2005 using values simulated by the process model. Prior information on parameters can also be included in the regression, if available.

The computer codes that are part of the UCODE_2005 package are documented in Poeter et al. (2005), Christensen and Cooley (2006), and Hill and Tiedeman (2007). Limited discussions of most of the methods used may also be found in Hill (1994, 1998) and Cooley (2004).

2.3.3 SIM_ADJUST

SIM_ADJUST is a FOR TRAN-90 computer code developed by Poeter and Hill (2008) to adjust simulated equivalents for observations or predictions.

Universal-analysis computer codes such as UCODE_2005 (Poeter et al., 2005) are programmed to read simulated equivalents from an output file generated by the process model being used (MODFLOW-2000 in this case). Under certain conditions (no useful solution), values needed by the universal code (UCODE_2005 in this case) are missing or assigned default values that are not appropriate for the problem at hand. SIM_ADJUST (Poeter and Hill, 2008) alleviates this problem by allowing the user to easily identify missing or default observations in the process model output file and replace them with appropriate values or defaults specified by the user.

2.3.4 ZONBUD

ZONBUD (Harbaugh, 1990) is a FORTRAN computer program developed by the USGS to compute subregional groundwater budgets for MODFLOW groundwater flow models. Documentation about changes to the original version of the code (Harbaugh, 1990) is available from the USGS website (<http://water.usgs.gov/nrp/gwsoftware/zonebud3/zonebudget3.html>).

Given an input file defining numbered zones as complex areas in terms of MODFLOW grid cells, ZONBUD calculates groundwater-budget components for each zone using the MODFLOW output files. ZONBUD reads cell-by-cell budget data written by MODFLOW, sums each flow component for all the cells in each specified zone, and writes the zone budgets to an output file.

2.3.5 Cygwin and Utility Codes

Cygwin is a UNIX/Linux-like environment that runs concurrently with Microsoft Windows XP or Windows Vista. Most of the Cygwin tools are covered by the GNU General Public License, so they can be freely distributed. Specific details regarding the licenses can be found at the Cygwin website (<http://www.cygwin.com/> and <http://cygwin.com/licensing.html>).

Many scripts and utility codes were developed to execute the codes in the Cygwin environment. While the Cygwin environment is not strictly needed to run the CCRP steady-state model, many of the scripts and support codes require its use.

2.4 Numerical Model Construction

The Conceptual Model Report (SNWA, 2009a), Baseline Report (SNWA, 2008), and [Appendixes A through C](#) of this report include data and information necessary for numerical model construction and calibration. Numerical model construction consisted of simplifying the components of the conceptual

model, selecting the appropriate MODFLOW-2000 packages, and preparing the files necessary for MODFLOW-2000, UCODE_2005, and ZONBUD. Besides the setup of the physical aspects of the flow system, other important information included in the input files is the identification of the parameters and their initial values and the observations and their weights. Numerical model construction consisted of the following steps (MODFLOW-2000 package or supporting code shown in parentheses):

1. Discretization of the model domain to define a 3D finite-difference grid (DIS)
2. Representation of the hydrogeologic framework in the model to include:
 - RMUs (HUF2)
 - RMU zones (HUF2)
 - Structural features affecting groundwater flow (HFB) and RMU zones (HUF2)
3. Definition of external model-boundary conditions (CHD)
4. Representation of groundwater discharge in the model including groundwater ET and major springs and streams as:
 - Evapotranspiration (DRN)
 - Springs and streams (DRN and SFR2)
 - Groundwater use (well pumping and stream baseflow diversions)
5. Representation of areal recharge from precipitation in the model (RCH)
6. Addition of hydraulic-head and flow observations (CHOB, DROB, GAGE, UCODE_2005, and ZONBUD)

Information compiled and evaluated in the Baseline and Conceptual Model reports (SNWA, 2008, 2009a) and in the appendixes of this report was used in the development of the numerical model. This information consists of the following:

- Hydrogeologic framework
- Simplified hydrogeologic framework
- Aquifer-property data
- Major surface-water features (springs and Muddy River stream flow)
- Precipitation distribution
- Initial estimates of groundwater recharge efficiencies (RE) (from precipitation)
- Initial distribution of potential recharge from precipitation
- Locations and rates of groundwater ET under predevelopment conditions
- Locations and discharge rates of major springs under predevelopment and transient conditions
- Hydraulic-head data under predevelopment and transient conditions
- Locations and rates of interbasin flow under predevelopment conditions
- Groundwater budgets under predevelopment conditions
- Historical anthropogenic stresses on the aquifer system

Additional information was obtained from other studies in a few instances. References to these studies are provided where appropriate.

2.5 Numerical Model Calibration

Because the CCRP conceptual and numerical models are complex, inconsistencies may occur. The calibration process enabled inconsistencies between the numerical model and field observations to be identified as various features of the conceptual model were tested. As a result, refinements to the conceptual and numerical models were necessary during the calibration process. The calibration processes included both an automated parameter-estimation and trial-and-error manual calibration approaches.

UCODE_2005 (Poeter et al., 2005) proved useful for estimating parameter sensitivities, calculating observation residuals, estimating parameters, and indirectly identifying problems with the conceptual model and numerical model implementation. The manual trial-and-error approach was useful for testing alternative scenarios or for fitting the model to local but important areas of the model that might be overlooked or be mishandled by UCODE_2005. Optimized solutions estimated by UCODE_2005 could produce unreasonable solutions because of issues of model nonlinearity, model design, and inherent difficulties associated with weighting the accuracy of field data and weighting the relative importance of different types of observations. The iterative use of automated and manual techniques minimized the limitations of the automated approach and allowed a reasonable calibration of the transient numerical model to be achieved.

After a given refinement to the conceptual model was made, a set of MODFLOW-2000 simulations were performed through UCODE_2005. The sensitivities, residuals, and fit statistics generated by UCODE_2005 were then used to evaluate the model results and to identify potential additional refinements to the conceptual model. The following sections describe the nonlinear regression methods, parameters, parameter sensitivities, and observations.

2.5.1 Nonlinear Regression Objective Function

Parameter estimation using nonlinear regression consists of finding parameter values that minimize the Sum of Squared Weighted Residuals (SoSWR) objective function. In UCODE_2005 (Poeter et al., 2005; Hill and Tiedeman, 2007), this objective function may be expressed as follows:

$$S(b) = (y - y')^T W (y - y') \quad (\text{Eq. 2-1})$$

where,

$S(b)$ = Objective function

b = $np \times 1$ vector containing parameter values (where np = the number of parameters estimated by regression)

y and y' = $n \times 1$ vectors with elements equal to observed and simulated (using b) values respectively (for the CCRP model, the observed and simulated quantities are hydraulic heads and groundwater discharge)

- $y - y'$ = vector of residuals, defined as the observed minus simulated values
 W = $n \times n$ weight matrix (where n = the number of measured and simulated hydraulic heads and flows)
 T = Superscript indicating the transpose of the vector

The parameters being estimated are assigned initial values that are then changed during the optimization process using a modified version of the Gauss-Newton method (Hill, 1998, p. 7–13; Hill and Tiedeman, 2007) to minimize the objective function (Equation 2-1). The resulting values are called optimal parameter values. This procedure is repeated for each conceptual model considered.

For the CCRP model, the weight matrix is diagonal; each diagonal entry is equal to the inverse of the estimated variance of the observation measurement error, where measurement error is defined more broadly than might be expected in that some types of model error are included. This weighting will result in parameter estimates with the smallest possible variance if (1) the estimated variances and the model are accurate, (2) the model is effectively linear, and (3) the number of observations is asymptotically large (Bard, 1974). In addition to variances, UCODE_2005 permits the designation of standard deviations or coefficients of variation (COV), from which variances are calculated as described by Hill et al. (2000) and Hill and Tiedeman (2007). These indicators of measurement precision are based on an analysis of likely measurement error.

2.5.2 Parameter Definition

Parameters may be defined to represent most physical quantities of interest, such as hydraulic conductivity and recharge. MODFLOW-2000 allows these spatially distributed physical quantities to be represented using zones over which the parameter is constant or by using more sophisticated interpolation methods. In either case, multipliers and/or multiplication arrays can be used to modify parameter values in a predictable way.

2.5.3 Parameter Sensitivities

As part of the regression, sensitivities are calculated as $(\partial y'_i)/(\partial b_j)$, the partial derivative of the simulated hydraulic head or flow; y'_i , with respect to the j^{th} estimated parameter; and b_j , using the sensitivity-equation method as described by Hill et al. (2000, p. 67–70) and Hill and Tiedeman (2007). Because the groundwater flow equations are nonlinear with respect to many parameters, sensitivities calculated for the same parameter for different sets of parameter values will be different.

Besides being used in the regression calculations, sensitivities are useful to the modeler because they reflect how important each measurement is to the estimation of each parameter. The composite-scaled sensitivity (CSS) is a statistic that summarizes all the sensitivities for one parameter and therefore indicates the cumulative amount of information that the measurements contain toward the estimation of that parameter. Because they are dimensionless, composite-scaled sensitivities can be used to compare the amount of information provided by various types of data for different types of parameters. Using the weight matrix W in Equation 2-2, CSS for parameter j , CSS_j , is calculated as:

$$CSS_j = \{[\sum_{i=1}^n W_i (\partial y'_i / \partial b_j)^2 b_j^2] / n\}^{1/2} \quad (\text{Eq. 2-2})$$

Parameters with large CSS values relative to those for other parameters are likely to be easily estimated by the regression; parameters with smaller CSS values are likely to be difficult or impossible to estimate. Generally, parameters with a CSS less than 1 or a CSS that is more than two orders of magnitude smaller than the largest CSS are difficult to estimate. For some parameters, the available measurements may not provide enough information for estimation. In this circumstance, the parameter value will need to be set by the modeler, or more head and flow measurements will need to be added to the regression. Parameters with values set by the modeler are called unestimated parameters. If the parameters are insensitive or correlated, they can be left as unestimated during the regression and their uncertainty included as parameters for prediction in UCODE. Composite-scaled sensitivities calculated for different sets of parameter values will be different (Hill, 1998), but in this work, they are rarely different enough to indicate that a previously unestimated parameter can subsequently be estimated. An alternative to setting a parameter value is to use prior information on the parameter. This alternative is especially important when evaluating prediction uncertainty because it allows measures of uncertainty in model predictions, such as confidence intervals, to reflect uncertainty in the unestimated parameter.

Linear and nonlinear confidence and prediction intervals on simulated values may be calculated using equations shown in Hill (1998, eq. 28), Christensen and Cooley (2006), and Hill and Tiedeman (2007). If the model is sufficiently linear and adequately represents the flow system, the linear estimates of these intervals may be good indicators of prediction uncertainty. Otherwise, the stated significance level of the linear intervals becomes questionable. In such cases, estimates of the confidence intervals may be derived using the nonlinear option of UCODE_2005, or other means such as sensitivity analysis using low and high estimates of the most important parameters.

2.5.4 Observations

Observations are required input to parameter-estimation codes such as UCODE_2005. They are weighted and used in the objective function (Equation 2-1).

Observations consist of estimates of hydraulic heads, drawdowns, and flow rates derived from the available measurements. Values of hydraulic heads were derived from the available water-level data and land-surface elevations at spring locations. Flow rates include fluxes estimated for permeable segments of the external model boundary, mean annual volumes of groundwater ET, and mean annual spring flow rates.

Weights are calculated based on the uncertainty associated with the observations and are calculated based on the inverse of the variance reported for each observation. Observation weights may be manually adjusted during model calibration by the modeler. This reweighting of the observations must be conducted carefully (Hill and Tiedeman, 2007).

2.6 Evaluation of Model Fit

Model fit is evaluated through analyses of weighted and unweighted residuals of hydraulic heads, drawdowns, and flows. More detailed analyses of the simulated values provide additional insight into the calibrated model.

Weighted and unweighted residuals (defined after [Equation 2-1](#)) are important indicators of model fit and depend somewhat on data quality and model accuracy. Consideration of unweighted residuals is intuitively appealing because the values have the dimensions of the observations and indicate, for example, that a hydraulic head is matched to within 33 ft (10 m). However, unweighted residuals can be misleading because observations are measured with different accuracies.

Weighted residuals demonstrate model fit relative to what is expected in the calibration based on the precision, or noise, of the data. They are less intuitively appealing because they are dimensionless quantities that equal the number of standard deviations or coefficients of variation needed to equal the unweighted residual.

Unweighted hydraulic-head residuals tend to be larger in areas (1) with moderate to large hydraulic gradients than in areas with flat gradients (e.g., at the mountain-front and alluvial-fan interface) and (2) where surface topography varies dramatically (e.g., along mountain ranges). However, these areas are not always coincident.

Residual analyses primarily include summary statistics, probability distributions, and spatial distributions of residuals. Distributions of weighted residuals relative to unweighted simulated values are also a useful part of the evaluation.

More detailed evaluations generally include graphical analyses comparing simulated values to observed ranges of observations but vary depending on the type of observations as described below:

1. Evaluations of estimated hydraulic-head distribution:
 - Review simulated hydraulic-head distribution at the water table. Evaluate general flow directions.
 - Review simulated hydraulic-head distribution of the regional potentiometric surface for the lower carbonate aquifers. Note regions, groundwater divides, and flow directions.
2. Evaluations of estimated groundwater discharge:
 - Review ET rate distribution and range by ET type.
 - Review simulated ET rates by type, flow system, and hydrographic area.
 - Review simulated spring discharge.
 - Review simulated stream flow rates.

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3. Evaluations of estimated groundwater budgets:
 - Review groundwater budget organized by flow system.
 - Review groundwater budget organized by hydrographic area.
 4. Evaluations of model-simulated general flow directions
 5. Evaluations of estimated model parameters
 - Review K and transmissivity (T) by layer.
 - Review cumulative transmissivities.
 - Review storage parameters.
 - Review calibrated total, in-place, and runoff recharge distribution.
 - Review calibrated recharge efficiencies by flow system.

3.0 PRELIMINARY NUMERICAL MODEL TESTING

This section describes the preliminary testing of the numerical model up to the start of the transient calibration phase conducted as part of the development of the CCRP model. The development process was initiated with the formulation of a conceptual model, followed by its translation into a numerical model, and subsequent model calibration phases. Results from the preliminary testing were presented to the Hydrology Technical Group for review throughout the development of the CCRP model in the form of presentation and draft reports. Review comments were also incorporated in the CCRP model throughout the process. Results from the last test simulation of predevelopment conditions were used as the starting point for the transient model. The major issues identified by the Hydrology Technical Group in the conceptual and numerical models and their resolution are described in this section.

3.1 Major Issues and Their Resolution

The development of the CCRP model included several review and revision cycles. The Hydrology Technical Group primarily requested improvements in this model. Comments relating to the conceptual model and the preliminary numerical model are summarized in the remainder of this section. Comments relating to the transient version of the numerical model have been considered during the construction and calibration of the transient numerical model presented in the remaining sections of this document. The issues identified by the Hydrology Technical Group were subdivided into two groups: (1) conceptual model issues resolved in the Conceptual Model Report (SNWA, 2009a) and (2) numerical model issues resolved in the preliminary numerical model (construction and preliminary calibration).

3.1.1 Conceptual Model Issue Resolution

Comments on the conceptual model pertained to the hydrogeologic framework, groundwater flow patterns in the model domain including the external boundaries, and groundwater-budget components.

3.1.1.1 Hydrogeologic Framework

Issues identified in the hydrogeologic framework concern the hypothesis that extensional terrains may be subdivided into zones of hydraulic properties and the lack of discussion of storage properties in the document (SNWA, 2009a).

3.1.1.1.1 Extensional Terrains

The Hydrology Technical Group commented that if no hydraulic-property data are available to support the zonation of the carbonate aquifer based on extensional terrains, the zones should be removed.

As discussed in the Baseline Report (SNWA, 2008), most of the effects of the extensional period have already been incorporated into the hydrogeologic framework of the model. These effects include interpreted unit thicknesses and locations of structural features, such as faults. Another effect of the extension that was not included in the hydrogeologic framework is the potential impact on the spatial variation of hydraulic conductivity. It was postulated that (1) the hydraulic conductivities are expected to be moderate in carbonate terrains that are slightly extended and thick and (2) the hydraulic conductivities are expected to be larger if any significant thickness of the carbonate rock is present in extremely extended carbonate terrains.

The available data on the hydraulic conductivity of the carbonate aquifer are insufficient to prove or disprove this assumption. However, the delineation of slightly and extremely extended terrains interpreted by Dettinger and Schaefer (1996) was used in the zonation of the carbonate aquifer in the numerical model. Adding these zones to the model does not necessarily mean that the calibrated hydraulic-conductivity distribution will follow this logical expectation but it allows testing of its validity at the regional scale. The additional zones also provide more flexibility to the calibration process just in case these zones are needed.

The preliminary simulations revealed that assigning different hydraulic conductivities to the two types of zones did not significantly affect simulation results. Thus, the hydraulic conductivities assigned to the two types of zones are approximately the same. This essentially removes the extensional-terrain zones from the numerical model.

3.1.1.1.2 Hydraulic Properties

The Hydrology Technical Group commented that the documentation of the storage properties should be revised to include a detailed review of the available storage-property data applicable to the study area. Furthermore, the group requested that a summary of the expected values and uncertainty ranges by RMU be included in the Conceptual Model Report (SNWA, 2009a).

A discussion of the data analysis of storage properties compiled in the aquifer-property database was added to Appendix C and summarized in Section 4.0 of the Conceptual Model Report (SNWA, 2009a). Unfortunately, the available data are scarce, and the estimated values derived may not reflect the large scales represented in the numerical model. Therefore, an additional analysis was conducted to derive estimates of T and S using long-term irrigation-pumping estimates together with water-level records in wells determined to be affected by irrigation pumping ([Appendix A](#)). Ranges of vertical anisotropy of hydraulic conductivity were also summarized from the available data. However, these ranges may not be representative of large portions of the aquifer systems because of scarce data. Thus, a value between 10 and 100 was used in the numerical model, as recommended by the Hydrology Technical Group. This range is within the vertical anisotropy of 2 to 100 reported by Walton (1988).

3.1.1.2 Groundwater Flow Patterns and External Flow Boundaries

Initially, the simplified conceptual model consisted of a single interpretation of regional groundwater flow configuration and corresponding locations of external flow boundaries. Annual boundary flows were derived from the literature only for these model-boundary segments. Other interpretations of flow patterns, including other potential locations of boundary flow, had been considered for comparison purposes only. The uncertainty associated with the boundary flows was quantified using only literature ranges.

Issues identified with this approach were (1) the estimates of boundary flow were not derived independently but were derived from previous conceptual models, and (2) BARCASS interbasin flow estimates were not considered in the derivation of the conceptual model.

These issues were addressed as follows:

- The simplified interpretation of regional patterns of groundwater flow was still used to describe the simplified conceptual model. A specific interpretation of groundwater flow is necessary to derive an initial distribution of precipitation recharge for the numerical model. Groundwater flows across the corresponding model-boundary segments were estimated independently using Monte Carlo simulations of Darcy's equation where possible.
- Other major interpretations of groundwater flow in the model domain, such as the one derived for BARCASS, were incorporated within the uncertainty envelope of the conceptual model (SNWA, 2009a). This means that no previous interpretation was dismissed from the conceptual model. The sparse data available for the model area do not permit a single accurate interpretation of flow everywhere in the flow system.

In summary, the CCRP conceptual model of groundwater flow now described in SNWA (2009a) is not only represented by the simplified interpretation but also by the uncertainties associated with every component of the conceptual model, including flow directions where information is insufficient.

3.1.1.3 Groundwater Budget

Groundwater-budget issues identified in the conceptual model relate to estimates of groundwater ET in Lower Meadow Valley Wash and excess water in Hamlin Valley. The methods used to estimate these quantities link these two components of the groundwater budget. The first issue was that the estimated annual rate of groundwater ET from Lower Meadow Valley Wash was too large and should be replaced with the estimate derived by DeMeo et al. (2008), reduced by surface water. The resulting value of groundwater ET must be less than 10,000 af y. The second issue was that the amount of interbasin flow from Hamlin Valley to Snake Valley was too large. The excess water was due to the large annual recharge volumes estimated for Hamlin Valley.

- These issues were resolved by (1) adjusting the groundwater ET estimates for Meadow Valley Flow System (MVFS) to be consistent with those estimated by DeMeo et al. (2008), adjusted for surface water as necessary; (2) recalculating the recharge efficiencies for MVFS;

(3) assigning these efficiencies to the southern portion of Hamlin Valley (volcanic rocks); and (4) recalculating the recharge efficiencies for the remainder of the Great Salt Lake Desert Flow System (GSLDFS). The corresponding solution also yielded a new lesser estimate of outflow through the Confusion Range. The details are provided in SNWA (2009a).

3.2 Numerical Model Issue Resolution

Revisions to the construction of the numerical model included modification of the model-domain discretization and representation of the conceptual model.

3.2.1 Model-Domain Discretization

Initially, the model domain was discretized into 474 rows, 202 columns, and 15 layers. In addition, in the preliminary calibration runs, the top model layer was simulated as a convertible layer between confined and unconfined conditions to accommodate the unconfined portions of the flow system. Under this setup, when the simulated hydraulic head falls below the top of a convertible-layer cell, water-table conditions are assumed to prevail in that cell. Consequently, saturated thickness and transmissivity are recalculated at each iteration based on the simulated hydraulic head. This setup of the top model layer caused numerical instabilities and prevented model convergence.

To resolve these instabilities, the top four layers were removed, and the tops of the upper layers were adjusted to approximate the elevation of the water table. As a result, the number of model layers was reduced to 11 layers. This was accompanied by a simplification of the top layers from convertible to confined. The last version of the model spatial discretization is described in [Section 4.0](#).

3.2.2 Conceptual Model Representation

Four major types of changes were made to the conceptual model represented in the numerical model during calibration. These changes pertained to (1) hydrogeologic framework, (2) boundary conditions, (3) definition of recharge processes, and (4) definition of discharge areas.

3.2.2.1 Hydrogeologic Framework

Issues included in this category pertain to (1) hydrogeologic structures, (2) RMU zonation, and (3) hydraulic properties.

3.2.2.1.1 Hydrogeologic Structures

Faults important to groundwater flow act as conduits or barriers or both. Practically no data are available to accurately identify the role of the faults present in the model domain. Generally, faults that are oriented in the dominant direction of flow may be assumed to be conduits of variable permeability along their strikes. However, these faults may also act as barriers to groundwater flow across them. Faults are discussed in greater detail in [Section 4.2.3.2](#).

3.2.2.1.2 RMU Zonation

Preliminary calibration runs revealed that the RMUs provided an overly simplified hydrogeologic framework of the model domain. As a result, the RMUs were subdivided into zones based on natural regional spatial variations. In addition to these regional variations, more localized variations were tested and incorporated into the model. Refinements to the RMUs are summarized below and details are provided in [Section 4.0](#).

- The Upper Valley Fill (UVF) RMU was subdivided into several zones representing the lithologic variations of this unit.
- The Lower Valley Fill (LVF) RMU was subdivided into zones to separate volcanic rocks from the consolidated basin fill.
- The Upper Carbonate (UC) and Lower Carbonate (LC) RMUs were subdivided into several zones to delineate various regions within the carbonate rocks based on regional variations.
- Geographic zonations of the “basement” rock (BASE or BAS) and pluton (PLUT) RMUs were based on regional-scale structural features.
- The Upper Aquitard (UA) and LC RMUs in the areas of Long, Jakes, Steptoe, Butte, and White River valleys were subdivided into zones mainly to add and test a possible groundwater flowpath from Long Valley to White River Valley, via Jakes Valley.
- Zones were added to some RMUs to represent local hydrogeologic features to better simulate flows at some springs. This zonation is designed to improve, but still only approximate, the representation of local geologic features controlling spring flow.

3.2.2.1.3 Hydraulic Properties

Issues associated with hydraulic properties in the preliminary numerical model included the spatial distributions of transmissivity and hydraulic conductivity, the values of anisotropy ratios, the variation of horizontal hydraulic conductivity with depth, and the hydraulic conductivity of structures. The following text reflects comments made by the Hydrology Technical Group.

In many areas, transmissivity values were too high, while in other areas they were too low. For example, the thickness of the carbonate rocks near the eastern boundary along the Confusion Range in Snake Valley was large. However, the simulated values of transmissivity in this area were on the order of only 500 ft²/day, while they ranged from 5,000 to 50,000 ft²/day in the RASA model (Prudic et al., 1995). Simulated transmissivities should be compared to field values to ensure that they are reasonable.

- This issue was addressed by deriving reasonable estimates of transmissivity at scales larger than aquifer tests. This was accomplished by deriving ranges of transmissivities from historical agricultural groundwater-use and aquifer-response data collected over long, dry periods for areas where sufficient data were available ([Appendix A](#)). The derived

transmissivity ranges were interpreted to represent the aquifer properties at the appropriate scale for the numerical model. The transmissivity values simulated by the model were compared to these values during calibration.

The spatial distribution of hydraulic conductivity in the preliminary numerical model was inconsistent with the conceptual model. In the conceptual model, the most conductive areas were located along the structural zones or in the carbonates. However, in the numerical model, the most conductive units were simulated in the basin fill.

- The numerical model was revised to correct this issue. The spatial hydraulic-conductivity distribution in the numerical model was revised to follow the conceptualization of groundwater flow.

The preliminary numerical model did not include a decrease of horizontal hydraulic conductivity with depth. However, consolidation of the geologic materials is expected to occur and increase with depth. As a result the hydraulic conductivities of the RMUs should decrease with depth. The Hydrology Technical Group requested that the results of the analysis of hydraulic conductivity versus depth reported in the Conceptual Model Report (SNWA, 2009a) be used to set up the variation of hydraulic-conductivity depth-dependence (KDEP) capability of MODFLOW-2000. The Hydrology Technical Group stated that this should have been included in the numerical model, primarily in the UVF RMU.

- Decrease of horizontal hydraulic conductivity with depth was added where appropriate as recommended by the Hydrology Technical Group, using the KDEP capability of MODFLOW-2000. Details are provided in [Section 4.2.4](#).

3.2.2.2 Boundary Conditions

The flow patterns, particularly across some lateral boundaries of the model domain, could not be simulated as depicted in the simplified conceptual model. The available information is insufficient to support unique interpretations. Therefore, several interpretations of external boundary flows were derived from the available water-level data, interpretive hydrogeologic framework information, and estimates from previous studies. The following modifications were made to the external boundaries based on testing during the model-calibration process.

- Steptoe Valley to Goshute Valley: This boundary was shifted slightly to the east, from its identified location in the simplified conceptual model (SNWA, 2009a), to account for lower hydraulic heads near the model boundary in this area.
- Snake Valley to Tule Valley: The length of this flow segment located along the Confusion Range is uncertain. Initially, it was lengthened to represent the extent of the Confusion Range but was later reduced to match the length of Cowboy Pass.
- Garden Valley to Penoyer Valley: This flow-boundary segment was shifted more to the south, from its identified location in the simplified conceptual model (SNWA, 2009a), to better coincide with a larger section of carbonate rock.

- Tikaboo North Valley to Coyote Spring Valley, Snake Valley to Pine Valley, and Snake Valley to Wah Wah Valley: These flow-boundary segments were deactivated in the preliminary versions of the numerical model. They were, however, reactivated in the numerical model and assigned the flows estimated in the conceptual model as calibration targets as requested by the Hydrology Technical Group.

The following flow-boundary segments were added to the numerical model to improve calibration. These additions are within the uncertainty envelope of the conceptual model (SNWA, 2009a).

- Pahrana gat Valley to Tikaboo Valley: This flow-boundary segment was added to the southwest side of Pahrana gat Valley to allow potential flow out to Tikaboo Valley.
- Long Valley to Ruby Valley: This flow-boundary segment was added to the northwest boundary between Long Valley and Ruby Valley to allow potential flow out to Ruby Valley.
- Tippett Valley to Antelope Valley South: This flow-boundary segment was added between Tippett Valley and Antelope Valley to allow potential flow out to Antelope Valley.
- Snake Valley to Fish Springs Flat: This flow-boundary segment was added to allow potential west-to-east flow within the carbonate-rock aquifer through the Fish Springs Range.

The Hydrology Technical Group commented that the hydraulic head at Lake Mead was assigned the average lake level between 1937 and 2007. However calibration of the numerical model during preliminary testing was to steady-state predevelopment conditions (pre-1945). The average elevation of Lake Mead between 1937 and 1945 should have been used as the boundary condition.

- The effect of the constant-head value assigned to Lake Mead was tested as part of the preliminary numerical model simulations. After the numerical model reached an acceptable level of calibration to predevelopment conditions assuming post-lake hydraulic heads, a UCODE-2005 optimization run was conducted after changing the constant head at that boundary to pre-lake conditions. Except for minor differences in the UVF aquifer located south of the Muddy Springs, the results were practically the same as for the post-lake version of the numerical model. It was then concluded that using a post-lake hydraulic head for that boundary would not introduce significant additional errors in the numerical model.

3.2.2.3 Recharge and Discharge Processes

The Hydrology Technical Group commented that the preliminary numerical model simulated excess water in several parts of the model area. This water excess results in groundwater discharge values that are larger than expected. The group stated that in the White River Flow System (WRFS), the simulated excess water was apparent as excess discharge in Pahrana gat Valley. In the GSLDFS, the excess recharge was evidenced by the large interbasin groundwater flow from Hamlin Valley to Snake Valley. Excess water in the MVFS was evidenced by excess discharge in Lower Meadow Valley Wash.

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- Adjustments were made to recharge within the WRFS, and modifications were made to the representation of Pahrangat Valley as described in [Section 4.4.4.2.2](#). These adjustments reduced the excess water in the WRFS.
 - Adjustments were made to the discharge targets used for Lower Meadow Valley Wash (SNWA, 2009a), which resulted in a new set of recharge efficiencies for both MVFS and GSLDFS, as described in SNWA (2009a). The recharge in Hamlin Valley was also adjusted during model calibration as described in [Section 5.3.3.4](#). These adjustments reduced the excess water in the MVFS as well as the excessive interbasin groundwater flow from Hamlin to Snake valleys in the GSLDFS.

4.0 NUMERICAL MODEL CONSTRUCTION

This section describes the construction of the transient numerical groundwater flow model, including the abstraction process of the flow systems in the model area into MODFLOW-2000 and UCODE_2005. This process includes the selection of the MODFLOW -2000 packages and the preparation of the necessary input files. The construction steps discussed are (1) numerical model discretization, (2) representation of hydrogeologic framework, (3) definition of external model boundary conditions, (4) representation of natural surface and groundwater discharge, (5) representation of areal recharge from precipitation, (6) estimation of anthropogenic stresses, and (7) derivation of observation data sets. Parameters associated with the various components of the numerical model are presented, where appropriate.

4.1 Numerical Model Discretization

The discretization of the numerical model is applied to the 3D spatial domain and the simulated time period.

4.1.1 Spatial Discretization

The spatial discretization includes the definition of a horizontal grid and layers in the vertical direction. The layers are then assigned the appropriate hydraulic conditions.

The horizontal discretization of the numerical model domain consisted of defining a finite-difference grid including appropriate grid orientation and grid-cell size.

- The grid orientation was selected to be north-south to approximately match the general direction of regional groundwater flow. Regional flow directions follow the north-south orientation of the prominent basins and ranges and dominant structures present in the model domain.
- A grid-cell size of approximately 3,281 ft (1,000 m) was selected. Factors considered in the selection of an appropriate grid-cell size were (1) computational efficiency, (2) appropriate representation of the available data, and (3) ability to effectively simulate regional-scale groundwater flow. Thus, the model grid used to simulate regional flow results in the averaging of hydraulic properties over grid-cell areas of about $3,281 \times 3,281 \text{ ft}^2$ ($1,000 \times 1,000 \text{ m}^2$).

The vertical discretization of the numerical model consisted of subdividing the total thickness of the model into layers.

A total of 11 model layers were selected. [Table 4-1](#) lists the grid layer tops and bottoms represented in the numerical model. Cross sections for each numerical model row were developed by sampling the RMU grids, a 30-m resolution surface-elevation grid, and several fault layers (see DVD). In general, the model layers cannot coincide with the RMUs because of the complex geometries of the RMUs, which were caused by folding, faulting, volcanism, and other processes.

Table 4-1
Thickness and Elevation of Top and Bottom of Each Layer of the Numerical Model

Model Layer ^a	Top of Layer ft amsl (m amsl)	Bottom of Layer ft amsl (m amsl)	Thickness ft (m)
1	12,631 (3,850) or lower	6,070 (1,850)	328 (100) to 6,562 (2,000)
2	6,070 (1,850) or lower	5,085 (1,550)	328 (100) to 984 (300)
3	5,085 (1,550) or lower	4,101 (1,250)	328 (100) to 984 (300)
4	4,101 (1,250) or lower	3,117 (950)	328 (100) to 984 (300)
5	3,117 (950) or lower	2,133 (650)	328 (100) to 984 (300)
6	2,133 (650) or lower	1,148 (350)	328 (100) to 984 (300)
7	1,148 (350)	164 (50)	984 (300)
8	164 (50)	-1,312 (-400)	1,476 (450)
9	-1,312 (-400)	-3,527 (-1,075)	2,215 (675)
10	-3,527 (-1,075)	-6,726 (-2,050)	3,199 (975)
11	-6,726 (-2,050)	-10,000 (-3,048)	3,274 (998)

^aThe top or bottom of a layer may be 328 ft (100 m) lower to ensure top model layer is at least 328 ft (100 m) thick.

The north-south-oriented model grid consists of 474 rows, 202 columns, and 11 layers ([Figure 4-1](#)). The model domain corresponds to 589,391 active cells and encompasses an area of about 20,688 mi² (53,581 km²) ([Figure 4-1](#)). The lower, left-corner origin of the grid is located at Universal Transverse Mercator (UTM) coordinates ($X = 607069.15225$ m; $Y = 3998858.038990$ m). Grid dimensions along both rows and columns are constant at 3,281 ft (1,000 m). The model extends vertically from -10,000 ft amsl (-3,048 m amsl) to the water table, which varies from about 1,148 ft amsl (350 m amsl) to more than 9,022 ft amsl (2,750 m amsl).

Ideally, the numerical model would have been modeled under confined and unconfined conditions. However, the use of convertible layers (unconfined) resulted in instabilities in model convergence. To address this issue, all model layers were treated as confined, and the model grid was adjusted in two ways:

- The top elevation of the top model layer was adjusted to approximately match the expected water-table surface. Thus, the confined layer thickness approximates the unconfined saturated thickness, and calculated flows are similar. The transmissivity (T) will be similar as it equals the hydraulic conductivity (K) times the saturated thickness (b ; $T = Kb$). During model calibration, the top of the model was adjusted to the last calculated steady-state water table.

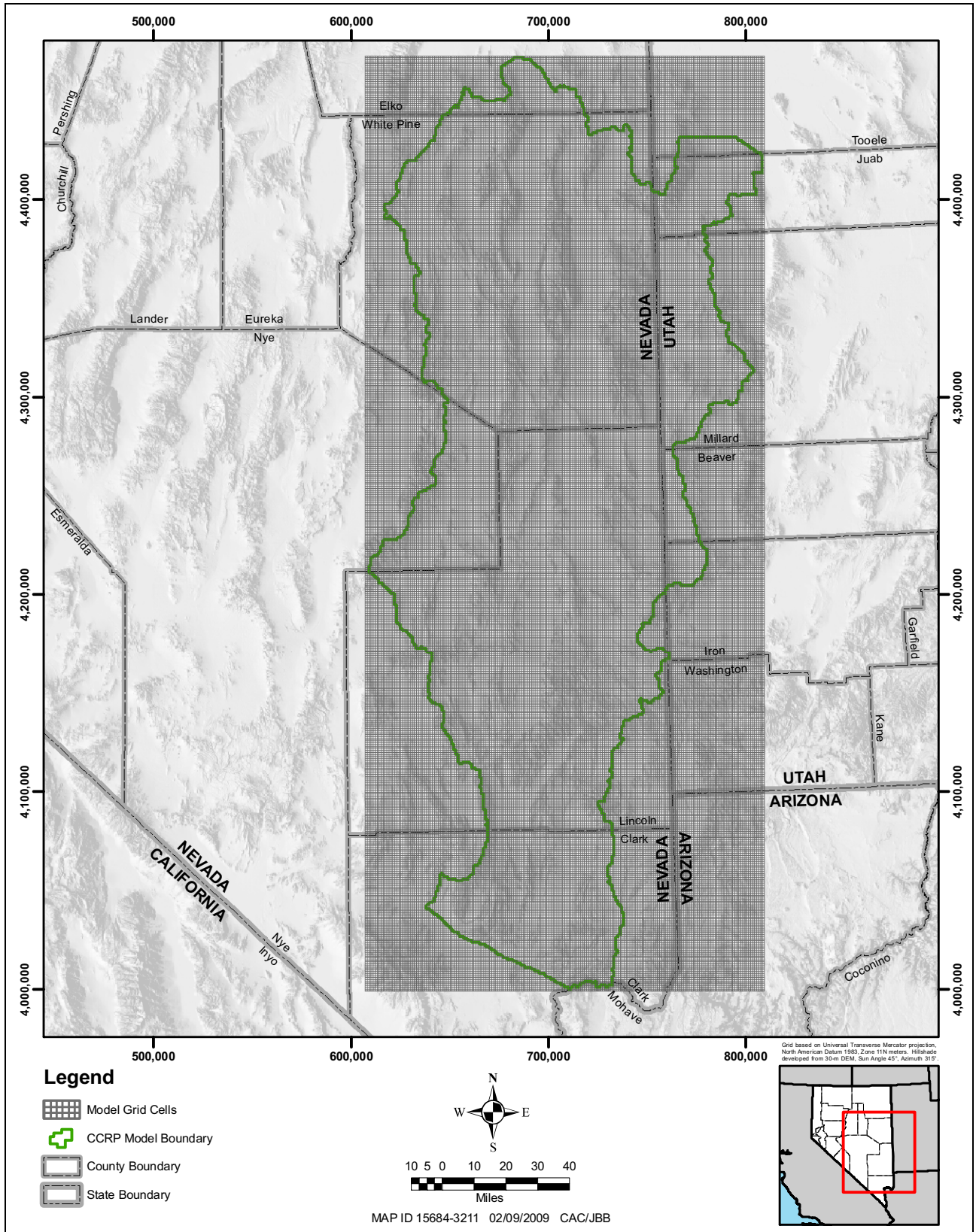


Figure 4-1
Numerical Model Finite-Difference Grid

- Under steady-state conditions, adjusting the top elevation of the model minimizes many of the problems. Under transient conditions, the water table can change, and the assumption of confined flow can become less accurate. For example, if the calculated hydraulic head in the uppermost saturated layer decreases because of a stress (e.g., pumping), the transmissivity does not change, but the effective K increases. To minimize the impact of this issue, the top model layer was defined to have a minimum thickness of 328.1 ft (100 m). In areas where the model layer would normally be less than 328.1 ft (100 m), the underlying layers were adjusted to maintain the 100-m thickness in the upper layer. The underlying layers are typically 984.3 ft (300 m) thick. The grid adjustments described reduced the underlying layer thickness a maximum of approximately 656.2 ft (200 m). Except in places of large drawdown, this approach maintains a large saturated thickness, minimizing numerical inaccuracies of the confined assumption.

4.1.2 Time Discretization

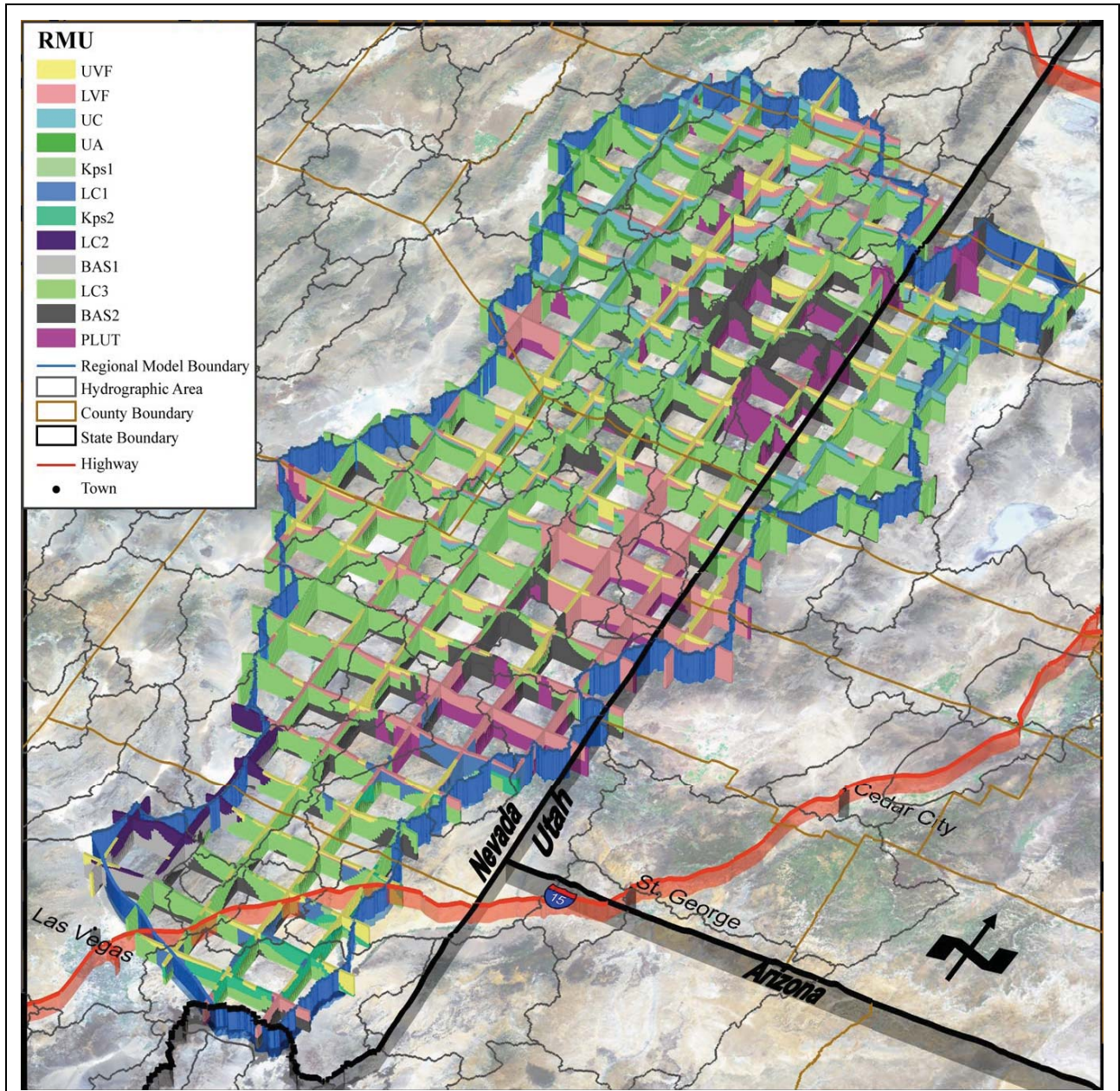
The numerical model combines steady-state and transient stress periods. The initial stress period is steady-state and represents predevelopment conditions prior to January 1, 1945. The transient portion of the model extends over the period from January 1, 1945, through December 31, 2004. The 60-year time period was subdivided into 60 transient 1-year stress periods, each lasting 365 or 366 days, as appropriate. Each stress period was subdivided into 12 equal-length time steps.

4.2 Hydrogeologic Framework

The simplified hydrogeologic framework described by SNWA (2009a) consists of eight RMUs (Table 4-2) and major structural features. This hydrogeologic framework was discretized based on the model grid described earlier in the previous section. Figure 4-2 illustrates an oblique view of the discretized hydrogeologic framework model. The RMUs are illustrated in the cross sections across each numerical model row (see DVD). In addition to model layers, the framework was represented in the numerical model using the hydrogeologic-unit flow (HUF2) package (Anderman and Hill, 2003) and the horizontal flow barrier (HFB) package (Hsieh and Freckleton, 1993). These two software packages are described, followed by a description of how the hydrogeologic framework was represented using these packages.

**Table 4-2
RMUs Represented in the Numerical Model**

RMU Description	RMU Abbreviation
Upper Valley Fill	UVF
Lower Valley Fill and Volcanic Rocks	LVF
Upper Carbonate	UC
Upper Aquitard	UA
Cretaceous Plateau Sediments	Kps
Lower Carbonate	LC
Basement Rocks	BASE (or BAS)
Plutonic Rocks	PLUT



Note: Three times the vertical exaggeration.

Figure 4-2
Oblique View of 3D Framework of RMUs Using a Series of
North-South and East-West Cross Sections Oriented at 20 km

4.2.1 HUF2 Package Description

The HUF2 computer code (Anderman and Hill, 2003) builds on the HUF package (Anderman and Hill, 2000). Three additions are documented by Anderman and Hill (2003): (1) alternative storage for the uppermost active cells (SYTP parameter type), (2) modified calculation of flows in hydrogeologic units, and (3) the KDEP capability. The HUF2 package allows the vertical geometry of the flow system to be different from the model layers. An advantage of the HUF2 package is that

the hydrogeologic framework is set up in the numerical model independently of the model grid. In other words, the model grid can be modified without affecting the hydrogeologic framework.

When using the HUF2 package, the hydraulic properties are assigned to the hydrogeologic units. Initial estimates of all hydraulic properties must be provided for each hydrogeologic unit. Hydraulic properties are treated as parameters and include hydraulic conductivity and storage characteristics. Hydraulic-conductivity characteristics consist of horizontal and vertical hydraulic conductivities (K_h and K_v) and the KDEP factor. The vertical hydraulic conductivity, K_v , can also be represented as a ratio relative to K_h . There are some advantages to keeping the K_v value proportional to K_h during model calibration. Given that the horizontal and vertical hydraulic-conductivity values of a material are typically correlated, it is reasonable that when one value is adjusted, the other should be as well. This tied behavior is defined by the vertical anisotropy ratio (the ratio of horizontal to vertical hydraulic conductivity). The vertical anisotropy (VANI) is expressed as follows:

$$VANI = \frac{K_h}{K_v} \quad (\text{Eq. 4-1})$$

where,

- $VANI$ = Vertical anisotropy (-)
- K_h = Horizontal hydraulic conductivity (L/T)
- K_v = Vertical hydraulic conductivity (L/T)

Using the hydraulic properties specified for the hydrogeologic units, HUF2 internally calculates hydraulic properties for every cell in the model grid that are adjusted to depth using [Equation 4-2](#). If a model cell contains a single hydrogeologic unit, the properties of the cell are the same as for the hydrogeologic unit. If a grid cell contains multiple hydrogeologic units, HUF2 calculates the hydraulic properties for that cell by averaging the hydraulic properties of the hydrogeologic units occurring in that cell. The K_h values are calculated using the thickness-weighted arithmetic mean, and the K_v values are calculated using the geometric mean.

The same hydraulic properties may be assigned to an entire hydrogeologic unit. However, for large numerical models, it is reasonable to expect local variations or variation controlled by geologic structure within a given hydrogeologic unit. To account for these variations, the hydrogeologic unit may be subdivided into zones. Zones allow the user to assign different hydraulic parameters to different portions of the hydrogeologic unit.

The variation of hydraulic conductivity with depth is handled by the KDEP capability of the HUF2 package (Anderman and Hill, 2003). This capability allows the horizontal hydraulic conductivity of the hydrogeologic units (RMUs in the numerical model) to decrease with depth using an exponential decay function. The equation is as follows:

$$K_{Depth} = K_{Surface} 10^{-\lambda d} \quad (\text{Eq. 4-2})$$

where,

- K_{Depth} = Hydraulic conductivity at depth d [L/T]
- d = Depth below the reference surface [L]
- $K_{Surface}$ = Hydraulic conductivity projected to a reference surface [L/T]
- λ = Depth-dependence coefficient [1/L]

The reference surface may be the ground surface or other surface, such as the top of the top model layer. The depth-dependence coefficients, λ , can be treated as parameters in MODFLOW-2000. If the *VANI* option is used to calculate vertical hydraulic conductivity, the values of vertical hydraulic conductivities are automatically adjusted with depth too.

4.2.2 HFB Package Description

The HFB package was added to the MODFLOW code by Hsieh and Freckleton (1993). The HFB package is designed to simulate thin, vertical, low-permeability geologic features that impede horizontal groundwater flow.

These features are represented in the model “as a series of horizontal flow barriers conceptually situated on the boundaries between pairs of adjacent cells in the finite-difference grid” (Hsieh and Freckleton, 1993, p. 1). The only function of these features is to lower the horizontal branch conductance between the two adjacent cells they separate. The storage capacity of the features is assumed to be zero.

The width of the thin barrier is assumed to be negligible relative to the horizontal dimensions of the grid cells and is implicitly included in the expression of the hydraulic property of the flow barrier. This hydraulic property may be expressed in two ways:

- If the flow barrier is located within a constant-transmissivity layer, its hydraulic property is defined as its transmissivity divided by its width.
- If the barrier is located within a variable-transmissivity layer, its hydraulic property is defined as its hydraulic conductivity divided by its width.

4.2.3 Representation of Framework

The RMUs are represented as zones of variable hydraulic properties in the HUF2 package. The major faults are also represented in the HUF2 package as zones of larger permeability along their strikes within the RMUs. The HFB package is used to simulate the potential ability of selected faults represented in the model to also act as barriers to cross flow. Regional faults can be simulated as both conduits along their strike (HUF2) and barriers to cross flow (HFB).

4.2.3.1 Hydrogeologic Features Represented in HUF2 Package

The HUF2 package was used to represent the distribution of RMUs and their hydraulic properties in the model domain (hydraulic conductivity and storage properties). The RMUs were subdivided into zones based on natural features of the hydrogeologic framework conceptualized to affect groundwater flow. A description of the natural features forming the basis of Rmu zonation is presented, followed by a discussion of the parameter zones associated with each Rmu.

4.2.3.1.1 Rmu Zonation Basis

All RMUs were subdivided into parameter zones. Although the zonation was based on natural features conceptualized to affect groundwater flow, the resulting zones are not necessarily supported by aquifer-property data, as such data are scarce in this region. The features are, however, supported by other sources of information and interpretations. Nonetheless, incorporating these zones into the construction of the model allowed variation of the hydraulic properties within a given Rmu during model calibration, if necessary. The zones were delineated based on the following features:

- Mountain blocks, structural basins, and normal faults
- Alluvial deposition zones
- Extensional terrains
- Plutonic intrusion events
- Subregional features

Mountain blocks, structural basins, moderate-displacement faults, and large-displacement faults form natural zones of increasingly disturbed materials. Within a given Rmu, the portions forming the mountain blocks are the least disturbed materials and therefore form zones of relatively lower hydraulic conductivities. Portions of the same Rmu located with the structural basins are more disturbed than the mountain blocks and generally have relatively larger hydraulic conductivities. The moderate- and large-displacement faults (normal faults) are the most disturbed zones and are interpreted to be zones of increased hydraulic conductivity along the strike of the normal faults.

Alluvial deposition zones are natural zones of varying hydraulic properties in the UV F Rmu only. Four such zones were delineated: alluvial fans, fluvial deposits, valley bottoms, and playa deposits. The alluvial fans and fluvial sediments are expected to be zones of larger hydraulic conductivity, whereas the playa deposits are expected to be zones of lower hydraulic conductivity. The valley bottoms encompass all other alluvial deposits in a given basin and generally have moderate hydraulic conductivities.

Brittle rocks, such as the carbonate rocks, were extended to varying degrees during extensional deformation. Most of the effects of this extension (thicknesses and faults) were incorporated into the framework model. However, the effects of the extension on the hydraulic conductivity of the Rmu blocks were not accounted for. Based on geologic interpretations, Dettinger and Schaefer (1996) have delineated areas of slight and extreme extension in the Carbonate-Rock Province. Carbonate rocks located within the areas of slight extension are interpreted to essentially have their original thicknesses and moderate hydraulic conductivities. Carbonate rocks located within the areas of

extreme extension are interpreted to be thinner to absent and have larger hydraulic conductivities when present.

Plutonic intrusion events cause hydrothermal and thermal alterations to the materials surrounding the intrusion sites. The altered materials form an aureole or halo around the plutonic intrusion. Such areas occur around a number of plutonic intrusions (PLUT RMU) present in the model area. In the numerical model, it was assumed that an alteration aureole could exist in surrounding materials extending 1.2 mi (2 km) laterally around plutonic intrusions that are more than 3,281 ft (1,000 m) thick (from base of model). This alteration is expected to affect all the RMUs except the UVF. The effect of the alteration is a reduction in the hydraulic conductivity. To manage this attribute, the ALT_FACT parameter was added. Cells affected by these alteration zones have their *K* values divided by ALT_FACT using derived UCODE parameters and specially designated HUF2 parameters.

Additional zones were added at the basin and subregional scales as needed during the calibration to improve the fit of the numerical model to the target observations. These zones were based on the available information and included adding zones to reflect local hydrogeology, including texture changes or the presence of faults not already included in the numerical model.

4.2.3.1.2 Parameter Zones

This section discusses the subdivision of the individual RMUs into parameter zones. All RMUs, except the UVF, were assumed to be altered within the halos surrounding the plutons described in the previous subsection. [Table 4-3](#) lists the zone types used to add detail to the hydrogeologic framework. The hydraulic parameters were named by zone and assigned initial values (see DVD).

**Table 4-3
Zones Applied to RMUs in the Numerical Model**

Zone Type	UVF	LVF	UC	UA	Kps	LC	BASE	PLUT
Mountain Block	---	X	X	---	---	X	---	---
Structural Basin	---	X	X	---	---	X	---	---
Normal Faults ^a	---	X	X	---	---	X	---	---
Alluvial Deposition Zones ^b	X	---	---	---	---	---	---	---
Extension Terrain	---	---	X	---	---	X	---	---
Plutonic Intrusion Events	---	X	X	X	X	X	X	X
Subregional Zones ^c	X	X	X	X	---	X	X	X

^aLarge- or Moderate-Displacement Faults (LDF and MDF)

^bStreams, alluvial fans, valley bottoms, and playas

^cZones applied at basin and subregional scale

Upper Valley Fill

Zones were defined in the numerical model to represent variation within the UVF RMU based on the types of alluvial deposits or on the geographic distribution of the unit. The se zones include playas and playa deposits, stream channels, valley bottom materials, alluvial fans, and subregional zones. [Figure 4-3](#) illustrates the UVF parameter zones. The spatial distribution of the detailed hydrogeologic units forming the UVF RMU was obtained from published maps, including county geologic maps.

Lower Valley Fill

The LVF RMU consists of discontinuous Tertiary and Cretaceous sediments as well as middle-Tertiary volcanic rocks. These rocks are composed of conglomerates, sandstones, siltstones, nonwelded to densely welded ash-flow tuffs, ash-fall tuffs, and lava flows. LVF zones represented in the model are calderas and consolidated basin fill. The LVF zones allow materials with different origin and different material properties (volcanic rocks versus various sedimentary basin deposits) to be estimated separately. Sedimentary basin deposits (such as lithified Tertiary basin-fill deposits) and volcanic basin deposits (such as ash and lava flows outside the caldera complexes) are grouped into a single zone. [Figure 4-4](#) illustrates LVF parameter zones. The spatial distribution of the detailed hydrogeologic units forming the LVF RMU was obtained from published maps, including county geologic maps.

Upper Aquitard

The UA RMU consists predominantly of the Eleana and Chainman Formations. These rocks are composed of siltstones and shales. The UA consists of low-permeability, fine-grained sedimentary deposits that restrict vertical flow between the lower carbonate and the upper carbonate and other shallow units. [Figure 4-5](#) illustrates the UA parameter zones. The spatial distribution of the detailed hydrogeologic units forming the UA RMU was obtained from the hydrogeologic framework described in the Baseline Report (SNWA, 2008). Little data are available for the UA, particularly in Butte Valley South, Jakes Valley, and Long Valley. Thus, the UA was assigned a uniform thickness of 3,000 ft (914 m) throughout its extent. Because of the large uncertainty associated with its thickness, the UA composition (all shale versus shale and sandstone interbeds), its competence (degree of faulting), and corresponding hydrologic conditions were allowed to strongly influence its hydraulic-conductivity values.

Upper Carbonate and Lower Carbonate

The UC and LC RMUs consist of Cambrian to Pennsylvanian carbonate rocks, including limestone and dolomite with lesser amounts of shale, siltstone, sandstone, and quartzite. The LC is present throughout the study area, while the UC is predominantly present in the northern areas. Overthrown blocks caused by major thrust faults disrupt the LC's regional continuity (SNWA, 2008). Therefore, three RMUs (LC1, LC2, and LC3) form the LC RMU (SNWA, 2009a). The carbonate RMUs were further subdivided into zones based on their location relative to major basin structures. As shown in [Table 4-3](#), the UC and LC RMUs were subdivided into multiple zones. The zones identified for the UC and LC1 RMUs are shown in [Figures 4-6](#) and [4-7](#), respectively. The zones identified for the LC2 and LC3 RMUs are shown in [Plate 1](#).

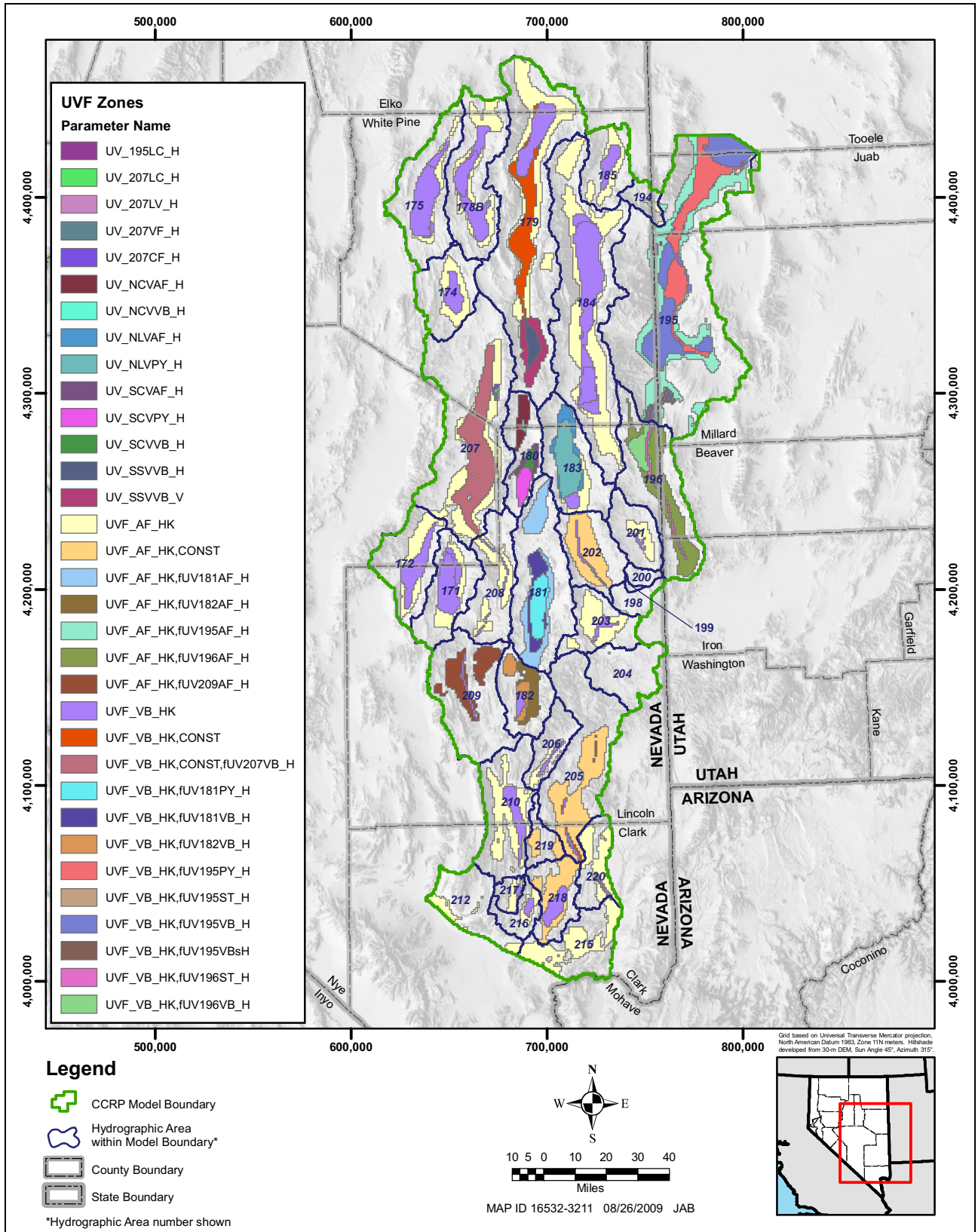


Figure 4-3
Parameter Zones Defined for the UVF RMU in the Numerical Model

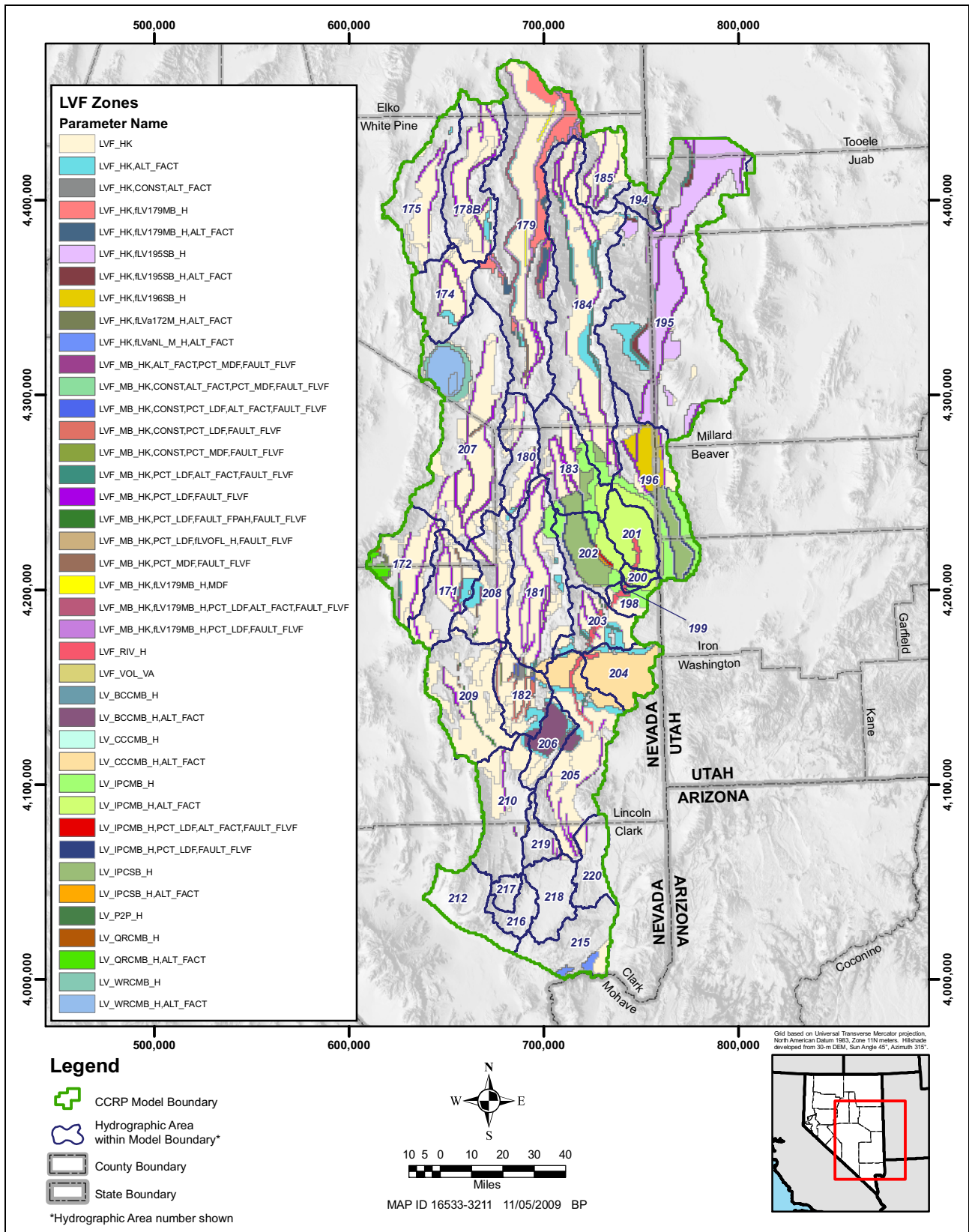


Figure 4-4
Parameter Zones Defined for the LVF RMU in the Numerical Model

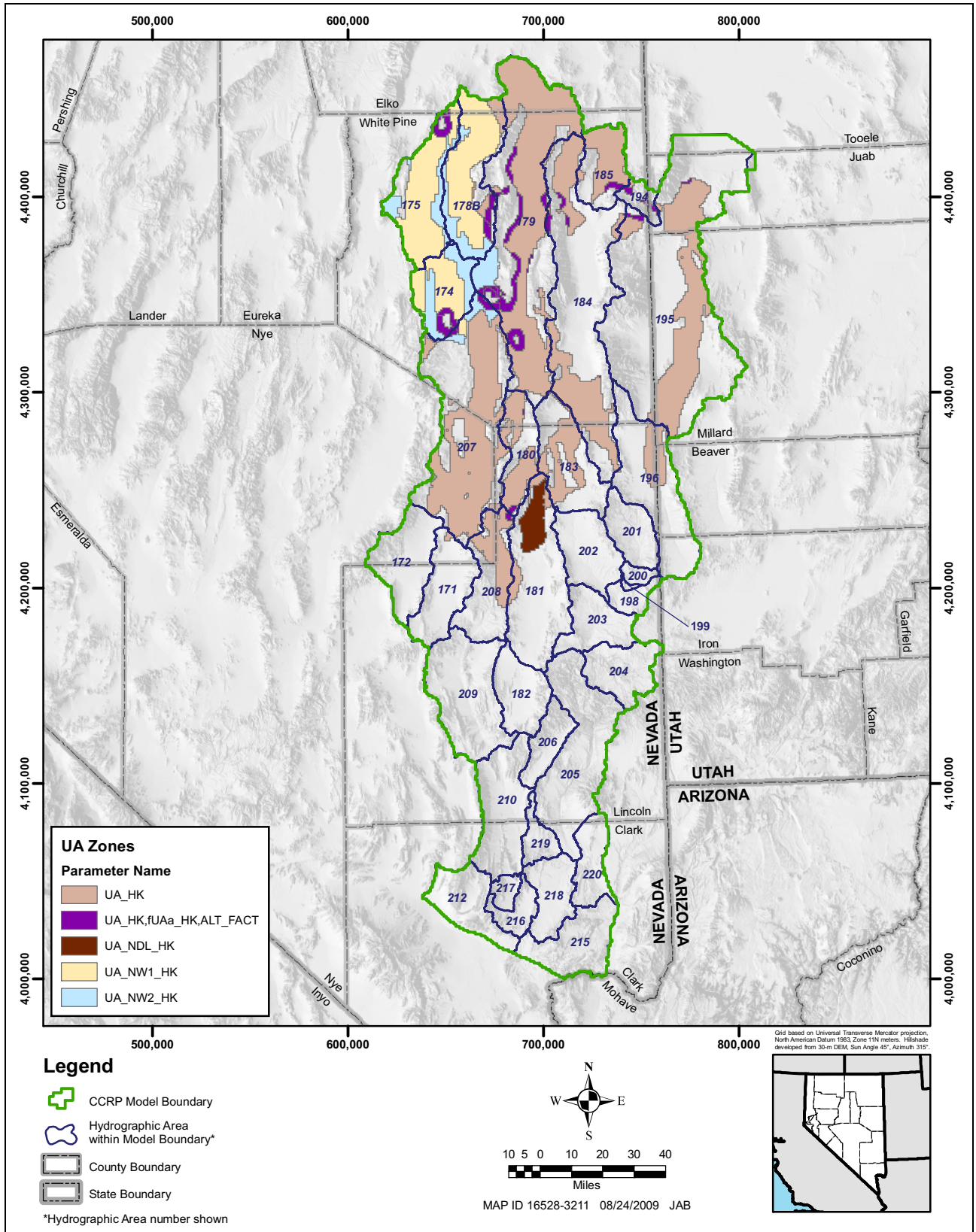


Figure 4-5
Parameter Zones Defined for the UA RMU in the Numerical Model

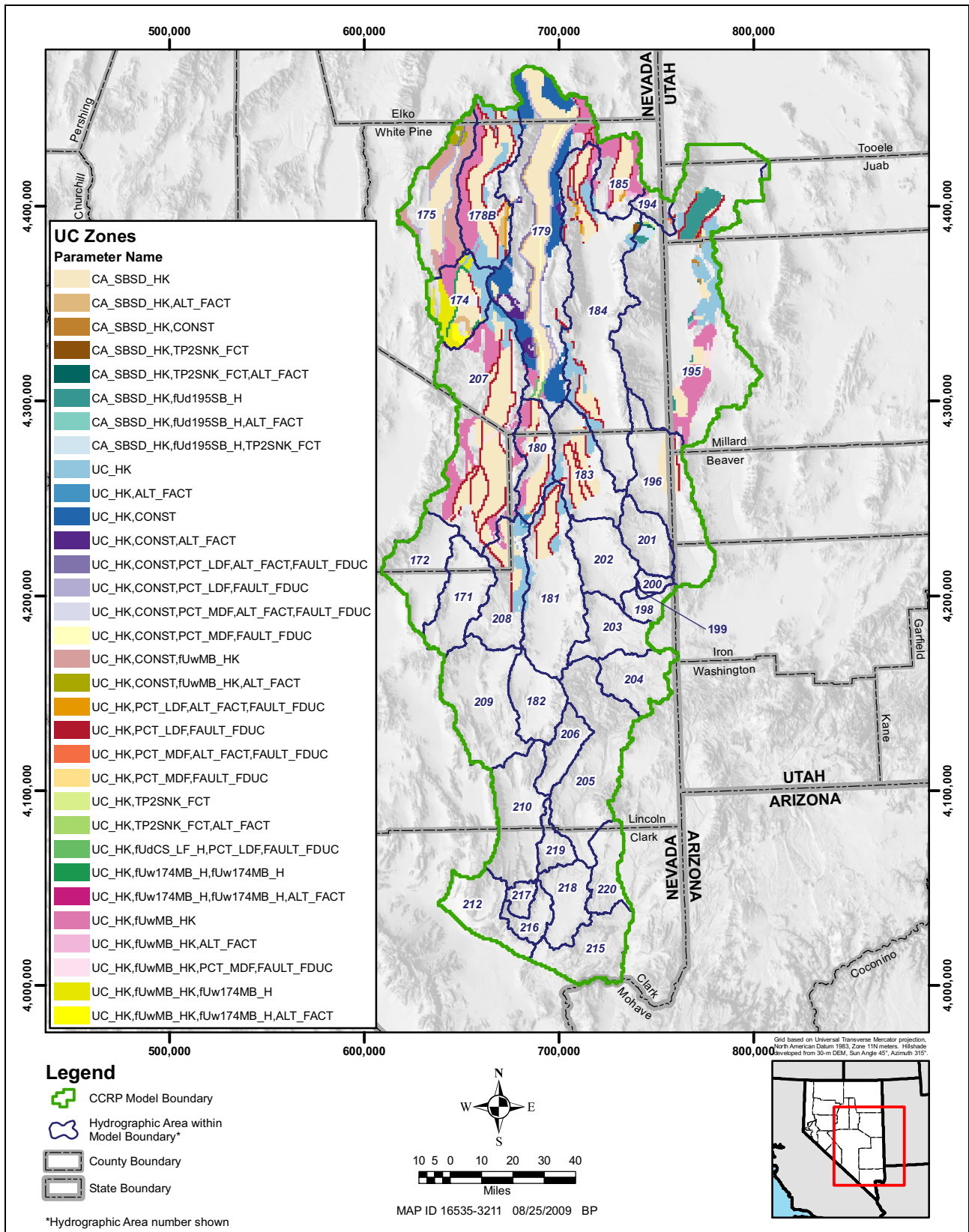


Figure 4-6
Parameter Zones Defined for the UC RMU in the Numerical Model

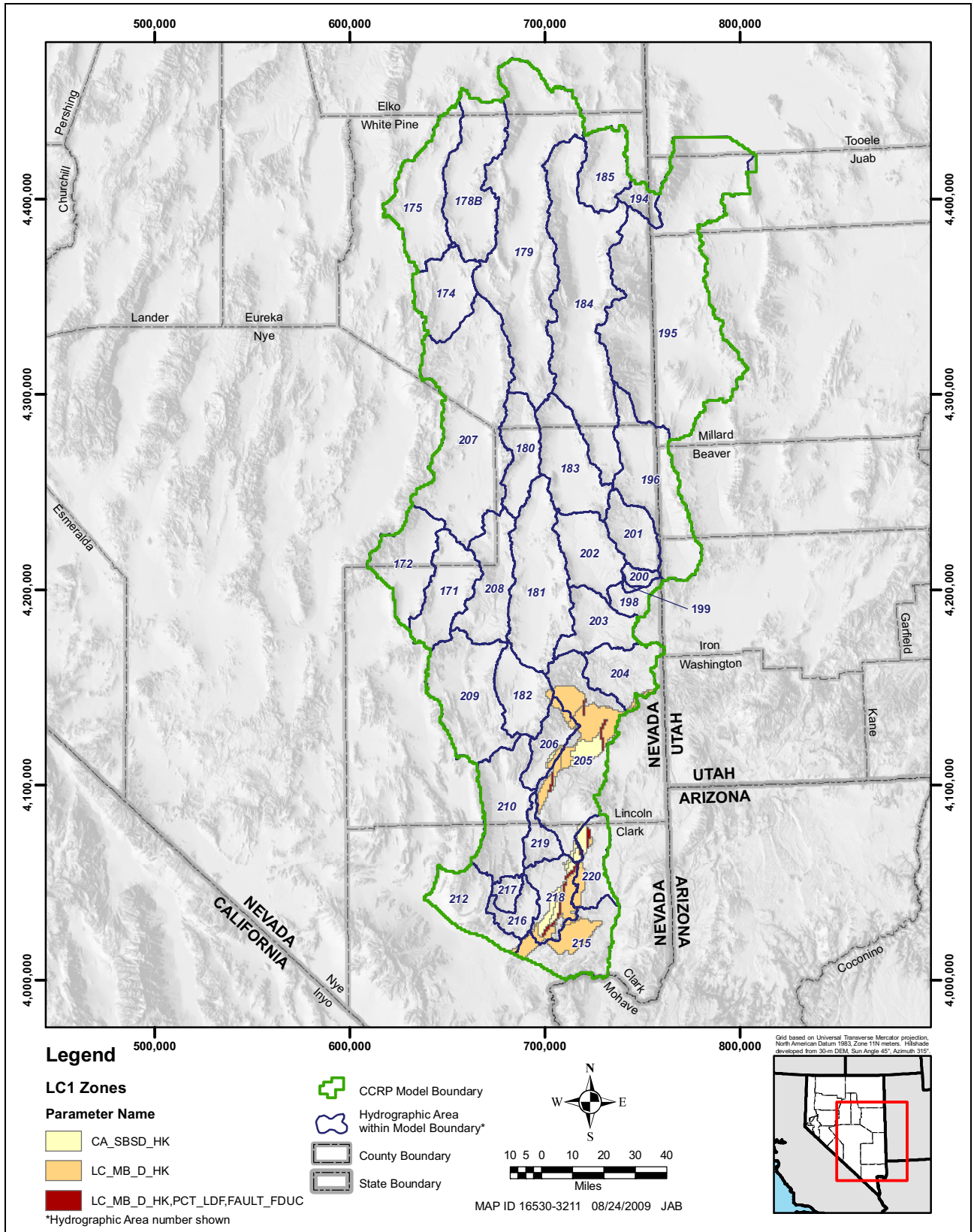


Figure 4-7
Parameter Zones Defined for the LC1 RMU in the Numerical Model

Plateau Sediments

The Kps RMU consists of Cretaceous to Triassic siliciclastic rocks and is generally of low permeability. The Kps RMU is present only in the southern part of the study area. [Figure 4-8](#) illustrates the Kps RMU parameter zone. The Kps RMU was subdivided into two parts, as shown in [Figure 4-8](#).

Plutons

The PLUT RMU consists of all intrusive rocks, including granodiorite, quartz monzonite, and granitic rocks. The PLUT RMU is found sporadically in the study area as several large irregularly shaped bodies within the area. This RMU generally has small hydraulic conductivities unless fractured. The PLUT RMU was subdivided into four parameter zones as shown in [Figure 4-9](#).

Basement

The BASE RMU (also referred to as BAS in the model files) consists of Precambrian metamorphic and Precambrian and early Cambrian clastic rocks. This unit occurs at significant depths in most, but not all, areas. Much like the LC, overthrown blocks of basement rock are present at the Gass Peak thrust fault. BASE1 and BASE2 account for the repeating units caused by this thrust fault. BASE1 represents the basement rock present at the hanging wall of the Gass Peak thrust fault. The extent of BASE1 is very similar to the LC1 extent with the exception of an outcrop band of basement rock in the Las Vegas Range. The BASE2 extent covers the entire model area with the exception of areas where the PLUT RMU has replaced it and where the model thickness is not sufficient to extend to the top of the BASE RMU. BASE2 also represents the basement rock of the footwall at the Gass Peak thrust fault. The BASE RMU zones were defined based on their areal isolation, structural separation, or the thermal alteration halo around a given pluton ([Figure 4-10](#)).

4.2.3.2 Structural Features Represented with HFB Package

The HFB package (Hsieh and Freckleton, 1993) was used to represent barriers to flow in the numerical model across selected lateral and normal faults where these faults are conceptualized as barriers to groundwater flow across these geologic features. These flow barriers are located along cell boundaries approximating the location of selected mapped lateral and normal faults. Horizontal flow barriers, in most cases, penetrate all RMUs and have a vertical orientation (see DVD). For two cases in White River Valley, the HFBs cross valley basin material, and it was assumed that the low K barriers did not extend into the UVF. The normal faults in the model are typically represented by moderate- or large-displacement faults zones where K is expected to be higher to the basin side of the HFB.

[Figure 4-11](#) illustrates lateral and normal faults represented using the HFB package. Horizontal flow barriers are illustrated in cross sections for each model row (see DVD). [Table 4-4](#) describes the lateral faults represented as flow barriers and their parameters. [Table 4-5](#) describes the normal faults represented as flow barriers and their parameters. Fifty fault groups are represented in the numerical model using the HFB package. The thickness of all flow barriers was assumed to be 3.28 ft (1 m). Their hydraulic conductivities were treated as parameters and, therefore, were estimated during the calibration process. The initial hydraulic conductivity of HFBs was set to 1×10^{-6} m/d.

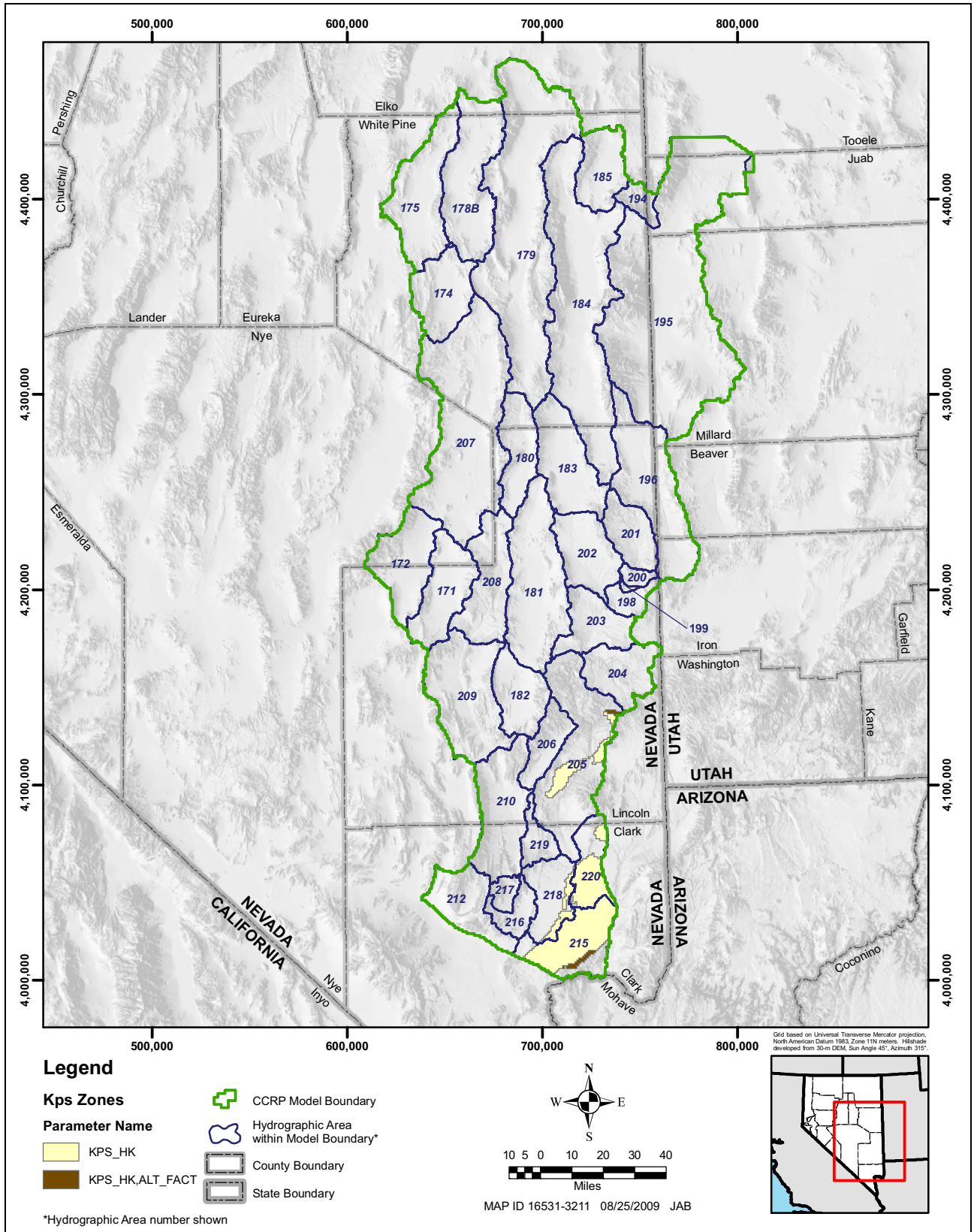


Figure 4-8
Parameter Zones Defined for the Kps RMU in Numerical Model

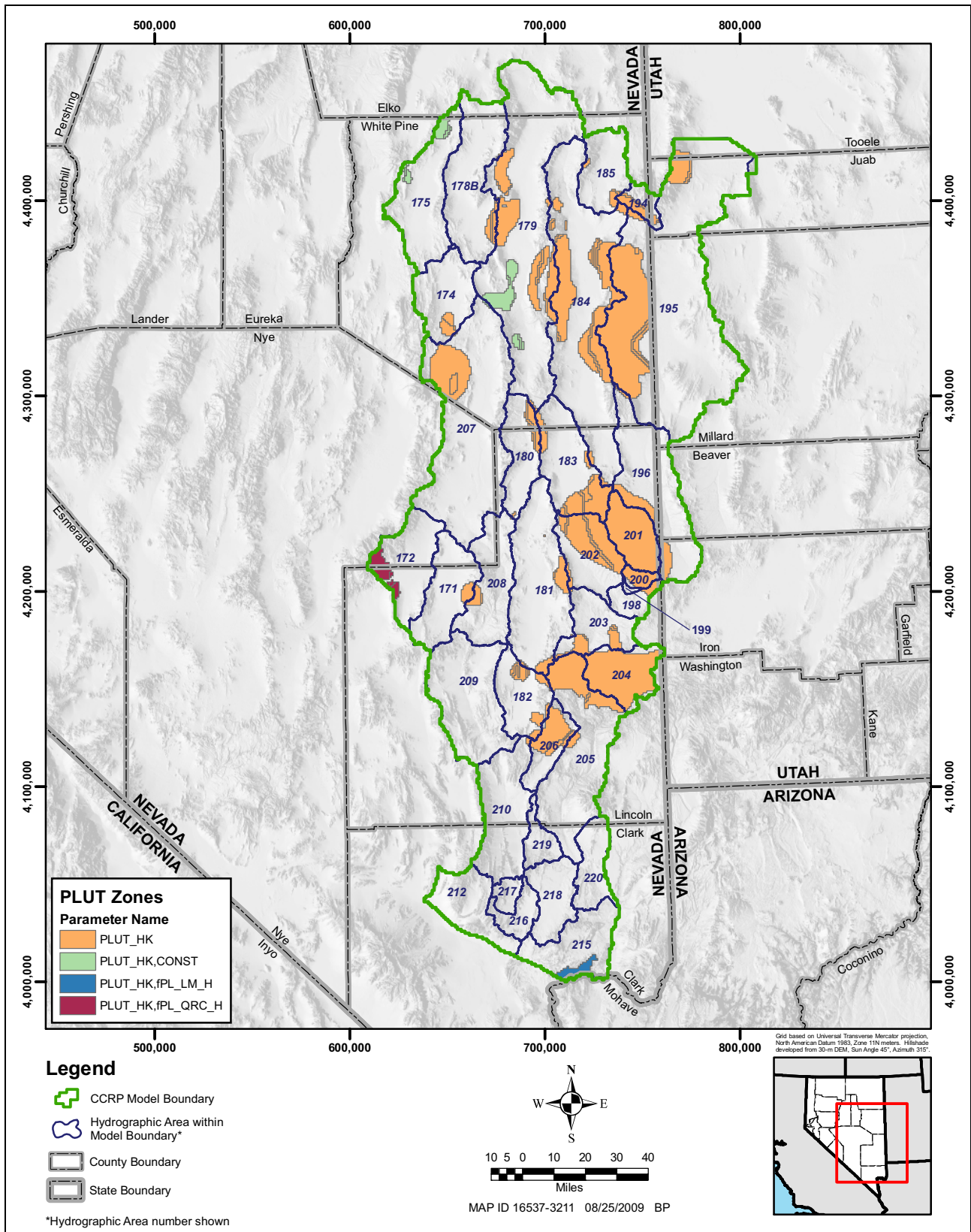


Figure 4-9
Parameter Zones Defined for the PLUT RMU in Numerical Model

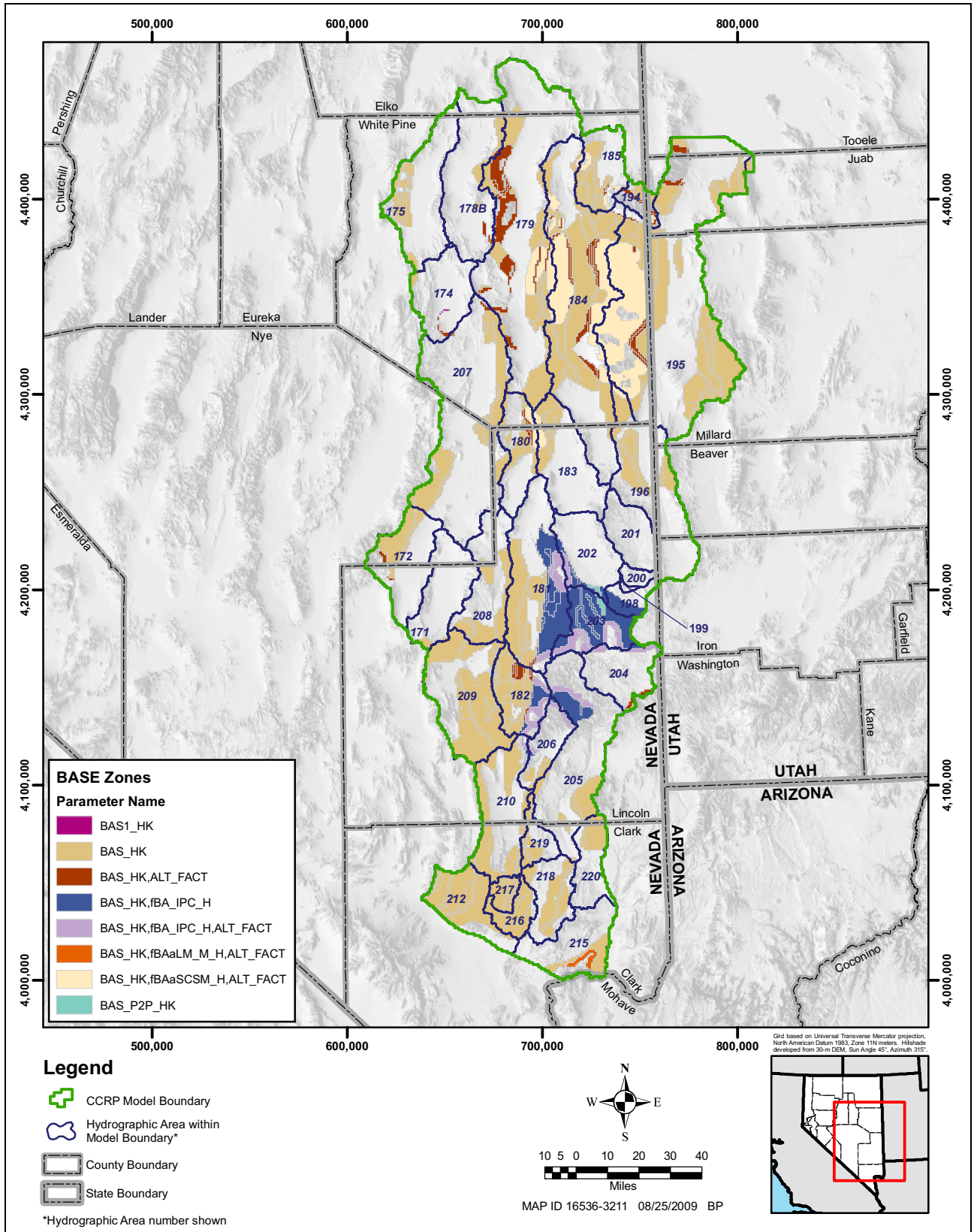


Figure 4-10
Parameter Zones Defined for the BASE RMU in Numerical Model

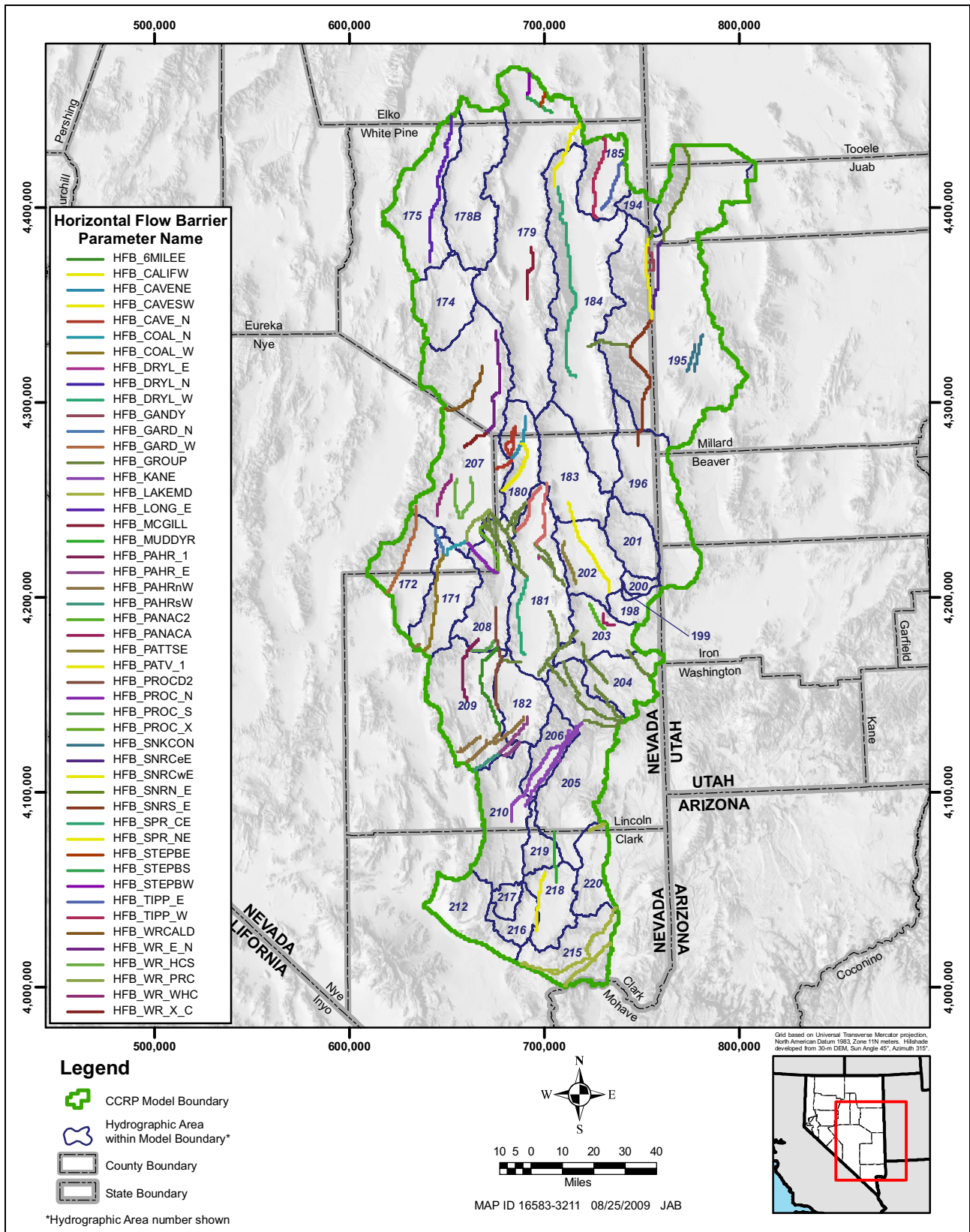


Figure 4-11
Lateral and Normal Faults Defined as Horizontal Flow Barriers in the Numerical Model

**Table 4-4
Description of Lateral Faults Defined as
Horizontal Flow Barrier (HFB) Package Parameters**

Feature Description	MODFLOW-2000 Parameter Name	UCODE_2005 Parameter Definition
Black Mountains Area	HFB_LAKEMD	HFB_HK * fHFB_LAKEMD
Caliente Caldera Area	HFB_GROUP	HFB_HK
Kane Springs Area	HFB_KANE	HFB_HK
North Dry Lake Area	HFB_GROUP	HFB_HK
Snake Range	HFB_GROUP	HFB_HK
South Dry Lake Area	HFB_GROUP	HFB_HK
Pahranagat Shear Zone		
Eastern Section	HFB_PAHR_E	tHFB_PAHR_E
Northwestern Section	HFB_PAHRnW	HFB_HK * fHFB_PAHRnW
Southwestern Section	HFB_PAHRsW	HFB_HK

Horizontal flow barriers, in most cases, penetrate all RMUs and have a vertical orientation (see DVD). The UVF was assumed to be unfaulted, or if faulted, the faults were assumed to not form barriers to flow. Two cases occur in White River Valley where HFBs extend across basin-fill material, and the low-*K* barriers do not extend into the UVF. A third case occurs west of Warm Springs near Gandy, Utah, in Snake Valley.

Faulting in the Gandy area is complex. However, because of the regional nature of the hydrogeologic framework described in the Baseline Report (SNWA, 2008), the rather complex geology of the immediate vicinity around Gandy Warm Springs is overly simplified. In the Baseline Report (SNWA, 2008), a carbonate horst is described. This feature and faults associated with this feature contribute to the spring discharge at Gandy Warm Springs. Given the magnitude of the flow at Gandy Warm Springs, additional faulting besides that described by the large-displacement faults in the framework is needed. It also appears faulting to the west helps direct subsurface flow from Indian George Wash and Tangstina Wash toward Gandy Warm Springs.

4.2.4 KDEP Parameters - HUF2 Package

In addition to using the HUF2 module (Anderman and Hill, 2003) to define hydrogeologic units and their material properties, a modified version of the KDEP submodule of HUF2 (Anderman and Hill, 2003) was used to model depth decay for the UVF and for carbonate fault zones. KDEP describes how materials under load are compressed and how this causes *K* to decrease with depth. In the Conceptual Model Report (SNWA, 2009a), while the correlation is minimal, evidence suggests depth decay occurs in the basin-fill deposits of the model area.

In the numerical model, depth decay was assumed to occur only in the UVF and the carbonate moderate- and large-displacement fault zones (MDF and LDF). The UVF deposits are unconsolidated. It is therefore reasonable to expect that compaction due to burial reduces hydraulic

Table 4-5
Description of Normal Faults Defined as
Horizontal Flow Barrier (HFB) Package Parameters
 (Page 1 of 2)

Feature Description	MODFLOW-2000 Parameter	UCODE_2005 Parameter
Cave Valley		
Cave Valley - Northern	HFB_CAVE_N	HFB_HK
	HFB_CAVENE	HFB_HK
	HFB_CAVESW	HFB_HK
California Wash		
California Wash - Western	HFB_CALIFW	HFB_HK
Coal Valley		
Northern	HFB_COAL_N	HFB_HK * fHFBCOAL_N
Western	HFB_COAL_W	tHFBCOAL_W
Dry Lake Valley		
Eastern	HFB_DRYL_E	HFB_HK
Northern	HFB_DRYL_N	HFB_HK
Western	HFB_DRYL_W	HFB_HK
Garden Valley		
Northern	HFB_GARD_N	HFB_HK * fHFBGARD_N
Western	HFB_GARD_W	HFB_HK * fHFBGARD_W
Long Valley		
Northeast	HFB_LONG_E	HFB_HK
Muddy River Springs Area		
Muddy River Springs Area	HFB_MUDDYR	HFB_HK * fHFBMUDDYR
Pahrnagat Valley		
East Side Near Ash Springs	HFB_PAHR_1	HFB_HK
Eastern Sixmile Flat	HFB_6MILEE	HFB_HK
Pahroc Valley		
Central Valley into Delamar	HFB_PROCD2	HFB_HK
Cross Valley	HFB_PROC_X	HFB_HK * fHFBPROC_X
Northern	HFB_PROC_N	HFB_HK * fHFBPROC_N
Southern	HFB_PROC_S	HFB_HK
Panaca Valley		
Northern	HFB_PANACA	HFB_HK
	HFB_PANAC2	HFB_HK

Table 4-5
Description of Normal Faults Defined as
Horizontal Flow Barrier (HFB) Package Parameters
 (Page 2 of 2)

Feature Description	MODFLOW-2000 Parameter	UCODE_2005 Parameter
Patterson Valley		
Southeast	HFB_PATTSE	HFB_HK
Central	HFB_PATV_1	HFB_HK
Snake Range and Snake Valley		
Near Confusion Range	HFB_SNKCON	HFB_HK
Eastern Flank – Southern Section	HFB_SNRS_E	HFB_HK
Eastern Flank – Central Section: East	HFB_SNRCeE	HFB_HK * fHFB SNRN_E
Eastern Flank – Central Section: West	HFB_SNRCwE	HFB_HK * fHFB SNRCwE
Eastern Flank – Northern Section	HFB_SNRN_E	HFB_HK * fHFB SNRN_E
Warm Spring near Gandy	HFB_GANDY	HFB_HK
Spring Valley		
North	HFB_SPR_NE	HFB_HK
Central	HFB_SPR_CE	HFB_HK
Steptoe Valley		
McGill Springs Area	HFB_MCGILL	HFB_HK
Northern Boundary: East Flank	HFB_STEPBE	HFB_HK
Northern Boundary: West Flank	HFB_STEPBW	HFB_HK
Northern Boundary: South Flank	HFB_STEPBS	HFB_HK
Tippett Valley		
Eastern	HFB_TIPP_E	HFB_HK
Western	HFB_TIPP_W	HFB_HK
White River Valley		
Caldera Area	HFB_WRCALD	HFB_HK
Crossing Central Valley	HFB_WR_X_C	HFB_HK
Eastern Side, Northern End	HFB_WR_E_N	HFB_HK
Eastern Side, Southern End	HFB_WR_E_S	HFB_HK
Hot Creek Springs Area	HFB_WR_HCS	HFB_HK
West of Hot Creek Springs Area	HFB_WR_WHC	HFB_HK
To Pahroc	HFB_WR_PRC	HFB_HK

conductivity in this RMU. The fault zones were assumed to be composed of fractured material, which would fuse with depth, thereby reducing the hydraulic conductivity of the material.

A potential shortcoming of the KDEP method, as implemented in HUF2, is that there is no lower limit on how much the hydraulic conductivity of the source material may be reduced. For example, the numerical model has some sections of UVF that are more than 16,400 ft (5,000 m) thick. Using the KDEP function and a depth-dependence coefficient of valley-fill deposits (0.0123 m/day) reported in the DVRFS model analysis (Belcher, 2004), K reduces to $3E-62$ m/day at the base of the model. At a depth of 1,640 ft (500 m), the K reduces almost six orders of magnitude (Figure 4-12).

Plots illustrating K versus depth presented in the Conceptual Model Report (SNWA, 2009a) suggest a possible lower limit to the reduction of hydraulic conductivity as a result of confining pressures. Based on these observations and the unlikely reduction of hydraulic conductivity to near zero, the KDEP function was modified so that the lower limit of K reduces to a user-defined percentage of the base K value (see DVD). The reduction in K was limited to two orders of magnitude in the numerical model. In other words, if the initial K value were 1 ft/day, KDEP could not reduce the K value to less than 0.01 ft/day (Figure 4-12).

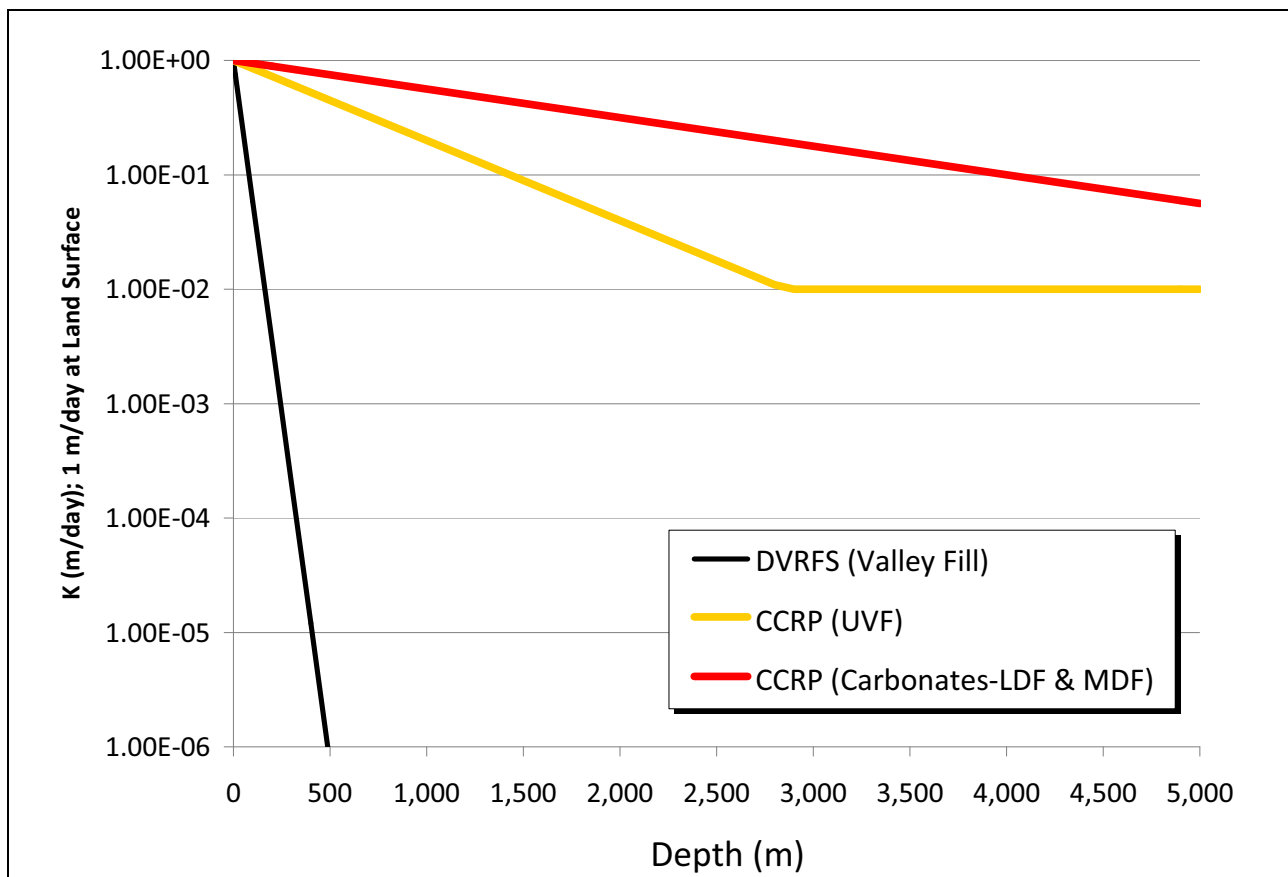


Figure 4-12
Hydraulic Conductivity versus Depth Used in Numerical Model

4.2.5 Specific Storage and Specific Yield

The transient numerical model simulates the aquifer-system response, assuming confined conditions for all model layers. This assumption does not affect the simulated results under predevelopment steady-state conditions. However, this assumption greatly affects the results simulated under transient conditions when anthropogenic stresses are imposed on the flow system: well yields are underestimated, and drawdowns are overestimated. If the aquifer system were actually confined, the only storage parameters that would need to be defined would be the specific storage (S_s) for each hydrogeologic unit (HGU) and/or RMU. However, the flow system underlying the study area is actually composed of a mixture of confined and unconfined aquifers. Therefore, the transient numerical model must be set up to simulate unconfined conditions using specific yield (S_y).

An alternate method was used in the numerical model to assign S_y to the top model layer using the SYTP property type of HUF2. This alternate method allows the averaging of S_y values assigned to RMUs, when multiple RMUs occur within a single model cell, in a manner similar to the averaging of HK , $VANI$, and S by the HUF2 module. The averaging in the alternate method uses the thicknesses of the RMUs as weights. In this method, the averaging of the S_y values for each RMU must be implemented outside of MODFLOW-2000, as the S_y values are input as an array that must be generated before MODFLOW-2000 starts. If the S_y for an RMU is changed during manual calibration, for example, the average SYTP array must be adjusted before MODFLOW-2000 is executed again.

The easiest way to update the SYTP array was to create a modified version of MODFLOW-2000 that implements SYTP in the same way it implements HK , $VANI$, and S . However, this is a significant change to the MODFLOW-2000 code, so the modified code was limited to only producing the updated SYTP array. The modified MODFLOW program was then terminated, and the original, unadjusted version of MODFLOW-2000 was started. The unadjusted version of MODFLOW then read the updated SYTP array and executed as originally designed.

In the study area, and even in most of Nevada, few S_s and S_y data exist. As a result, initial estimates were based on a combination of the information provided in SNWA (2009a), in [Appendix A](#) of this report, and from the literature.

4.3 External Boundary Conditions

The Time-Variant Specified-Head (CHD) package (Leake and Prudic, 1991; Harbaugh et al., 2000) was used in conjunction with the Specified-Head Flow Observation Package (CHOB) of the observation process to represent the boundary conditions in the numerical model. A summary of the CHD package is presented, followed by brief descriptions of the external flow boundaries represented using this package. The CHOB portion is described at the end of this section.

4.3.1 CHD Package Description

Before Leake and Prudic (1991) created the CHD package, constant-head cells were part of the finite-difference solution formulation of MODFLOW. McDonald and Harbaugh (1988, p. 3-15) describe constant-head cells as follows:

A finite-difference equation...is formulated for each variable-head cell in the mesh. For constant-head cells, no equation is formulated; however, the equation for each variable-head cell adjacent to a constant-head cell contains a term describing flow to and from the constant-head cell...

Leake and Prudic (1991) designed the CHD package to simulate constant-head boundary conditions with time-dependent, constant-head values. However, the creation of the CHD package does not affect the formulation of the constant-head boundaries in the finite-difference equations of MODFLOW.

Harbaugh et al. (2000) further modified the CHD package in MODFLOW-2000 to allow the specified heads to be treated as parameters during model calibration.

4.3.2 External Flow Boundaries Represented in Numerical Model

The external model boundaries represented by constant-head cells in the numerical model are shown on [Figure 4-13](#). Constant hydraulic heads were specified for all model layers containing the UVF, LVF, or UC/LC RMUs. Maps showing the constant-head boundaries for each model layer are presented in electronic form (see DVD). The following sections describe the sources of the initial estimates of constant-head values. The constant-head boundaries simulated in the numerical model are then discussed by hydrographic area. Target observations are composed of flows across these boundary segments and are presented in [Section 4.7](#).

4.3.2.1 Constant-Head Values

Except for Lake Mead, no data were available along the model boundary to provide values of hydraulic heads assigned to the constant-head cells. Thus, the constant-head values assigned to the boundaries were derived from the interpreted hydraulic-head distributions made by Prudic et al. (1995), Bedinger and Harrill (2004), Welch et al. (2008), and SNWA (2009a). For the boundary representing Lake Mead, the constant-head value was set to 1,169.3 ft (356.4 m), which is the average water level for the reservoir from January 1937 to April 2007 (USBR, 2007). The constant-head values were treated as parameters and were estimated during the model calibration process. The MODFLOW-2000 parameter names for the constant-head boundary segments are listed in [Table 4-6](#). The constant-head parameters are multiplication factors applied to designated boundary hydraulic heads.

4.3.2.2 Description of Constant-Head Boundaries

The constant-head boundaries included in the numerical model are described by basin.

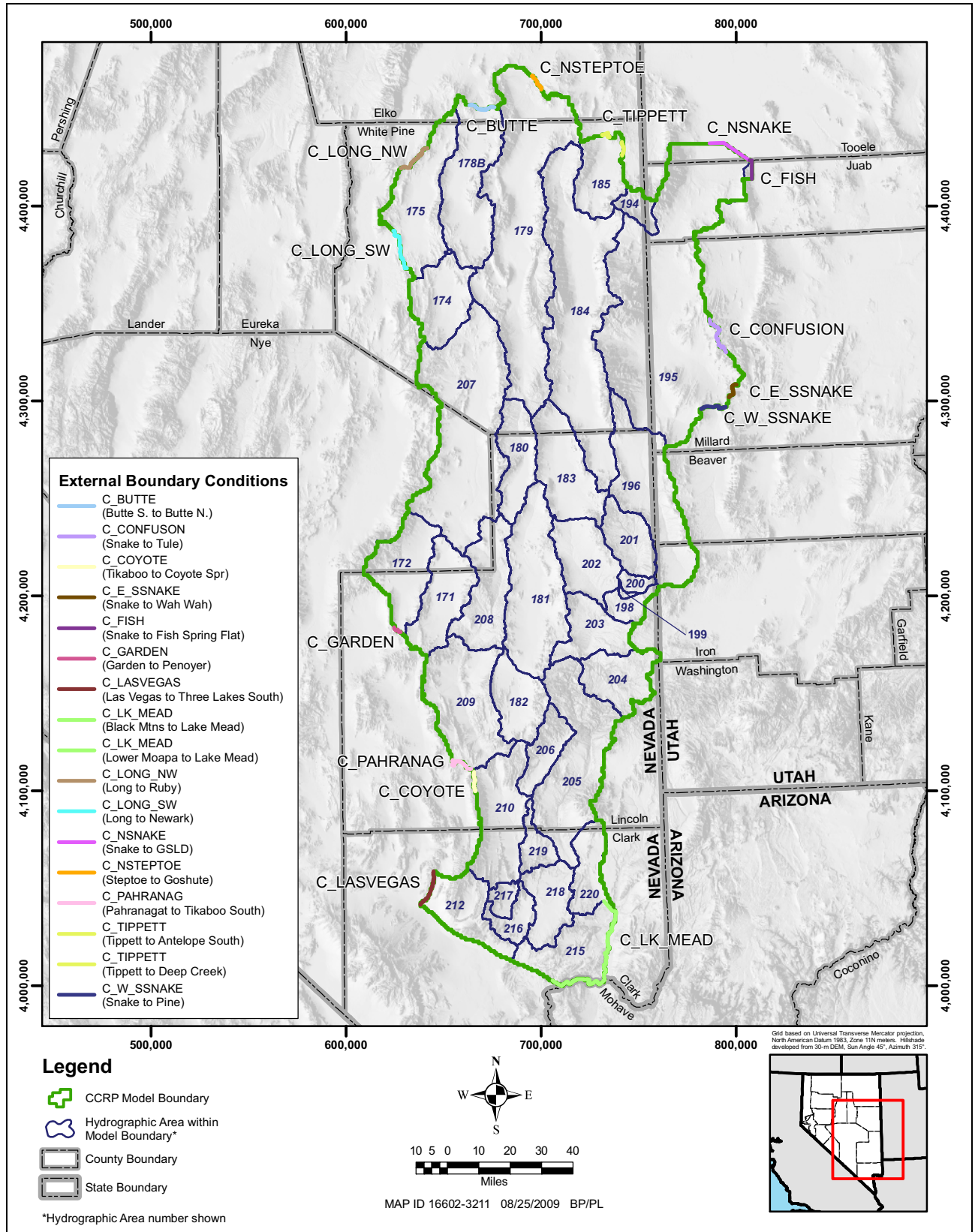


Figure 4-13
Location and Parameter Names of Constant-Head Boundaries in Numerical Model

**Table 4-6
Parameters for Constant-Head Boundaries
in Numerical Model**

Boundary Name	Parameter Name
Step toe to Goshute	C_NSTEPTOE
Snake to Great Salt Lake Desert (deep)	C_NSNAKE
Snake to Great Salt Lake Desert (shallow)	C_NSNAKE_G
Snake to Fish Springs Flat (deep)	C_FISH
Snake to Fish Springs Flat (shallow)	C_FISH_G
Tippett to Antelope Valley South	C_TIPPETT
Snake to Tule	C_CONFUSON
Butte South to Butte North	C_BUTTE
Garden to Penoyer	C_GARDEN
Long to South Newark	C_LONG_SW
Long to Ruby	C_LONG_NW
Coyote Spring to Tikaboo	C_COYOTE
Snake to Wah Wah	C_E_SSNAKE
Snake to Pine	C_W_SSNAKE
Lower Moapa to Lake Mead	C_LK_MEAD
Black Mountains to Lake Mead	
Las Vegas to Three Lakes South	C_LASVEGAS
Pahranagat to Tikaboo South	C_PAHRANAG

Butte Valley South

One segment of the northern boundary of Butte Valley South ([Figure 4-14](#)) was defined as a constant-head boundary in the numerical model. This boundary segment is positioned to permit groundwater flow through the basin-fill and bedrock aquifers. Most of the groundwater flow across this boundary segment appears to pass through the structural basin from Butte Valley South toward Butte Valley North.

Step toe Valley

One segment of the northeastern boundary of Step toe Valley ([Figure 4-14](#)) was defined as a constant-head boundary. This boundary segment is positioned to permit groundwater flow through the basin-fill aquifer and the bedrock aquifer. The lowest observed hydraulic heads in this valley are not in the structural basin but are actually in the mountain-block material to the east. Thus, groundwater flow from Step toe Valley to Goshute Valley is interpreted to occur in the mountain block.

Tippett Valley

Tippett Valley is interpreted to have groundwater flow moving out of the model area through the northern and eastern boundaries of the valley. These two outflow locations are represented by constant-head boundaries in the numerical model ([Figure 4-15](#)). The outflows are as follows:

- Groundwater flow from Tippett Valley to Antelope Valley is through a structural basin.
- Groundwater flow from Tippett Valley to Deep Creek Valley is through fractured mountain block.

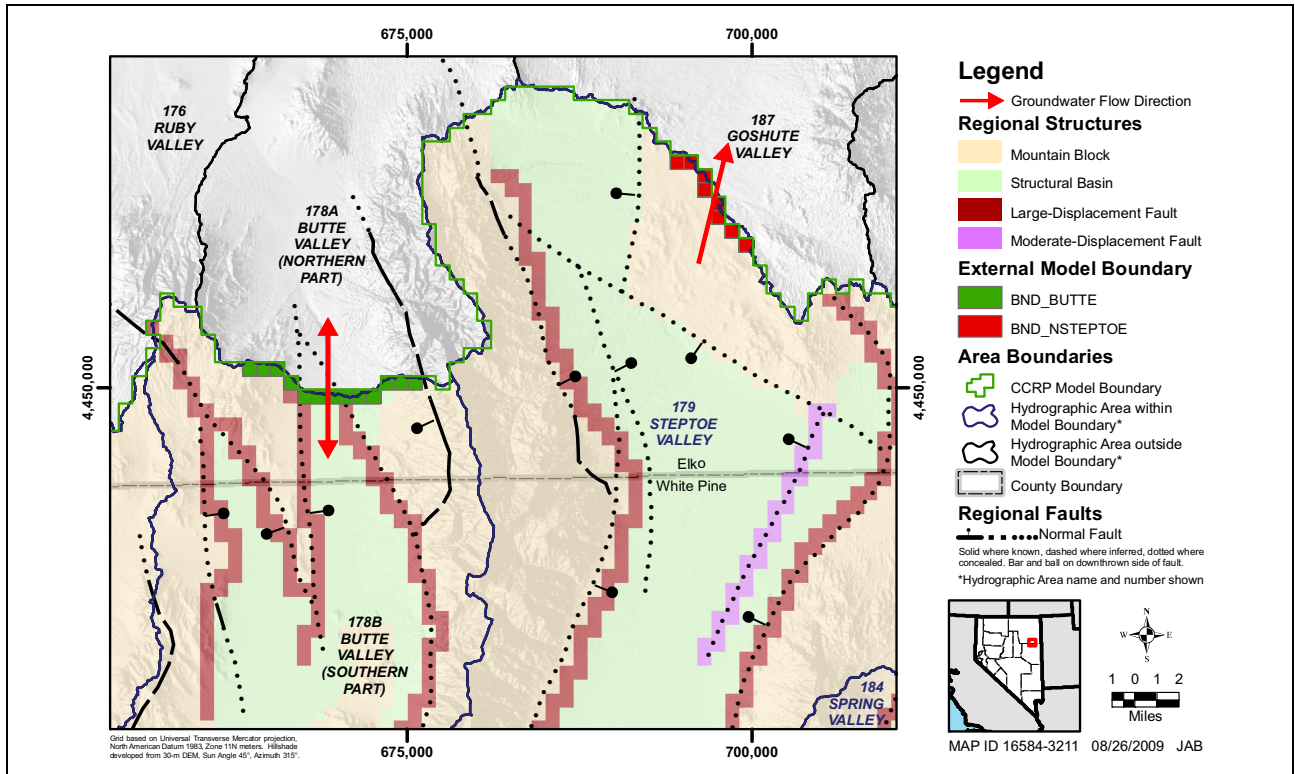


Figure 4-14
Butte Valley South and Steptoe Valley Constant-Head Boundaries

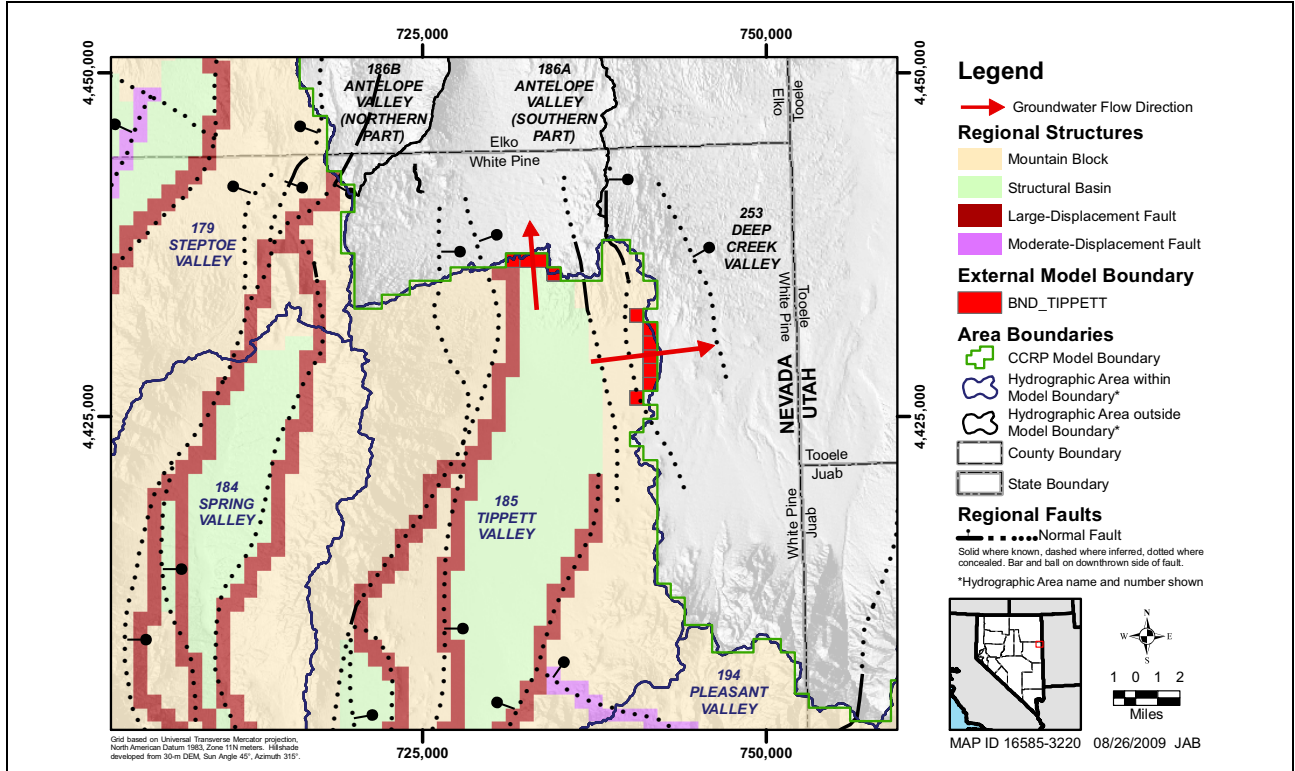


Figure 4-15
Tippett Valley Constant-Head Boundaries

Snake Valley

Snake Valley is interpreted to have groundwater flow moving out of the model area through boundary segments located in the northern and southern parts of the valley (Figure 4-16). These outflow locations are represented as constant-head boundaries in the numerical model. The flow boundaries are as follows:

- The two constant-head boundaries defined in the northern part of Snake Valley consist of one segment along the boundary of Snake Valley with the Great Salt Lake Desert to the north and one segment along the boundary with Fish Springs Flat to the east (Figure 4-16A).
- The three constant-head boundaries defined in the southern part of Snake Valley consist of one segment located along a portion of the Confusion Range on the eastern boundary of Snake Valley, one segment located along the boundary between Snake Valley and Pine Valley, and one segment located along the boundary between Snake Valley and Wah Wah Valley at the southeastern end of the valley (Figure 4-16B).

Long Valley

Long Valley was interpreted to have two constant-head boundaries allowing flow out of the valley (Figure 4-17). Both flow boundaries are consistent with the interpretations of Prudic et al. (1995) and are as follows:

- The first boundary allows flow from Long Valley to Newark Valley.
- The second boundary, located on the northwestern and western edge of Long Valley, allows flow from or to Ruby Valley.

Garden Valley

The Garden Valley constant-head boundary is located along the hydrographic boundary between Garden Valley and Penoyer Valley. This boundary segment is interpreted to be highly transmissive as it coincides with a significant thickness of the LC3 RMU. Groundwater flow is interpreted to be from Garden Valley to Penoyer Valley (Figure 4-18).

Coyote Spring Valley

In the conceptual model report (SNWA, 2009a), water is interpreted to flow from Tikaboo Valley into the north end of Coyote Spring Valley (see Figure 4-19). Some of this water is suspected to be from Pahranaagat Valley, flowing along the Pahranaagat Shear Zone to Tikaboo Valley. Some of the flow may have more regional sources from the northwest. The boundary of Coyote Spring Valley and Tikaboo Valley parallels the Gass Peak thrust fault. Head values in the area suggest the Gass Peak thrust fault is a barrier to flow, as heads to the west of the fault can be hundreds of feet higher than those measured east of the fault in the central valley area. It has been suggested that for flow to move across this boundary, it may have to move at depth under the shallow-angle thrust fault.

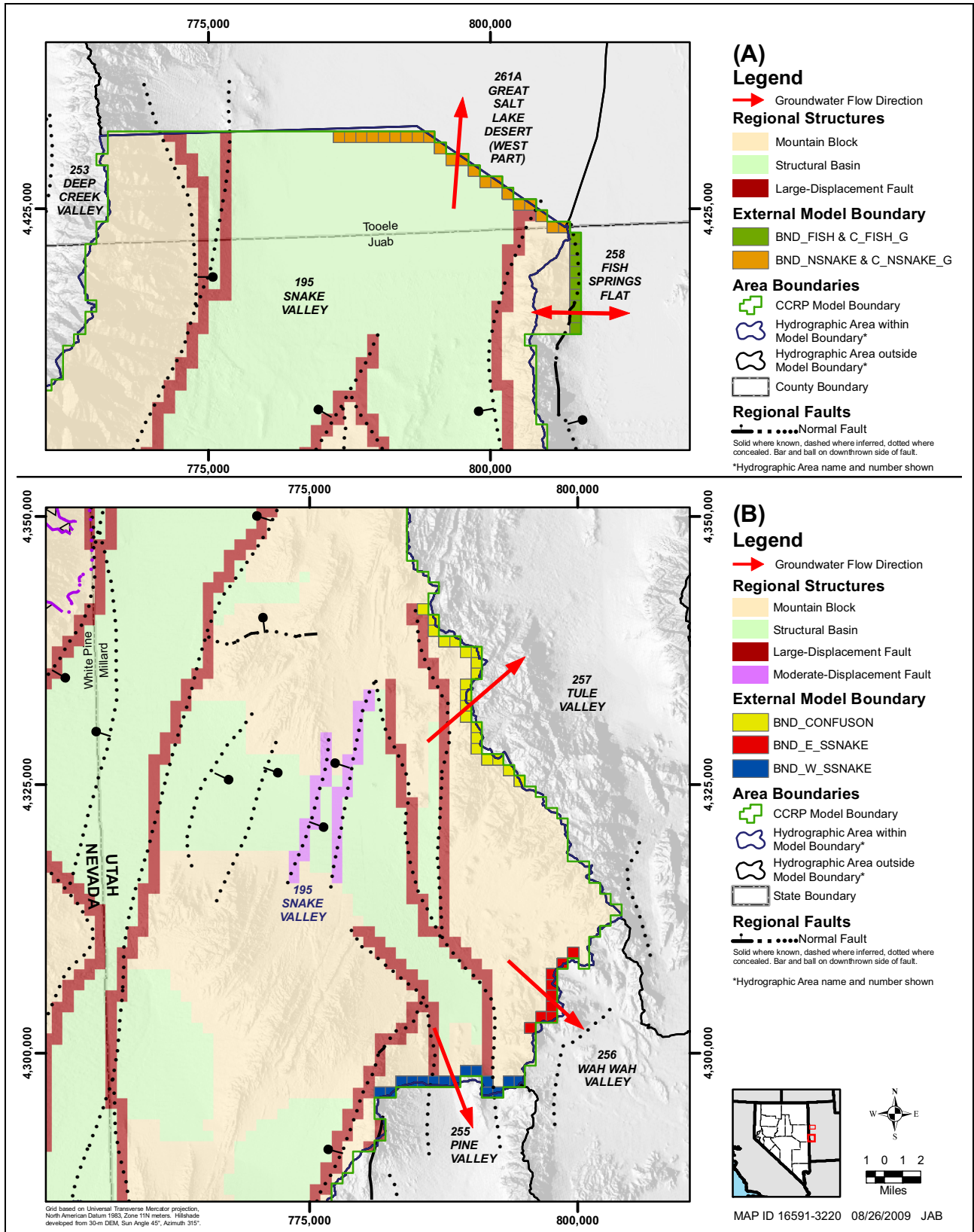


Figure 4-16
Northern and Southern Snake Valley Constant-Head Boundaries

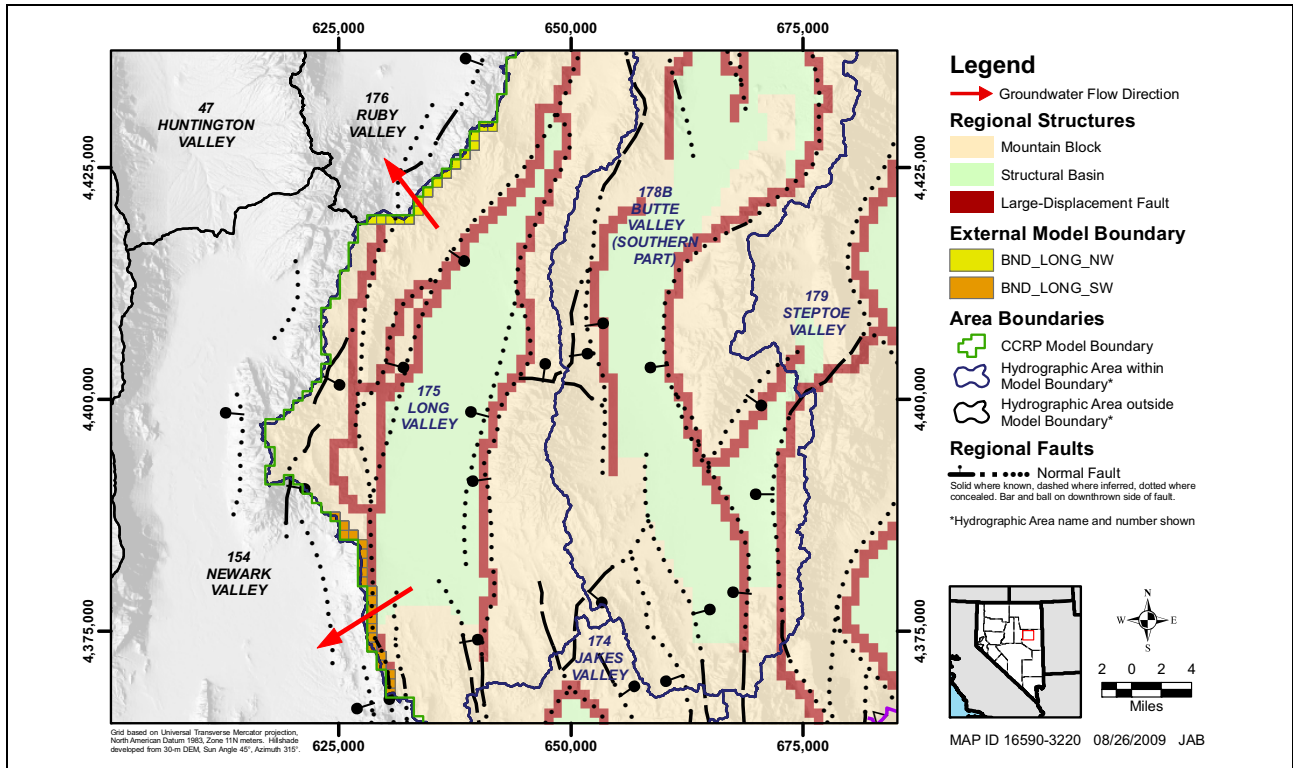


Figure 4-17
Long Valley Constant-Head Boundaries

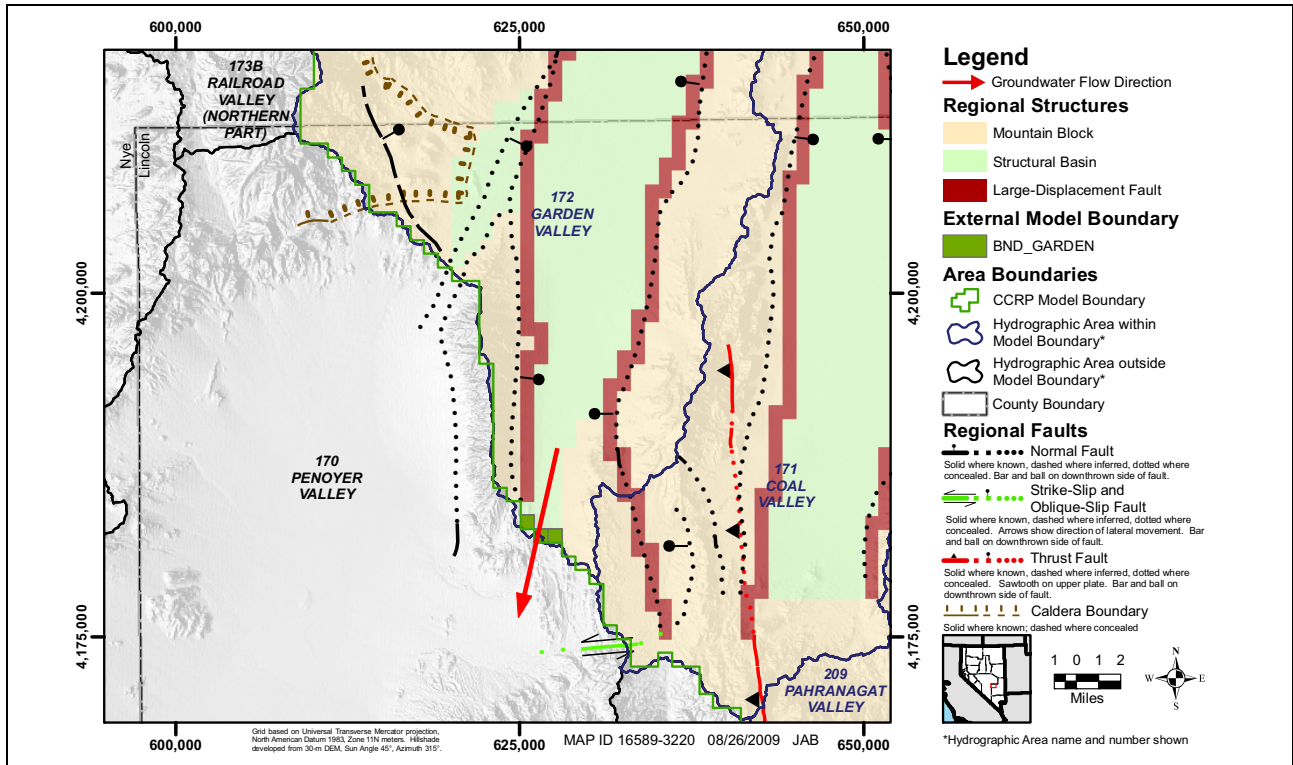


Figure 4-18
Garden Valley Constant-Head Boundary

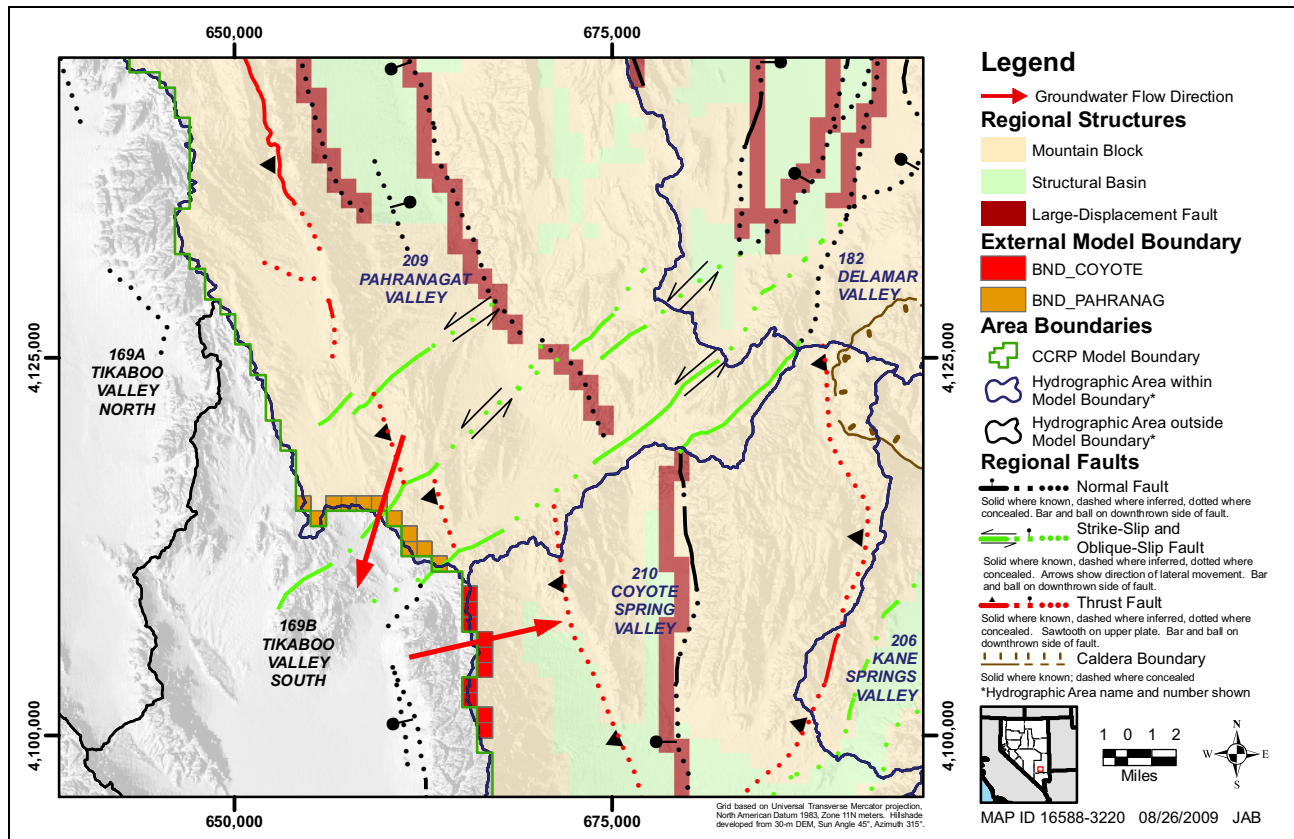


Figure 4-19
Coyote Spring Valley and Pahranaagat Valley Constant-Head Boundaries

Pahranaagat Valley

In the simplified conceptual model (SNW A, 2009a), groundwater flows roughly parallel to Pahranaagat Valley and the North and South Tikaboo Valley boundaries. It was assumed that some of this southwesterly flow then moves into northern Coyote Spring Valley, southwest of the Pahranaagat Shear Zone. It has also been suggested that flow from Pahranaagat Valley moves out to South Tikaboo Valley. This flow may be going around the southwest side of the Pahranaagat Shear Zone and into Coyote Spring Valley. Significant flow may also move farther southwest toward the Amargosa Desert. This interpretation had previously been postulated by D’Agnese et al. (2002) and Belcher (2004) and falls within the uncertainty of the conceptual model. This new flow-boundary segment was also defined as a constant-head boundary (Figure 4-19).

Lower Moapa Valley

A constant-head boundary is interpreted along the boundary between Lower Moapa Valley and Lake Mead (Figure 4-20). The Lower Moapa Valley constant-head boundary accounts for groundwater flow out of the model domain.

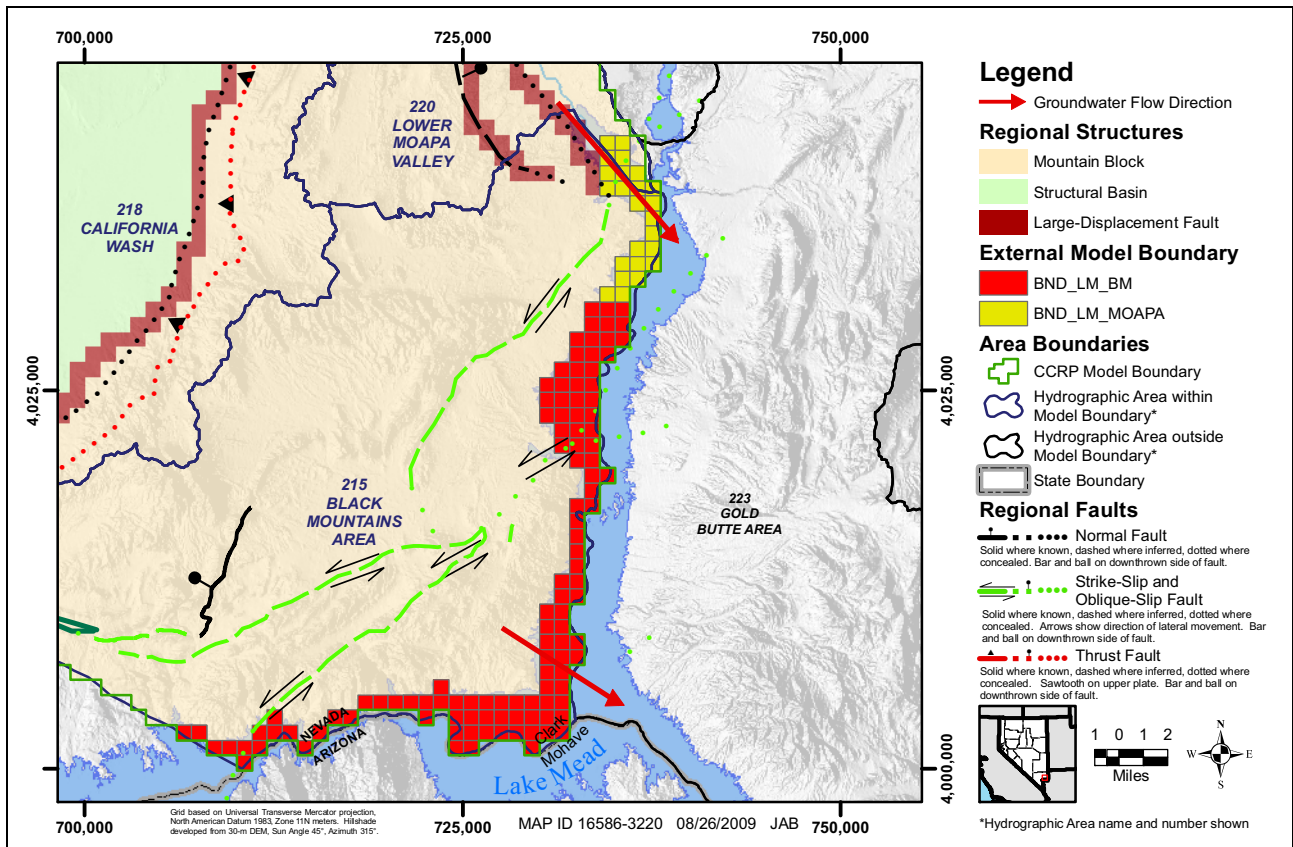


Figure 4-20
Lower Moapa Valley and Black Mountains Area Constant-Head Boundaries

Black Mountains Area

A constant-head boundary was defined along the boundary of this area with Lake Mead (Figure 4-20). Groundwater flow is interpreted as moving out of the flow system across this boundary.

Las Vegas Valley

Groundwater flow is interpreted to occur across the boundary along the northwest end of Las Vegas Valley (Figure 4-21). The direction of flow is uncertain and may be into or out of the numerical model domain.

4.4 Natural Groundwater Discharge

Groundwater discharge, including ET and spring flow, was simulated in MODFLOW-2000 using the Drain (DRN) and Streamflow-Routing (SFR2) packages (Harbaugh et al., 2000). Brief descriptions of the DRN and SFR2 packages are provided, followed by a presentation of how groundwater-discharge components were represented in the numerical model using these packages.

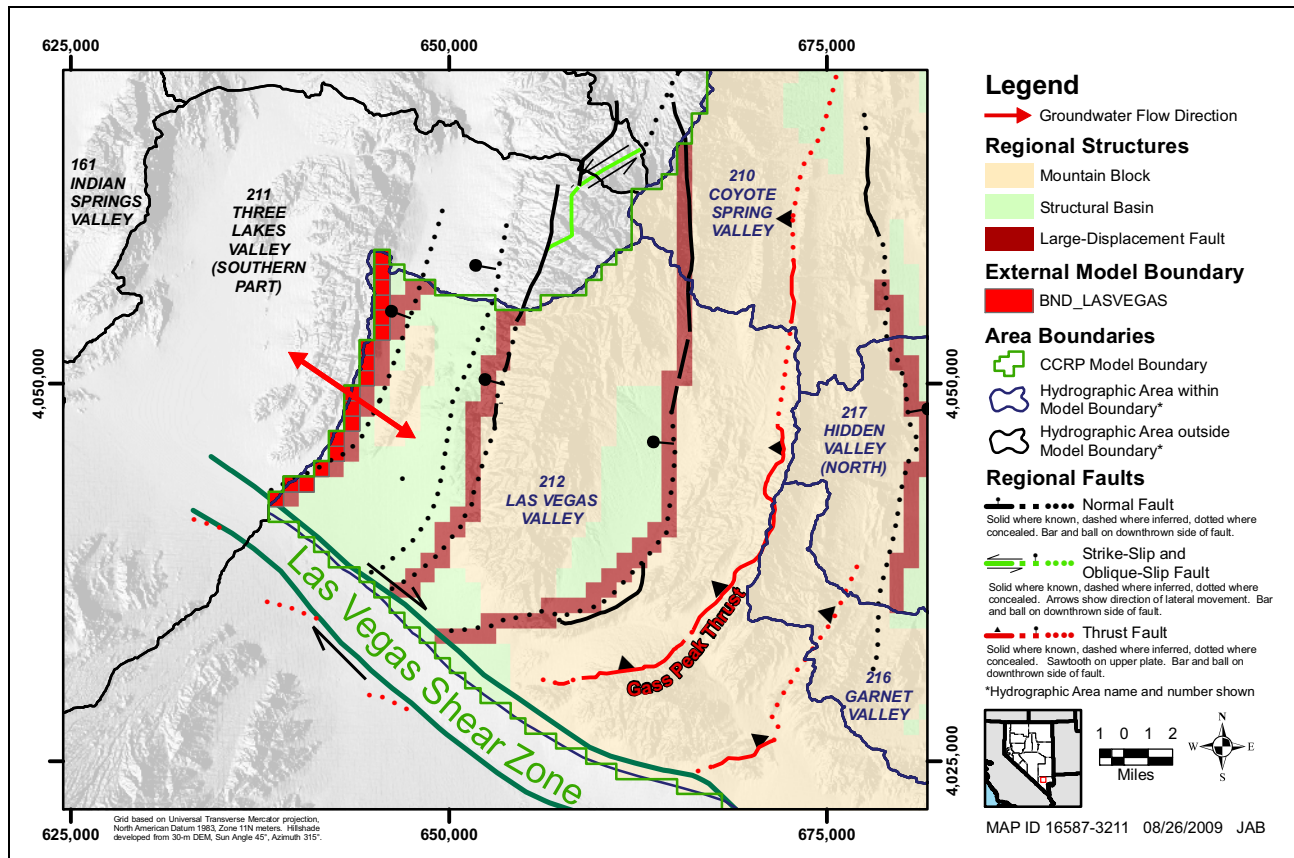


Figure 4-21
Las Vegas Valley Constant-Head Boundary

4.4.1 DRN Package

The DRN package simulates groundwater discharge through a head-dependent flow boundary. The DRN package is used to represent groundwater discharge from groundwater ET areas and springs.

Groundwater discharges from a cell specified as a drain when the simulated hydraulic head in the cell rises above a threshold level, called the drain elevation. The rate of flow is dependent on the conductance term, which is a combination of several parameters used in Darcy's law. The conductance across a prism in a given direction is expressed as follows (McDonald and Harbaugh, 1988):

$$C = Q / (h_A - h_B) \quad (\text{Eq. 4-3})$$

where,

- C = Conductance (L^2/T)
- Q = Flow rate across the prism (L^3/T)
- $h_A - h_B$ = Hydraulic-head change across the prism (L)

In the case of a drain, flow is oriented vertically and represents discharge to the surface— h_A is the hydraulic head at the top, and h_B is the hydraulic head at the bottom of the drain—or the drain elevation.

4.4.2 SFR2 Package

The SFR2 package (Niswonger and Prudic, 2006) simulates stream-aquifer interactions like the SFR1 package (Prudic et al., 2004) but has the extended ability to simulate unsaturated flow beneath streams. Stream flow is routed in the same way as in SFR1 based on the continuity equation assuming steady, uniform flow (i.e., the volumetric inflow is equal to the outflow minus all sources and sinks to the channel).

In both SFR1 and SFR2, the streams are represented by a network of channels, and each channel is subdivided into segments (Figure 4-22A). The cross-sectional geometry of each segment is represented by several points (Figure 4-22B). The case where an unsaturated zone exists between the stream and the water table (functionality exists within SFR2 only) is depicted in Figure 4-22C.

Niswonger and Prudic (2006, p. 6) describe the flow process in the SFR2 package:

In SFR2 (as in SFR1), flows are routed through a network of channels where flow is always in the same direction along channels, and where seepage (ground-water recharge or discharge) is constant for each MODFLOW time step. Ground-water recharge resulting from streambed seepage and flow through the unsaturated zone may be variable within a MODFLOW time step, because the time steps used in calculating flow through the unsaturated zone may be shorter than those used in the saturated zone. Thus, all water reaching the water table from the unsaturated zone is totaled over the MODFLOW time step.

In the numerical model, SFR2 simulates groundwater discharge of large-volume regional springs to a stream channel, which then redistributes this water downstream as surface water. Ultimately, the surface water evaporates or recharges the groundwater system, which can then be consumed by ET.

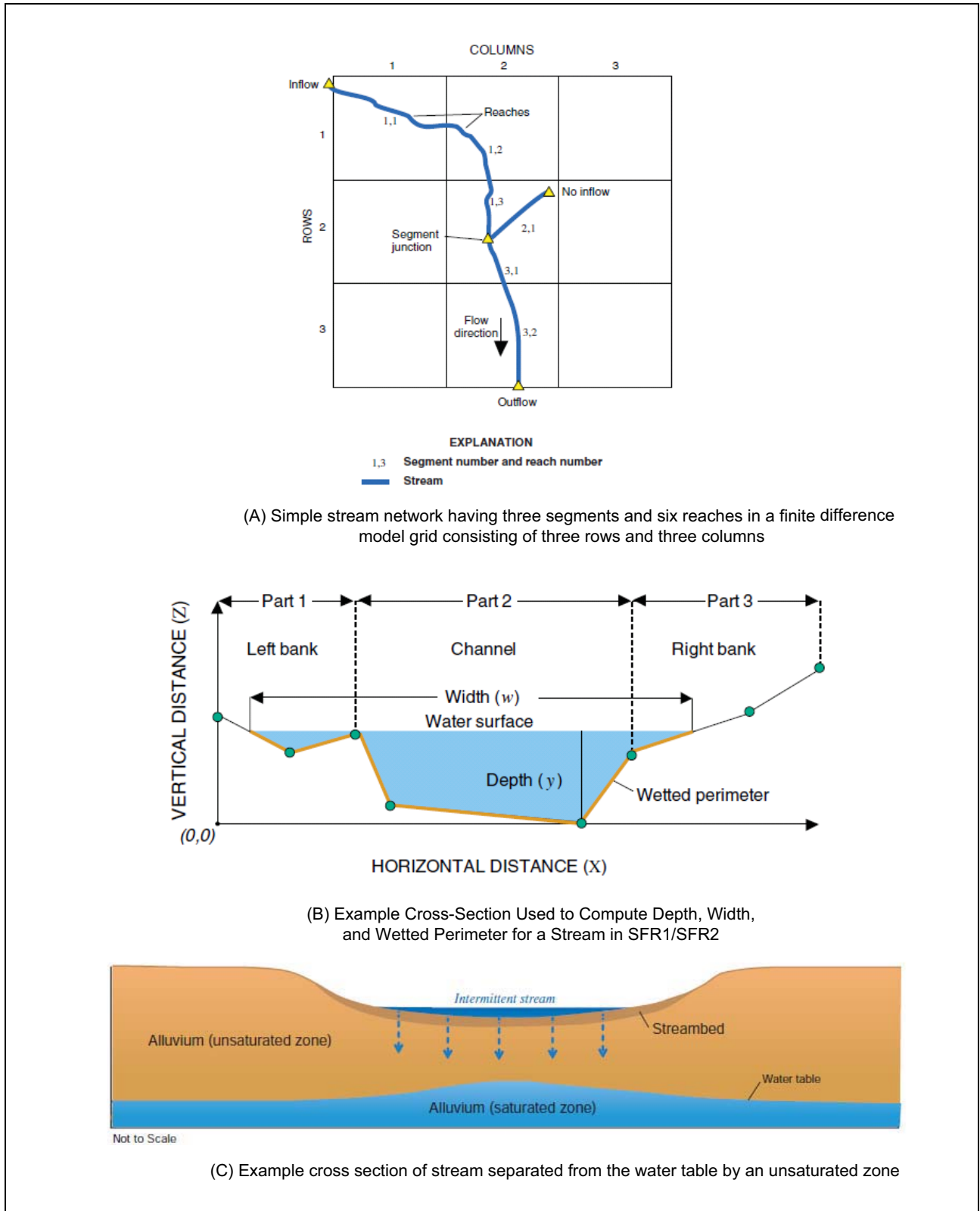
4.4.3 Groundwater Evapotranspiration

This section describes the way in which the groundwater ET process was performed under predevelopment steady-state conditions and transient conditions in the numerical model.

4.4.3.1 Steady-State Conditions

Groundwater ET for steady-state conditions was set up in the numerical model as estimated for natural conditions prior to development by man in the Conceptual Model Report (SNWA 2009a).

The estimates of groundwater ET derived by SNWA (2009a) for the model area included four ET regions (Wetland, Shrubland, Playa, and Open Water) and annual discharge rates. The groundwater ET regions were grouped into three categories. Category 1 consists of groundwater ET areas



Source: Adapted from Prudic et al. (2004) and Niswonger and Prudic (2006)

Figure 4-22
Example Representation of Streams in MODFLOW-2000 Using SFR2 Package

intersecting the regional groundwater table. Category 2 consists of groundwater ET areas tapping intermediate aquifers. Category 3 consists of groundwater ET areas tapping local or perched aquifers. Only Category 1 and 2 groundwater ET areas were represented in the numerical model. The groundwater ET areas were further subdivided by sub-basin and their extents approximated by grid cells as shown in [Figure 4-23](#). The DRN package was used to represent groundwater ET as four groups of drains corresponding to the four types of ET zones. The groundwater ET area within each grid cell was represented by a single drain. The representation of groundwater ET areas as drains is presented in this section. The annual discharge rates were used as target observations and are presented in [Section 4.7.4](#).

4.4.3.1.1 Drain Elevations

The drain elevation was assumed to approximate the ET-extinction depth. The drain elevation in a given ET cell corresponds to the elevation of the ET-extinction-depth surface at the location of the drain. The drain elevation is calculated as the difference between the ground-surface elevation and the extinction depth. Two values of extinction depths were used, depending on the location of the groundwater ET area. For ET grid cells located in low-topographic relief, the extinction depth was assumed to be 16.4 ft bgs (5 m bgs). For all other ET grid cells, the extinction depth was assumed to be 32.8 ft bgs (10 m bgs). The ground-surface elevations for the ET grid cells were derived from the USGS 30-m digital elevation model (DEM). A single grid cell has an area of 247.1 acres (1 km²) and includes about 900 DEM points. The ground-surface elevations for the ET grid cells were calculated as follows:

- For a given ET grid cell located in low-topographic relief, the land-surface elevation was calculated as the mean of the DEM points in that grid cell. The extinction depth was set to 16.4 ft bgs (5 m bgs) for these grid cells.
- For a given ET grid cell located in other areas, the land surface of a given grid cell was set equal to the minimum DEM elevation within that grid cell. The extinction depth was set to 32.8 ft bgs (10 m bgs) for these grid cells.

The drain elevation is an approximation of the ET-extinction depth. This approach of using the DRN package to simulate groundwater ET has previously been used in other regional Great Basin modeling studies, such as Prudic et al. (1995) and D'Agnese et al. (2002).

4.4.3.1.2 Drain Conductances

The drain conductance was set up to approximate the maximum ET rate corresponding to the type of ET region (i.e., Wetland, Shrubland, Playa/Wet Soil, or Open Water). In some instances, the ET drain conductances were modified. The drain conductances were treated as parameters during the calibration of the numerical model. Initial estimates of drain conductances were calculated as the quotient of the estimated discharge and the difference of interpolated hydraulic head and drain elevation. The drain conductances were estimated by ET-region type. Thus, four values were calculated to represent Open Water, Wetland, Shrubland, and Playa. The four values were adjusted using conductance-modifier parameters ([Table 4-7](#)) representing Wetland, Shrubland, Playa, and

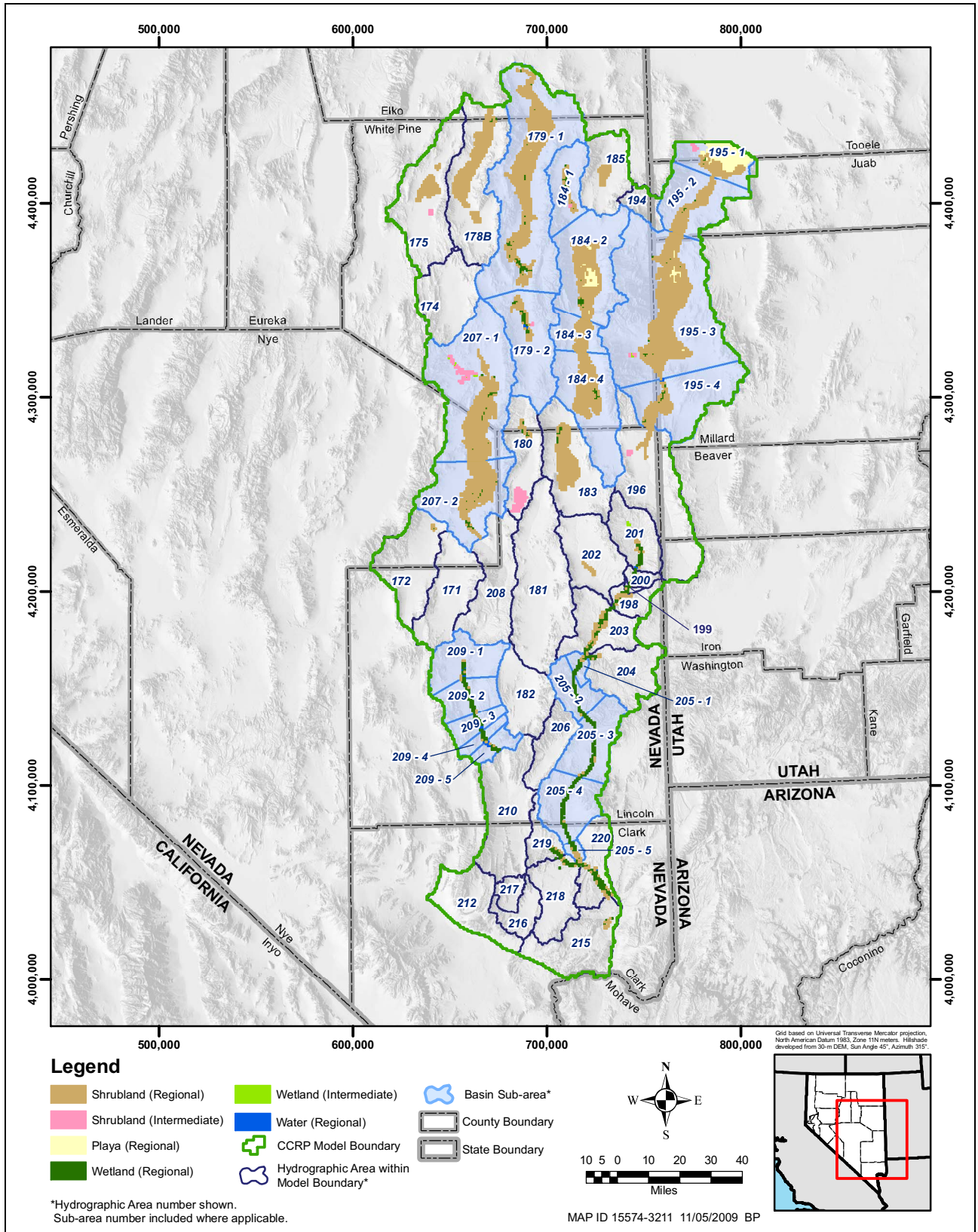


Figure 4-23
Groundwater ET Areas Represented as DRN Cells in the Numerical Model

Open Water for both regional- and intermediate-discharge areas. Note that it was assumed regional and intermediate ET rates were identical; hence, their parameters were combined (Table 4-7). The initial estimates of the conductance-modifier values for the ET grid cells are described in the following text.

**Table 4-7
ET Regions and Conductance Modifier Parameters**

ET Regions	Parameter Name
Wetland	ETrWET and ETiWET
Shrubland	ETrSHR and ETiSHR
Playa/Wet Soil	ETrPLY
Open Water	ETrWAT
HA 209 Wetland	ETr209WET
HA 209 Open Water	ETr209WAT

Note: There are no intermediate Playa and Open Water ET areas.

Groundwater ET are as covered grid cells either entirely or partially. The partial coverage was accounted for by scaling the conductance of the ET drain in that grid cell by the percentage of grid cell ET coverage, using the conductance modifier (CONDFACT) in the DRN cell. The default value of CONDFACT was set equal to 1,000,000, reflecting the total area of a model grid cell (1,000,000 m²). Several cases arose and were handled as follows:

- For ET grid cells that were entirely covered with a single ET-region type, the grid cell was assigned the conductance value corresponding to the ET-region type present. In this case, the ET coverage is 100 percent of the area of the cell; thus, the default conductance modifier of 1,000,000 was assigned.
- For ET grid cells that were partially covered by a single ET-region type, the grid cell was assigned the conductance value corresponding to the ET-region type and an adjusted conductance modifier. For example, cells with 10 percent ET coverage have a conductance modifier of 100,000.
- In cases where multiple ET regions corresponded to a single cell and entirely covered the cell, the most prevalent ET-region type in the grid cell was assumed to control the conductance of the ET drain. For example, if a cell contains 15 percent Playa, 1 percent Open Water, 30 percent Shrubland, and 54 percent Wetland, the cell is assigned to Wetland, with the Wetland conductance value and the default conductance modifier of 1,000,000.
- In cases where multiple ET regions corresponded to a single cell and partially covered the cell, the most prevalent ET-region type in the grid cell was assumed to control the conductance of the ET drain. The conductance modifier was, however, adjusted to reflect the ET-covered area only. For example, if a cell contains 5 percent Playa, 10 percent Wetland, 1 percent Open Water, 30 percent Shrubland, and 54 percent non-ET area, the cell was

assigned the Shrubland conductance value. The conductance modifier was 460,000, corresponding to the 46 percent of the cell area where groundwater ET occurs.

This approach resulted in the exclusion of certain limited ET zones in the model. This situation occurs when a particular ET type never dominates any cell within a basin or sub-basin but has a significant area in the entire basin or sub-basin. This occurs in White River Valley, for example, where open-water evaporation accounts for over 2,961 afy (10,000 m³/d) discharge, but no single cell is designated as Open Water in the model grid. Although such areas were not explicitly represented in the model, the corresponding volume of groundwater was accounted for by assuming that it was removed by the Wetland or Shrubland ET cells. Two additional ET zones were created in Pahranaagat Valley to account for ET rates in Pahranaagat Wash. Pahranaagat Wash is configured as a semiperched riparian zone. Most of the ET derives its source from the outflows of Ash, Crystal, and Hiko springs. Some ET, however, is still derived from groundwater. To restrict the amount of ET from regional groundwater and to show the weak connection between the regional aquifer system and the perched flow system, the ET rates in Pahranaagat Wash were set to 50 percent of the regional ET rates. [Section 4.4.4.2.2](#) describes the representation of discharge in Pahranaagat Valley further. This is described in more detail in the observations in [Section 4.7.4](#). The ET units not represented in the numerical model as a result of this simplification are listed in [Table 4-8](#).

**Table 4-8
ET Zones Not Represented in the Numerical Model^a**

Open Water	Wetland	Shrubland	Playa
ER178B_WATER	EI175_WET	EI201_SHRUB	EI195a_PLAYA
ER179a_WATER	EI179b_WET	---	ER183_PLAYA
ER183_WATER	EI180_WET	---	ER184c_PLAYA
ER184b_WATER	EI195a_WET	---	ER184d_PLAYA
ER195b_WATER	EI196_WET	---	ER185_PLAYA
ER195c_WATER	ER175_WET	---	ER195b_PLAYA
ER198_WATER	ER184c_WET	---	ER207a_PLAYA
ER205d_WATER	ER185_WET	---	ER207b_PLAYA
ER205e_WATER	ER196_WET	---	---
ER207b_WATER	---	---	---

^aIndicates ET type does not occur in any cell in the model. Occurs when an ET type is dominated spatially by other types within a model cell.

4.4.3.2 Transient Conditions

Conceptually, when anthropogenic stresses (described in [Section 4.6](#)) are imposed on a flow system, particularly within or near natural ET areas, the rates and areal extents of groundwater ET areas may decrease. Portions of the groundwater ET areas are converted to agricultural areas to be irrigated with groundwater obtained from nearby wells. In such cases, natural groundwater ET would likely decrease substantially, or cease, depending on the depth to water. The crops replacing the phreatophytes would, initially, use the groundwater available at the water table and require an

additional amount of water supplied by pumping from nearby irrigation wells. At later times, if the drawdown caused by the irrigation pumping wells under the irrigated areas were to increase, the croplands would likely require more irrigation water until all their needs were eventually satisfied by irrigation water from wells. If pumping were stopped during this transitional period, natural groundwater discharge within the converted areas would gradually resume as the water table rose back to prepumping conditions.

An accurate representation of this process cannot be simulated in the numerical model, not only because the data are not available at that level of detail but also because the processes of ET and agricultural activities are very simplified in the model. The two processes can be approximately simulated in the numerical model in different ways but the question is how to simulate the conversion from groundwater ET to agricultural areas without irreversibly turning off natural groundwater ET. The conversion of the groundwater ET areas to agricultural areas may be simulated by using one of three options: (1) by setting the drain conductances at the ET cells to zero, (2) by completely removing the ET drains from the model cells at the time they are converted, or (3) by decreasing the water table below the drain elevations.

Although Options 1 and 2 were considered, Option 3 appeared to be the most viable. Options 1 and 2 would essentially remove natural ET from the specified model cells but would not allow the groundwater ET process to resume if pumping for agricultural purposes were stopped in some areas. In addition, the Option 1 is infeasible in the numerical model as constructed because ET drain conductances are assigned by type of vegetation, rather than by ET cell. The model was set up this way to minimize the number of parameters, as the drain conductances associated by the four types of vegetation are calibration parameters. Option 3, though not exactly representative of reality, does allow the ET process to resume, should agricultural pumping cease, and therefore was selected.

Groundwater pumping is the only way to decrease the water table in the converted agricultural areas under Option 3. This process does not accurately represent reality because the conversion does not occur rapidly as it would actually. The water table under the former groundwater ET area decreases gradually as pumping from agricultural wells within or near the agricultural areas is started. The error associated with Option 3 is that the ET drain cells continue to discharge groundwater as long as the water table is above the ET drain. However, this error is relatively negligible because, as described in the next paragraph, the converted areas are relatively small. In addition, as pumping continues and the water levels decrease, the ET rates in the converted areas decrease further.

The extents of the groundwater ET areas under natural conditions and the irrigated croplands for the period 2001 to 2004 are shown in [Figure 4-24](#). As can be seen from this figure, the extent of the irrigated croplands located within the ET areas (converted areas) is relatively small. In fact, the total area of irrigated croplands located within the ET areas represent about 3 percent of the total ET area for the period 2001 to 2004.

In terms of volumes, the maximum volume of ET discharging from all irrigated croplands located within the ET areas represents 4 percent of the total groundwater discharge from all ET areas for the period 2001 to 2004. As listed in [Table 4-9](#), the relative importance of the converted areas and the corresponding annual volume of lost groundwater ET are small for basins with the largest converted areas.

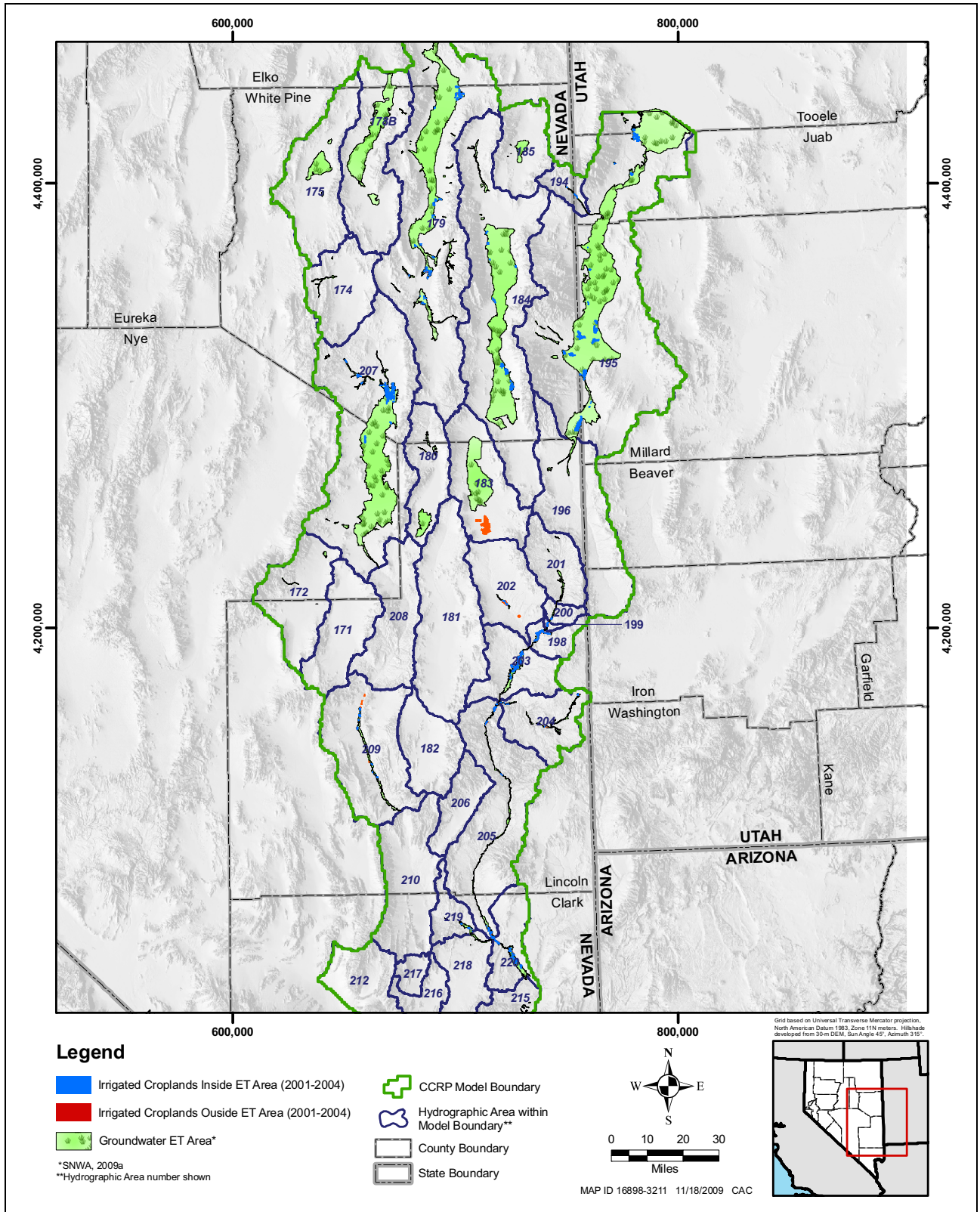


Figure 4-24
 Extents of Irrigated Croplands (2001-2004) and
 Groundwater ET Areas under Natural Conditions

Table 4-9
Relative Importance of ET Areas Converted to Croplands

HA	Basin Name	Total Extent of ET Area (acres)	Total Annual ET Volume (af)	Areal Extent of Croplands Inside the ET Areas (acres)	Annual Volume of ET from Croplands Inside the ET Areas ^a (af)	Converted Areas (% of Total ET Area)	Converted Areas (% of Total Annual ET Volume)
179	Steptoe Valley	174,614	101,715	4,249	1,900	2	2
184	Spring Valley	177,772	75,436	2,568	600	1	1
195	Snake Valley	320,269	129,350	8,222	3,800	3	3
207	White River Valley	178,172	76,446	5,542	1,200	3	2

Source: SNWA (2009a)

^aCalculated value using areal extent of croplands and ET rate information.

4.4.4 Springs

This section describes the setup of springs in the numerical model. No special considerations were needed to simulate spring flow under transient conditions. The changes in hydraulic heads determined flow rates, which were calibrated to the spring flow target observations presented in [Section 4.7](#). The elevations at the spring locations were also included as hydraulic-head observations for tracking purposes only (see [Section 4.7.3](#)). [Table 4-10](#) lists the springs considered in the numerical model.

Except for a few, all regional and selected intermediate springs located in the model area were simulated in the numerical model using the DRN or SFR2 packages. The exceptions consist of springs that lie within or are adjacent to a model-boundary cell. [Table 4-10](#) defines how the springs were represented in the model. The springs were categorized into several spring model types as follows:

- DRN: Represented in the MODFLOW-2000 Drain package
- SFR2: Represented in the MODFLOW-2000 Streamflow-Routing package
- CHD: Represented in the MODFLOW-2000 Constant-Head package

[Figure 4-25](#) illustrates the location of springs modeled with the DRN and SFR2 package.

Most of the springs included in the numerical model were simulated using the DRN package. Exceptions occur in Pahrnagat Valley, Muddy River Springs Area, and at Big Springs, where spring discharge can flow as surface water for significant distances. The SFR2 package was used to simulate the springs in these areas. Exceptions were also made for very small springs with flows less than 0.05 cfs that occurred in active ET areas already represented as ET DRN cells. It was assumed that the flow from these springs would be accounted for by the ET DRN cells.

Table 4-10
Setup of Regional and Intermediate Springs
in the Numerical Model of the Central Carbonate-Rock Province
 (Page 1 of 2)

Model Type ^a	Spring Name	DRN and SFR2 Spring Name ^b	Observation Type	Comment
CHD	Deadman Spring	---	---	---
CHD	North Springs	---	---	In an active cell next to CHD
CHD	Walter Spring	---	---	---
CHD	Wilson Hot Spring 1	---	---	---
CHD	Wilson Hot Spring 2	---	---	---
CHD	Wilson Hot Spring 3	---	---	In an active cell next to CHD
CHD	Wilson Hot Spring 5	---	---	---
DRN	Arnoldson Spring	SPiw07_2_01	Flow	---
DRN	Blue Point Spring	SDiw15_2_##	Flow	---
DRN	Brownie Spring	SPis09_4_01	Flow	---
DRN	Butterfield Spring	SPib07_10_01	Flow	---
DRN	Caine Spring	SPis95_3_01	Flow	---
DRN	Campbell Ranch Springs	SPib79_5_01	Flow	---
DRN	Cherry Creek Hot Springs	SPr79_2_01	Flow	---
DRN	Cold Spring	SPiw07_3_01	Flow	---
DRN	Cold Spring	SPis79_4_01	Flow	---
DRN	Currie Spring	SPib79_6_01	Flow	---
DRN	Emigrant Springs	SPib07_15_01	Flow	---
DRN	Flag Springs 1	SPiw207_7	Flow	Flag Springs 1, 2, and 3 in same cell; flow aggregated in one observation
DRN	Flag Springs 2			
DRN	Flag Springs 3			
DRN	Foote Res. Spring	SPib95_12_01	Flow	---
DRN	Four Wheel Drive Spring	SPis84_11_01	Flow	---
DRN	Hardy Spring NW	SPis07_11_01	Flow	Hardy and Hardy NW in same cell; flow aggregated in one observation
DRN	Hardy Springs			
DRN	Hot Creek Spring	SPr07_1_01	Flow	---
DRN	Keegan Spring	SPis84_12_01	Flow	---
DRN	Kell Spring	SPis95_13_01	Flow	---
DRN	Knoll Spring	SPis95_4_01	Flow	---
DRN	Layton Spring	SPis84_7_01	Flow	---
DRN	Lund Spring	SPib07_5_01	Flow	---
DRN	McGill Spring	SPiw79_1_01	Flow	---
DRN	Minerva Spring	SPis84_13_01	Flow	---
DRN	Monte Neva Hot Springs	SPr79_3_01	Flow	---
DRN	Moon River Spring	SPr07_14_01	Flow	---
DRN	Moorman Spring	SPr07_6_01	Flow	---
DRN	Nicholas Spring	SPiw07_13_01	Flow	---

Table 4-10
Setup of Regional and Intermediate Springs
in the Numerical Model of the Central Carbonate-Rock Province
 (Page 2 of 2)

Model Type ^a	Spring Name	DRN and SFR2 Spring Name ^b	Observation Type	Comment
DRN	North Millick Spring	SPis84_3_01	Flow	---
DRN	North Spring	SPiw84_8_01	Flow	---
DRN	Osborne Springs	SPis84_10_01	Flow	---
DRN	Panaca Spring	SPr03_1_01	Flow	---
DRN	Preston Big Spring	SDr07_4_##	Flow Change	---
DRN	Preston Big Spring	SDr07_4_58	Flow Change	---
DRN	Preston Big Spring	SPr07_4_01	Flow	---
DRN	Rogers Spring	SDiw15_1_##	Flow Change	---
DRN	Rogers Spring	SPiw15_1_01	Flow	---
DRN	South Bastian Spring	SPis84_5_01	Flow	---
DRN	South Bastian Spring 2	SPis84_6_01	Flow	---
DRN	South Millick Spring	SPib84_4_01	Flow	---
DRN	Stonehouse Spring	SPis84_14_01	Flow	---
DRN	The Seep	SPiw84_15_01	Flow	---
DRN	Twin Spring	SPib95_15_01	Flow	---
DRN	Unnamed 5 Spring	SPis84_16_01	Flow	---
DRN	Unnamed Spring	SPis95_14_01	Flow	---
DRN	Warm Creek near Gandy, UT	SPiw95_2_01	Flow	---
DRN	Willard Springs	SPis84_2_01	Flow	---
DRN	Willow Spring	SPiw84_1_01	Flow	---
SFR2	Ash Springs	GdASH_61	Flow	---
SFR2	Big Springs	GdBIG_SPR_61	Flow	---
SFR2	Crystal Springs	GdXTL_61	Flow	---
SFR2	End of Lake Creek	GdLKCK_END_##	Flow	---
SFR2	End of Pahrnagat Wash	GdPW_7_##	Flow	---
SFR2	Hiko Spring	GdHIKO_01	Flow	---
SFR2	Muddy River at Lake Mead	GdLK_MEAD_01	Flow	---
SFR2	Muddy River at Overton	GdOVERTON_61	Flow	---
SFR2	Muddy River near Glendale	GdmrGLEND_08	Flow	---
SFR2	Muddy River near Moapa	GdmrMOAPA_##	Flow	Baldwin Spring, Jones Spring, M-10, M-11, M-12, M-13, M-15, M-16, M-19, M-20, Muddy Spring, Pederson East Spring, Pederson Spring, and Warm Springs East aggregated in Muddy River near Moapa SFR2 gage observation

^aDRN: MODFLOW-2000 Drain package; SFR2: MODFLOW-2000 Streamflow-Routing package;

CHD: MODFLOW-2000 Constant-Head package (Springs within CHD cells not represented in the model).

^bUsed as MODFLOW-2000 and UCODE_2005 observation names in DRN and SFR2 packages. ## indicates two-digit number corresponding to stress period.

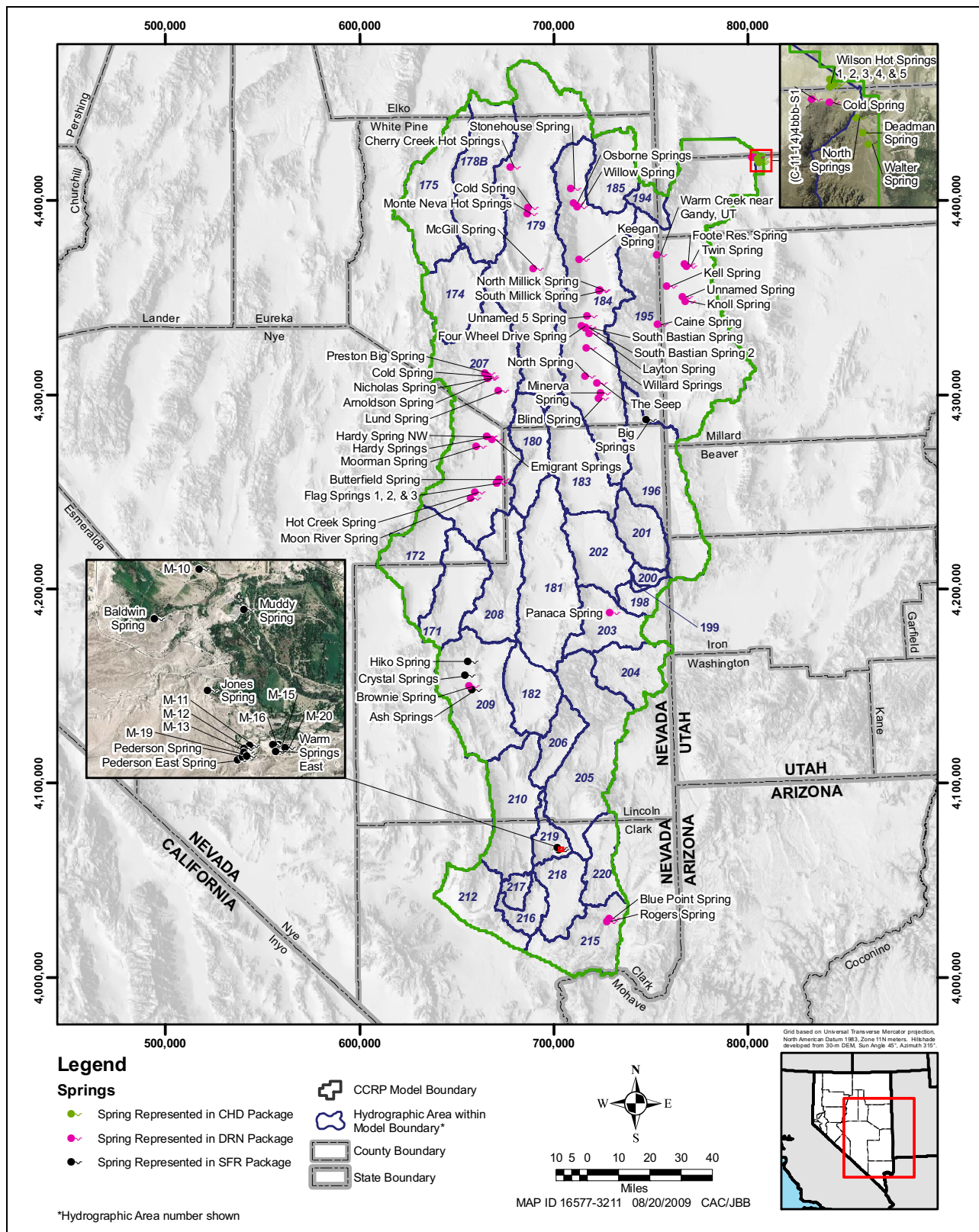


Figure 4-25
Locations of Springs Simulated with the CHD, DRN, and SFR2 Packages in the Numerical Model

4.4.4.1 Springs Simulated Using DRN Package

Spring discharge at selected springs was simulated using the MODFLOW-2000 DRN package. The corresponding observations are included in the drain observation (DROB) module discussed later in this section. Each spring was assigned to a particular model cell. Where multiple springs occupy the same model cell, the springs were simulated as a group. A given spring (or group of springs) was represented by one or more drains linked to a different model layer. A single spring could, therefore, be represented by a maximum of 11 drains. However, all drains representing the spring were assigned the same drain elevation.

The depths of the spring drains were assumed to be at 32.8 ft bgs (10 m bgs). The ground surface was assumed to equal the minimum 30-m DEM elevation within the 1 km² grid cell in which the spring is located. The elevation of a given spring drain was calculated as this value of the ground surface minus the depth of the spring drain. This method of calculating the spring drain elevations was used because spring cells in the model are typically surrounded by ET drain cells. In such cases, when the drain elevation is set to the pool elevation or the land surface, surrounding ET drain cells effectively restrict flows to the spring drain cell. Lowering the spring drain to 32.8 ft bgs (10 m) provides a preferential gradient to the spring cell. If a spring occupies the same cell as an ET drain cell, the ET drain cell is reassigned to a Wetland ET DROB observation, regardless of its original type. A similar approach was used in the DVFS model (Faunt et al., 2004).

Spring conductance was estimated using the following equation:

$$C = (Q/(GS - DE))/L \quad (\text{Eq. 4-4})$$

where,

- C = Conductance (L²/T)
- Q = Pre-1945 target discharge rates (L³/T)
- GS = Spring head elevation approximated by ground surface (L)
- DE = Drain elevation (L)
- L = Number of layers that contain spring cells

Spring conductances were treated as parameters. Initial estimates of drain conductance were calculated as the quotient of measured spring discharge and the difference of interpolated field hydraulic-head and drain elevation. The values of initial estimates of spring conductance are listed in [Table 4-11](#). Individual spring conductances were adjusted during manual portions of the model calibration to better approximate spring discharge. Conductance adjustments are generally limited to within one order of magnitude of the starting value.

4.4.4.2 Springs and Streams Simulated Using SFR2 Package

If all springs were represented as drains using the DRN package, groundwater ET from basins with significant surface-water flow could not be well represented. Where spring discharge flows in streams, the surface water can infiltrate into the groundwater system and then be available for

Table 4-11
Initial Estimates of Conductances for Spring Drains
 (Page 1 of 2)

Spring Name	DRN and SFR2 Observation Name	Initial Spring DRN Conductance ft ² /d (m ² /d)	Comment
Arnoldson Spring	SPiw07_2_01	644.0 (59.83)	---
Blue Point Spring	SDiw15_2_##	57.69 (5.360)	---
Brownie Spring	SPis09_4_01	491.2 (45.63)	---
Butterfield Spring	SPib07_10_01	1,175 (109.2)	---
Caine Spring	SPis95_3_01	NA	Small spring represented by ET DRN
Campbell Ranch Springs	SPib79_5_01	NA	Small spring represented by ET DRN
Cherry Creek Hot Springs	SPr79_2_01	3.693 (0.3431)	---
Cold Spring	SPiw07_3_01	428.8 (39.84)	---
Cold Spring	SPis79_4_01	NA	Small spring represented by ET DRN
Emigrant Springs	SPib07_15_01	537.7 (49.95)	---
Flag Springs 1	SPiw07_9_01	205.5 (19.09)	Flag #1, #2, and #3 are in the same cell
Flag Springs 2	SPiw07_8_01		
Flag Springs 3	SPiw07_7_01		
Foote Res. Spring	SPib95_12_01	2,199 (204.3)	---
Four Wheel Drive Spring	SPis84_11_01	NA	Small spring represented by ET DRN
Hardy Spring NW	SPis07_12_01	627.1 (58.26)	Small spring represented by ET DRN
Hardy Springs	SPis07_11_01		
Hot Creek Spring	SPr07_1_01	2,174 (202.0)	---
Keegan Spring	SPis84_12_01	927.0 (86.12)	---
Kell Spring	SPis95_13_01	302.5 (28.10)	---
Lund Spring	SPib07_5_01	5,899 (548.0)	---
McGill Spring	SPiw79_1_01	5,386 (500.4)	---
Minerva Spring	SPis84_13_01	1,484 (137.9)	---
Monte Neva Hot Springs	SPr79_3_01	141.3 (13.13)	---
Moon River Spring	SPr07_14_01	380.0 (35.30)	---
Moorman Spring	SPr07_6_01	206.0 (19.14)	---
Nicholas Spring	SPiw07_13_01	463.3 (43.04)	---
North Millick Spring	SPis84_3_01	1,069 (99.28)	---
North Spring	SPiw84_8_01	NA	Small spring represented by ET DRN
Osborne Springs	SPis84_10_01	NA	Small spring represented by ET DRN
Panaca Spring	SPr03_1_01	511.7 (47.54)	---
Preston Big Spring	SDr07_4_##	1,218 (113.2)	---
Rogers Spring	SDiw15_1_##	120.9 (11.23)	---
South Bastian Spring	SPis84_5_01	NA	Small spring represented by ET DRN
South Bastian Spring 2	SPis84_6_01	NA	Small spring represented by ET DRN
South Millick Spring	SPib84_4_01	1,114 (103.5)	---
Stonehouse Spring	SPis84_14_01	NA	Small spring represented by ET DRN

Table 4-11
Initial Estimates of Conductances for Spring Drains
 (Page 2 of 2)

Spring Name	DRN and SFR2 Observation Name	Initial Spring DRN Conductance ft ² /d (m ² /d)	Comment
The Seep	SPiw84_15_01	NA	Small spring represented by ET DRN
Twin Spring	SPib95_15_01	3,514 (326.5)	---
Unnamed 5 Spring	SPis84_16_01	NA	Small spring represented by ET DRN
Unnamed Spring	SPis95_14_01	NA	Small spring represented by ET DRN
Gandy Warm Springs near Gandy, UT	SPiw95_2_##	2,947 (273.8)	---
Gandy Warm Springs near Gandy, UT	SPiw95_2_01	2,947 (273.8)	---
Willard Springs	SPis84_2_01	NA	Small spring represented by ET DRN
Willow Spring	SPiw84_1_01	6.958 (0.6464)	---

Note: NA = Not applicable

indicates two-digit number corresponding to stress period.

discharge by ET. In such cases, use of the SFR2 package is more applicable. SFR2 allows springs to discharge to streams and stream water to infiltrate into the flow system downstream from the spring orifice. The spring systems in the Muddy River Springs Area, Pahrangat Valley, and the Big Springs area in Snake Valley are represented with SFR2.

4.4.4.2.1 General Representation of Springs

The SFR2 package simulates the discharge of groundwater from a spring and the flow of this discharged water in a stream channel. SFR2 typically accounts for surficial stream-aquifer interactions. Springs in the numerical model, however, are conceptualized to discharge from geologic units at depths beyond surficial and alluvial layers.

To represent springs within the framework of the SFR2 package, SFR2 cells are defined at depth. The only apparent restriction on the reach cells is that the stream stage or, in this case, aquifer hydraulic head have a gradient downstream. Downstream is specified by the order of the SFR2 reaches (model cells) and river segments (collections of reaches).

For springs, a stream segment is defined to represent the spring structure extending from the ground surface to the top or bottom of the carbonate, depending on the spring type. To monitor spring flow, gages (Table 4-12) are added at the surface reach of the SFR2 segments. These gages allow the spring flow discharge to be monitored. Where SFR2 cells at the spring reach the surface, SFR2 segments are connected to conventional stream segments to allow flow downstream.

Once the spring flow reaches the ground surface, flow is confined to stream segments in the top active model layer. Water in the channel can flow downstream, evaporate, be removed by diversion (ditch or pipe), or infiltrate into the aquifer (a losing channel). Water from the aquifer can also seep into the river (gaining channel). Because of the small surface area of the channels relative to the model

Table 4-12
Spring Flow Gages Modeled Using SFR2 Package

Spring Name	Observation Name	Spring Type ^a
Big Springs Area		
Big Springs	GdBIG_SPR_61	INT
End of Lake Creek	GdLKCK_END_##	RIV
Muddy River Springs Area		
Muddy River near Moapa	GdmrMOAPA_##	RIV
Muddy River near Glendale	GdmrGLEND_##	RIV
Muddy River at Overton	GdOVERTON_61	RIV
Muddy River at Lake Mead	GdLK_MEAD_01	RIV
Pahranagat Valley Area		
Hiko Spring	GdHIKO_01	REG
Crystal Springs	GdXTL_61	REG
Ash Springs	GdASH_61	REG
End of Pahranagat Wash	GdPW_7_##	RIV

^aREG: Regional flow system designation; INT: Intermediate flow system designation;
RIV: Surface-water flow
indicates two-digit number corresponding to stress period.

cell size, recharge is not applied to the river (recharge is applied to the entire cell via the RCH module).

In most parts of the model, evaporation accounted for by the SFR2 module is relatively small, as it is a function of the surface area of the open water channel. The rate of ET is defined as the open-water ET rate for the area of the model (Table 4-13). Evaporation due to riparian vegetation is not accounted for using SFR2. For the water to be evapotranspired, it must leak back into the aquifer, where it can then be discharged in ET DRN cells. Note that the SFR2 and ET DRN cell may be the same cell.

Table 4-13
Open-Water ET Rates for SFR2 Streams

SFR2 Stream	ET Rate ft/yr (m/d)
Big Springs Creek/Lake Creek	5.63 (0.004699)
Muddy River	6.71 (0.0056)
Pahranagat Wash	6.12 (0.005105)

Flow to springs simulated using the SFR2 package was controlled by riverbed hydraulic conductivities. Table 4-14 lists the spring names and their corresponding parameter name and initial estimates of riverbed hydraulic conductivities.

Table 4-14
Parameter Names and Initial Estimates for Springs
Simulated Using SFR2 Package

Spring Name	Parameter Name	Hydraulic-Conductivity Estimate ft/d (m/d)
Big Springs Area		
Big Springs	SFR_COND3	0.328 (0.1)
Muddy River Springs Area		
Baldwin Spring	SFR_COND19	0.328 (0.1)
Jones Spring	SFRaCOND19	0.328 (0.1)
M-10	SFR_COND19	0.328 (0.1)
M-11	SFRaCOND19	0.328 (0.1)
M-12	SFRaCOND19	0.328 (0.1)
M-13	SFRaCOND19	0.328 (0.1)
M-15	SFRaCOND19	0.328 (0.1)
M-16	SFRaCOND19	0.328 (0.1)
M-19	SFRaCOND19	0.328 (0.1)
M-20	SFRaCOND19	0.328 (0.1)
Muddy Spring	SFR_COND19	0.328 (0.1)
Pederson East Spring	SFRaCOND19	0.328 (0.1)
Pederson Spring	SFRaCOND19	0.328 (0.1)
Warm Springs East	SFRaCOND19	0.328 (0.1)
Pahranagat Valley Area		
Ash Springs	SFR_COND17	0.328 (0.1)
Crystal Springs	SFR_COND16	0.328 (0.1)
Hiko Spring	SFR_COND15	0.328 (0.1)

4.4.4.2.2 Detailed Descriptions of Springs/Streams Simulated with SFR2 Package

Detailed descriptions of the SFR2 package representation of the Muddy River Springs, Pahranagat Valley, and the Big Springs areas in Snake Valley are provided in this section.

Muddy River Springs Area

The Muddy River Springs Area is the largest spring discharge area in the model area. Predevelopment conditions for spring discharge from 14 significant springs, groundwater ET, and Muddy River stream flow measured at the Muddy River near Moapa, Nevada (09416000), gage are estimated at 26,315 afy (88,870 m³/d), 5,988 afy (20,224 m³/d), and 34,000 afy (114,821 m³/d), respectively. Additional unmeasured springs and seeps occur in this area and account for the difference between the measured spring discharge and the groundwater ET and Muddy River stream flow, a difference of about 14,000 afy (47,279 m³/d). Because only a small portion of the spring discharge in this area is consumed by ET, the remainder enters the Muddy River, where it is measured at the Muddy River near Moapa, Nevada, gage (approximately 1 mi downstream), and flows

downstream through the hydrographic areas of California Wash, Lower Meadow Valley Wash, and Lower Moapa Valley.

The spring discharge in the Muddy River Springs Area could have been removed from the model at the spring locations, but by the time the Muddy River reaches Overton, Nevada, stream flow was about 7,100 afy (24,000 m³/d) during predevelopment conditions, assuming about half of the stream flow measured from Water Year 1914 to Water Year 1916 was groundwater discharge (Wells, 1954). This suggests that about 27,000 afy (91,000 m³/d) seeped back into the aquifer or was consumed by riparian vegetation simulated as Wetland ET. This volume of water accounts for more than half the ET estimated in California Wash, southern Lower Meadow Valley Wash, and Lower Moapa Valley. The stream and aquifer interactions of the Muddy River were approximated using the SFR2 package as follows:

- The Muddy River channel was subdivided into 18 stream segments and 87 reach cells. [Figure 4-26](#) illustrates the SFR2 cells defining the Muddy River ([Table 4-15](#)).
- The Open Water ET rate for the Muddy River Springs Area from SNWA (2009a) was used for the surface SFR2 channels. For stream segments representing connections to deep springs, zero ET was specified.
- Stream channel elevations were approximated from 2-ft contour data of the Muddy River channel area. Riverbed spring channel elevations for segments were based on the minimum and maximum spring pool elevations in an SFR2 cell.
- Surface channel widths were approximated, ranging from 10 ft (3 m) to 75 ft (23 m). Subsurface channel widths were assumed to be 328 ft (100 m). Surface channel segment lengths were based on the mapped river channel length in each model cell. Model layer thicknesses were used to represent the channel length for subsurface springs.

Three gages were used in the model calibration (see [Figure 4-26](#)). An additional seven gages were defined to monitor trends in the total stream flow. These gages are defined in [Table 4-16](#) and shown in [Figure 4-27](#).

Pahranagat Valley

Three regional springs discharge at the northwest part of Pahranagat Valley. Down-gradient of these springs is a significant extent of wetland phreatophyte along Pahranagat Wash, which flows south along the axis of the valley. SNWA (2009a) explains that these wetlands are maintained by the groundwater discharge from these regional springs. In other words, groundwater is made available to wetland phreatophyte communities supported by a shallow alluvial aquifer that is recharged by groundwater discharge from the regional springs.

The representation of groundwater discharge in Pahranagat Valley is complex, in part, because the conceptual model predicts that 93 percent of the water that evapotranspires from Pahranagat Valley first flows out of Ash, Brownie, Crystal, and Hiko springs. This prediction implies that there is relatively little other groundwater discharge in Pahranagat Valley. From a practical standpoint, discharging 26,735 afy (90,287 m³/d) out of four springs and having relatively little other

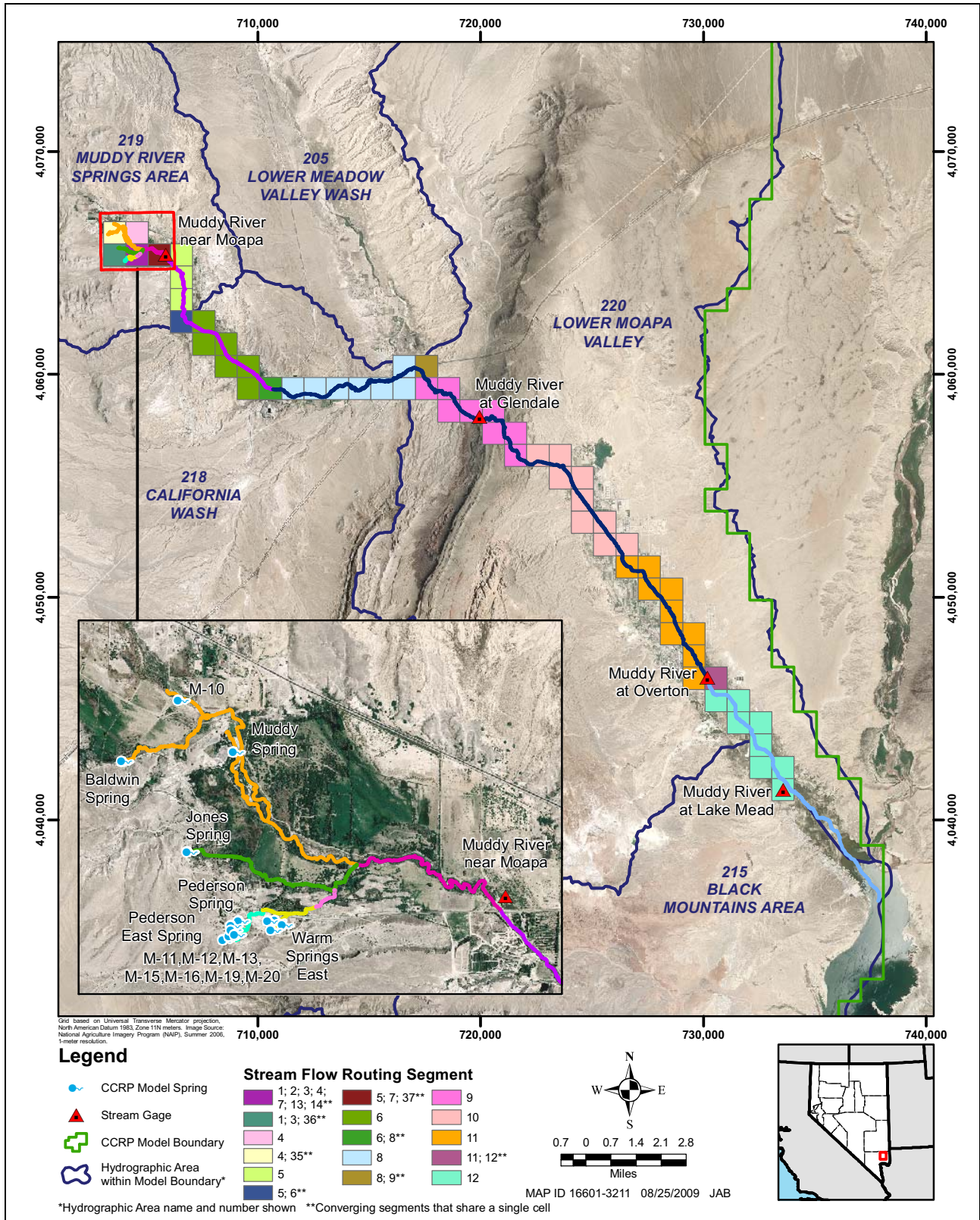


Figure 4-26
Representation of the Muddy River Springs and Muddy River
in the Numerical Model Using the SFR2 Package

Table 4-15
Characteristics of Muddy River Stream Flow Routing Segments

Segment	Number of Reaches	Downstream Segment ID	Segment Length ft (m)	Conductance Parameter	Riverbed Elevation		Channel Width ft (m)	ET Rate ft/yr (m/d)	Reynolds Number	Description
					Upstream ft amsl (m amsl)	Downstream ft amsl (m amsl)				
1	2	2	1,867 (569)	SFR_COND1	1,800 (548.64)	1,775 (541)	10 (3)	6.71 (0.0056)	0.041	Warm Springs West Channel
2	1	13	2,438 (743)	SFR_COND1	1,775 (541)	1,745 (532)	10 (3)	6.71 (0.0056)	0.041	Iverson Flume Channel
3	2	14	3,931 (1,198)	SFR_COND1	1,784 (543.76)	1,729 (527)	10 (3)	6.71 (0.0056)	0.041	Jones Spring Channel
4	2	7	13,482 (4,109)	SFR_COND1	1,777 (541.54)	1,719 (524)	10 to 23 (3 to 7)	6.71 (0.0056)	0.041	Muddy Springs Channel
5	5	6	13,879 (4,230)	SFR_COND24	1,709 (521)	1,663 (507)	49 to 75 (15 to 23)	6.71 (0.0056)	0.030	Moapa to California Wash HA
6	8	8	16,792 (5,118)	SFR_COND25	1,663 (507)	1,591 (485)	49 to 75 (15 to 23)	6.71 (0.0056)	0.030	California Wash HA to Glendale
7	2	5	5,033 (1,534)	SFR_COND1	1,719 (524)	1,709 (521)	23 to 49 (7 to 15)	6.71 (0.0056)	0.035	Moapa Channel
8	9	9	29,539 (9,003)	SFR_COND2	1,591 (485)	1,512 (461)	36 to 75 (11 to 23)	6.71 (0.0056)	0.035	Glendale to Lower Moapa HA
9	9	10	29,358 (8,948)	SFR_COND20	1,512 (461)	1,458 (444.5)	36 to 75 (11 to 23)	6.71 (0.0056)	0.035	Lower Moapa HA toward Overton
10	9	11	22,885 (6,975)	SFR_COND21	1,458 (444.5)	1,322 (403)	36 to 75 (11 to 23)	6.71 (0.0056)	0.035	Mid #1 Overton to mid #2 Overton
11	10	12	25,159 (7,668)	SFR_COND22	1,322 (403)	1,243 (379)	36 to 75 (11 to 23)	6.71 (0.0056)	0.035	Mid #2 Overton to mid #3 Overton
12	9	Lake Mead	24,221 (7,383)	SFR_COND23	1,243 (379)	1,169 (356.4)	36 to 75 (11 to 23)	6.71 (0.0056)	0.025	Overton to Lake Mead
13	1	14	705 (215)	SFR_COND1	1,745 (532)	1,729 (527)	10 (3)	6.71 (0.0056)	0.041	Below Iverson Flume
14	1	7	912 (278)	SFR_COND1	1,729 (527)	1,719 (524)	10 to 23 (3 to 7)	6.71 (0.0056)	0.041	Below Jones Spring and Iverson Flume
15	5	4	10,794 (3,290)	SFR_COND19	1,798 (548.03)	1,777 (541.54)	328 (100)	0	0.050	Baldwin, Muddy, and M-10 springs
16	1	3	3,281 (1,000)	SFR_COND19	1,788 (545)	1,785 (544)	328 (100)	0	0.050	Jones Spring Channel
17	5	1	10,815 (3,296)	SFR_COND19	1,811 (551.99)	1,800 (548.46)	328 (100)	0	0.050	Pederson, Pederson East, M-12, M-13, and M-19 springs
18	5	2	10,804 (3,293)	SPR_COND19	1,800 (548.64)	1,775 (541)	328 (100)	0	0.050	M-11, M-15, M-16, M-20, and Warm Springs East springs

Table 4-16
Muddy River Gages

Gage Name	Segment	Reach
Warm Springs West	2	1
Iverson Flume	13	1
Muddy River near Moapa	5	2
Muddy River at California Wash HA Boundary	5	6
California Wash	8	1
Muddy River near Glendale	8	9
Muddy River at mid #1 to mid #2 Overton Segment	10	1
Muddy River at mid #2 to mid #3 Overton Segment	11	1
Muddy River at Lewis Avenue at Overton	12	1
Muddy River at Lake Mead	12	9

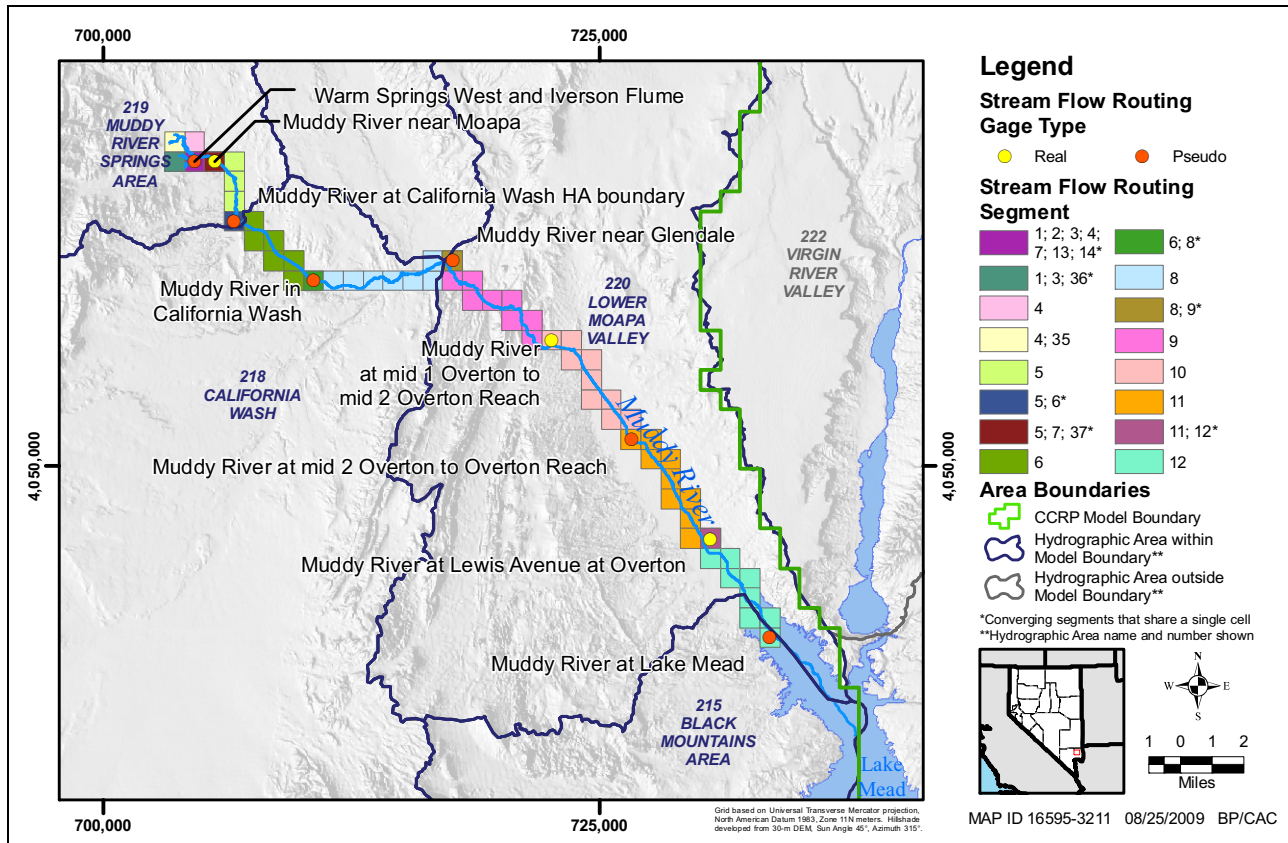


Figure 4-27
Gages Along the Muddy River

regional/intermediate aquifer water discharging 1,785 afy (6,029 m³/d) from neighboring model cells requires special treatment and/or adjustments to the conceptual model.

To approximate the discharges estimated in the conceptual model, the following assumptions were made for Pahranaagat Wash:

1. The Wash channel floor and phreatophyte (ET DRN cells) from Hiko to Ash springs is essentially impermeable. This allows significant artesian pressures (head above ground surface) to build in the area of the springs, providing sufficient flow out the springs and into Pahranaagat Wash, without allowing any other groundwater seepage. In the numerical model, the SFR2 channel conductances and ET DRN cell conductances were set to zero or near zero.
2. From Ash Spring south to the Pahranaagat Shear Zone, Pahranaagat Wash, and wells drilled near the wash, and the riparian vegetation along the river sides are drawing water largely from a perched or semiperched, stream-channel aquifer sustained by Pahranaagat Wash. The numerical model was not configured to manage perched conditions, but the net result can be approximated. Along the entire length of the wash, the channel width is defined to be between 492 ft (150 m) and 984 ft (300 m) wide. The actual channel width is closer to 15 to 33 ft (5 to 10 m). These excessively wide channel widths are meant to reflect the open water area as well as the riparian areas supported by Pahranaagat Wash. This approach allowed sufficient discharge as ET without maintaining higher hydraulic heads in the aquifer necessary to achieve groundwater-derived ET rates.

The SFR2 package represents the regional springs and Pahranaagat Wash to approximate these processes, which are similar to what is occurring at Muddy River Springs Area and along the Muddy River. A vertical segment was defined below each spring pool to the bottom of the carbonate RMU. Additional segments were added to carry flows southeast into the Pahranaagat Shear Zone. In addition to matching spring flows in Pahranaagat Wash, flows in Pahranaagat Wash should be zero at the point where Pahranaagat Wash reaches Coyote Spring Valley.

Pahranaagat Wash was defined using 10 stream segments and 92 reach cells (see [Figure 4-28](#)). The description of each segment is presented in [Table 4-17](#).

Spring SFR2 cells at depth for Hiko and Crystal springs were shifted one cell west so that the springs would be drawing water from the larger-*K* large-displacement and moderate-displacement fault zones. They were originally located in carbonate-mountain-block materials. Prior to this adjustment, expected flows were impossible to obtain.

SFR2 package specifications for Pahranaagat Wash included the following:

1. The Open Water ET rate for the Pahranaagat Valley hydrographic area from SNWA (2009a) was used for the surface SFR2 channels. For spring channel segments, zero ET was defined.
2. Riverbed stream channel elevations were estimated from the USGS 30-m DEM. Riverbed spring channel elevations were based on the spring pool elevation and the 30-m DEM

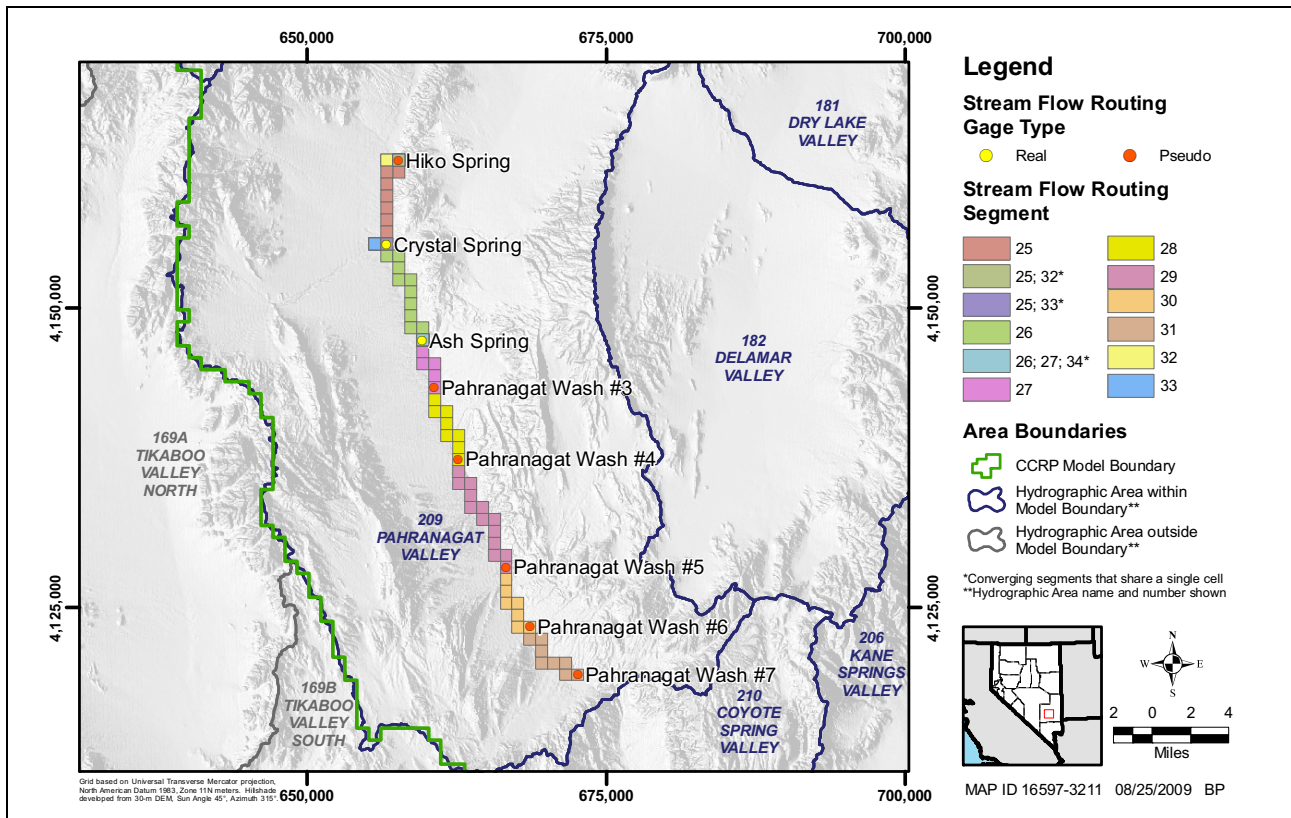


Figure 4-28
Pahrnagat Wash Stream Flow Routing Segments

elevation where the spring tributary left the model cell or at its confluence with Pahrnagat Wash.

3. Surface channel widths were assumed to be 10 ft (3 m). Subsurface channel widths were assumed to be 328 ft (100 m).
4. Surface channel segment lengths were based on the mapped river channel length in each model cell. Channel lengths for spring segments occurring at depth were based on model layer thicknesses.
5. The Pahrnagat Wash is assumed and required to dry up before the last SRF2 reach.

Four flow observations were specified as gages and used as model constraints. An additional six gages were defined to monitor trends in the total stream flow. These are defined in [Table 4-18](#) and shown in [Figure 4-28](#).

Big Springs Area

In southern Snake Valley, Big Springs is a large intermediate-class spring that supplies water to Big Springs Creek, Lake Creek, and Pruess Lake. Significant Wetland ET occurs along the length of the creek. The SFR2 package was used to represent the process of supplying Big Springs discharge to Wetland ET areas along the creek.

Table 4-17
Characteristics of Pahranagat Wash Stream Flow Routing Segments

Segment	Number of Reaches	Downstream Segment ID	Segment Length ft (m)	Conductance Parameter	Riverbed Elevation		Channel Width ft (m)	ET Rate ft/yr (m/d)	Reynolds Number	Description
					Upstream ft amsl (m amsl)	Downstream ft amsl (m amsl)				
25	9	26	26,540 (8,089)	SPR_COND8	3,853 (1,174.4)	3,803 (1,159.1)	984 (300)	6.12 (0.0051)	0.035	Hiko Spring to Crystal Springs
26	11	27	28,315 (8,630)	SPR_COND9	3,803 (1,159.1)	3,600 (1,097.0)	984 (300)	6.12 (0.0051)	0.035	Crystal Springs to Ash Springs
27	6	28	18,139 (5,529)	SPR_COND10	3,600 (1,097.0)	3,533 (1,076.9)	492 (150)	6.12 (0.0051)	0.035	Stream Segment #3
28	8	29	22,390 (6,825)	SPR_COND11	3,533 (1,076.9)	3,468 (1,056.9)	492 (150)	6.12 (0.0051)	0.035	Stream Segment #4
29	13	30	33,615 (10,246)	SPR_COND12	3,468 (1,056.9)	3,349 (1,020.7)	492 (150)	6.12 (0.0051)	0.035	Stream Segment #5
30	7	31	18,821 (5,737)	SPR_COND13	3,349 (1,020.7)	3,221 (981.8 m)	492 (150)	6.12 (0.0051)	0.035	Stream Segment #6
31	12	End of River	29,679 (9,046)	SPR_COND14	3,221 (981.8)	3,110 (947.8)	492 (150)	6.12 (0.0051)	0.035	End of Stream
32	8	25	13,820 (4,212)	SPR_COND15	3,875 (1,181.1)	3,853 (1,174.4)	328 (100)	0	0.05	Hiko Spring
33	9	26	16,058 (4,894)	SPR_COND16	3,803 (1,159.2)	3,803 (1,159.1)	328 (100)	0	0.05	Crystal Springs
34	9	27	15,849 (4,831)	SPR_COND17	3,622 (1,104.0)	3,600 (1,097.0)	328 (100)	0	0.05	Ash Springs

**Table 4-18
Pahranagat Wash Gages**

Gage Name	Segment	Reach
Pahranagat Wash at Crystal Springs	25	9
Pahranagat Wash at Ash Springs	26	11
Pahranagat Wash #3	27	6
Pahranagat Wash #4	28	8
Pahranagat Wash #5	29	13
Pahranagat Wash #6	30	7
End of Wash	31	8
Hiko Spring	32	8
Crystal Springs	33	8
Ash Springs	34	8

Similar to the Muddy River Springs Area, a vertical stream segment was defined below the spring pool. Additional stream segments carry flows northeast to Pruess Lake and slightly beyond toward Baker. Big Springs discharge was used as a model observation. Stream flows at the final reach should be approximately zero.

Big Springs Creek and Lake Creek were defined using 6 stream segments and 50 reach cells (Figure 4-29). The description of each segment is presented in Table 4-19.

SFR2 package specifications for Big Springs included the following:

1. The Open Water ET rate for the Snake Valley hydrographic area from SNWA (2009a) was used for the surface SFR2 channels. For spring channel segments, zero ET was defined.
2. Riverbed stream channel elevations were estimated from the USGS 30-m DEM. Riverbed spring channel elevations were based on the spring pool elevation and the 30-m DEM elevation where the spring tributary left the model cell or at its confluence with Big Springs Creek.
3. Surface channel widths were assumed to be 10 ft (3 m). Subsurface channel widths were assumed to be 328 ft (100 m).
4. Surface channel segment lengths were based on the mapped river channel length in each model cell. Channel lengths for spring segments occurring at depth were based on model layer thicknesses.
5. Lake Creek is assumed and required to dry up north of Pruess Lake and before the final SRF2 reach.

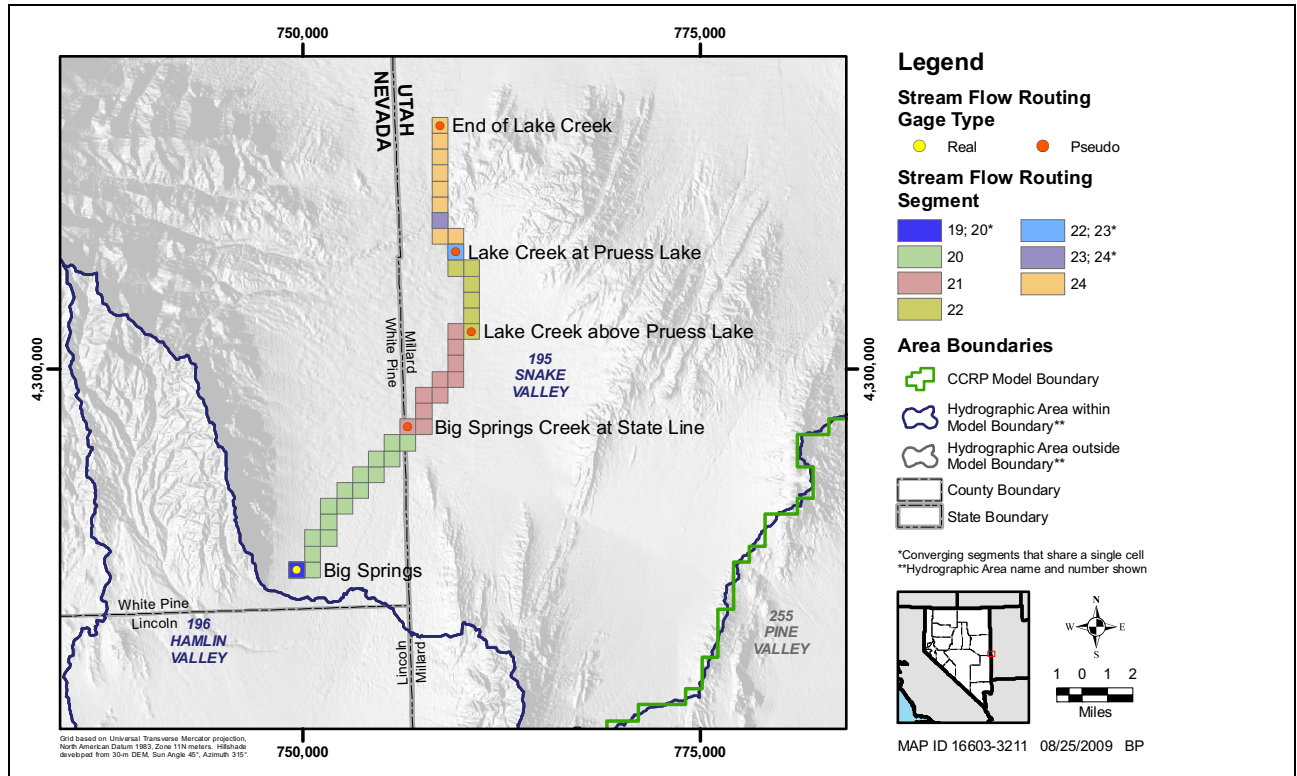


Figure 4-29
Big Springs Creek and Lake Creek Stream Flow Routing Segments and Gages

Table 4-19
Characteristics of Big Springs Area Stream Flow Routing Segments

Segment	Number of Reaches	Downstream Segment ID	Segment Length ft (m)	Conductance Parameter	Riverbed Elevation		Channel Width ft (m)	ET Rate ft/yr (m/d)	Reynolds Number	Description
					Upstream ft amsl (m amsl)	Downstream ft amsl (m amsl)				
19	6	20	5,404 (1,647)	SFR_COND3	5,568 (1,697.1)	5,528 (1,685.0)	328 (100)	0 (0.00)	0.05	Big Springs
20	16	21	40,753 (12,421)	SFR_COND4	5,528 (1,685.0)	5,430 (1,655)	32.8 (10)	5.63 (0.0047)	0.035	Utah Border
21	10	22	26,753 (8,154)	SFR_COND5	5,430 (1,655)	5,361 (1,634)	32.8 (10)	5.63 (0.0047)	0.035	Stream Segment #2
22	7	23	18,925 (5,768)	SFR_COND6	5,361 (1,634)	5,358 (1,633)	32.8 (10)	5.63 (0.0047)	0.035	Stream Segment #3
23	4	24	7,041 (2,146)	SFR_COND7	5,358 (1,633)	5,355 (1,632)	1,969 (600)	5.63 (0.0047)	0.035	Pruess Lake
24	7	End of Creek	20,756 (6,326)	SFR_COND18	5,355 (1,632)	5,227 (1,593)	32.8 (10)	6.11 (0.0051)	0.035	End of Lake Creek

Two flow observations were specified as gages and used as model constraints along Big Springs and Lake creeks. An additional three gages were defined to monitor trends in the total stream flow. These gages are defined in [Table 4-20](#) and shown in [Figure 4-29](#).

**Table 4-20
Big Springs Area Gages**

Gage Name	Segment	Reach
Big Springs	20	1
Big Springs Creek at State Line	21	1
Lake Creek above Pruess Lake	22	1
Lake Creek at Pruess Lake	23	1
End of Lake Creek	24	7

4.5 Precipitation Recharge

Groundwater recharge was represented in the numerical model using the MODFLOW-2000 recharge (RCH) package (McDonald and Harbaugh, 1988). A brief description of the RCH package is presented, followed by the methodology used to generate the input recharge grid and its implementation in the numerical model.

4.5.1 RCH Package

The RCH package simulates areally distributed recharge to the flow system represented in the model flow domain. In general, the sole source of the simulated areal recharge is precipitation (McDonald and Harbaugh, 1988).

The recharge distribution is input to the model in the form of a grid of recharge rate values (in units of length per unit time). The recharge flow rate applied to the model through the top face of each model cell is calculated by the RCH package as the input recharge rate times the area of the top face of the model cell. The resulting recharge flow rate is applied to the top model layer (McDonald and Harbaugh, 1988). The RCH package could be used to simulate areal recharge from other sources, such as artificial recharge or secondary recharge from irrigation.

A limitation of the RCH package allows the input of recharge rates only as a distributed recharge-rate grid. If recharge needs to be varied during model calibration, the recharge rates themselves must be treated as parameters. A methodology was developed to allow more flexibility in the parameterization of the recharge distribution.

4.5.2 Methodology

The methodology described in this section uses the potential-recharge-estimation process described in SNWA (2009a), distributes the recharge to appropriate locations, and integrates the generation of the input recharge grid in the model-calibration process. The integration of this methodology into the

model calibration is a complex process that requires numerous operations prior to the execution of MODFLOW-2000. Some operations are done once; others must be repeated with each change to a recharge-related parameter. Because of the complexity of the problem, the recharge distribution cannot be calculated inside MODFLOW-2000. Therefore, UCODE_2005 was used to manage these tasks.

The methodology was developed to use precipitation as the starting point for estimating the input recharge distribution for the model and to allow recharge rates to vary during the numerical-model calibration process, where necessary. This methodology also resolves issues associated with the limitations stemming from the use of a groundwater-balance method to derive the initial distribution of recharge from precipitation.

Groundwater-balance recharge methods, such as the Maxey-Eakin method (Maxey and Eakin, 1949) and that used by SNWA (2009a) for the numerical model, only provide an estimate of the distribution of potential recharge. Potential recharge is defined as the sum of the in-place recharge and the undistributed portion of runoff recharge. In these groundwater-balance methods, the precipitation distribution and estimated annual discharge volumes are used to derive a spatial distribution of RE (SNWA, 2009a). Limitations of this method are that (1) the hydrogeology of the rocks located above the water table through which in-place recharge infiltrates is ignored; (2) as a result, the in-place and runoff recharge components are lumped; and (3) the runoff recharge component is not distributed along the runoff pathways where it infiltrates.

The methodology was developed and implemented in a preprocessing step to MODFLOW-2000 to separate the two components of potential recharge and distribute the runoff recharge along likely pathways (Figure 4-30). The following describes each step of the process:

- Step 1: The process is initiated by discretizing precipitation, RE, and potential recharge areas using the model grid and then combining the grids to obtain a grid of potential recharge.
 - The precipitation is in the form of a grid of annual mean rates.
 - The RE are specified for predefined precipitation intervals and are expressed as a fraction of the precipitation rates. The RE are also in grid form.
 - Potential recharge consists of two components: in-place recharge and recharge from runoff. For a given basin, potential recharge areas are defined as the area of the basin, excluding areas where precipitation is less than 8 in. or within an ET area. This is a masking grid where valley-bottom grid values are set to zero and all other grid values are set to 1.
 - A distribution of potential recharge is derived for the model area by multiplying the precipitation grid, the recharge efficiency grid, and the potential recharge area grid.
- Step 2: This step requires the potential recharge grid and a grid of hydrogeologic factors accounting for the type of rock receiving the precipitation. The hydrogeologic factors represent the fraction of the potential recharge that becomes in-place recharge. The remainder is runoff recharge.

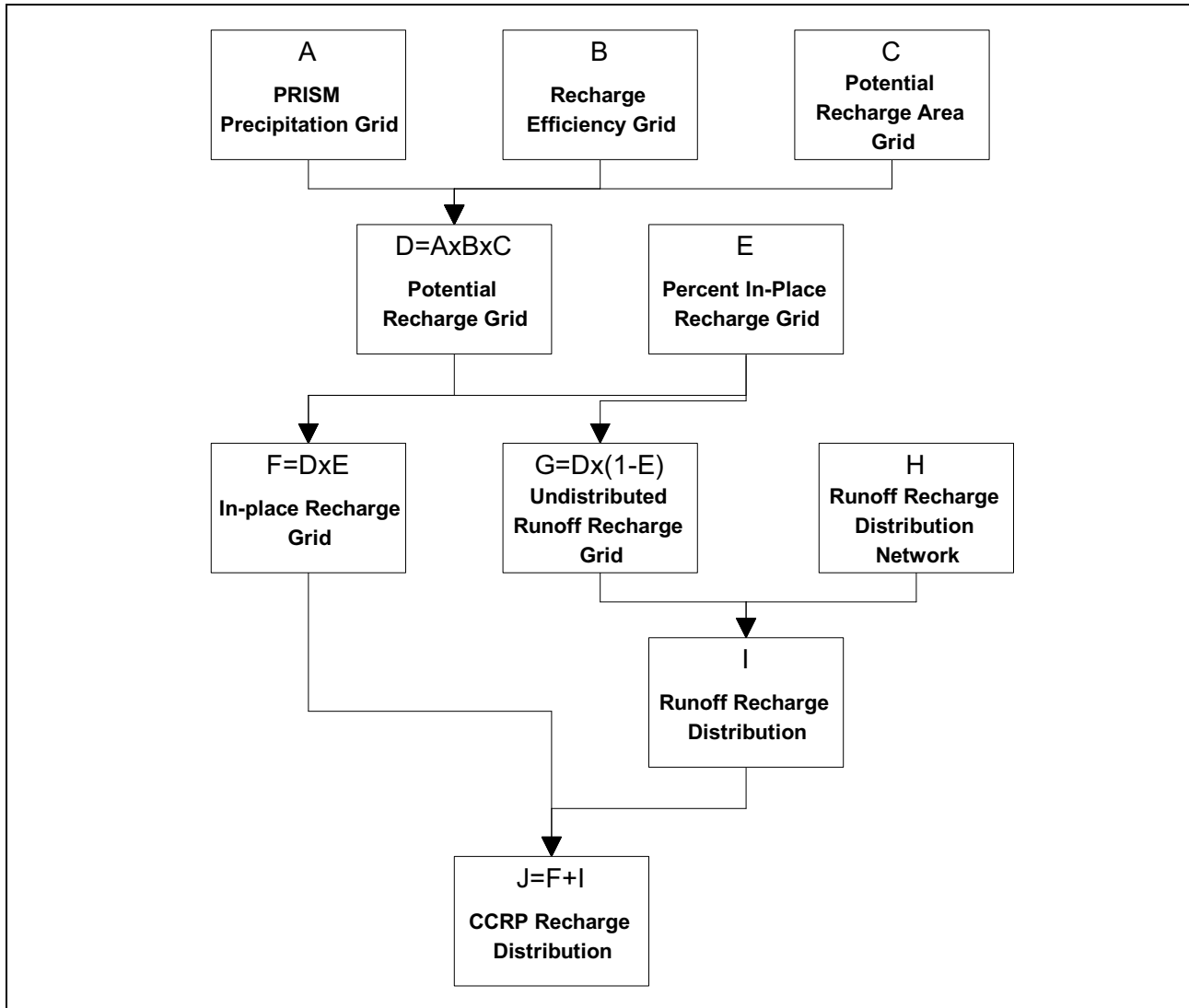


Figure 4-30
Process to Develop Recharge Distribution

- Step 3: This step requires the portion of potential recharge that constitutes runoff recharge calculated in the previous step and a grid of runoff pathways derived from watershed analysis. The volume of runoff recharge calculated for each watershed is distributed along the system of runoff pathways.
- Step 4: This step consists of adding the two grids representing the in-place recharge and the distributed runoff recharge to derive a recharge grid for MODFLOW-2000.

4.5.3 Methodology Application

The methodology described above was implemented in a preprocessing step to MODFLOW-2000 to separate the two components of potential recharge and distribute the runoff recharge along likely pathways. Specific details about the methodology steps are provided in this section.

4.5.3.1 Potential Recharge (Step 1)

This section describes the potential recharge distribution generated for the numerical model area following Step 1 of the methodology outlined previously. Descriptions of the precipitation, RE, and potential recharge area grids are provided first.

The precipitation distribution used in the conceptual model (SNWA, 2009a) is the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (800-m 1971 to 2000 normal, version 2) precipitation grid. This grid was resampled to the numerical model grid (i.e., the grid was converted from its 6,888,903 ft² [640,000 m²] grid to the numerical model's 10,763,910 ft² [1-km²] grid). These data estimate the amount of annual precipitation for every model grid cell (Figure 4-31).

As discussed in SNWA (2009a), RE were estimated for the four interpreted major flow systems in the model area (Table 4-21): the White River, Goshute Valley, Great Salt Lake Desert, and Meadow Valley flow systems. During modeling, several subregions were also divided out (Table 4-22). Hamlin Valley, for example, is within the Great Salt Lake Desert, but its surficial geology is similar, over most of the basin, to that of the MVFS. As a result, RE from the two flow systems were applied to the appropriate portions of Hamlin Valley (Figure 4-32). The RE were assumed to be the same as for the WRFS. As discussed in Section 3.0, to facilitate model calibration using the limited data available for the northernmost portion of the WRFS, Long Valley and a portion of Jakes Valley were reclassified as being part of the Newark Flow System. The initial RE for the Newark Flow System were assumed to be the same as for the WRFS. Several parameters were defined to vary the RE (Table 4-21). The recharge efficiency distribution for the numerical model is represented by a grid and is illustrated in Figure 4-32.

Areas of potential recharge are defined in SNWA (2009a) as areas where most of the in-place recharge occurs and mountain-front runoff is generated. This area of potential recharge is used to estimate the recharge distribution. Potential recharge is assumed to occur in all areas of a given basin except in (1) groundwater-discharge areas and (2) areas where the precipitation is less than 8 in. The valley bottom of each basin was delineated using the USGS 30-m DEM. The potential recharge areas and valley bottoms were represented in grid form by values of 1 and 0.

The distribution of potential recharge to the aquifer system is a function of local precipitation and recharge efficiency. Additionally, zero recharge is assumed to occur where precipitation is less than 8 in. and in ET areas. Thus, the distribution of potential recharge in the numerical model area was calculated as the product of the three grids and is illustrated in Figure 4-33.

4.5.3.2 In-Place Recharge and Runoff Recharge (Step 2)

The potential recharge from precipitation for a given area is portioned into in-place and runoff recharge components based on the hydraulic conductivity of the material present between the land surface and the water table (unsaturated zone). Because the model used in this project was not designed to simulate the detailed processes of recharge, a simplification was made to partition the potential recharge using hydrogeologic factors.

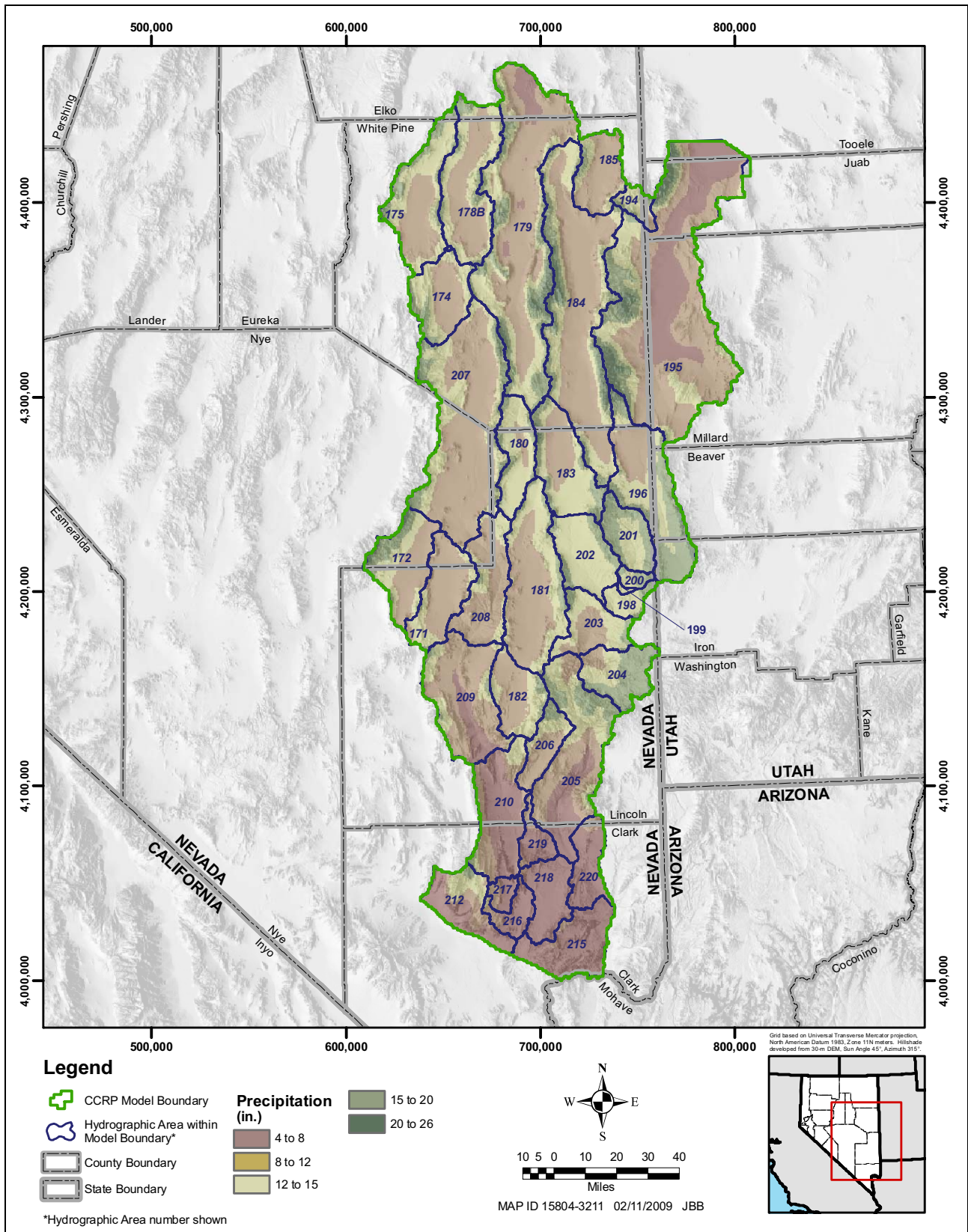


Figure 4-31
Distribution of PRISM Precipitation

Table 4-21
Recharge Efficiencies as Fraction of Precipitation and
MODFLOW-2000 and UCODE_2005 Parameter Names

Precipitation Zone (in./yr)	Recharge Efficiency (fraction of precipitation)	MODFLOW-2000 Parameter Name	UCODE_2005 Parameter Name
Goshute Valley Flow System			RSC_ME_GV
<8	0	---	---
8 to 12	0.0141	R_ME2_GV_R	RtME2_GV_R
12 to 15	0.0530	R_ME3_GV_R	RtME3_GV_R
15 to 20	0.1266	R_ME4_GV_R	RtME4_GV_R
>20	0.3165	R_ME5_GV_R	RtME5_GV_R
Great Salt Lake Desert Flow System			RSC_ME_GSL
<8	0	---	---
8 to 12	0.0091	R_ME2_GSLD	RtME2_GSLD
12 to 15	0.0455	R_ME3_GSLD	RtME3_GSLD
15 to 20	0.1136	R_ME4_GSLD	RtME4_GSLD
>20	0.3059	R_ME5_GSLD	RtME5_GSLD
Las Vegas			
<8	0	---	---
8 to 12	0.0061	R_ME2_LV_R	---
12 to 15	0.0347	R_ME3_LV_R	---
15 to 20	0.1186	R_ME4_LV_R	---
>20	0.3728	R_ME5_LV_R	---
Meadow Valley Flow System			RSC_ME_MVW
<8	0	---	---
8 to 12	0.0006	R_ME2_MVW_	RtME2_MVW_
12 to 15	0.0108	R_ME3_MVW_	RtME3_MVW_
15 to 20	0.0625	R_ME4_MVW_	RtME4_MVW_
>20	0.2304	R_ME5_MVW_	RtME5_MVW_
Newark Flow System			
<8	0	---	---
8 to 12	0.0061	R_ME2_NE_R	RtME2_NE_R
12 to 15	0.0347	R_ME3_NE_R	RtME3_NE_R
15 to 20	0.1186	R_ME4_NE_R	RtME4_NE_R
>20	0.3728	R_ME5_NE_R	RtME5_NE_R
White River Flow System			RSC_ME_WR
<8	0	---	---
8 to 12	0.0061	R_ME2_WR_R	RtME2_WR_R
12 to 15	0.0347	R_ME3_WR_R	RtME3_WR_R
15 to 20	0.1186	R_ME4_WR_R	RtME4_WR_R
>20	0.3728	R_ME5_WR_R	RtME5_WR_R

**Table 4-22
Recharge Efficiencies of Flow System Subregions**

Precipitation Zone (in./yr)	Recharge Efficiency (fraction of precipitation)	UCODE-Derived Parameter Name
Great Salt Lake Desert Flow System (Fish Springs)		
<8	0	---
8 to 12	R_ME2_GSLD	R_ME2_GSFS
12 to 15	R_ME3_GSLD	R_ME3_GSFS
15 to 20	R_ME4_GSLD	R_ME4_GSFS
>20	R_ME5_GSLD	R_ME5_GSFS
Great Salt Lake Desert Flow System (Gandy Area Watershed)		
<8	0	---
8 to 12	R_ME2_GSLD * 1.25	R_ME2_GSGY
12 to 15	R_ME3_GSLD * 1.25	R_ME3_GSGY
15 to 20	R_ME4_GSLD * 1.25	R_ME4_GSGY
>20	R_ME5_GSLD * 1.25	R_ME5_GSGY
Great Salt Lake Desert Flow System (Garden Valley)		
<8	0	---
8 to 12	R_ME2_WR_R	R_ME2_GSGD
12 to 15	R_ME3_WR_R	R_ME3_GSGD
15 to 20	R_ME4_WR_R	R_ME4_GSGD
>20	R_ME5_WR_R	R_ME5_GSGD
Great Salt Lake Desert Flow System (Hamlin Valley - North)		
<8	0	---
8 to 12	R_ME2_GSLD * 0.50	R_ME2_GSHM
12 to 15	R_ME3_GSLD * 0.50	R_ME3_GSHM
15 to 20	R_ME4_GSLD * 0.50	R_ME4_GSHM
>20	R_ME5_GSLD * 0.50	R_ME5_GSHM
Meadow Valley Flow System (Hamlin Valley - South)		
<8	0	---
8 to 12	R_ME2_MVW_ * 0.50	R_ME2_MVHM
12 to 15	R_ME3_MVW_ * 0.50	R_ME3_MVHM
15 to 20	R_ME4_MVW_ * 0.50	R_ME4_MVHM
>20	R_ME5_MVW_ * 0.50	R_ME5_MVHM
White River Flow System (Dry Lake)		
<8	0	---
8 to 12	R_ME2_WR_R	R_ME2_WRDL
12 to 15	R_ME3_WR_R	R_ME3_WRDL
15 to 20	R_ME4_WR_R	R_ME4_WRDL
>20	R_ME5_WR_R	R_ME5_WRDL

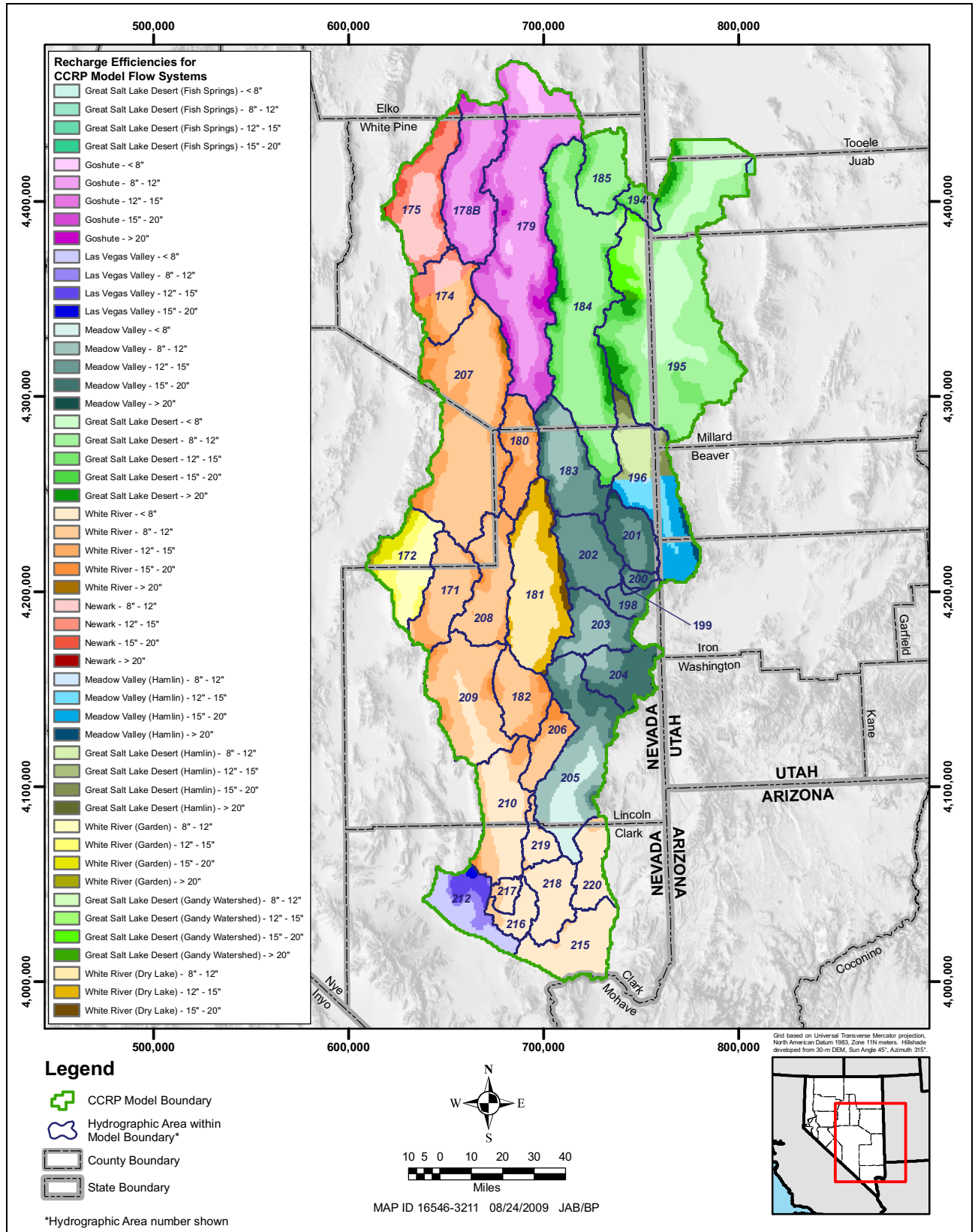


Figure 4-32
Distribution of Recharge Efficiencies

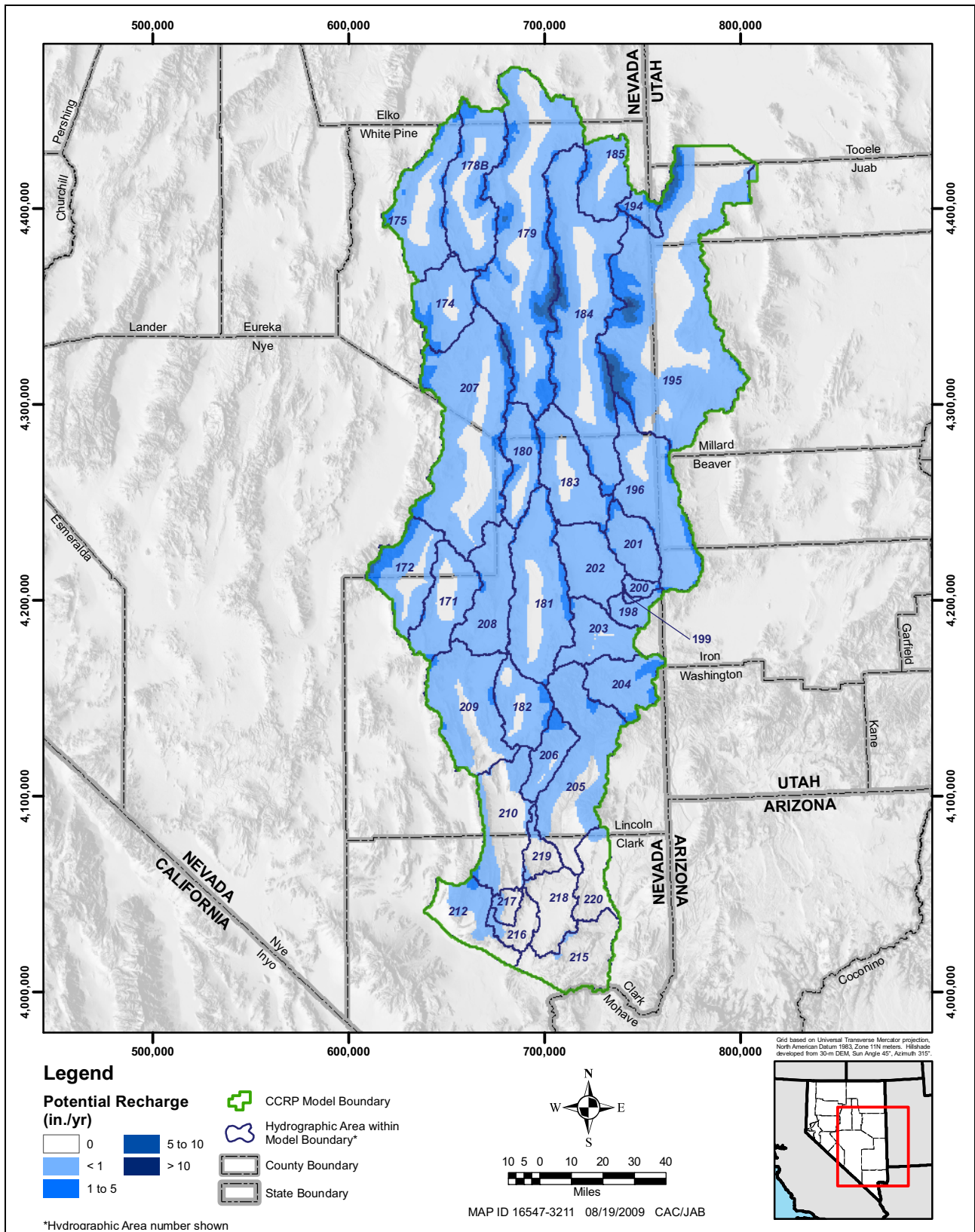


Figure 4-33
Distribution of Potential Recharge

The hydrogeologic factor represents the portion of potential recharge that becomes in-place recharge. This factor takes into account the type of material present at and above the water table. Table 4-23 lists the hydrogeologic factors or fractions of potential recharge allowed to infiltrate in-place by RMU or group of RMUs. These factors are indicative of the hydraulic conductivity of the materials present. In high-*K* (highly-permeable) materials, 100 percent in -place infiltration is possible. In low-*K* materials such as the BASE RMU, as little as 2 percent is assumed to infiltrate in-place, with 98 percent running off. For example, little infiltration occurs in low-*K* plutonic or basement rock, resulting in a small in-place-to-runoff recharge ratio and runoff of most of the potential recharge to more permeable materials along alluvial fans or valley bottoms. The hydrogeologic factors were treated as parameters during model calibration. The parameter names are listed in Table 4-23. Figure 4-34 illustrates the distribution of geologically controlled infiltration zones. The amount of runoff recharge is then distributed along runoff pathways and infiltration areas discussed in the next section.

**Table 4-23
Rock-Type Relationship to Runoff and In-Place
Recharge in the Calibrated Steady-State Model**

Hydrogeologic Factor (In-Place Recharge as Fraction of Potential Recharge)	Rock Type Present ^a	UCODE_2005 Parameter Name
0.6	Carbonate at Water Table	R_ROCARB_W
0.3	Carbonate at Water Table, below LVF	R_ROCARB_L
1.0	Carbonate at Water Table, below UVF	R_ROCARB_U
1.0	UVF at Water Table	R_ROUVF_WT
0.35	LVF at Water Table	R_ROLVF_WT
1.0	LVF at Water Table, below UVF	R_ROLVF_UU
0.02	BASE, PLUT, UA, Kps at Water Table	R_ROLOWK_W

^aGeneral infiltration categories based on RMU between land surface and the estimated regional water table.

4.5.3.3 Runoff Pathways (Step 3)

To distribute the runoff recharge, it was necessary to identify the likely runoff pathways and infiltration areas.

To accomplish this task, a watershed analysis was conducted using the USGS 30-m DEM resampled to the model grid. The purpose of the watershed analysis is to define small, local watersheds along mountain fronts. Watersheds define areas of runoff and catchment points, and distribution paths define where the runoff infiltrates into the corresponding model layer. The identified features can only be changed prior to the execution of UCODE_2005 and MODFLOW-2000. These features cannot be programmatically adjusted during a model run (or during parameter-estimation runs).

Approximately 7,000 catchment points were defined. From these catchment points, the watersheds were delineated. Conceptually, recharge above a catchment point can infiltrate in-place in the cell

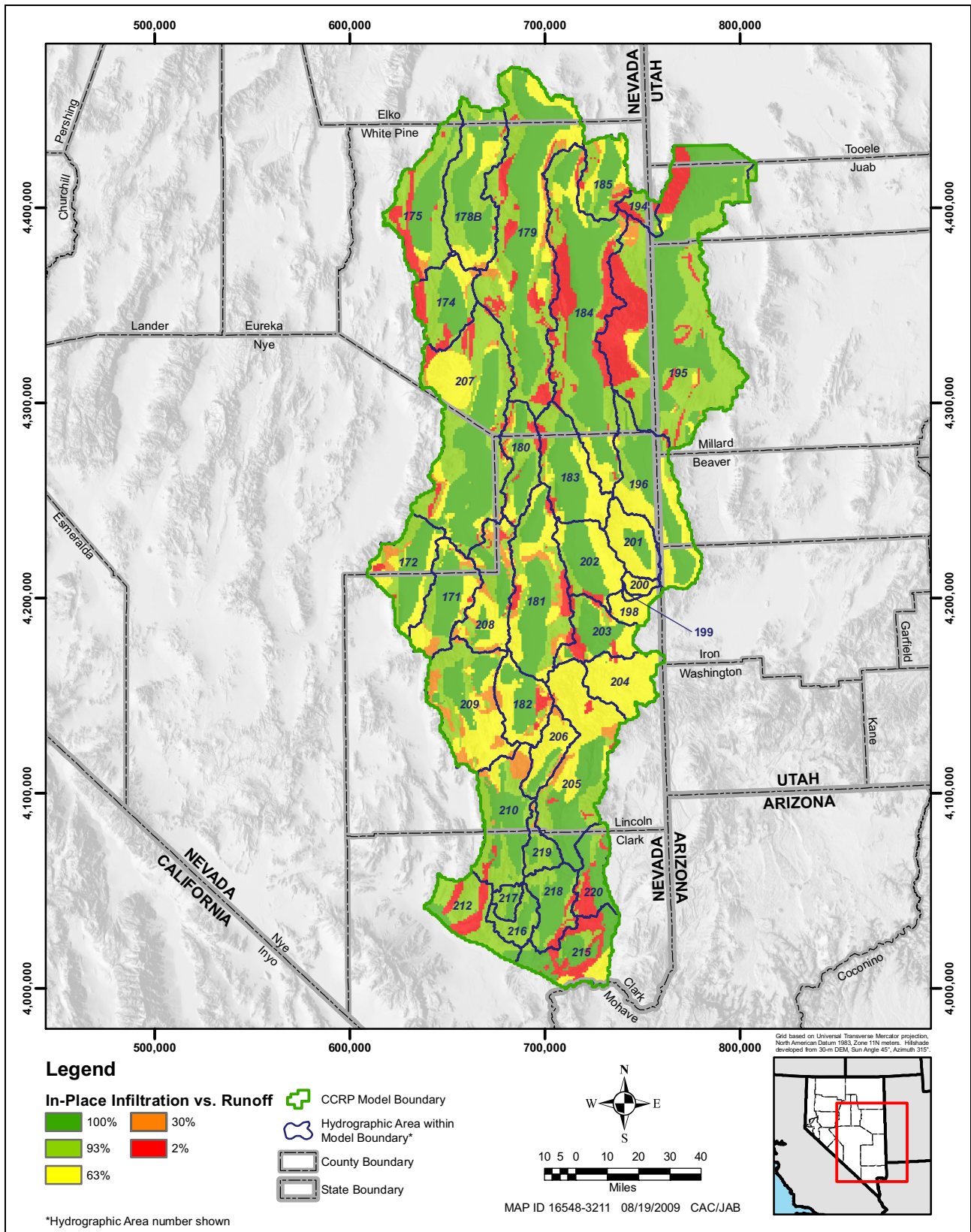


Figure 4-34
Distribution of Geologically Controlled Infiltration Zones

where the precipitation falls or can runoff to lower ground. Above a catchment point, though, no runoff water is allowed to infiltrate into another cell. In other words, all runoff in a watershed will accumulate at the catchment point.

From each catchment point, a distribution path is defined. Typically, the distribution path extends from the valley bottom where at least four cells extend into the UVF. This distribution path could be 4 cells long or as long as 40 cells. If the distribution path overlies non-UVF material, no infiltration occurs along the segment. A distribution path can contain multiple infiltration segments. [Figure 4-35](#) shows a set of catchment points and redistribution routes in the south Snake Valley area. A linear algorithm was used to distribute the runoff volume in the catchment along the distribution path. In other words, the total runoff volume at a catchment point was equally allocated to cells along the distribution path. [Figure 4-36](#) shows the redistributed runoff recharge.

4.5.3.4 Recharge Distribution (Step 4)

The recharge distribution grid used as the input to MODFLOW-2000 is obtained by adding the in-place recharge grid and the distributed runoff recharge grid ([Figure 4-37](#)). The grid and associated parameters are described in this section.

The total recharge in a grid cell is the sum of in-place and runoff recharge. In-place recharge is dependent on the RE and hydrogeologic factors described earlier, which are treated as UCODE_2005 parameters. Before MODFLOW-2000 is started by UCODE_2005, a new MODFLOW-2000 cell-by-cell recharge rate array (RCH) is calculated. This approach allows UCODE_2005 to estimate sensitivities and optimal values for these parameters.

Some constraints are placed on these parameters. The hydrogeologic factors (in-place recharge as percent of potential recharge) were set to range between 0 and 100 percent. RE were set to increase with precipitation following a step-function. Specifically, RE for lower precipitation zones were required to be less than or equal to RE for higher precipitation zones.

4.5.4 Transient Recharge

Because of the lack of accurate time-variant data, recharge was based on average annual rates, and those rates were held constant during the entire modeling period. As a result, while seasonal fluctuations, drought, and wet periods were observed in some areas, such as Steptoe Valley, the model was not set up to represent those fluctuations.

4.6 Anthropogenic Stresses

Two types of anthropogenic stresses were applied to the numerical model: well pumping and stream diversions. The influences of Lake Mead were considered as a predevelopment condition. Predevelopment conditions were assumed to prevail before 1945. Under predevelopment conditions, while there was some groundwater use by humans within the model area, it was assumed to be minimal. Pre-1945 conditions were modeled as steady state with no pumping and no stream diversions. As discussed in [Appendix C](#), groundwater was used consumptively for irrigation, mining,

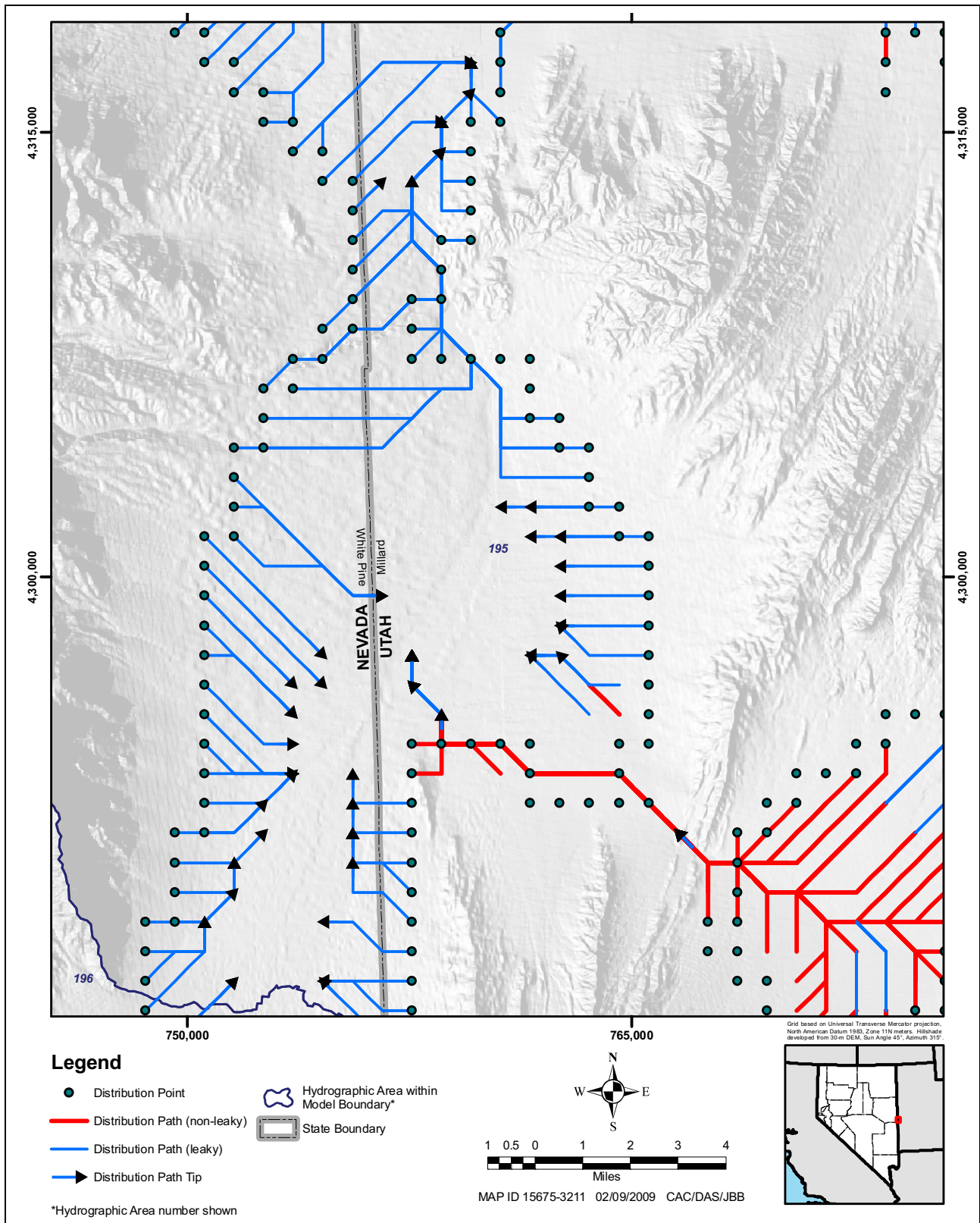


Figure 4-35
Redistributed Recharge, In-Place Recharge, and
Total Recharge in the Snake Valley and Vicinity

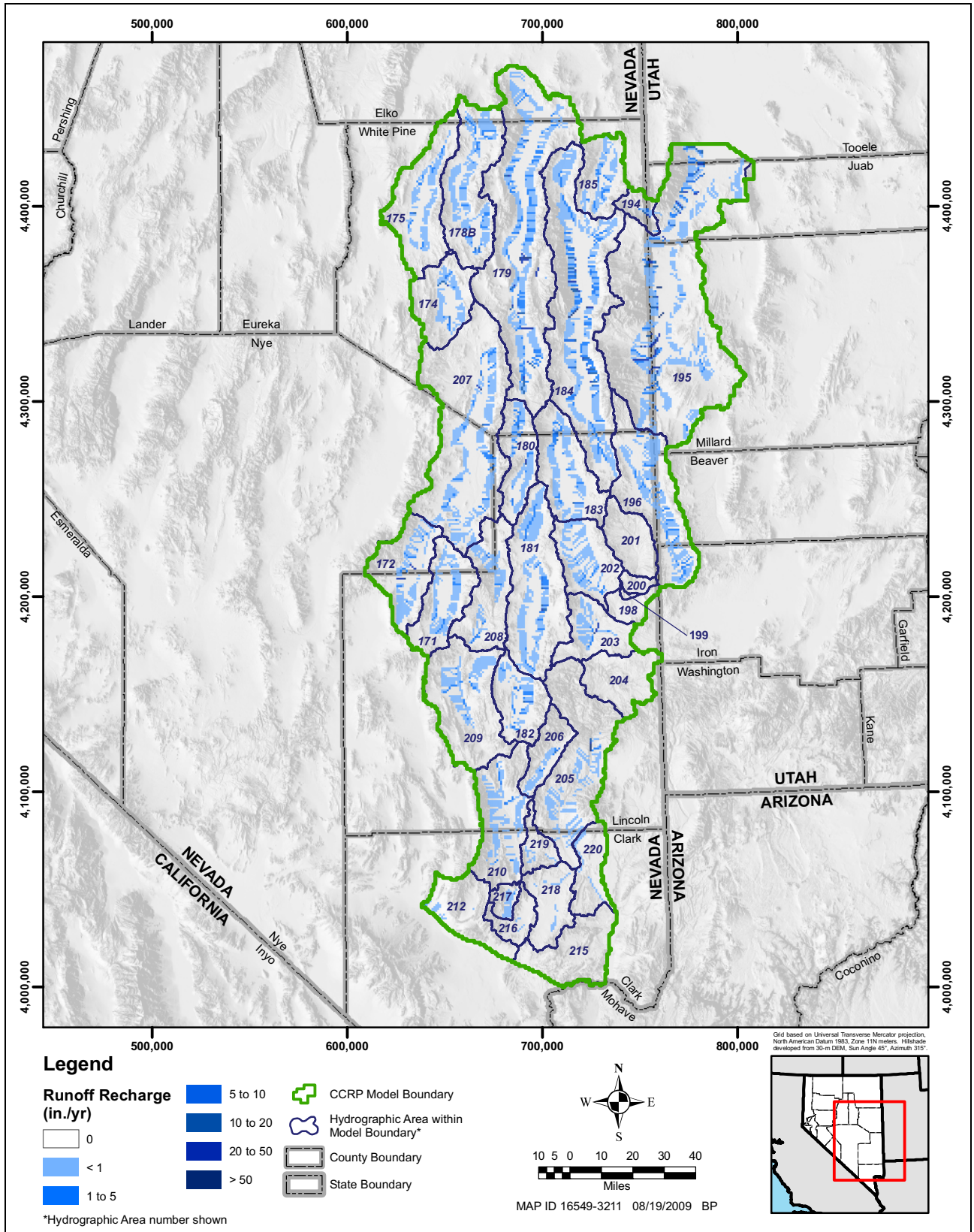


Figure 4-36
Redistributed Runoff Recharge

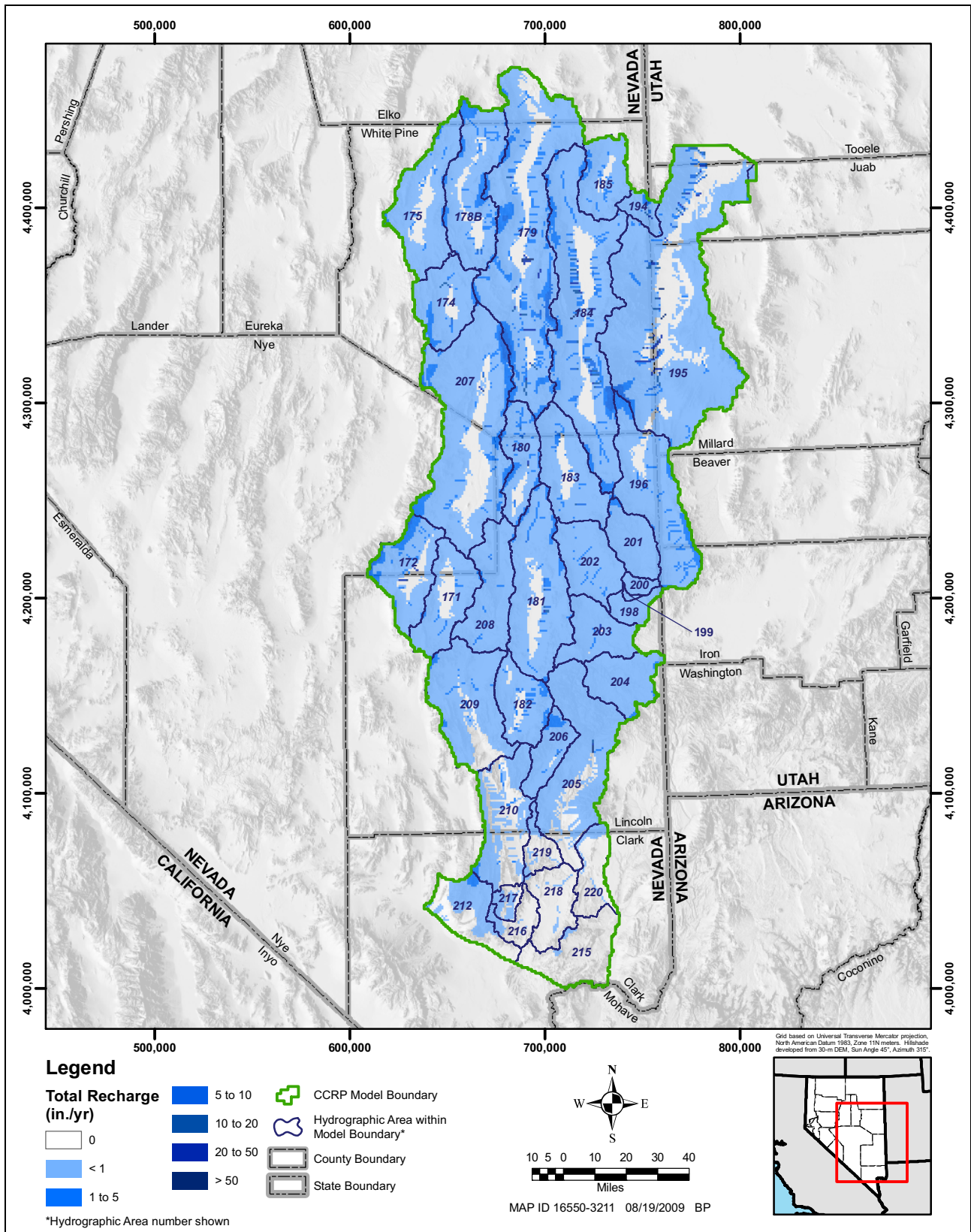


Figure 4-37
Distribution of Total Recharge (Input to MODFLOW-2000)

municipal, and industrial purposes. These uses are all tied either to a point of diversion (POD) permitted by NDWR or UDWR or known well or diversion locations. The minimum stress period is one year.

4.6.1 Well Pumping

The MODFLOW Multi-Node Well (MNW) (Halford and Hanson, 2002) module was used to simulate all pumping wells. The MNW module was used because pumping from a single well could be distributed over multiple model layers, and the MNW module would properly apportion pumping to each model layer based on the layer material properties and relative saturated thickness. The pumping rates were as defined in [Appendix C](#) and are provided in the MNW input file on the DVD. The estimation of the screened intervals and identification of perched wells are discussed below.

4.6.1.1 Estimation of Screened Intervals

For many of the wells assigned as PODs, the ground-surface elevation and the screened interval(s) were described in driller's logs. This information was required to define the model layers from which water should be extracted. For some wells, either the ground-surface elevation was missing or the screened interval information was not available. In these cases, the screened interval elevations were estimated using one of the following rules:

- Rule 1: If the well elevation was unknown, the elevation was approximated based on 98.4 ft (30 m) USGS DEM data.
- Rule 2: Where available, screen top and screen bottom were based on original driller's logs. In cases where the vertical spacing between multiple interval records was insignificant, the multiple screened intervals were merged into a single screened interval.
- Rule 3: For wells with missing screened interval information, the nearest well screened in a similar unit (UC, LC, etc.), with known screen-depth information was found. If a well with known screen-depth information was within 3.1 mi (5 km) and within the same hydrographic basin, screen-depth information from a neighboring well was used to calculate screen elevations.
- Rule 4: For wells not meeting rules 1, 2, or 3, the screen top was assumed to be at ground-surface elevation. The screen bottom was assumed to be at ground-surface elevation minus the maximum screen depth from wells within its hydrographic basin.

A saturated screen thickness was calculated as a check to ensure that the assumptions described above yielded an estimated screen interval with sufficient saturated thickness. The screen bottom elevation was subtracted from the simulated steady-state stress period water table to estimate the saturated screen thickness. [Figure 4-38](#) shows the distribution of saturated screen thicknesses estimated by the method described above. [Figure 4-39](#) illustrates each POD and the rule used to estimate the screen interval information for the well.

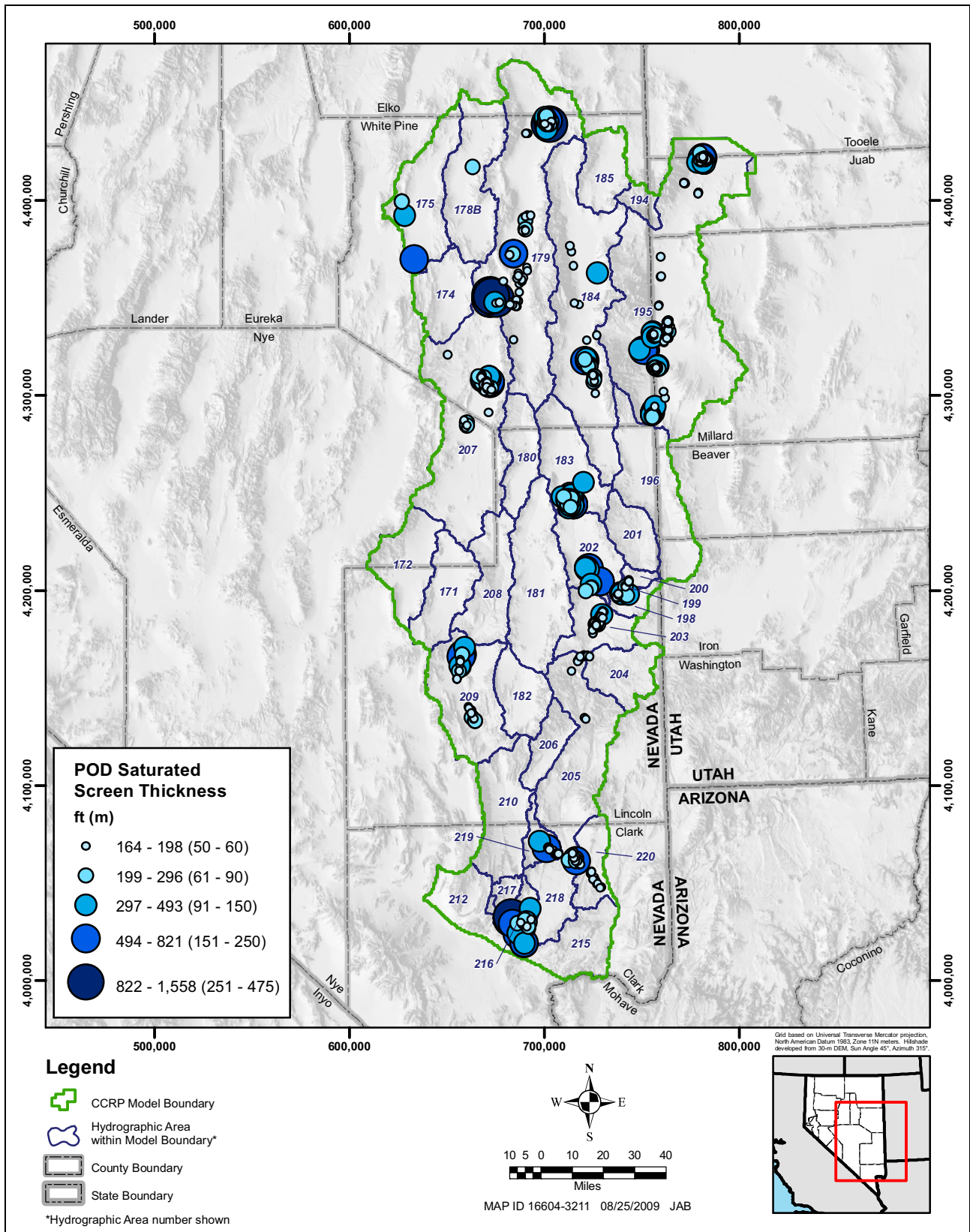


Figure 4-38
Pumping Well Saturated Screen Thickness

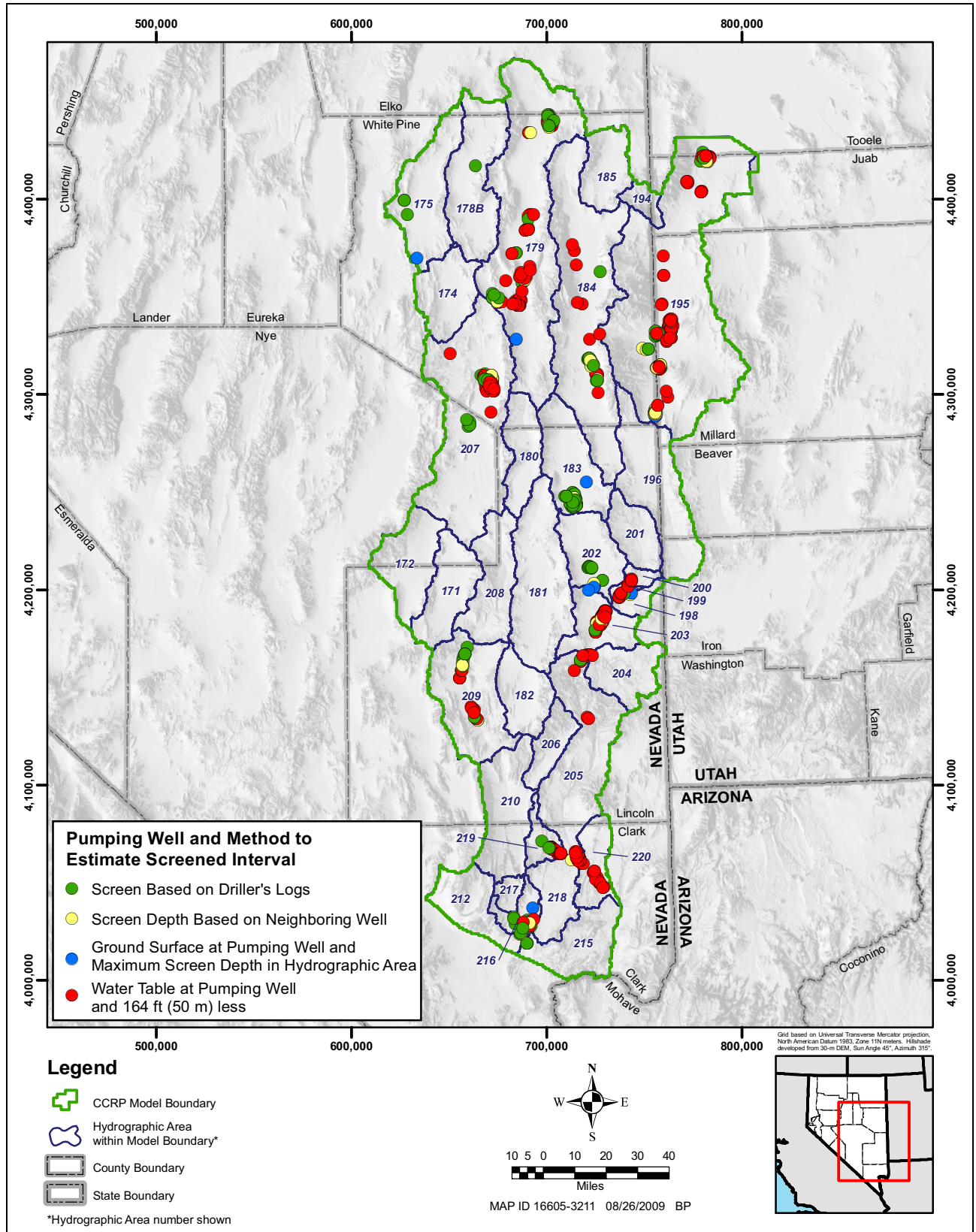


Figure 4-39
Method Used to Estimate Pumping Well Screened Interval

4.6.1.2 Perched Wells

Several pumping wells (Table 4-24) in the study area were not included in the numerical model. These wells were removed because they appeared to be in perched aquifer systems, typically located within unconsolidated materials not represented in the framework model.

**Table 4-24
Pumping Wells Not Included in the Numerical Model**

Eliminated Pumping Well	HA	Reason
WU_179_MM_1	179 (Steptoe Valley)	Groundwater diversion in Duck Creek for mine related operations.
WU194_IRR_1	194 (Pleasant Valley)	Well in perched, unconsolidated deposits not represented in model.
WU194_IRR_2		
WU204_IRR_6	204 (Clover Valley)	
WU204_IRR_8		
WU207_IRR_12	207 (White River Valley)	
WU207_IRR_16		
WU207_IRR_17		
WU207_IRR_19		

4.6.2 Stream Diversions

While there are a number of ditch and pipe diversions from springs and streams in the model area, only three stream PODs were evaluated. These were along the Muddy River near Pipeline Jones Spring, Baldwin Spring, and just upstream of the Muddy River near Moapa gage. The diverted flows were as large as 3,468.5 afy (11,713 m³/d).

These diversions were represented in the numerical model using the SFR2 module (Table 4-14). When water was diverted, if data available, the diversion amount was removed from the channel and removed from the model.

4.7 Observation Data

Several types of observations, including external boundary flows, hydraulic heads, groundwater ET, spring discharge, stream flow gages, and ground-surface elevations, were used in the numerical model. These observations and their corresponding weights were used by MODFLOW-2000 and UCODE_2005 during parameter estimation to provide values to define the objective function for the model simulation. Observation weights in MODFLOW-2000 and UCODE_2005 were derived from measures of uncertainty specified either as the variance, standard deviation, or COV. The observation data set for boundary flows, hydraulic heads, groundwater discharges (ET and spring flows), and stream discharges are described below.

4.7.1 Steady-State and Transient Observations

Observation wells were divided into steady-state and transient observations. Table 4-25 summarizes the observation types used for calibration statistics. External boundary flows, groundwater ET, and most small-spring observations were treated as steady-state observations. An observation was treated as a steady-state target if there was no specific time reference associated with the data, the data was pre-1945, or the estimate was specifically estimated as a predevelopment target.

**Table 4-25
Observation Types Used for Calibration
and SoSWR Statistics**

Observation Type	Observations	
	Steady-State	Transient
External Boundary Flux	X	---
ET Discharge	X	---
Ground-Surface Mounding	X	---
Hydraulic Heads	X	X
Spring Flows	X	X
Spring Heads	---	---
Stream Gage Flows	X	X

4.7.2 External Boundary Flow Observations

Estimates of flow across external model boundaries are presented in SNWA (2009a). These estimates represent flow-observation calibration targets for the steady-state stress period. These boundary flows are computed using the CHOB module.

At model cells assigned constant-head values, such as cells along constant-head boundaries, MODFLOW-2000 calculates the amount of flow to and from the cell required to keep the hydraulic head at that cell constant. Flow across a given face of a grid cell is calculated as the conductance times the hydraulic-head difference. These are the conductances of the material between the center of the constant-head cell and the center of the adjacent cell within the model domain. The hydraulic-head difference is also calculated between these two points.

In the numerical model, the external boundaries represented by constant hydraulic heads were used as groundwater-flow observations. The flow rates across these boundaries were constrained within an estimated range of values derived by SNWA (2009a). The cell conductances were treated as parameters during model calibration. The external boundary flow targets, errors, and observation names are listed in Table 4-26.

Table 4-26
External Boundaries, Observation Names,
Estimated Flow Targets, and Estimated Errors

Boundary Name	Observation Name	Estimated Boundary Flow into (+) out of (-) Model Domain afy (m ³ /d)	Standard Deviation afy (m ³ /d)
Goshute Flow System			
Butte South to Butte North	B_BUTTE_001	-1,000 (-3,377)	1,750 (5,910)
Steptoe to Goshute	B_STEPTO_001	-2,000 (-6,754)	2,000 (6,754)
Great Salt Lake Desert Flow System			
Snake to Tule	B_CONFUS_001	-15,000 (-50,656)	5,000 (16,885)
Snake to Fish Springs Flat	B_FISH_001	0 (0)	1,000 (3,377)
Snake to Great Salt Lake Desert (Carbonate)	B_NSNAKE_001	-9,375 (-31,660)	7,250 (24,484)
Snake to Wah Wah	B_SNAKEE_001	0 (0)	2,500 (8,443)
Snake to Pine	B_SNAKEW_001	0 (0)	2,500 (8,443)
Tippett to Antelope Valley (South) and Deep Creek Valley	B_TIPPET_001	-3,874 (-13,083)	6,500 (21,951)
White River Flow System			
Tikaboo to Coyote Spring Valley	B_COYOTE_001	5,000 (16,886)	2,750 (9,287)
Northwest Garden to Penoyer	B_GARDEN_001	0 (0)	1,000 (3,377)
Las Vegas Valley to Three Lakes Valley South	B_LASVEG_001	0 (0)	1,497 (5,057)
Black Mountains to Lake Mead	B_LM_BM_001	0 (0)	250 (844)
North Long to Ruby	B_LONGNW_001	-2,000 (-6,754)	2,000 (6,754)
North Long to Newark	B_LONGSW_001	-12,000 (-40,525)	3,000 (10,131)
Lower Moapa to Lake Mead	B_MOAPA_001	-11,000 (-37,148)	4,250 (14,353)
Pahranagat to Tikaboo Valley South	B_PAHRAN_001	-4,000 (-13,508)	3,000 (10,131)

4.7.3 Hydraulic-Head Observations

Appendix B presents the data set of hydraulic-head observations and variances that were used in calibrating the transient model. The distribution of hydraulic-head observation wells by aquifer material is presented in Figure 4-40.

Hydraulic-head observations were treated as both steady-state and transient observations. Only wells with pre-1945 observations, though, were defined as steady-state observations. For wells with multiple hydraulic-head observations, usually only the first observation was treated as a hydraulic-head observation. Generally, any following observation was treated as a drawdown observation. This was done because for many wells, there is much less measurement uncertainty in the change in hydraulic head over time than in the actual elevation of the well or the static water surface (many wells are only located to the nearest 1/4-1/4 section). In some wells, particularly in Steptoe Valley, multiple hydraulic-head observations were assigned for all of the water-level

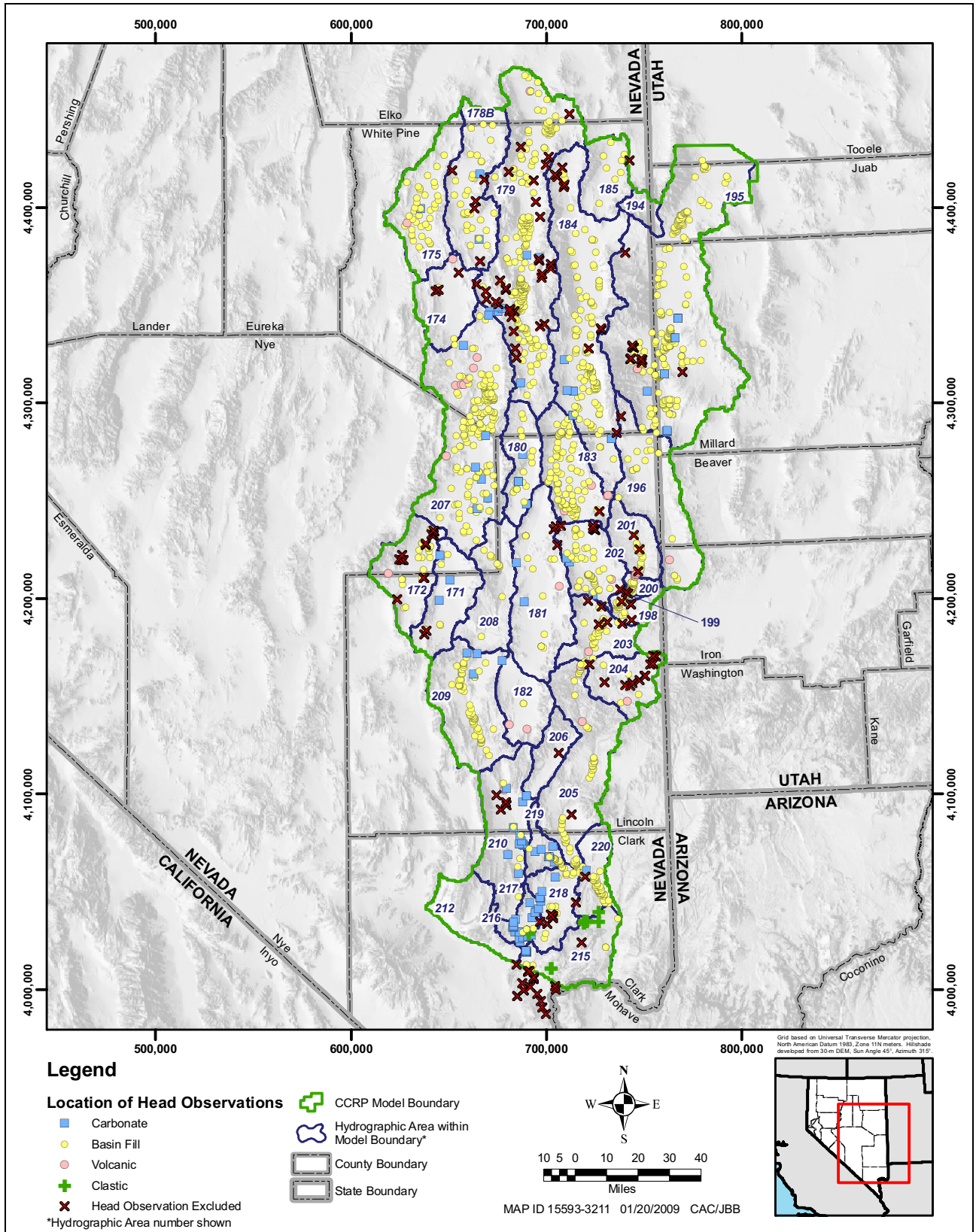


Figure 4-40
Distribution of Hydraulic-Head Observation Wells by Aquifer-Material Type

measurements at a well. This was done because the seasonal or longer-term climatic oscillations were more significant than the apparent drawdowns.

[Appendix B](#) provides a detailed listing of observation locations, target hydraulic heads, variances, rationale for variance calculations, and rationale for excluding the observation. Two variance adjustments were performed in addition to those described in [Appendix B](#):

- Where more than one hydraulic-head observation exists in a single cell, data declustering was performed. Each observation was retained; however, the variance of each observation was multiplied by the number of observations in the cell.
- Where a hydraulic-head observation is in an ET cell, the variance was set equal to the range of 30m DEM elevation within the 1 km² cell.

Throughout the calibration process, the observations with large weighted residuals were scrutinized. If reasons, as described above, existed in dictating the observation was suspect, the variance was increased or the observation was removed. [Figure 4-41](#) illustrates the spatial distribution of declustered observations. [Figure 4-42](#) illustrates the spatial distribution of resulting variances assigned to hydraulic-head observations.

4.7.4 Evapotranspiration Flow Observations

SNWA (2009a) presents an uncertainty analysis of groundwater ET estimates using a Monte Carlo simulation approach. [Table 4-27](#) lists the resulting ET observation targets, uncertainty, and model observation names represented in the numerical model. The MODFLOW-2000 DRN and SFR2 packages simulate ET discharge. The DROB package was used to extract ET discharge values from the DRN package. ET from Open Water (open water represented as streams) was extracted from the SFR2 package and added to Wetland ET components in corresponding hydrographic areas.

In larger basins, ET observation targets were developed at a sub-basin scale. These larger basins consist of two to five sub-basins. In the calibrated model, sub-basin divisions were applied to Lower Meadow Valley Wash and Steptoe, Snake, Spring (HA 184), and White River valleys. These sub-basins were beneficial in the accounting of groundwater discharge by ET. Observations in the Pahrnat sub-basins were aggregated to a single value for each ET type to simplify implementation and calibration related to the SFR2 package at Pahrnat Wash. Similarly, sub-basins 3 and 4 in Snake Valley were aggregated to simplify stream flow routing calibration at Big Springs. Sub-basin designations are presented in [Table 4-27](#).

Thus, simulated ET rates for these ET types may be elevated. However, with the uncertainty in the ET area, type, and rate information, this simplification is reasonable. With the integration of UCODE_2005, each cell's conductance could be modified to balance the different ET rates by coverage area. However, given the data uncertainties, this additional complexity was determined to be inappropriate for this regional-scale model.

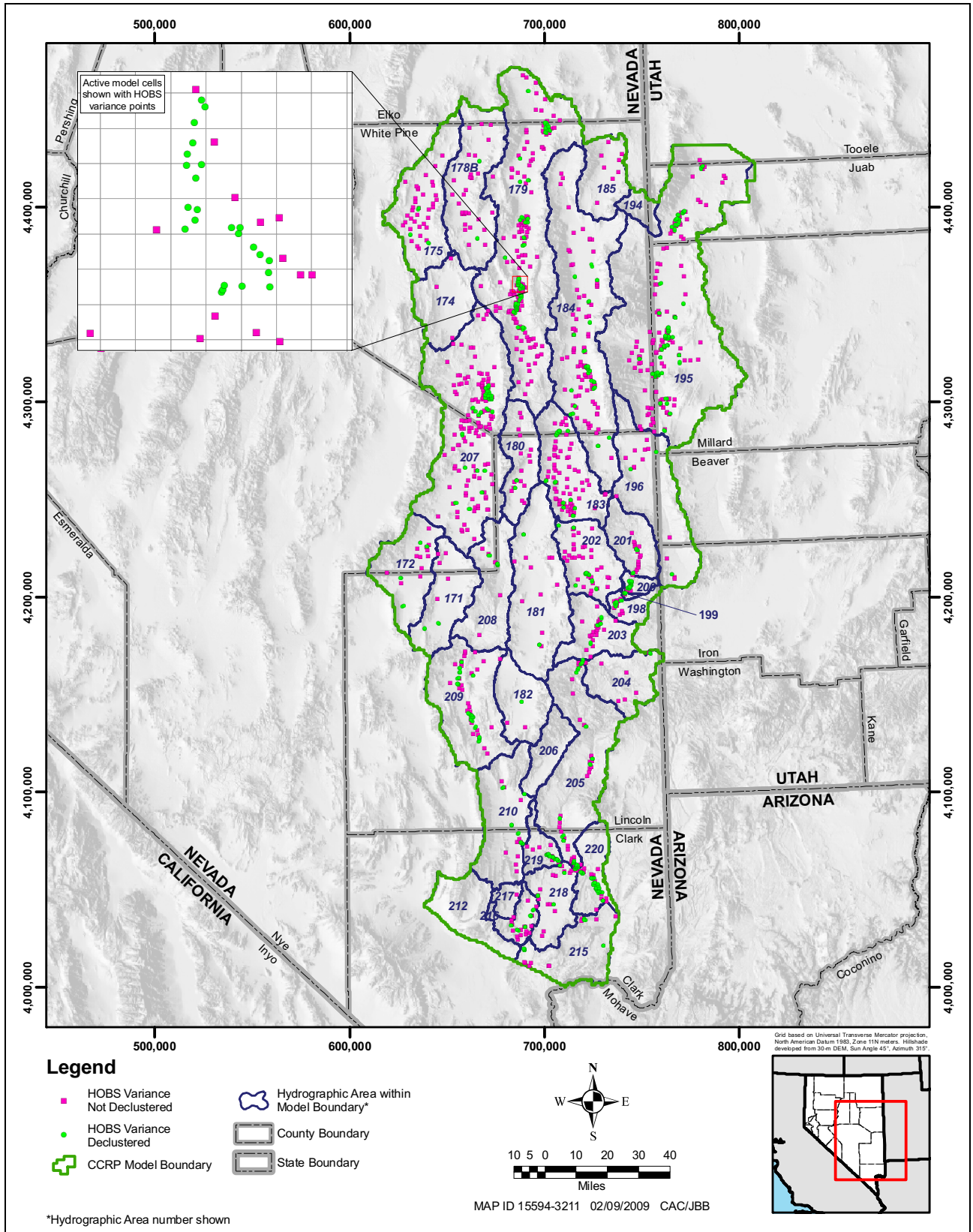


Figure 4-41
Distribution of Declustered Hydraulic-Head Observation Wells

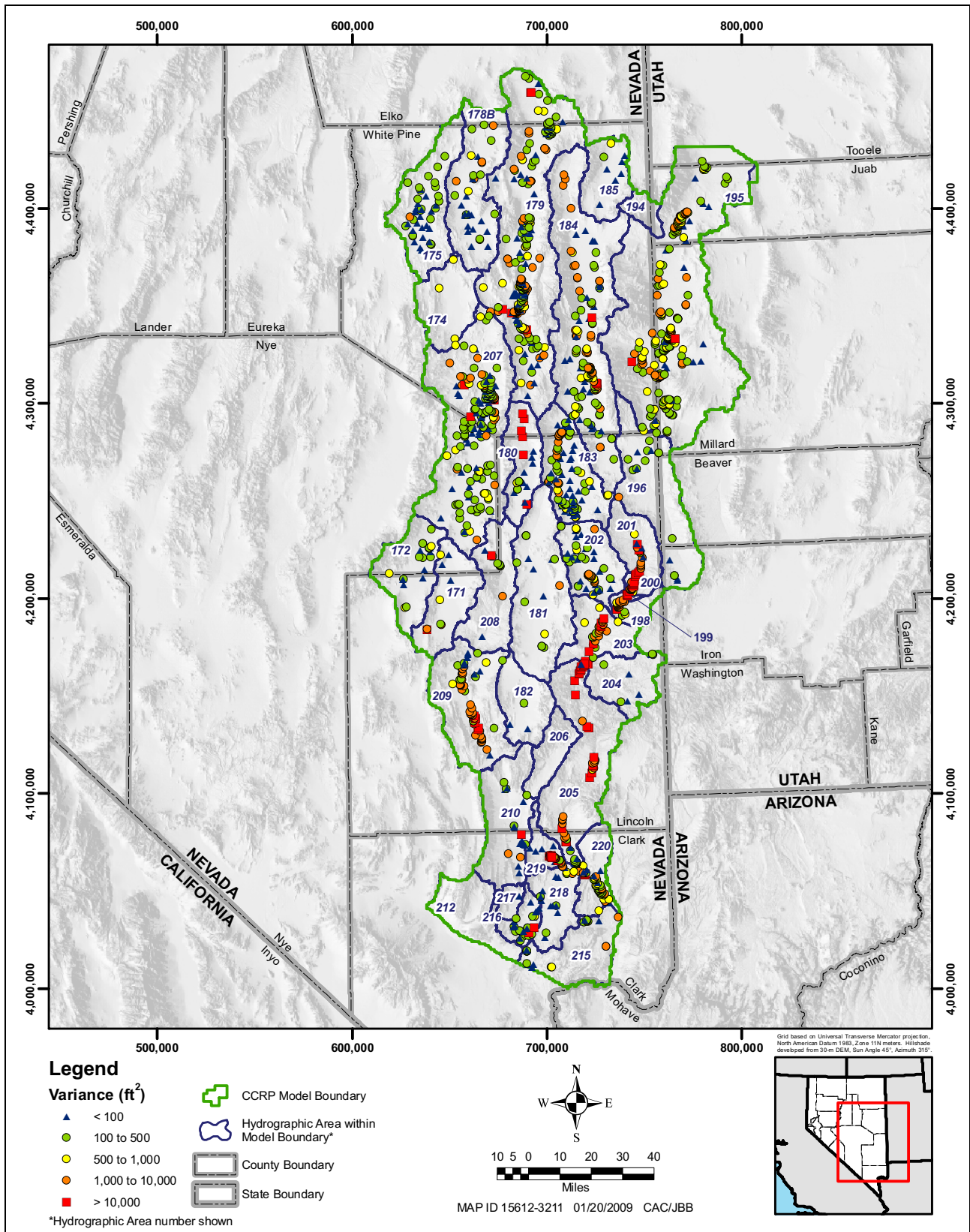


Figure 4-42
Distribution of Hydraulic-Head Observation Variances

Table 4-27
ET Observation Targets, Uncertainty, and Observation Names
 (Page 1 of 3)

HA Name	HA Number	Sub-Basin	ET Observation Name ^a	Observation	Standard Deviation
				afy (m ³ /d)	
Goshute Flow System					
Butte Valley (South)	178B	178B_1	ER78B_S_01	-10,185 (-34,395)	10,097 (34,099)
			ER78B_W_01	-1,559 (-5,266)	Deviation ^b
Step toe Valley	179	179_1	ER79a_P_01	-692 (-2,338)	441 (1,490)
			ER79a_S_01	-58,115 (-196,258)	25,380 (85,711)
			ER79a_W_01	-26,521 (-89,563)	4,708 (15,899)
		179_2	EI79b_S_01	-128 (-433)	296 (1,000)
			ER79b_H_01	-1,238 (-4,182)	296 (1,000)
			ER79b_W_01	-6,743 (-22,771)	1,325 (4,475)
ER79b_S_01	-2,815 (-9,507)	1,534(5,181)			
Meadow Valley Flow System					
Clover Valley	204	204_1	ER04_S_01	-225 (-759)	296 (1,000)
			ER04_W_01	-674 (-2,275)	296 (1,000)
Dry Valley	198	198_1	ER98_W_01	-1,394 (-4,706)	560 (1,890)
			ER98_S_01	-2,133 (-7,204)	826 (2,791)
Eagle Valley	200	200_1	ER00_S_01	-253 (-856)	296 (1,000)
			ER00_W_01	-780 (-2,635)	346 (1,170)
Lake Valley	183	183_1	ER83_S_01	-1,094 (-3,696)	1,207 (4,075)
			ER83_W_01	-4,743 (-16,018)	1,270 (4,289)
Lower Meadow Valley Wash	205	205_1	ER05a_S_01	-318 (-1,074)	296 (1,000)
			ER05a_W_01	-975 (-3,292)	757 (2,556)
		205_2	ER05b_S_01	-151 (-510)	296 (1,000)
			ER05b_W_01	-808 (-2,728)	721 (2,435)
		205_3	ER05c_S_01	-175 (-590)	296 (1,000)
			ER05c_W_01	-3,020 (-10,198)	2,194 (7,409)
		205_4	ER05d_W_01	-1,161 (-3,920)	761 (2,570)
			ER05d_S_01	-55 (-185)	296 (1,000)
205_5	ER05e_W_01	-1,899 (-6,414)	1,228 (4,147)		
	ER05e_S_01	-1,107 (3,737)	675 (2,280)		
Panaca Valley	203	203_1	ER03_W_01	-11,226 (-37,912)	3,996 (13,496)
			ER03_S_01	-7,669 (-25,898)	2,627 (8,870)
Patterson Valley	202	202_1	ER02_S_01	-1,346 (-4,546)	523 (1,766)
Rose Valley	199	199_1	ER99_W_01	-441 (-1,491)	296 (1,000)
			ER99_S_01	-153 (-517)	296 (1,000)

Table 4-27
ET Observation Targets, Uncertainty, and Observation Names
 (Page 2 of 3)

HA Name	HA Number	Sub-Basin	ET Observation Name ^a	Observation	Standard Deviation
				afy (m ³ /d)	
Spring Valley	201	201_1	EI01_W_01	-82 (-278)	296 (1,000)
			ER01_H_01	-266 (-900)	296 (1,000)
			ER01_S_01	-955 (-3,225)	398 (1,346)
			ER01_W_01	-2,441 (-8,245)	1,064 (3,592)
Great Salt Lake Desert Flow System					
Hamlin Valley	196	196_1	EI96_S_01	-206 (-695)	296 (1,000)
			ER96_S_01	-1,744 (-5,888)	705 ^c (2,381)
Snake Valley	195	195_1	EI95a_S_01	-215 (-727)	296 (1,000)
			ER95a_P_01	-4,205 (-14,200)	4,400 (14,858)
			ER95a_W_01	-2,852 (-9,631)	419 (1,416)
			ER95a_S_01	-4,968 (-16,777)	2,343 (7,912)
		195_2	ER95b_W_01	-3,188 (-10,765)	480 (1,622)
			ER95b_S_01	-11,566 (-39,060)	3,735 (12,613)
		195_3	ER95c_P_01	-1,314 (-4,438)	884 (2,987)
			ER95c_S_01	-69,431 (-234,475)	25,638 ^c (86,581)
			EI95c_S_01	-248 (-836)	296 (1,000)
			ER95c_W_01	-8,787 (-29,675)	1,526 (5,155)
			EI95c_W_01	-558 (-1,883)	296 (1,000)
			ER95d_H-01	-1,344 (-4,539)	296 (1,000)
ER95d_S_01	-11,613 (-39,217)	4,780 (16,143)			
ER95d_W_01	-6,643 (-22,433)	1,105 (3,732)			
Spring Valley	184	184_1	ER84a_S_01	-994 (-3,356)	458 (1,546)
			EI84a_S_01	-96 (-324)	296 (1,000)
			ER84a_W_01	-1,608 (-5,431)	296 (1,000)
		184_2	ER84b_P_01	-5,500 (-18,575)	2,613 (8,825)
			ER84b_S_01	-19,612 (-66,230)	8,654 (29,227)
			ER84b_W_01	-13,056 (-44,092)	2,156 (7,282)
		184_3	ER84c_S_01	-7,527 (-25,418)	3,817 (12,889)
		184_4	ER84d_S_01	-19,297 (-65,168)	10,207 (34,469)
ER84d_W_01	-6,695 (-22,609)		1,127 (3,807)		
Tippett Valley	185	185_1	ER85_S_01	-1,617 (-5,462)	1,186 (4,006)
White River Flow System					
Black Mountains Area	215	215_1	ER15_W_01	-567 (-1,915)	296 (1,000)
			ER15_S_01	-865 (-2,923)	296 (1,000)

Table 4-27
ET Observation Targets, Uncertainty, and Observation Names
 (Page 3 of 3)

HA Name	HA Number	Sub-Basin	ET Observation Name ^a	Observation	Standard Deviation
				afy (m ³ /d)	
California Wash	218	218_1	ER18_S_01	-517 (-1,746)	296 (1,000)
			ER18_W_01	-3,988 (-13,468)	1,119 (3,778)
Cave Valley	180	180_1	ER80_W_01	-1,135 (-3,831)	361 (1,218)
			ER80_S_01	-56 (-188)	296 (1,000)
			EI80_S_01	-395 (-1,334)	458 (1,548)
Garden Valley	172	172_1	ER72_S_01	-907 (-3,062)	333 (1,124)
			ER72_W_01	-226 (-764)	296 (1,000)
Long Valley	175	175_1	EI75_S_01	-71 (-240)	296 (1,000)
			ER75_S_01	-2,236 (-7,550)	2073 (7,001)
Lower Moapa Valley	220	220_1	ER20_H_01	-1,182 (-3,993)	296 (1,000)
			ER20_S_01	-3,410 (-11,515)	907 (3,065)
			ER20_W_01	-20,719 (-69,972)	5,833 (19,698)
Muddy River Springs Area	219	219_1	ER19_S_01	-795 (-2,686)	296 (1,000)
			ER19_W_01	-5,193 (-17,538)	1,477 (4,987)
Pahranagat Valley	209	209_1	ER09a_H_01	-2,693 (-9,095)	375 (1,266) ^c
			ER09a_S_01	-722 (-2,437)	296 (1,000) ^c
			ER09a_W_01	-2,268 (-7,660)	715 (2,415) ^c
			ER09b_S_01	-816 (-2,756)	296 (1,000) ^c
			ER09b_W_01	-7,885 (-26,628)	2398 (8,098) ^c
			ER09c_H_01	-3,302 (-11,151)	449 (1,517) ^c
			ER09c_W_01	-2,308 (-7,795)	691 (2,333) ^c
			ER09d_H_01	-527 (-1,780)	296 (1,000) ^c
			ER09d_S_01	-184 (-620)	296 (1,000) ^c
			ER09d_W_01	-,2492 (-8,415)	735 (2,482) ^c
			ER09e_H_01	-2,686 (-9,072)	358 (1,208) ^c
			ER09e_S_01	-321 (-1,083)	296 (1,000) ^c
ER09e_W_01	-2063 (-6,966)	606 (2,046) ^c			
White River Valley	207	207_1	EI07a_S_01	-806 (-2,721)	562 (1,898)
			EI07a_W_01	-807 (-2,726)	296 (1,000)
			ER07a_S_01	-30,749 (-103,841)	21,444 (72,419)
		ER07a_W_01	-8,914 (-30,104)	2,467 (8,331)	
		207_2	ER07b_S_01	-19,455 (-65,701)	13,707 (46,290)
			ER07b_W_01	-11,528 (-38,931)	1,928 (6,511)

^aH = water; S = shrubs; W = wet

^bFor ET less than 1,000 afy, the standard deviation was set to 296.1 afy (1,000 m³/d).

^cStatistics calculated using coefficient of variation estimate described in the Conceptual Model Report (SNWA, 2009a).

A minimum 1,000-afy standard deviation was used, so relatively large errors for small ET discharge areas would not dominate the parameter estimation objective function or the Sum of Squared Weighted Residual (SoSWR).

4.7.5 Spring Flow Observations

Spring discharge targets were represented in the numerical model as ET observations and as spring discharge from a selected set of springs. [Table 4-28](#) defines how the spring discharge targets were represented in the numerical model. The two types are as follows:

- Spring flow represented as ET indicates spring discharge is aggregated with Wetland ET; spring flow was not used as an observation target.
- Spring flow represented as deep DRN cell indicates spring discharge target is aggregated with Wetland ET; spring discharge was used as an observation target. Springs represented as deep DRN cells are shown in [Figure 4-25](#) as regional or intermediate springs.

Most of the springs in the model have limited observation data. These springs were generally represented as steady-state targets. For the springs with transient data, the model attempted to match the target flows in time and ignored any estimated steady-state observation target. For transient springs with more than one annual average measurement, the first observation was a flow estimate. Subsequent observations were evaluated based on the change in flow. Note that for the springs modeled, none showed a discernible reduction in flow; hence, any significant change in flow simulated during model calibration was penalized by the calibration statistics. The Muddy River near Moapa gage was used to estimate flow out of the Muddy Spring Area. Representation of the Muddy River in the numerical model is discussed in [Section 4.7.6](#).

In addition to the spring discharge targets, spring pool elevations were specified as hydraulic-head observations to monitor head potential at each spring in the model. Specified errors for these observations were large, which effectively eliminated the observation from the objective function. In other words, pool hydraulic-head errors did not affect the model calibration or parameter-sensitivity calculations. For convenience, spring hydraulic-head observation names and targets are provided in [Table 4-28](#). Spring observation names in [Table 4-28](#) have embedded codes defining the following spring characteristics:

- r - Hot springs and warm regional springs
- iw - Intermediate warm springs
- ib - Large intermediate springs with > 1 cfs
- is - Small intermediate springs with < 1 cfs

These spring types and name characteristics determined how springs were represented in the model. The representation of springs in the model was as follows:

- Hot spring model cells (DRN or SFR2) extend from the ground surface to the bottom of the model

Table 4-28
CCRP Spring Types and Hydraulic-Head Observation Names and Targets
 (Page 1 of 2)

Spring Name	Model Type ^a	Target Type ^b	Spring Type ^c	Head Observation Name ^d	Observation ft amsl (m amsl)
Deadman Spring	CHD	---	---	---	---
North Springs	CHD	---	---	---	---
Walter Spring	CHD	---	---	---	---
Wilson Hot Spring 1	CHD	---	---	---	---
Wilson Hot Spring 2	CHD	---	---	---	---
Wilson Hot Spring 3	CHD	---	---	---	---
Wilson Hot Spring 5	CHD	---	---	---	---
(C-11-14)4bbb-S1	DRN	1	---	Sis195_11	4,298.1 (1,310.0)
Arnoldson Spring	DRN	1	---	Siw207_2	5,625.3 (1,714.5)
Blind Spring	DRN	1	---	Sis184_9	5,773.2 (1,759.6)
Blue Point Spring	DRN	2	INT	Siw215_2	1,549.9 (472.4)
Brownie Spring	DRN	1	---	Sis209_4	3,695.1 (1,126.2)
Butterfield Spring	DRN	1	---	Sib207_10	5,320.1 (1,621.5)
Caine Spring	DRN	1	---	Sis195_3	5,028.1 (1,532.5)
Cherry Creek Hot Springs	DRN	1	---	Sr179_2	6,250.6 (1,905.1)
Cold Spring	DRN	1	---	Siw207_3	5,653.2 (1,723.0)
Cold Spring	DRN	1	---	Sis195_10	4,310.2 (1,313.7)
Cold Spring	DRN	1	---	Sis179_4	5,958.0 (1,815.9)
Emigrant Springs	DRN	1	---	Sib207_15	5,480.3 (1,670.3)
Flag Springs 1	DRN	---	---	Siw207_9	5,290.3 (1,612.4)
Flag Springs 2	DRN	---	---	Siw207_8	5,280.1 (1,609.3)
Flag Springs 3	DRN	1	---	Siw207_7	5,290.3 (1,612.4)
Foote Res. Spring	DRN	1	---	Sib195_12	4,825.4 (1,470.7)
Four Wheel Drive Spring	DRN	1	---	Sis184_11	5,754.2 (1,753.8)
Hardy Spring NW	DRN	---	---	Sis207_12	5,345.4 (1,629.2)
Hardy Springs	DRN	1	---	Sis207_11	5,354.3 (1,631.9)
Hot Creek Spring	DRN	2	REG	Sr207_1	5,225.3 (1,592.6)
Keegan Spring	DRN	1	---	Sis184_12	5,617.4 (1,712.1)
Kell Spring	DRN	1	---	Sis195_13	4,910.3 (1,496.6)
Knoll Spring	DRN	1	---	Sis195_4	4,869.3 (1,484.1)
Layton Spring	DRN	1	---	Sis184_7	5,698.4 (1,736.8)
Lund Spring	DRN	2	INT	Sib207_5	5,608.2 (1,709.3)
McGill Spring	DRN	2	INT	Siw179_1	6,104.3 (1,860.5)
Minerva Spring	DRN	1	---	Sis184_13	5,825.4 (1,775.5)
Monte Neva Hot Springs	DRN	1	---	Sr179_3	6,011.4 (1,832.2)
Moon River Spring	DRN	2	REG	Sr207_14	5,223.4 (1,592.0)
Moorman Spring	DRN	2	REG	Sr207_6	5,299.1 (1,615.1)
Nicholas Spring	DRN	1	---	Siw207_13	5,635.4 (1,717.6)
North Millick Spring	DRN	1	---	Sis184_3	5,590.2 (1,703.8)

Table 4-28
CCRP Spring Types and Hydraulic-Head Observation Names and Targets
 (Page 2 of 2)

Spring Name	Model Type ^a	Target Type ^b	Spring Type ^c	Head Observation Name ^d	Observation ft amsl (m amsl)
North Spring	DRN	1	---	Siw184_8	5,763.4 (1,756.6)
Osborne Springs	DRN	1	---	Sis184_10	6,127.0 (1,867.5)
Panaca Spring	DRN	2	REG	Sr203_1	4,799.0 (1,462.7)
Preston Big Spring	DRN	2	REG	Sr207_4	5,732.0 (1,747.1)
Rogers Spring	DRN	2	INT	Siw215_1	1,594.2 (485.9)
South Bastian Spring	DRN	1	---	Sis184_5	5,660.4 (1,725.2)
South Bastian Spring 2	DRN	1	---	Sis184_6	5,669.0 (1,727.9)
South Millick Spring	DRN	1	---	Sib184_4	5,592.0 (1,704.4)
Stonehouse Spring	DRN	1	---	Sis184_14	6,256.2 (1,906.8)
The Seep	DRN	1	---	Siw184_15	5,764.4 (1,756.9)
Twin Spring	DRN	1	---	Sib195_15	4,826.6 (1,471.1)
Unnamed 5 Spring	DRN	1	---	Sis184_16	5,645.3 (1,720.6)
Unnamed Spring	DRN	1	---	Sis195_14	4,853.3 (1,479.2)
Warm Creek near Gandy, UT	DRN	2	INT	Siw195_2	5,156.4 (1,571.6)
Willard Springs	DRN	1	---	Sis184_2	5,755.2 (1,754.1)
Willow Spring	DRN	1	---	Siw184_1	5,982.2 (1,823.3)
Ash Springs	SFR2	2	REG	Sr209_3	3,622.2 (1,104.0)
Baldwin Spring	SFR2	2	REG	Sr219_4	1,798.0 (548.0)
Big Springs	SFR2	2	INT	Sib195_1	5,568.2 (1,697.1)
Crystal Springs	SFR2	2	REG	Sr209_2	3,803.3 (1,159.2)
Hiko Spring	SFR2	2	REG	Sr209_1	3,875.2 (1,181.1)
Jones Spring	SFR2	2	REG	Sr219_3	1,784.2 (543.8)
M-10	SFR2	2	REG	Sr219_14	1,722.2 (524.9)
M-11	SFR2	2	REG	Sr219_6	1,800.0 (548.6)
M-12	SFR2	2	REG	Sr219_7	1,800.0 (548.6)
M-13	SFR2	2	REG	Sr219_8	1,800.0 (548.6)
M-15	SFR2	2	REG	Sr219_9	1,780.0 (542.5)
M-16	SFR2	2	REG	Sr219_10	1,780.0 (542.5)
M-19	SFR2	2	REG	Sr219_11	1,800.0 (548.6)
M-20	SFR2	2	REG	Sr219_12	1,778.0 (541.9)
Muddy Spring	SFR2	2	REG	Sr219_5	1,747.0 (532.5)
Pederson East Spring	SFR2	2	REG	Sr219_1	1,800.0 (548.6)
Pederson Spring	SFR2	2	REG	Sr219_2	1,811.0 (552.0)
Warm Springs East	SFR2	2	REG	Sr219_13	1,790.0 (545.6)

^aDRN: MODFLOW-2000 Drain package; SFR2: MODFLOW-2000 Streamflow-Routing package; CHD: MODFLOW-2000 Constant-Head package.

^b1: Spring flow represented as ET; 2: Spring represented as deep DRN cell. Deep spring flow aggregated with ET observation.

^cREG: Regional flow system designation; INT: Intermediate flow system designation.

^dSpring head observation names. Head observations used for monitoring purposes only.

- Regional, intermediate warm and large intermediate spring model cells extend from the ground surface to the bottom of the deepest layer containing a carbonate RMU
- Small intermediate spring model cells are defined in the uppermost model layers.

Table 4-29 also identifies key regional and intermediate springs, represented by DRN cells, that were used as flow observation targets to provide additional constraints on the model. The MODFLOW-2000 DROB module was used to extract spring discharges from springs modeled using the DRN module.

4.7.6 Stream Discharge Flow Observations

The SFR2 package added additional flexibility to the model, allowing groundwater to leave the aquifer system as spring discharge but still interact with the aquifer and the ET areas. Diversions directly from the river are also supported. Four types of observations were of interest: (1) spring discharge, (2) surface water remaining at the end of the stream, (3) gaining and losing river sections, and (4) gaining and losing river sections.

The SFR2 package calibration targets, errors, and observation names are listed in Tables 4-30, 4-31, and 4-32 for Muddy River, Pahrnagat Wash, and Big Springs stream reaches, respectively. As discussed in Section 4.4.4.2.1, springs modeled using the SFR2 package incorporate a vertical stream segment to represent a spring. A gage is defined at the surface of the vertical reach. These gages monitor spring discharge before entering the main stream channel.

Fourteen springs in the Muddy River Springs Area were represented in the SFR2 module. The G_MR_MOAPA gage was used as the flow observation for these up-gradient springs. This simplification was necessary because of the model grid size and close proximity of springs in this area.

Zero flow rates were specified as targets at the end stream reaches in Lake Creek (G_LKCK_END) and Pahrnagat Wash (G_PAHW_7). Target flow at the final Muddy River reach is unknown. The USGS gage at Overton, Nevada, has flowed an average of approximately 9,900 afy (33,445 m³/d) since year 2000. Extensive irrigation in Lower Moapa Valley above the gage, however, makes this a questionable target for predevelopment conditions. The St. Thomas gage, located outside of the model domain near the confluence of the Muddy and Virgin rivers, operated before Lake Mead was filled. The groundwater component of the flows at the St. Thomas gage were estimated at 7,000 afy (24,000 m³/d) assuming about half of the stream flow in Water Years 1914-1916 were surface-water runoff. To constrain flows out of the Muddy River, a target of 7,403 afy (25,000 m³/d) was estimated. A large error, 5,000 afy (16,885 m³/d), was assigned to this observation (G_LK_MEAD) to account for the significant uncertainty.

**Table 4-29
Regional and Intermediate Springs Represented
by DRN Cells and Observation Targets**

Spring Name	DRN Observation Name	Date	Time	Spring Type ^a	Observation Type	Observation Target afy (m ³ /d)	Observation Standard Deviation afy (m ³ /d)
Blue Point Spring	SPiw15_2_01	12/31/1944	0:00	INT	Flow	-399 (-1,347)	60 (202)
Blue Point Spring	SDiw15_2_58	6/15/2001	6:00	INT	Flow	0 (0)	31 (104)
Blue Point Spring	SDiw15_2_59	6/15/2002	12:00	INT	Flow	0 (0)	25 (84)
Blue Point Spring	SDiw15_2_60	6/15/2003	18:00	INT	Flow	0 (0)	7 (23)
Blue Point Spring	SDiw15_2_61	6/15/2004	0:00	INT	Flow	0 (0)	11 (39)
Hot Creek Spring	SPr07_1_01	12/31/1944	0:00	REG	Flow	-10,184 (-34,392)	2,552 (8,618)
Lund Spring	SPib07_5_01	12/31/1944	0:00	INT	Flow	-5,675 (-19,165)	1,405 (4,746)
McGill Spring	SPiw79_1_01	12/31/1944	0:00	INT	Flow	-7,641 (-25,806)	1,185 (4,000)
Moon River Spring	SPr07_14_01	12/31/1944	0:00	REG	Flow	-2706 (-9,137)	927 (3,131)
Moorman Spring	SPr07_6_01	12/31/1944	0:00	REG	Flow	-843 (-2,848)	1,523 (5,144)
Panaca Spring	SPr03_1_01	12/31/1944	0:00	REG	Flow	-2,348 (-7,930)	2,707 (9,143)
Preston Big Spring	SPr07_4_01	12/31/1944	0:00	REG	Flow	-5,681 (-19,185)	852 (2,878)
Preston Big Spring	SDr07_4_41	6/14/1984	6:00	REG	Flow Change	0 (0)	349 (1,180)
Preston Big Spring	SDr07_4_58	6/15/2001	0:00	REG	Flow Change	0 (0)	129 (434)
Preston Big Spring	SDr07_4_59	6/15/2002	6:00	REG	Flow Change	0 (0)	194 (653)
Preston Big Spring	SDr07_4_60	6/15/2003	12:00	REG	Flow Change	0 (0)	231 (779)
Preston Big Spring	SDr07_4_61	6/14/2004	18:00	REG	Flow Change	0 (0)	361 (1,220)
Rogers Spring	SPiw15_1_01	12/31/1944	0:00	INT	Flow	-1,205 (-4,068)	181 (610)
Rogers Spring	SDiw15_1_44	6/15/1987	6:00	INT	Flow Change	0 (0)	137 (463)
Rogers Spring	SDiw15_1_45	6/14/1988	12:00	INT	Flow Change	0 (0)	60 (203)
Rogers Spring	SDiw15_1_46	6/14/1989	18:00	INT	Flow Change	0 (0)	115 (388)
Rogers Spring	SDiw15_1_47	6/15/1990	0:00	INT	Flow Change	0 (0)	122 (412)
Rogers Spring	SDiw15_1_48	6/15/1991	6:00	INT	Flow Change	0 (0)	68 (228)
Rogers Spring	SDiw15_1_49	6/14/1992	12:00	INT	Flow Change	0 (0)	152 (512)
Rogers Spring	SDiw15_1_50	6/14/1993	18:00	INT	Flow Change	0 (0)	170 (575)
Rogers Spring	SDiw15_1_51	6/15/1994	0:00	INT	Flow Change	0 (0)	50 (168)
Rogers Spring	SDiw15_1_52	6/15/1995	6:00	INT	Flow Change	0 (0)	85 (286)
Rogers Spring	SDiw15_1_53	6/14/1996	12:00	INT	Flow Change	0 (0)	65 (219)
Rogers Spring	SDiw15_1_54	6/14/1997	18:00	INT	Flow Change	0 (0)	94 (316)
Rogers Spring	SDiw15_1_55	6/15/1998	0:00	INT	Flow Change	0 (0)	31 (104)
Rogers Spring	SDiw15_1_56	6/15/1999	6:00	INT	Flow Change	0 (0)	55 (185)
Rogers Spring	SDiw15_1_57	6/14/2000	12:00	INT	Flow Change	0 (0)	49 (167)
Rogers Spring	SDiw15_1_58	6/14/2001	18:00	INT	Flow Change	0 (0)	44 (149)
Rogers Spring	SDiw15_1_59	6/15/2002	0:00	INT	Flow Change	0 (0)	8 (28)
Rogers Spring	SDiw15_1_60	6/15/2003	6:00	INT	Flow Change	0 (0)	22 (73)
Rogers Spring	SDiw15_1_61	6/14/2004	12:00	INT	Flow Change	0 (0)	36 (122)
Warm Creek near Gandy, UT	SPiw95_2_01	12/31/1944	0:00	INT	Flow	-12,027 (-40,616)	1,804 (6,092)

^aREG: Regional flow system designation; INT: Intermediate flow system designation

Table 4-30
Muddy River Gages, Discharge Targets, Errors, and Observation Names
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Gage Name	Observation Name	Date	Observation Type	Segment	Reach	Calibration Target afy (m ³ /d)	Standard Deviation afy (m ³ /d)
Warm Springs West	G_WARM_SW_01	12/31/1944	Flow	2	1	NA	NA
Iverson Flume	G_IVERSON_01	12/31/1944	Flow	13	1	NA	NA
Muddy River near Moapa	GdmrMOAPA_02	6/15/1945	Flow	5	2	33,386 (112,747)	5,008 (16,912)
Muddy River near Moapa	GdmrMOAPA_03	6/15/1946	Flow	5	2	33,928 (114,577)	5,089 (17,186)
Muddy River near Moapa	GdmrMOAPA_04	6/15/1947	Flow	5	2	34,223 (115,575)	5,134 (17,336)
Muddy River near Moapa	GdmrMOAPA_05	6/15/1948	Flow	5	2	33,513 (113,176)	5,027 (16,976)
Muddy River near Moapa	GdmrMOAPA_06	6/15/1949	Flow	5	2	34,092 (115,133)	5,114 (17,270)
Muddy River near Moapa	GdmrMOAPA_07	6/15/1950	Flow	5	2	33,314 (112,506)	4,997 (16,876)
Muddy River near Moapa	GdmrMOAPA_08	6/15/1951	Flow	5	2	34,108 (115,187)	5,116 (17,278)
Muddy River near Moapa	GdmrMOAPA_09	6/15/1952	Flow	5	2	34,001 (114,825)	5,100 (17,224)
Muddy River near Moapa	GdmrMOAPA_10	6/15/1953	Flow	5	2	33,207 (112,144)	4,981 (16,822)
Muddy River near Moapa	GdmrMOAPA_11	6/15/1954	Flow	5	2	33,173 (112,030)	4,976 (16,804)
Muddy River near Moapa	GdmrMOAPA_12	6/15/1955	Flow	5	2	33,756 (113,997)	5,063 (17,100)
Muddy River near Moapa	GdmrMOAPA_13	6/15/1956	Flow	5	2	33,179 (112,050)	4,977 (16,807)
Muddy River near Moapa	GdmrMOAPA_14	6/15/1957	Flow	5	2	35,122 (118,612)	5,268 (17,792)
Muddy River near Moapa	GdmrMOAPA_15	6/15/1958	Flow	5	2	34,809 (117,553)	5,221 (17,633)
Muddy River near Moapa	GdmrMOAPA_16	6/15/1959	Flow	5	2	35,672 (120,468)	5,351 (18,070)
Muddy River near Moapa	GdmrMOAPA_17	6/15/1960	Flow	5	2	34,255 (115,683)	5,138 (17,352)
Muddy River near Moapa	GdmrMOAPA_18	6/15/1961	Flow	5	2	32,014 (108,115)	4,802 (16,217)
Muddy River near Moapa	GdmrMOAPA_19	6/15/1962	Flow	5	2	31,963 (107,941)	4,794 (16,191)
Muddy River near Moapa	GdmrMOAPA_20	6/15/1963	Flow	5	2	32,782 (110,709)	4,917 (16,606)
Muddy River near Moapa	GdmrMOAPA_21	6/15/1964	Flow	5	2	31,667 (106,942)	4,750 (16,041)
Muddy River near Moapa	GdmrMOAPA_22	6/15/1965	Flow	5	2	31,258 (105,561)	4,689 (15,834)
Muddy River near Moapa	GdmrMOAPA_23	6/15/1966	Flow	5	2	30,196 (101,976)	4,529 (15,296)
Muddy River near Moapa	GdmrMOAPA_24	6/15/1967	Flow	5	2	30,225 (102,073)	4,534 (15,311)
Muddy River near Moapa	GdmrMOAPA_25	6/15/1968	Flow	5	2	29,617 (100,018)	4,443 (15,003)
Muddy River near Moapa	GdmrMOAPA_26	6/15/1969	Flow	5	2	30,422 (102,736)	4,563 (15,410)
Muddy River near Moapa	GdmrMOAPA_27	6/15/1970	Flow	5	2	28,855 (97,444)	4,328 (14,617)
Muddy River near Moapa	GdmrMOAPA_28	6/15/1971	Flow	5	2	28,295 (95,554)	4,244 (14,333)
Muddy River near Moapa	GdmrMOAPA_29	6/15/1972	Flow	5	2	30,548 (103,162)	4,582 (15,474)
Muddy River near Moapa	GdmrMOAPA_30	6/15/1973	Flow	5	2	31,425 (106,124)	4,714 (15,919)
Muddy River near Moapa	GdmrMOAPA_31	6/15/1974	Flow	5	2	29,071 (98,175)	4,361 (14,726)
Muddy River near Moapa	GdmrMOAPA_32	6/15/1975	Flow	5	2	28,281 (95,507)	4,242 (14,326)
Muddy River near Moapa	GdmrMOAPA_33	6/15/1976	Flow	5	2	28,305 (95,588)	4,246 (14,338)
Muddy River near Moapa	GdmrMOAPA_34	6/15/1977	Flow	5	2	25,699 (86,787)	3,855 (13,018)
Muddy River near Moapa	GdmrMOAPA_35	6/15/1978	Flow	5	2	26,234 (88,593)	3,935 (13,289)
Muddy River near Moapa	GdmrMOAPA_36	6/15/1979	Flow	5	2	27,404 (92,545)	4,111 (13,882)
Muddy River near Moapa	GdmrMOAPA_37	6/15/1980	Flow	5	2	28,346 (95,729)	4,252 (14,359)
Muddy River near Moapa	GdmrMOAPA_38	6/15/1981	Flow	5	2	27,239 (91,988)	4,086 (13,798)

Table 4-30
Muddy River Gages, Discharge Targets, Errors, and Observation Names
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Gage Name	Observation Name	Date	Observation Type	Segment	Reach	Calibration Target afy (m ³ /d)	Standard Deviation afy (m ³ /d)
Muddy River near Moapa	GdmrMOAPA_39	6/15/1982	Flow	5	2	26,989 (91,144)	4,048 (13,672)
Muddy River near Moapa	GdmrMOAPA_40	6/15/1983	Flow	5	2	28,424 (95,990)	4,264 (14,398)
Muddy River near Moapa	GdmrMOAPA_41	6/15/1984	Flow	5	2	26,187 (88,436)	3,928 (13,265)
Muddy River near Moapa	GdmrMOAPA_42	6/15/1985	Flow	5	2	27,332 (92,303)	4,100 (13,846)
Muddy River near Moapa	GdmrMOAPA_43	6/15/1986	Flow	5	2	26,473 (89,401)	3,971 (13,410)
Muddy River near Moapa	GdmrMOAPA_44	6/15/1987	Flow	5	2	27,877 (94,143)	4,182 (14,121)
Muddy River near Moapa	GdmrMOAPA_45	6/15/1988	Flow	5	2	27,193 (91,834)	4,079 (13,775)
Muddy River near Moapa	GdmrMOAPA_46	6/15/1989	Flow	5	2	24,002 (81,056)	3,600 (12,158)
Muddy River near Moapa	GdmrMOAPA_47	6/15/1990	Flow	5	2	24,835 (83,871)	3,725 (12,581)
Muddy River near Moapa	GdmrMOAPA_48	6/15/1991	Flow	5	2	25,780 (87,062)	3,867 (13,059)
Muddy River near Moapa	GdmrMOAPA_49	6/15/1992	Flow	5	2	26,830 (90,608)	4,025 (13,591)
Muddy River near Moapa	GdmrMOAPA_50	6/15/1993	Flow	5	2	28,255 (95,420)	4,238 (14,313)
Muddy River near Moapa	GdmrMOAPA_51	6/15/1994	Flow	5	2	28,422 (95,983)	4,263 (14,397)
Muddy River near Moapa	GdmrMOAPA_52	6/15/1995	Flow	5	2	24,091 (81,358)	3,614 (12,204)
Muddy River near Moapa	GdmrMOAPA_53	6/15/1996	Flow	5	2	23,879 (80,641)	3,582 (12,096)
Muddy River near Moapa	GdmrMOAPA_54	6/15/1997	Flow	5	2	25,060 (84,629)	3,759 (12,694)
Muddy River near Moapa	GdmrMOAPA_55	6/15/1998	Flow	5	2	24,605 (83,094)	3,691 (12,464)
Muddy River near Moapa	GdmrMOAPA_56	6/15/1999	Flow	5	2	24,556 (82,926)	3,683 (12,439)
Muddy River near Moapa	GdmrMOAPA_57	6/15/2000	Flow	5	2	24,479 (82,668)	3,672 (12,400)
Muddy River near Moapa	GdmrMOAPA_58	6/15/2001	Flow	5	2	22,716 (76,713)	3,407 (11,507)
Muddy River near Moapa	GdmrMOAPA_59	6/15/2002	Flow	5	2	23,510 (79,394)	3,526 (11,909)
Muddy River near Moapa	GdmrMOAPA_60	6/15/2003	Flow	5	2	22,011 (74,333)	3,302 (11,150)
Muddy River near Moapa	GdmrMOAPA_61	6/15/2004	Flow	5	2	22,761 (76,867)	3,414 (11,530)
Muddy River near Glendale	GdmrGLEND_08	6/15/1951	Flow	8	9	32,086 (108,359)	4,813 (16,254)
Muddy River near Glendale	GdmrGLEND_09	6/15/1952	Flow	8	9	34,522 (116,584)	5,178 (17,488)
Muddy River near Glendale	GdmrGLEND_10	6/15/1953	Flow	8	9	32,378 (109,344)	4,857 (16,402)
Muddy River near Glendale	GdmrGLEND_11	6/15/1954	Flow	8	9	31,757 (107,246)	4,764 (16,087)
Muddy River near Glendale	GdmrGLEND_12	6/15/1955	Flow	8	9	34,383 (116,116)	5,157 (17,417)
Muddy River near Glendale	GdmrGLEND_13	6/15/1956	Flow	8	9	31,193 (105,342)	4,679 (15,801)
Muddy River near Glendale	GdmrGLEND_14	6/15/1957	Flow	8	9	34,818 (117,583)	5,223 (17,637)
Muddy River near Glendale	GdmrGLEND_15	6/15/1958	Flow	8	9	32,442 (109,558)	4,866 (16,434)
Muddy River near Glendale	GdmrGLEND_16	6/15/1959	Flow	8	9	32,461 (109,625)	4,869 (16,444)
Muddy River near Glendale	GdmrGLEND_17	6/15/1960	Flow	8	9	33,278 (112,382)	4,992 (16,857)
Muddy River near Glendale	GdmrGLEND_18	6/15/1961	Flow	8	9	32,854 (110,950)	4,928 (16,642)
Muddy River near Glendale	GdmrGLEND_19	6/15/1962	Flow	8	9	30,322 (102,400)	4,548 (15,360)
Muddy River near Glendale	GdmrGLEND_20	6/15/1963	Flow	8	9	28,453 (96,090)	4,268 (14,413)
Muddy River near Glendale	GdmrGLEND_21	6/15/1964	Flow	8	9	29,279 (98,879)	4,392 (14,832)
Muddy River near Glendale	GdmrGLEND_22	6/15/1965	Flow	8	9	31,302 (105,711)	4,695 (15,857)
Muddy River near Glendale	GdmrGLEND_23	6/15/1966	Flow	8	9	27,573 (93,117)	4,136 (13,968)

Table 4-30
Muddy River Gages, Discharge Targets, Errors, and Observation Names
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Gage Name	Observation Name	Date	Observation Type	Segment	Reach	Calibration Target afy (m ³ /d)	Standard Deviation afy (m ³ /d)
Muddy River near Glendale	GdmrGLEND_24	6/15/1967	Flow	8	9	29,826 (100,723)	4,474 (15,109)
Muddy River near Glendale	GdmrGLEND_25	6/15/1968	Flow	8	9	30,767 (103,904)	4,615 (15,586)
Muddy River near Glendale	GdmrGLEND_26	6/15/1969	Flow	8	9	30,927 (104,443)	4,639 (15,666)
Muddy River near Glendale	GdmrGLEND_27	6/15/1970	Flow	8	9	31,192 (105,337)	4,679 (15,801)
Muddy River near Glendale	GdmrGLEND_28	6/15/1971	Flow	8	9	29,614 (100,011)	4,442 (15,002)
Muddy River near Glendale	GdmrGLEND_29	6/15/1972	Flow	8	9	28,886 (97,552)	4,333 (14,633)
Muddy River near Glendale	GdmrGLEND_30	6/15/1973	Flow	8	9	29,228 (98,705)	4,384 (14,806)
Muddy River near Glendale	GdmrGLEND_31	6/15/1974	Flow	8	9	28,356 (95,762)	4,253 (14,364)
Muddy River near Glendale	GdmrGLEND_32	6/15/1975	Flow	8	9	27,873 (94,129)	4,181 (14,119)
Muddy River near Glendale	GdmrGLEND_33	6/15/1976	Flow	8	9	28,806 (97,279)	4,321 (14,592)
Muddy River near Glendale	GdmrGLEND_34	6/15/1977	Flow	8	9	24,872 (83,995)	3,731 (12,599)
Muddy River near Glendale	GdmrGLEND_35	6/15/1978	Flow	8	9	28,729 (97,019)	4,309 (14,553)
Muddy River near Glendale	GdmrGLEND_36	6/15/1979	Flow	8	9	26,945 (90,996)	4,042 (13,649)
Muddy River near Glendale	GdmrGLEND_37	6/15/1980	Flow	8	9	27,368 (92,425)	4,105 (13,864)
Muddy River near Glendale	GdmrGLEND_38	6/15/1981	Flow	8	9	25,642 (86,596)	3,846 (12,989)
Muddy River near Glendale	GdmrGLEND_39	6/15/1982	Flow	8	9	26,642 (89,971)	3,996 (13,496)
Muddy River near Glendale	GdmrGLEND_42	6/15/1985	Flow	8	9	25,995 (87,786)	3,899 (13,168)
Muddy River near Glendale	GdmrGLEND_43	6/15/1986	Flow	8	9	26,934 (90,958)	4,040 (13,644)
Muddy River near Glendale	GdmrGLEND_44	6/15/1987	Flow	8	9	27,098 (91,512)	4,065 (13,727)
Muddy River near Glendale	GdmrGLEND_45	6/15/1988	Flow	8	9	25,865 (87,350)	3,880 (13,103)
Muddy River near Glendale	GdmrGLEND_46	6/15/1989	Flow	8	9	21,886 (73,911)	3,283 (11,087)
Muddy River near Glendale	GdmrGLEND_47	6/15/1990	Flow	8	9	23,395 (79,006)	3,509 (11,851)
Muddy River near Glendale	GdmrGLEND_48	6/15/1991	Flow	8	9	24,855 (83,937)	3,728 (12,591)
Muddy River near Glendale	GdmrGLEND_49	6/15/1992	Flow	8	9	26,368 (89,048)	3,955 (13,357)
Muddy River near Glendale	GdmrGLEND_50	6/15/1993	Flow	8	9	28,760 (97,124)	4,314 (14,569)
Muddy River near Glendale	GdmrGLEND_51	6/15/1994	Flow	8	9	24,369 (82,296)	3,655 (12,344)
Muddy River near Glendale	GdmrGLEND_52	6/15/1995	Flow	8	9	23,192 (78,322)	3,479 (11,748)
Muddy River near Glendale	GdmrGLEND_53	6/15/1996	Flow	8	9	22,130 (74,736)	3,320 (11,210)
Muddy River near Glendale	GdmrGLEND_54	6/15/1997	Flow	8	9	23,104 (78,024)	3,466 (11,704)
Muddy River near Glendale	GdmrGLEND_55	6/15/1998	Flow	8	9	27,674 (93,456)	4,151 (14,018)
Muddy River near Glendale	GdmrGLEND_56	6/15/1999	Flow	8	9	26,061 (88,011)	3,909 (13,202)
Muddy River near Glendale	GdmrGLEND_57	6/15/2000	Flow	8	9	24,211 (81,764)	3,632 (12,265)
Muddy River near Glendale	GdmrGLEND_58	6/15/2001	Flow	8	9	23,160 (78,212)	3,474 (11,732)
Muddy River near Glendale	GdmrGLEND_59	6/15/2002	Flow	8	9	23,077 (77,933)	3,462 (11,690)
Muddy River near Glendale	GdmrGLEND_60	6/15/2003	Flow	8	9	22,781 (76,934)	3,417 (11,540)
Muddy River near Glendale	GdmrGLEND_61	6/15/2004	Flow	8	9	23,482 (79,302)	3,522 (11,895)
Muddy River at Overton	GdOVERTON_61	6/15/2004	Flow	12	1	9,903 (33,445)	5,000 (16,885)
Muddy River at Lake Mead	GdLK_MEAD_01	12/31/1944	Flow	12	9	7,403 (25,000)	5,000 (16,885)

Note: NA = Not applicable

**Table 4-31
Pahranagat Wash Gages, Discharge Targets, Errors, and Observation Names**

Gage Name	Observation Name	Date	Observation Type	Segment	Reach	Calibration Target afy (m ³ /d)	Standard Deviation afy (m ³ /d)
Hiko Spring	GdHIKO_01	12/31/1944	Flow	32	8	4,170 (14,082)	643 (2,173)
Crystal Springs	GdXTL_61	6/15/2004	Flow	33	8	9,205 (31,086)	5,713 (19,293)
Pahranagat Wash at Crystal Spring	G_PW_XTL_01	12/31/1944	Flow	25	9	NA	NA
Ash Springs	GdASH_61	6/15/2004	Flow	34	8	13,027 (43,992)	1,418 (4,788)
Pahranagat Wash at Ash Spring	G_PW_ASH_01	12/31/1944	Flow	26	11	NA	NA
Pahranagat Wash #3	G_PW_3_01	12/31/1944	Flow	27	6	NA	NA
Pahranagat Wash #4	G_PW_4_01	12/31/1944	Flow	28	8	NA	NA
Pahranagat Wash #5	G_PW_5_01	12/31/1944	Flow	29	13	NA	NA
Pahranagat Wash #6	G_PW_6_01	12/31/1944	Flow	39	7	NA	NA
End of Pahranagat Wash	GdPW_7_01	12/31/1944	Flow	31	8	0 (0)	1,000 (3,377)
End of Pahranagat Wash	GdPW_7_06	6/15/1949	Flow	31	8	0 (0)	1,000 (3,377)
End of Pahranagat Wash	GdPW_7_11	6/15/1954	Flow	31	8	0 (0)	1,000 (3,377)
End of Pahranagat Wash	GdPW_7_16	6/15/1959	Flow	31	8	0 (0)	1,000 (3,377)
End of Pahranagat Wash	GdPW_7_21	6/15/1964	Flow	31	8	0 (0)	1,000 (3,377)
End of Pahranagat Wash	GdPW_7_26	6/15/1969	Flow	31	8	0 (0)	1,000 (3,377)
End of Pahranagat Wash	GdPW_7_31	6/15/1974	Flow	31	8	0 (0)	1,000 (3,377)
End of Pahranagat Wash	GdPW_7_36	6/15/1979	Flow	31	8	0 (0)	1,000 (3,377)
End of Pahranagat Wash	GdPW_7_41	6/15/1984	Flow	31	8	0 (0)	1,000 (3,377)
End of Pahranagat Wash	GdPW_7_46	6/15/1989	Flow	31	8	0 (0)	1,000 (3,377)
End of Pahranagat Wash	GdPW_7_51	6/15/1994	Flow	31	8	0 (0)	1,000 (3,377)
End of Pahranagat Wash	GdPW_7_56	6/15/1999	Flow	31	8	0 (0)	1,000 (3,377)
End of Pahranagat Wash	GdPW_7_61	6/15/2004	Flow	31	8	0 (0)	1,000 (3,377)

Note: NA = Not available

4.7.7 Ground-Surface-Elevation Observations

Large parts of the numerical model have limited hydraulic-head observations, particularly in the mountain blocks. The elevations of the ground surface were used as observations in the numerical model to provide additional constraints on the simulated hydraulic heads in these areas. The intent of these observations was to limit unrealistic groundwater mounding above the ground surface. Note that these observations were made only during the steady-state stress period. Hydraulic heads should only decline from steady-state conditions as pumping during the transient-state stress periods occur.

Table 4-32
Big Springs Gages, Discharge Targets, Errors, and Observation Names

Gage Name	Observation Name	Date	Time	Observation Type	Segment	Reach	Calibration Target afy (m ³ /d)	Standard Deviation afy (m ³ /d)
Big Springs	GdBIG_SPR_61	6/15/2004	0:00	Flow	20	1	7,431 (25,094)	411 (1,387)
Utah/Nevada State Line	G_ST_LIN_01	12/31/1944	0:00	Flow	21	1	NA	NA
Above Pruess Lake	GaLKPRUES_01	12/31/1944	0:00	Flow	22	1	NA	NA
Pruess Lake	G_LKPRUES_01	12/31/1944	0:00	Flow	23	1	NA	NA
End of Lake Creek	GdLKCK_END_01	12/31/1944	0:00	Flow	24	7	0 (0)	1,000 (3,377)
End of Lake Creek	GdLKCK_END_06	6/15/1949	6:00	Flow	24	7	0 (0)	1,000 (3,377)
End of Lake Creek	GdLKCK_END_11	6/15/1954	12:00	Flow	24	7	0 (0)	1,000 (3,377)
End of Lake Creek	GdLKCK_END_16	6/15/1959	18:00	Flow	24	7	0 (0)	1,000 (3,377)
End of Lake Creek	GdLKCK_END_21	6/15/1964	0:00	Flow	24	7	0 (0)	1,000 (3,377)
End of Lake Creek	GdLKCK_END_26	6/15/1969	6:00	Flow	24	7	0 (0)	1,000 (3,377)
End of Lake Creek	GdLKCK_END_31	6/15/1974	12:00	Flow	24	7	0 (0)	1,000 (3,377)
End of Lake Creek	GdLKCK_END_36	6/15/1979	18:00	Flow	24	7	0 (0)	1,000 (3,377)
End of Lake Creek	GdLKCK_END_41	6/15/1984	0:00	Flow	24	7	0 (0)	1,000 (3,377)
End of Lake Creek	GdLKCK_END_46	6/15/1989	6:00	Flow	24	7	0 (0)	1,000 (3,377)
End of Lake Creek	GdLKCK_END_51	6/15/1994	12:00	Flow	24	7	0 (0)	1,000 (3,377)
End of Lake Creek	GdLKCK_END_56	6/15/1999	18:00	Flow	24	7	0 (0)	1,000 (3,377)
End of Lake Creek	GdLKCK_END_61	6/15/2004	0:00	Flow	24	7	0 (0)	1,000 (3,377)

NA = Not available

It is necessary to understand that in groundwater ET areas, groundwater occurs at or near the ground surface. Thus, simulated hydraulic head is expected to be near the ground surface in discharge areas. Moreover, it is possible for a model cell on the surface to have a hydraulic head higher than the ground surface. In fact, for water to flow out of an artesian spring, the hydraulic head must be higher than the ground-surface elevation at the spring. Therefore, ground-surface observation targets were used to minimize substantial mounding above ground surface without overconstraining the model. To accomplish this goal, the maximum estimate of the ground-surface elevation within a grid cell was used as a target and was calculated as follows:

$$T = ME + 2SD \quad (\text{Eq. 4-5})$$

where,

- T = Target not to exceed elevation
- ME = Mean 30-m DEM elevation in the 247.1 acre (1 km²) grid cell
- SD = Standard deviation of 30-m DEM elevations in the 247.1 acre (1 km²) grid cell

The resulting ground-surface observations minimize mounding in valley bottoms but give flexibility in steep topographic areas. Ground-surface observations were configured in UCODE_2005 as follows:

- If the simulated hydraulic-head was below the target ground-surface elevation, the residual was set to zero.
- If the simulated hydraulic head was above the target ground-surface elevation, the actual residual was calculated.

Initially, a ground-surface target was used for every model grid cell, resulting in 53,581 observations. This large number of observations significantly extended the model run time. Consequently, this number was reduced by using every twenty-fifth cell (one on every fifth row and fifth column). This reduced the number to 2,145 ground-surface observations in the final model configuration, as depicted in [Figure 4-43](#).

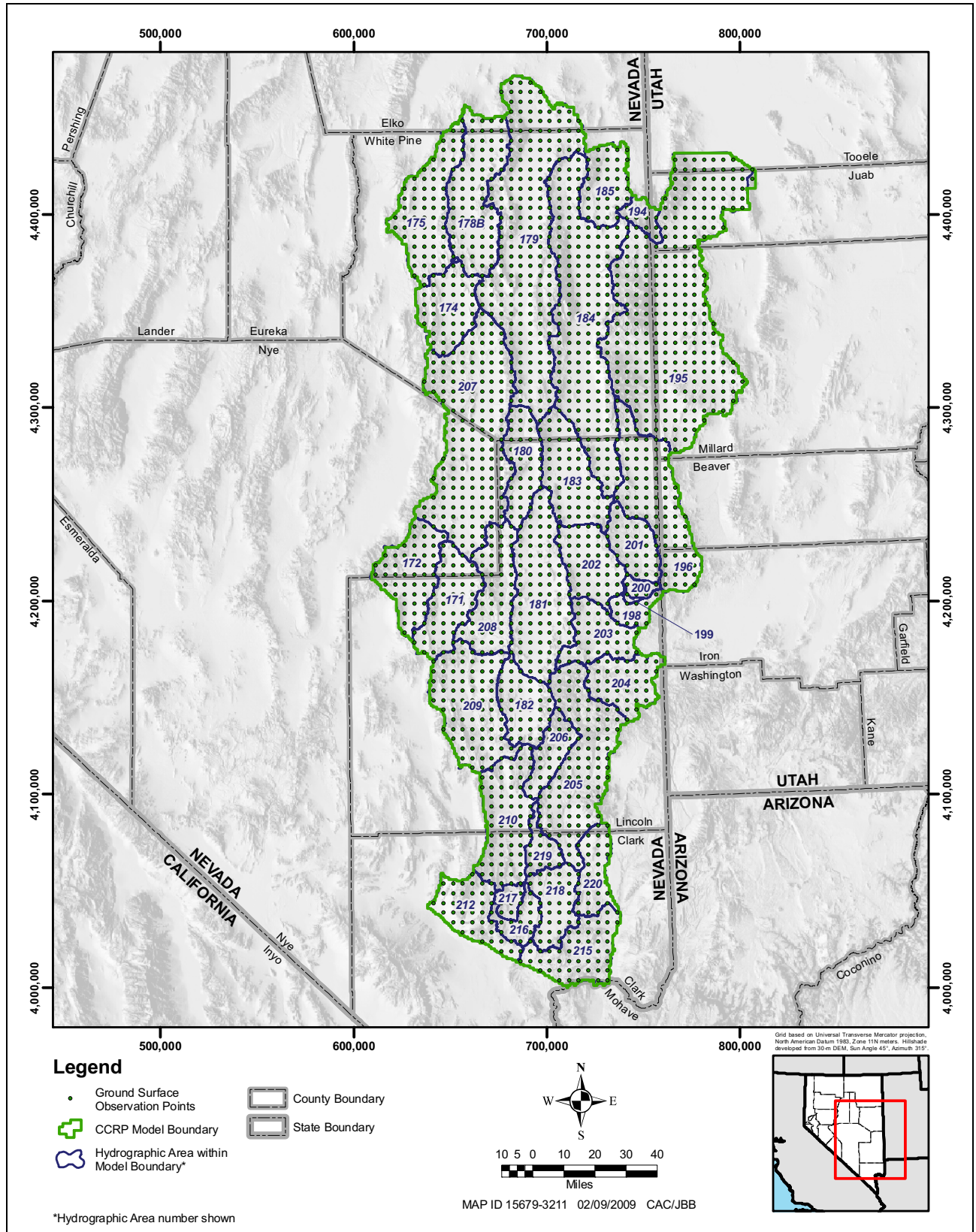


Figure 4-43
Location of Ground-Surface Observations Used to Constrain Potentiometric Surface

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5.0 NUMERICAL MODEL CALIBRATION PROCESS AND CONCEPTUAL MODEL TESTING

The process followed to calibrate the numerical model is described in this section, followed by a presentation of calibration activities designed to test and adjust the conceptual model represented in the numerical model. These calibration activities consisted of reweighting the observations and testing and adjusting the various components of the conceptual model. Additional adjustments made to the western portion of the model domain, which coincided mostly with the WRFS as defined in the Conceptual Model Report (SNWA, 2009a), are presented separately at the end of this section. Model parameters were also refined during these calibration activities, but the final parameter-estimation simulations are discussed in [Section 6.0](#) along with the evaluation of the calibrated numerical model.

5.1 Calibration Process

Although automated-regression techniques may constitute more efficient and accurate tools for model calibration, manual trial-and-error calibration is often necessary to develop a reasonable representation of a complex hydrogeologic system with sparse data and significant uncertainties. In fact, combining the two methods provided greater flexibility in testing the representation of various features of the flow system in the numerical model.

5.1.1 Model Calibration Guides

The parameter-estimation and testing-analysis capabilities of UCODE_2005 provided valuable insights, which were used to guide the calibration of the numerical model. Useful model-calibration guides consisted of indicators of data quality, the relative importance of each parameter in the parameter-estimation process, and indicators of calibration improvement. Particularly useful were the dimensionless sensitivities, the CSS, the SoSWR, and the weighted residuals.

- The dimensionless sensitivities quantify the influence of a single observation on a single parameter estimate. They are not only used internally by UCODE_2005 to seek a solution, but they were also used externally by the modelers to evaluate the importance of observations to the parameter estimation.
- CSS were used during calibration to decide which parameters to include and exclude from the parameter-optimization process. In general, parameters with relatively high CSS values were typically included in the estimation process, while parameters with relatively low CSS values were not. In the case of two correlated parameters (as determined from parameter-correlation coefficients), the parameter with the lower sensitivity typically was not optimized directly.

-
- As the SoSWR is a reflection of the fit of the simulated values to the observed values, it represents an indicator of overall model fit. A decrease in the SoSWR was used as a general measure of improvement in model fit. Being dimensionless, the SoSWR is also useful for comparing observation errors of different types, such as flows and hydraulic heads.
 - Weighted residuals, while indicative of model fit, are dimensionless and can be less intuitive compared to unweighted residuals. A weighted residual is the product of the residual and the square root of its weight. In UCODE_2005, the weight is the inverse of the variance. Considering that the variance is the square of the standard deviation, the weighted residual may be calculated as the ratio of the unweighted value to the standard deviation. Therefore, if the unweighted residual is twice as large as the standard deviation, the value of the weighted residual is 2.0 (Hill, 1998; Hill and Tiedeman, 2007). Decreasing weighted residuals of individual observations indicate a better match to weighted observations and therefore an improvement of model fit to those observations.
 - Another indicator of model-calibration improvement is more realistic calibrated parameter values (Hill, 1998; Hill and Tiedeman, 2007).

5.1.2 Conceptual Model Testing and Adjustment Process

The representation of the conceptual model in the numerical model was iteratively refined using a combination of trial and error and the parameter-estimation methods of UCODE_2005.

An iteration generally consisted of (1) modifying a given component of the conceptual model representation (observation weight or model construction element), (2) adjusting the component by trial and error (UCODE_2005 run with single MODFLOW-2000 simulation), and (3) performing a UCODE_2005 optimization run (UCODE_2005 run with multiple MODFLOW-2000 simulations), when the results of the trial-and-error simulations were judged reasonable.

The results of the UCODE_2005 testing analyses were used throughout the process to evaluate the state of the calibration and to make decisions about subsequent adjustments. These results were used to reevaluate observation weights and to make changes to the model construction, both regionally and locally, by adjusting defined parameters or modifying aspects of model construction.

5.1.3 Final Parameter Estimation

During the model simulations described in this section, the conceptual model representation in the numerical model was refined to yield a better fit of the model to the observations. At the same time, parameter estimates were improved but were not considered to all be final calibrated values. At the end of the calibration process, attempts were made to refine these estimates using the optimization capabilities of UCODE_2005. The details of these activities are provided in [Section 6.1](#).

5.2 Observation Data Review and Reweighting

Weighted residuals simplify the evaluation of overall model fit by lumping observed data of different types into a single observation data set. The weights were initially assigned based on the uncertainty associated with each of the observations. During the model-calibration process, hydraulic-head and drawdown, spring flow, stream flow, and groundwater-flow observations and corresponding weights were evaluated to determine if they appropriately constrained the flow model.

The DVD included with this report provides a detailed listing of observation locations, target heads, variances, rationale of variance calculations, and rationale for excluding the observation. [Section 4.7.3](#) introduces variance adjustments performed in addition to those reported on the DVD. As described in [Section 4.0](#), several types of observations were used in the numerical model and these are listed again in [Table 5-1](#). During calibration of the numerical model, observations were given equal consideration, regardless of type. In other words, a well observation with a COV of 10 percent carried equal weight as a spring flow observation or an ET observation with a COV of 10 percent. This approach gave hydraulic-head observations more overall importance in the model calibration because of the significant number of hydraulic-head observations (see [Table 5-1](#)). A large number of ground-surface observations were also used. However, ground-surface observations have small individual weights.

**Table 5-1
Number of Calibration Observations by Type**

Observation Type	Count	Comment
Hydraulic-Head Observations	2,707	---
Hydraulic-Drawdown Observations	4,301	---
Spring Hydraulic-Head Observations	0	---
Groundwater ET Discharge	126	Includes spring flows.
Steady-State Spring Flows	44	---
Transient Spring Flow Change	27	---
CHD Boundary Flow	16	---
Interbasin Flow	0	---
SFR2 Spring/Stream Gage	144	---
Ground Surface	2,145	Selected where surface ponding occurred but fell between the regular ground-surface observations. Mounding could occur between the 5 x 5 cell ground-surface-observation grid locations. These targeted specific problem locations.
Total	9,510	

The bias toward hydraulic-head observations was apparent during parameter-estimation simulations. For example, an optimization simulation would converge (TOLPAR = 0.01). However, flow errors from the major springs in Pahrangat Valley and Muddy River exceeded one standard deviation. While the total SoS WR was reduced, the model fit at these key features was unacceptable. As a result, the standard deviation of key spring and gage observations was adjusted ([Table 5-2](#)) by a factor of 10, increasing the influence of these observations.

**Table 5-2
Selected Observations and Revised Standard Deviations**

Observation	Standard Deviation		Rationale for Revising Observation Weight
	Original afy (m ³ /d)	Deviation afy (m ³ /d)	
GdBIG_SPR_61	---	---	Intermediate spring (Big Springs; 2004)
GdLKCK_END_##	1,000 (3,377)	100 (337.7)	End of Big Springs Creek/Lake Creek. Channel should be dry.
GdASH_61	---	---	Regional spring (Ash Springs; 2004)
GdHIKO_01	---	---	Regional spring (Hiko Spring; 1944)
GdXTL_61	---	---	Regional spring (Crystal Springs; 2004)
GdPW_7_##	1,000 (3,377)	100 (337.7)	End of Pahrnagat Wash. Channel should be dry.
GdmrGLEND_08	4,813 (16,254)	481 (1,625.4)	Muddy River near Glendale gage measurement (1951)
GdmrGLEND_##	various	various/10	Muddy River near Glendale gage measurement (1952 to 2004)
GdmrMOAPA_02	5,008 (16,912)	501 (1,691.2)	Muddy River near Moapa gage measurement (1945).
GdmrMOAPA_##	various	various/10	Muddy River near Moapa gage measurement (1946 to 2004)
GdOVERTON_61	5,000 (16,885)	500 (1,688.5)	Muddy River at Overton (2004)
GdLK_MEAD_01	5,000 (16,885)	500 (1,688.5)	Muddy River at Lake Mead shore (1944)

refers to stress-period identifier.

5.3 Conceptual Model Testing and Adjustment

As described in [Section 3.0](#) and [Section 4.0](#), variations of four major components of the conceptual model were evaluated to test additional features of the flow system. These variations were refinements to the simplified conceptual model. Conceptual model variations were considered for (1) hydrogeologic framework, (2) external flow boundaries, (3) definition of recharge processes, and (4) definition of discharge areas. For each change in the conceptual model, sensitivities were calculated, and parameter values were estimated. In general, conceptual model changes contributing to significant improvement in model fit, as indicated by a reduction in the SoSWR, were retained in the final calibrated model. Variations in hydrogeologic framework interpretation contribute most to improving the numerical model fit.

5.3.1 Variations in the Hydrogeologic Framework

The simplified hydrogeologic framework developed for the conceptual model (SNWA, 2009a) lacks sufficient detail to represent certain characteristics of the flow systems. Some of these detailed characteristics were obtained from SNWA (2008) or from the literature and were tested in the model but only as allowed by the size of the model grid cells. Many of the hydrogeologic framework complexities are much smaller than the size of the grid cells and cannot be represented in the model. Tested aspects consist of the spatial variations in RMUs and the representation of partial barriers to flow in the numerical model.

5.3.1.1 Spatial Variations in RMUs

More details were added to the representation of the RMUs in the numerical model both at the scale of the hydrographic areas and at the local scale.

At the scale of the hydrographic areas, zones were identified based on natural characteristics or important processes at that scale. Zones were defined based on (1) lithologic variation, (2) regional faulting, (3) thermal alteration, and (4) regional tectonism. In some cases, the final number of zones was arrived at by evaluating different numbers of zones through multiple model simulations. Multiplication factors on the original zone parameters were typically used to adjust zone properties. The final zonation was described in [Section 4.0](#). Parameters derived by UCODE_2005 define zones with similar properties into a smaller set of model parameters.

The resolution of the numerical model grid inhibits accurate representation of geometries. In some cases, the lack of detail limits the ability to represent important local- or intermediate-scale hydrogeologic features that result in springs or ET zones.

5.3.1.1.1 Warm Springs near Gandy, Utah

At Warm Springs near Gandy, Utah ([Figure 4-25](#)), the simplified hydrogeologic framework model lacks sufficient detail to represent the interpreted geologic structure controlling spring flow. The target flow is 12,027 afy (40,616 m³/d), but simulating flows larger than 4,341 afy (14,662 m³/d) has proved elusive. To improve the representation of this spring and increase flow, the following steps have been implemented or tested:

- In SNWA (2008), a carbonate feature is described as extending through the Quaternary-Tertiary alluvium (QTa) in the UVE. This feature is not represented in the regional hydrogeologic framework (SNWA, 2009a). An LC zone was added into the UVE RMU to incorporate this feature into the model and better approximate the interpreted hydrogeologic setting. Spring flows increased slightly (100 to 800 afy) with this change. This adjustment was kept in the numerical model.
- Mankinen and McKee (2009) identified a gravity anomaly area in the Confusion Range. Decreasing *K* in this area increases hydraulic heads along the east side of Snake Valley. This adjustment increased flow at Warm Springs (hundreds of afy). This adjustment was kept in the numerical model.
- Two large watersheds are west of Warm Springs. Runoff from these areas have the potential to deliver significant volumes of water to the Warm Springs Area. Adjustments to runoff pathways (see [Section 4.5.3.3](#)) were made to test the effects on spring flow. First the runoff was arranged to occur near the spring or up-gradient of faults represented by HFBs. The result was increased hydraulic heads yielding approximately 1,000 afy (2,961 m³/d) of additional flow. Second, the runoff pathway was adjusted to place all runoff at the DRN spring cells. This test yielded only 2,961 afy (10,000 m³/d) flow at Warm Springs (up from about 1,000 afy). The first runoff pathway test was kept in the numerical model.

-
- Numerous normal faults are mapped in the area. Some are represented in the framework model. Additional HFBs were added in an attempt to direct flow toward the spring. Slight increases in flow at Warm Springs were achieved. This adjustment was kept in the numerical model.
 - The K of the BASE RMU between northern Spring Valley and Snake Valley was increased. This also had the advantage of moving some excess water out of Spring Valley. While this did increase flows somewhat at Warm Springs, the total flow from Spring Valley to Snake Valley was not considered reasonable, and the K of the BASE RMU was returned to its starting value.
 - Recharge efficiencies were increased by 25 percent over the initial GSLDFS efficiencies along the east side of the Snake Range in Snake Valley. This adjustment yielded 4,341 afy (14,662 m³/day). This adjustment was kept in the numerical model.

While flow at Warm Springs is 36 percent of the target, total discharge in Snake Valley is within 4 percent (Figure 6-18). Thus, discharges to ET zones on the basin floor account for the deficit of spring flows.

5.3.1.1.2 Patterson Valley to Panaca Valley

Southern Patterson Valley and Panaca Valley had opposite problems, more or less, through most of the model development. In southern Patterson Valley, the simulated water table was more than 82 ft (25 m) above ground surface, while Panaca Spring flows were undersimulated at 296 afy (1,000 m³/day), and the target was 2,348 afy (7,930 m³/day). The framework model, however, provided no means to move the excess water from Patterson Valley to Panaca Spring. Zonation testing in the area was ineffective. Review of faulting mapped in the area (SNWA, 2008) indicates northwest-southwest trending faults, which could provide preferential flow through the mountain block separating these valleys. A fault zone was added to the BASE, LC, and LVF RMUs to test the possible connection from Patterson Valley to Panaca Spring. The result was decreased hydraulic heads in southern Patterson Valley and increased flow at Panaca Spring. This adjustment to the framework was kept in the numerical model.

5.3.1.1.3 Upper Meadow Valley Wash

The transient calibration process revealed shortcomings of the hydrogeologic framework in northern Panaca Valley and the northern part of Meadow Valley Wash. For example, irrigation pumping from surficial materials in these areas resulted in drawdowns of 1,640 ft (500 m). Expected drawdowns are generally less than 5 m.

Comparison of the hydrogeologic framework model to the geologic maps indicates that oversimulated drawdown occurs in areas where the framework model has been oversimplified. Specifically, unconsolidated deposits (UVF) are not represented in these areas. As a result, pumping was simulated from the less permeable LVF. Zones (for K and S) along Meadow Valley Wash were applied to these areas in the LVF and LC. Simulated drawdowns decreased to approximately 262 ft

(80 m). The faulting applied to the mountain block between Patterson Valley and Panaca Spring (described above) also reduced oversimulated drawdowns.

Significant improvements were achieved by the adjustments described above; however, drawdowns in two observation wells remained significantly oversimulated. Errors from these wells (Z03_4_### and Z03_6_###) accounted for over 40 percent of the objective function SoSWR. As a result, parameter-estimation simulations were biased by these observations. To resolve this issue, the initial hydraulic-head observation from each well was kept as an observation. The remaining drawdown observations were not included as observations. This area is expected to continue reporting larger than expected drawdowns during model prediction.

5.3.1.2 Horizontal Flow Barriers

The representation of some faults as partial barriers to groundwater flow was evaluated by considering alternative conceptual models that would also result in reasonable simulated hydraulic-head or spring flow distributions. During the initial stages of model development, two basic conceptual models were considered. In the first one, rocks in the mountain blocks were assigned significantly low hydraulic conductivities. In the second one, rocks in the mountain blocks were assigned moderately low hydraulic conductivities associated with faults containing small cross-fault transmissivity. During model calibration, focus shifted from the first to the second conceptual model, which was implemented using the HFB package as described in [Section 4.0](#). The adoption of the second conceptual model was influenced by three major factors, which support the explicit inclusion of faults in the model using the HFB package. These three factors are discussed in the following text, followed by the final list of HFBs included in the model and their parameters.

5.3.1.2.1 Mountain-Block Hydraulic Heads, Recharge, and Runoff

Early in the model calibration, it was noted that mountain blocks with significantly low K created very large groundwater recharge mounds (water modeled above the ground surface). To maintain effective recharge rates under this conceptual model, it was necessary to increase recharge runoff.

Aspects of this increase of recharge that are of particular note include:

- For UA, BASE, and PLUT materials, because of their perceived competence, 98 percent of the recharge applied to mountain blocks containing these units had to be moved to the valley bottoms. Given the limited capacity of small- K mountain blocks to absorb water, matching hydraulic-head elevations in these mountain blocks was very difficult. Small changes in the recharge rate, the percent of in-place recharge, or the host rock K could all cause large changes in hydraulic head.
- For carbonate (LC and UC) and LVF units, more evidence existed to suggest that more infiltration was possible in these areas. Carbonates in the model area are known to act as good aquifers. LVF materials, in many cases, were more transmissive than UA, BASE, and PLUT units. Carbonate and LVF units required larger K to prevent mounding.

-
- The hydraulic properties of the UVF unit also needed to be adequately large to allow infiltration of this water at the base of mountain fronts. It was generally assumed that most redistributed-runoff recharge occurred not more than 2 to 5 mi from the mountain-front transitional areas. If too much runoff was generated, the model would predict large mounds in these transitional areas, particularly in places where the UVF RMU was quite thin. To prevent this, the following measures were taken:
 - The K of the UVF unit was increased within reasonable limits.
 - Runoff from the mountains was reduced. This led to increasing K in the mountain block, which sometimes resulted in a significant decrease in hydraulic heads in the mountain block.
 - Recharge was reduced; however, in many areas, recharge rates needed to be maintained in order to maintain spring and ET flows.

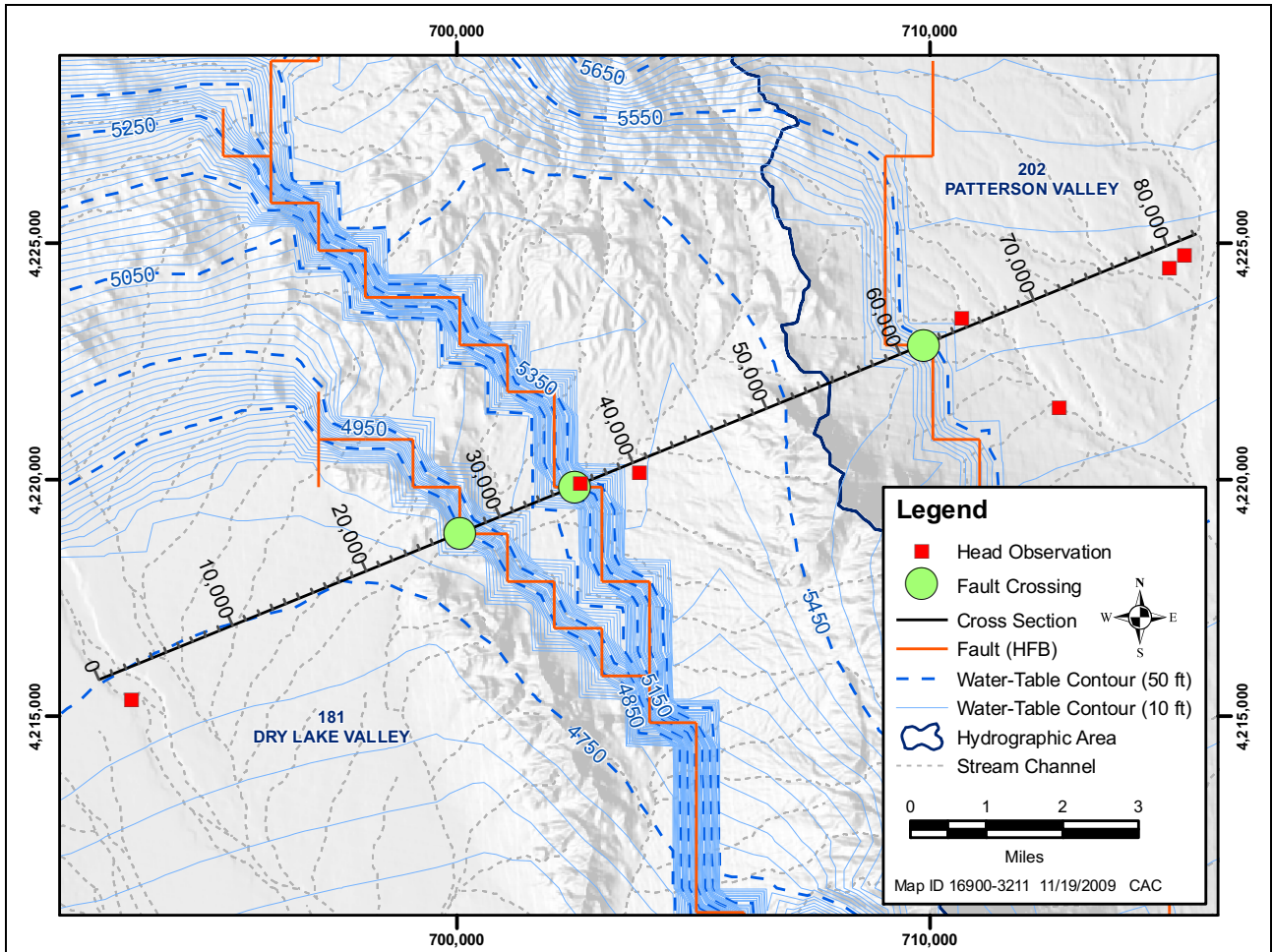
5.3.1.2.2 Hydraulic-Head Changes across Faults

Regional water levels suggest that faults act as barriers to groundwater flow. Although well-documented examples are scarce, water levels occurring in several key areas close to, or on both sides, of faults display significant hydraulic-head drops. One example of this occurs between Dry Lake Valley and Patterson Valley (Figure 5-1). Hydraulic heads in Patterson Valley are fairly flat at about 5,650 ft. There are additional hydraulic-head observations on the Dry Lake Valley side of the carbonate mountain block, where hydraulic heads have dropped to 5,450 ft. The large drop in hydraulic head occurs across two normal faults represented by HFBs. Hydraulic heads drop an additional 1,100 ft down to about 4,300 ft in central Dry Lake Valley. Even with low K flow barriers, the numerical model had trouble in this area matching the large hydraulic-head drop across the fault zone on the Dry Lake Valley side of the mountain block (Bristol Range). From these and other observations in Dry Lake Valley, the large hydraulic-head drop appears to be controlled by faulting rather than by mountain-block material.

5.3.1.2.3 Spring Flows at Faults

The occurrence of springs in areas immediately up-gradient of faults is another indicator of faults acting as hydraulic barriers to groundwater flow. Examples include Lund Spring (in White River Valley) and Muddy Springs (in the Muddy River Springs Area). In many cases where springs are associated with faults, sufficient flow was not simulated from these springs until a horizontal-flow barrier was incorporated into the hydrogeologic framework and numerical model.

In most cases, model fit improved more dramatically when HFBs were used in these hydrogeologic settings. HFBs were much more effective than using hydraulic-conductivity changes from small K mountain-block units to larger K valley-fill units. Because HFBs were added in places where data were present to indicate a dramatic hydraulic gradient change, it is quite possible that there are locations in the model domain where faults act as flow barriers, but the data were not available to indicate their presence. Thus, the model may actually underrepresent HFBs model-wide.



Dry Lake Valley to Patterson Valley Head Observations

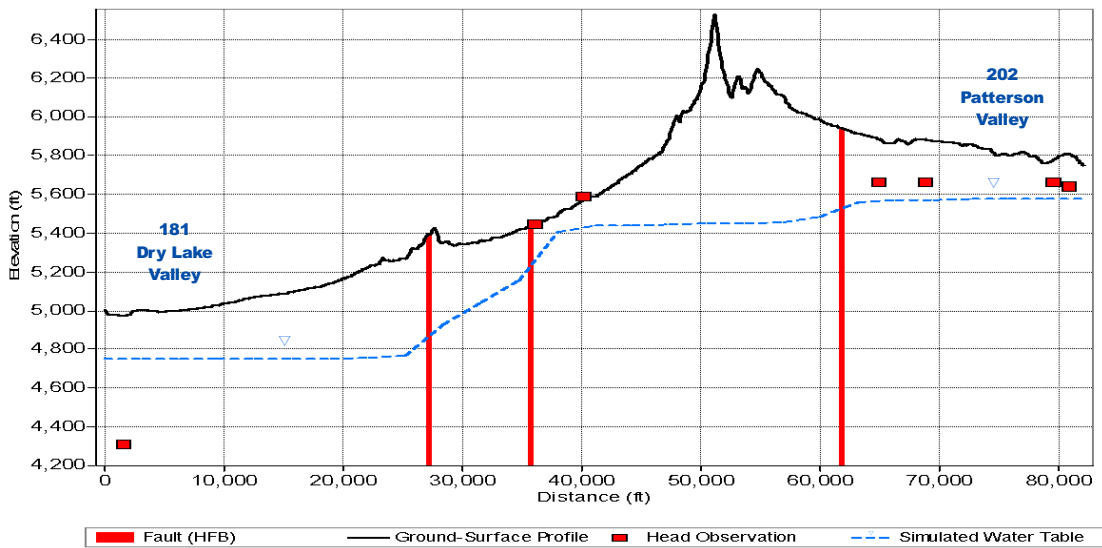


Figure 5-1
Evaluation of Hydraulic-Head Changes
across Faults between Patterson and Dry Lake Valleys

5.3.1.2.4 Final HFB Configuration

The evidence described above demonstrates that barriers to groundwater flow were necessary in many cases to better control simulated hydraulic heads and improve gradients and flows. Therefore, the second conceptual model was adopted with barriers to groundwater flow explicitly represented in the model using HFBs. Initially, HFBs were assigned to lateral and normal faults of regional significance and were tested during model calibration. This testing resulted in the removal of many faults as potential horizontal flow barriers. Table 5-3 lists all tested HFBs including the ones that were removed during testing. Normal faults identified as potential barriers to flow are listed in Table 5-3 and are illustrated in Figure 4-11. The selected normal and lateral faults were represented both as high-transmissivity zones and HFBs (Section 4.0).

5.3.2 Location and Nature of Flow Boundaries

External boundary flows were estimated from sparse water-level data, interpretive hydrogeologic framework information, and estimates from previous studies. Because of limited data, external boundary flow observations are difficult to characterize. The model-calibration process includes modification of external boundaries to test the adequacy of their representation. Adjustments to external boundaries include the following:

- Northern Steptoe Valley at the boundary with Goshute Valley (Figure 4-14) – This boundary was shifted from the structural basin into a mountain-block area. Observed hydraulic heads (W179_280 and W179_283) in the mountain-block area were 160 to 200 ft (50 to 60 m) lower than surrounding water levels in northern Steptoe Valley. Water levels in Steptoe Valley appear to be influenced by faults near these two observations.
- Tippett Valley (Figure 4-15) – An additional constant-head boundary was added to the northeastern side of the hydrographic area near Deep Creek Valley. This was done because hydraulic-head observations along the Antelope and Deep Creek boundaries indicate a relatively flat gradient, while hydraulic heads in central Tippett Valley show elevated heads. The flatter gradient suggests some possible leakage through the mountain block to Deep Creek Valley.
- Long Valley (Figure 4-17) – The target flow to Newark Valley was increased from 0 to 12,000 afy (40,525 m³/d). As discussed in Section 4.3.2.2, it was not possible to simulate large quantities of groundwater flow from Long Valley to Jakes Valley, as suggested in the simplified conceptual model (SNWA, 2009a). To help balance the groundwater budget in Long Valley, some of the excess water was allowed to flow out of the valley southwest into Newark Valley and northwest into Ruby Valley. Although the revised target for flow to Newark Valley is consistent with other interpretations (e.g., Prudic et al., 1995), it is highly uncertain because of the lack of data in that area. The target flow for the additional flow-boundary segment added to the model to help remove the rest of the excess water simulated in Long Valley was set to 2,000 afy (6,754 m³/d). The location of this flow-boundary segment is also consistent with Prudic et al. (1995). However, Prudic et al. (1995) show, in their upper model layer for the northwestern boundary of Long Valley, that flow moves into Long Valley.

Table 5-3
Normal and Lateral Faults Identified as Flow Barriers
 (Page 1 of 2)

Fault Description	Subdivision	Fault Type	Extends Through All RMUs	Added and Tested During Calibration	Tested and Eliminated	Parameter Name	Modeled Conductance (1/d)
Caliente Caldera Area	---	Lateral	Yes	---	---	HFB_GROUP	9.014E-07
California Wash	East	Normal	Yes	X	X	HFB_CALIFE	9.014E-07
	West	Normal	Yes	X	---	HFB_CALIFW	9.014E-07
Cave Valley	North	Lateral	Yes	---	---	HFB_CAVE_N	9.014E-07
	Northeast	Normal	Yes	X	---	HFB_CAVENE	9.014E-07
	Southwest	Normal	Yes	X	---	HFB_CAVESW	9.014E-07
Coal Valley	North	Normal	Yes	X	---	HFB_COAL_N	2.704E-06
	West	Normal	Yes	X	---	HFB_COAL_W	2.323E-06
Dry Lake Area	North	Lateral	Yes	---	---	HFB_GROUP	9.014E-07
	North	Normal	Yes	X	---	HFB_DRYL_N	9.014E-07
	South	Lateral	Yes	---	---	HFB_GROUP	9.014E-07
	East	Normal	Yes	X	---	HFB_DRYL_E	9.014E-07
	West	Normal	Yes	X	---	HFB_DRYL_W	9.014E-07
Garden Valley	Central	Normal	Yes	X	X	HFB_GARD_C	9.014E-05
	East	Normal	Yes	X	X	HFB_GARD_E	9.014E-05
	North	Normal	Yes	X	---	HFB_GARD_N	9.014E-07
	West	Normal	Yes	X	---	HFB_GARD_W	2.704E-06
Hamlin Valley	---	Normal	Yes	X	X	HFB_HAMLIN	9.014E-07
Kane Springs Area	---	Lateral	Yes	---	---	HFB_KANE	9.014E-07
Lake Mead	Black Mountain	Lateral	Yes	---	---	HFB_LAKEMD	9.014E-08
Long Valley	East	Normal	Yes	X	---	HFB_LONG_E	9.014E-07
Muddy River Springs Area	East of Muddy Springs	Normal	Yes	X	---	HFB_MUDDYR	9.014E-04
Pahranagat Shear Zone	Eastern	Lateral	Yes	---	---	HFB_PAHR_E	1.426E-05
	Northwestern	Lateral	Yes	---	---	HFB_PAHRnW	2.704E-05
	Southwestern	Lateral	Yes	---	---	HFB_PAHRsW	2.704E-06
Pahranagat Valley	East Side of Wash South to Ash Spring	Normal	Yes	X	---	HFB_PAHR_1	9.014E-07
	Sixmile Flat - East	Normal	Yes	X	---	HFB_6MILEE	9.014E-07
	Sixmile Flat - West	Normal	Yes	X	X	HFB_6MILEW	9.014E-07
Pahroc Valley	North Pahroc to Delamar	Normal	Yes	X	X	HFB_PROCDM	9.014E-07
	Central to Delamar	Normal	Yes	X	---	HFB_PROCD2	9.014E-07
	Cross Valley	Normal	Yes	X	---	HFB_PROC_X	9.014E-06
	North	Normal	Yes	X	---	HFB_PROC_N	2.704E-06
	South	Normal	Yes	X	---	HFB_PROC_S	9.014E-07

Table 5-3
Normal and Lateral Faults Identified as Flow Barriers
 (Page 2 of 2)

Fault Description	Subdivision	Fault Type	Extends Through All RMUs	Added and Tested During Calibration	Tested and Eliminated	Parameter Name	Modeled Conductance (1/d)
Panaca Valley	Below Panaca Spring	Normal	Yes	X	---	HFB_PANACA	9.014E-07
	Further South in Central Valley	Normal	Yes	X	---	HFB_PANAC2	9.014E-07
Patterson Valley	Central Valley	Normal	Yes	X	---	HFB_PATV_1	9.014E-07
	Southeast	Normal	Yes	X	---	HFB_PATTSE	9.014E-07
Snake Range and Snake Valley	At Warm Springs near Gandy, UT	---	Yes	---	---	HFB_GANDY	9.014E-08
	Eastern Flank, Southern Section	Normal	Yes	X	---	HFB_SNRS_E	1.532E-06
	Eastern Flank, Central Section, West of Warm Springs	Normal	Yes	X	---	HFB_SNRCwE	9.014E-07
	Eastern Flank, Central Section, East of Warm Springs	Normal	Yes	X	---	HFB_SNRCeE	4.507E-05
	Eastern Flank, Northern Section	Normal	Yes	X	---	HFB_SNRN_E	9.014E-05
	West of Baker	Lateral	Yes	---	---	HFB_GROUP	9.014E-07
	Near Confusion	Normal	Yes	X	---	HFB_SNKCON	9.014E-07
Spring Valley	Northeast	Normal	Yes	X	---	HFB_SPR_CE	9.014E-07
	Central-east	Normal	Yes	X	---	HFB_SPR_NE	9.014E-07
Steptoe Valley	To Cave Valley	Normal	Yes	X	X	HFB_SwSTEP	9.014E-07
	Near McGill Spring	Normal	Yes	X	---	HFB_MCGILL	9.014E-07
	East Model Boundary	Normal	Yes	X	---	HFB_STEPBE	9.014E-07
	South Model Boundary	Normal	Yes	X	---	HFB_STEPBS	9.014E-07
	West Model Boundary	Normal	Yes	X	---	HFB_STEPBW	9.014E-07
Tippett Valley	East	Normal	Yes	X	---	HFB_TIPP_E	9.014E-07
	West	Normal	Yes	X	---	HFB_TIPP_W	9.014E-07
White River Valley	Caldera	Lateral	Yes	---	---	HFB_WRCALD	9.014E-07
	Cross Valley, Near Moorman Spring	Normal	Not UVF	X	---	HFB_WR_X_C	9.014E-07
	East Side of Valley, North Near Lund	Normal	Yes	X	---	HFB_WR_E_N	9.014E-07
	Hot Creek Springs Area	Normal	Yes	X	---	HFB_WR_HCS	9.014E-07
	Near Pahroc Valley	Normal	Not UVF	X	---	HFB_WR_PRC	9.014E-07
	West of Hot Creek Springs Area, Along Mountain Block	Normal	Yes	X	---	HFB_WR_WH_C	9.014E-07
	East Side of Valley, Southern End	Normal	Yes	X	X	HFB_WR_E_S	9.014E-07

- Pahranaḡat Valley (Figure 4-19) – During model calibration, discharge by groundwater ET from Pahranaḡat Valley tended to be larger than expected. A constant-head boundary was added to southwestern Pahranaḡat Valley to allow some of the discharge to flow out of the model area through the Pahranaḡat Shear Zone, thereby decreasing discharge by groundwater ET to more reasonable levels. This is consistent with some previous studies (Winograd and Friedman, 1972; Dettinger, 1989; Kirk and Campana, 1990; Thomas et al., 1996), and models (D’Agnese et al., 1997) have suggested that groundwater flow from Pahranaḡat Valley toward the DVFS is possible. However, Thomas et al. (2001) and Thomas and Mihevc (2007) balanced a deuterium-mass-balance model of the WRF S based on updated deuterium measurements without any subsurface outflow from the western boundary of Pahranaḡat Valley. San Juan et al. (2004) found that the most reasonable estimate of boundary flow between Tikaboo Valley and Pahranaḡat Valley is 800 afy of inflow to Pahranaḡat Valley. While the calibrated groundwater ET rates are still high, opening the Pahranaḡat Shear Zone boundary allows some of the excess water to exit. At the same time, adequate flow is delivered to Coyote Spring Valley and the Muddy River through the Pahranaḡat Shear Zone.
- Confusion Range (Figure 4-16) – The constant-head boundary at the Confusion Range in southeastern Snake Valley was tested to evaluate its extent along the range. A reduced boundary length along the Confusion Range resulted in a better representation of hydraulic heads in Snake and Hamlin valleys and discharges through ET and springs. In the conceptual model, the Confusion Range boundary extended about 28 mi (45 km) north of that shown in Figure 4-13. Simulated hydraulic heads were predicted to decline to the north. During model calibration, this tended to reduce flows at Twin Springs and Foot e Reservoir Spring and to lower hydraulic heads in the mountain block, often to levels lower than those seen on the floor of Snake Valley. Analysis of recent data collection (Mankinen, pers. comm., 2008) suggests a significant gravity anomaly in this northern section of the Confusion Range. This indicates a change in material type from the southern boundary area. The K could be higher or lower, but given the behavior of the model in the area, a low K zone appears more reasonable, making representing this section with a constant-head boundary less reasonable. During early testing, hydraulic heads were raised along this boundary to improve flow at Twin Springs and surrounding hydraulic-head observations. However, hydraulic heads were raised 650 ft (200 m) along the northern boundary before good matches were attained. Given that no source existed for this water, the approach was abandoned and a reduction in boundary length was used.
- Fish Springs Range/Fish Springs Area (Figure 4-16) – The source of water at Fish Springs was evaluated throughout the model-calibration process. Initial calibration efforts assigned no flow conditions along the Fish Springs Range between Snake Valley and Fish Springs Flat. The volume of discharge at Fish Springs suggests that the origin of water occurs outside of Fish Springs Flat (Bolke and Summison, 1978; Gates and Krueger, 1981; Carlton, 1985; Harrill et al., 1988). The calibrated model suggests 718 afy (2,425 m³/d) is flowing into Snake Valley from Fish Springs Flat. In general, small flows (<1,000 afy) across this boundary alternated between, into, and out of the model domain. Flows predicted at this boundary appear to be small, but whether flow is really into or out of the model domain is unclear.

The flow-boundary segments and their representation in the model are only interpretations. Their actual locations and flow rates may differ from simulated flow because of uncertainties in the recharge estimates and because the hydraulic properties of the rocks are unknown over most of the model domain.

5.3.3 Definition of Recharge Processes

Section 4.5 describes the development of recharge input to the CCRP model. Recharge was based on five basic processes, including:

- PRISM precipitation distribution
- Runoff watershed areas and catchment points
- Runoff distribution pathways
- Recharge efficiencies
- In-place versus runoff recharge percentages for potential recharge

Of the five processes, PRISM precipitation distribution and watershed areas and catchment points were not modified during calibration. Runoff pathways, efficiencies, and in-place percentages were adjusted during calibration. The following sections describe the calibration of these recharge processes.

5.3.3.1 Runoff Distribution Paths

The runoff distribution paths were the result of an automated topographic-based geographic information system (GIS) algorithm described in Section 4.0. The paths were not modified programmatically during model calibration. Instead, they were adjusted manually prior to model execution. Therefore, runoff distribution paths were not manipulated by UCODE _2005 for sensitivity calculations or parameter estimation. As part of the calibration process, adjustments to runoff pathways refined the runoff recharge component. For example, the recharge process could produce runoff to model cells with a very small thickness of permeable rock type. This could result in unrealistic mounding. In addition, converging distribution paths could also result in unrealistic simulated mounds in the water table. In short, manual modifications to runoff pathways resolved unrealistic mounding. Extending a distribution path typically resolved unrealistic water-table mounding.

5.3.3.2 Recharge Efficiencies

SNWA (2009a) provides initial estimates RE for the flow systems within the model domain. For each flow system, four efficiency intervals were defined in the model, and the following rules describe their implementation:

- RE for larger precipitation rates were equal to or larger than the efficiency for smaller precipitation rates (i.e., $RE_4 \geq RE_3 \geq RE_2 \geq RE_1 \geq 0.0$).

- RE were grouped with a multiplication factor by flow system. When the factor was modified, all the efficiencies for the flow system were raised or lowered by an equal percentage.
- RE multiplication factors were limited to a range of 0.1 to 2.0 in UCODE_2005. A factor of 1.0 implies the initial RE were unchanged. A factor of 2 would imply twice the expected recharge enters the flow system, and 0.1 would imply only 10 percent of the expected recharge enters the flow system. The bound on the multiplication factor was found to stabilize the recharge-efficiency parameters during the estimation process.

Convergence issues were encountered with the RE during parameter estimation. Therefore, manual adjustment was the primary calibration method for these parameters.

During the calibration, the RE were some of the most sensitive model parameters, second to the constant-head boundary parameters. Early in the calibration when using parameter estimation to estimate parameter values, the initial values for RE were often unreasonable. In some cases, rates could exceed 100 percent of precipitation or trend toward zero. In the calibrated model, the RE estimates were very similar to those defined in the conceptual model, with the exception of the Goshute Valley Flow System (GVFS) efficiencies. These were raised by 25 percent because simulated heads and ET rates in Steptoe Valley were typically low and because the recharge rate used in the conceptual model was at the low end of the literature for Steptoe Valley (discussed more in [Section 6.0](#)).

5.3.3.3 In-Place and Runoff Recharge Efficiencies

The range of possible values of in-place recharge efficiency is 0.0 to 1.0 in UCODE_2005. Two parameters, R_ROCARB_W and R_ROLVF_WT, are commonly sensitive parameters. The final model calibration estimates these parameters. The R_ROLVF_WT parameter controls volcanic areas and had significant influence on hydraulic-head observations in Clover Valley and the Caliente Caldera Complex.

Convergence issues were encountered with the in-place and runoff efficiencies during parameter estimation. Therefore, manual adjustment was the primary calibration method for these parameters.

5.3.3.4 Additional Recharge Zonations

In the original conceptual model, there were four primary recharge efficiency regions. These represented the Great Salt Lake Desert, Goshute Valley, Meadow Valley, and White River flow systems. During model calibration, all the flow systems other than Goshute Valley were subdivided. Because some of these flow systems cover extensive regions, it is not surprising that there would be local variations.

Hamlin Valley is an example where the hydrogeologic conditions do not match the recharge efficiencies established for the flow system. While Hamlin Valley is part of the GS LDFS (see [Figure 4-32](#)), the climate and rock types in the southern half of the basin are more similar to those

seen in the MVFS. As a result, Hamlin Valley was divided approximately in half for recharge purposes, with the southern half being reassigned to the MVFS.

Long Valley was originally modeled as being part of the WRFS. As a result of the calibration process, Long Valley and the northern half of Jakes Valley appear to be part of the Newark Valley Flow System (see Figure 4-32). RE were originally equal to the WRFS efficiencies. However, RE were decreased by 50 percent to minimize groundwater mounding simulated in the area.

An additional subzone was defined in the GSLDFS. This subzone occurs in Snake Valley in the northern Snake Range south of the Kern Mountains (see Figure 4-32). This subzone was created in an effort to increase spring flows at Warm Springs, west of Gandy, Utah (see Section 5.3.1.1.1). This predominantly north- and east-facing area of the Snake Range was assumed to have a 25 percent higher recharge efficiency.

In tests to reduce ET discharge in some areas, RE in Dry Lake and Garden Valley (Figure 4-32) were defined. The final numerical model left the efficiencies in these areas unchanged (same as WRFS).

5.3.4 Definition of Discharge Areas

The two basic types of groundwater-discharge parameters defined in the numerical model are (1) ET and spring flow discharge, which are simulated using the DRN package and associated parameters, and (2) spring-fed stream flows, which are simulated using the SF R2 package and associated parameters. Groundwater ET and spring flows are grouped because the water that discharges from springs may be derived from greater depths in the flow system and supplies the wetlands, shrublands, playas, and open water bodies. Spring-fed stream flow is routed to ET areas that are somewhat distant from immediate groundwater-discharge locations. Groundwater ET was represented with the DRN package using four conductance modifiers treated as parameters and representing wetland, shrubland, playa, and open water for both regional and intermediate discharge areas (Table 5-4).

**Table 5-4
ET Regions and Conductance Modifier Parameters**

ET Regions	Parameter Name
Wetland	ETrWET and ETiWET
Shrubland	ETrSHR and ETiSHR
Playa/Wet Soil	ETrPLY
Open Water	ETrWAT
HA 209 Wetland	ETr209WET
HA 209 Open Water	ETr209WAT

Note: There are no intermediate Playa and Open Water ET areas.

5.3.4.1 ET Sub-Basins

To better constrain the distribution of ET across large valley bottoms, larger valleys were subdivided into ET sub-basins. ET estimates for each of the ET sub-basins were provided in SNWA (2009a). This more detailed constraint on the spatial distribution of ET facilitated a more even distribution of simulated ET along the large valley bottoms. However, considering the uncertainty in the ET estimates, matching these targets by hydrographic area remained the primary goal.

5.3.4.2 ET-Extinction Depth

The elevation of drains representing ET areas was initially defined to equal the minimum elevation of the USGS 30-m DEM cell occurring within the 247.1-acre (1 km²) model grid cell, minus 33 ft (10 m). This drain elevation approximates the elevation in the model domain below which groundwater ET ceases (corresponds to extinction depth). As model calibration improved, some ET areas required an adjustment to better approximate extinction depth. In these areas, simulated hydraulic heads were consistently low. To evaluate the ET-extinction depth, the depth subtracted from the minimum DEM elevation was adjusted. In the calibrated model, one of two drain depths was used: (1) the mean USGS 30-m DEM elevation within the 247.1-acre (1 km²) model grid cell, minus 33 ft (10 m) or (2) the minimum USGS 30-m DEM elevation within the 247.1-acre (1 km²) model grid cell, minus 16.4 ft (5 m). In a given model cell with an ET drain, the lower of these two values was used.

5.3.4.3 Spring Depth

Different types of springs were conceptualized to draw water from different model layers (depths). Regional springs were initially assigned to the uppermost model layer containing the LC RMU. Spring flows at these regional springs improved when the springs were assigned to model layers containing the LC RMU. Intermediate springs were initially assigned to the upper one or two model layers to represent shallow groundwater flow features. Spring flows improved when these springs were assigned to shallow and deep model layers, suggesting that these features have a mixture of deep and shallow groundwater sources.

5.3.4.4 Spring Conductances

Drain conductance was adjusted during calibration to better simulate spring discharge. [Table 5-5](#) lists initial conductance estimates and the calibrated conductance. The largest modification (factor of 10) to drain conductance occurs at Hot Creek Spring.

5.3.4.5 Spring (Riverbed) Hydraulic Conductivities

Springs simulated using the SFR2 package were assigned riverbed hydraulic conductivities. For these springs, the riverbed hydraulic conductivities were adjusted manually to improve matches with the spring flow observations. [Table 5-6](#) lists initial estimates and the calibrated hydraulic conductivities.

**Table 5-5
Conductances for Springs Modeled with DRNs**

Spring Name	Observation Name	Original Conductance Estimate ft ² /d (m ² /d)	Updated Conductance Estimate ft ² /d (m ² /d)
Arnoldson Spring	SPiw07_2_##	644.0 (59.83)	No Change
Blue Point Spring	SPiw15_2_##	57.70 (5.360)	173.1 (16.08)
Brownie Spring	SPis09_4_##	491.2 (45.63)	No Change
Butterfield Spring	SPib07_10_##	1,175 (109.2)	587.6 (54.59)
Cherry Creek Hot Springs	SPr79_2_##	3.693 (0.3431)	No Change
Cold Spring	SPiw07_3_##	428.8 (39.84)	No Change
Emigrant Springs	SPib07_15_##	537.7 (49.95)	No Change
Flag Springs 1	SPiw07_7_##	205.5 (19.09)	821.8 (76.35)
Flag Springs 2			
Flag Springs 3			
Foote Res. Spring	SPib95_12_##	2,199 (204.3)	No Change
Hardy Spring NW	SPis07_11_##	627.1 (58.26)	No Change
Hardy Springs			
Hot Creek Spring	SPr07_1_##	2,174 (202.0)	21,740 (2,020)
Keegan Spring	SPis84_12_##	927.0 (86.12)	No Change
Kell Spring	SPis95_13_##	302.5 (28.10)	No Change
Lund Spring	SPib07_5_##	5,899 (548.0)	973.4 (90.42)
McGill Spring	SPiw79_1_##	5,386 (500.4)	No Change
Minerva Spring	SPis84_13_##	1,484 (137.9)	No Change
Monte Neva Hot Springs	SPr17_3_##	141.3 (13.13)	No Change
Moon River Spring	SPr07_14_##	380.0 (35.30)	759.9 (70.60)
Moorman Spring	SPr07_6_##	206.0 (19.14)	No Change
Nicolas Spring	SPiw07_13_##	463.3 (43.04)	No Change
North Millick Spring	SPis84_3_##	1,069 (99.28)	No Change
Panaca Spring	SPr03_1_##	511.7 (47.54)	No Change
Preston Big Spring	SPr07_4_##	1,218 (113.2)	3,655 (339.6)
Rogers Spring	SPiw15_1_##	120.9 (11.23)	241.6 (22.45)
South Millick Spring	SPib84_4_##	1,114 (103.5)	No Change
Twin Spring	SPib95_15_##	3,514 (326.5)	No Change
Warm Creek near Gandy, UT	SPiw95_2_##	2,947 (273.8)	No Change
Willow Spring	SPRiw184_1_##	6.958 (0.6464)	No Change

refers to stress-period identifier.

**Table 5-6
Hydraulic Conductivities for Springs Modeled with SFR2 Package**

Spring Name	Observation Name	Parameter Name	Hydraulic Conductivity Estimate ft/d (m/d)	Updated Hydraulic Conductivity Estimate ft/d (m/d)
Ash Springs	G_ASH_SPR	SFR_COND17	0.328 (0.1)	No Change
Baldwin Spring	G_MR_MOAPA	SFR_COND19	0.328 (0.1)	0.131 (0.04)
Big Springs	G_BIG_SPR	SFR_COND3	0.328 (0.1)	3.28 (1.0)
Crystal Springs	G_XTL_SPR	SFR_COND16	0.328 (0.1)	0.0197 (0.006)
Hiko Spring	G_HIKO_SPR	SFR_COND15	0.328 (0.1)	0.0098 (0.003)
Jones Spring	G_MR_MOAPA	SFR_COND19	0.328 (0.1)	0.0328 (0.01)
M-10	G_MR_MOAPA	SFR_COND19	0.328 (0.1)	0.131 (0.04)
M-11	G_WARM_SW	SFR_COND19	0.328 (0.1)	0.0328 (0.01)
M-12	G_WARM_SW	SFR_COND19	0.328 (0.1)	0.0328 (0.01)
M-13	G_WARM_SW	SFR_COND19	0.328 (0.1)	0.0328 (0.01)
M-15	G_IVERSON	SFR_COND19	0.328 (0.1)	0.0328 (0.01)
M-16	G_IVERSON	SFR_COND19	0.328 (0.1)	0.0328 (0.01)
M-19	G_WARM_SW	SFR_COND19	0.328 (0.1)	0.0328 (0.01)
M-20	G_IVERSON	SFR_COND19	0.328 (0.1)	0.0328 (0.01)
Muddy Spring	G_MR_MOAPA	SFR_COND19	0.328 (0.1)	0.131 (0.04)
Pederson East Spring	G_WARM_SW	SFR_COND19	0.328 (0.1)	0.0328 (0.01)
Pederson Spring	G_WARM_SW	SFR_COND19	0.328 (0.1)	0.0328 (0.01)
Warm Springs East	G_IVERSON	SFR_COND19	0.328 (0.1)	0.0328 (0.01)

5.3.5 Storage Parameters

Many aquifer storage parameters were generally found to be insensitive (see [Section 6.0](#)). The exception is UVF_SYTP. The sensitivity of the UVF storage parameter is reasonable because most pumping occurs in the shallow unconsolidated UVF deposits. Relatively few features are in the system to stress the other parameters.

The initial S_y estimate for UVF_SYTP was 10 percent. This was a conservative value for unconsolidated deposits and within literature ranges. During initial modeling, though, drawdowns across the model generally significantly exceeded observed drawdowns. Early parameter-estimation runs predicted UVF S_y values in excess of 30 percent regionally. This was considered unreasonably large. During conversations with the USGS, and based on S NWA work (see [Appendix A](#)), UVF S_y values in the Snake Valley and Baker, Nevada, area were estimated in the 12 to 28 percent range. Based on this work, the UVF_SYTP was increased to 18 percent. Drawdown in some areas remains overpredicted (e.g., 183 N06 E66 35C 1 USBLM - Pony Springs Well). However, this value appears to be reasonable.

5.4 Adjustments in Western Model Area

The western side of the numerical model study area was particularly difficult to calibrate and required additional efforts. The difficulties stem from two major issues within the WRFS (1) groundwater flow in the Long Valley area and (2) groundwater flow in the Pahrana gat Valley area.

5.4.1 Groundwater Flow in Long Valley

Originally, the RE for Long Valley were assumed to be the same as the rest of the WRFS. Considering the relatively high elevation of Long Valley, relative to other nearby valleys (with lower elevation), recharge was expected to be significant (i.e., nonzero). Based on the simplified conceptual model used to derive the initial recharge distribution (SNWA, 2009a), 20,000 afy of precipitation recharge and additional groundwater was estimated to flow from Long Valley to Jakes Valley and, ultimately, to White River Valley.

The hydrogeologic framework model in the Long Valley area contains a significant thickness of the UA RMU. The presence of such a thickness of UA in conjunction with the initial recharge rates caused extreme groundwater mounding in Long Valley. The UA prevented vertical flow from the upper unconsolidated UVF deposits to the lower carbonate (LC3). The UA acted more or less as an effective confining unit at various tested thicknesses and/or hydraulic conductivities for the unit.

The northwestern portion of the model area, including Long and Jakes valleys, lacks well information to accurately assess the thickness of the UA in this area. Faulting from Long Valley through Jakes Valley and into White River Valley has been mapped from satellite imagery and aerial photography. Tests were initially performed to identify appropriate adjustments to the hydrogeologic framework model to allow approximately 37,000 afy of groundwater to flow from Long and Jakes Valley into White River Valley. It was found that even with a zone of LC extending from Long Valley to White River Valley, between the major normal faults through Jakes Valley, with K 's as high as 33 ft/d, large fluxes through Jakes Valley were still not possible. This finding is consistent with the potential presence of a groundwater divide in central Jakes Valley, with flow from northern Jakes Valley to Long Valley to Newark Valley (Prudic et al., 1995). Because simulating large flows through Jakes Valley was not possible, it was concluded that (1) either the initial recharge in Long and Jakes valleys was too high (2) or the groundwater resulting from recharge had to be moving through areas other than Jakes Valley. After review of earlier work in the area, it was found that Prudic et al. (1995) simulated 12,700 afy of groundwater from Long Valley to Newark Valley. It was assumed that an additional 4,000 afy of flow might be moving from Butte Valley and Long Valley northwest to Rose Valley.

5.4.2 Groundwater Flow in Pahrana gat Valley

The aquifer system of Pahrana gat Valley was difficult to represent in the numerical model. This difficulty is due to the large uncertainties associated with the hydrogeologic conceptualization of this basin and vicinity. This basin occurs at the confluence of groundwater flow from many of the WRFS valleys. The Pahrana gat Shear Zone, which is located at the southern end of Pahrana gat Valley, constitutes a major structural feature, controlling groundwater flow into Coyote Spring Valley and

ultimately Muddy River Springs and Muddy River. Groundwater may also flow along the Pahrana gat Shear Zone to the southwest into Tikaboo Valley and on toward the Amargosa Desert (Prudic et al., 1995). Further complicating the conceptual model of groundwater flow in Pahrana gat Valley, nearly 90 percent of the ET discharging from this valley is reported to be a result of groundwater discharge from Ash, Hiko, and Crystal springs. These springs discharge to the Pahrana gat Wash and probably feed the local riparian vegetation. Although no data are available to confirm it, Pahrana gat Wash may be interpreted to be perched or semiperched.

Given the representation of the simplified hydrogeology of the Pahrana gat Valley region represented in the model, it was not possible to simulate approximately 30,000 afy of groundwater discharge only from Ash, Crystal, and Hiko springs. Simulating these large volumes of groundwater discharge from the springs in the north end of the valley, while maintaining hydraulic heads well below land surface in the southern part of the valley, was not feasible by reasonable means. To reduce the excess groundwater flow in Pahrana gat Valley a reduction in potential recharge in and around this basin was tested. However, this reduction as a reduction in in-place recharge and/or an increase in runoff recharge in basins up-gradient of Pahrana gat Valley, resulted in undersimulated flow at many of the important regional springs throughout the WRFS. This same issue occurred when recharge was reduced in Garden and Coal valleys. Therefore, the excess groundwater in Pahrana gat Valley must be removed from the basin by other processes: (1) groundwater flow through the Pahrana gat Shear Zone to Coyote Spring Valley (2) discharge into Pahrana gat Wash and ET, and/or (3) groundwater flow by another route.

Allowing more groundwater to flow through the Pahrana gat Shear Zone results in anomalously high water levels in Coyote Spring Valley. The water could be sent farther south, but the hydraulic properties required to transmit water through faults and fractured carbonate rocks to Muddy River Springs and Muddy River would need to be unreasonably large. Thus, the first route was deemed unreasonable. Prudic et al. (1995) suggested that an additional 10,000 afy of ET may discharge from a shallow water table south of the spring along Pahrana gat Wash. A similar feature was included in the numerical model but was insufficient to significantly reduce the excess groundwater simulated in Pahrana gat Valley to acceptable levels. Previous investigators (Winograd and Thordarson, 1975) suggested that water from Pahrana gat Valley may also flow southwest to the Ash Meadows groundwater basin. This interpretation corresponds to the third route and was incorporated in the final version of the numerical model. In summary, given the current framework model, the best solution was a combination of two processes: (1) allow more ET to discharge from Pahrana gat Wash as suggested by Kirk and Campana (1990) and (2) allow some groundwater to flow out to Tikaboo Valley toward Amargosa Desert, as suggested by other researchers (Winograd and Thordarson, 1975).

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6.0 FINAL PARAMETER ESTIMATION AND MODEL EVALUATION

This section presents the evaluation of the transient numerical model calibration and describes the final parameter-estimation simulations. The calibration process and conceptual model refinements were presented in [Section 5.0](#). The nonlinear regression method discussed in [Section 5.0](#) provides a better understanding of model strengths and weaknesses, and has a built-in protocol to help evaluate how well simulated hydraulic heads and groundwater discharge match the observed values. It also provides a means for assessing the relative sensitivity of estimated parameter values and other measures of parameter and prediction uncertainty.

The evaluation of the numerical model calibration includes (1) reviewing the model fit and simulated hydraulic heads and flows, (2) evaluating parameter sensitivities and parameter-estimation results, and (3) evaluating the modeling parameter values. Finally, an evaluation of the flow systems as simulated by the model is provided. This evaluation includes detailed descriptions of interbasin flow, groundwater-flow regions, and groundwater budgets. The details are based on the optimized solution obtained through model calibration using sparse data, which is only one of many other potential reasonable solutions.

6.1 Evaluation of Model Fit

This section provides an evaluation of model fit, including a discussion of overall model fit, simulated hydraulic heads and drawdowns, simulated flows, distribution of weighted residuals versus unweighted simulated values, and normality of weighted residuals and model linearity.

6.1.1 Overall Model Fit

The contributions of each type of observation to the objective function are listed in [Table 6-1](#). The SoSWR for the hydraulic-head observations constitute the largest portion of the objective function (64.4 percent), followed by hydraulic-head drawdown observations (24.8 percent). SFR2 spring and stream flow observations account for 7.5 percent of the objective function, but this percentage is only this large because the standard deviations of the regional springs and Muddy River gage flow targets were divided by 10.0. The standard deviations for these observations were decreased because (1) they were felt to be some of the most important observations in the study area, and (2) without the modification, the parameter-estimation routine did not honor these observations adequately. ET-discharge observations constitute 2.35 percent of the total SoSWR, and the remaining observations contribute less than 1 percent of the objective function. More details on the model fit by observation type are provided in the following sections.

**Table 6-1
Calibrated Model - Summary of Observation Statistics**

Observation Type	Observation Type Code	Count	Average Positive Weighted Residuals	Average Negative Weighted Residuals	SoSWR	Percent of Objective Function
Hydraulic-Head Observations	W	2,707	1.1	-1.52	19,804.3	64.36%
Hydraulic-Drawdown Observations	Z	4,301	0.68	-1	7,625.0	24.78%
Spring Head Observations	S	0	---	---	0.0	0.00%
Groundwater ET	E	126	2	-1.53	723.9	2.35%
Spring Flow	SP	44	1.26	-1.67	251.4	0.82%
Spring Flow Change	SD	27	0.28	---	13.3	0.04%
CHD Boundary Flow	BND	16	0.79	-1.09	21.2	0.07%
Interbasin Flow	IBF	0	---	---	0.0	0.00%
SFR2 Spring/Stream Gage	G	144	2.65	-3.38	2,312.6	7.52%
Ground Surface	GS	2,145	---	-0.84	19.7	0.06%
Total	---	9,510	---	---	30,771.4	100.00%

As listed in [Table 6-1](#), the SoSWR is 19,804 for hydraulic heads, 7,625 for hydraulic drawdowns, 724 for ET discharge, 265 for spring flow and spring flow change, 21 for CHD boundary flows, 2,313 for spring and/or stream gage flows, and 20 for ground-surface observations. The standard error of the regression equals 1.7994, which indicates that overall model fit is consistent with hydraulic-head standard deviations that are 1.7994 times the assigned values. For flow out of groundwater ET cells, overall model fit is consistent with 1.7994 times the assigned COVs of 10 to 120 percent. Thus, effective model fit for groundwater ET is between approximately 18 and 216 percent.

The observations represented in the numerical model and listed in [Table 6-1](#) fall into one of the following categories:

- Observations used in the objective function for parameter-optimization purposes.
- Observations used to derive observations used in the objective function for parameter-optimization purposes (i.e., spring head observations).
- Observations not used by the objective function. These observations were for informational or monitoring purposes only and did not affect model statistics.

Observations, such as hydraulic heads, hydraulic drawdowns, ET-discharge rates, spring flows, spring flow changes, CHD boundary flow, and stream gage flow, were assigned realistic variances. The uncertainty of these observations could be quantified. It was therefore reasonable to include them when optimizing the parameters to minimize the objective function. In some cases, the variances were reduced in order to increase the influence of some observations over others.

Additional observations, such as estimated regional potential hydraulic head at a spring, small spring flows, or interbasin flows, were typically flagged by using very large variances (greater than 1.0E10). In UCODE, noncalibration target types were given a Use-Code Flag of “N” (see [Appendix B](#)). This eliminated these observations from statistical consideration. These observations were treated in this manner for one of the following reasons: (1) the observations were estimated with very little confidence (e.g., interbasin flow); (2) the observations were related to a feature that could not be reasonably simulated with a regional-scale model (e.g., small spring flows less than 1 cfs); or (3) the observations were being tracked for informational purposes only (hydraulic heads at spring pools).

Observations monitored during model calibration, such as spring hydraulic heads, interbasin flows, and small spring flows, were assigned large variances to minimize their weights in the objective function. In the final sensitivity run, these parameters were removed from the model to simplify the output and to eliminate their small contribution to the objective function. Similarly, 2,145 ground-surface observations with a zero residual were removed from the final sensitivity run. If these zero-residual pseudo-observations were used in the statistical analyses of the results, they would create a significant statistical bias and inhibit the interpretation of model-calibration results.

6.1.2 Simulated Hydraulic Heads and Drawdowns

The simulated hydraulic heads are shown on [Plates 2 and 3](#). While significantly more detail is in these model results, the overall regional hydraulic-head levels and flow directions are consistent with previous models and studies for this area (Prudic et al., 1995). The model results are compared in greater detail in [Section 6.4.2](#).

Stress period 1 in the numerical model is steady-state and represents predevelopment conditions. Drawdown calculated for subsequent stress periods (2 through 61) represents changes in simulated hydraulic head from stress period 1. [Figure 6-1](#) shows drawdowns at the end of stress period 61 (December 31, 2004) in detail. [Figure 6-2](#) shows the progression of drawdowns through time. Plots of simulated hydraulic heads and drawdowns for all wells are presented in electronic form (see DVD).

In general, simulated transient drawdowns match observed drawdowns. Seasonal and larger-term climatic cycles are not simulated, but the overall trends also generally match well. Wells (C-11-17) 1bdc 2 and (C-20-20)12acc 1 are distributed across Snake Valley and represent how the numerical model matches the general trend of hydraulic-head observations ([Figures 6-3 and 6-4](#)). Similarly, wells Behmer-MW and 219 S14 E65 21AC 1 EH-4 illustrate the response of wells in the Muddy River Springs Area ([Figures 6-5 and 6-6](#)). In some instances, the numerical model may simulate one well poorly and one well adequately in the same model cell. Wells 219 S14 E65 23BB 1 and 219 S14 E65 23ABBB 1 are examples ([Figures 6-7 and 6-8](#)).

6.1.2.1 Evaluation of Weighted Residuals

Statistics for the weighted residuals associated with the observation groups were presented in [Table 6-1](#) and discussed in [Section 6.1](#). The spatial distributions of hydraulic-head and drawdown

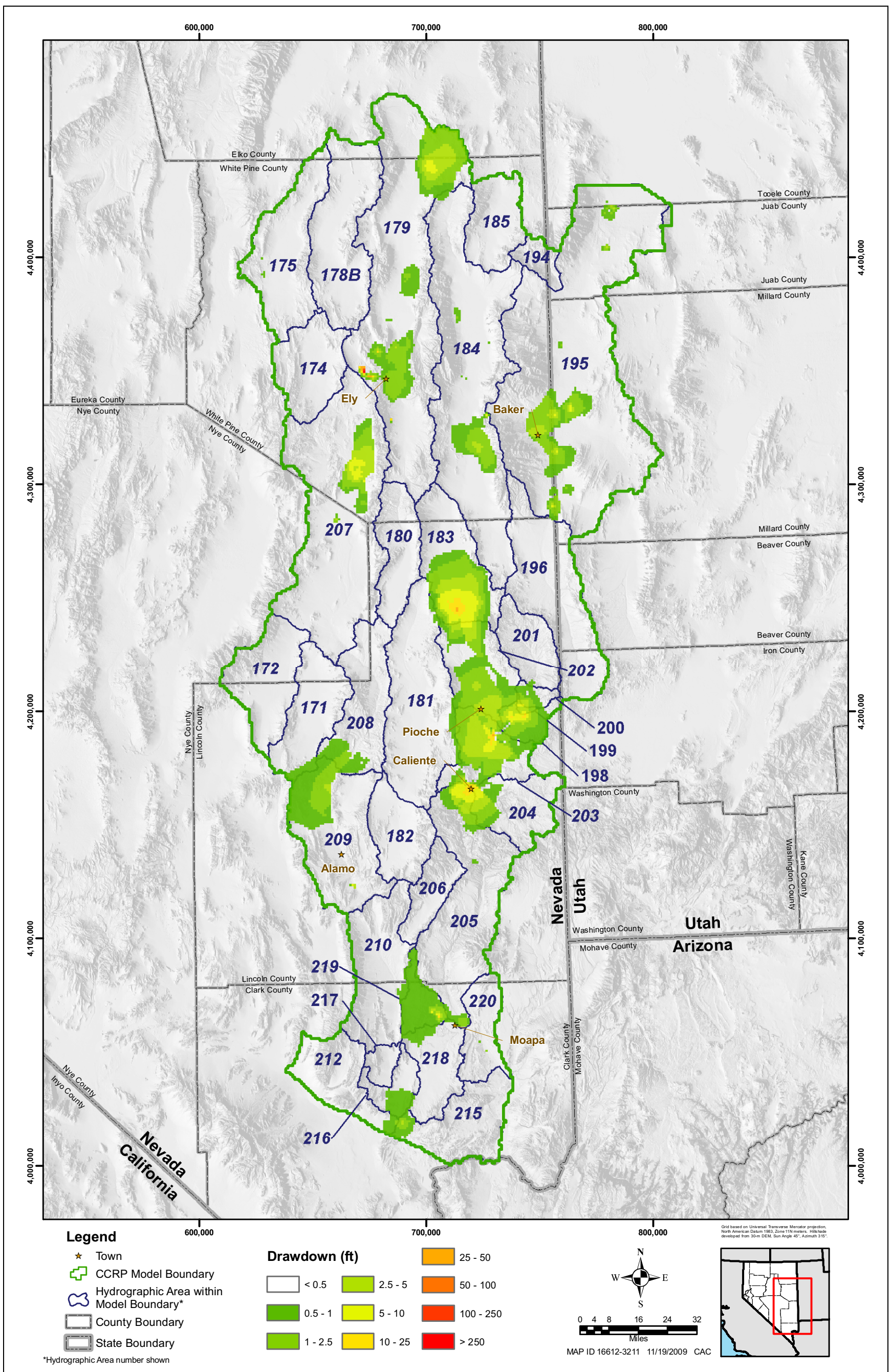


Figure 6-1
Simulated Drawdowns for End of Stress Period 61 (December 31, 2004)

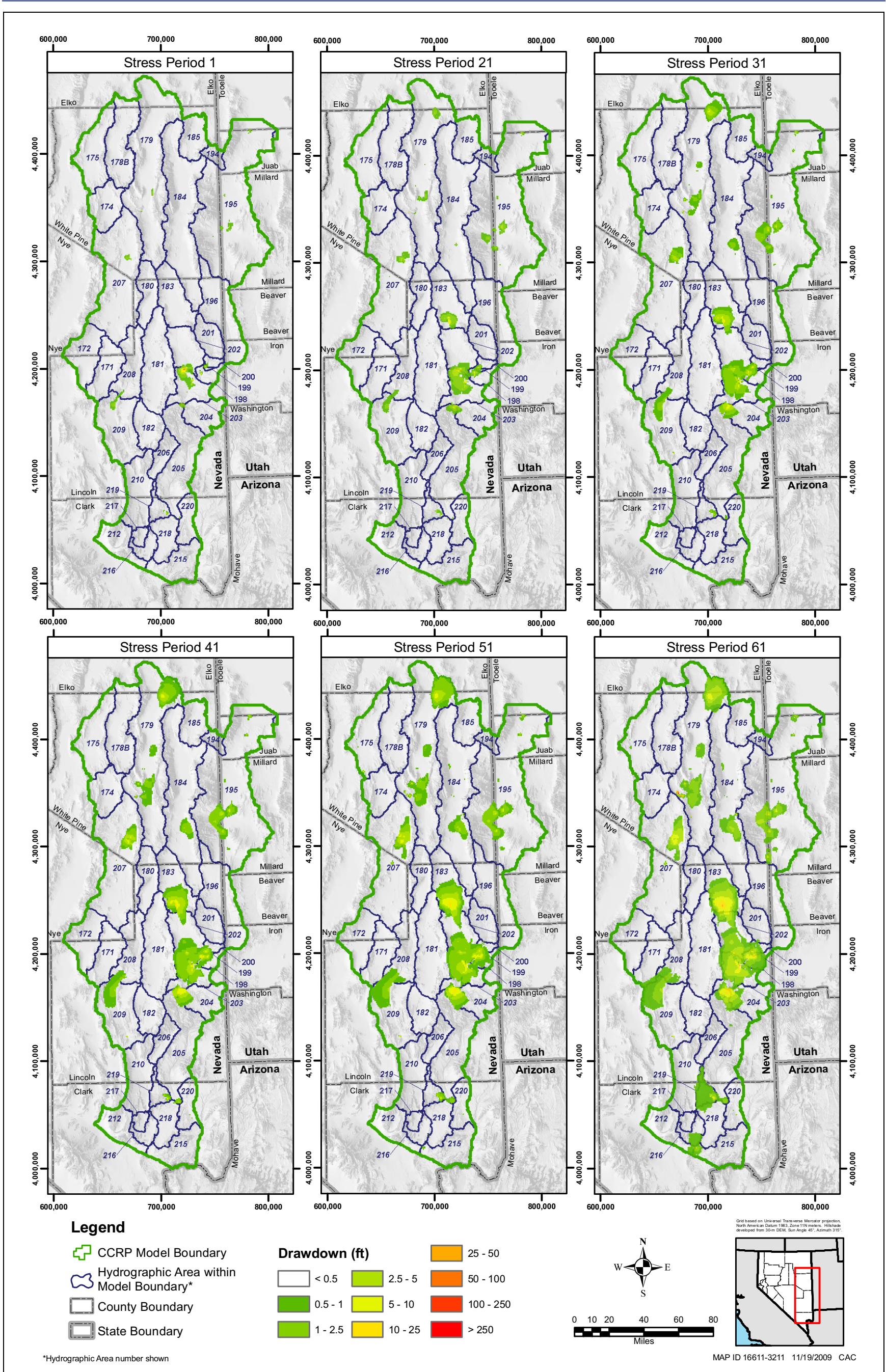


Figure 6-2
Simulated Progression of Drawdowns

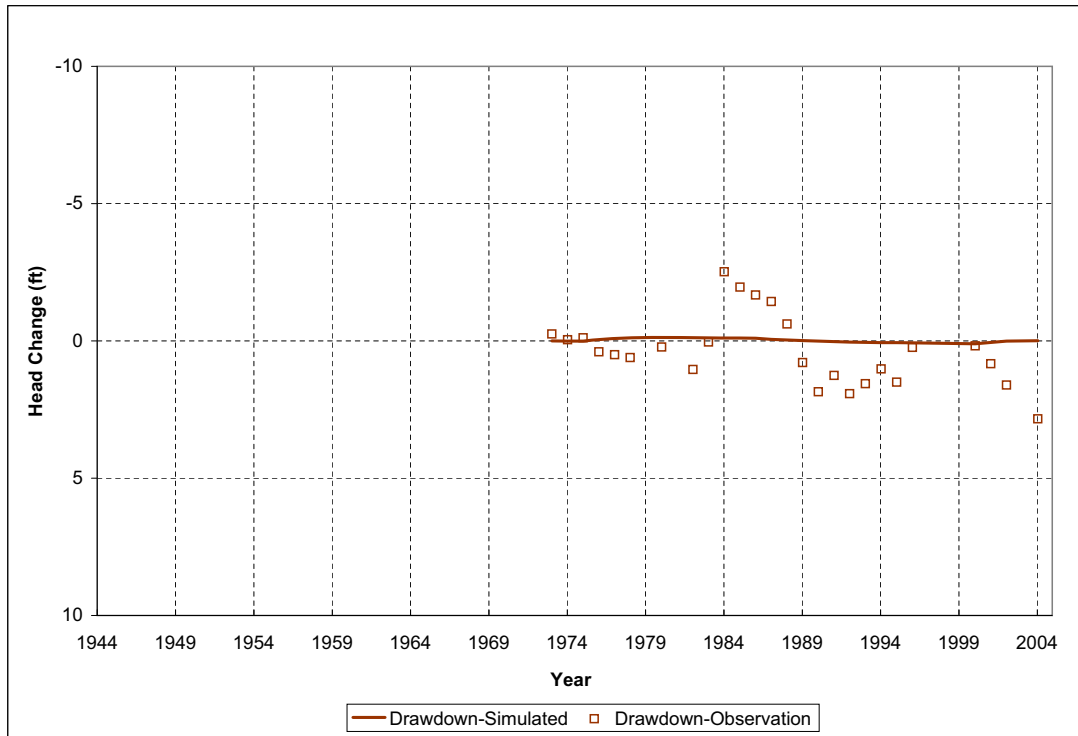


Figure 6-3
Simulated and Observed Drawdowns for Well (C-11-17) 1bdc 2

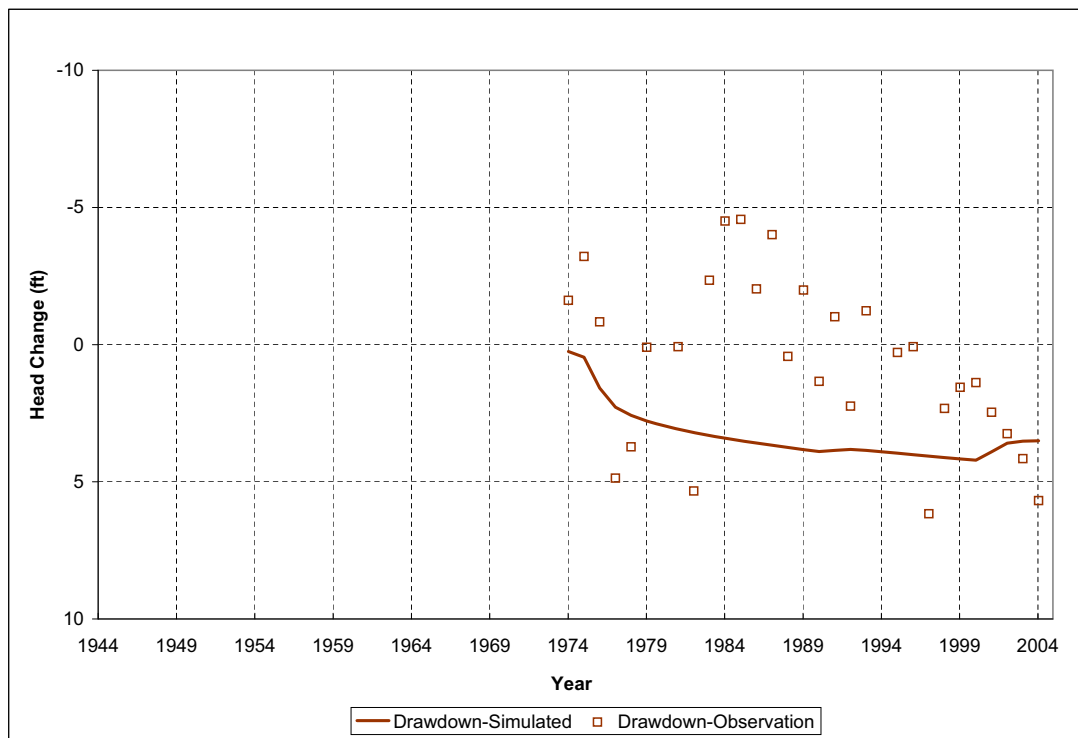


Figure 6-4
Simulated and Observed Drawdowns for Well (C-20-20) 12acc 1

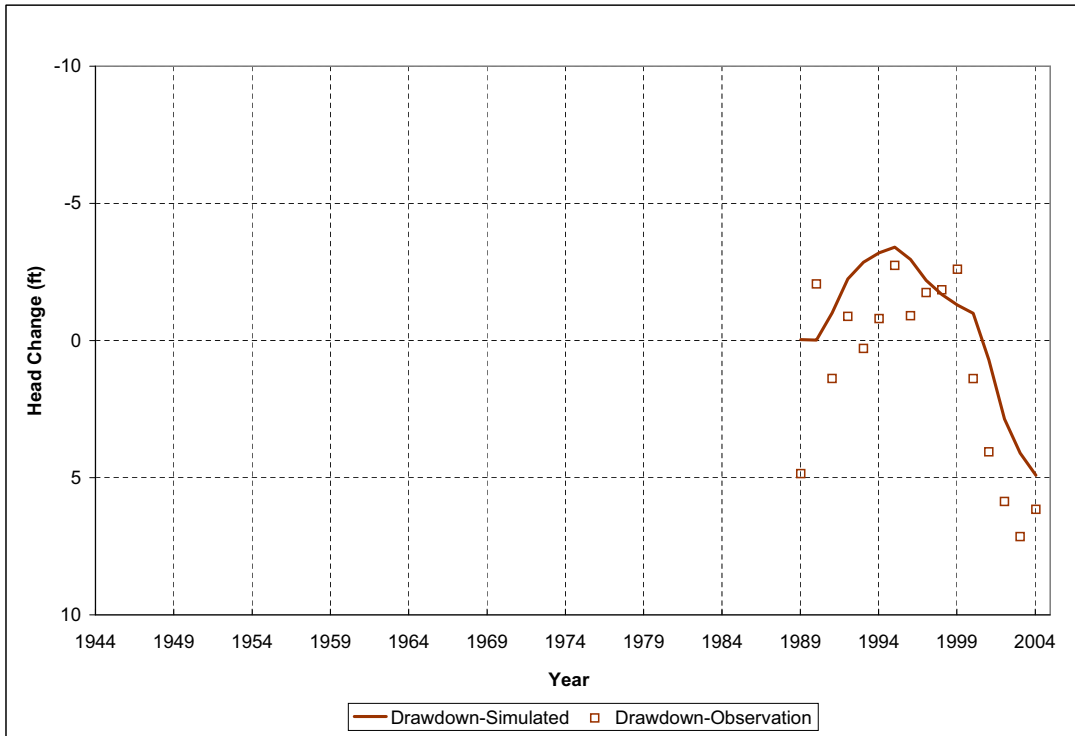


Figure 6-5
Simulated and Observed Drawdowns for Well Behmer-MW

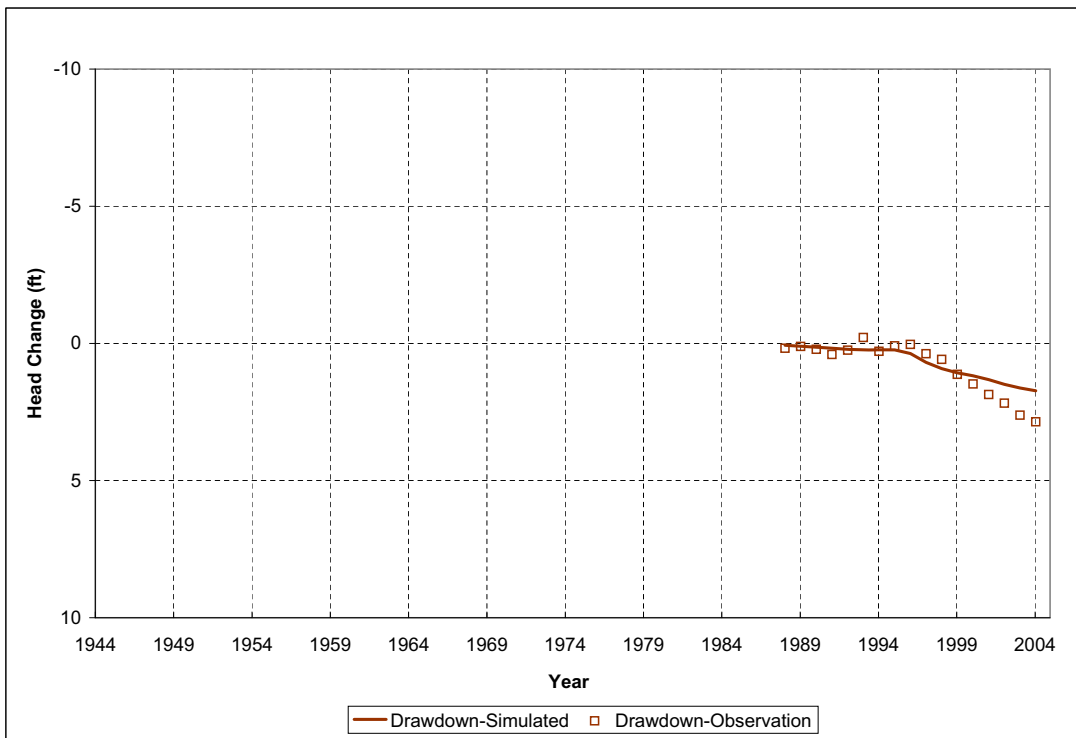


Figure 6-6
Simulated and Observed Drawdowns for Well 219 S14 E65 21AC 1 EH-4

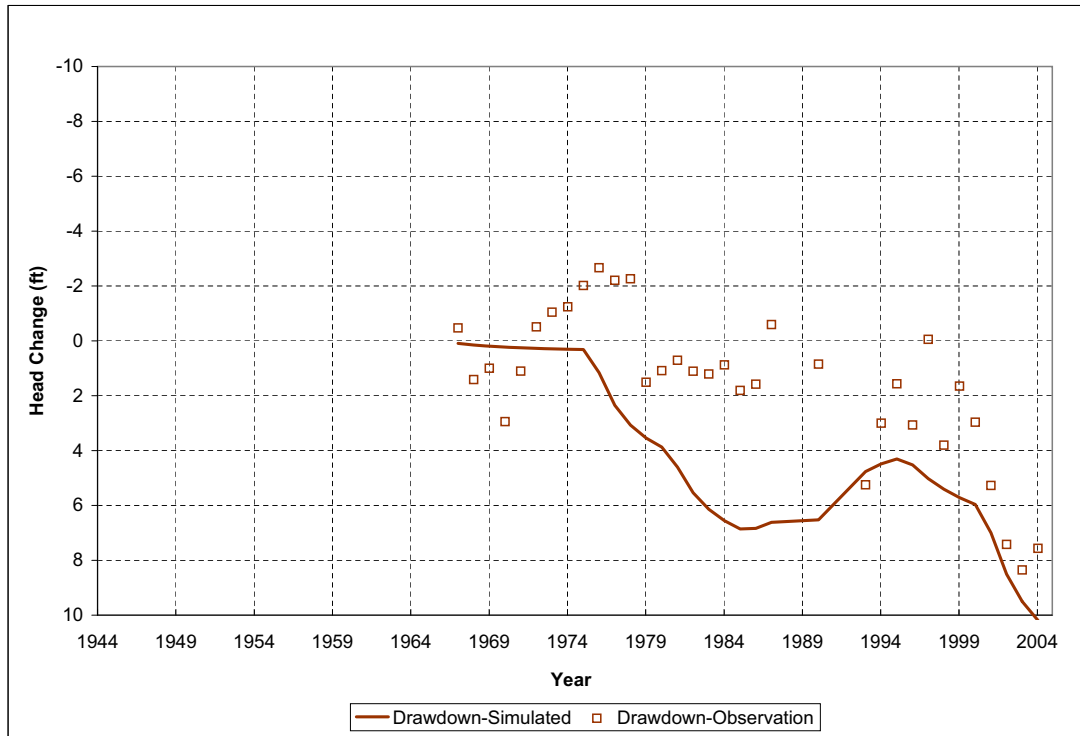


Figure 6-7
Simulated and Observed Drawdowns for Well 219 S14 E65 23BB 1

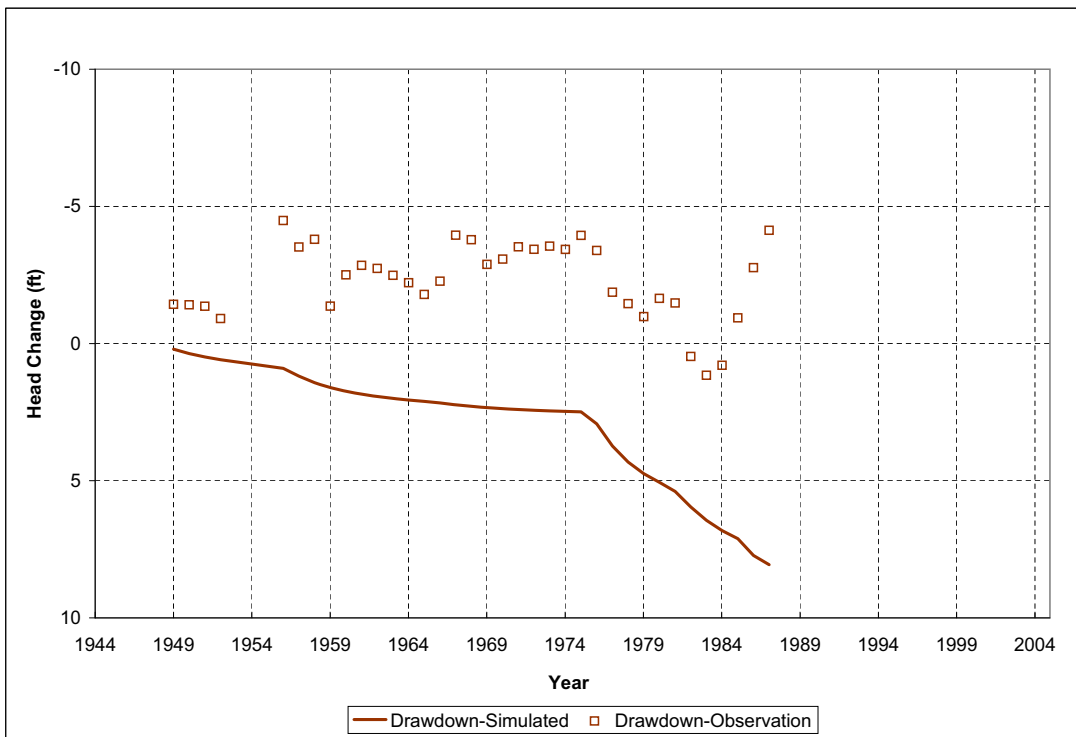


Figure 6-8
Simulated and Observed Drawdowns for Well 219 S14 E65 23ABBB 1

residuals are described and presented in figures in the following sections. More detailed versions of these figures are also included on the DVD.

6.1.2.2 Unweighted Residuals

Statistics for the unweighted residuals associated with the observations are presented in Table 6-2. Such statistics are listed for boundary flux, stream gage flow, ground-surface elevation, groundwater ET discharge, spring flow, well head, and well drawdown.

**Table 6-2
Unweighted Observed versus Simulated Observation Statistics**

Observation Type	Units	Number of Samples	Mean Error	Mean Absolute Error	Root Mean Square Error	Standard Deviation	Target Data Range	RMSE/Range	Expected Error Size with Increasing Target Size ^a
Boundary Flux	afy	16	1,169	1,703	2,273	2,013	20,000	11%	Increasing
Gage Flow ^b	afy	140	255	1,211	1,687	1,674	35,672	5%	Increasing
Ground Surface ^c	ft	2,145	(0)	0	5	5	---	NA	Constant
Regional ET Discharge	afy	108	(250)	1,769	2,912	2,915	69,431	4%	Increasing
Spring Flow ^d	afy	48	(685)	816	1,666	1,534	13,027	13%	Increasing
Well Drawdown	ft	4,301	(1)	4	9	9	238	4%	Constant
Well Head	ft	2,707	15	45	91	90	6,461	1%	Constant

NA = Not Applicable

^aThe error associated with hydraulic head would be expected to be constant with elevation. The error associated with spring flow would be expected to increase with larger flows.

^bAsh, Big, Crystal, and Hiko springs measurements removed from gage statistics.

^cBecause 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.

^dAsh, Big, Crystal, and Hiko springs measurements added to spring statistics.

Note that for observations such as hydraulic head and drawdown, average error is a useful metric across the full range of data. The error in the model would be expected to be similar at low, intermediate, and high elevations in the model. The average error for observations such as spring or stream flow, however, may be less useful. For example, similar errors would be expected for a spring with flows of 0.01 cfs and another with 100 cfs. For some observations, the magnitude of the error should be fairly constant through the target data range (minimum to maximum observed value). For other data types, the magnitude of the error would be expected to grow with the size of the observation.

Figure 6-9 illustrates the spatial distribution of unweighted hydraulic-head residuals. Unweighted residuals were calculated as observed hydraulic head minus simulated hydraulic head. Thus, unweighted residuals provide a direct comparison of the observed to the simulated hydraulic heads. As shown in Figure 6-9, large unweighted residuals are generally distributed across the model domain, located within mountain ranges or at the mountain-block/valley bottom margin. Some spatial bias, however, is illustrated with the unweighted residuals, including overestimates of

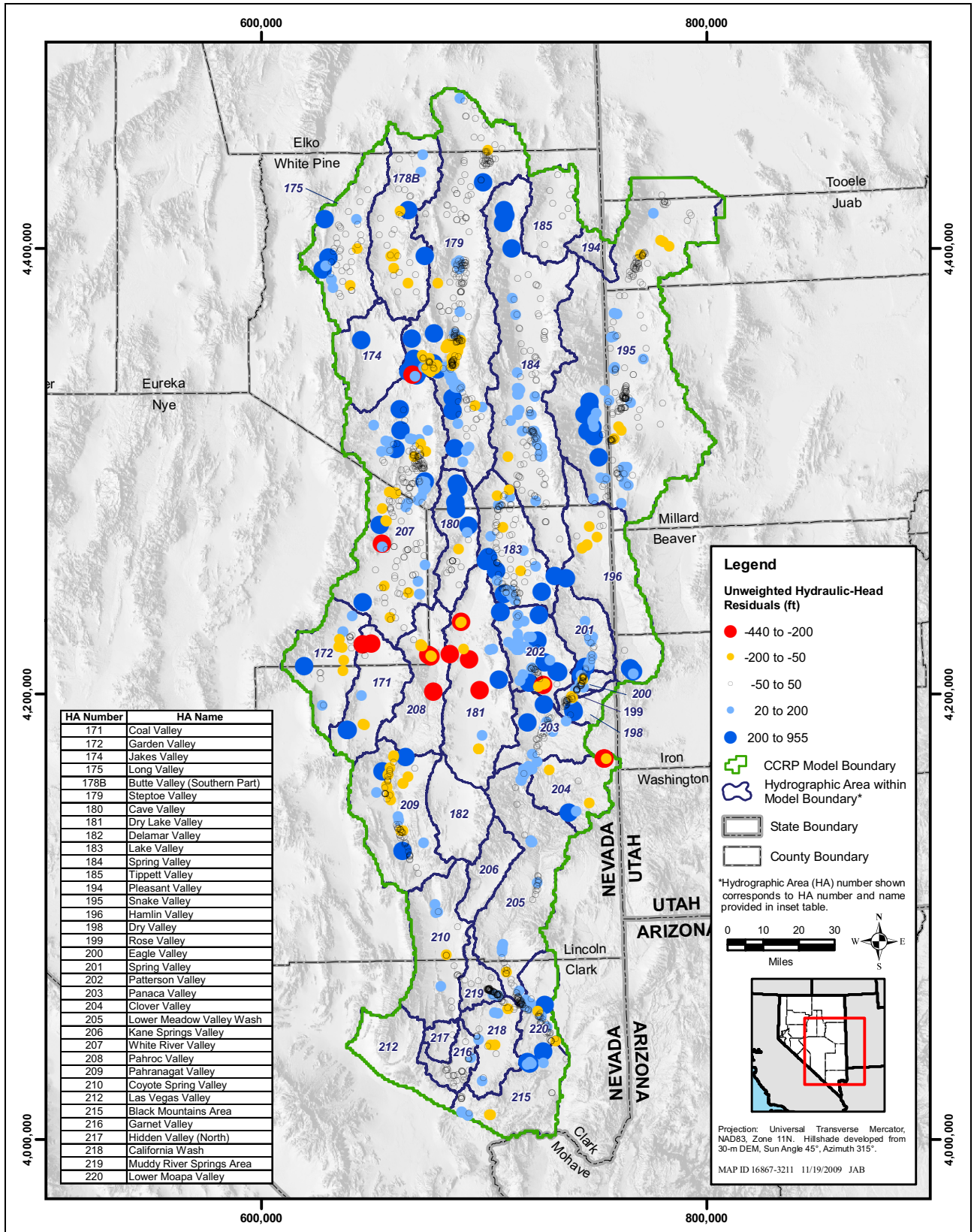


Figure 6-9
Spatial Distribution of Unweighted Hydraulic-Head Residuals

hydraulic head (negative residuals) in Pahroc Valley and Dry Lake Valley and underestimates (positive residuals) in northern Cave Valley and Spring Valley.

Caution should be used when evaluating unweighted residuals because observation uncertainty is not considered in the calculation of the residual. Observation uncertainty can include many factors and can be significant in some cases. [Appendix B](#) describes the rigorous process used in developing the hydraulic-head observation data set, which includes observation uncertainty. The observation uncertainty is used by UCODE_2005 in the regression process. In simple terms, observations with large uncertainty are considered less important in the regression. Thus, evaluation of unweighted residuals without consideration of observation uncertainty can lead to misleading interpretations.

6.1.2.3 Spatial Distribution of Weighted Residuals

[Figure 6-10](#) illustrates the spatial distribution of unweighted drawdown residuals. The spatial distributions of the weighted residuals of hydraulic heads and drawdowns are evaluated separately and then in combination.

[Figure 6-11](#) illustrates the spatial distribution of weighted hydraulic-head residuals. Less spatial bias is observed with weighted residual hydraulic heads as compared to unweighted residual hydraulic heads. This spatial distribution shows that wells with poorer model fit are generally scattered across the model domain or are located predominantly within mountain ranges or at the mountain-block/valley bottom margins. Spatial bias, however, is still observed in Pahroc and Dry Lake valleys.

[Figure 6-12](#) illustrates the spatial distribution of weighted drawdown residuals. Overpredicted drawdown is evident in northern White River Valley, southern Lake Valley, Dry Valley, and Panaca Valley. Spatial bias is observed in Pahroc and Dry Lake valleys.

[Figure 6-13](#) illustrates the spatial distribution of the SoSWR by well. The SoSWR by well statistic was developed to provide a single residual per well. The SoSWR by well statistic sums the squares of weighted residuals for hydraulic heads and drawdowns at each well. In other words, all weighted hydraulic-head and drawdown residuals are included in the SoSWR by well. As shown in [Figure 6-13](#), the spatial distribution shows that wells with poorer model fit are generally located in isolated areas, predominantly within mountain ranges or at the mountain-block/valley bottom margin. Areas with large SoSWR include central Steptoe Valley, central Cave Valley, southern Lake Valley, northern Coal Valley, central Delamar Valley, southern Patterson Valley, and extreme southern Hamlin Valley. In many cases, these ranges may represent areas where potentially and/or locally controlled water levels were used in the model as hydraulic-head targets to represent regional groundwater conditions.

6.1.3 Evaluation of Simulated Flows

Evaluation of the simulated flows to observed ranges using graphical methods is provided in this section. Simulated flows include flow into and out of external boundaries, groundwater discharge by ET, discharge by springs, and discharge by stream flow routing.

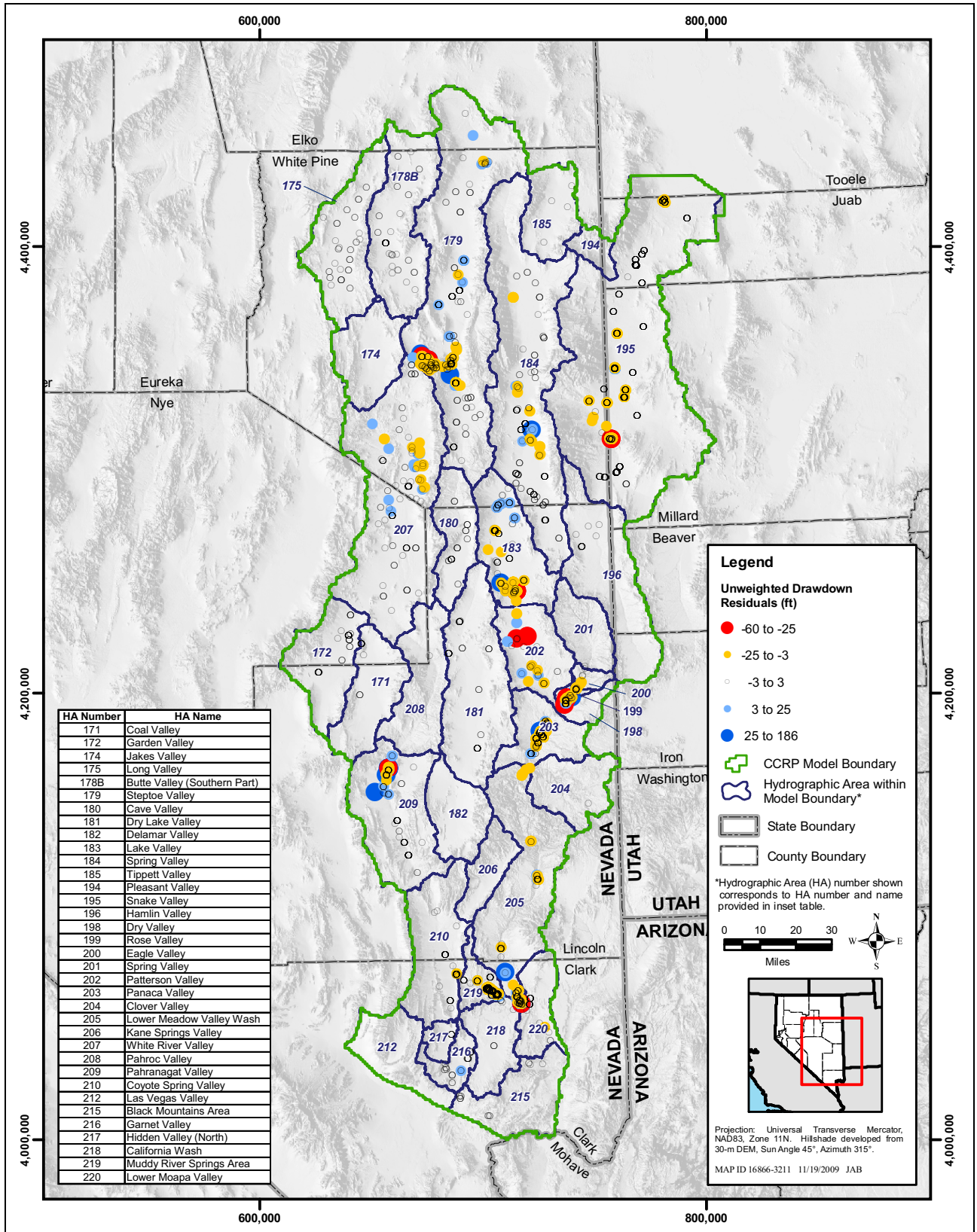


Figure 6-10
Spatial Distribution of Unweighted Drawdown Residuals

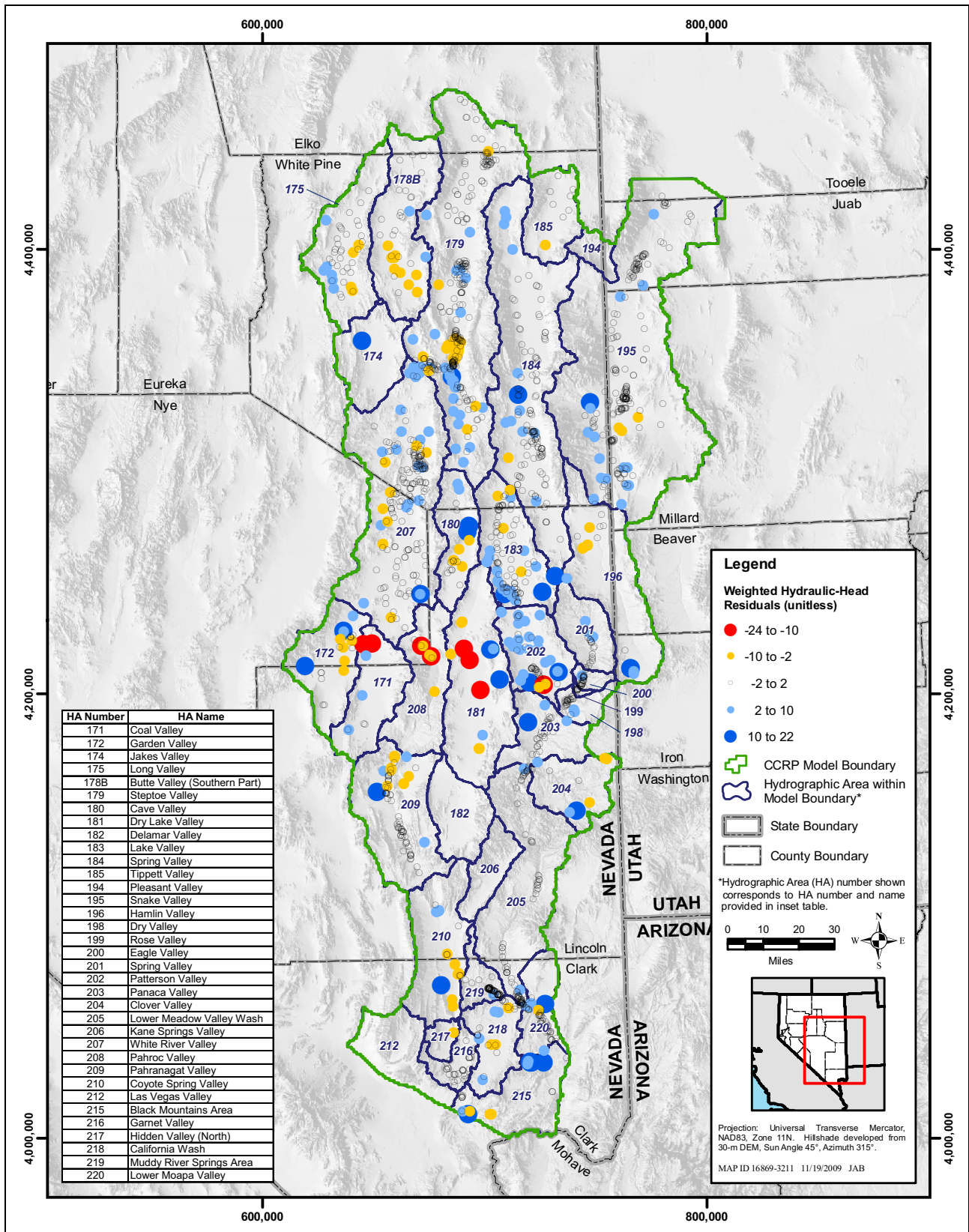


Figure 6-11
Spatial Distribution of Weighted Hydraulic-Head Residuals

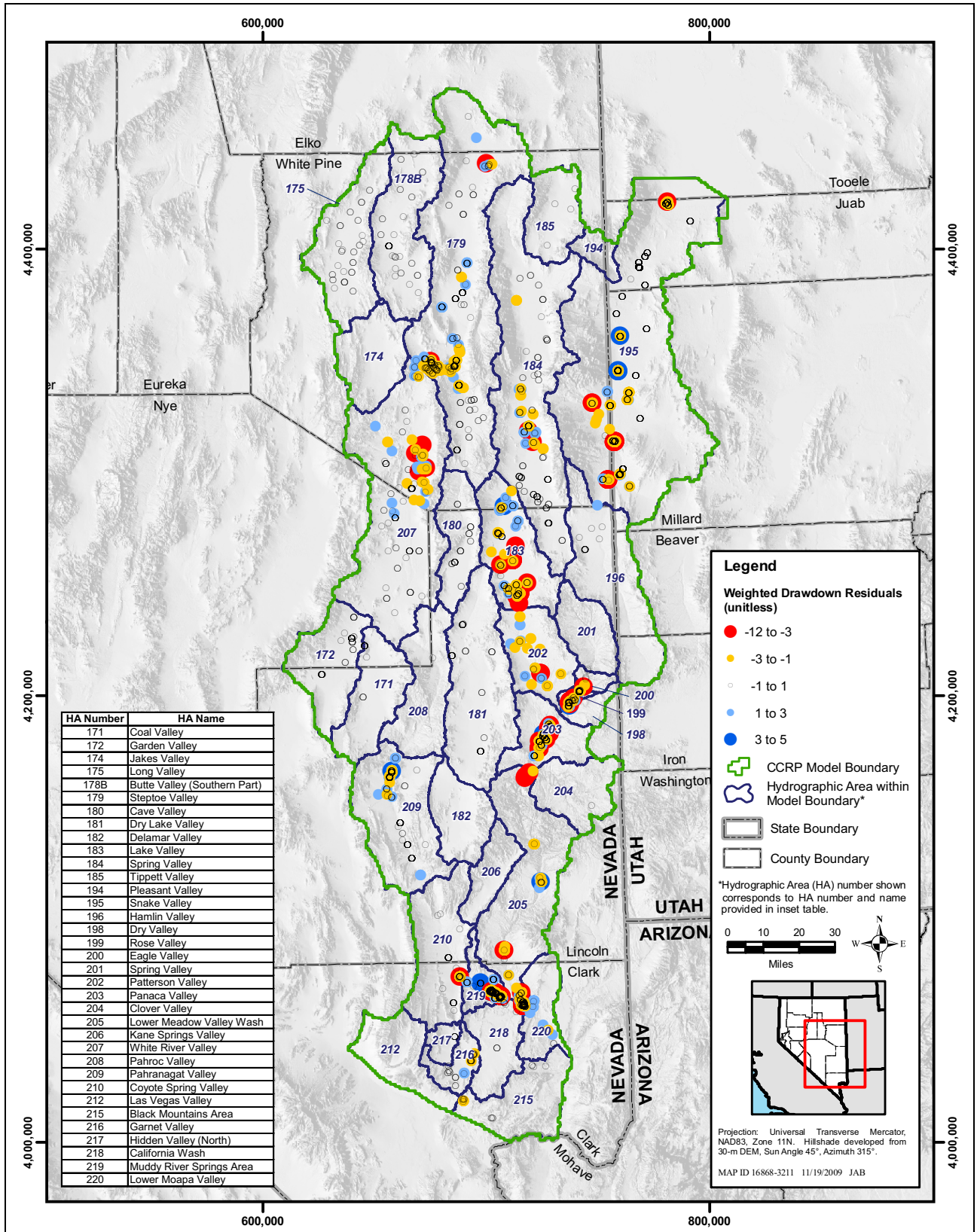


Figure 6-12
 Spatial Distribution of Weighted Drawdown Residuals

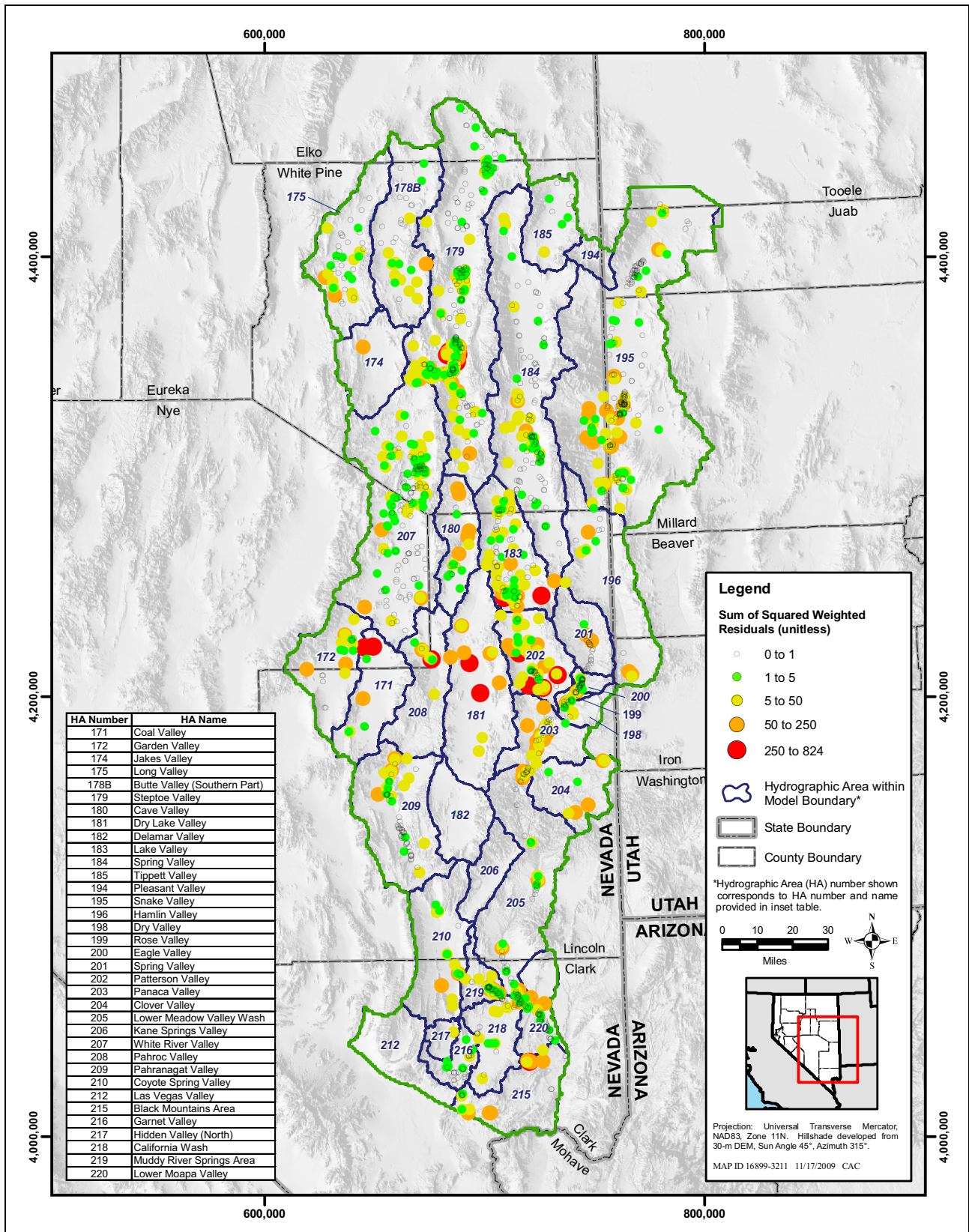


Figure 6-13
Spatial Distribution of SoSWR for Wells

6.1.3.1 External Boundary Flow

This section describes the simulated steady-state groundwater flows through external boundaries in the calibrated numerical model and their comparison to estimates provided in the Conceptual Model Report (SNWA, 2009a) for predevelopment conditions.

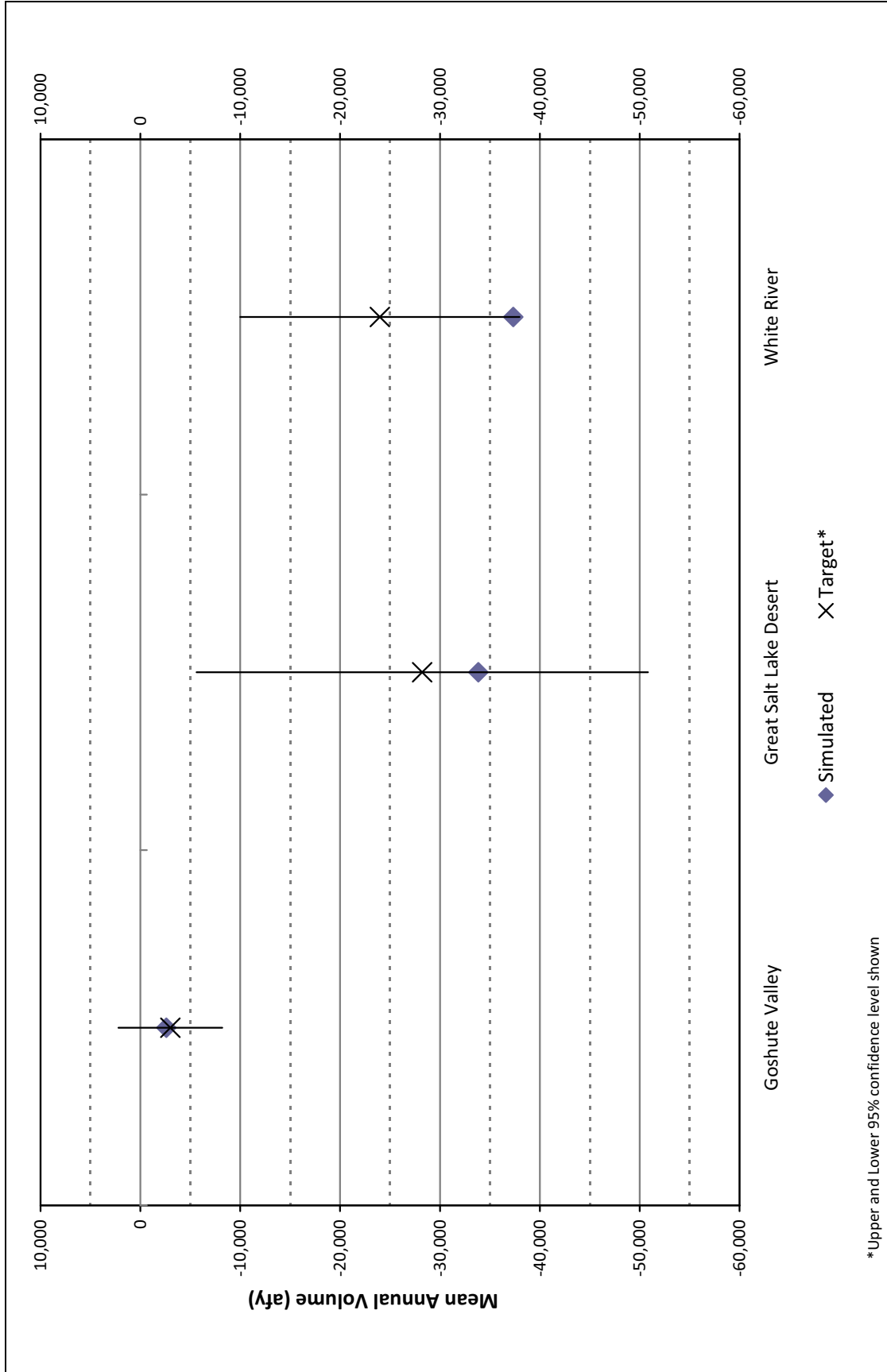
The final CHD parameters, while being some of the most sensitive parameters in the numerical model, were not optimized. These parameters were manually calibrated. This calibration was done because the hydraulic heads were reasonably well known or because the lack of observation constraints near the boundary caused limited application of model parameter estimation. The final hydraulic heads used at each constant-head boundary are defined in [Table 6-3](#).

**Table 6-3
Final Constant-Head Boundary (CHD) Values (Manually Estimated)**

Parameter Name	Flow-Boundary Segment Name	Final CHD Parameter Value ^a (-)	Calibrated Constant-Head Values ft (m)
C_BUTTE	Butte Valley	1.021	6,211 (1,893)
C_COYOTE	Coyote Spring Valley	1	2,362 (720)
C_FISH	Fish Springs Flat (Depth)	0.988	4,287 (1,307)
C_FISH_G	Fish Springs Flat (Ground Layer)	1	4,291 (1,308) – 4,335 (1,321)
C_GARDEN	Garden Valley	1	4,806 (1,465)
C_LK_MEAD	Lake Mead	1	1,169 (356.43)
C_LASVEGAS	Las Vegas Valley	1	2,329 (710)
C_LONG_NW	Long Valley (NW)	0.99	6,139 (1,871)
C_LONG_SW	Long Valley (SW)	0.97	5,789 (1,764)
C_PAHRANAG	Pahrnanagat Valley	0.985	3,167 (980) – 3,264 (995)
C_CONFUSON	Snake Valley (Confusion Range)	1.01	4,709 (1,435)
C_NSNAKE	Snake Valley (North; Depth)	0.983	4,266 (1,300)
C_NSNAKE_G	Snake Valley (North; Ground Layer)	1	4,267 (1,301)
C_E_SSNAKE	Snake Valley (Southern - East)	0.99	4,944 (1,507)
C_W_SSNAKE	Snake Valley (Southern - West)	1.005	5,045 (1,538)
C_NSTEPTOE	Step toe Valley	1	5,627 (1,715)
C_TIPPETT	Tippett Valley	1	5,508 (1,679)

^aThe CHD parameters are factors used to adjust the constant heads at the boundary during calibration.

Figures 6-14 through 6-16 present the simulated and estimated target flows through external model boundaries by flow system, hydrographic area, and individual flow-boundary segment. Intervals of ± 2 standard deviations are shown on these figures to illustrate the uncertainties associated with the targets. A negative sign indicates flow out of the numerical model domain; a positive sign indicates flow into the numerical model domain. [Table 6-4](#) lists the simulated and estimated target external boundary fluxes. The boundary fluxes are within the expected flow range ([Table 6-4](#)).



* Upper and Lower 95% confidence level shown

Note: Negative sign indicates flow out of model.

Figure 6-14
Groundwater Flow through External Boundaries for Flow Systems
Simulated and Target with ± 2 Standard Deviations

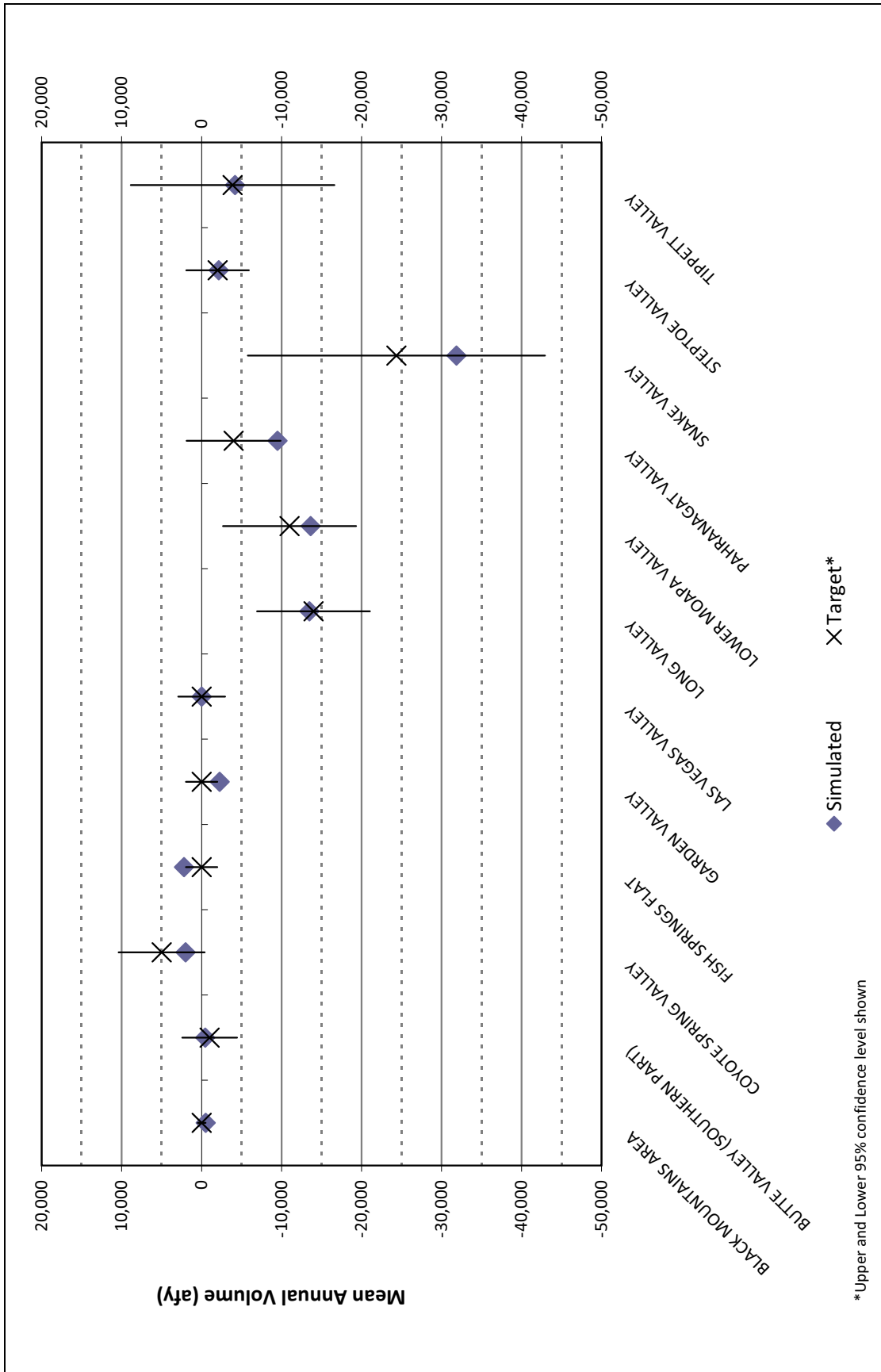


Figure 6-15
Groundwater Flow through External Boundaries for Hydrographic Areas
Simulated and Target with ± 2 Standard Deviations

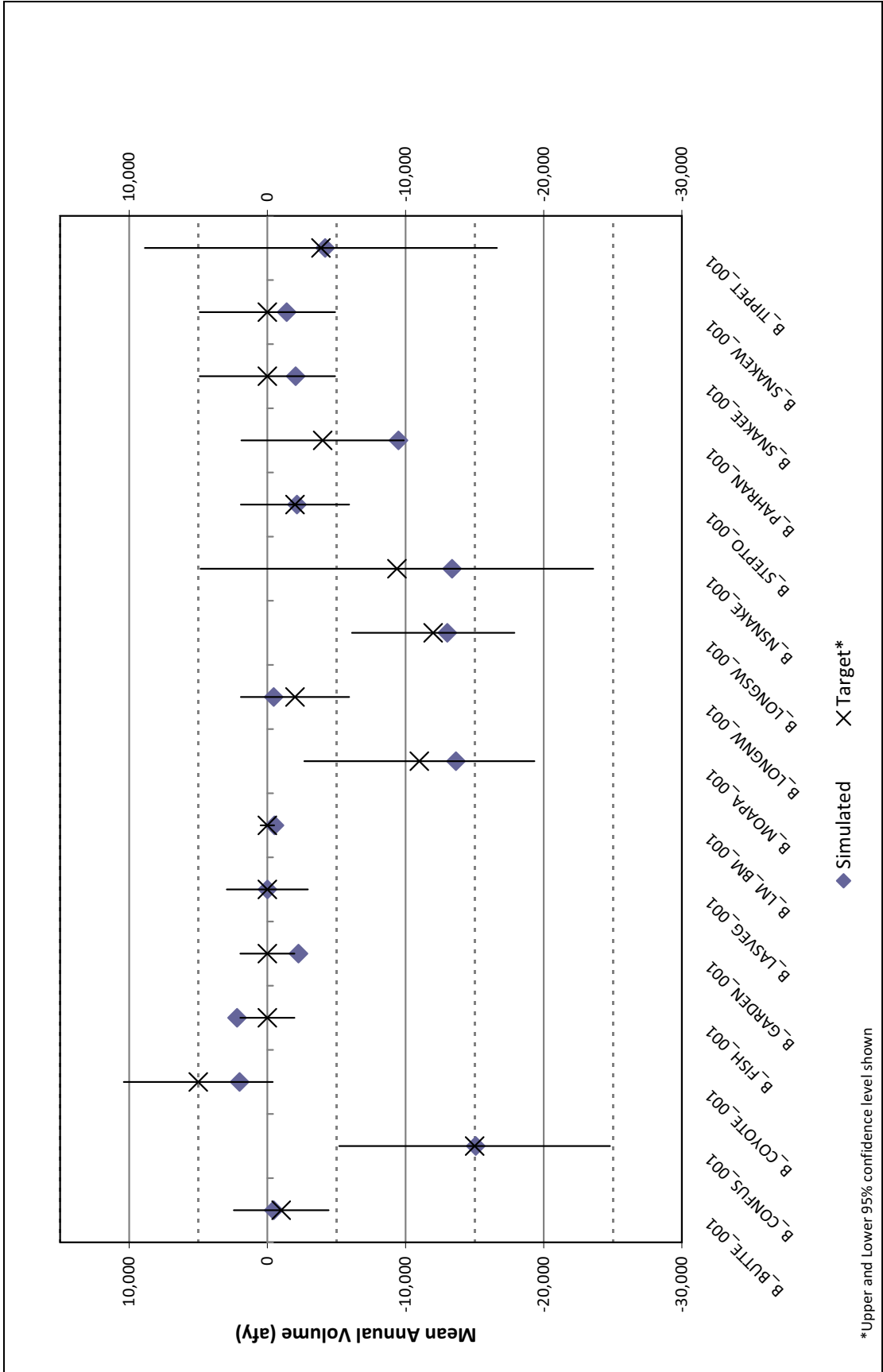


Figure 6-16
Groundwater Flow through External Boundaries for Individual Flow Boundaries
Simulated and Target with ±2 Standard Deviations

Table 6-4
Simulated and Target Values for Groundwater Flow
through External Boundaries

Flow System	HA Name	Observation Name	Simulated Value afy (m ³ /d)	Target Value afy (m ³ /d)
Goshute Valley	Butte Valley (Southern Part)	B_BUTTE_001	-472 (-1,592)	-1,000 (-3,377)
	Steptoe Valley	B_STEPTO_001	-2,145 (-7,245)	-2,000 (-6,754)
Great Salt Lake Desert	Fish Springs Flat	B_FISH_001	2,200 (7,428)	0 (0)
	Snake Valley	B_CONFUS_001	-15,127 (-51,085)	-15,000 (-50,656)
		B_NSNAKE_001	-13,354 (-45,097)	-9,375 (-31,660)
		B_SNAKEE_001	-2,053 (-6,933)	0 (0)
	B_SNAKEW_001	-1,387 (-4,684)	0 (0)	
Tippett Valley	B_TIPPET_001	-4,170 (-14,082)	-3,874 (-13,083)	
White River	Black Mountains Area	B_LM_BM_001	-512 (-1,729)	0 (0)
	Coyote Spring Valley	B_COYOTE_001	2,004 (6,768)	5,000 (16,886)
	Garden Valley	B_GARDEN_001	-2,254 (-7,612)	0 (0)
	Las Vegas Valley	B_LASVEG_001	-1 (-5)	0 (0)
	Long Valley	B_LONGNW_001	-449 (-1,516)	-2,000 (-6,754)
	Lower Moapa Valley	B_MOAPA_001	-13,666 (-46,150)	-11,000 (-37,148)
	Pahrnanagat Valley	B_PAHRAN_001	-9,526 (-32,169)	-4,000 (-13,508)

Note: Negative sign indicates flow out of model; simulated values are as output by model and do not imply this level of accuracy, values were not rounded for tracking purposes.

It should be noted that external boundaries in Long and Pahrnanagat valleys differ from those described in the Conceptual Model Report (SNWA, 2009a). The numerical model simulates a regional flow divide at Jakes Valley (see Section 6.4 and Plates 2 and 3). Thus, an external boundary (Long Valley to Newark Valley Flow System) was necessary to simulate hydraulic heads in Long Valley. The Conceptual Model Report (SNWA, 2009a) describes the primary regional flowpath from Long Valley to Jakes Valley but also indicates the possibility that some flow may occur from Long Valley to Newark Valley.

The regional flowpath from Long Valley to Newark Valley is postulated in other investigations. The Carbonate-Rock Province (CRP) model (Prudic et al., 1995) simulates 12,700 afy from Long Valley to Newark Valley and simulates a regional divide in the Jakes Valley area. Regional potentiometric surfaces from Belcher (2004) and Welch et al. (2008) suggest the potential for some outflow to occur from Long Valley to Newark Valley. Others (Thomas et al., 2001; San Juan et al., 2004; and Thomas and Mihevc, 2007) interpret flow across this boundary to be zero or in the other direction. Because of the lack of data in this particular region, the flow patterns near this boundary are uncertain.

The numerical model also includes an external boundary between Pahrnanagat and Tikaboo valleys. This external boundary was not considered in the conceptual model, which is consistent with the interpretation of Eakin (1966). However, this boundary was necessary to simulate hydraulic head and discharge in Pahrnanagat Valley. The target outflow in Pahrnanagat Valley along the Pahrnanagat Shear

Zone was set to 4,000 afy. This target was based on estimates provided in SNWA (2009a). The numerical model simulates approximately 9,500 afy of outflow from Pahrana gat Valley.

6.1.3.2 Groundwater Discharge by ET

This section discusses simulated steady-state groundwater discharge in ET areas in the calibrated numerical model. Simulated ET discharge and estimated ET targets include groundwater discharge to regional springs. Section 6.1.3.3 discusses simulated discharge from regional and intermediate springs.

Figure 6-17 shows simulated and estimated groundwater discharge in ET areas for flow systems. Intervals of ± 2 standard deviations are shown to illustrate uncertainties of the targets. Simulated ET discharge in Goshute, Meadow Valley, Great Salt Lake Desert, and White River flow systems are within 10 percent, 1 percent, 2 percent, and less than 1 percent of estimated targets, respectively (Figure 6-17). Figure 6-18 through Figure 6-19 summarize groundwater ET by hydrographic area and sub-basin. For the entire numerical model domain, simulated groundwater discharge in ET areas (491,700 afy) is within 3 percent of the estimated target (506,500 afy).

As shown in Figure 6-18, ET discharge in Steptoe Valley is undersimulated by approximately 8,000 afy. ET discharge (including spring discharge) in Snake Valley is undersimulated by 4,700 afy. Although different from the estimated targets, these results are within the uncertainty ranges associated with the ET-discharge estimates provided in SNWA (2009a).

As described in SNWA (2009a), groundwater discharge in Pahrana gat Valley occurs as the result of both spring flow and ET from a shallow water table. Spring flow discharge occurs at three regional springs (Hiko, Ash, and Crystal). The target spring discharge is approximately 26,000 afy and the simulated value is approximately 23,800 afy. The target ET discharge, which includes spring discharge, in Pahrana gat Valley is 28,500 afy and the simulated value is approximately 37,000 afy.

Figures 6-20 through 6-31 summarize simulated ET discharge by ET type for flow systems, hydrographic areas, and sub-basins, respectively. These figures provide more detail on the components of simulated discharge by ET type. In general, where discharge in Shrubland is oversimulated, discharge in Wetland is undersimulated. Similarly, where discharge in Wetland is oversimulated, discharge in Shrubland is undersimulated. Open Water and Playa represent a small component of the total discharge.

Simulated ET rates were computed for each ET type, by model cell. Figure 6-32 illustrates the minimum, 25th percentile, median, maximum, and 75th percentile as box plots. Based on the area-weighted mean groundwater ET rates reported by SNWA (2009a) for each ET unit of each sub-basin, the expected ranges of groundwater ET by unit are:

- 1.34 to 3.46 ft/yr for Wetland
- 0.02 to 2.90 ft/yr for Shrubland
- 0.01 to 0.31 ft/yr for Playa
- 4.11 to 8.61 ft/yr for Open Water

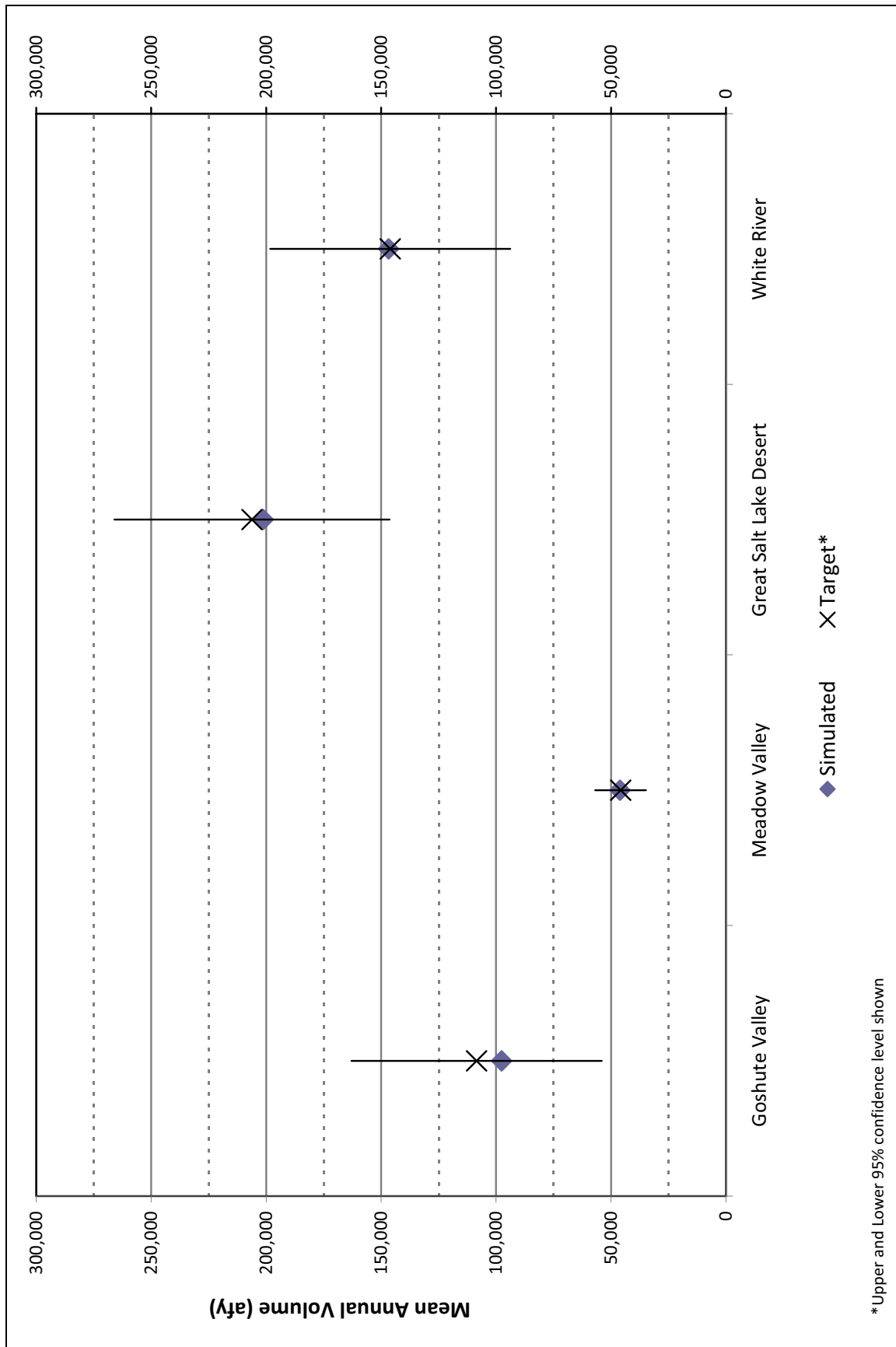


Figure 6-17
Groundwater Discharge by ET and Springs for Flow Systems
Simulated and Target with ± 2 Standard Deviations

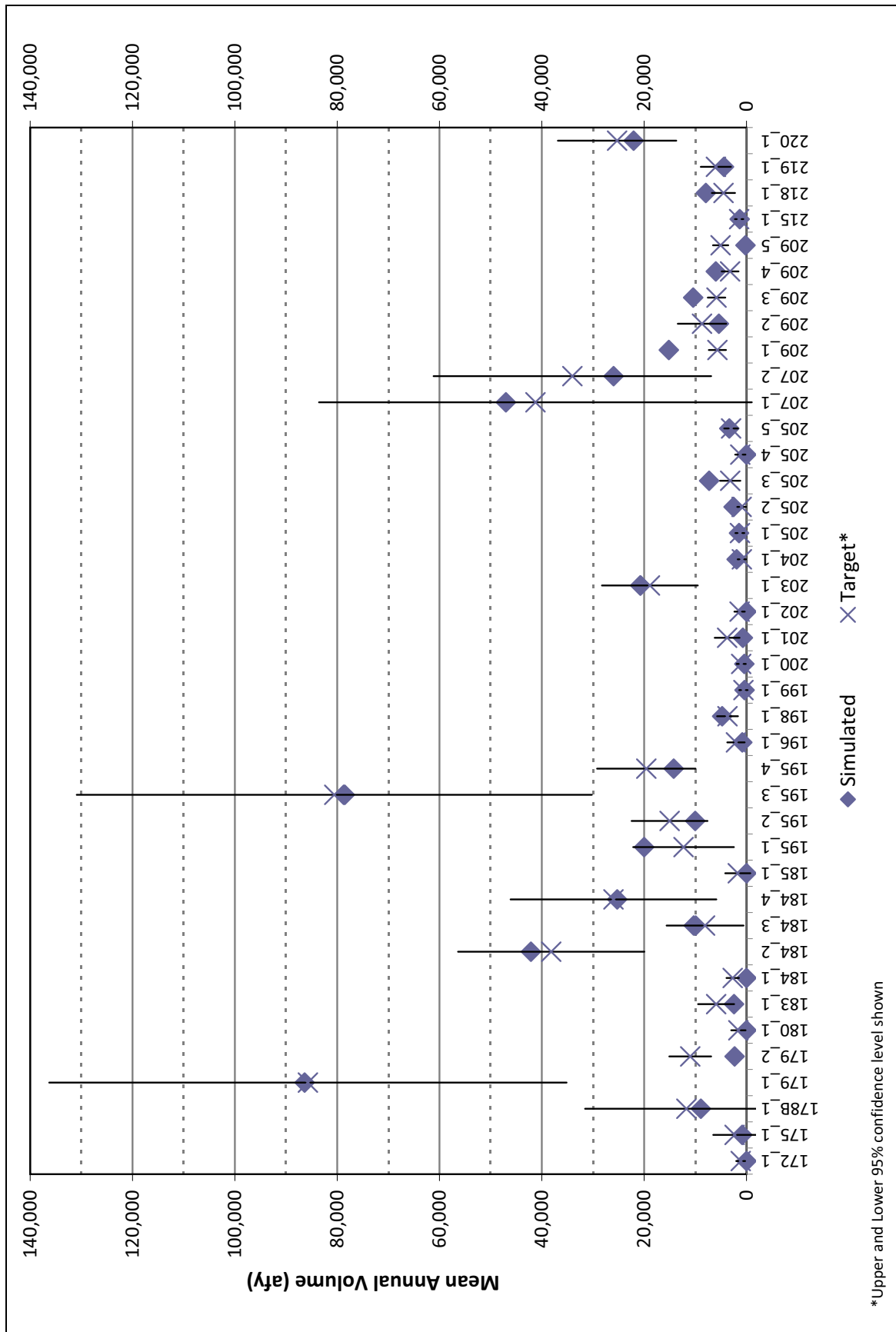
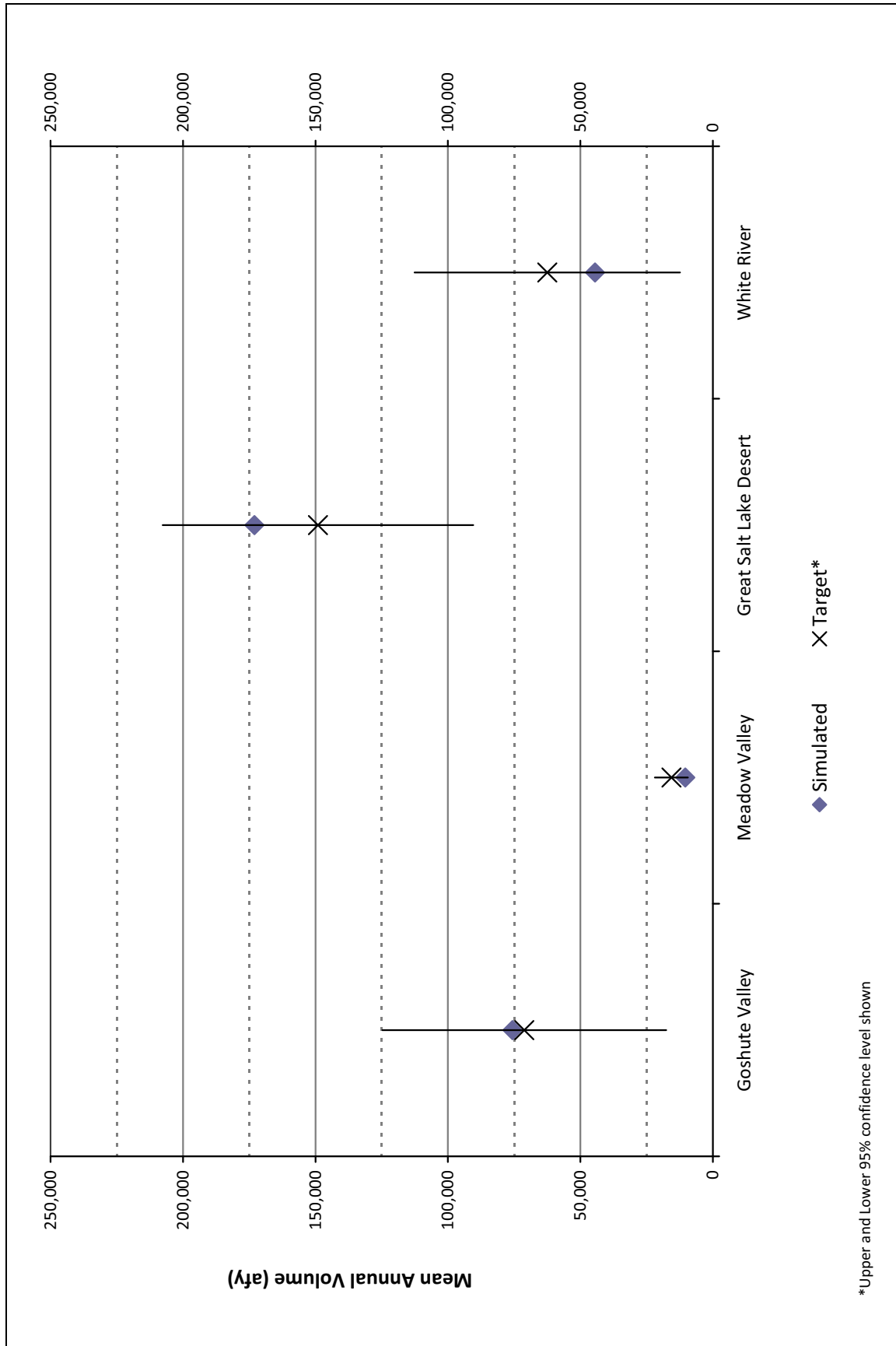


Figure 6-19
Groundwater Discharge by ET and Springs for Sub-Basins
Simulated and Target with ±2 Standard Deviations



*Upper and Lower 95% confidence level shown

Figure 6-20
Groundwater Discharge by ET and Springs in Flow Systems for Shrubland
Simulated and Target with ±2 Standard Deviations

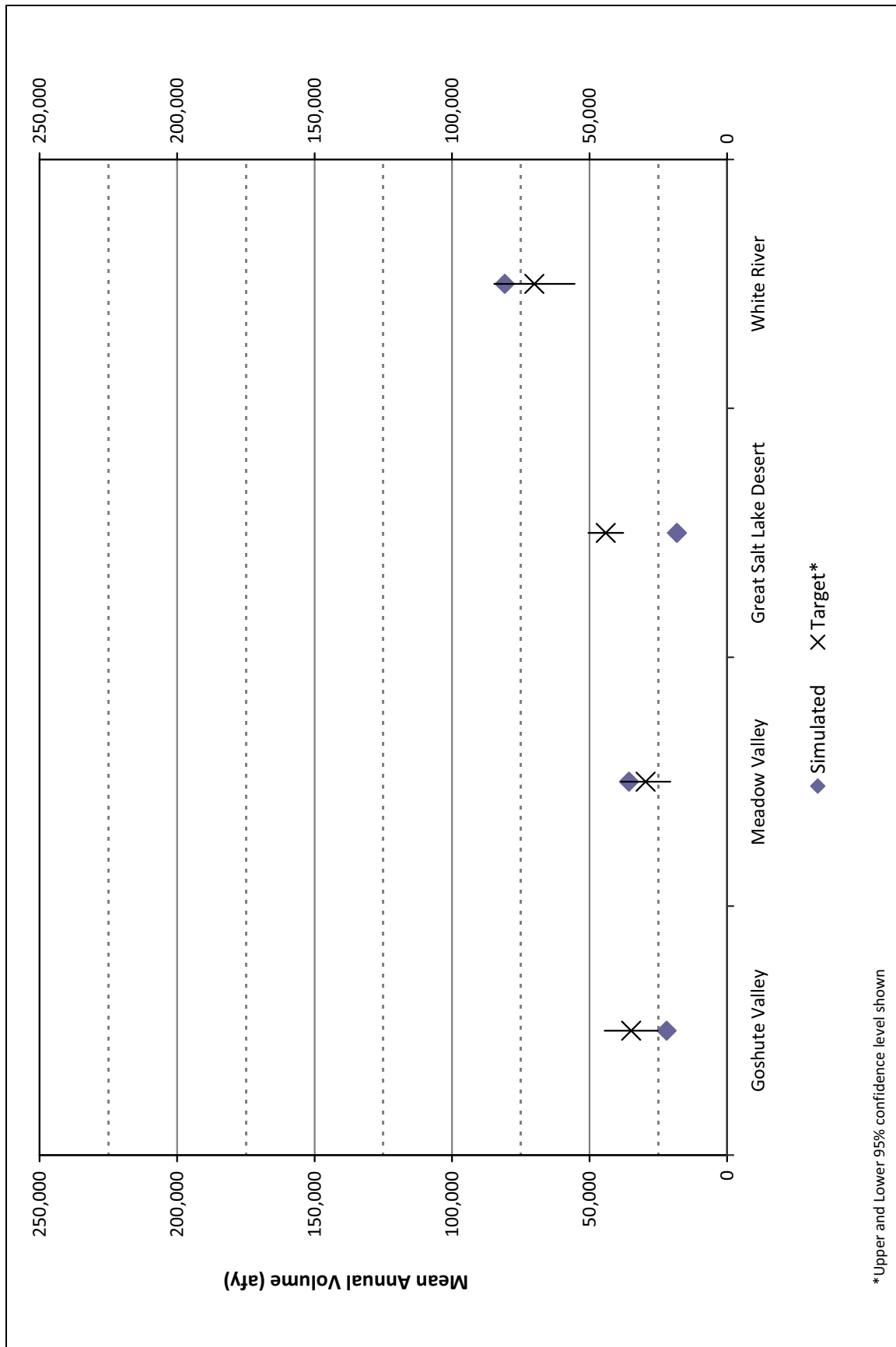


Figure 6-21
Groundwater Discharge by ET and Springs in Flow Systems for Wetland
Simulated and Target with ±2 Standard Deviations

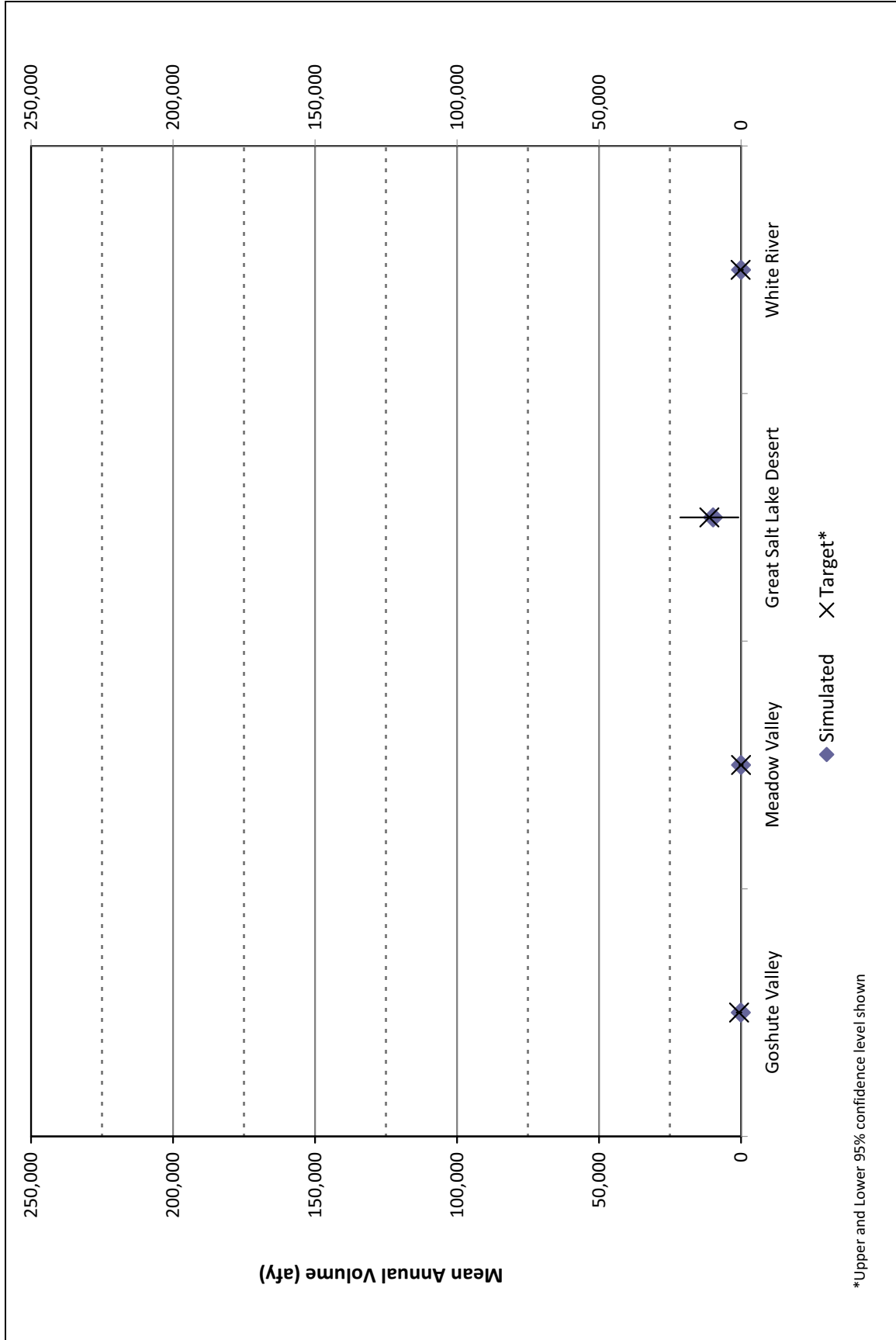


Figure 6-22
Groundwater Discharge by ET and Springs in Flow Systems for Playa
Simulated and Target with ±2 Standard Deviations

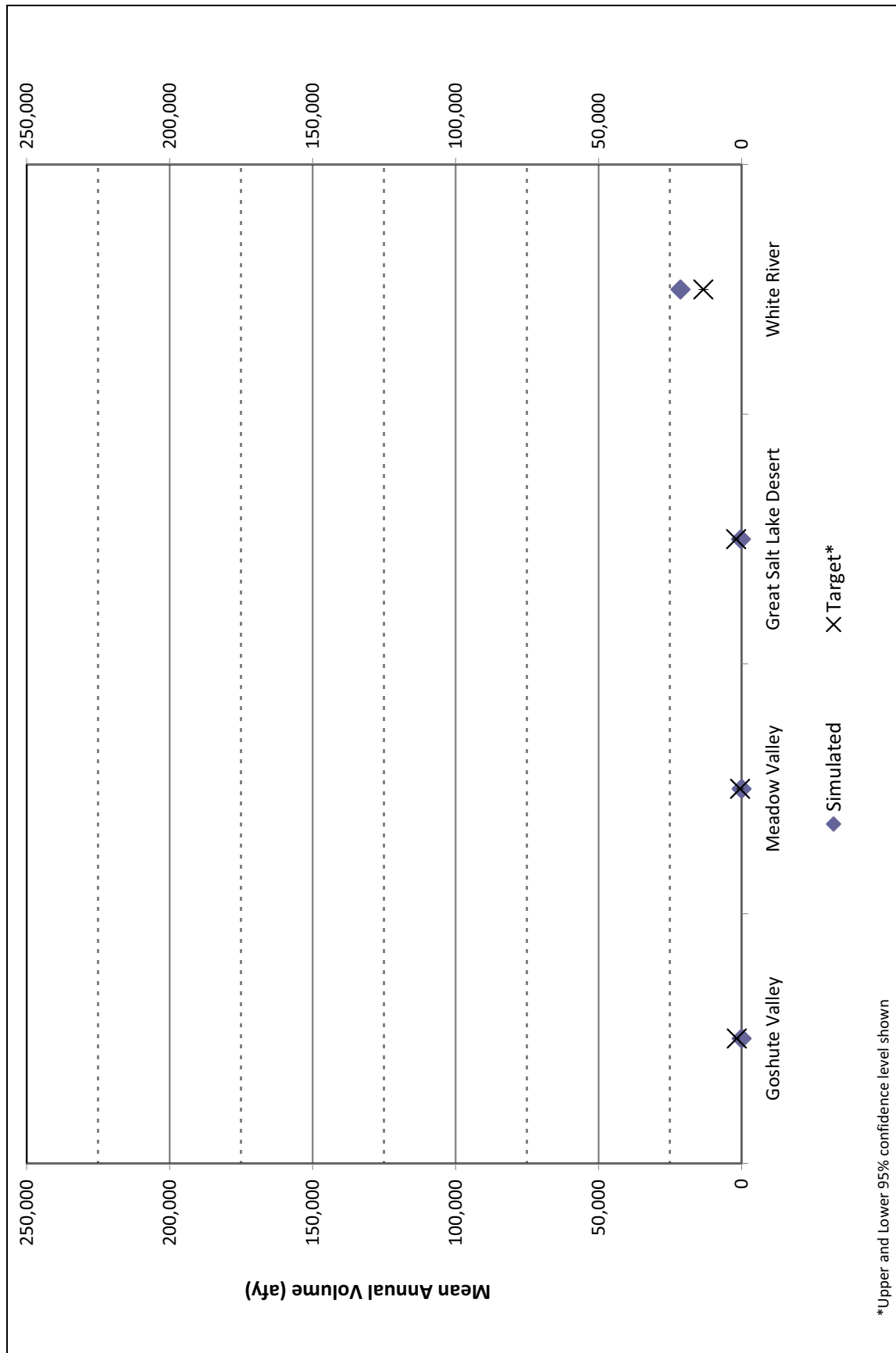
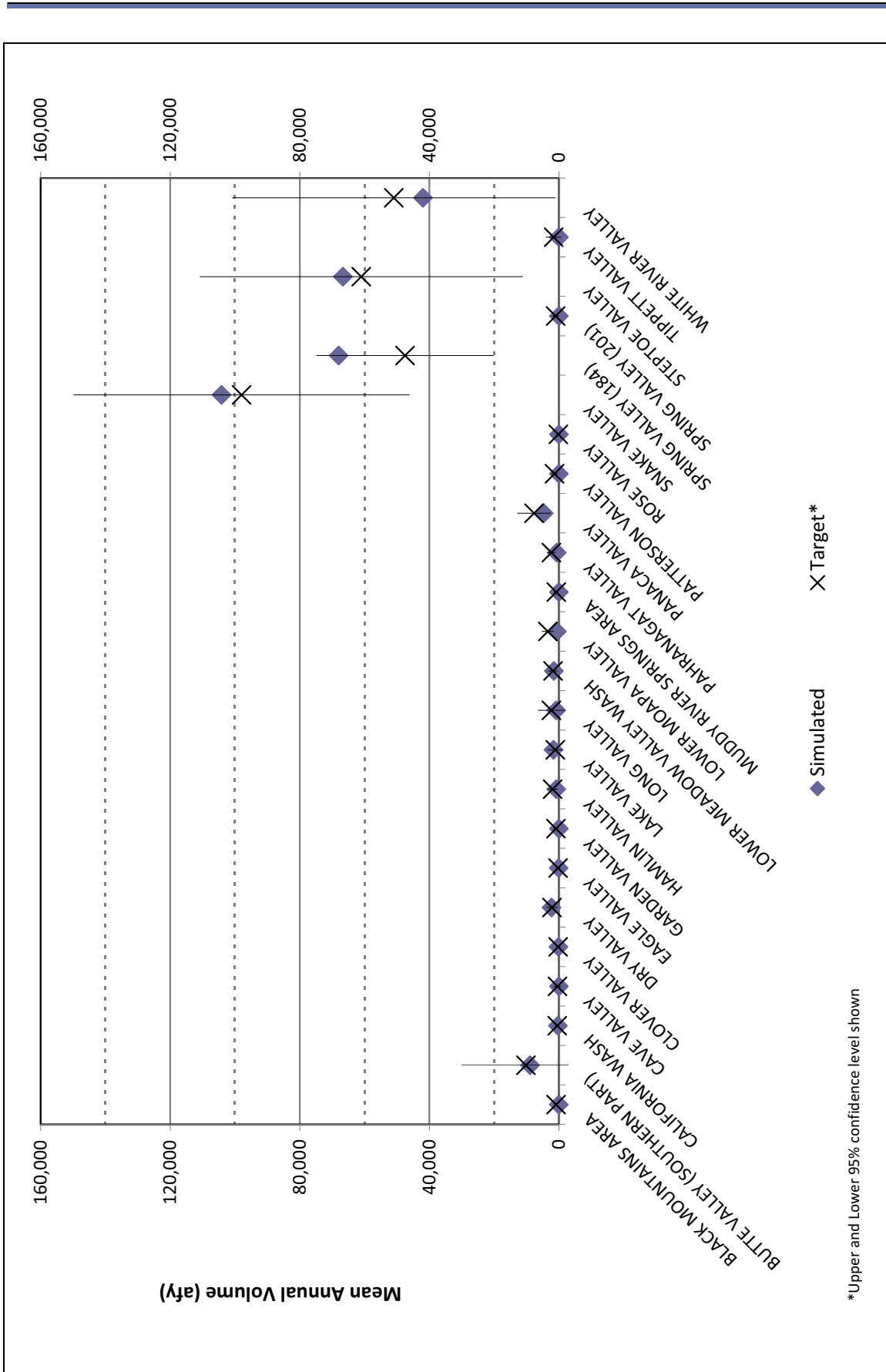
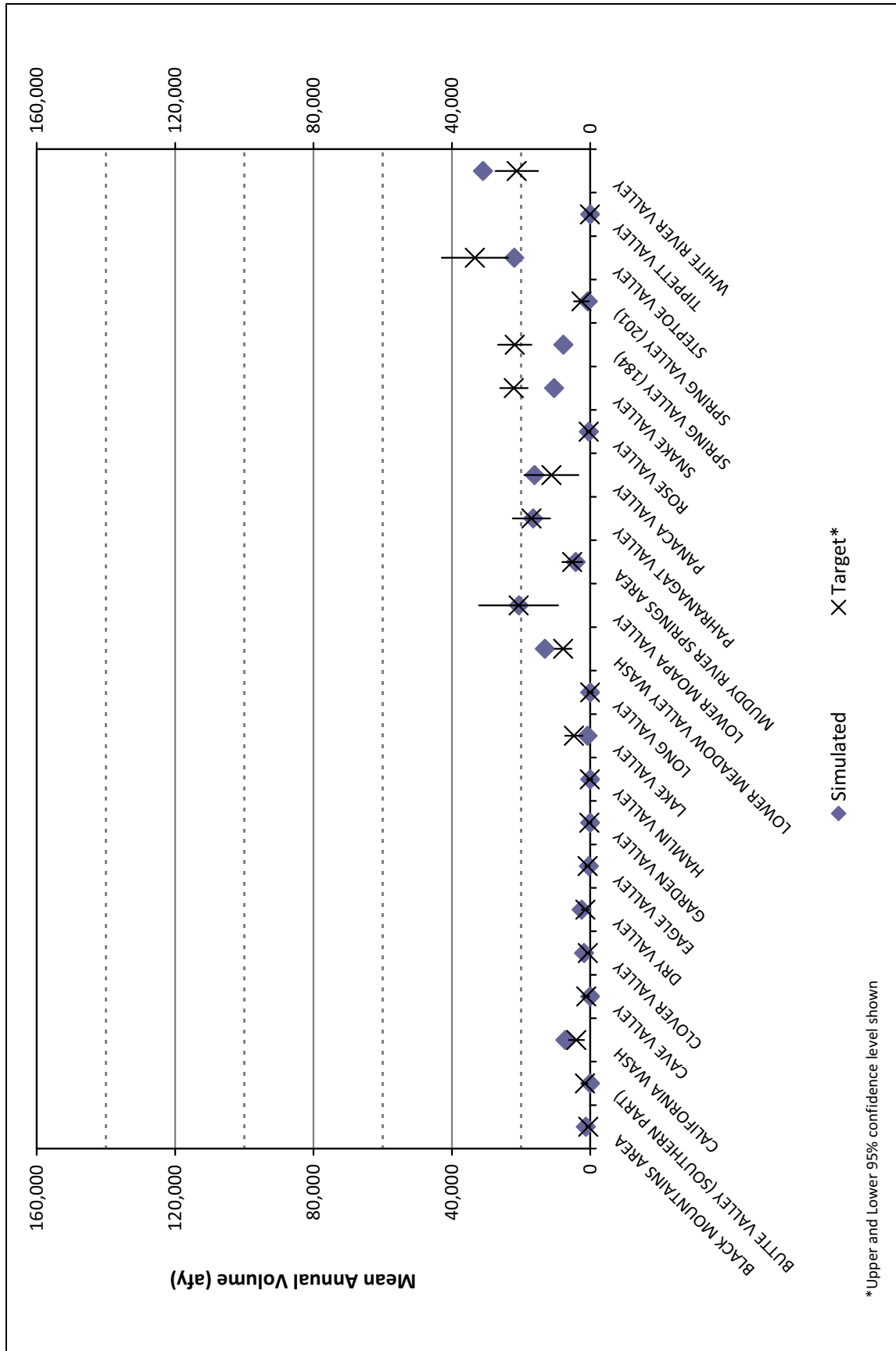


Figure 6-23
Groundwater Discharge by ET and Springs in Flow Systems for Open Water
Simulated and Target with ±2 Standard Deviations



*Upper and Lower 95% confidence level shown

Figure 6-24
Groundwater Discharge by ET and Springs in Hydrographic Areas for Shrubland
Simulated and Target with ±2 Standard Deviations



*Upper and Lower 95% confidence level shown

Figure 6-25
Groundwater Discharge by ET and Springs in Hydrographic Areas for Wetland
Simulated and Target with ±2 Standard Deviations

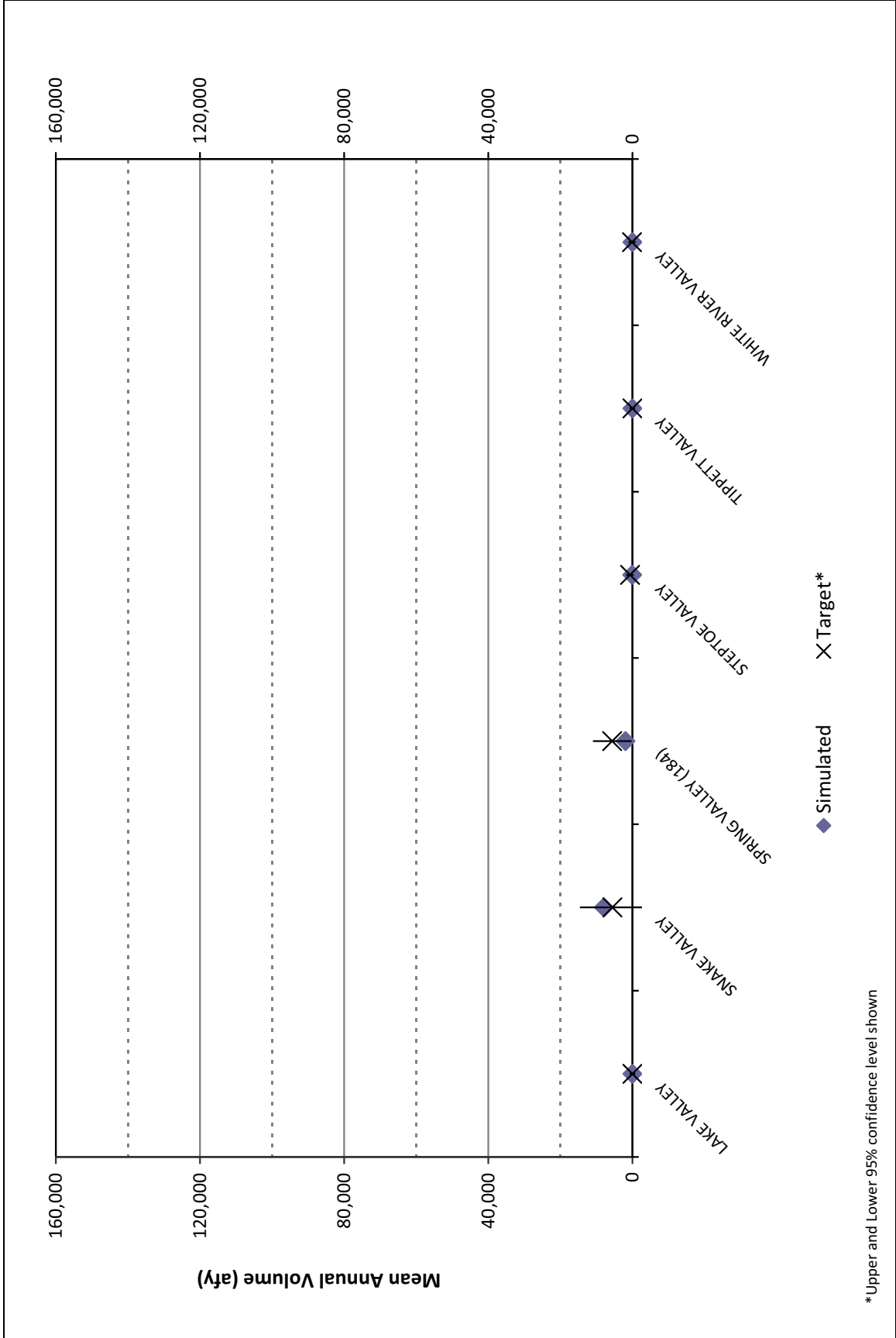
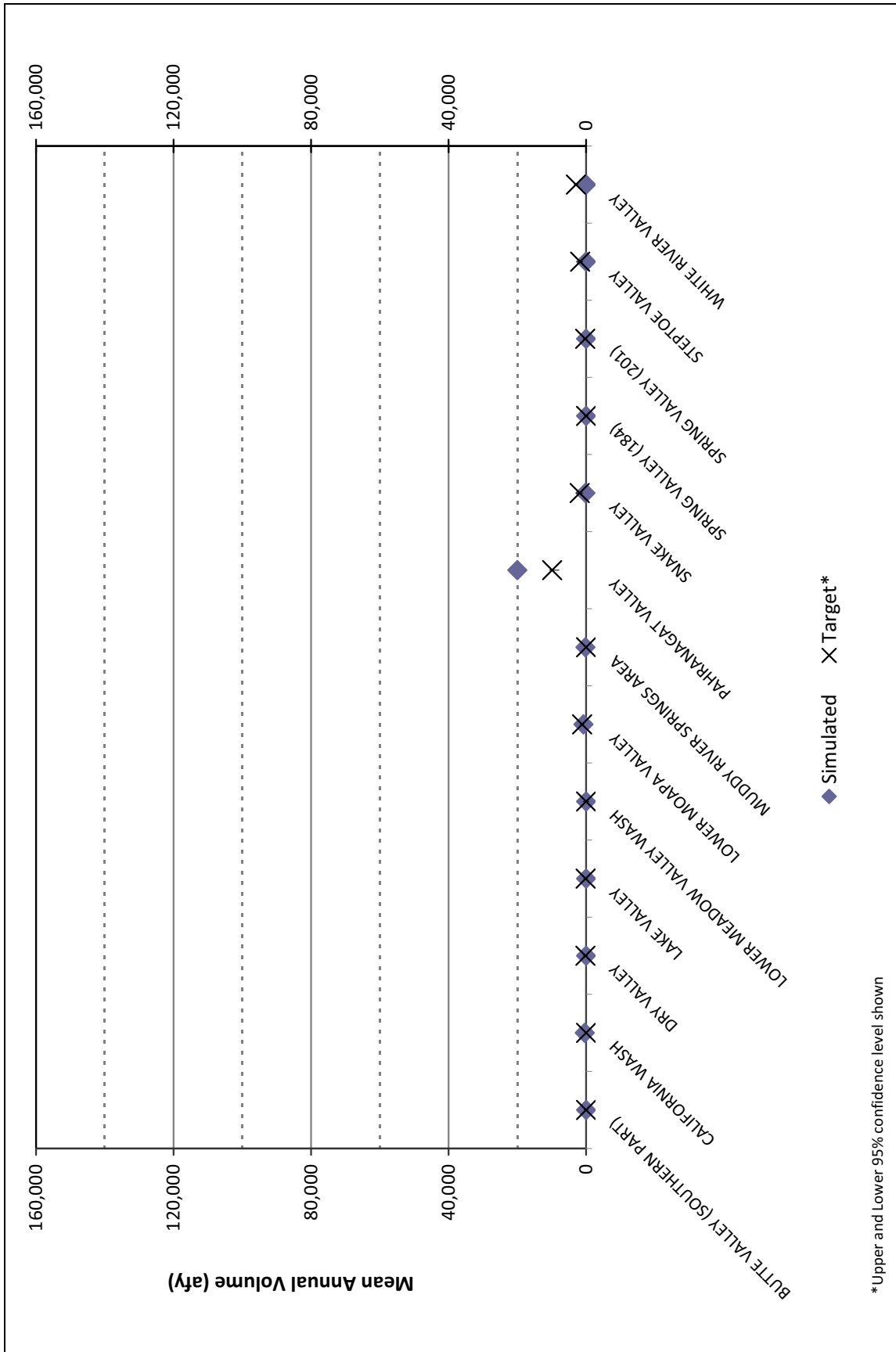
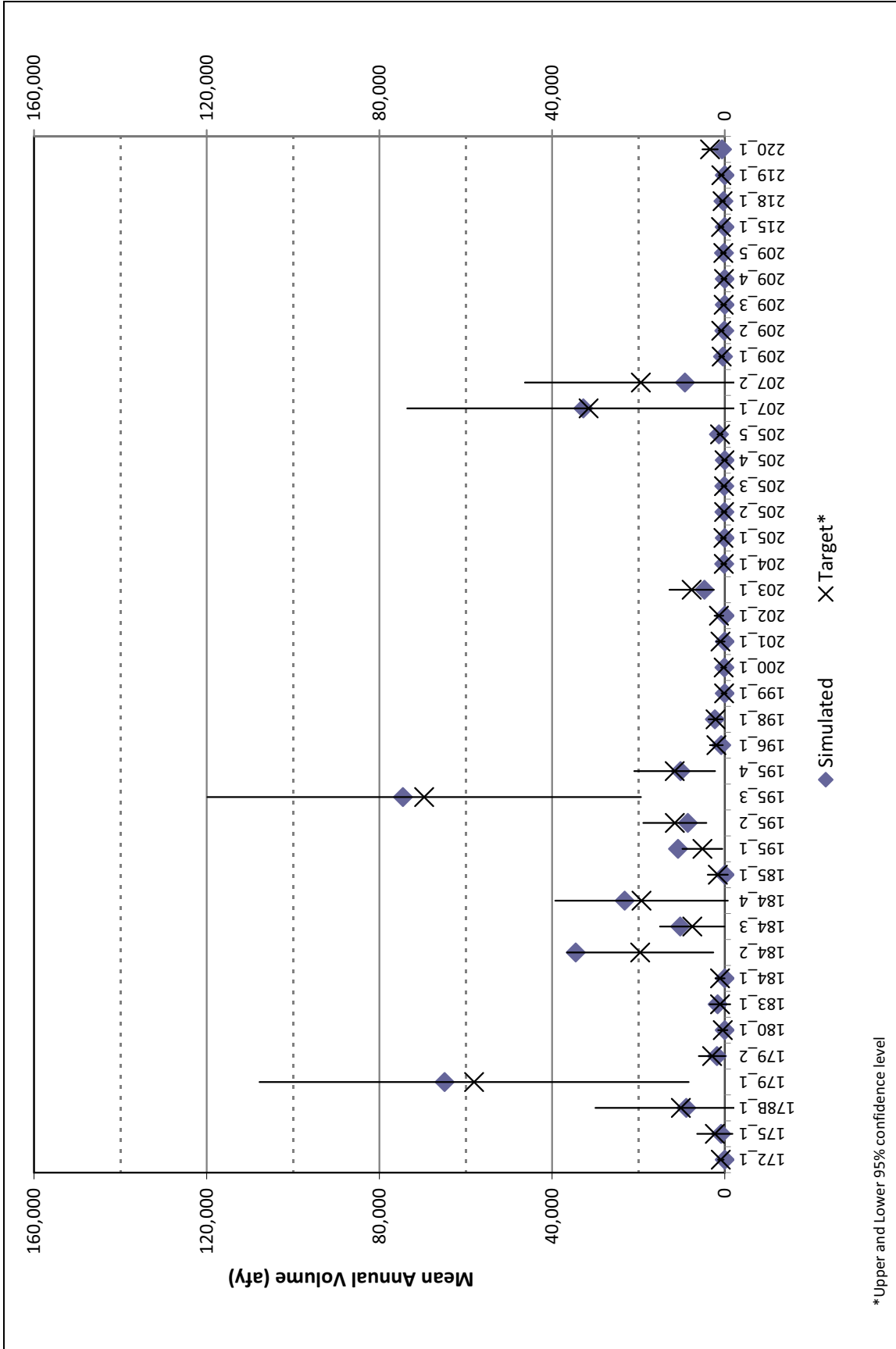


Figure 6-26
Groundwater Discharge by ET and Springs in Hydrographic Areas for Playa
Simulated and Target with ±2 Standard Deviations



* Upper and Lower 95% confidence level shown

Figure 6-27
Groundwater Discharge by ET and Springs in Hydrographic Areas for Open Water
Simulated and Target with ± 2 Standard Deviations



*Upper and Lower 95% confidence level

Figure 6-28
Groundwater Discharge by ET and Springs in Sub-Basins for Shrubland
Simulated and Target with ±2 Standard Deviations

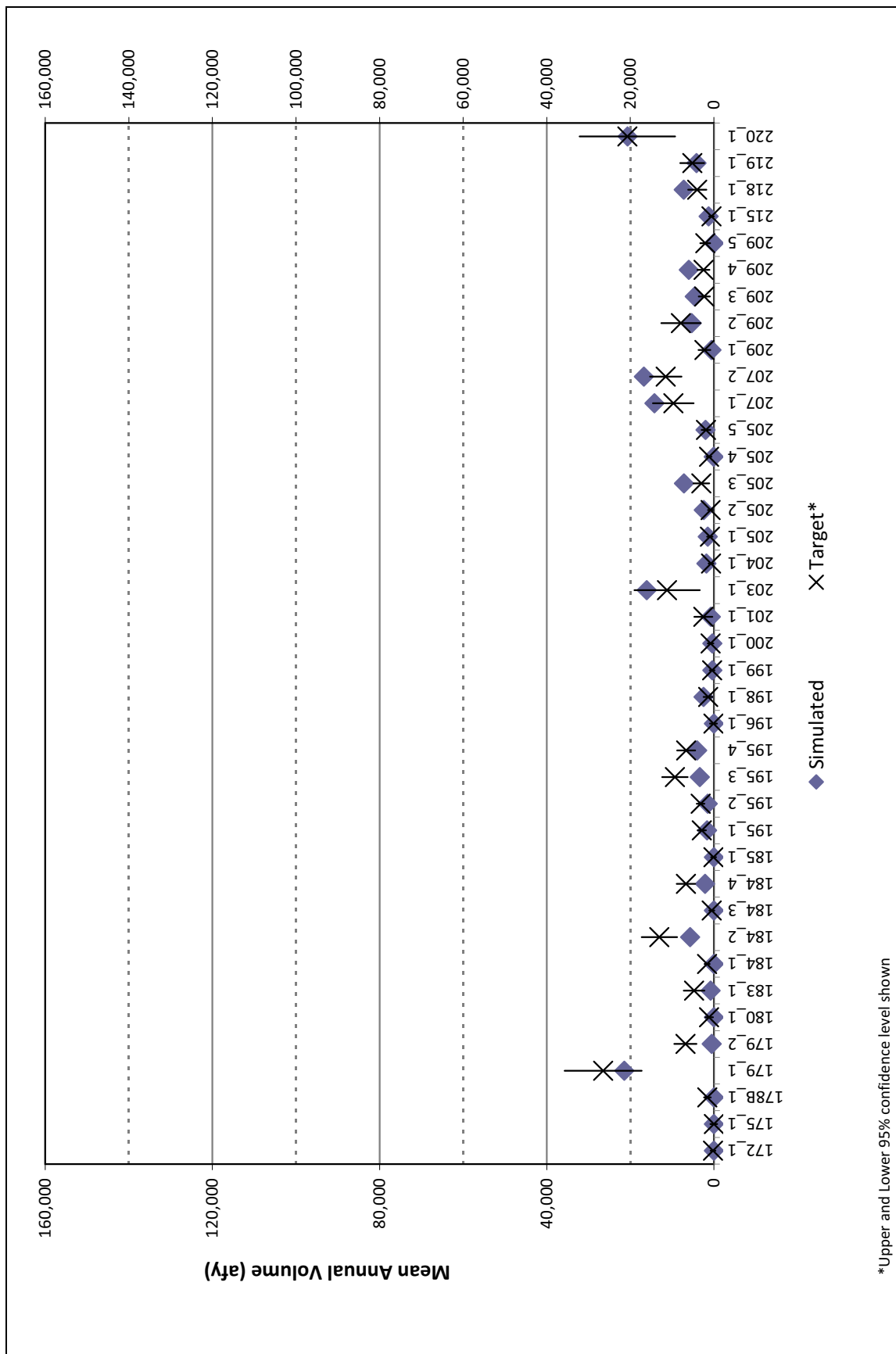
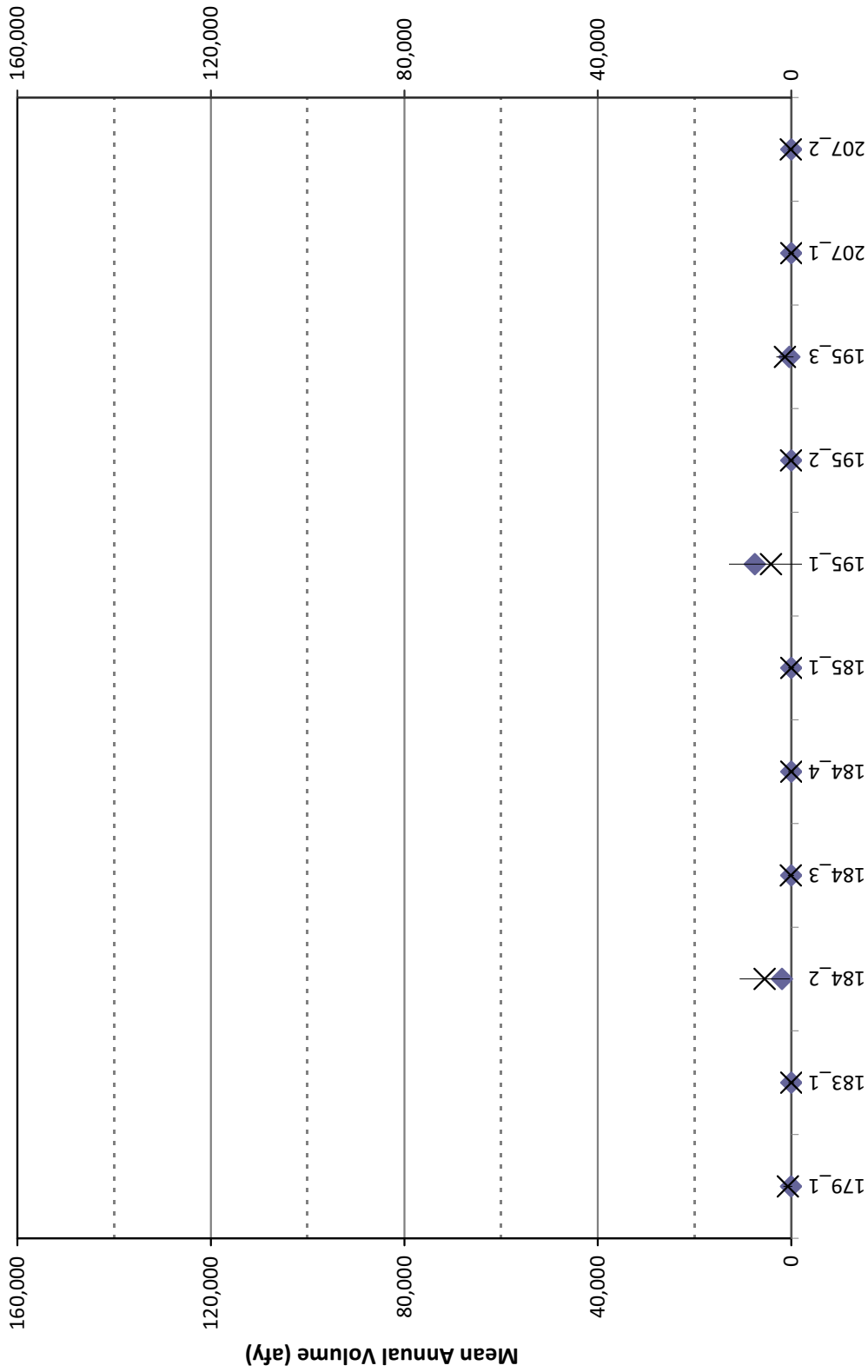


Figure 6-29
Groundwater Discharge by ET and Springs in Sub-Basins for Wetland
Simulated and Target with ±2 Standard Deviations



*Upper and Lower 95% confidence level shown

Figure 6-30
Groundwater Discharge by ET and Springs in Sub-Basins for Playa
Simulated and Target with ±2 Standard Deviations

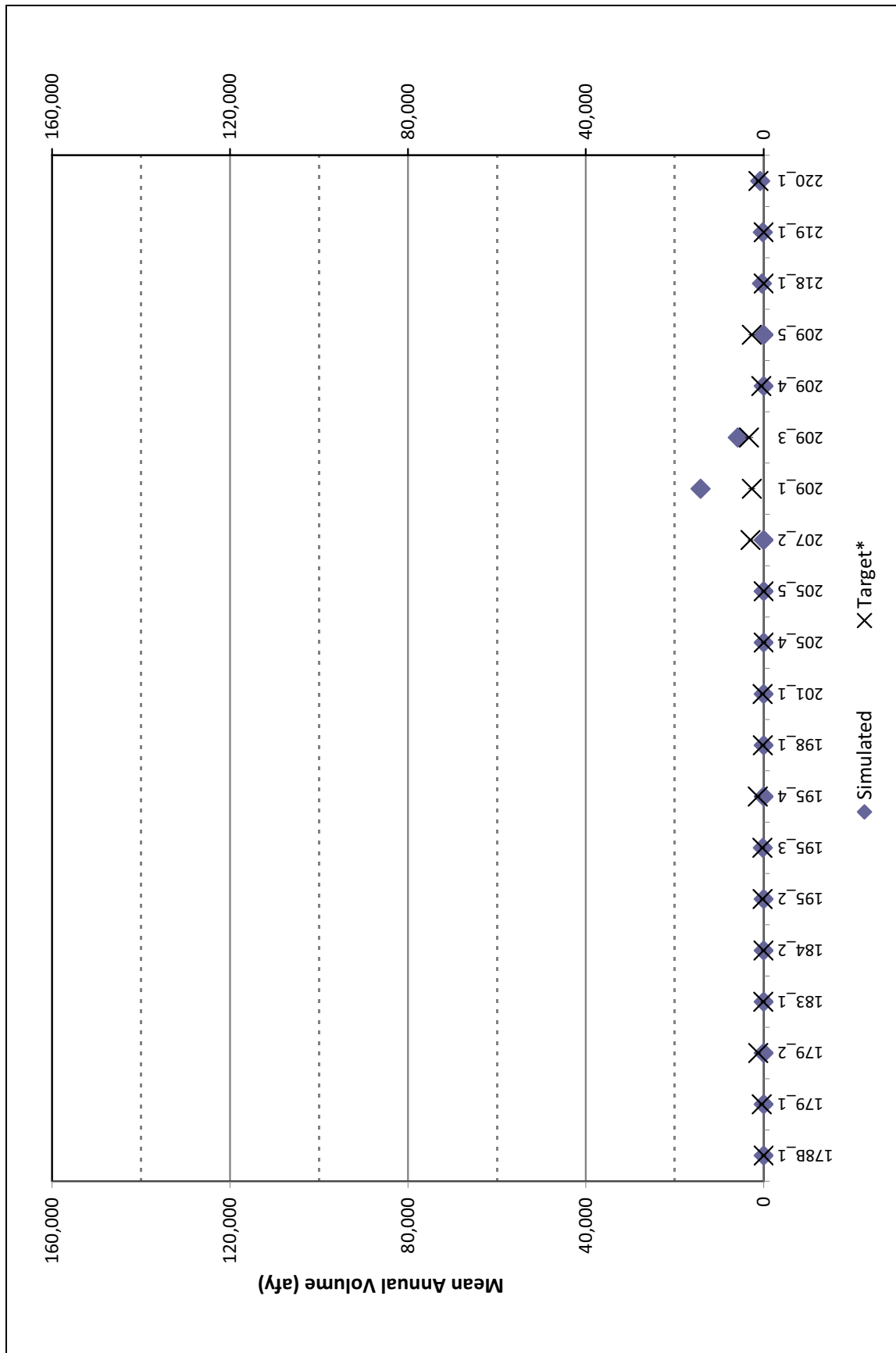


Figure 6-31
Groundwater Discharge by ET and Springs in Sub-Basins for Open Water
Simulated and Target with ± 2 Standard Deviations

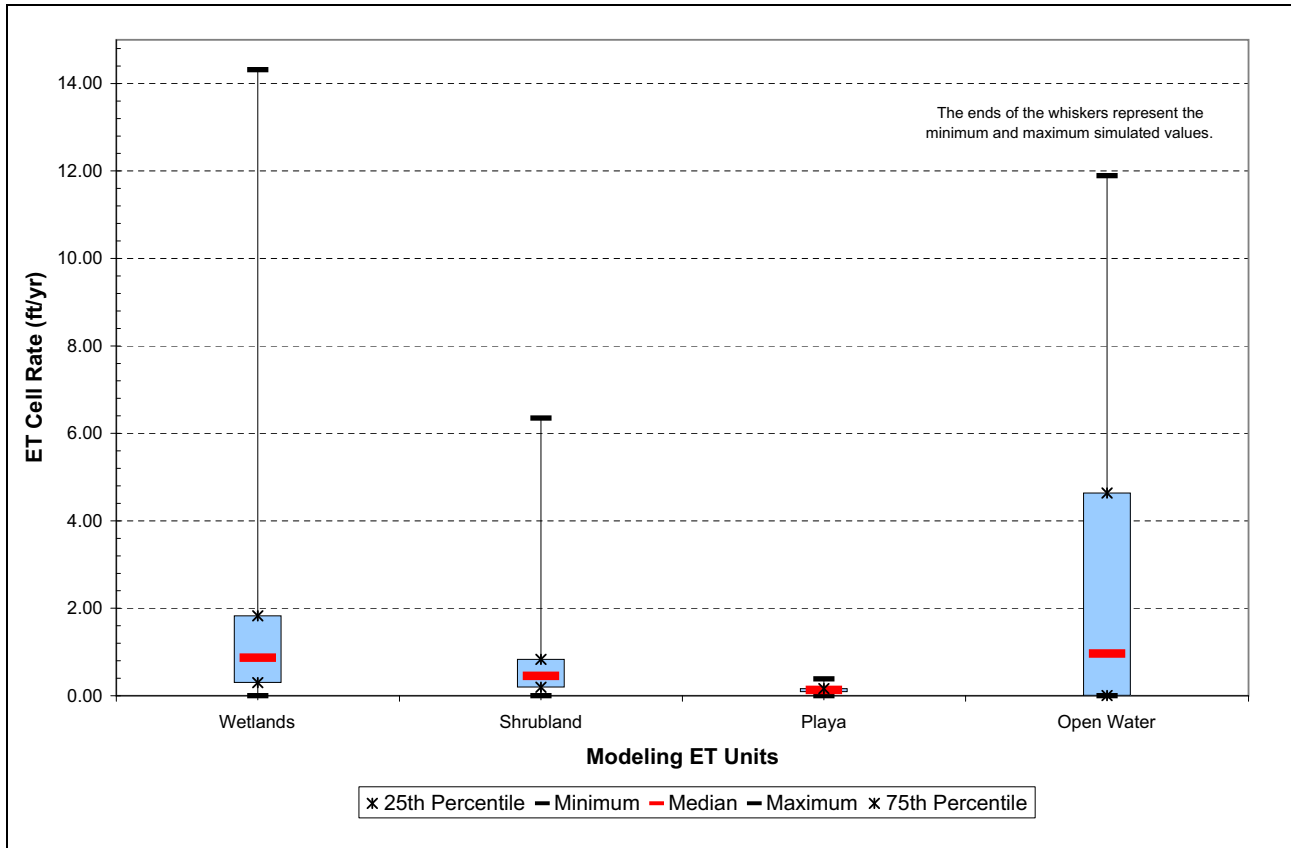


Figure 6-32
Simulated Groundwater ET Discharge Rates by ET Type

These ranges overlap with the simulated ranges and the ranges defined by the 25th and 75th percentiles presented in [Figure 6-32](#).

6.1.3.3 Spring Discharge

This section discusses groundwater discharge to regional and intermediate springs simulated using the DRN package in the numerical model. Regional springs in Pahrangat Valley, the Muddy River Springs Area, and at the intermediate spring, Big Springs in Snake Valley, are represented using the SFR2 package and are discussed in [Section 6.1.3.4](#).

[Figure 6-33](#) shows simulated and observed discharge rates to springs. Intervals of ± 2 standard deviations are shown to illustrate uncertainties on the targets. [Figure 6-33](#) summarizes spring discharge by (A) Regional Springs and (B) Intermediate Springs.

As shown on [Figure 6-33](#), regional spring flow rates match closely to observed targets. Hot Creek Spring and Preston Big Spring flow rates are within 10 percent of the target. Spring flow for Moorman, Moon River, and Panaca springs are within 13 percent, 32 percent, and 15 percent of target observations, respectively.

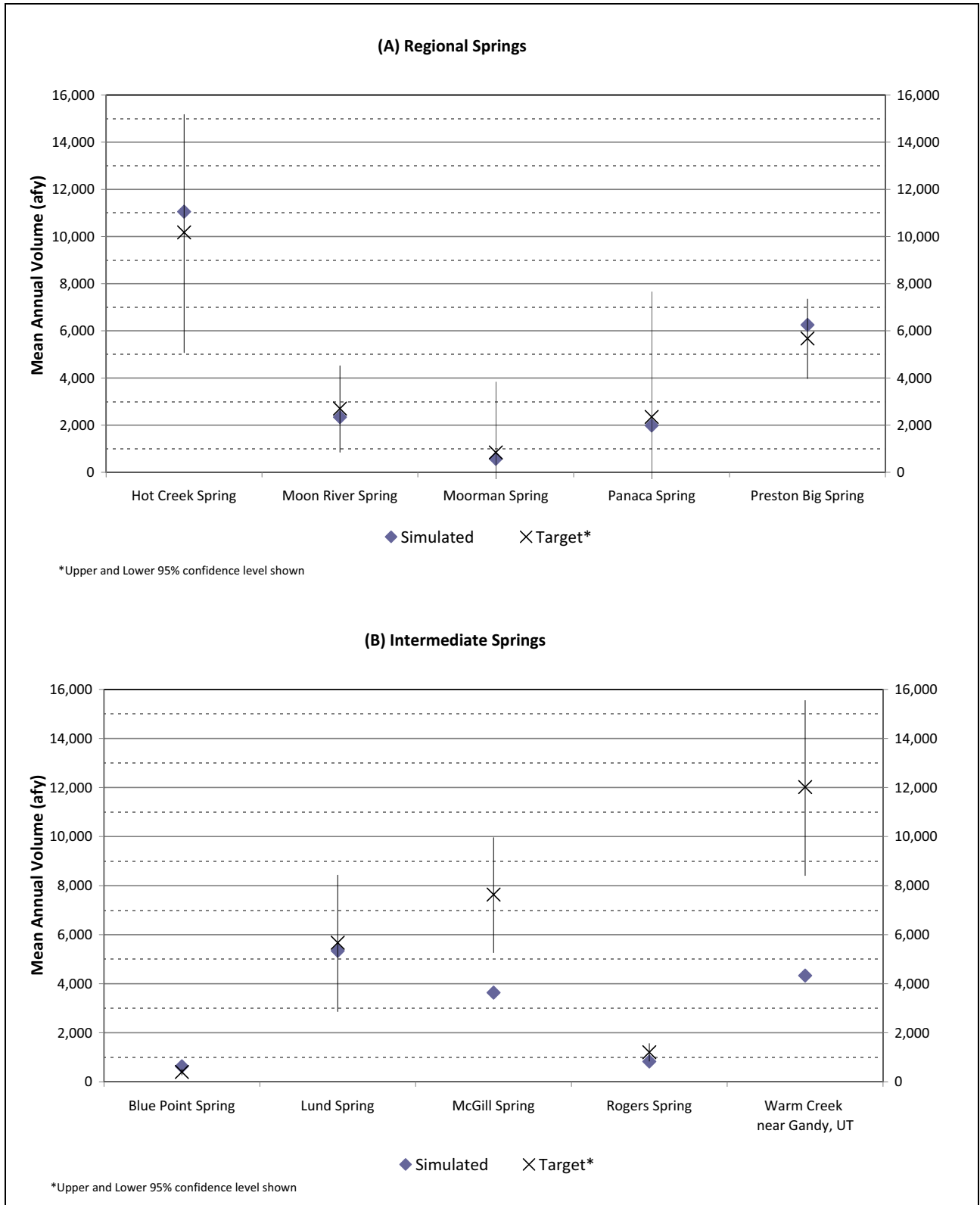


Figure 6-33
Groundwater Discharge from Regional (A) and Intermediate (B) Springs
Simulated and Target with ± 2 Standard Deviations

Intermediate spring flow rates are not matched as closely to observed targets as compared to regional springs. McGill S spring and Warm Springs near Gandy, Utah, springs are undersimulated by 52 percent and 64 percent, respectively. Errors occurring in intermediate spring flows may be derived from inadequate representation of the complex hydrogeologic framework that gives rise to these springs. In addition, a major component of the flow at intermediate springs may be derived from localized groundwater-flow processes that are not represented in this regional-scale model.

6.1.3.4 Stream Flow Routing Discharge

This section discusses simulated steady-state groundwater discharge to spring-fed streams in the calibrated numerical model. Regional springs in Pahrnatag Valley, the Muddy River Springs Area, and at Big Springs are represented using the SFR2 package.

Figure 6-34 shows simulated and observed discharge to streams. Intervals of ± 2 standard deviations are shown to illustrate uncertainties on the targets. As shown on Figure 6-34, regional springs and stream gages are simulated closely to observed targets.

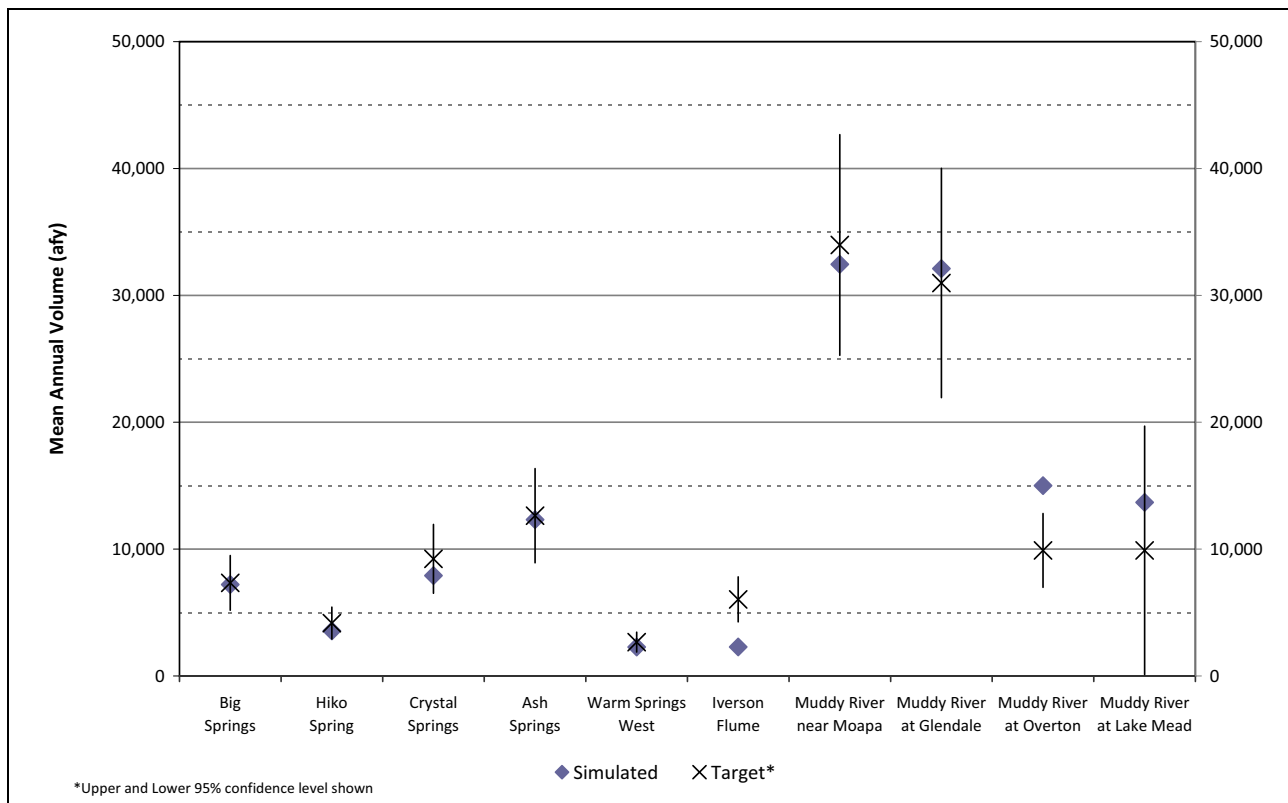


Figure 6-34
Groundwater Discharge at Stream Flow Routing Gages
Simulated and Target with ± 2 Standard Deviations

Gages at the Muddy River near Moapa and the Muddy River near Glendale simulate flows within 4 percent of the targets. The Muddy River gage at Lake Mead is a surrogate gage (used for tracking purposes only). Flow at this surrogate gage represents surface-water outflow in the Muddy River out of the model domain and is simulated at 13,700 afy.

In Pahranaagat Valley, gages representing Ash, Crystal, and Hiko springs simulate spring flow rates within 2 percent, 14 percent, and 15 percent of the targets, respectively.

Discharge to the intermediate Big Springs in Snake Valley is within 2 percent of the target flow observation.

ET from open water along stream channels is simulated in the SFR2 module. This ET component is added to ET simulated by the DRN package. Additions are done at the hydrographic-area scale. [Figure 6-35](#) illustrates the ET component resulting from the SFR2 module, in the form of surface-water evaporation.

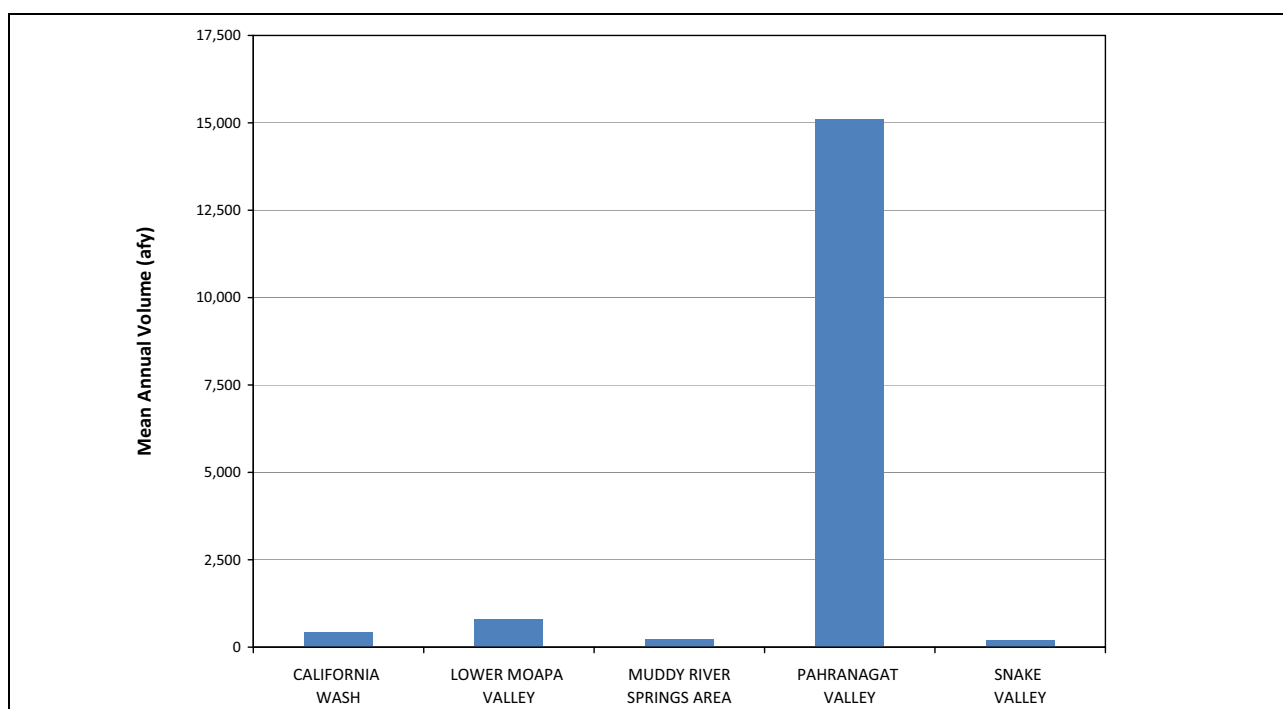


Figure 6-35
Simulated Evaporation from Surface Water in the SFR2 Package

6.1.4 Distribution of Weighted Residuals versus Unweighted Simulated Values

To evaluate model results for systematic model error or errors in assumptions concerning observations and weights, weighted residuals were plotted against unweighted simulated values for hydraulic-head observations. Ideally, weighted residuals will vary randomly about zero regardless of the simulated value.

Figure 6-36 shows that most of the weighted residuals for hydraulic heads in the numerical model vary randomly about a value of zero. Eighty-seven values are greater than +5.3982, which is three times the regression standard error of 1.7994; 105 values are less than -5.3982. For normally distributed sample populations, approximately 3 in 1,000, on average, would be so different from the expected value. For this sample set of 7,007 observations, 21 observations would be expected to exceed ± 5.3982 . Clearly, quite a few more exceed the 3 in 1,000 limit. While this distribution is somewhat biased by large negative values, the distribution is still largely random (Figure 6-36).

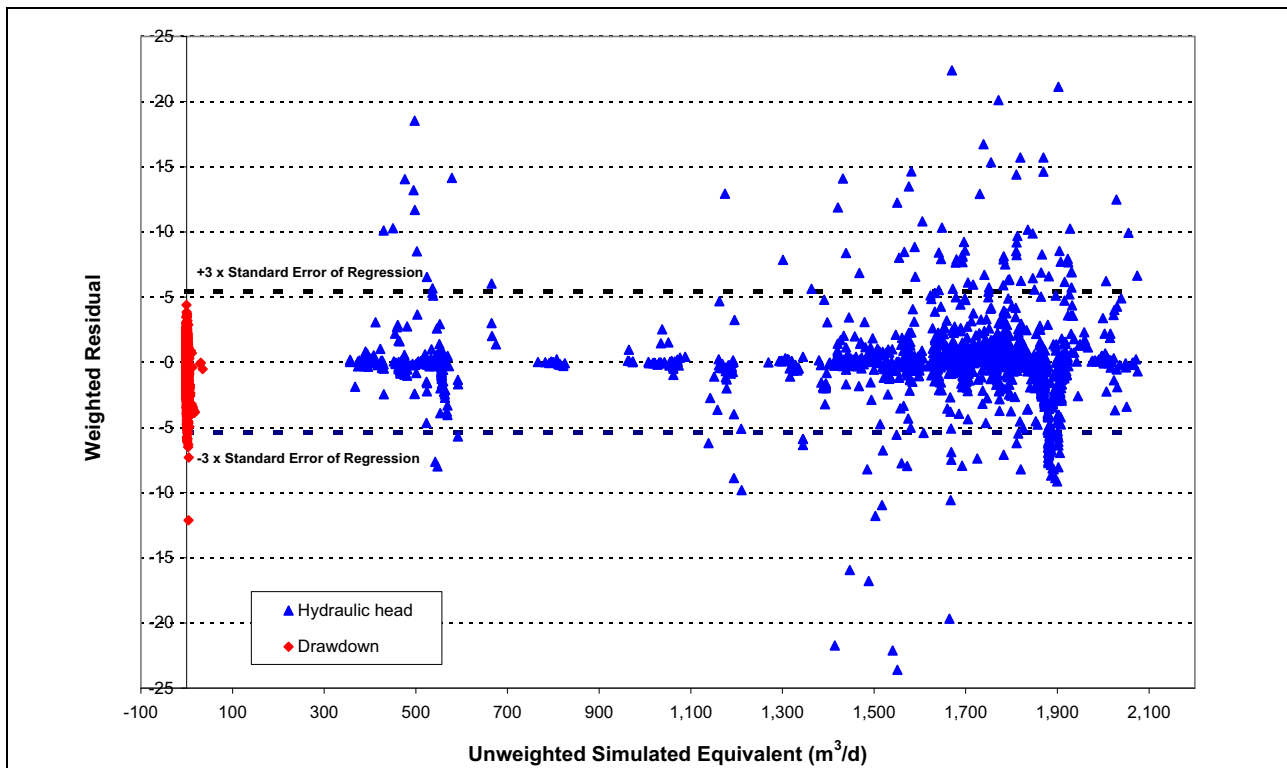


Figure 6-36

Weighted Residuals Relative to Unweighted Simulated Equivalent Hydraulic Heads

Figure 6-37 through Figure 6-40 show weighted residuals for flow observations plotted against unweighted simulated values for flow observations. These plots demonstrate that relatively few of the weighted residuals for flow observations exceed ± 5.3982 .

6.1.5 Normality of Weighted Residuals and Model Linearity

The normality of the weighted residuals and model linearity are important to measures of parameter and prediction uncertainty, such as linear confidence intervals. Specifically, the weighted residuals need to be normally distributed. In addition, the model must be effectively linear for the calculated linear confidence intervals on estimated parameters and predicted hydraulic heads and flows to accurately represent simulation uncertainty. In the numerical model, confidence intervals were considered only on estimated parameter values.

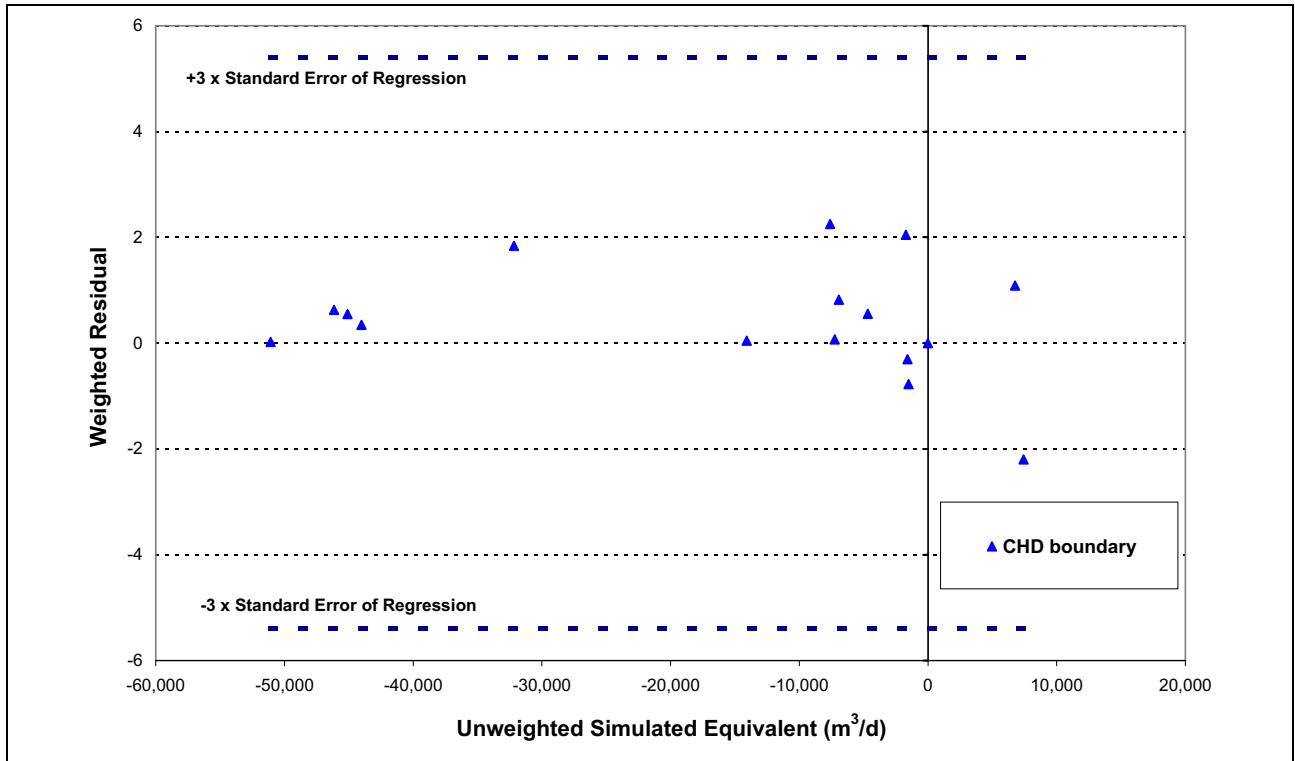


Figure 6-37
Weighted Residuals versus Unweighted Simulated Equivalents for CHD

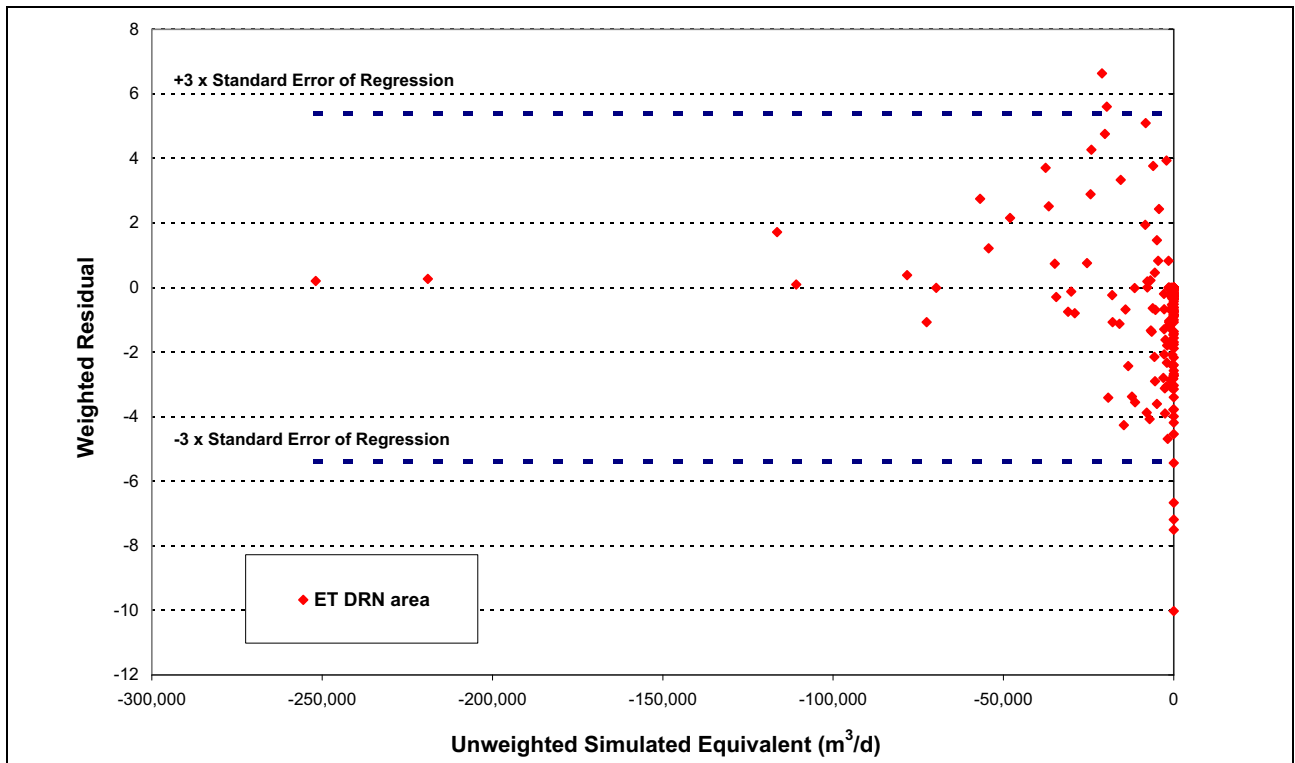


Figure 6-38
Weighted Residuals versus Unweighted Simulated Equivalents for ET Drains

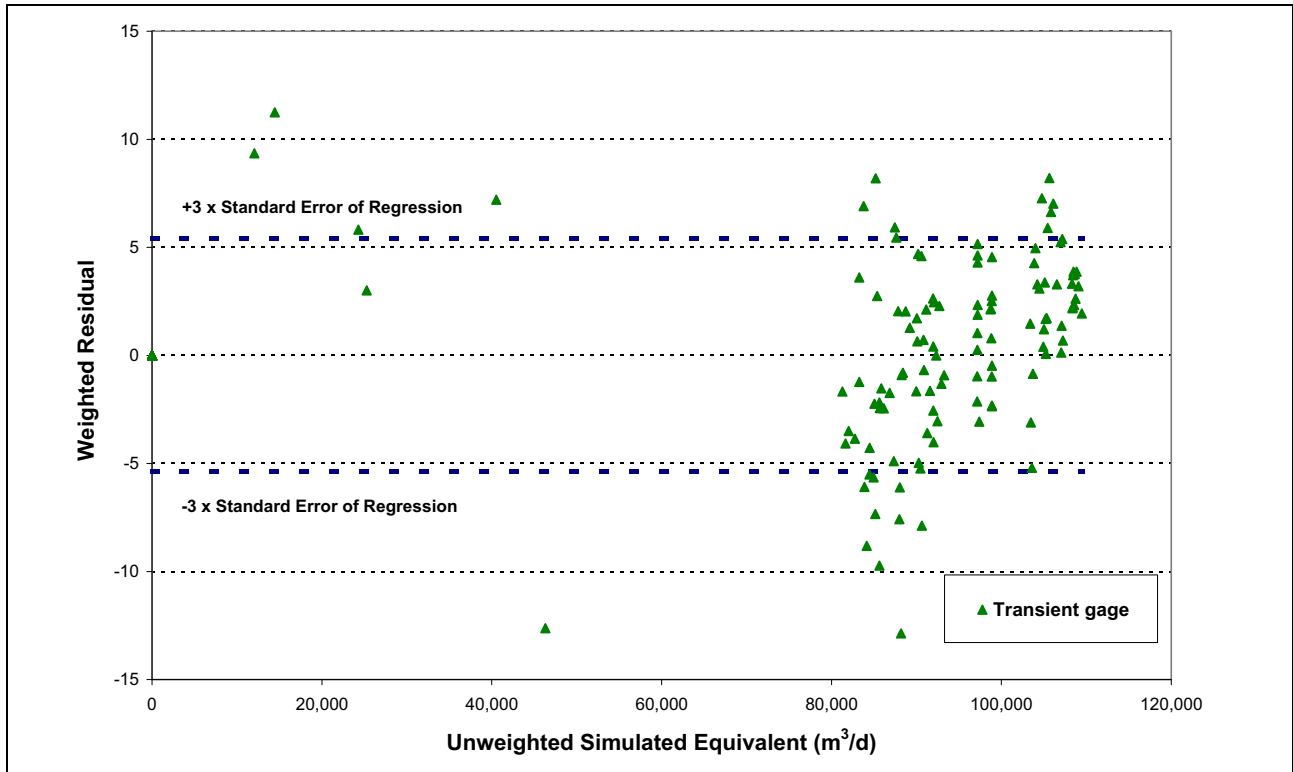


Figure 6-39
Weighted Residuals versus Unweighted Simulated Equivalents for Stream Flow

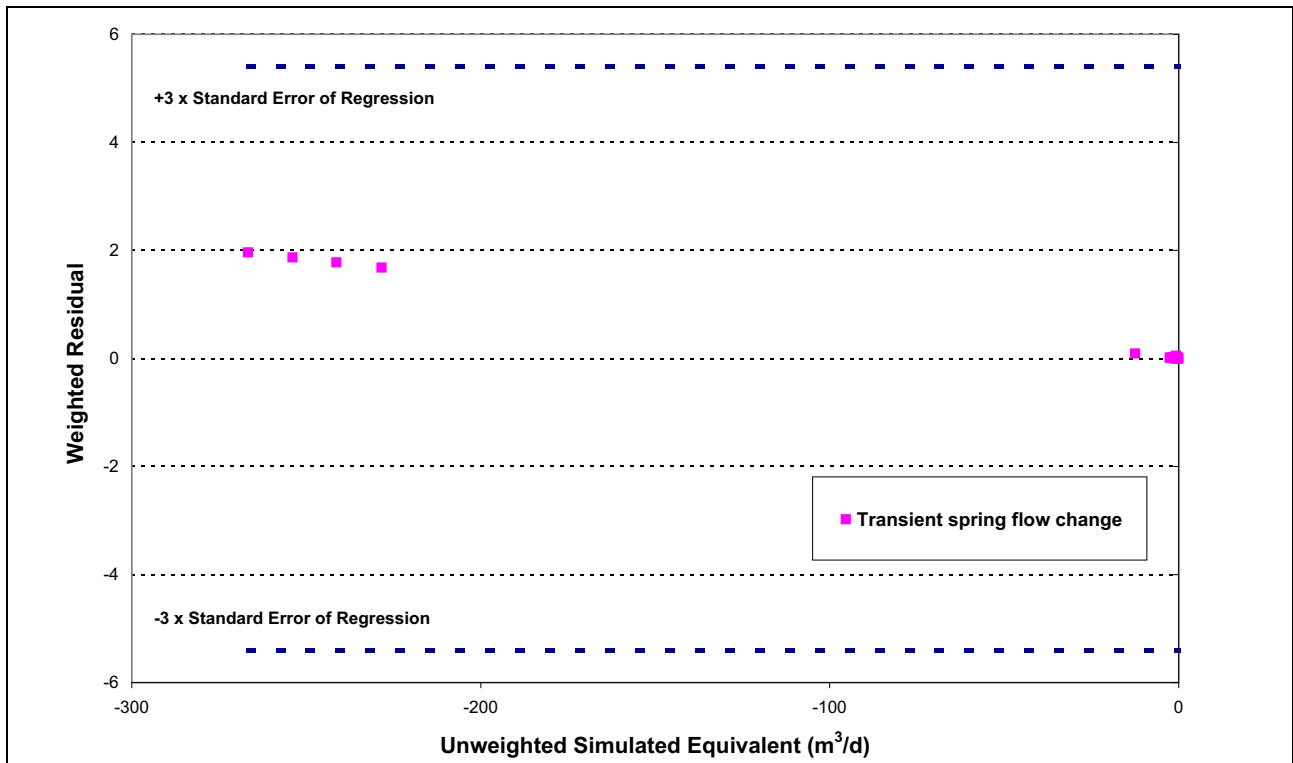


Figure 6-40
Weighted Residuals versus Unweighted Simulated Equivalents for Spring Flow

The normal probability plot of the weighted residuals for the final calibrated model is shown in Figure 6-41. The points would be expected to fall along a straight line if the weighted residuals were both independent and normally distributed. Clearly, the points do not fall along a straight line. One possibility is that the residuals are normally distributed, but they are correlated instead of being independent. Correlations are derived from the fitting of the regression.

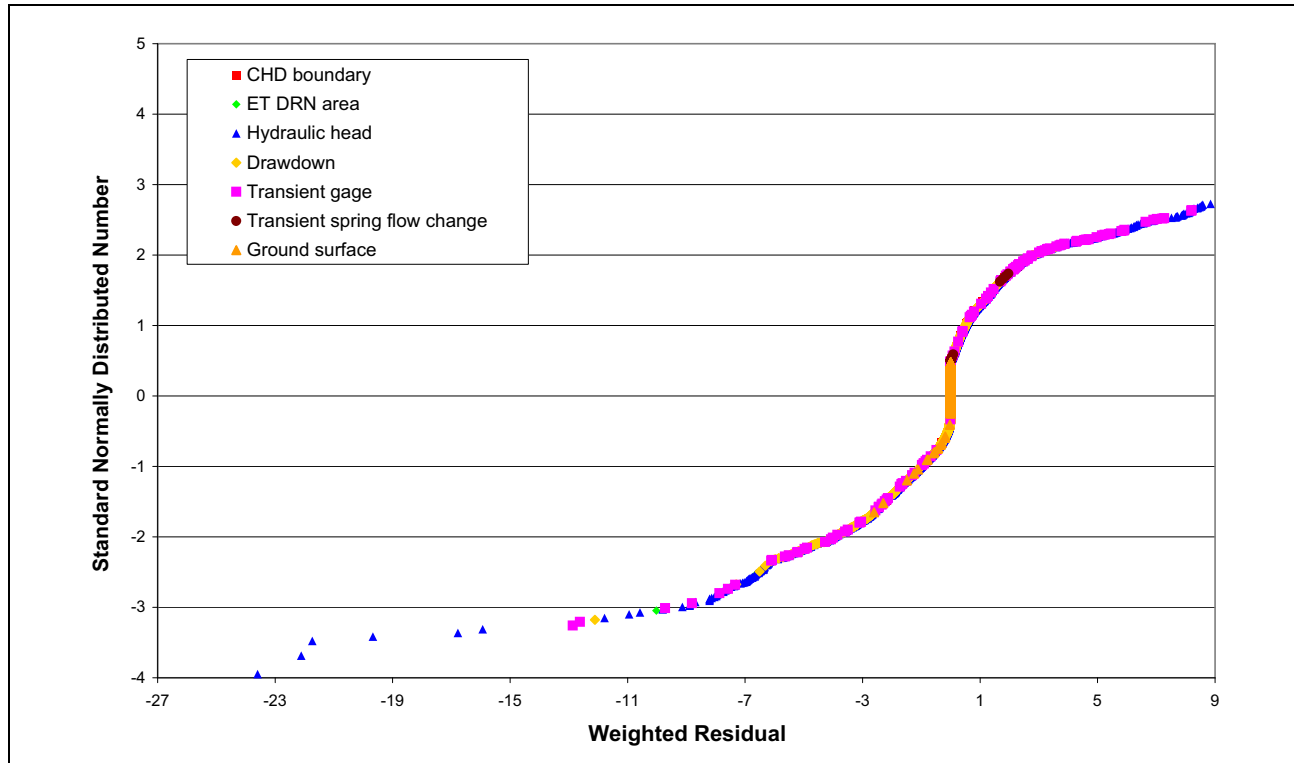


Figure 6-41
Normal Probability Plot of Weighted Residuals

The source of correlation can be investigated using the graphical procedures described by Cooley and Naff (1990). Normally distributed, random numbers generated to be consistent with the regression-derived correlations are called correlated-normal numbers and are shown in Figure 6-42. Most of the curvilinearity in Figure 6-42 cannot be attributed to regression-derived correlations. This analysis suggests that the weighted residuals are not normally distributed and that they are not correlated.

Model linearity was tested using a statistic referred to as the modified Beales measure (Cooley and Naff, 1990). The modified Beales measure calculated for the numerical model equals $0.972 \times 10^{+9}$. If the Beales measure is less than 0.044, the model is effectively linear. If the Beales measure is greater than 0.48, the model is highly nonlinear. Thus, the final calibrated model is highly nonlinear.

The lack of normality of the weighted residuals and the degree of nonlinearity of the numerical model indicate that linear confidence intervals may be inaccurate. Despite this problem, linear confidence intervals were used in the numerical model as rough indicators of the uncertainty in estimated parameter values in the presence of model nonlinearity. This approach is consistent with the previous work of Christensen and Cooley (1996).

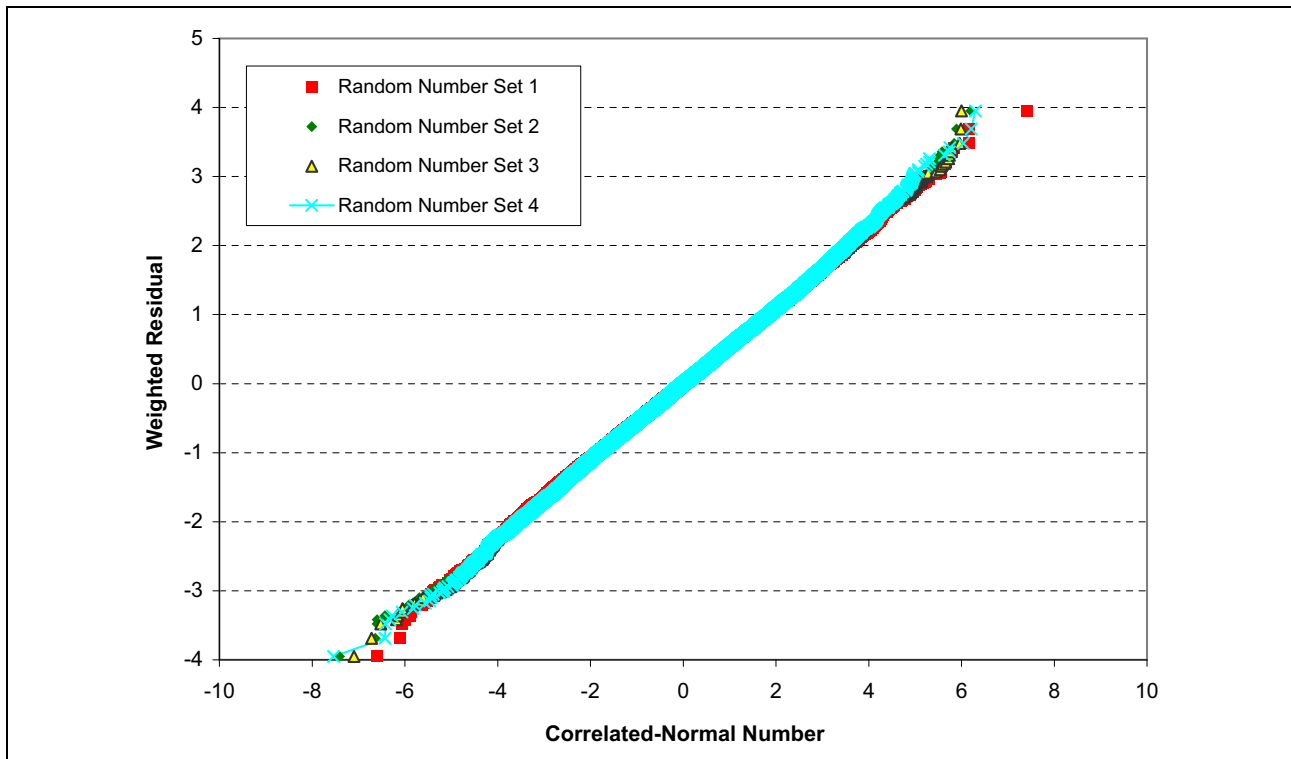


Figure 6-42

Normal Probability Plot of Weighted Residuals versus Correlated-Normal Numbers

6.2 Evaluation of Parameter Sensitivities and Parameter-Estimation Results

CSS are provided on the DVD for all parameters. The CSS of the 100 most sensitive UCODE parameters are shown in Table 6-5. These sensitivities are based on the input values to the last parameter-estimation run and were not recalculated with the final model estimates.

Given the large number of parameters in the model, and the small number of parameters that can be practically estimated, a second set of parameters was created that combined nearly all the model parameters into 10 aggregate parameters (Table 6-6). These parameters combined like materials and were used to assign a multiplication factor to raise or lower the values for the entire group. These group parameters did not capture all the individual model parameters but did account for or influence approximately 95 percent of them.

In this stage of the optimization process, two groups of parameters were excluded, constant-head boundaries (CHDs) and recharge parameters:

- CHDs were the most sensitive parameters. Because some, like Lake Mead or North Snake Valley, were well constrained, estimating them made little sense, as the actual values were well known. In other cases, such as when the boundary is in a mountain block where there is no control, an appropriate hydraulic-head selection depends on a proper estimate of the K of the host rock. In these cases, it is better to estimate the K value and manually adjust the boundary head. Except during preliminary simulations, CHD parameters were not optimized.

Table 6-5
Model Composite-Scaled Sensitivities for Final Calibrated Model (Top 100)

Position ^a	Parameter Name	Composite-Scaled Sensitivity	Parameter Type ^b	Position ^a	Parameter Name	Composite-Scaled Sensitivity	Parameter Type ^b		
x	1	LC_MB_S_HK	6.110	K	---	51	fUV207VB_H	0.1960	Kx
---	2	fLw210LFtH	3.282	Kx	---	52	fUV196AF_H	0.1957	Kx
---	3	RSC_ME_WR	2.890	RCH-ME	---	53	UA_VA	0.1939	K
x	4	KDEP_LCLDF	2.654	KDEP	---	54	fHFBPAHRnW	0.1933	Kx
x	5	UVF_AF_HK	2.639	K	---	55	fLd219SB_H	0.1929	Kx
---	6	RSC_ME_MVW	2.341	RCH-ME	---	56	fHFBCOAL_N	0.1885	Kx
x	7	KDEP_UVF	2.089	KDEP	---	57	UC_HK	0.1826	K
---	8	R_ROLVF_WT	2.039	RCH-RO	---	58	fHFBMUDDYR	0.1824	Kx
---	9	FAULT_FDUC	1.672	Kx	---	59	fLw180MB_H	0.1801	Kx
---	10	ETrWET	1.656	ET	---	60	ETr209WAT	0.1789	ET
x	11	LC_MB_D_HK	1.467	K	---	61	fLw171SB_H	0.1737	Kx
---	12	RSC_ME_GV	1.370	RCH-ME	---	62	fLwJWRMB_H	0.1736	Kx
---	13	HFB_HK	1.358	HFB	---	63	fUV209AF_H	0.1720	Kx
---	14	tHFBPAHR_E	1.298	K	---	64	fUV195VB_H	0.1682	Kx
---	15	ALT_FACT	1.164	Kx	---	65	LC_MB_VA	0.1546	K
---	16	RSC_ME_GSL	1.126	RCH-ME	---	66	fUV195AF_H	0.1545	Kx
---	17	R_ROCARB_W	1.097	RCH-RO	---	67	fLw174SB_H	0.1545	Kx
---	18	fLPSZ_MB_H	1.085	Kx	---	68	fLdOFZ_H	0.1537	Kx
x	19	CA_SBSD_HK	1.058	K	---	69	fUV181AF_H	0.1529	Kx
x	20	LV_CCCMB_H	0.9017	K	---	70	UV_SSVAF_H	0.1490	K
---	21	SFR_COND19	0.8642	SFR	---	71	R_ROLOWK_W	0.1460	RCH-RO
---	22	FAULT_FPAH	0.7860	Kx	---	72	fUAa_HK	0.1424	Kx
---	23	fLw207SB_H	0.7208	Kx	---	73	fLdPW_LF_H	0.1379	Kx
---	24	UVF_VB_HK	0.5280	K	---	74	UV_NLVPY_H	0.1352	K
---	25	tHFBCOAL_W	0.4774	K	---	75	fLd182MB_H	0.1273	Kx
---	26	fLw209MB_H	0.4482	Kx	---	76	fUV196VB_H	0.1232	Kx
---	27	BAS_HK	0.3808	K	---	77	SFRaCOND19	0.1218	SFR
---	28	SFR_COND15	0.3759	SFR	---	78	UVF_VA_Spc	0.1152	K
---	29	LV_WRCMB_H	0.3758	K	---	79	fUV195VBsH	0.1130	Kx
---	30	LV_IPCMB_H	0.3606	K	---	80	LVF_RIV_V	0.1108	K
---	31	fBA_IPC_H	0.3588	Kx	---	81	fLw172MB_H	0.1083	Kx
---	32	SPR_REGION	0.3466	SPR	---	82	fUV181PY_H	0.1029	Kx
---	33	UVF_VA	0.3452	K	---	83	fHFBGARD_W	0.1017	Kx
---	34	KDEP_LCMDF	0.3277	KDEP	---	84	PLUT_HK	0.0982	K
---	35	ETr209WET	0.3250	ET	---	85	FAULT_FLVF	0.0981	Kx
---	36	LVF_RIV_H	0.3091	K	---	86	fLe195MB_H	0.0968	Kx
---	37	BAS_P2P_HK	0.3057	K	---	87	LV_QRCMB_H	0.0959	K
---	38	f207LF_TST	0.2908	Kx	---	88	LV_IPCSB_H	0.0951	K
---	39	fLw209MFtH	0.2823	Kx	---	89	LVF_VA	0.0946	K
---	40	UVF_SYTP	0.2822	K	---	90	fUV195PY_H	0.0918	Kx
---	41	LVF_HK	0.2701	K	---	91	fLw171LF_H	0.0910	Kx
---	42	LVF_VOL_VA	0.2592	K	---	92	CA_SBSD_VA	0.0898	K
---	43	fLw171MB_H	0.2404	Kx	---	93	fHFBPROC_N	0.0799	Kx
---	44	BAS1_HK	0.2360	K	---	94	UA_NW1_HK	0.0773	K
---	45	R_ROUVF_WT	0.2358	RCH-RO	---	95	fUV181VB_H	0.0760	Kx
---	46	SFR_COND16	0.2308	SFR	---	96	UV_SSVVB_H	0.0746	K
---	47	SPR_INTRMD	0.2292	SPR	---	97	SFR_COND17	0.0725	SFR
---	48	fLw219MB_H	0.2238	Kx	---	98	fUwMB_HK	0.0697	Kx
---	49	ETrSHR	0.2131	ET	---	99	UA_NW1_VA	0.0697	K
---	50	UA_HK	0.2111	K	---	100	fLw218MB_H	0.0693	Kx

^ax indicates parameter optimized using UCODE_2005 parameter estimation

^bHFB = Horizontal flow barrier conductance
K = Hydraulic conductivity K_p , $VANI$, or fault factor
Kx = Multiplication factor for K parameter of K group

RCH-ME = Maxey-Eakin recharge efficiency
RCH-RO = In-place / runoff recharge efficiency
SFR = Stream flow routing riverbed conductance
SPR = Spring drain conductance factor

Table 6-6
Model Composite-Scaled Sensitivities for Grouped Model Parameters

Position		Parameter Name	Composite-Scaled Sensitivity	Parameter Type	Group Composition
x	1	CARBK_FACT	7.0475	K	All carbonate horizontal K parameters
x	2	HFBC_FACT	2.6403	K	All HFB parameters
x	3	UVF_K_FACT	2.4493	K	All UVF horizontal K parameters
x	4	OTHRK_FACT	1.4098	K	All non-carbonate and non-UVF horizontal K parameters
x	5	SFRC_FACT	1.0197	SFR	All SFR river bed conductance parameters
x	6	UVF_SY_VAL	0.2824	Sy	All UVF Sy parameters
x	7	CARBSY_VAL	0.0710	Sy	All carbonate Sy parameters
---	8	UVF_SS_VAL	0.0416	Ss	All UVF Ss parameters
---	9	OTHRSS_VAL	0.0297	Ss	All non-UVF Ss parameters
---	10	OTHRSY_VAL	0.0235	Sy	All non-carbonate and non-UVF Sy parameters

Note: x indicates parameter optimized using UCODE_2005 parameter estimation

- RE parameters were not optimized using parameter estimation. During early model work and work up to the final calibration, attempts were made to estimate RE parameters. Typically the optimization process added unreasonable volumes of water to the model, but RE parameters were not allowed to exceed two times their starting values. Part of the problem may be related to efforts to raise hydraulic heads in the mountain blocks to match potentially perched hydraulic-head observations.
- Recharge runoff efficiencies were not optimized as they were being unreasonably estimated during calibration. During calibration, the R_ROLVF_WT parameter was manually adjusted to control hydraulic heads in Clover Valley. Other parameters could control heads in this area without the wider impacts across the model.

In late-stage model testing, attempts were made to optimize several sets of parameters ([Table 6-7](#)).

Table 6-7
Late-Stage Parameter Optimization Runs

Run Number	Description
Run 1	A set of 7 of the 20 most sensitive, non-CHD and nonrecharge parameters (Table 6-5)
Run 2	A set of 7 grouped parameters (Table 6-6)
Run 3	The 20 most sensitive, non-CHD and nonrecharge parameters (Table 6-5)

Run 1 included some of the lower-sensitivity parameters that were selected over higher-sensitivity parameters listed in [Table 6-5](#) based on information from previous sensitivity runs, including:

- The HFB_HK conductance was fixed near the end of the calibration process because (1) it was not changing by large amounts, and (2) in some cases, even small changes in this parameter were causing the model to fail to converge in the steady-state stress period because of issues with the SFR2 module in the area near the Pahranaagat Shear Zone.
- Some parameters, while sensitive, did not always improve model results in acceptable ways. While improving one section of the model, another area might be significantly degraded. Because of the different observation types and the uneven distribution of observations, properly balancing observation weights was difficult.

These parameters were also relatively uncorrelated (< 85 percent correlation). The optimized values from Run 1 were used as inputs into the remaining two optimizations.

Run 2 included a set of 7 of the most sensitive of the 10 grouped parameters listed in [Table 6-6](#). The three least sensitive parameters were dropped because of their relatively small CSSs. Two of the included parameters, UVF_SY_VAL and CARBSY_VAL, while also having fairly small sensitivities, were known to be very important in calculating proper drawdowns in pumping areas.

Run 3 included the 20 most sensitive, non-constant head and non-recharge parameters listed in [Table 6-5](#).

Both Runs 2 and 3 failed to converge.

- Run 2 failed to converge after 30 iterations. It was apparent that more iterations would not result in convergence. The convergence criteria measure (maximum calculated parameter change) in this run was also oscillating. The principal parameter being adjusted in this case was CARBSY_VAL. It was oscillating between 1 and 6 percent, at what appeared to be more or less random adjustments. The SoSWR was reduced by several percent in this run, but this was mainly due to an increase in the UVF Sy value. The UVF Sy value was limited to 23 percent, as previous tests estimated values closer to 40 percent, which was unreasonably large.
- Run 3 was terminated after 19 iterations (five days) because of large oscillations in parameter values.

These final estimated parameters are interpreted as representing the most important system characteristics. This analysis helps ensure that the measures of prediction uncertainty, calculated using the numerical model, reflect most of the uncertainty in the system; all measures of prediction uncertainty presently available propagate to the uncertainty of the estimated parameter values. Uncertainty in other aspects of the model is not propagated into the uncertainty measures; therefore, the total uncertainty as estimated here is considered to be underestimated.

If a model represents a physical system adequately and the observations used in the regression provide substantial information about the parameters being estimated, it is reasonable to think that the

parameter values that produce the best match between the observed and simulated values would be realistic. Thus, model error would be indicated by unreasonable estimates of parameters for which the data provide substantial information.

A measure of the amount of information provided by the observations for any parameter is the CSS value and the linear confidence interval on the parameter. Generally, a parameter with a large CSS value will have a small confidence interval relative to a parameter with a smaller CSS value. If an estimated parameter value is unreasonable and the data provide enough information so that the linear 95 percent confidence interval on the parameter estimate also excludes reasonable parameter values, the problem is less likely to be lack of data or insensitivity and more likely to be model error or misinterpreted hydraulic-conductivity data.

The model's calibrated parameter values and the 95 percent linear confidence intervals are presented in Table 6-8. The 95 percent confidence intervals for the selected parameters were calculated assuming a log-normal distribution at ± 2 standard deviations from the geometric mean (Helsel and Hirsch, 1992, p. 73-74). In most cases, the estimated parameter values and related model-calculated 95 percent linear confidence intervals are within the range of K values determined by baseline data analysis. As stated in Section 6.1.5, the model statistics are very clear that this model is highly nonlinear; therefore, the 95 percent linear confidence intervals are not very meaningful for this model.

Table 6-8
95 Percent Linear Confidence Intervals
for Calibrated Parameters

Parameter	Description	Upper 95% Confidence Interval	Final Estimated Value	Lower 95% Confidence Interval
UVF_AF_HK	UVF K_h Alluvial Fan	14.2	13.31	12.5
LV_CCCMB_H	LVF K_h Caliente Caldera Mountain Block	0.0425	0.04075	0.0391
LC_MB_D_HK	LC K_h Mountain Block Detachment Zone	0.13	0.1261	0.122
LC_MB_S_HK	LC K_h Mountain Block Slight Extension Zone	0.0941	0.09085	0.0878
CA_SBSD_HK	LC K_h Structural Basin (All)	0.0567	0.05217	0.048
KDEP_UVF	UVF KDEP λ	0.00142	0.001311	0.00121
KDEP_LCLVF	LC LDF KDEP λ	0.000215	0.0001979	0.000182

Even with a nonlinear model, however, linear confidence intervals are useful when the range of possible values for the optimized parameter does not overlap with reasonable values for the parameter (Hill, 1998). This generally indicates there is a problem with the conceptual model represented in the numerical model. The model-estimated confidence intervals on the parameter estimates shown in Table 6-8 appear unrealistically small. This is largely because they represent the confidence interval for the mean hydraulic-conductivity value of the defined hydrogeologic unit or zone. As pointed out by Hill (1998), confidence intervals on mean values are rapidly reduced from the entire range of the population as data are applied to the estimation of the mean. The validity of the idea that the

hydrogeologic units have uniform mean or effective values is, of course, a basic assumption of the modeling approach used in this work.

No prior information was included in the objective function to restrict the estimation process; only the model design and the observation data influenced parameter estimation. Estimation of the most important parameters without prior information has the advantage of allowing a more direct test of the model using the observation data. In this approach, the available information on reasonable parameter values was used to evaluate the estimated parameter values.

Partly because of the numerical model's nonlinearity, the CSS values change somewhat as the parameter values change. As a result, the evaluation of CSS values was repeated frequently. The final values changed somewhat but were still quite similar to initial values and generally indicate that the parameters being estimated were the most important parameters. Exceptions occur for parameters that were correlated with parameters with larger CSS values and for parameters that mostly influence model fit to a single observation.

6.3 Evaluation of Estimated Parameter Values

This section contains an evaluation of the modeling parameters, including hydraulic conductivity, storage, and recharge.

6.3.1 Hydraulic Conductivities

The calibrated hydraulic-conductivity values fall within, or are near, literature ranges. The calibrated hydraulic-conductivity values are shown in [Figures 6-43](#) through [6-49](#) and are compared to published ranges for like materials (left-most bar) and to the range of values in the adjacent DVRFS model and study area (second bar on left).

Quantitatively, the estimated values of K appear reasonable. They fall within published ranges. From a qualitative perspective, the spatial distribution of K is consistent with the conceptual model. Mountain-block areas are generally less disturbed and therefore have lower K and T values. Valley basins tend to have higher K and T values because they are more disturbed and contain higher- K alluvial deposits. Areas with volcanic, plutonic, or basement clastic rocks also tend to have lower K . Fault zones tend to be of higher K and T , sometimes significantly higher.

A list of all MODFLOW HUF2 parameters is provided on the DVD. Note that most MODFLOW HUF2 parameters are not directly estimated. There are over 2,000 HUF2 HGU-named HK and $VANI$ parameters. Most are derived from one or more UCODE parameters. This allows for a great deal of flexibility when manually calibrating because relatively isolated areas of the model can be tested independently of the rest of the model. If necessary, a new UCODE factor parameter can be added to act as a modifier to the base parameter. During the automated calibration process, though, a few parameters can still be adjusted to influence the overall model. This approach was used to allow model flexibility without drastically overparameterizing the model.

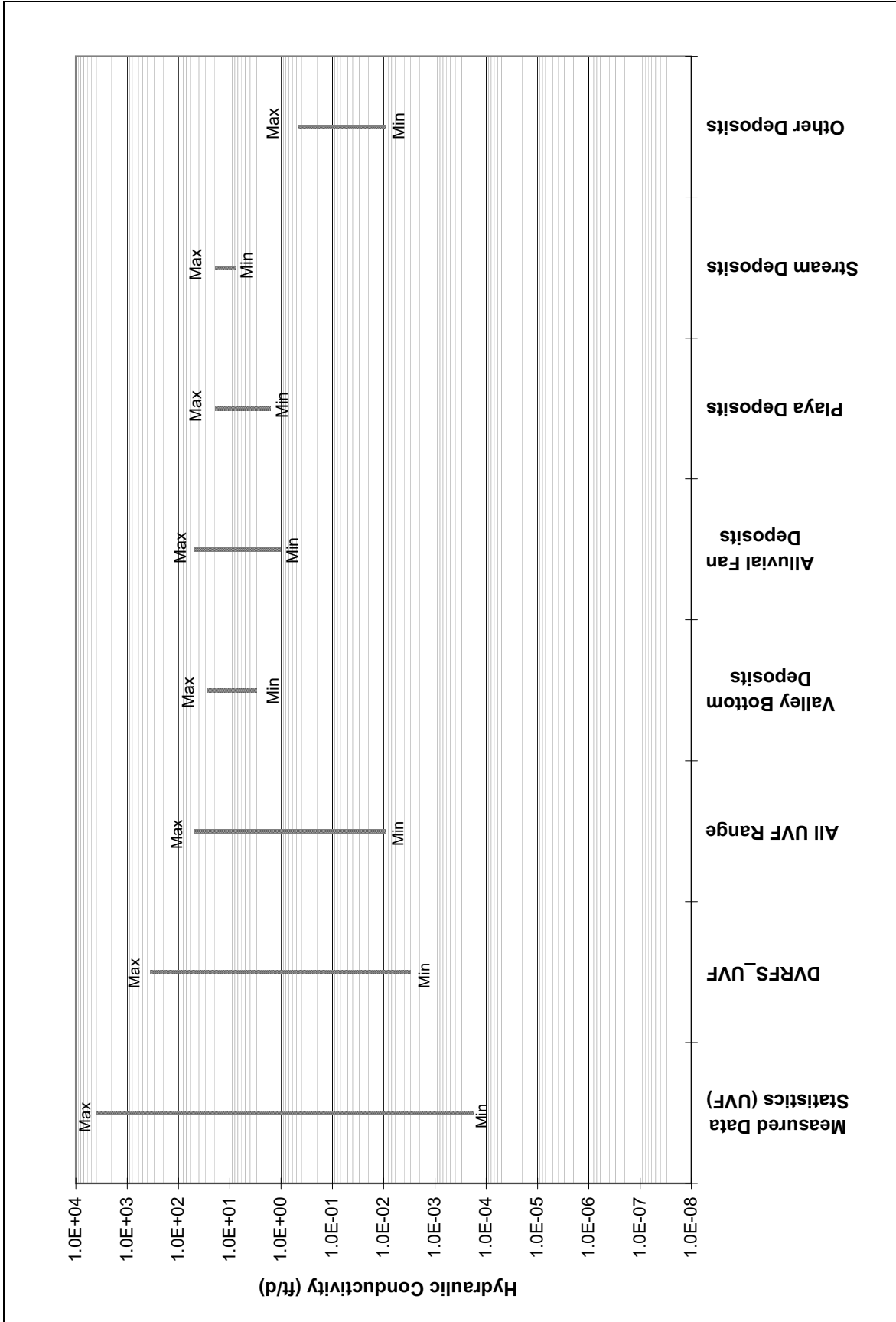


Figure 6-43
Parameters Defining Hydraulic Conductivity for UVF

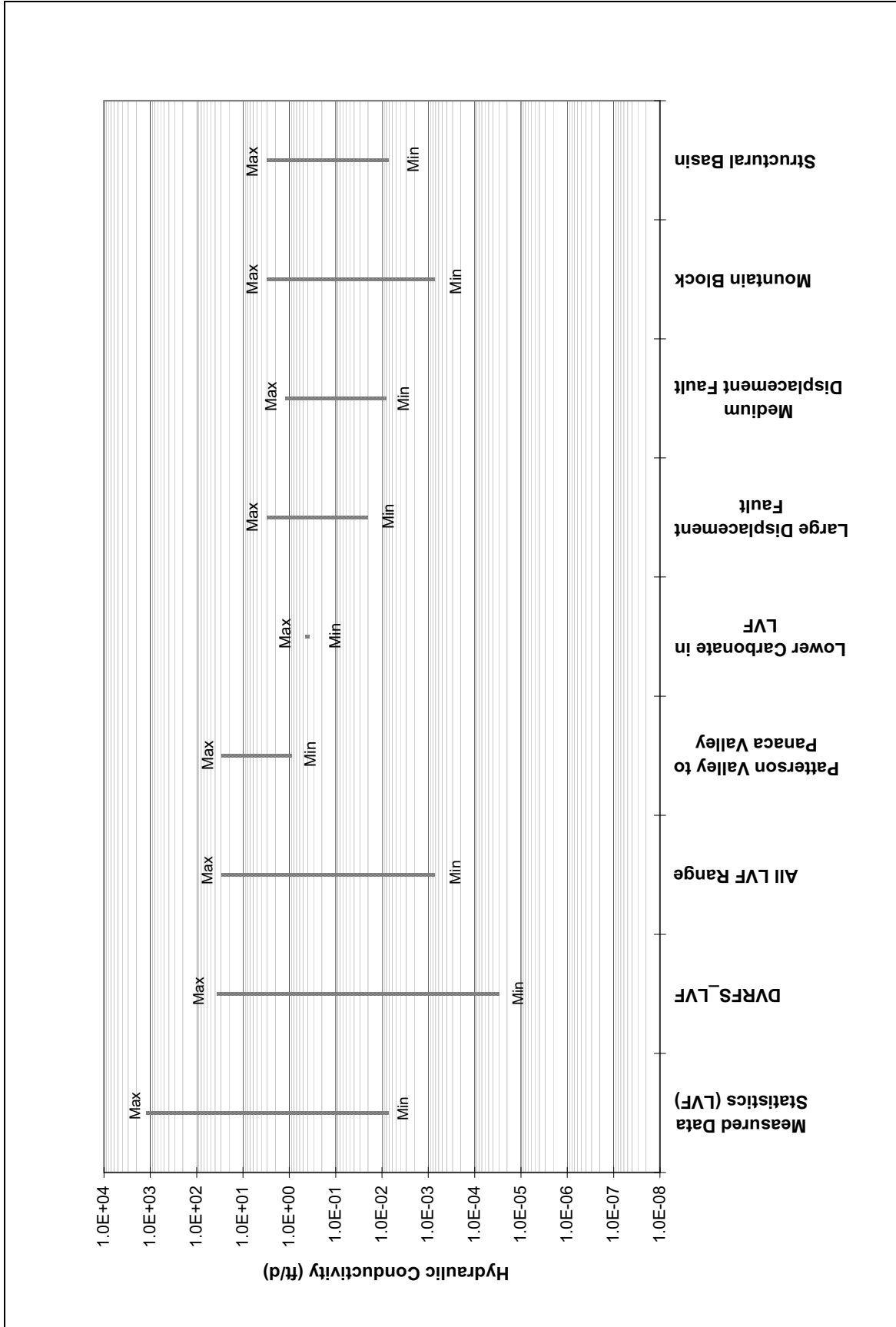


Figure 6-44
Parameters Defining Hydraulic Conductivity for LVF

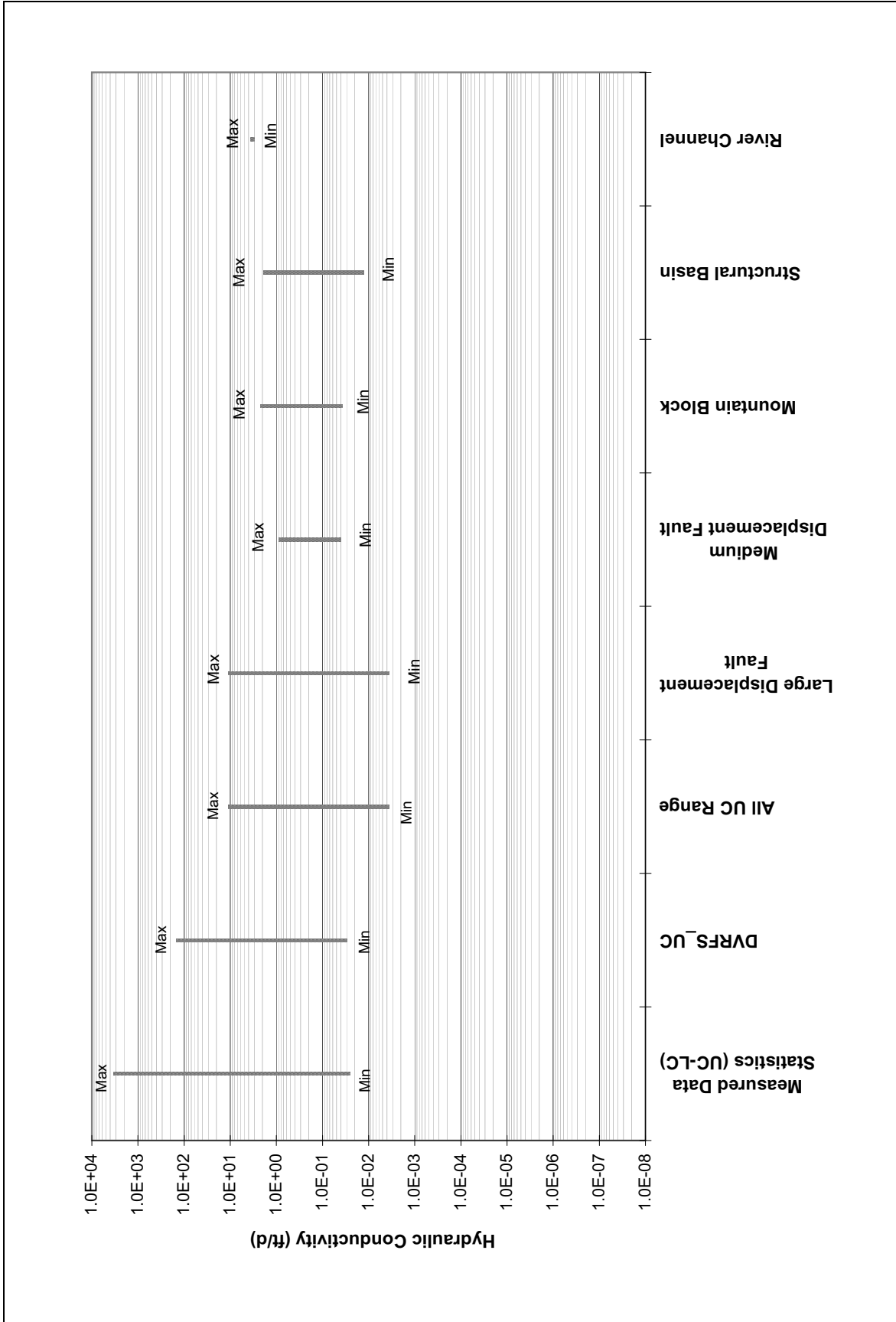


Figure 6-45
Parameters Defining Hydraulic Conductivity for UC

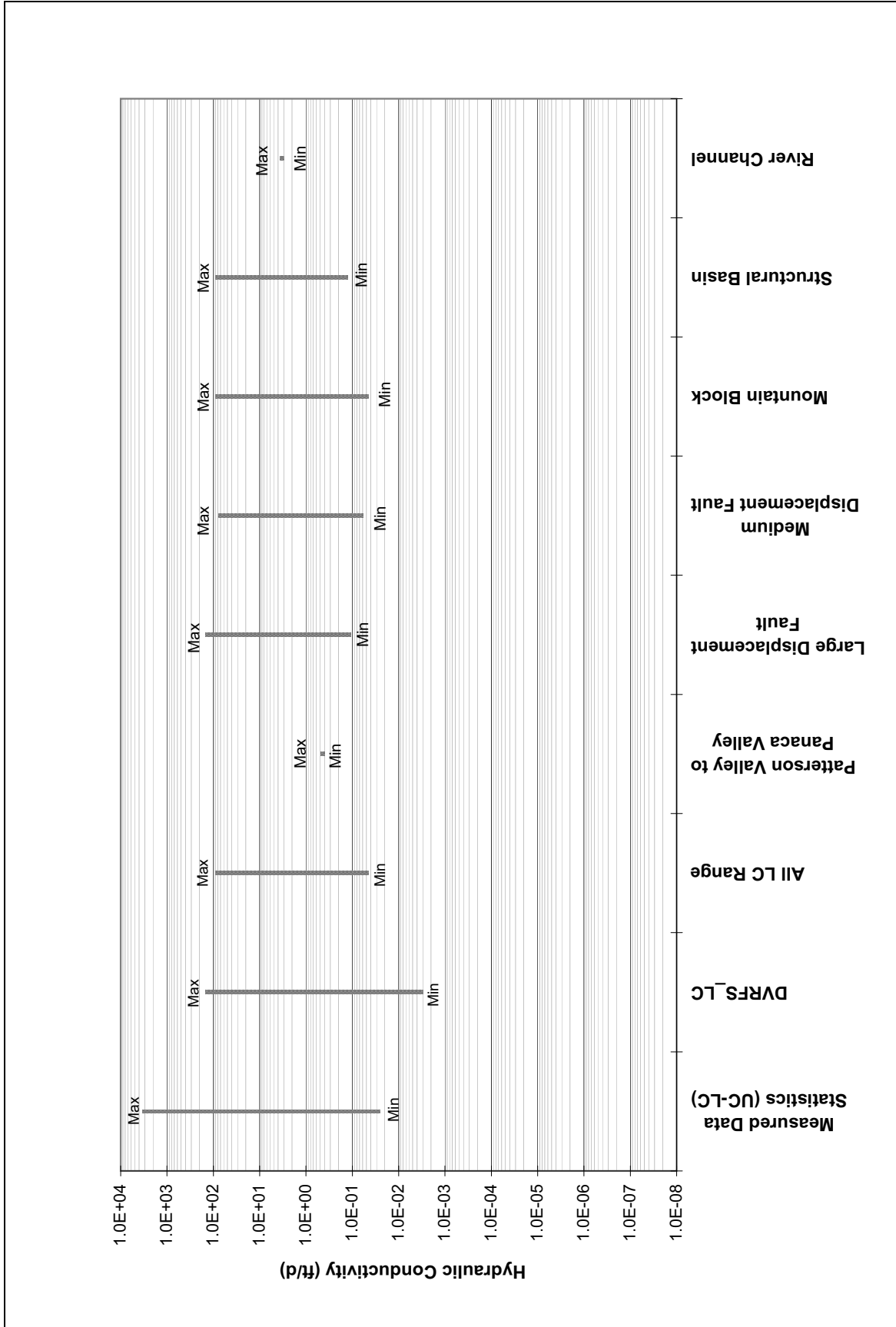


Figure 6-46
Parameters Defining Hydraulic Conductivity for LC

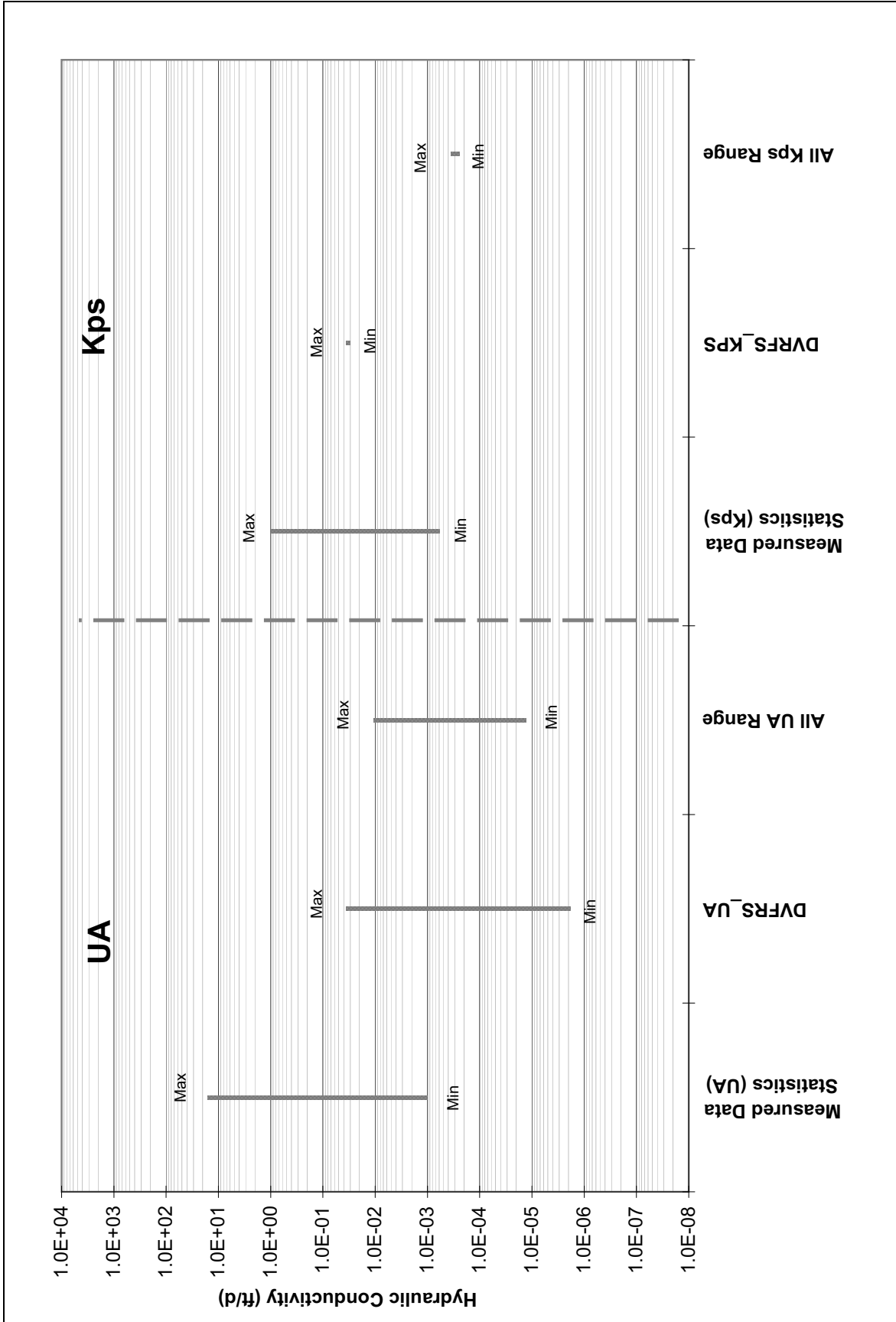


Figure 6-47 Parameters Defining Hydraulic Conductivity for UA and Kps

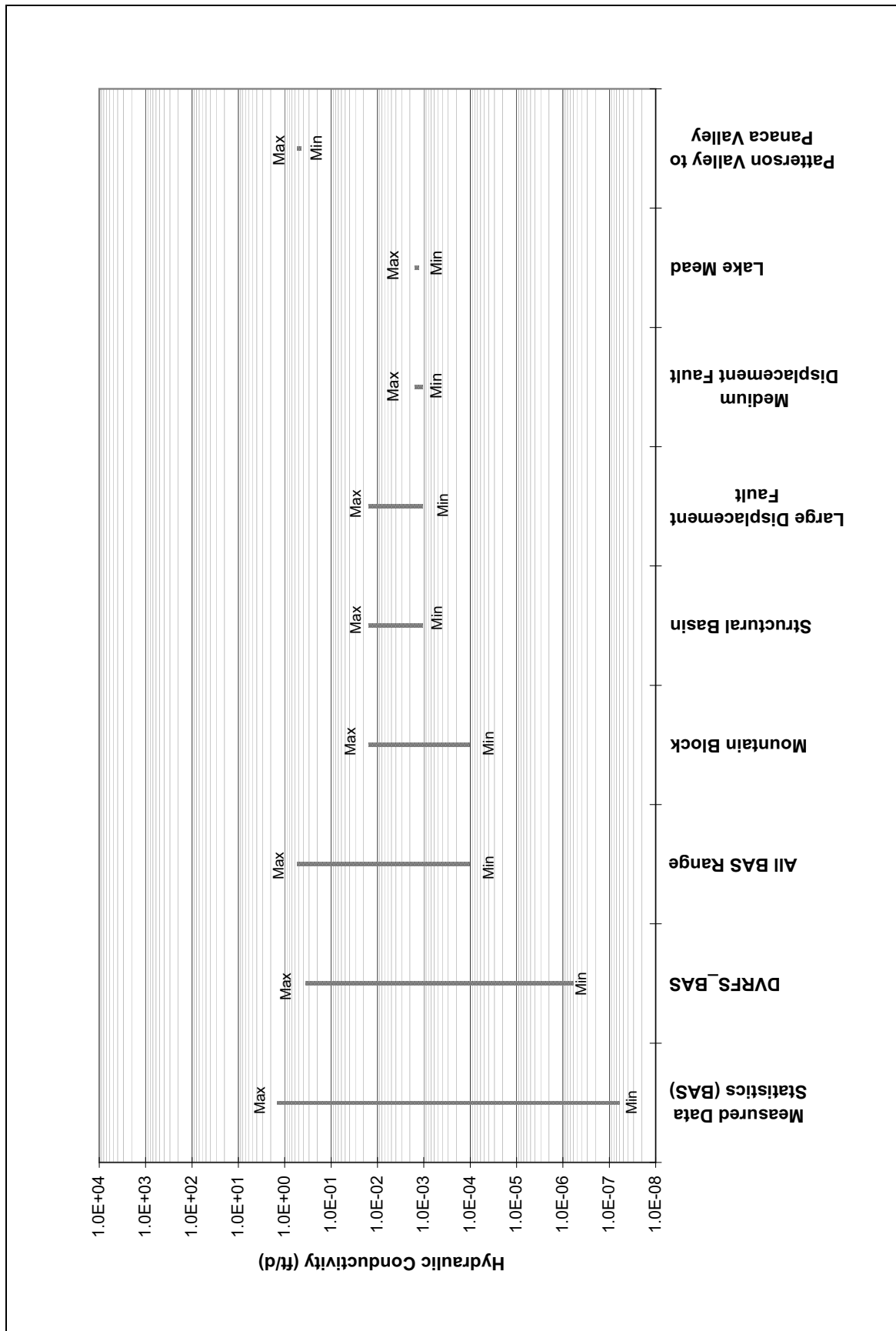


Figure 6-48
Parameters Defining Hydraulic Conductivity for BASE (BAS)

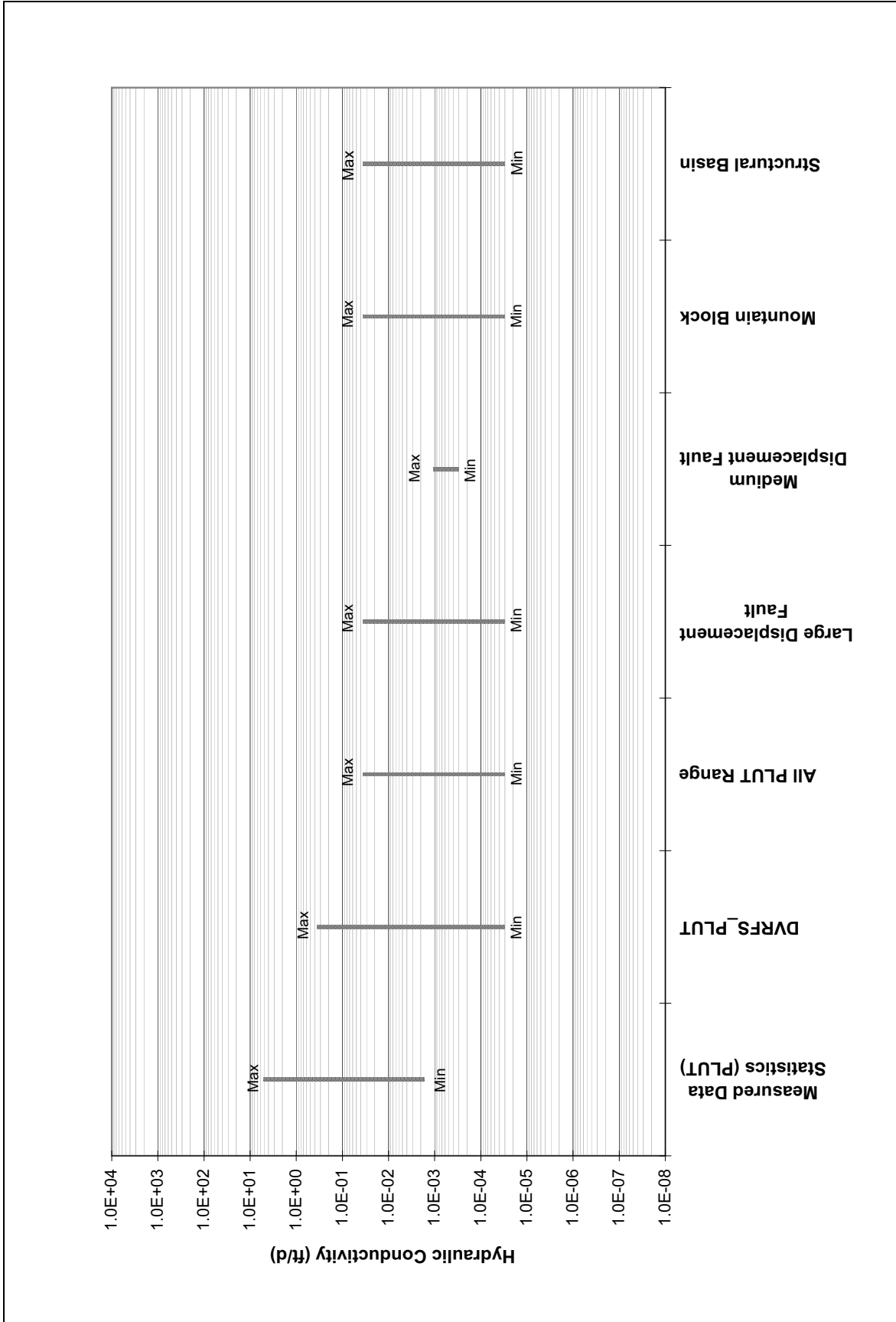


Figure 6-49
Parameters Defining Hydraulic Conductivity for PLUT

6.3.1.1 KDEP Values

The K values presented in Figures 6-43 through 6-49 all reference the K of materials at or near the ground surface. For UVF and presented faulted carbonate materials, it is assumed that K decreases up to two orders of magnitude with depth. Two KDEP parameters, KDEP_UVF and KDEP_LCLDF were optimized using parameter estimation. The KDEP values used in the model are presented in Table 6-9, and the influence on K is shown in Figure 6-50. KDEP for the unfaulted carbonates was essentially zero ($1.0E-7$).

Table 6-9
Estimated KDEP Values

Parameter Name	Calibration Method	Estimated Value (1/m)
KDEP_UVF	UCODE Optimization	1.311E-03
KDEP_LC_NF	Manual	1.000E-07
KDEP_LCLDF	UCODE Optimization	1.979E-04
KDEP_LCMDF	Manual	2.500E-04
KDEP_PANAC	Manual	7.000E-03

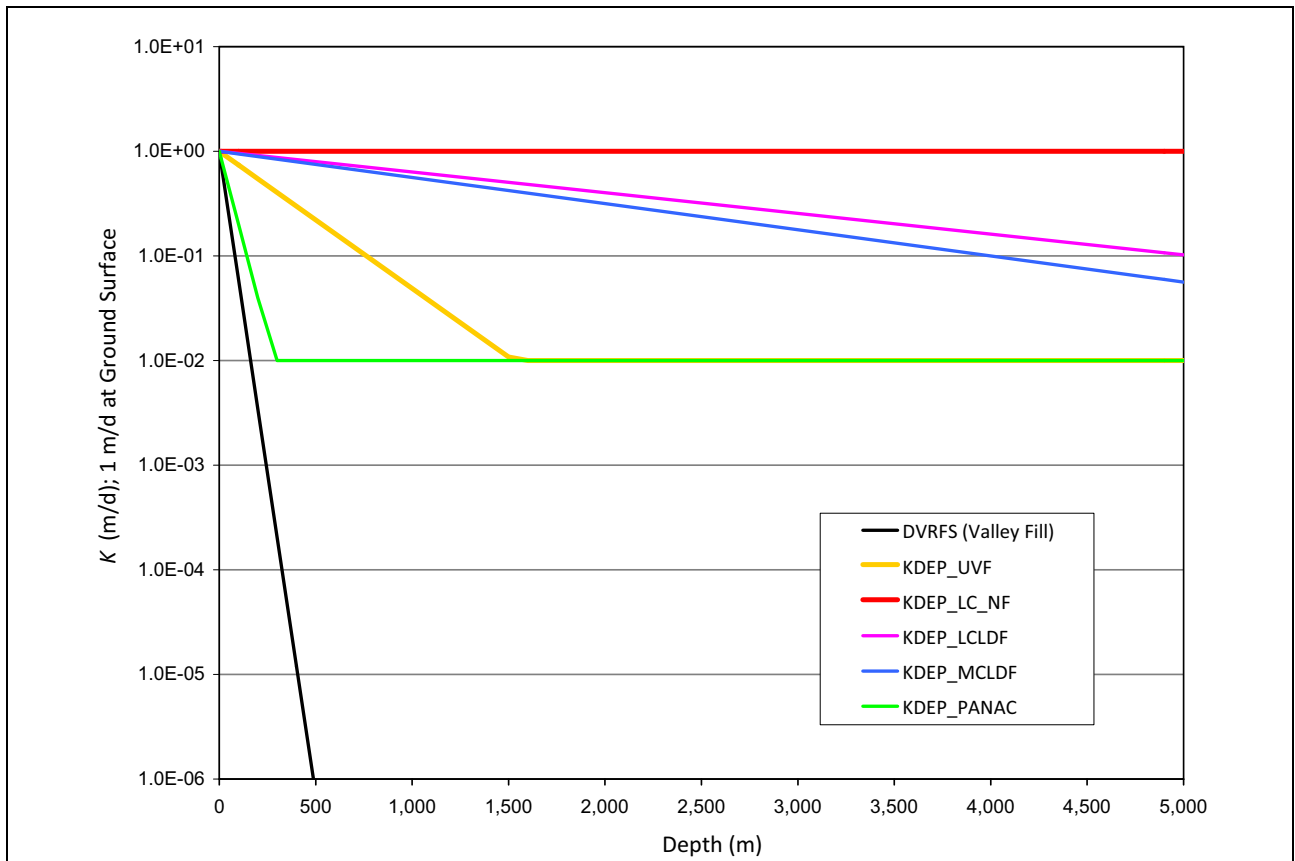


Figure 6-50
KDEP Influence on Hydraulic Conductivity

6.3.1.2 Spatial Distribution

The spatial distribution of hydraulic conductivity for each numerical model layer is presented in electronic form (see DVD). Transmissivity for the entire saturated thickness of the numerical model is shown in [Figure 6-51](#). [Figure 6-51](#) also illustrates the transmissivity of the DVRFS transient flow model (Faunt et al., 2004) for comparative purposes. As shown in [Figure 6-51](#), the range of transmissivity of the numerical model compares well to that of the DVRFS model.

6.3.2 Storage

While storage parameters significantly influence the magnitude of drawdowns in the study area, particularly in the UVF, the S_s and S_y parameters are not the most sensitive parameters. In fact, the UVF_SYTP CSS is the most sensitive S_s or S_y parameter but is the 40th most sensitive parameter ([Table 6-5](#)). The UVF_SYTP (S_y) was initially set at 10 percent. After manual calibration and review of other studies in the area ([Appendix A](#)), UVF_SYTP was increased to 18 percent. No other S_s and S_y parameters were adjusted. As shown in [Figures 6-52](#) and [6-53](#), these values lie well within published ranges. The S_s and S_y spatial distribution is also provided by model layer in electronic form (see DVD).

6.3.3 Recharge

Recharge is the most significant component of groundwater budgets in the numerical model. As expected, recharge efficiencies are sensitive parameters. Unfortunately, applying parameter-estimation methods to RE parameters resulted in efficiencies increasing to unreasonable rates. Underestimated spring flows and hydraulic heads in mountain blocks appear to drive this behavior. As a result, RE were not estimated; these parameters were manually calibrated. The results achieved are reasonable. The final RE are reported in [Tables 6-10](#) and [6-11](#).

[Figures 6-54](#) and [6-55](#) show the simulated recharge, target recharge, and range of recharge from literature sources for flow systems and hydrographic areas. The simulated recharge (580,700 afy) is within 1 percent of the target recharge (571,000 afy) for the entire numerical model. Moreover, the simulated recharge in each flow system is within literature ranges. Simulated recharge in the GVFS is 28,400 afy above target recharge, mostly due to simulated recharge in Steptoe Valley which is overestimated by 21,900 afy, as compared to the target value. While it is overestimated based on the target value, simulated Steptoe Valley recharge is still well within the literature range provided in the conceptual model (SNWA, 2009a). Thus, Steptoe Valley accounts for the majority of the recharge difference in the GVFS.

[Figures 6-56](#) through [6-58](#) illustrate the simulated in-place and runoff recharge components for flow systems, hydrographic areas, and sub-basins. The potential recharge is also shown (see [Section 4.0](#) for a discussion of the development of these recharge components). At the flow-system scale, potential recharge is equivalent to the sum of runoff and in-place recharge. At the hydrographic-area and sub-basin scale, the potential recharge can slightly deviate from the sum of runoff and in-place recharge. This deviation results from a small component of runoff moving down-gradient to an adjacent hydrographic area or sub-basin. The notable feature of the graphs in [Figure 6-56](#) is the larger

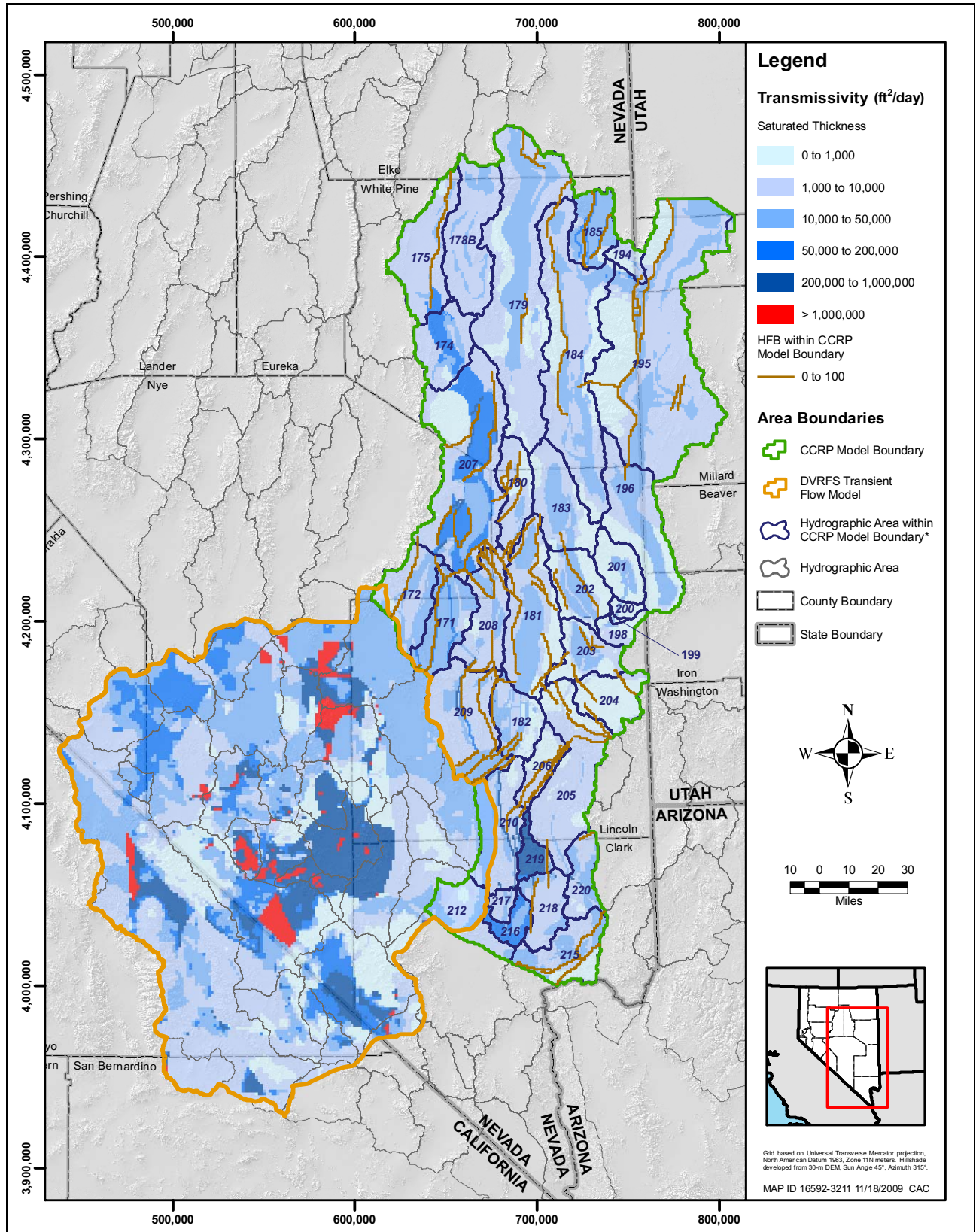


Figure 6-51
Cumulative Transmissivity Distributions of CCRP and DVRFS Models

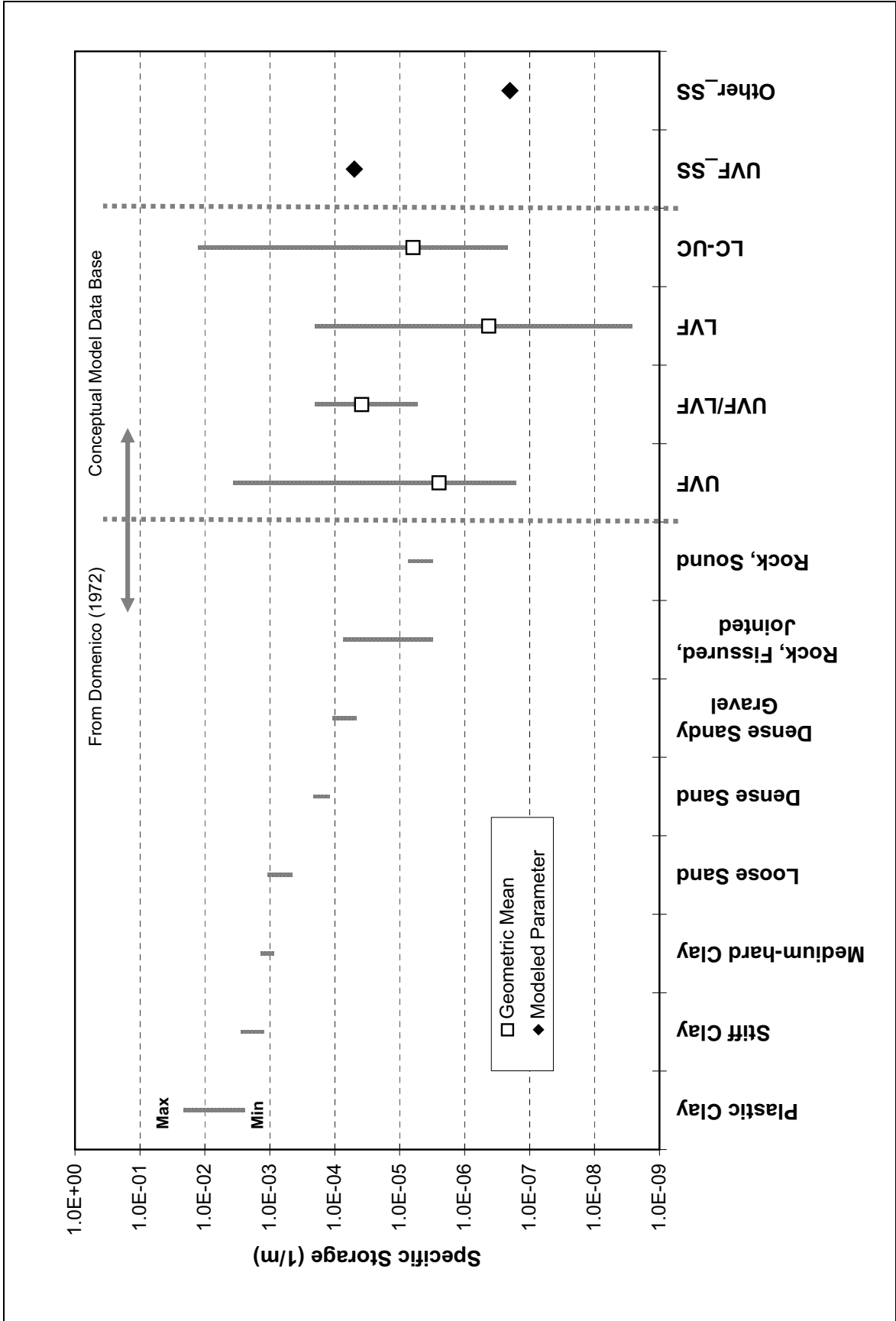


Figure 6-52
Specific-Storage Parameter Values

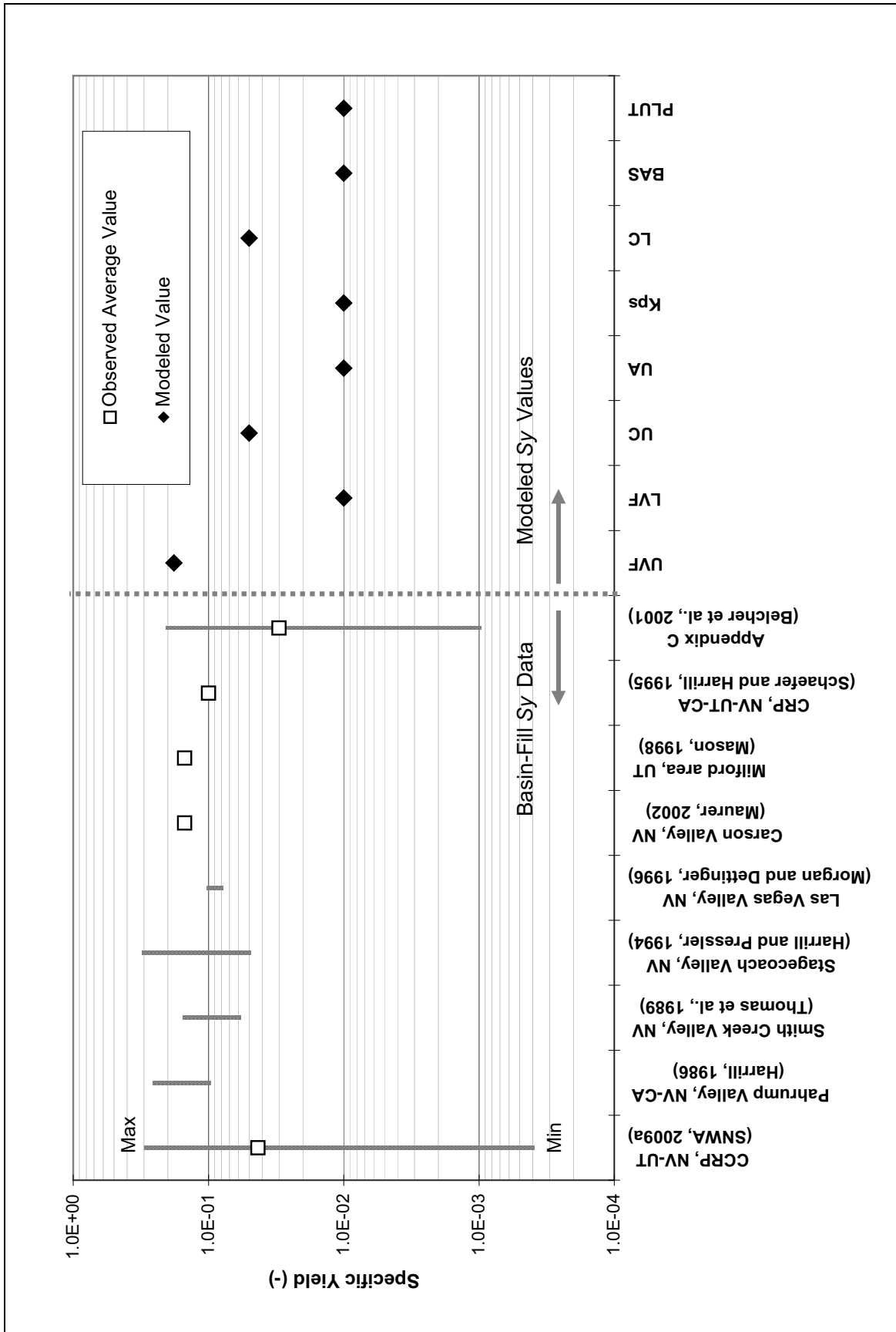


Figure 6-53
Specific-Yield Parameter Values

Table 6-10
Manually Estimated Recharge Efficiencies as Fraction of Precipitation

Precipitation Zone (in./yr)	Parameter Name	Estimated Parameter Value (-)	Final Recharge Efficiency (fraction of precipitation)	UCODE-Derived Parameter Name
Goshute Flow System				
<8	NE	1	0.000	NE
8 to 12	RSC_ME_GV	1.25	0.018	R_ME2_GV_R
12 to 15	RSC_ME_GV	1.25	0.066	R_ME3_GV_R
15 to 20	RSC_ME_GV	1.25	0.158	R_ME4_GV_R
>20	RSC_ME_GV	1.25	0.396	R_ME5_GV_R
Great Salt Lake Desert Flow System				
<8	NE	1	0.000	NE
8 to 12	RSC_ME_GSL	1	0.011	R_ME2_GSLD
12 to 15	RSC_ME_GSL	1	0.050	R_ME3_GSLD
15 to 20	RSC_ME_GSL	1	0.120	R_ME4_GSLD
>20	RSC_ME_GSL	1	0.328	R_ME5_GSLD
Las Vegas Flow System				
<8	NE	1	0.000	NE
8 to 12	RSC_ME_WR	1.052	0.006	R_ME2_LV_R
12 to 15	RSC_ME_WR	1.052	0.037	R_ME3_LV_R
15 to 20	RSC_ME_WR	1.052	0.125	R_ME4_LV_R
>20	RSC_ME_WR	1.052	0.392	R_ME5_LV_R
Meadow Valley Flow System				
<8	NE	1	0.000	NE
8 to 12	RSC_ME_MVW	1.1	0.001	R_ME2_MVW_
12 to 15	RSC_ME_MVW	1.1	0.010	R_ME3_MVW_
15 to 20	RSC_ME_MVW	1.1	0.054	R_ME4_MVW_
>20	RSC_ME_MVW	1.1	0.193	R_ME5_MVW_
Newark Valley Flow System				
<8	NE	1	0.000	NE
8 to 12	RSC_ME_WR * 0.5	1.052	0.003	R_ME2_NE_R
12 to 15	RSC_ME_WR * 0.5	1.052	0.018	R_ME3_NE_R
15 to 20	RSC_ME_WR * 0.5	1.052	0.062	R_ME4_NE_R
>20	RSC_ME_WR * 0.5	1.052	0.196	R_ME5_NE_R
White River Flow System				
<8	NE	1	0.000	NE
8 to 12	RSC_ME_WR	1.052	0.006	R_ME2_WR_R
12 to 15	RSC_ME_WR	1.052	0.037	R_ME3_WR_R
15 to 20	RSC_ME_WR	1.052	0.125	R_ME4_WR_R
>20	RSC_ME_WR	1.052	0.392	R_ME5_WR_R

NE: Not Estimated

Table 6-11
Manually Estimated Recharge Efficiencies for
Recharge Subzone as Fraction of Precipitation

Precipitation Zone (in./yr)	Parameter Name	Estimated Parameter Value (-)	Final Recharge Efficiency (fraction of precipitation)	UCODE-Derived Parameter Name
Great Salt Lake Desert Flow System (Fish Springs)				
<8	NE	NE	0.000	NE
8 to 12	R_ME2_GSLD	1	0.011	R_ME2_GSFS
12 to 15	R_ME3_GSLD	1	0.050	R_ME3_GSFS
15 to 20	R_ME4_GSLD	1	0.120	R_ME4_GSFS
>20	R_ME5_GSLD	1	0.328	R_ME5_GSFS
Great Salt Lake Desert Flow System (Gandy Area Watershed)				
<8	NE	NE	0.000	NE
8 to 12	R_ME2_GSLD * 1.25	1	0.013	R_ME2_GSGY
12 to 15	R_ME3_GSLD * 1.25	1	0.062	R_ME3_GSGY
15 to 20	R_ME4_GSLD * 1.25	1	0.150	R_ME4_GSGY
>20	R_ME5_GSLD * 1.25	1	0.410	R_ME5_GSGY
Great Salt Lake Desert Flow System (Garden Valley)				
<8	NE	NE	0.000	NE
8 to 12	R_ME2_WR_R	1.052	0.006	R_ME2_GSGD
12 to 15	R_ME3_WR_R	1.052	0.037	R_ME3_GSGD
15 to 20	R_ME4_WR_R	1.052	0.125	R_ME4_GSGD
>20	R_ME5_WR_R	1.052	0.392	R_ME5_GSGD
Great Salt Lake Desert Flow System (Hamlin Valley - North)				
<8	NE	NE	0.000	NE
8 to 12	R_ME2_GSLD * 0.50	1	0.005	R_ME2_GSHM
12 to 15	R_ME3_GSLD * 0.50	1	0.025	R_ME3_GSHM
15 to 20	R_ME4_GSLD * 0.50	1	0.060	R_ME4_GSHM
>20	R_ME5_GSLD * 0.50	1	0.164	R_ME5_GSHM
Meadow Valley Flow System (Hamlin Valley - South)				
<8	NE	NE	0.000	NE
8 to 12	R_ME2_MVW_ * 0.50	1.1	0.0003	R_ME2_MVHM
12 to 15	R_ME3_MVW_ * 0.50	1.1	0.004	R_ME3_MVHM
15 to 20	R_ME4_MVW_ * 0.50	1.1	0.025	R_ME4_MVHM
>20	R_ME5_MVW_ * 0.50	1.1	0.088	R_ME5_MVHM
White River Flow System (Dry Lake)				
<8	NE	NE	0.000	NE
8 to 12	R_ME2_WR_R	1.052	0.006	R_ME2_WRDL
12 to 15	R_ME3_WR_R	1.052	0.037	R_ME3_WRDL
15 to 20	R_ME4_WR_R	1.052	0.125	R_ME4_WRDL
>20	R_ME5_WR_R	1.052	0.392	R_ME5_WRDL

NE: Not Estimated

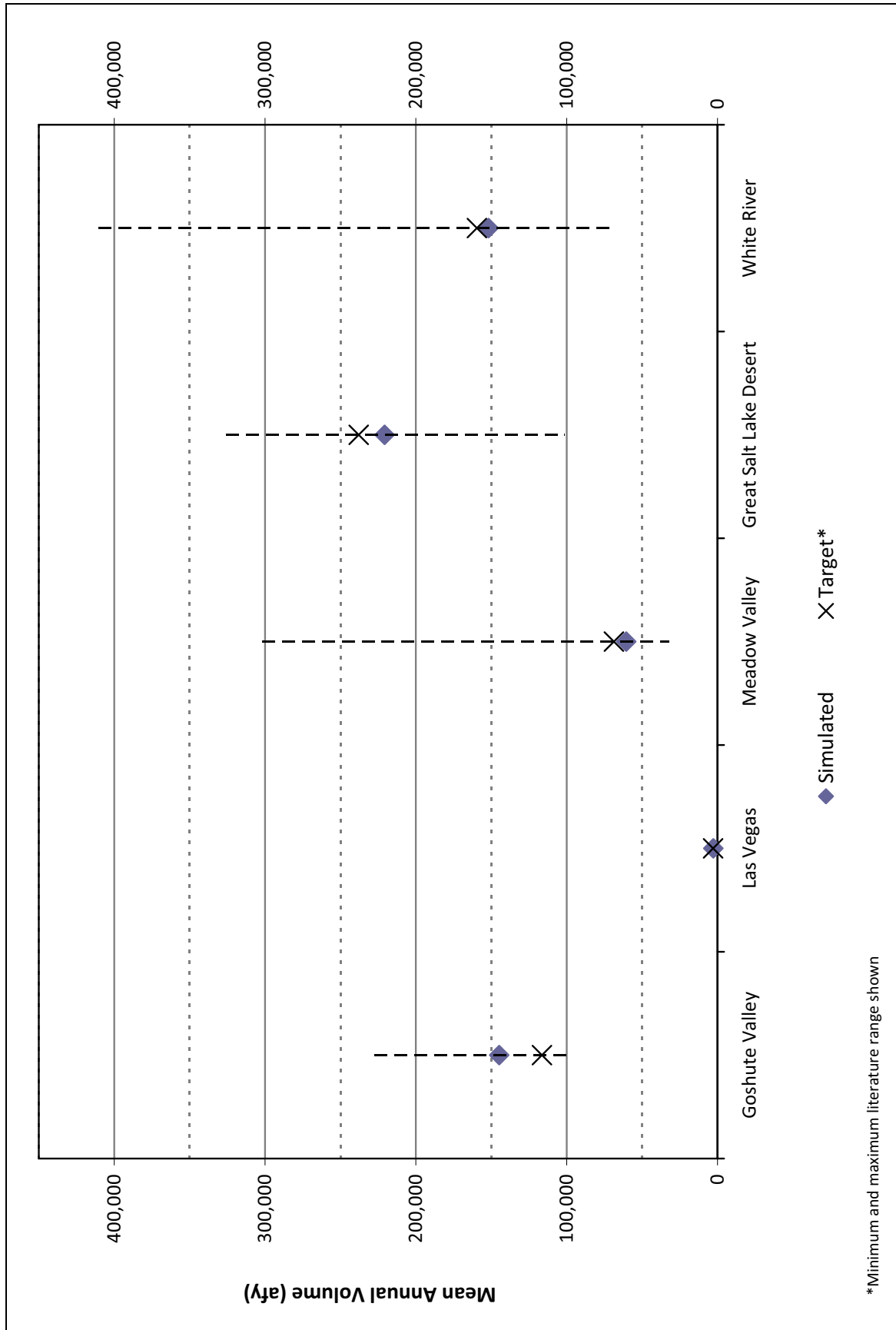


Figure 6-54
Simulated Recharge, Target Recharge, and Range of Recharge from Literature Sources for Flow Systems

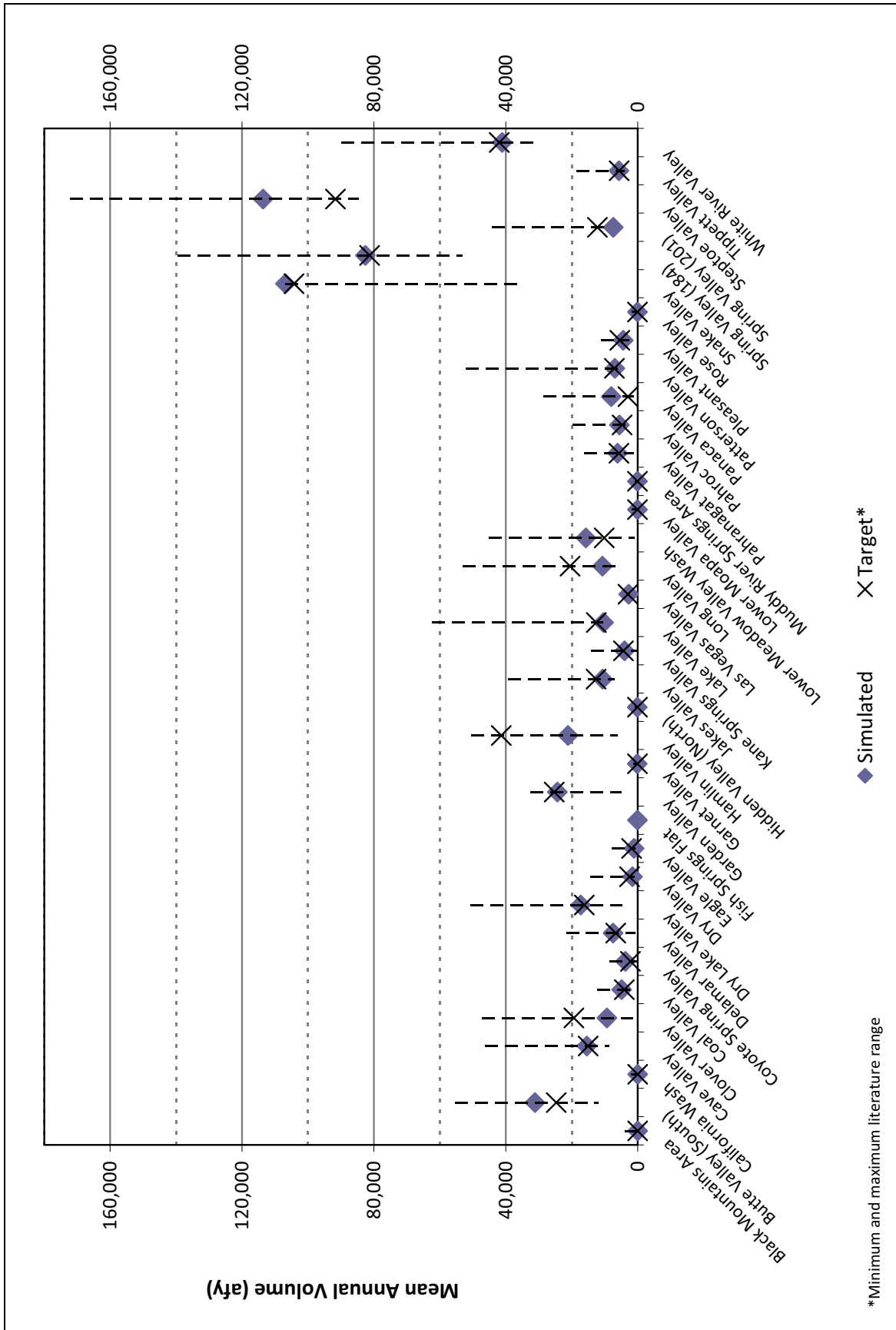


Figure 6-55 Simulated Recharge, Target Recharge, and Range of Recharge from Literature Sources for Hydrographic Areas

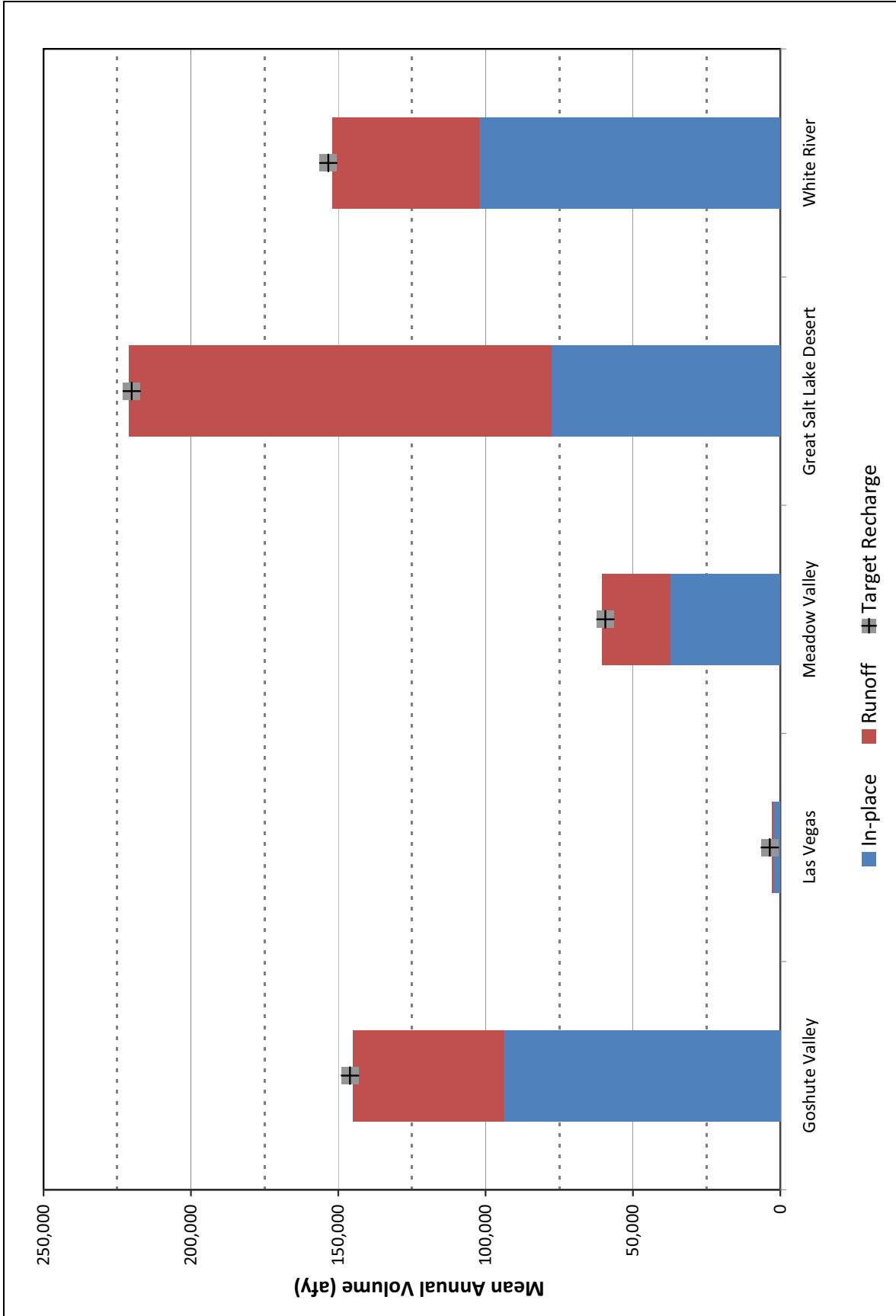


Figure 6-56
Simulated In-Place and Runoff Recharge Components and Target for Flow Systems

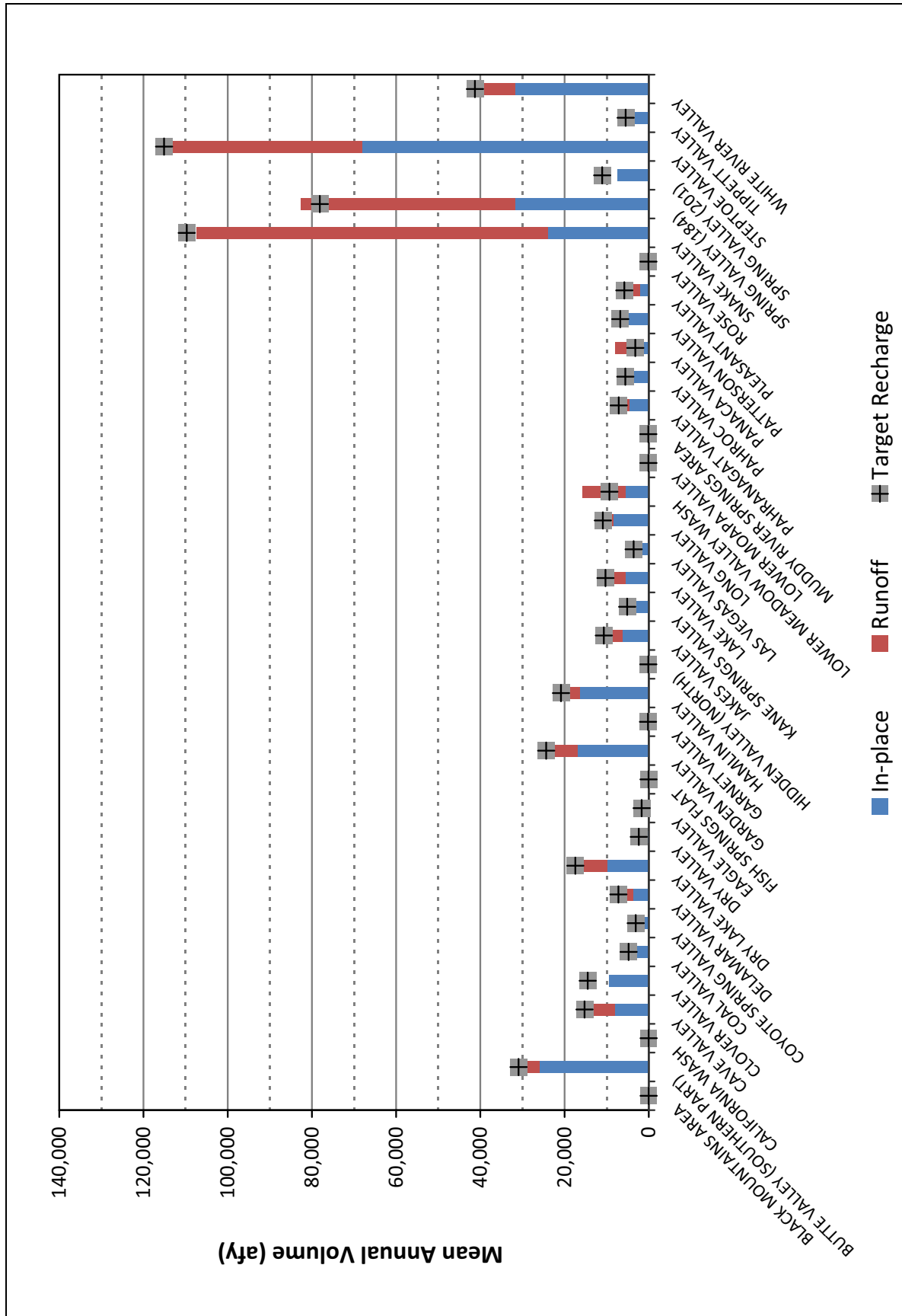


Figure 6-57
 Simulated In-Place and Runoff Recharge Components and Target for Hydrographic Areas

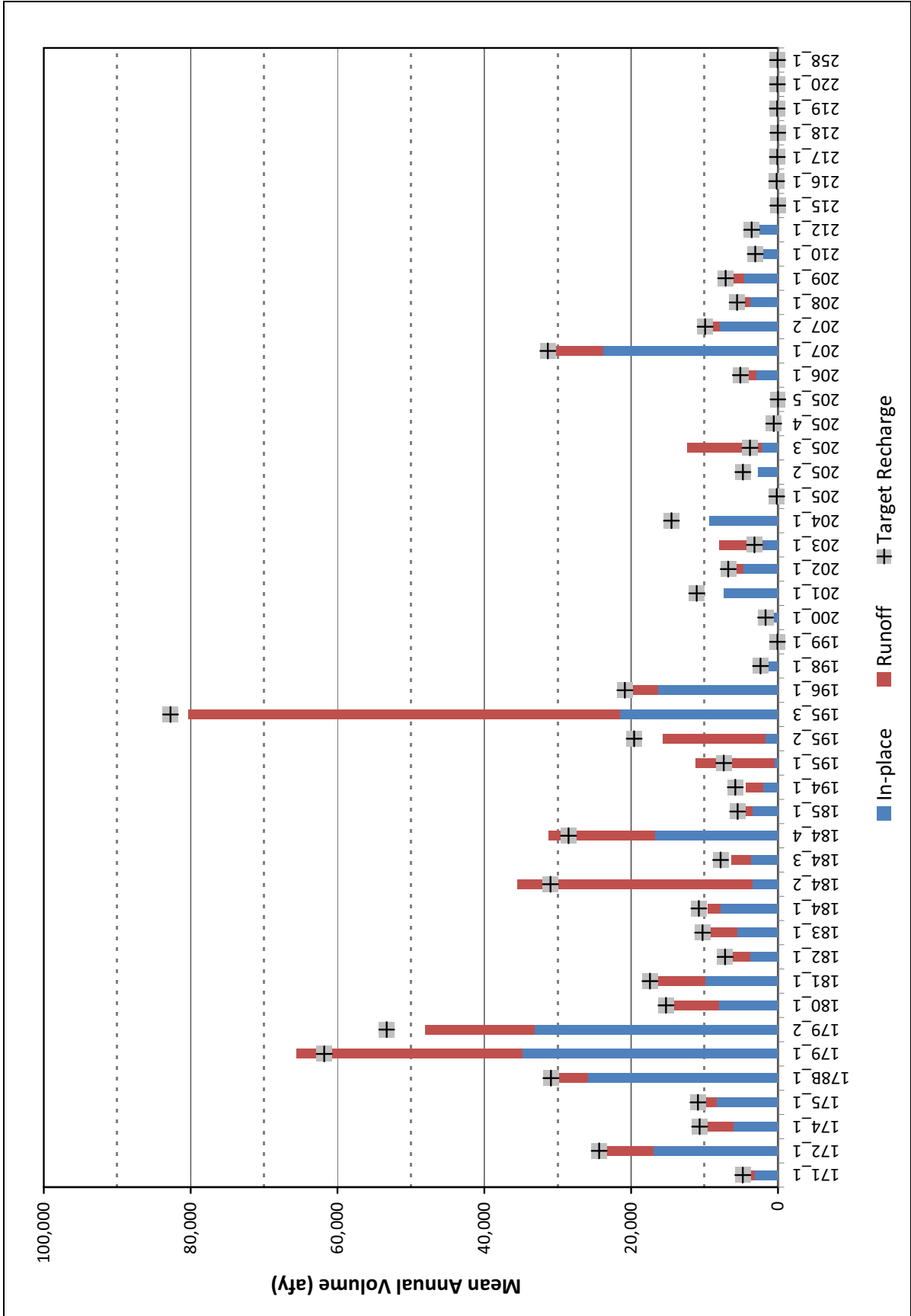


Figure 6-58
Simulated In-Place and Runoff Recharge Components and Target for Sub-Basins

percentage of runoff in the GSLDFS. This is consistent with the less permeable rock types (PLUT and BASE) associated with the Snake and Deep Creek ranges.

6.4 Evaluation of Simulated Flow Systems

The flow systems simulated in the numerical model, including interbasin flow, flow regions, and groundwater budget, are discussed in this subsection. The discussion contains many details that are solely based on model interpretation. Modeling results are not unique and may not be representative of reality in many portions of the model domain because of sparse or nonexistent data.

6.4.1 Simulated Interbasin Flow

Simulated interbasin flow between basins (hydrographic areas) for predevelopment and 2004 conditions are presented in [Tables 6-12](#) and [6-13](#), respectively. The net groundwater flows between flow-system boundaries for predevelopment and 2004 conditions are presented in [Table 6-14](#). Interbasin flow between two given basins represents the net groundwater flow between the two basins. Totals of interbasin flows simply demonstrate the balance of the inflow and outflow components into a given flow system.

The interbasin flow rates simulated by the numerical model ([Table 6-14](#)) are shown on [Plates 2](#) and [3](#). These two plates also illustrate simulated potentiometric surfaces and simulated groundwater flow regions for the shallow (water table) ([Plate 2](#)) and regional (carbonate) ([Plate 3](#)) portions of the flow system. The shallow portion of the flow system represents the water table, and the deep portion represents the potentiometric surface of the LC3 RMU. The hydraulic heads simulated in the LC3 RMU were selected to represent the regional carbonate aquifer because the LC3 RMU is the most areally-extensive carbonate unit.

As shown on [Plates 2](#) and [3](#), simulated flow regions differ slightly from the flow-system boundaries adopted in the simplified conceptual model but are within the uncertainty envelope of the conceptual model (SNWA, 2009a). [Plates 2](#) and [3](#) show that the simulated flow regions differ between the shallow and deep (regional) portions of the flow system. For example, the southeast boundary of Steptoe Valley and southern end of South Goshute Valley show shallow flow regions generally coincident with hydrographic-area boundaries, while the deep flow region extends toward central Steptoe and central South Butte valleys.

Interbasin flows, illustrated on [Plates 2](#) and [3](#), are calculated for the entire saturated thickness of the numerical model. Therefore, interpretation of the interbasin flows should consider shallow and deep flow-region information and shallow and deep potentiometric surfaces to understand where flows occur across boundaries (i.e., vertically and laterally). [Section 6.4.2](#) provides additional discussion of regional flows simulated by the numerical model.

6.4.2 Simulated Flow Regions

This section describes the characteristics of the flow systems as simulated by the numerical model (see [Plates 2](#) and [3](#)) and compares them to flow systems defined by previous studies. As similarly

Table 6-12
Net Groundwater Flow Between Hydrographic Areas (Steady-State)
 (Page 1 of 2)

From Hydrographic Area	Interbasin Flow afy (m ³ /d)	To Hydrographic Area
Butte Valley (South)	3,300 (11,300)	Jakes Valley
	5,600 (18,900)	Long Valley
	12,800 (43,200)	Steptoe Valley
Steptoe Valley	500 (1,800)	Tippett Valley
	2,600 (8,800)	Cave Valley
	3,600 (12,200)	Jakes Valley
	4,400 (14,900)	Lake Valley
	8,800 (29,900)	Spring Valley
	15,500 (52,500)	White River Valley
Las Vegas Valley	700 (2,300)	Coyote Spring Valley
	1,000 (3,200)	Garnet Valley
Clover Valley	2,000 (6,900)	Panaca Valley
	5,400 (18,200)	Lower Meadow Valley Wash
Dry Valley	1,900 (6,500)	Panaca Valley
Eagle Valley	0 (100)	Dry Valley
	4,600 (15,400)	Rose Valley
Lake Valley	1,900 (6,400)	Cave Valley
	3,000 (10,000)	Dry Lake Valley
	3,700 (12,500)	Spring Valley
	4,500 (15,100)	Patterson Valley
Lower Meadow Valley Wash	13,600 (45,800)	Lower Moapa Valley
Panaca Valley	800 (2,700)	Lower Meadow Valley Wash
Patterson Valley	200 (500)	Eagle Valley
	800 (2,700)	Dry Valley
	1,600 (5,400)	Dry Lake Valley
	9,500 (32,000)	Panaca Valley
Rose Valley	4,300 (14,500)	Dry Valley
Spring Valley	700 (2,300)	Patterson Valley
	800 (2,700)	Lake Valley
	1,500 (5,000)	Hamlin Valley
	3,700 (12,500)	Eagle Valley
Fish Springs Flat	2,300 (7,600)	Snake Valley
Hamlin Valley	0 (0)	Dry Valley
	100 (200)	Eagle Valley
	29,400 (99,300)	Snake Valley
Pleasant Valley	0 (0)	Spring Valley
	4,400 (14,800)	Snake Valley

Table 6-12
Net Groundwater Flow Between Hydrographic Areas (Steady-State)
 (Page 2 of 2)

From Hydrographic Area	Interbasin Flow afy (m ³ /d)	To Hydrographic Area
Spring Valley	7,600 (25,700)	Hamlin Valley
	11,800 (40,000)	Snake Valley
Tippett Valley	0 (0)	Pleasant Valley
	2,000 (6,900)	Spring Valley
California Wash	700 (2,300)	Black Mountains Area
	1,600 (5,500)	Lower Meadow Valley Wash
	4,100 (13,900)	Lower Moapa Valley
Cave Valley	1,300 (4,300)	Dry Lake Valley
	1,600 (5,300)	Pahroc Valley
	17,100 (57,700)	White River Valley
Coal Valley	10,800 (36,400)	Pahroc Valley
	29,200 (98,600)	Pahranagat Valley
Coyote Spring Valley	2,400 (8,000)	Hidden Valley (North)
	49,200 (166,200)	Muddy River Springs Area
Delamar Valley	0 (100)	Lower Meadow Valley Wash
	27,300 (92,300)	Pahranagat Valley
	2,400 (8,114)	Coyote Spring Valley
Dry Lake Valley	100 (400)	Panaca Valley
	300 (1,200)	Lower Meadow Valley Wash
	900 (3,000)	Pahroc Valley
	21,800 (73,500)	Delamar Valley
Garden Valley	25,300 (85,300)	Coal Valley
Garnet Valley	3,400 (11,300)	California Wash
Hidden Valley (North)	3,000 (10,000)	Garnet Valley
Jakes Valley	19,600 (66,200)	White River Valley
Kane Springs Valley	200 (800)	Delamar Valley
	1,800 (6,000)	Coyote Spring Valley
	2,000 (6,800)	Lower Meadow Valley Wash
Long Valley	2,000 (6,700)	Jakes Valley
Lower Moapa Valley	9,300 (31,400)	Black Mountains Area
Muddy River Springs Area	2,500 (8,600)	Lower Meadow Valley Wash
	8,600 (29,200)	California Wash
Pahranagat Valley	41,700 (140,700)	Coyote Spring Valley
Pahroc Valley	25,700 (86,900)	Pahranagat Valley
White River Valley	3,200 (10,700)	Garden Valley
	7,300 (24,500)	Pahroc Valley
	9,800 (33,200)	Coal Valley

Table 6-13
Net Groundwater Flow Between Hydrographic Areas (2004)
 (Page 1 of 2)

From Hydrographic Area	Interbasin Flow afy (m ³ /d)	To Hydrographic Area
Butte Valley (South)	3,300 (11,300)	Jakes Valley
	5,600 (18,900)	Long Valley
	12,800 (43,400)	Steptoe Valley
Steptoe Valley	500 (1,700)	Tippett Valley
	2,600 (8,800)	Cave Valley
	3,600 (12,200)	Jakes Valley
	4,400 (14,900)	Lake Valley
	8,800 (29,600)	Spring Valley
	15,500 (52,300)	White River Valley
Las Vegas	700 (2,300)	Coyote Spring Valley
	1,100 (3,600)	Garnet Valley
	1,100 (3,700)	Black Mountains Area
Clover Valley	2,100 (7,100)	Panaca Valley
	5,500 (18,700)	Lower Meadow Valley Wash
Dry Valley	1,900 (6,400)	Panaca Valley
Eagle Valley	0 (100)	Dry Valley
	4,800 (16,200)	Rose Valley
Lake Valley	1,700 (5,900)	Patterson Valley
	1,900 (6,300)	Cave Valley
	2,900 (9,700)	Dry Lake Valley
	3,700 (12,300)	Spring Valley
Lower Meadow Valley Wash	13,100 (44,100)	Lower Moapa Valley
Panaca Valley	900 (3,100)	Lower Meadow Valley Wash
Patterson Valley	200 (500)	Eagle Valley
	800 (2,900)	Dry Valley
	1,600 (5,300)	Dry Lake Valley
	9,400 (31,900)	Panaca Valley
Rose Valley	4,500 (15,200)	Dry Valley
Spring Valley	700 (2,300)	Patterson Valley
	800 (2,700)	Lake Valley
	1,500 (5,000)	Hamlin Valley
	3,800 (12,800)	Eagle Valley
Fish Springs Flat	2,300 (7,600)	Snake Valley
Hamlin Valley	0 (0)	Dry Valley
	100 (300)	Eagle Valley
	30,100 (101,600)	Snake Valley
Pleasant Valley	0 (0)	Spring Valley
	4,400 (14,800)	Snake Valley

Table 6-13
Net Groundwater Flow Between Hydrographic Areas (2004)
 (Page 2 of 2)

From Hydrographic Area	Interbasin Flow afy (m ³ /d)	To Hydrographic Area
Spring Valley	7,600 (25,600)	Hamlin Valley
	11,800 (40,000)	Snake Valley
Tippett Valley	0 (0)	Pleasant Valley
	2,100 (6,900)	Spring Valley
California Wash	800 (2,600)	Black Mountains Area
	1,900 (6,300)	Lower Meadow Valley Wash
	4,100 (13,800)	Lower Moapa Valley
Cave Valley	1,300 (4,400)	Dry Lake Valley
	1,600 (5,300)	Pahroc Valley
	17,100 (57,700)	White River Valley
Coal Valley	10,900 (36,800)	Pahroc Valley
	29,400 (99,300)	Pahranagat Valley
Coyote Spring Valley	2,400 (8,000)	Hidden Valley (North)
	50,000 (168,900)	Muddy River Springs Area
Delamar Valley	0 (100)	Lower Meadow Valley Wash
	27,300 (92,400)	Pahranagat Valley
	2,400 (8,114)	Coyote Spring Valley
Dry Lake Valley	200 (600)	Panaca Valley
	300 (1,200)	Lower Meadow Valley Wash
	900 (3,100)	Pahroc Valley
	21,800 (73,500)	Delamar Valley
Garden Valley	25,300 (85,400)	Coal Valley
Garnet Valley	3,300 (11,300)	California Wash
Hidden Valley (North)	3,100 (10,500)	Garnet Valley
Jakes Valley	19,700 (66,400)	White River Valley
Kane Springs Valley	200 (800)	Delamar Valley
	1,800 (6,100)	Coyote Spring Valley
	2,000 (6,800)	Lower Meadow Valley Wash
Long Valley	2,000 (6,700)	Jakes Valley
Lower Moapa Valley	9,300 (31,400)	Black Mountains Area
Muddy River Springs Area	2,100 (7,200)	Lower Meadow Valley Wash
	8,300 (27,900)	California Wash
Pahranagat Valley	41,700 (140,700)	Coyote Spring Valley
Pahroc Valley	26,000 (87,700)	Pahranagat Valley
White River Valley	3,200 (10,700)	Garden Valley
	7,300 (24,500)	Pahroc Valley
	9,800 (33,200)	Coal Valley

**Table 6-14
Net Groundwater Flow Between Flow Systems**

From Flow System	Net Groundwater Flow (Predevelopment) afy (m³/d)	Net Groundwater Flow (2004) afy (m³/d)	To Flow System	Comment
Goshute Valley	4,400 (14,900)	4,400 (14,900)	Meadow Valley	Step toe Valley to Lake Valley
	9,400 (31,600)	9,300 (31,300)	Great Salt Lake Desert	Step toe Valley to Spring Valley (HA 184); Step toe Valley to Tippet Valley
	30,700 (103,700)	30,600 (103,500)	White River	Butte Valley to Jakes Valley; Step toe Valley to Jakes Valley; Step toe Valley to White River Valley; Step toe Valley to Cave Valley
Las Vegas Valley	2,800 (9,300)	3,300 (11,100)	White River	Las Vegas Valley to Coyote Springs Valley, Hidden Valley (North), Garnet Valley, and Black Mountains Area
Meadow Valley Wash	5,200 (17,600)	5,200 (17,400)	Great Salt Lake Desert	Lake Valley to Spring Valley (HA 184); Spring Valley (HA 201) to Hamlin Valley
	13,700 (46,100)	13,100 (44,200)	White River	Meadow Valley Wash to Lower Moapa Valley, and Muddy River Springs Area; Patterson Valley to Dry Lake Valley; Lake Valley to Dry Lake Valley; Lake Valley to Cave Valley

stated by Prudic et al. (1995), it is important to recognize that even though the simulated directions and amounts of groundwater flow are provided in detail in [Plates 2 and 3](#), they constitute but one solution to groundwater flow within the model domain. Because data are scarce in the model area, groundwater flow patterns and, therefore, flow-system boundaries, are uncertain. In fact, several interpretations exist as described by SNWA (2009a). The conceptualization resulting from the CCRP model is discussed for the following flow systems: Great Salt Lake Desert, Goshute Valley and Newark Valley, Meadow Valley, White River, and Las Vegas.

6.4.2.1 Great Salt Lake Desert Flow System

The GSLDFS is simulated to predominantly include Tippet, Pleasant, Spring, Snake, a portion of Lake, and Hamlin valleys hydrographic areas. The characteristics of the simulated GSLDFS shown in [Plates 2 and 3](#) are as follows:

- Simulated groundwater recharge is derived from precipitation dominantly on the Schell Creek, Snake, and Deep Creek ranges with lesser amounts derived on the White Rock Mountains and Indian Peak Range above Hamlin Valley.
- Simulated groundwater discharge to the surface occurs both in the form of ET and spring flow throughout the flow system. Simulated groundwater ET occurs in Spring and Snake valleys and to a lesser degree in Tippet and Hamlin valleys.

- Simulated outflow occurs at northern Tippet Valley, at northern Snake Valley, out of Snake Valley at the southern Confusion Range, out of Snake Valley to Wah Wah Valley, and out of Snake Valley to Pine Valley.

The simulated flow patterns and flow-system boundaries are very similar to those described in BARCASS (Welch et al., 2008) and in the RASA model (Prudic et al., 1995) but are somewhat different from the interpretations of Harrill et al. (1988) and Eakin (1966).

6.4.2.2 Goshute Valley and Newark Valley Flow Systems

The GVFS is simulated to predominantly include the northern part of South Butte Valley and most of Steptoe Valley. The Newark Valley Flow System is simulated to predominantly include the southern part of South Butte Valley, Long Valley, and northern Jakes Valley. The characteristics of the simulated GVFS and Newark Valley Flow System shown in [Plates 2 and 3](#) are as follows:

- Much of the groundwater recharge in these flow systems is derived from precipitation predominantly on the Cherry Creek, northern Egan, and White Pine ranges and the Butte Mountains.
- Simulated groundwater discharge in the GVFS occurs both in the form of ET and spring flow. Simulated ET occurs along the valley bottom throughout Steptoe Valley and northern Butte Valley South. Simulated groundwater discharge in the Newark Valley Flow System occurs predominantly in the form of ET in southern Butte Valley South and Long Valley.
- Simulated outflow from the GVFS occurs at northern South Butte Valley and at northern Steptoe Valley. Simulated outflow from the Newark Valley Flow System occurs at northern Long Valley and at southwestern Long Valley.
- The simulated flow patterns and flow-system boundaries are somewhat different from those described by Harrill and Prudic (1998). They are, however, similar to those described by Bedinger and Harrill (2004) and Welch et al. (2008). Similarities also exist with the CRP model (Prudic et al., 1995) in the northwestern part of the CCRP model domain.

6.4.2.3 Meadow Valley Flow System

The MVFS is located in the southeastern part of the CCRP model domain. The simulated MVFS includes a small part of southern Lake Valley and all or most of Dry, Rose, Eagle, Spring (HA 201), Patterson, Panaca, Clover, and Lower Moapa valleys, and Lower Meadow Valley Wash. Only the southernmost portion of Lake Valley is simulated as part of the MVFS. The general characteristics of the simulated MVFS shown in [Plates 2 and 3](#) are as follows:

- Much of the groundwater recharge is derived from precipitation on the White Rock Mountains, the Wilson Creek Range, and the Clover Mountains.

- Simulated groundwater discharge occurs both as ET and spring flow along Meadow Valley Wash.
- Groundwater flowpaths are predominantly toward and along Meadow Valley Wash. Groundwater outflow is to Lower Moapa Valley and the Muddy River Springs Area.
- Simulated groundwater flow patterns are very similar to those described by Bedinger and Harrill (2004) and those simulated by Prudic et al. (1995) in the CRP model.

6.4.2.4 White River Flow System

The WRFS is located in the western part of the CCRP model domain. The simulated WRFS predominantly includes Jakes, White River, Cave, Garden, Coal, Pahroc, Dry Lake, Pahranaagat, Delamar, Kane Springs, Coyote Spring, Hidden (North), and Garnet valleys and Muddy River Springs Area, California Wash, parts of South Butte Valley, Steptoe Valley, Lower Moapa Valley, and the Black Mountains Area. The general characteristics of the simulated WRFS shown in [Plates 2 and 3](#) are as follows:

- Groundwater recharge is derived from precipitation predominantly on the White Pine, Egan, Schell Creek, Quinn Canyon, Seaman, Bristol and Sheep ranges with lesser amounts derived from the Delamar Mountains and Hiko, Pahranaagat, and Pahroc ranges.
- Simulated groundwater discharge to the surface occurs both by ET and spring flow throughout the flow system. The largest areas of simulated ET occur along the valley bottom in White River Valley and along Pahranaagat Wash in Pahranaagat Valley.
- Flowpaths from the WRFS ultimately converge with groundwater flow from the MVFS at Muddy River that is either discharged to the river or evapotranspired into Lower Moapa Valley. Outflow is from the Muddy River Springs Area to Lower Moapa, the Black Mountains Area to Lake Mead, from Garden Valley to Penoyer Valley, and from Pahranaagat Valley to Tikaboo Valley South.
- Flow patterns in the northern part of the WRFS are comparable to interpretations in BARCASS (Welch et al., 2008). As simulated, shallow flowpaths in Lake Valley contribute flow to the WRFS, and deep flowpaths in Lake Valley contribute flow to the GSLDFS.

6.4.2.5 Las Vegas Groundwater Basin

The extreme southern end of the CCRP model domain contains an area of simulated flow that originates predominantly as recharge on the Sheep Range. This groundwater flows east to southeast along the model boundary at the Las Vegas Valley Shear Zone and ultimately discharges to Las Vegas Valley or as spring flow at Rogers and Blue Point springs or as outflow to Lake Mead through the Black Mountains Area.

6.4.3 Simulated Groundwater-Budget Components

The large areal extent of the numerical model and the large uncertainties associated with external boundary conditions preclude a comprehensive and accurate assessment of all groundwater inflows and outflows. As a result, comparing the simulated volumetric budget to conceptual groundwater-budget estimates is difficult. Thus, when evaluating the groundwater budget, it is important to note that significant uncertainties still exist with regard to the groundwater-budget components of the flow system, including external boundary flows, groundwater discharge, and indirectly, groundwater recharge. A discussion of the simulated groundwater budget, however, is warranted.

Tables 6-15 and 6-16 list the simulated groundwater budget for the model area for the steady-state and 2004 stress periods. The budgets are organized by hydrographic area and flow system. A grand total for the model domain is also provided. Groundwater-inflow components are positive values; groundwater-outflow components are negative values.

As shown in Table 6-15, totals of interbasin-flow components are provided only to demonstrate the balance of in and out components.

As shown in Table 6-15, Constant Head is the net groundwater flow through external boundaries in each hydrographic area and flow system. ET and Springs is the discharge from ET zones and springs in each hydrographic area and flow system. Recharge is the total recharge (sum of in-place and runoff recharge components) in each hydrographic area and flow system. Stream Flow is the net groundwater flow from stream flow routing cells in each hydrographic area and flow system.

6.5 Summary of Model Calibration Evaluation

The results presented in this section suggest that the numerical model reproduces the measured hydraulic heads and estimated groundwater-budget components reasonably accurately but with noted levels of uncertainty. In addition, the estimated parameter values are reasonable. The K distribution patterns are generally consistent with the conceptual model. The transmissivities across the model area, while high in some locations, are reasonable.

Because the weighted residuals are not entirely random, some model error is indicated. This is mostly related to the occurrence of large positive-weighted residuals for some hydraulic-head observations located predominantly in large hydraulic-gradient areas and large weighted residuals for intermediate spring discharge and groundwater discharges in areas such as Pahranaagat Valley. These errors are largely the result of sparse data and the way in which these areas relate to the regional flow system.

In addition, weighted residuals are not normally distributed. Previous groundwater modeling exercises in other parts of the southern Great Basin (D'Agnese et al., 1997, 2002; Faunt et al., 2004) suggest that additional calibration and reduction in conceptual model uncertainty may significantly improve model accuracy. This analysis suggests that the numerical model is a reasonable representation of the physical system, but evidence of model error exists.

**Table 6-15
Simulated Groundwater-Budget Components Organized by Hydrographic Area**

HA Number and Name	Net Interbasin Flow	Change in Storage	Groundwater Withdrawals	Constant Head	ET and Springs	Recharge	Stream Flow
	afy						
178B Butte Valley (South)	-21,700	0	0	-500	-8,900	31,100	0
179 Steptoe Valley	-22,800	0	0	-2,100	-88,700	113,600	0
Goshute Valley Total	-44,500	0	0	-2,600	-97,600	144,700	0
212 Las Vegas Valley	-2,800	0	0	0	0	2,800	0
Las Vegas Valley Total	-2,800	0	0	0	0	2,800	0
183 Lake Valley	-7,900	0	---	0	-2,400	10,400	0
198 Dry Valley	3,200	0	---	0	-4,800	1,600	0
199 Rose Valley	300	0	---	0	-400	100	0
200 Eagle Valley	-700	0	---	0	-400	1,100	0
201 Spring Valley	-6,700	0	---	0	-700	7,400	0
202 Patterson Valley	-6,900	0	---	0	0	6,900	0
203 Panaca Valley	12,800	0	---	0	-20,800	8,000	0
204 Clover Valley	-7,400	0	---	0	-1,900	9,400	0
205 Lower Meadow Valley Wash	-1,100	0	---	0	-14,600	15,700	0
Meadow Valley Total	-14,400	0	0	0	-46,000	60,600	0
184 Spring Valley	-4,900	0	0	0	-77,700	82,600	0
185 Tippett Valley	-1,500	0	0	-4,200	0	5,700	0
194 Pleasant Valley	-4,400	0	0	0	0	4,400	0
195 Snake Valley	47,900	0	0	-31,900	-122,600	106,900	-200
196 Hamlin Valley	-20,300	0	0	0	-800	21,100	0
258 Fish Springs Flat	-2,300	0	0	2,200	0	100	0
Great Salt Lake Desert Total	14,500	0	0	-33,900	-201,100	220,800	-200
171 Coal Valley	-4,900	0	0	0	0	4,900	0
172 Garden Valley	-22,100	0	0	-2,300	0	24,300	0
174 Jakes Valley	-10,700	0	0	0	0	10,700	0
175 Long Valley	3,600	0	0	-13,500	-800	10,700	0
180 Cave Valley	-15,400	0	0	0	0	15,400	0
181 Dry Lake Valley	-17,300	0	0	0	0	17,300	0
182 Delamar Valley	-7,500	0	0	0	0	7,500	0
206 Kane Springs Valley	-4,000	0	0	0	0	4,000	0
207 White River Valley	32,000	0	0	0	-73,100	41,100	0
208 Pahroc Valley	-5,500	0	0	0	0	5,500	0
209 Pahrnagat Valley	40,600	0	0	-9,500	-23,000	6,100	-14,200
210 Coyote Spring Valley	-5,700	0	0	2,000	0	3,700	0
215 Black Mountains Area	11,600	0	0	-7,500	-2,100	0	-2,000
216 Garnet Valley	-200	0	0	0	0	200	0
217 Hidden Valley (North)	-200	0	0	0	0	200	0
218 California Wash	6,400	0	0	0	-7,500	0	1,200
219 Muddy River Springs Area	38,000	0	0	0	-4,200	100	-33,900
220 Lower Moapa Valley	8,400	0	0	-6,700	-21,300	100	19,500
White River Total	47,100	0	0	-37,500	-132,000	151,800	-29,400
Grand Total	-100	0	0	-74,000	-476,700	580,700	-29,600

Table 6-16
Simulated Groundwater-Budget Components Organized by Hydrographic Area (2004)

HA Number and Name	Net Interbasin Flow	Change in Storage	Groundwater Withdrawals	Constant Head	ET and Springs	Recharge	Stream Flow
	afy						
178B Butte Valley (South)	-21,800	0	-200	-500	-8,800	31,100	0
179 Steptoe Valley	-22,600	2,500	-11,900	-2,100	-79,600	113,600	0
Goshute Valley Total	-44,400	2,500	-12,100	-2,600	-88,400	144,700	0
212 Las Vegas Valley	-3,300	500	0	0	0	2,800	0
Las Vegas Valley Total	-3,300	500	0	0	0	2,800	0
183 Lake Valley	-5,000	10,600	-13,600	0	-2,400	10,400	0
198 Dry Valley	3,500	300	-3,500	0	-1,900	1,600	0
199 Rose Valley	300	100	-400	0	-100	100	0
200 Eagle Valley	-800	100	-100	0	-200	1,100	0
201 Spring Valley	-6,800	100	0	0	-700	7,400	0
202 Patterson Valley	-9,700	6,000	-3,300	0	0	6,900	0
203 Panaca Valley	12,700	4,900	-9,300	0	-16,400	8,000	0
204 Clover Valley	-7,600	300	-200	0	-1,800	9,400	0
205 Lower Meadow Valley Wash	-500	800	-3,100	0	-13,000	15,700	0
Meadow Valley Total	-13,900	23,200	-33,500	0	-36,500	60,600	0
184 Spring Valley	-4,900	2,000	-5,600	0	-74,100	82,600	0
185 Tippet Valley	-1,600	0	0	-4,200	0	5,700	0
194 Pleasant Valley	-4,400	0	0	0	0	4,400	0
195 Snake Valley	48,600	2,800	-21,600	-31,800	-104,700	106,900	-200
196 Hamlin Valley	-21,000	600	0	0	-700	21,100	0
258 Fish Springs Flat	-2,300	0	0	2,200	0	100	0
Great Salt Lake Desert Total	14,400	5,400	-27,200	-33,800	-179,500	220,800	-200
171 Coal Valley	-5,200	300	0	0	0	4,900	0
172 Garden Valley	-22,100	0	0	-2,200	0	24,300	0
174 Jakes Valley	-10,700	0	0	0	0	10,700	0
175 Long Valley	3,600	0	0	-13,500	-800	10,700	0
180 Cave Valley	-15,500	0	0	0	0	15,400	0
181 Dry Lake Valley	-17,500	100	0	0	0	17,300	0
182 Delamar Valley	-7,500	0	0	0	0	7,500	0
206 Kane Springs Valley	-4,000	0	0	0	0	4,000	0
207 White River Valley	32,000	3,400	-10,900	0	-65,600	41,100	0
208 Pahroc Valley	-5,700	100	0	0	0	5,500	0
209 Pahrnagat Valley	41,100	400	-2,800	-9,500	-21,800	6,100	-13,500
210 Coyote Spring Valley	-6,500	800	0	2,000	0	3,700	0
215 Black Mountains Area	12,100	1,200	-1,700	-7,400	-2,100	0	-2,000
216 Garnet Valley	100	700	-1,000	0	0	200	0
217 Hidden Valley (North)	-300	200	0	0	0	200	0
218 California Wash	5,700	400	0	0	-7,500	0	1,400
219 Muddy River Springs Area	39,600	700	-8,100	0	-2,100	100	-30,200
220 Lower Moapa Valley	7,800	100	-2,700	-6,700	-20,900	100	22,200
White River Total	47,000	8,400	-27,200	-37,300	-120,800	151,800	-22,100
Grand Total	-200	40,000	-100,000	-73,700	-425,200	580,700	-22,300

Some of the simulated flow-system boundaries in the calibrated transient numerical model are similar to those described in BARCASS (Welch et al., 2008) and in the RASA model (Prudic et al., 1995). They do differ, however, from the interpretations of Harrill et al. (1988) and Eakin (1966) adopted in the simplified conceptual model as described in [Sections 3.0](#) and [5.0](#). Because of the lack of regional data in the northwestern region of the model area, particularly in Jakes Valley, and the uncertainty associated with the recharge estimate, different interpretations of flow patterns and, therefore, flow-system boundaries are possible. This area of the model is located a significant distance away from the Project basins, and the locations of these flow-system boundaries should not affect the EIS analysis for which the numerical model is intended. Previous studies like Belcher (2004), for example, have shown that drawdowns are mostly sensitive to the hydraulic properties of the aquifers. The distribution of hydraulic conductivities derived from this model appears to be reasonable.

7.0 MODEL LIMITATIONS AND UNCERTAINTIES

The numerical model contains the most up-to-date representation of hydrogeologic data for the Central Carbonate-Rock Province of the Great Basin region. However, it is still a model covering a vast portion of remote Nevada where data are limited. This lack of data causes limitations and uncertainties in values simulated by the numerical model. These limitations and uncertainties are common for models developed in this region, as the DVRFS model describes many of the same (Belcher, 2004). Uncertainties are unavoidable but can be reduced with additional data collected in the future. Inherent model limitations result from uncertainty in five basic aspects of the model, including inadequacies in (1) the hydrogeologic framework, (2) the precipitation recharge, (3) the historical anthropogenic data, (4) the observations, and (5) the representation of hydrologic conditions. These limitations are disclosed below.

7.1 Hydrogeologic Framework

Accurate simulation of many of the important flow-system characteristics depends on an accurate understanding and representation of the hydrogeologic framework. Limitations exist in the numerical model because of the difficulties inherent in the interpretation and representation of the complex geometry and spatial variability of hydrogeologic materials and structures in a hydrogeologic framework and numerical model. The hydrogeologic framework is further complicated by the lack of data within the model area.

7.1.1 Complex Geometry

Geometric complexity of hydrogeologic materials and structures is apparent throughout the model domain. Notable large-scale examples that have a significant effect on regional groundwater flow are (1) the fault system at the Muddy River Springs Area, (2) the lateral faults of the Pahrnatag Shear Zone, and (3) the calderas of the Caliente Caldera complex.

A system of apparent regional-scale normal and lateral faults likely provides the mechanisms for groundwater discharge at the Muddy River Springs Area. The complexity of this system is not fully known; however, the current understanding suggests that the hydrogeologic framework represented in the model is grossly simplified because of the coarse numerical model resolution.

Regional-scale lateral faults associated with the Pahrnatag shear zone give rise to hydrogeologic features that contribute to a generally southward stair-stepping of the regional water table. The lack of available knowledge on this fault system adds uncertainty to the simulation of directions and quantities of groundwater flow out of Pahrnatag Valley.

East and northeast of the Pahranaagat shear zone, a series of calderas and intracaldera intrusions cause regional discontinuities in the flow system. The complex geometries associated with these calderas are not fully known and cause uncertainties in simulating the regional, large-hydraulic gradient coincident with these volcanic features.

7.1.2 Complex Spatial Variability

As with complex hydrogeologic geometries, spatial variability of material properties of the hydrogeologic units and structures is also a limitation in the CCR P model. The assumption of homogeneity within a given RMU in the hydrogeologic framework model, or hydraulic-conductivity parameter zone in the numerical model, limits the simulation by removing the potential effects of variability in grain-size distribution, degree of welding, and fracture density and orientation. This limitation is the direct result of data limitations and simplifications due to hydrogeologic framework and flow model construction and discretization.

The LVF RMU is a good example of a hydrogeologic unit that has significant spatial variability. This highly heterogeneous unit consists of (1) older Tertiary sediments, which possess varying grain-size distributions and degrees of lithification and (2) Tertiary volcanic rocks, which possess units of varying composition, degrees of welding, and hydrothermal alterations. These heterogeneities, which can affect hydraulic properties and consequently groundwater flow, cannot be represented in the hydrogeologic framework and numerical models. In fact, many of the limitations of the simulation within the Caliente Caldera complex and related calderas are in part due to the underrepresentation of local-scale hydrogeologic complexities in the regional-scale hydrogeologic framework and numerical models.

7.1.3 Hydrogeologic Model Representation

Discretization and abstraction of the physical hydrogeologic framework impose limitations on all components of the hydrogeologic framework and numerical models. While the 3,281 ft (1,000 m) resolution is appropriate to represent regional-scale conditions, it presents difficulty in accurately simulating areas of geologic complexity. The grid cells tend to generalize important local-scale complexities that have an impact on regional hydrologic conditions. This situation is particularly prevalent in large-hydraulic-gradient areas where sharp geologic contacts or local-scale fault characteristics can influence regional hydraulic heads and groundwater discharges. The current level of understanding of the geology throughout the model area does not warrant a higher-resolution regional flow model at this time.

7.2 Precipitation Recharge

Limitations in precipitation recharge stem from the approximate methods used to estimate recharge and the assumption that the effects of climate variability on recharge are negligible.

Groundwater recharge cannot be measured directly in the field for areas as large as the model area. Furthermore, groundwater recharge is spatially and temporally variable. The yearly rates and spatial distribution of the mean recharge were estimated through model calibration. Although a solution was

obtained in this manner, the actual annual rates and particularly the spatial distribution of recharge remain very uncertain. Another source of uncertainty is the assumption that recharge does not vary with time. This assumption constitutes an important limitation, particularly in the simulations of the groundwater development scenarios. Under this assumption, potential variations in recharge due to climate change or the lowering of the water table by pumping, for example, cannot be simulated.

Climate variability over the course of the simulation affects precipitation and therefore groundwater recharge. The numerical model simulates a constant average recharge from precipitation rates averaged over 30 years (PRISM normal precipitation grid) and does not consequently account for climate variability over the simulation period.

7.3 Historical Anthropogenic Data

No historical groundwater-pumping or surface-water diversion records from which historical stress data sets can be derived exist for most of the hydrographic areas in the model area. Therefore, the historical anthropogenic data sets were estimated from the available information. The estimation process has important limitations leading to uncertainties in the data set.

As historical records of actual groundwater use are sparse, the consumptive water-use estimates were derived using estimates of consumptive water use based on water-rights information obtained from NDWR and the Utah Division of Water Rights (UDWR). Reported groundwater-production or surface-water diversion data were used where available to support the estimation process.

In many of the croplands, irrigation with groundwater could not be clearly identified because irrigation water is supplied by both surface water and groundwater. In these areas, groundwater is commonly pumped to supplement surface-water sources used to irrigate crops. This adds another layer of complexity to estimating groundwater use in that supplemental groundwater pumping generally only occurs when conditions warrant it, such as in low runoff years.

7.4 Observations

Hydraulic-head and groundwater-discharge observations constrain model calibration through the parameter-estimation process; therefore, uncertainty in these observations results in uncertainty in the numerical model. All available hydraulic-head-observation data were thoroughly analyzed prior to and throughout the calibration process. However, uncertainty still exists in (1) the quality of the observation data, (2) the appropriateness of the hydrogeologic interpretations, and (3) the way in which the observation was represented in the numerical model.

7.4.1 Quality of Observations

The sparse distribution and high concentration, or clustering, of hydraulic-head observations are numerical model limitations. Because available data in the overall region are scarce and available multiple observations in isolated areas are overemphasized, biasing occurs in those parts of the model. Water-level-data scarcity is particularly noticeable in Long, Jakes, Coal, Garden, Dry Lake, and Delamar valleys and Lower Meadow Valley Wash because of the lack of wells in those valleys.

High clustering of observations occurs along riparian areas of Pahrangat Wash, Meadow Valley Wash, and the Muddy River. A declustering method was used to address this situation; however, this declustering only applies to situations where multiple water levels occur in a given model cell.

7.4.2 Interpretation of Observations

It is difficult to determine whether hydraulic-head observations represent regional versus perched or localized conditions. Field testing is often not sufficient to distinguish conclusively between regional or localized conditions. The data necessary to determine unequivocally the presence of perched or local groundwater are rarely, if ever, available. Because large simulated hydraulic-head residuals in recharge areas often suggest the possibility of perched water, either the hydraulic-head observations in this category were removed or the observation weight was decreased. Fewer observations, or observations with lower weights, result in higher uncertainty in the numerical model.

Large-hydraulic-gradient areas also are difficult to interpret. Limited water-level data in these areas exacerbate the situation. Hydraulic-head observations defining large hydraulic gradients are also typically associated with perched or localized water.

The model also does not account for climate variability over the course of the simulation. Approximately 6 percent of the water-level hydrographs and 16 percent of the hydraulic-head or drawdown observations in the model are clearly influenced by climate variability. The majority of these (85 out of 112 climate-affected wells and 919 out of 1,225 observations) occur in Steptoe Valley. These wells and their associated observations however, only occur in isolated geographic locations within Steptoe Valley and occur within the time period of an extremely wet cycle in the region. The value of, or the ability to, extrapolate this climate variability information to the remainder of the 1,751 wells and 6,322 hydraulic-head and drawdown observations was not practical or considered valuable.

Accurate groundwater-discharge estimates for many of the springs and ET areas are not available and are thus numerical model limitations. Higher quality, spatially distributed, groundwater-discharge observations for the region only began to be collected in 2002 (SNWA, 2008; SNWA 2009a; Welch et al., 2008). The lack of estimates as well as the variability in the estimates, based on long-term data, limits how well these groundwater-discharge areas and related areas can be simulated. In addition, the assumptions necessary to use present-day groundwater discharge to approximate predevelopment groundwater-discharge conditions may introduce error. Reliable historical groundwater-discharge estimates are an unrecoverable data gap in the model that will add uncertainty to any groundwater flow simulation of this region.

7.4.3 Representation of Observations

Although the volumetric discharge from ET is reasonably matched, the model does not accurately simulate the areas where ET occurs. This is due to the limitations associated with the representation of groundwater ET areas in the model, including the course resolution and the setup of the drains.

Simulating small discharge volumes less than 296 afy (less than 1,000 m³/d) was difficult in the CCRP numerical model. For instance, incised drainages and other focused discharge areas are difficult to simulate accurately. This difficulty is particularly noticeable along Meadow Valley Wash and Pahranaagat Wash. In many cases, the hydraulic conductivity of the hydrogeologic units present at the land surface and the geometry of these topographic features control the simulated discharge.

The elevations assigned to define drains in the numerical model also affects the ability to simulate groundwater conditions more accurately. The elevations of drains in ET areas were set to values of land-surface elevation reduced by one of two values of extinction depth depending on location. The values of land-surface elevation were based on a 1:24,000-scale digital elevation model, and the extinction depth values were set to either 16.4 ft (5 m bgs) or 32.8 ft bgs (10 m bgs). This simplified method of representing drain elevations in the numerical model may not accurately approximate the extinction depth for all discharge areas, particularly in areas with highly variable rooting depths and discontinuous areas of capillary fringe. Snake Valley is an example of a discharge area that may have a zone of extensive capillary fringe. In areas of the model where these conditions exist, observed hydraulic heads may be lower than the drain elevations. The consequence of this limitation is that the numerical model has difficulty simulating groundwater discharge within the delineated ET areas.

In summary, in several cases, the distribution of ET is not simulated accurately; however, the total ET from a given ET area matches well. This limitation will cause drawdowns to propagate faster between the basin edge and simulated ET areas until ET is captured. Errors in ET simulation minimally affect drawdown propagation after capture starts because simulated discharge volumes are approximately correct.

7.5 Hydrologic Conditions Representation

The hydrologic conditions that, perhaps, most influence the CCRP numerical model are the representation of external and internal boundary conditions. Limitations in external-boundary-condition definition are the result of both incomplete understanding of natural conditions and associated poor representation of the natural conditions in the numerical model. Because very little data exist in the areas defined as lateral flow-system boundaries, the boundaries are highly uncertain. Also, defining these boundaries in the numerical model is effectively limited to either a no-flow or a constant-head boundary. Both types of boundary definitions impose significant constraints on model results.

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8.0 SUMMARY

A numerical groundwater flow model was developed for the CCRP in Nevada and Utah. A summary of the objectives, approach, model construction and calibration, evaluation of results, and limitations is presented, followed by a statement of the conclusions.

The numerical model described in this document was developed to support the environmental analysis for the Clark, Lincoln, and White Pine Counties Groundwater Development Project. Specifically, the numerical model was used to simulate groundwater development scenarios to evaluate the potential water-related effects of the Project's groundwater production at the regional scale (SNWA, 2009b). As pumping, monitoring, and testing data become available in the future, this numerical model will be improved and used as a management tool.

The modeling approach was consistent with the model-calibration guidelines established by Hill and Tiedeman (2007) and incorporated a nonlinear, regression technique to estimate aquifer parameters. The numerical model was developed using the computer program MODFLOW-2000 and was calibrated using a combination of trial-and-error and automatic parameter-estimation methods. The parameter-estimation code UCODE_2005 was used to implement the automatic parameter-estimation method and assist in the calibration process. The numerical model was constructed based on a conceptual model described mainly in SNWA (2009a). Additional information supporting the conceptual model may be found in the Baseline Report (SNWA, 2008) and in [Appendixes A through C](#) of this report.

The finite-difference numerical model consists of 474 rows, 202 columns, and 11 layers. The grid cells are oriented north-south and are of uniform size, with side dimensions of 3,281 ft (1,000 m). The model grid encompasses about 20,688 mi² (53,581 km²), and the layers vary in thicknesses from 328 ft (100 m) to 6,562 ft (2,000 m) each. The required grid-cell values, including initial parameter values, were supplied by discretization of a 3D hydrogeologic framework model and digital representations of the remaining hydrologic model components. The initial conditions of the aquifer system used in the transient model were obtained through preliminary test simulations conducted to refine the numerical representation of the conceptual model.

During model calibration, techniques available in MODFLOW-2000 and UCODE_2005 allowed for estimation of a series of parameters that provided a best fit to observed hydraulic heads, groundwater discharge, and boundary flows. As part of calibration, numerous conceptual models were evaluated to test the validity of various interpretations about the flow systems. For each hypothesis tested, a new set of parameters was estimated using MODFLOW-2000 and UCODE_2005, and the resulting simulated hydraulic heads and groundwater-discharge rates were compared to observed values. Only those conceptual model changes contributing to a significant improvement in model fit, as indicated by a reduction in the sum of weighted squared errors, were retained in the final calibrated model.

The final calibrated numerical model was evaluated to assess the likely accuracy of its results by comparing simulated values to measured and expected quantities for hydraulic heads, drawdowns, and groundwater discharge. Resulting model fit and calibration accuracy were assessed and reported. An evaluation of the calibrated parameter values was performed to assess their level of reasonableness. The calibrated parameter values were found to be within the range of expected values. In addition, the simulated general regional flow directions were found to be similar to previous interpretations (Prudic et al., 1995; Welch et al., 2008; SNWA, 2009a). Despite important remaining uncertainties due to sparse data and model error, the evaluation process indicates that the numerical model is a reasonable representation of the natural flow system.

The inherent, unavoidable limitations result from uncertainty in five basic aspects of the model:

1. Lack of geologic and hydraulic-property data and limitations on the ability to represent the complex geometry and spatial variability of hydrogeologic materials and structures in the hydrogeologic framework and numerical models.
2. Limitations on the ability to measure and represent precipitation recharge in the numerical model.
3. Lack of an accurate historical record of the anthropogenic stresses imposed on the aquifer system.
4. Lack of observation data and associated difficulties in the interpretation and representation of these in the numerical model.
5. Limitations on the ability to represent hydrologic conditions, particularly external and internal boundary conditions, in the numerical model.

In conclusion, given that (1) the current numerical model contains the most up-to-date representation of hydrogeologic data for this part of the Great Basin, (2) the model was calibrated and evaluated using state-of-the-art methods, (3) the model fit the observations reasonably well, and (4) the estimated aquifer parameters are comparable to the available data, this numerical model is a reasonable representation of the flow system at the regional scale. Therefore, this numerical model achieves the primary objective of the CCRP model, which is to simulate estimates of potential drawdowns from groundwater withdrawals from the Project basins.

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Appendix A

Estimation of Large-Scale Hydraulic Properties

A.1.0 INTRODUCTION

Hydraulic-property estimates have been derived from many types of tests, but only a few of these sometimes yield hydraulic properties of the aquifer system at scales large enough for use in large-scale numerical groundwater flow models. This appendix describes an alternate approach to deriving large-scale hydraulic properties and its application to portions of the model area. These activities were conducted independently by the USGS, in cooperation with SNWA, in support of the CCRP numerical model described in the main report. Preliminary results are included in this appendix. The final results will be made available on a USGS website: <http://nevada.usgs.gov/water/aquifertests/index.htm> (Halford, 2009).

A.1.1 Limitations Associated with Aquifer Tests

The best type of aquifer test to derive transmissivity (T) and hydraulic-conductivity (K) values for the numerical model is the multiple-well, constant-rate aquifer test. Although estimates of T and K can also be derived from single-well tests, aquifer-storage properties can only be estimated from data collected from observation wells in multiple-well, constant-rate aquifer tests. This type of test is considered to be the best but usually has two primary issues, both of which are associated with the limited duration of testing. Such tests are usually conducted for short periods of time for logistical reasons.

The first issue pertains to the scale of the aquifer tests. If testing time is limited, then the aquifer volume tested must be limited too. Therefore, the properties derived from these tests only represent small portions of the aquifer. This presents a problem for the estimates of T , K , and storage coefficients (S), as the derived values may not be representative of the areas located outside the tested area. Regional effects due to long-term pumping cannot be accurately predicted with the use of hydraulic properties derived from the typical pumping tests. To derive hydraulic properties at the appropriate scale, the multiple-well aquifer tests would have to be conducted for larger areas and longer times. It is extremely impractical to conduct aquifer tests at such scales.

The second issue arises for estimates of specific yield, as this property has been observed to vary with time during aquifer testing. Nwankwor et al. (1984) reported a comparative study of S_y determinations for a shallow sand aquifer. The results from the study indicate that the S_y values derived from a pumping test increase with the time of pumping. The S_y values derived from a pumping test at 15, 40, 600, 1,560, 2,690, and 3,870 minutes are 0.02, 0.05, 0.12, 0.20, 0.23, and 0.25, respectively. The S_y of 0.25 at 3,870 minutes closely approaches the S_y of 0.30 derived from the laboratory drainage curve. Nwankwor et al. (1984) concluded that the S_y derived from the short pumping duration based on the type-curve models is not suitable for use in the context of long-term aquifer-yield analysis, but the S_y derived from the pumping test at late times with the volume-balance

method or the S_y derived from the laboratory drainage curve provides a more reasonable estimate of the long-term S_y of the aquifer.

An approach to derive hydraulic properties at large scales from the existing anthropogenic data (stress and response) was applied to the modeled area and is described in the next section.

A.1.2 Approach

The response of wells (water-level changes) that are located in an area where groundwater pumping occurs was analyzed to derive reasonable ranges of T and S , which were used to simulate the regional effects of pumping. In essence, the available stress/response data associated with human activities, such as irrigation with groundwater, constitute large-scale aquifer-test data that can be analyzed to derive T and S values for large portions of the aquifer system. Two solution methods were used and are described in the following sections, including a list of the steps necessary to complete the analysis.

A.1.2.1 Method 1 - Analytical Model

In Method 1, estimates of T and S are derived by applying the Theis equation (Theis, 1935), the principle of superposition, and an optimization method to historical pumping and water-level data.

In this method, the water-level changes caused by one or more pumping wells in a single observation well are simulated and compared to observed water-level changes. Adjustments are made to T and S until an acceptable fit is obtained between the simulated and observed values. Because there are two unknown parameters, T and S , a solution cannot be derived analytically. However, a solution may be derived using the Theis equation as implemented in “Function.xls” and the Excel solver. “Function.xls” (Hunt, 2005) was developed as a tool to facilitate the analysis of groundwater problems. It is a collection of user-defined functions written in Visual Basic grouped into modules for use in Excel spreadsheets. The Theis solution for flow to a well is part of the hydraulics module. The input consists of the locations of the observation and pumping wells, pumping schedules, time-water-level changes for the observation well, and initial values for T and S .

A.1.2.2 Method 2 - Local Numerical Model

Method 2 estimates of T and S are derived by calibration of a local numerical flow model using MODFLOW-96 (Harbaugh and McDonald, 1996) and MODOPTIM (Halford, 2006). In this method, the water-level changes caused by one or more pumping wells in one or more observation wells are simulated and compared to observed water-level changes. In addition to T and S , other parameters may be adjusted during calibration, depending on the flow-system features and processes incorporated in the numerical model.

A.1.2.3 Steps

The steps of the approach are as follows:

1. Compile relevant historical data.
 - Water-level data
 - Water-use data
 - Precipitation data
2. Identify potential sites suitable for analysis.
 - Identify wells with detailed hydrographs located within historically irrigated areas.
 - Identify relatively dry time periods for which sufficient water levels and groundwater-use estimates are available or have available information from which to derive them.
 - Perform preliminary calculations using one or both methods to evaluate site conditions.
 - Eliminate sites that are not suitable for this analysis.
3. Perform final calculations for selected sites and present results.

A.2.0 DATA COMPILATION

The necessary historical data available for the study area were first compiled. Data of interest consist of water-level, water-use, and precipitation data obtained from the following sources:

- USGS National Water Information System (NWIS) for the historical water levels
- BARCASS Reports, NDWR pumpage inventories and water-rights database for historical water-use information
- Western Regional Climate Center (WRCC) for precipitation station data

The water-level data were compiled from the NWIS database (USGS, 2009). These data indicate that most of the available information is for the UVF RMU. The surface extent of the UVF RMU is about 4,993,486 acres, as compared to the total area of the model of 14,085,099 acres, or is about 35 percent of the model area. Data for about 1,245 wells are in the NWIS database (USGS, 2009), of which 985 wells are completed in the UVF RMU. The NDWR water-right database contains 9,325 points of diversion (POD) in the model area, of which 5,378 are associated with the UVF RMU. The basin-fill aquifer is generally shallow and unconfined within the model area.

The NDWR maintains Nevada's water-right database and has also conducted pumping inventories for some of the basins in the study area. The records of historical water rights are available for all basins beginning when significant water use was initiated. The pumping inventories are available for Dry, Rose, Panaca, Pahrnagat, and Garnet valleys and the Black Mountains Area starting in 1989. As

part of BARCASS, Welborn and Moreo (2007) delineated irrigated acreage for basins in the BARCASS area using satellite imagery for the 2000, 2002, and 2005 growing seasons. Welborn and Moreo (2007) supplemented the acreages derived from the satellite imagery with information collected during field reconnaissance visits (water source, irrigation system, and crop type) in 2005. Spatial distributions of the croplands, including the acreage, the irrigation water sources, the irrigation system, and the crop types, were derived for Butte, Cave, Jakes, Long, Tippet, Snake, and White River valleys. The net groundwater volumes affecting water levels were estimated by multiplying the acreages by a low and high estimate of net use rates of 2 and 3 ft/yr. The approximate locations of irrigation pumping were obtained from the NDWR water-right database (NDWR, 2009).

Precipitation data compiled by the National Climatic Data Center were obtained from the WRCC website (DRI, 2009). Historical precipitation data were obtained for the following precipitation stations located in the study area:

- Pioche
- Caliente
- Great Basin National Park
- Callao

A.3.0 SITE SELECTION

This section describes the process of site selection, followed by the data used to select the sites and descriptions of sites eliminated from the process.

A.3.1 Process

Sites that qualify for the analysis approach described in this appendix must meet the following criteria: (1) the observation well must exhibit a continuously declining water-level trend that correlates with groundwater pumping for irrigation for a period of two years or longer; (2) the observation well must be located within 6 to 10 mi of lands irrigated with groundwater and be far enough from recharge areas so as to not be significantly affected by seasonal fluctuations in water levels due to natural responses; (3) the amount of water pumped for the irrigation must be known or can be estimated from satellite imagery and consumptive-use rates; and (4) the time period for which the needed types of data are available must contain a period of below-average precipitation. The process consists of the following steps:

1. Generate water-level hydrographs for wells that have more than 10 measurements made after 1980. A cutoff date of 1980 was selected for several reasons: (1) the water-level data are of better quality and therefore are more reliable than older measurements, (2) the effects of pumping are more pronounced and can therefore be identified; and (3) pumping data are available or can be reliably estimated.
2. Identify wells with 10 measurements or more located within 10,000 ft of one or more irrigated areas.

3. Select sites for which historical pumping data are available for long periods of time (two years or more).
4. Identify hydrographs exhibiting effects of pumping
 - Compare water-level hydrograph to precipitation record
 - Compare water-level hydrograph to water-use trend
5. Identify a relatively dry time period for which pumping schedules can be estimated.

A.3.2 Potential Site Selection and Elimination

The total number of wells located within the model area that have historical water-level records in the NWIS database is 1,245. Only 190 of these wells have 10 or more water-level measurements recorded after 1980. Among the 190 wells, only 55 wells are within 10,000 ft of an irrigation area. After a detailed examination of each of the 55 wells, 9 wells that satisfy the criteria listed in [Section A.3.1](#) were initially selected for the analysis. Two wells are located in northern Steptoe Valley; one well is located in northern Snake Valley; three wells are located near Baker, Nevada (central Snake Valley); one well is located in Lake Valley; one well is located in White River Valley; and the last well is located in Pahranaagat Valley ([Figure A-1](#)).

Preliminary calculations were conducted using Method 1 to evaluate the nine potential sites. All sites were deemed to be acceptable for further analysis, except for those located in Steptoe, White River, and Pahranaagat valleys. The unacceptable sites were eliminated based on the following findings.

A.3.2.1 Pahranaagat Valley Site

The hydrograph of Well 209 S03 E60 35dabd1 (USGS ID 373808115124301) in Pahranaagat Valley exhibits a significant drawdown consistent with pumping from March 18, 1992, to December 16, 1993. However, only four water-level measurements are available during this period, making it difficult to identify the start and the end of the annual pumping cycle. Another issue with this observation well is that it is located in the narrow alluvial floor where the alluvial deposits are bounded by bedrock on both sides at distances less than 5,000 ft. Therefore, the water levels at the observation well are probably affected by these boundaries, but the extent of the effect is unknown. Accounting for the effect of these boundaries in the analysis would introduce large uncertainties in the resulting T and S values.

A.3.2.2 White River Valley Site

The hydrograph of Well 207 N12 E62 18ddaa1, also known as USGS Well 24 (USGS ID 385400115024001), exhibits the effects of a pumping cycle from March 22, 1962, to September 16, 1966. However, this well was not used in the analysis because no reliable records of historical pumping exist for this period. Furthermore, no reliable pumping estimate could be derived from satellite imagery because the agricultural lands around this observation well are irrigated with both groundwater and surface water. The Nevada State Engineer water-right database indicates the

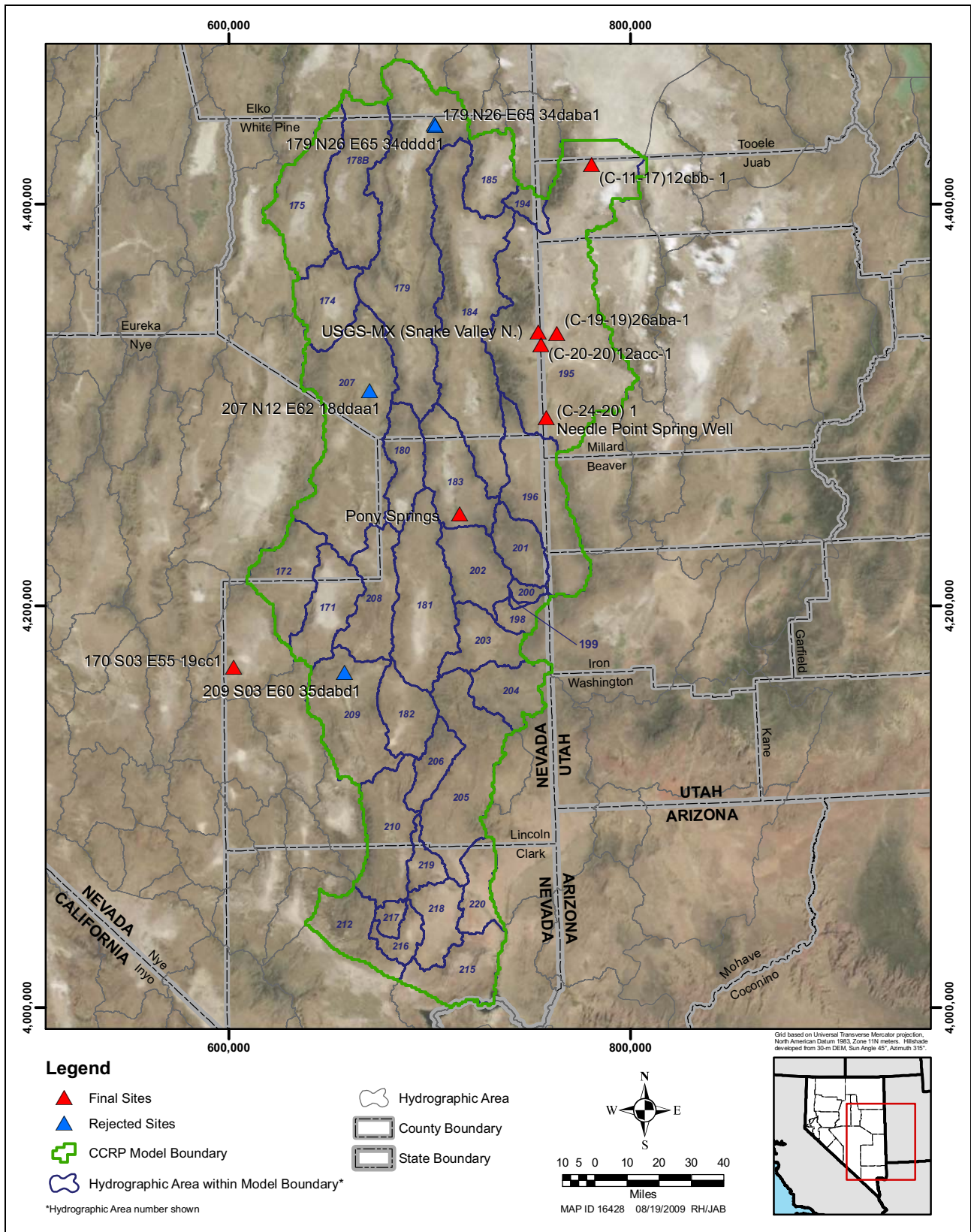


Figure A-1
Location of Sites Evaluated for Analysis

presence of both groundwater and surface-water rights in the area (NDWR, 2009). Although a percentage of groundwater use could be derived from the water rights, it is difficult to define the actual value of this percentage for the 1962 to 1966 time period, as the source of water use may vary depending on climatic and other conditions.

A.3.2.3 Steptoe Valley Sites

Two of the hydrographs selected from Steptoe Valley are for Wells 179 N26 E65 34daba1 (USGS ID 400504114373101) and 179 N26 E65 34dddd1 (USGS ID 400446114371501). The distance between the first two wells is about 3,000 ft, but their hydrographs show opposite trends (up and down) between the periods of 1984 to 1987 and 1981 to 1983. Therefore, it is difficult to distinguish the effects of groundwater pumping on their water-level hydrographs.

A.3.3 Final Site Selection

The five wells that were acceptable for further analysis were used to derive estimates of T and S (Figure A-2). Two additional wells were then selected for analysis: Needle Point Spring Well and well 170 S03 E55 19cc 1 (USGS ID 373955115490201). Needle Point Spring Well was added to the analysis because it has good water-level measurements and is close to a major irrigation area located at the southern end of Snake Valley (Summers, 2001). Well 170 S03 E55 19cc 1 is located in Penoyer Valley and is outside of the model area. This well was added to the analysis for comparison purposes. Information on each of the selected wells is provided in Table A-1. Descriptions of the observation wells and the time periods selected for inclusion in the analysis are provided in the remainder of this section.

A.3.3.1 Baker Sites (Central Snake)

The three selected observation wells near the town of Baker, Nevada, are (C-19-19) 26aba 1, (C-20-20) 12acc 1, and 195 N15 E70 25dd 1, all of which are located in central Snake Valley (Figure A-2).

Well 195 N15 E70 25dd 1 is completed in basin fill near the mountain block to a depth of 94 ft bgs. The depth to water in this well was at 14 ft bgs in 1981. The last recorded measurement was 16.73 ft bgs in 2008. The water level in this well not only exhibits a declining trend but also distinct seasonal variations.

Wells (C-19-19) 26aba 1 and (C-20-20) 12acc 1 are located 4 to 6 mi away from Well 195 N15 E70 25dd 1 toward the central part of the valley in bottom valley fill. The depth of Well (C-19-19) 26aba 1 is 103 ft bgs, and the well is completed in alluvial deposits. The NWIS database contains water-level measurements for these wells from 1973 to 2008 (USGS, 2009). The hydrographs of these wells show good seasonal variations prior to 1993. The water levels for these wells decline in subsequent years and do not exhibit the seasonal variations observed in Well 195 N15 E70 25dd 1.

The water-level measurements taken at the three observation wells between 2000 and 2004 were selected for this analysis for the following reasons:

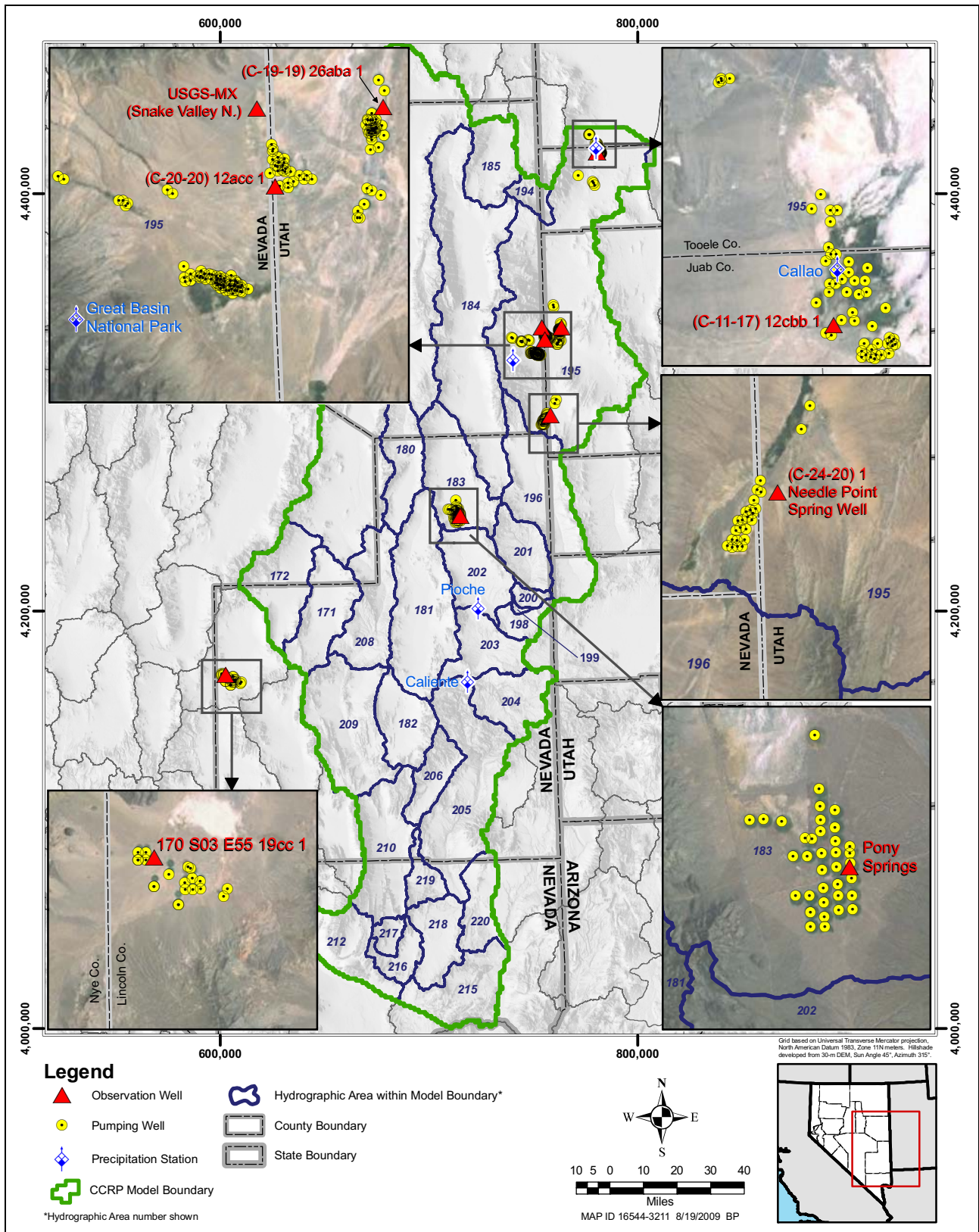


Figure A-2
Location of Selected Sites in Study Area

**Table A-1
Selected Site Information**

Observation Well	USGS ID	HA	UTM Northing ^a (m)	UTM Easting ^a (m)	Latitude ^b	Longitude ^b	Land-Surface Elevation ^c (ft amsl)	Time Period Available	Time Period Analyzed	Well Depth (ft bgs)
(C-20-20)12acc 1	390500114024501	195	4,330,171	755,459	39°05'00"	114°02'45"	5,120	1972–2009	2000–2003	300
(C-19-19)26aba 1	390758113565501	195	4,335,938	763,685	39°07'58"	113°56'55"	4,945	1977–2009	2000–2003	---
USGS-MX (Snake Valley N.)	390812114033601	195	4,336,051	754,041	39°08'12"	114°03'36"	5,068	1981–2009	2000–2003	94
(C-24-20) 1 Needle Point Spring	---	195	4,293,863	758,107	38°45'21"	114°01'47"	5,450	2002–2008	2002–2003	46
(C-11-17)12cbb 1	395259113430401	195	4,419,927	780,604	39°52'59"	113°43'04"	4,390	1986–2009	1989–1991	126
Pony Springs	382003114322501	183	4,245,749	714,916	38°20'03"	114°32'25"	5,950	1946–2008	2000–2004	161
170 S03 E55 19cc 1	373955115490201	170	4,169,399	602,402	37°39'58"	115°50'17"	4,850	1963–2002	1997–2002	238

^aNorth American Datum of 1983 (NAD83), Zone 11

^bNorth American Datum of 1927 (NAD27)

^cNational Geodetic Vertical Datum of 1929 (NGVD29)

-
- The extents of the croplands in the area where the three observation wells are located have been estimated as part of BARCASS from satellite imagery for 2000, 2002, and 2005 (Welborn and Moreo, 2007).
 - The annual precipitation rates measured for the same period of time at nearby stations are below the long-term annual average.

A.3.3.2 Northern Snake Valley Site

The selected observation well, (C-11-17) 12cbb 1, located in northern Snake Valley is close to the northern hydrographic boundary of Snake Valley.

The observation well is completed in alluvial deposits to a depth of 126 ft bgs. The Utah water-right database indicates that this well was drilled for domestic use. It has a duty of 10.86 afy, which is less than 1 percent of the estimated irrigation consumptive water use in the area around the selected observation well. No pumping inventory is available for this site.

Welborn and Moreo (2007) reported irrigated acreages for Snake Valley in 2000, 2002, and 2005. The irrigated acreage for Snake Valley in 2002 is about the same as the average of the acreages for 2000, 2002, and 2005.

The depth-to-water measurements in this observation well are available from 1986 to 2008 (USGS, 2009). The measurements indicate consistently declining water levels. The depth to water was 48.84 ft bgs on March 10, 1987, and 55.29 ft bgs on March 4, 2008.

The water-level measurements taken at this observation well between 1989 and 1991 were selected for this analysis for the following reasons:

- The most detailed portion of the hydrographs occurs between 1989 and 1991.
- Based on the nearest precipitation stations, this time period is relatively dry.
- The observation well's hydrograph exhibits drawdowns of similar magnitudes for the periods 1989 to 1991 and 2000 to 2004. Thus, it was deemed reasonable to use the acreage of the irrigated areas obtained from 2002 satellite imagery to estimate irrigation pumping for the period 1989 to 1991.

A.3.3.3 Southern Snake Valley Site

The selected observation well, (C-24-20) 1 Needle Point Spring Well, is a BLM monitoring well located in southern Snake Valley, about 6 mi from the hydrographic boundary of Snake Valley and Hamlin Valley.

The observation well log indicates that the well is completed in alluvial basin fill (Summers, 2001). However, the basin fill at this location is interpreted to be thin and underlain by carbonate rocks.

Water-level measurements for this well are available from 2002 to 2008, and the corresponding hydrograph shows very good seasonal variation that appears to correlate to irrigation pumping. The total decrease in water levels from 2002 to 2008 is only 1.65 ft. The declining water levels in this well may be due to both irrigation pumping and below-normal levels of precipitation. The acreages of the irrigated areas were derived from satellite imagery by Welborn and Moreo (2007) for 2000, 2002, and 2005. The acreages are consistent for these years.

The water-level measurements taken at this observation well between 2002 and 2003 were selected for this analysis for the following reasons:

- The acreages of irrigated areas are available for that time period (Welborn and Moreo, 2007).
- The time period between 2002 and 2003 is relatively dry.

A.3.3.4 Lake Valley Site

The selected observation well, Pony Springs Well, is located in southern Lake Valley. This well is completed in alluvial deposits to a total depth of 161 ft bgs. Based on driller's well logs from NDWR, the alluvial deposits extend to a depth greater than 545 ft bgs around this well.

Depth to water in the Pony Springs Well was 130.3 ft bgs on July 26, 1946; 130.0 ft bgs on September 9, 1949; and 130.4 ft bgs in July 17, 1963 (Rush and Eakin, 1963). The water level observed during that span of 17 years was consistent with insignificant pumping. Because groundwater is the only resource for irrigation, the water level in Pony Springs Well has been declining since 1963; the water level continuously declined from 130.4 ft bgs in 1963 to 153.85 ft bgs in 2006, which is consistent with seasonal irrigation pumping starting in the 1960s. During that period, the irrigated land around this well increased from 1,600 acres in the 1960s to 4,600 acres in the 2000s. The water-level hydrograph for this well also exhibits irrigation pumping cycles.

Rush and Eakin (1963) also reported that about 1,900 ac-ft was pumped from wells 6/66-22b1 and 22b2 for irrigation. These two wells were drilled to depths of 410 and 450 ft bgs, respectively, and approximately 2,400 gpm was yielded with a drawdown of 30 ft (Rush and Eakin, 1963). The transmissivity estimated with the associated specific capacity is about 21,000 ft²/d. These two wells are located about 3 mi from Pony Springs Well.

The water-level measurements taken at this observation well between 2000 and 2004 were selected for this analysis for the following reasons:

- The acreages of irrigated areas are available for that time period (Welborn and Moreo, 2007).
- The time period between 2000 and 2004 is relatively dry.

A.3.3.5 Penoyer Valley Site

The selected observation well, 170 S03 E55 19cc 1, is located in Penoyer Valley, which is outside of the model boundary and within the DVFS. The selected observation well is completed to a depth of 238 ft bgs in coarse alluvial deposits. Wells present around this observation well are also completed

in alluvial deposits. Water-level measurements and the pumping inventory for Penoyer Valley, including those for Well 170 S03 E55 19cc 1, are available in the USGS NWIS database and Moreo and Justet (2008), respectively. The selected observation well water-level hydrograph covers the period of 1963 to 2002.

The water-level measurements taken at this observation well between 1997 and 2002 were selected for this analysis for the following reasons:

- The acreages of the irrigated areas are available for that time period (Moreo and Justet, 2008).
- The time period between 1997 and 2002 is relatively dry.

A.4.0 DERIVATION OF T AND S

This section describes the estimates of net pumping rates, the solution process using the two methods described in Section A.1.2, preliminary results, and comparison to literature ranges.

A.4.1 Net Pumping Estimates

The volume of groundwater pumpage that is directly linked to the drawdown (also referred to as effective withdrawal rate) is calculated as follows:

$$Q_{DD} = Q_{Pump} - RF \quad (\text{Eq. A-1})$$

where,

- Q_{DD} = Pumpage directly linked to the drawdown
- Q_{Pump} = Total pumpage
- RF = Return flow or water that percolates past the root zone and returns to the aquifer

RF is estimated to be about 20 percent of the sum of the water available (total pumpage + precipitation). Therefore, Q_{DD} may be expressed as follows:

$$Q_{DD} = 0.8 \times Q_{Pump} - 0.2 \times P \quad (\text{Eq. A-2})$$

where,

- P = Precipitation falling in the irrigated area

Welch et al. (2008) examined the same equation expressing it in terms of rates with different variable names. In their study, the application rate, AR (ft/yr), corresponds to the pumping rate, and the net pumping rate, $Pump_{net}$ (ft/yr), corresponds to the portion of groundwater withdrawal causing the drawdown. The precipitation rate P_r (ft/yr) is equivalent to the precipitation rate used in this study. Using the BARCASS variable names, Equation A-2 can be written as follows:

$$Pump_{net} = 0.8 \times AR - 0.2 \times P_r \quad (\text{Eq. A-3})$$

The crop application and precipitation rates reported by Welch et al. (2008) for BARCASS are listed in Table A-2. The net pumping rate can be calculated using this information and Equation A-3. The results are presented in Table A-2.

Table A-2
Application Rates, Precipitation Rates, and Derived Net Pumping Rates

Hydrographic Area	Average Application Rate ^a (af/acre)	Area Weighted Precipitation ^a (ft/yr)	Net Pumping Rate (ft/yr)
Lake Valley	3.0	1.0	2.2
Snake Valley	3.7	0.6	2.8
Spring Valley	3.5	0.8	2.7
Steptoe Valley	3.4	0.7	2.6
White River Valley	3.6	0.8	2.7
		Average	2.6

^a Welch et al. (2008)

The rounded net pumping rates listed in Table A-2 range from 2 to 3 ft/yr. This range could change if a different percentage of return flow is used. This range was used at each site selected for the Theis superposition analysis.

A.4.2 Solutions and Preliminary Results

The results of the analysis using Method 1 for all selected sites and Method 2 for the Baker, Lake Valley and Penoyer Valley sites are described in this section.

The estimated ranges of T and S_y derived from the available stress/response data associated with agricultural activities, using Method 1, are summarized in Table A-3. Because of the large uncertainty associated with the estimated groundwater pumping and the actual correlation of the fluctuations in the hydrographs to the irrigation pumping, these estimates carry different levels of uncertainty depending on the site. In fact, as the optimization method could yield different solutions depending on the initial estimates for the parameters, it was necessary to assign initial values of T and S_y based on the available data for the study area. Initial values assigned to T and S_y were 3,500 ft²/d and 0.07, respectively. The T and S_y ranges derived from the Lake Valley and Penoyer Valley sites carry less uncertainty than the other sites because of the following reasons: (1) the groundwater is the only source of irrigation water in these two basins; (2) the estimated irrigation acreages are more accurate; (3) the hydrographs exhibit continuous declines and distinct annual pumping cycles; and (4) the site conditions are more consistent with the assumptions of the Theis equation because the observation wells are located on the valley floors. Major sources of uncertainty for the other sites include the sources of irrigation water, acreages of the irrigated areas, measurement errors in the water levels, and the potential presence of subsurface boundaries affecting the hydrographs.

Table A-3
Summary of *T* and *Sy* Values Derived with Method 1

Site	Observation Wells	UTM Northing ^a (m)	UTM Easting ^a (m)	<i>T</i> (ft ² /d)		<i>Sy</i>	
				Low	High	Low	High
Baker	(C-20-20)12acc 1	4,330,171	755,459	11,073	16,610	0.14	0.21
	(C-19-19)26aba 1	4,335,938	763,685	16,494	24,742	0.07	0.10
	USGS-MX (Snake Valley N.)	4,336,051	754,041	162,664	243,996	0.05	0.08
Needle Point Spring	(C-24-20) 1 Needle Point Spring	4,293,863	758,107	48,000	72,000	0.03	0.05
North Snake Valley	(C-11-17)12cbb 1	4,419,927	780,604	23,000	34,000	0.15	0.23
Lake Valley	Pony Springs	4,245,749	714,916	22,000	33,000	0.19	0.28
Penoyer Valley	170 S03 E55 19cc 1	4,169,399	602,402	19,000	29,000	0.09	0.13
Average^b				18,000	27,000	0.13	0.19

^aNorth American Datum of 1983 (NAD83), Zone 11

^bThe average doesn't include the Needle Point Spring Well and USGS-MX well in Baker because the *T* and *S* derived for the former observation well mainly represent carbonate-aquifer properties and the location of the later observation well is close to mountain block.

Thus far, Method 2 (local numerical model) has been applied only to the Baker, Lake Valley and Penoyer sites. Water-level changes observed in several observation wells and related to irrigation pumping were analyzed using a local numerical flow model to derive ranges of transmissivity and specific yield of the basin fill in these sites.

The values of *T* and *Sy* derived through model calibration are presented in Table A-4. Details will be provided in Halford (2009).

Table A-4
Solutions for Baker, Lake Valley and Penoyer Valley Sites with Methods 2

Lithology	Site	Number of Monitoring Wells	Duration (Years)	Volume Pumped (afy)		<i>T</i> (ft ² /d)		<i>Sy</i>	
				Low	High	Low	High	Low	High
Basin Fill	170_Penoyer	12	11	57,000	95,000	11,000	19,000	0.09	0.16
Basin Fill	183_Lake	7	42	210,000	310,000	9,000	13,000	0.12	0.18
Basin Fill	195_Baker	8	4	31,000	46,000	5,600	9,000	0.12	0.18

A.4.3 Comparison to Literature Ranges

The values obtained for *Sy* in Methods 1 and 2 compare favorably with those from the literature. Published values of specific yield, generally derived from aquifer tests or laboratory tests, for unconsolidated materials were compiled by Johnson (1967) and are summarized in terms of minimum, average, and maximum values for each type of material in Table A-5. The range of all reported *Sy* values, excluding zero values, is 0.02 to 0.35 for all samples (Table A-5). The last row in Table A-5 consists of the average values of each column. The average values serve as approximations of the overall mean and its range of uncertainty. Thus, the arithmetic mean of the

Table A-5
General Value of Specific Yield

Material	Sy (-)		
	Minimum	Average	Maximum
Clay	0	0.02	0.05
Sandy clay (mud)	0.03	0.07	0.12
Silt	0.03	0.08	0.19
Fine sand	0.10	0.21	0.28
Medium sand	0.15	0.26	0.32
Coarse sand	0.20	0.27	0.35
Gravelly sand	0.20	0.25	0.35
Fine gravel	0.21	0.25	0.35
Medium gravel	0.13	0.23	0.26
Coarse gravel	0.12	0.22	0.26
Average	0.12	0.19	0.25

Source: Johnson, 1967

averages (center column of [Table A-5](#)) is 0.19 with a range of uncertainty of 0.12 to 0.25 (arithmetic means of the minimum and maximum values located in the first and last columns of [Table A-5](#)).

[Table A-6](#) contains the ranges of T for alluvial aquifers in Nevada as reported in Halford (2009). The values obtained for T in Methods 1 and 2 compare favorably to those reported in [Table A-6](#).

**Table A-6
Transmissivity of Alluvial Aquifer from Pumping Tests in Nevada**

USGS Site ID	Local Name	Altitude (ft)	Uppermost Opening (ft)	Lowermost Opening (ft)	Opening Interval (ft)	Transmissivity (ft ² /d)
390136119451501	N. Nowlin	4,689	80	374	294	1,000
395734119595601	Knox Well	4,405	100	440	340	1,200
385338119415801	Hatchery#3	4,901	90	440	350	2,000
385749119432701	Minden#7	4,807	175	500	325	2,000
385419119451001	Ranchos 9	4,796	230	658	428	3,300
364708115574401	WW-5C	3,082	887	1,187	300	2,500
390118119451501	S. Nowlin	4,694	60	330	270	2,300
390206119440001	S. Clapham	4,727	55	220	165	1,900
385634119433801	g-ville No. 9	4,797	140	400	260	3,000
390219119440001	N Clapham	4,727	55	220	165	2,250
385646119451101	g-ville No. 2	4,742	40	290	250	5,000
364922115580101	RNM-2s	3,130	1,038	1,119	81	1,900
385926119451201	Airport	4,700	150	450	300	7,300
390018119462901	Aldax	4,687	100	400	300	8,300
385444119453301	Ranchos Rocky Terrace	4,761	240	390	150	5,900
385611119435601	g-ville No. 4	4,785	125	305	180	7,700
385738119433601	Minden#8	4,800	110	510	400	23,000
390321119465301	Brown's	4,654	100	400	300	20,000
385604119445201	g-ville No. 7	4,761	95	300	205	18,000
385604119435601	g-ville No. 6	4,785	100	300	200	19,000
385505119435901	Ranchos 8	4,795	260	500	240	23,000
385738119465301	Minden#4	4,701	200	400	200	31,000

Source: Halford (2009)

A.5.0 SUMMARY

The T and S_y values shown in [Table A-3](#) and [Table A-4](#) for alluvial deposits reflect a wide variation, especially for the results from Method 1. Because of the limitations of Method 1, the T and S_y derived from Method 2 is generally more representative. Therefore, the T of 5,600 to 13,000 ft²/d and the S_y of 0.12 to 0.18 from Method 2 for the sites within the study model area could be a representative range of mean T and S_y . However, the T and S_y derived from Method 1 may still reflect a range of site-specific data. The T and S_y derived from Methods 1 and 2 fall within the literature range (see [Tables A-5](#) and [A-6](#)), except for the T derived for the USGS_MX observation well at Baker, Nevada, using Method 1, which may reflect that this well has a connection with the underlying carbonate aquifer.

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Appendix B

Transient Data Compilation and Analysis

B.1.0 INTRODUCTION

Transient observations of hydrologic data are necessary for the calibration of the numerical model. This appendix details the development of model observations for select springs, stream gages, and well locations in the study area.

B.1.1 Purpose and Scope

The purpose of the work described in this appendix is to derive hydrologic model observations for the study area. To derive these observations, a series of steps were required that included the following:

- Update hydrologic data sets previously compiled and reported in SNWA (2008, 2009).
- Conduct a preliminary analysis on the updated hydrologic data.
- Derive transient flow observation data sets for calibration of the numerical model.

B.2.0 DATA COMPILATION

Data sets previously compiled and reported in SNWA (2008, 2009) were updated to include additional measurements to existing sites or to add completely new sites along with new hydrologic data. The updating of the data sets reported in SNWA (2008) was not a systematic effort to amend every well, spring, or stream gage location with data current to the end of 2008. Specific data sets were updated, however, in an effort to fill in potential data gaps or to enhance existing data sets to improve calibration of the transient model. The following sections discuss the incorporation of additional hydrologic data into the spring, stream flow, and water-level data sets originally documented in SNWA (2008).

B.2.1 Spring Discharge

The spring discharge data sets included in SNWA (2008, 2009) documented spring discharges as either individual miscellaneous measurements or as average discharges over the period of record for a given spring. For calibration of the transient model, however, calendar year average measurements of spring discharge were necessary. As a result, springs from the Conceptual Model Report (SNWA, 2009, Table G-1) were identified that had continuous discharge measurements available. For these springs, daily mean discharge data were obtained from the USGS's NWIS website (<http://waterdata.usgs.gov/nwis>) for the entire period of record available. In addition, the calendar year annual statistics for each site were also downloaded. The daily mean discharge data for all of the continuously monitored springs were then combined into one data set for further analysis. The springs that had continuous discharge measurements available and their calendar year periods of record are listed in [Table B-1](#).

Table B-1
Continuously Monitored Spring Discharge Locations
and Calendar Year Periods of Record

HA Number	USGS Site Number	USGS Site Name	Period of Record
195	10243224	BIG SPGS CK SOUTH CHANNEL NR BAKER, NV	2008
195	102432241	BIG SPGS CK NORTH CHANNEL NR BAKER, NV	2006–2007
195	10172860	WARM CREEK NEAR GANDY, UT	2006–2007
207	09415558	HOT CK NR SUNNYSIDE, NV	2007
207	09415510	PRESTON BIG SPRG NR PRESTON NV	1983–1984, 2001–2008
209	09415639	ASH SPGS DIV AT ASH SPGS, NV	2004–2007
209	09415640	ASH SPGS CK BLW HWY 93 AT ASH SPGS, NV	2000–2007
209	09415589	CRYSTAL SPGS DIV NR HIKO, NV	2005–2007
209	09415590	209 S05 E60 10 1 CRYSTAL SPGS NR HIKO, NV	1986–1987, 1991–1993, 1999–2007
215	09419547	BLUE POINT SPG NR VALLEY OF FIRE STATE PARK, NV	2000–2007
215	09419550	ROGERS SPNG NR OVERTON BEACH, NV	1986–2007
219	09415900	MUDDY SPGS AT LDS FARM NR MOAPA, NV	1986–1993, 1997–2007
219	09415908	PEDERSON E SPGS NR MOAPA, NV	2003–2004, 2007
219	09415910	PEDERSON SPGS NR MOAPA, NV	1987–1993, 1997–2007

B.2.2 Muddy River Stream Flow

Similar to the spring discharge data sets, the Muddy River stream flow data sets documented in SNWA (2008) were reported as water-year annual discharges for gaging stations or as a series of miscellaneous discharge measurements for ungaged streams in the study area. For calibration of the transient numerical model, however, calendar year discharge measurements of the stream flow along the Muddy River were necessary. As a result, the stream flow discharge data sets for the Moapa and Glendale gages were updated so that calendar year average discharge measurements could be derived. These updates included obtaining daily mean discharge data from the USGS’s NWIS website (<http://waterdata.usgs.gov/nwis>) for the entire period of record available for each of the gages. In addition, the calendar year annual statistics for each site were downloaded. The daily mean discharge data were combined into one data set for further analysis. The stream gage locations that had continuous discharge measurements available and their calendar year periods of record are provided in [Table B-2](#).

B.2.3 Water Levels

The water-level data set described in SNWA (2008) was updated to include both new water-level measurements for existing sites and new well locations and water-level measurements. The new

Table B-2
Continuously Monitored Stream Gage Locations and
Calendar Year Periods of Record

HA Number	USGS Site Number	USGS Site Name	Period of Record
219	09416000	MUDDY RV NR MOAPA, NV	1914, 1917, 1945–2007
220	09419000	MUDDY RV NR GLENDALE, NV	1951–1982, 1985–2008

water-level measurements and well locations were obtained from two main sources, which are described in the following sections.

B.2.3.1 NDWR Well Net Data

The water-level data reported in the Baseline Report (SNWA, 2008) were compiled prior to the availability of the online NDWR water-level database (a.k.a. Well Net). Because of the current availability of this data, a comparison of the existing water-level data from the Baseline Report to that from the Well Net database was performed. As a result of the comparison, 79 new well locations were added to the existing data set. These 79 locations corresponded to 4,051 new water-level measurements. In addition, 4,413 new water-level measurements were added to existing sites in the study area. Water-level data for the new locations were added for the following hydrographic areas:

1. Steptoe Valley (HA 179) - 15 new locations
2. Lake Valley (HA 183) - 9 new locations
3. Snake Valley (HA 195) - 3 new locations
4. Dry Valley (HA 198) - 7 new locations
5. Rose Valley (HA 199) - 3 new locations
6. Eagle Valley (HA 200) - 2 new locations
7. Panaca Valley (HA 203) - 9 new locations
8. Lower Meadow Valley Wash (HA 205) - 6 new locations
9. Pahrangat Valley (HA 209) - 4 new locations
10. Coyote Spring Valley (HA 210) - 2 new locations
11. Muddy River Springs Area (HA 219) - 18 new locations
12. Lower Moapa Valley (HA 220) - 1 new location

The new well locations are listed in [Table B-3](#). The table contains general information about each new site including the coordinates, land-surface elevations, and errors associated with both the coordinates and reference-point elevations. The spatial locations of the added wells are shown in [Figure B-1](#).

B.2.3.2 Magma Nevada Mining Company/Robinson Mine Area

In addition to the NDWR Well Net data, monitoring plan compliance reports from Magma Nevada Mining Company were also obtained from NDWR for the Robinson Mine area in Steptoe and White River valleys. The reports document quarterly water-level and well discharge measurements for 1992

**Table B-3
New Well Locations
(Page 1 of 4)**

HA Number	Site No.	Station Name	UTM-N ^a (m)	UTM-E ^a (m)	Reference Point Elevation (ft amsl)	Var Z Error (ft) ^b	VAR LSE (ft ²) ^b	Data Source
179	179 N16 E63 01BBD 1	179 N16 E63 01BBD 1	4,350,586	686,265	6,271	0.005412284	625	NDWR Well Net
179	179 N16 E63 14AB 1	179 N16 E63 14AB 1	4,347,704	685,358	6,358	0.284789354	625	NDWR Well Net
179	179 N17 E63 01AC 1	179 N17 E63 01AC 1	4,359,986	684,877	6,149	0.074879935	625	NDWR Well Net
179	179 N17 E64 19BA 1	179 N17 E64 19BA 1	4,355,120	688,020	6,185	0.006268994	625	NDWR Well Net
179	179 N19 E63 26CC 2	179 N19 E63 26CC 2	4,372,332	684,247	6,067	0.091575280	625	NDWR Well Net
179	179 N20 E63 01DA 1	179 N20 E63 01DA 1	4,388,921	686,371	6,024	0.114960118	625	NDWR Well Net
179	179 N20 E64 17DD 1	179 N20 E64 17DD 1	4,385,172	689,972	6,031	0.036228899	625	NDWR Well Net
179	179 N20 E64 21BB 1	179 N20 E64 21BB 1	4,384,526	690,490	6,051	0.055288885	625	NDWR Well Net
179	179 N21 E63 35AD 1	179 N21 E63 35AD 1	4,390,891	687,032	6,032	0.090443072	625	NDWR Well Net
179	179 N21 E64 30DC 2	179 N21 E64 30DC 2	4,392,626	690,186	5,976	0.049746987	625	NDWR Well Net
179	179 N25 E65 04CA 2	179 N25 E65 04CA 2	4,438,176	701,853	5,907	0.011544952	625	NDWR Well Net
179	179 N25 E65 05DA 2	179 N25 E65 05DA 2	4,438,031	700,914	5,889	0.025470366	625	NDWR Well Net
179	179 N25 E65 08AA 1	179 N25 E65 08AA 1	4,437,316	699,401	7,456	86.828668096	625	NDWR Well Net
179	179 N26 E65 27CA 2	179 N26 E65 27CA 2	4,440,925	702,179	5,896	0.010192182	625	NDWR Well Net
179	179 N26 E65 34DA 1	179 N26 E65 34DA 1	4,439,672	702,801	5,913	0.054384693	625	NDWR Well Net
183	183 N05 E66 03DD	183 N05 E66 03DD	4,243,702	713,892	5,970	0.001031484	625	NDWR Well Net
183	183 N06 E66 22DC 1	183 N06 E66 22DC 1	4,248,718	713,739	5,964	0.000137065	625	NDWR Well Net
183	183 N06 E66 27AC 1	183 N06 E66 27AC 1	4,247,928	713,748	5,961	0.002243660	625	NDWR Well Net
183	183 N06 E66 27CAA 1	183 N06 E66 27CAA 1	4,247,532	713,714	5,960	0.004909051	625	NDWR Well Net
183	183 N06 E66 34CD 1	183 N06 E66 34CD 1	4,245,318	713,768	5,963	0.000290348	625	NDWR Well Net
183	183 N09 E65 13CC 1	183 N09 E65 13CC 1	4,279,127	705,707	5,953	0.064842026	625	NDWR Well Net
183	183 N09 E65 26AA 1	183 N09 E65 26AA 1	4,276,703	705,256	5,934	0.107702673	625	NDWR Well Net
183	183 N10 E65 36AC 1	183 N10 E65 36AC 1	4,284,733	706,329	5,993	15.460115840	625	NDWR Well Net
183	183 N10 E66 31BA 1	183 N10 E66 31BA 1	4,285,135	706,343	6,015	15.840237847	625	NDWR Well Net
195	195 N10 E70 24BDD1	195 N10 E70 24BDD1	4,290,407	753,898	5,508	0.059577473	625	NDWR Well Net
195	195 N10 E70 25CB 1	195 N10 E70 25CB 1	4,288,321	753,394	5,510	0.187533056	625	NDWR Well Net
195	195 N14 E70 28ABBC1	195 N14 E70 28ABBC1	4,327,586	748,942	5,334	0.162634029	625	NDWR Well Net
198	198 N01 E69 31CA 1	198 N01 E69 31CA 1	4,198,171	738,008	5,188	6.594736621	625	NDWR Well Net

Table B-3
New Well Locations
(Page 2 of 4)

HA Number	Site No.	Station Name	UTM-N ^a (m)	UTM-E ^a (m)	Reference Point Elevation (ft amsl)	Var Z Error (ft ²) ^b	VAR LSE (ft ²) ^b	Data Source
198	198 N01 E69 31DD 1	198 N01 E69 31DD 1	4,197,794	738,826	5,327	670.452220000	625	NDWR Well Net
198	198 N01 E69 32BB 1	198 N01 E69 32BB 1	4,199,008	739,206	5,221	5.603920796	625	NDWR Well Net
198	198 N01 E69 32CA 1	198 N01 E69 32CA 1	4,198,218	739,621	5,272	32.244404746	625	NDWR Well Net
198	198 S01 E69 06AC 1	198 S01 E69 06AC 1	4,196,940	737,041	5,172	11.678357431	625	NDWR Well Net
198	198 S01 E69 06AC 2	198 S01 E69 06AC 2	4,197,146	737,101	5,174	0.015433806	625	NDWR Well Net
198	198 S01 E69 07AC 1	198 S01 E69 07AC 1	4,195,633	736,695	5,142	0.049338793	625	NDWR Well Net
199	199 N01 E69 21AA 1	199 N01 E69 21AA 1	4,202,481	741,864	5,403	0.557542387	625	NDWR Well Net
199	199 N01 E69 21AB 1	199 N01 E69 21AB 1	4,202,403	741,495	5,384	0.324415070	625	NDWR Well Net
199	199 N01 E69 21AC 1	199 N01 E69 21AC 1	4,201,931	741,522	5,371	0.028155778	625	NDWR Well Net
200	200 N01 E69 10AD 1	200 N01 E69 10AD 1	4,204,923	743,542	5,486	0.196315632	625	NDWR Well Net
200	200 N01 E69 10DD 1	200 N01 E69 10DD 1	4,204,325	743,233	5,471	0.073606731	625	NDWR Well Net
203	203 S01 E68 33BB 1	203 S01 E68 33BB 1	4,189,304	729,993	4,787	4.266487975	625	NDWR Well Net
203	203 S02 E67 24BB 1	203 S02 E67 24BB 1	4,182,969	725,562	4,711	0.017313195	625	NDWR Well Net
203	203 S02 E67 25AC 1	203 S02 E67 25AC 1	4,181,285	726,204	4,668	0.030867354	625	NDWR Well Net
203	203 S02 E68 05CB 1	203 S02 E68 05CB 1	4,186,917	728,469	4,749	13.036499732	625	NDWR Well Net
203	203 S02 E68 05CC 1	203 S02 E68 05CC 1	4,186,516	728,480	4,744	0.062956026	625	NDWR Well Net
203	203 S02 E68 07AD 1	203 S02 E68 07AD 1	4,185,610	728,241	4,734	0.013572913	625	NDWR Well Net
203	203 S02 E68 08BB 1	203 S02 E68 08BB 1	4,186,115	728,491	4,739	4.617912404	625	NDWR Well Net
203	203 S02 E68 19AA 1	203 S02 E68 19AA 1	4,182,898	728,188	4,700	4.128819508	625	NDWR Well Net
203	203 S03 E67 22AB 2	203 S03 E67 22AB 2	4,173,229	723,184	4,531	0.000000233	625	NDWR Well Net
205	205 S14 E66 04DB 1	205 S14 E66 04DB 1	4,069,216	713,430	1,631	14.203069592	625	NDWR Well Net
205	205 S14 E66 15CA 1	205 S14 E66 15CA 1	4,066,009	714,677	1,577	0.025168284	625	NDWR Well Net
205	205 S14 E66 22DC 1	205 S14 E66 22DC 1	4,064,015	715,100	1,565	8.817230757	625	NDWR Well Net
205	205 S14 E66 26CD 1	205 S14 E66 26CD 1	4,062,443	716,381	1,544	5.257635924	625	NDWR Well Net
205	205 S14 E66 35CA 1	205 S14 E66 35CA 1	4,061,241	716,387	1,534	2.874385203	625	NDWR Well Net
205	205 S14 E66 35CACC1	205 S14 E66 35CACC1	4,061,107	716,323	1,531	0.033761658	625	NDWR Well Net
209	209 S04 E60 11CCCA1	209 S04 E60 11CCCA1 (NDWR)	4,163,529	656,539	3,912	0.171325388	625	NDWR Well Net

**Table B-3
New Well Locations
(Page 3 of 4)**

HA Number	Site No.	Station Name	UTM-N ^a (m)	UTM-E ^a (m)	Reference Point Elevation (ft amsl)	Var Z Error (ft ²) ^b	VAR LSE (ft ²) ^b	Data Source
209	209 S05 E60 11DB 1	209 S05 E60 11DB 1	4,154,759	657,603	3,853	97.918324797	625	NDWR Well Net
209	209 S07 E61 09 1	209 S07 E61 09 1	4,135,923	664,138	3,612	0.791650546	625	NDWR Well Net
209	209 S07 E61 21AB 1	209 S07 E61 21AB 1	4,133,258	664,500	3,422	0.197873014	625	NDWR Well Net
210	210 S11 E62 24BD 1	210 S11 E62 24BD 1	4,094,391	678,990	2,536	0.537040456	625	NDWR Well Net
210	210 S11 E62 24DB 1	210 S11 E62 24DB 1	4,094,153	679,413	2,495	0.032465201	625	NDWR Well Net
219	219 S14 E65 08AB 1	219 S14 E65 08AB 1	4,068,141	702,237	1,828	0.127751829	625	NDWR Well Net
219	219 S14 E65 08AB 2	219 S14 E65 08AB 2	4,068,141	702,237	1,828	15.278992507	625	NDWR Well Net
219	219 S14 E65 08AC 1	219 S14 E65 08AC 1	4,067,740	702,222	1,829	3.237614303	625	NDWR Well Net
219	219 S14 E65 08AC 2	219 S14 E65 08AC 2	4,067,740	702,222	1,829	3.237614303	625	NDWR Well Net
219	219 S14 E65 08BD 1	219 S14 E65 08BD 1	4,067,731	701,850	1,839	2.308600849	625	NDWR Well Net
219	219 S14 E65 08DB 1	219 S14 E65 08DB 1	4,067,339	702,231	1,823	0.577945926	625	NDWR Well Net
219	219 S14 E65 08DB 2	219 S14 E65 08DB 2	4,067,339	702,231	1,823	0.004832364	625	NDWR Well Net
219	219 S14 E65 09CA 1	219 S14 E65 09CA 1	4,067,730	703,007	1,827	0.254086050	625	NDWR Well Net
219	219 S14 E65 09CC 1	219 S14 E65 09CC 1	4,066,958	703,035	1,801	20.027516919	625	NDWR Well Net
219	219 S14 E65 09DC 1	219 S14 E65 09DC 1	4,066,976	703,804	1,787	27.353193213	625	NDWR Well Net
219	219 S14 E65 14CD 1	219 S14 E65 14CD 1	4,065,438	706,547	1,725	0.000075838	625	NDWR Well Net
219	219 S14 E65 15AC 1	219 S14 E65 15AC 1	4,066,212	705,386	1,740	4.578752667	625	NDWR Well Net
219	219 S14 E65 21AB 1	219 S14 E65 21AB 1	4,064,941	703,827	1,920	9.869166603	625	NDWR Well Net
219	219 S14 E65 22AA 1	219 S14 E65 22AA 1	4,064,988	705,763	1,798	487.772668322	625	NDWR Well Net
219	219 S14 E65 23BB 1	219 S14 E65 23BB 1	4,064,997	706,160	1,713	0.807063339	625	NDWR Well Net
219	219 S14 E65 23BB 2	219 S14 E65 23BB 2	4,064,997	706,160	1,713	0.807063339	625	NDWR Well Net
219	219 S14 E65 23BC 1	219 S14 E65 23BC 1	4,064,596	706,145	1,783	44.102430928	625	NDWR Well Net
219	219 S14 E66 35DD 1	219 S14 E66 35DD 1	4,060,861	717,241	1,531	0.000000578	625	NDWR Well Net
220	220 S14 E67 29BCAD1	220 S14 E67 29BCAD1	4,063,501	721,009	1,754	0.477561122	625	NDWR Well Net
179	179 N16 E61 1AA 1 R-12	179 N16 E61 1AA 1 R-12	4,350,441	668,350	7,297	153,810,9845	625	Robinson Mine Data
179	179 N16 E62 10DB 1 DEEP RUTH SHAFT	179 N16 E62 10DB 1 DEEP RUTH SHAFT	4,348,053	674,434	6,946	51,627,29448	625	Robinson Mine Data
179	179 N16 E62 12CB 1 R-H	179 N16 E62 12CB 1 R-H	4,348,122	676,953	6,614	9,110,843423	625	Robinson Mine Data
179	179 N16 E62 13BB 1 R-C	179 N16 E62 13BB 1 R-C	4,347,192	676,607	7,018	449,117,2147	625	Robinson Mine Data

Table B-3
New Well Locations
(Page 4 of 4)

HA Number	Site No.	Station Name	UTM-N ^a (m)	UTM-E ^a (m)	Reference Point Elevation (ft amsl)	Var Z Error (ft ²) ^b	VAR LSE (ft ²) ^b	Data Source
179	179 N16 E62 13BD 1 SKKR13M	179 N16 E62 13BD 1 SKKR13M	4,346,650	677,200	7,003	810,763.8883	625	Robinson Mine Data
179	179 N16 E62 13CA 1 WCC6M	179 N16 E62 13CA 1 WCC6M	4,346,379	677,355	7,241	389,940.337	625	Robinson Mine Data
179	179 N16 E62 13DD 1 WCC1M	179 N16 E62 13DD 1 WCC1M	4,345,927	677,936	7,603	716,454.166	625	Robinson Mine Data
179	179 N16 E62 15CA 1 R-E	179 N16 E62 15CA 1 R-E	4,346,340	673,870	7,257	245,579.9514	625	Robinson Mine Data
179	179 N16 E62 16AD 1 SL-1M	179 N16 E62 16AD 1 SL-1M	4,346,779	673,406	7,301	554,774.1501	625	Robinson Mine Data
179	179 N16 E62 16BA 1 WCC5M	179 N16 E62 16BA 1 WCC5M	4,347,050	672,605	6,792	6,951,005.87	625	Robinson Mine Data
179	179 N16 E62 22AB 1 WCC2M	179 N16 E62 22AB 1 WCC2M	4,345,553	674,503	7,451	362,7461589	625	Robinson Mine Data
179	179 N16 E62 23DC 1 WCC4M	179 N16 E62 23DC 1 WCC4M	4,344,559	675,897	7,546	76,125.34	625	Robinson Mine Data
179	179 N16 E62 2CB 1 AB-3	179 N16 E62 2CB 1 AB-3	4,349,847	675,218	6,753	11,557.2194	625	Robinson Mine Data
179	179 N16 E62 2CC 1 K-2P	179 N16 E62 2CC 1 K-2P	4,349,372	675,300	6,810	104,808.4181	625	Robinson Mine Data
179	179 N16 E62 2CD 1 K-2M	179 N16 E62 2CD 1 K-2M	4,349,444	675,600	6,769	1,632,835.716	625	Robinson Mine Data
179	179 N16 E62 2CD 2 K-3M	179 N16 E62 2CD 2 K-3M	4,349,072	675,703	6,804	160,218.9475	625	Robinson Mine Data
179	179 N16 E62 3DA 1 AB-4	179 N16 E62 3DA 1 AB-4	4,349,857	674,815	6,763	3,849.965646	625	Robinson Mine Data
179	179 N16 E62 8DA 1 R-F	179 N16 E62 8DA 1 R-F	4,348,005	671,766	7,109	373,321.1523	625	Robinson Mine Data
179	179 N16 E63 18BA 1 R-B	179 N16 E63 18BA 1 R-B	4,347,373	678,801	6,557	2,071.315926	625	Robinson Mine Data
179	179 N16 E63 18DC 1 WCC3M	179 N16 E63 18DC 1 WCC3M	4,346,108	679,227	7,516	1,286,078.515	625	Robinson Mine Data
179	179 N16 E63 7CC 1 R-A	179 N16 E63 7CC 1 R-A	4,347,730	678,419	6,592	102,843.2134	625	Robinson Mine Data
179	179 N17 E62 33BB 1 NRC-2P	179 N17 E62 33BB 1 NRC-2P	4,352,071	671,944	6,912	3,197.239916	625	Robinson Mine Data
179	179 N17 E62 33CA 1 NRC-2M	179 N17 E62 33CA 1 NRC-2M	4,351,117	672,543	6,943	10,195.44048	625	Robinson Mine Data
179	179 N17 E62 33CA 2 NRC-3M	179 N17 E62 33CA 2 NRC-3M	4,351,086	672,296	7,015	637,526.9519	625	Robinson Mine Data
179	179 N17 E62 33DB 1 NRC-1P	179 N17 E62 33DB 1 NRC-1P	4,351,076	672,791	6,905	30,076.01055	625	Robinson Mine Data
179	179 N17 E62 35CC 1 R-1	179 N17 E62 35CC 1 R-1	4,350,890	675,311	6,726	30,111.43673	625	Robinson Mine Data
207	207 N16 E61 13AB 1 WCCG2	207 N16 E61 13AB 1 WCCG2	4,347,089	667,817	6,920	34,250.3139	625	Robinson Mine Data
207	207 N16 E61 25DB 1 WCCG1	207 N16 E61 25DB 1 WCCG1	4,343,332	667,894	6,677	15,630.01337	625	Robinson Mine Data
207	207 N16 E62 30CA 1 WCCG3	207 N16 E62 30CA 1 WCCG3	4,343,126	669,327	6,707	403,963.8922	625	Robinson Mine Data

^aUniversal Transverse Mercator projection, North American Datum 1983, Zone 11N

^bFor a discussion on the calculation of the error terms, Var Z Error and Var LSE, see SNWA (2008)

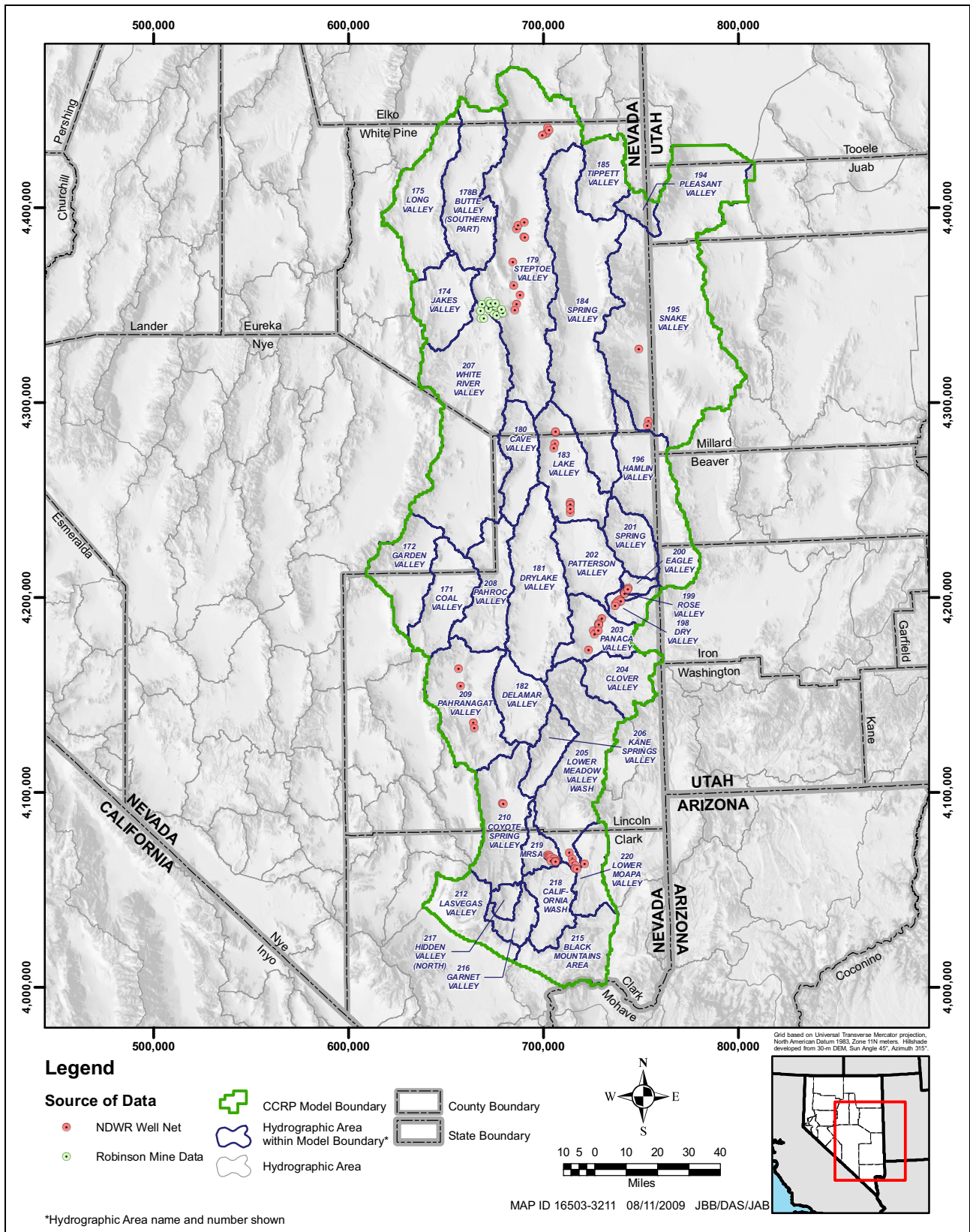


Figure B-1
Location of Wells Added to the Existing Water-Level Data Set

through 1996. Based on these quarterly reports, 29 new well locations were added to the existing Baseline Report data set. These 29 locations have 461 corresponding new water-level measurements. The added wells are listed in [Table B-3](#), and the spatial locations of the added wells are shown in [Figure B-1](#).

B.3.0 DATA ANALYSIS

Analysis of the hydrologic data included reducing the daily mean discharge and water-level measurements into calendar year average measurements. In addition, statistics for the reduction of multiple measurements into one yearly average measurement were also calculated. Analysis of the data also included assigning “well-qualifier” and “use-code” flags to the wells in the study area. The following sections discuss the analysis of the updated hydrologic data sets in greater detail.

B.3.1 Spring Discharge Data

Analysis of the spring discharge data set consisted of (1) deriving calendar year average spring discharge measurements and statistics for each of the springs from the updated daily mean discharge data and (2) combining the yearly average discharge measurements for springs where multiple gages were necessary to capture the entire discharge from the spring (e.g., Big Springs in Snake Valley).

These steps are discussed in greater detail in the following sections:

B.3.1.1 Data Reduction and Statistics

The daily mean discharge measurements were reduced to calendar year discharge measurements for the period of record for a given spring. This was done to reduce the data set so that the spring discharge values could be used as observations in the model. The data reduction was performed in Microsoft Access.

In addition to the determination of the calendar year average discharge measurement, summary statistics were also calculated, including the standard deviation and variance. The resulting transient spring discharge data set can be found on the DVD included with this report.

B.3.1.2 Combination of Gages

A complicating factor in the estimation of yearly spring discharges for several of the spring locations in [Table B-1](#) is that the total discharge is not always accounted for by one gage. For example, the total discharge for both Crystal and Ash springs is accounted for by gaging stations on both the main and irrigation diversion channels. Spring discharge for Big Springs in Snake Valley is accounted for by gages on both the north and south channels of Big Springs Creek. As a result, the reported discharges for those gages had to be combined to adequately account for the total discharge for the spring complexes.

For Crystal and Ash springs, the total spring discharge for the springs was derived by combining the calendar year average discharge measurements for years in which data were available for both gages. The calendar year averages and variances in flow from the daily mean data for Crystal and Ash springs can be seen in [Table B-4](#).

For Big Springs, however, there was never a calendar year in which spring discharges were available for both of the gage locations in the same year. As a result, the total discharge for Big Springs was calculated in a slightly different manner. Specifically, the total discharge for Big Springs was estimated by averaging the two calendar years of record for the north channel (i.e., 2006 and 2007) and adding the one calendar year of discharge for the south channel (i.e., 2008). The estimated total spring discharge for Big Springs was 10.26 cfs with a variance of 0.32 cfs².

The combination of the gage data for Crystal, Ash, and Big springs can also be found on the DVD included with this report.

**Table B-4
Calendar Year Average Discharges for Crystal and Ash Springs**

USGS Site Name	Calendar Year Average Discharges/Variations (cfs)/(cfs ²)			
	2004	2005	2006	2007
209 S05 E60 10 1 CRYSTAL SPGS NR HIKO, NV	---	11.13/13.10	10.89/11.99	11.76/7.34
CRYSTAL SPGS DIV NR HIKO, NV	---	1.63/12.12	1.51/10.13	1.19/7.51
Total Discharge for Crystal Springs	---	12.76/25.21	12.40/22.12	12.96/14.85
ASH SPGS CK BLW HWY 93 AT ASH SPGS, NV	15.83/2.88	13.13/1.53	12.69/3.42	16.43/4.33
ASH SPGS DIV AT ASH SPGS, NV	2.15/0.95	3.33/0.96	3.84/3.08	3.46/1.43
Total Discharge for Ash Springs	17.98/3.83	16.45/2.50	16.53/6.50	19.89/5.76

B.3.2 Muddy River Stream Flow Data

Analysis of the stream flow data for the Moapa and Glendale gages consisted of (1) removing flood flows from the daily mean stream flow measurements, (2) deriving monthly discharge volumes from the daily mean stream flow measurements, and (3) calculating calendar year stream flow measurements. These steps are discussed in greater detail in the following sections.

B.3.2.1 Removal of Flood Flows

Local precipitation events contribute to the stream flow measured at the Moapa and Glendale gages. These additional flows are referred to as flood flows. These flood flows were removed from the daily mean flows to determine the actual baseflow at the gages. The methodology for the removal of flood flows is described in Johnson (1999), and the adjusted record is reported in LVVWD (2001). The method of removing the flood flows from the daily mean flows consisted of identifying the flood flows and then using a calculated median flow in place of the flood-flow volumes.

B.3.2.2 Derivation of Monthly Stream Flows

After the removal of the flood flows, the monthly flows for each gage were derived by summing the daily mean flows for each month for the period of record of both of the gages. The resulting adjusted data set allowed for a determination of the calendar year stream flows for both gages.

B.3.2.3 Derivation of Calendar Year Stream Flows

The adjusted calendar year stream flows were derived from the monthly stream flow data for each gage. The adjusted calendar year stream flows were derived by summing the monthly stream flow values (i.e., January to December) in a given year for the period of record of the gage. The adjusted calendar year stream flows for both gages are listed in [Table B-5](#). This table also contains the unadjusted calendar year discharges from the NWIS website. The adjusted discharges represent the calendar year discharge measurements at the gages with the flood flows removed, while the unadjusted discharges represent the stream flows that would have passed by the gages including flood flows. Hydrographs of the calendar year flows for each of the gages can be seen in [Figure B-2](#) and [Figure B-3](#).

B.3.3 Water-Level-Elevation Data

Analysis of the updated water-level data set consisted of several steps. These steps were as follows:

1. Generated a transient water-level data set from the updated water-level data set.
2. Generated hydrographs for each well that show the original water-level-elevation data and the yearly averaged water-level elevations.
3. Assigned a well-qualifier flag to each well in the transient water-level data set.
4. Assigned a use-code flag to each well in the transient water-level data set.

The analysis of the transient water-level data set is discussed in greater detail in the following sections.

B.3.3.1 Transient Model Water-Level Data Set

The steps necessary to generate the water-level-elevation data set for the transient model were as follows:

1. Excluded specific water-level measurements from the water-level data set that are either considered to be outliers with respect to the rest of the water-level measurements or are flagged in such a way that indicates a specific measurement is affected by some type of external factor (e.g., pumping, a nearby site is pumping, or the site was recently pumping).

Table B-5
Stream Flow Measurements for the Moapa and Glendale Gages
 (Page 1 of 2)

Calendar Year	MUDDY RV NR MOAPA, NV Gage		MUDDY RV NR GLENDALE, NV Gage	
	NWIS Calendar Year Discharge (cfs) ^a	Adjusted Calendar Year Discharge (cfs) ^a	NWIS Calendar Year Discharge (cfs) ^a	Adjusted Calendar Year Discharge (cfs) ^a
1914	46.7	46.1	NA	NA
1917	46.6	46.6	NA	NA
1945	46.3	46.1	NA	NA
1946	47.1	46.8	NA	NA
1947	47.2	47.2	NA	NA
1948	46.1	46.3	NA	NA
1949	47.1	47.1	NA	NA
1950	46.0	46.0	NA	NA
1951	47.1	47.1	44.8	44.3
1952	46.9	46.9	54.5	47.7
1953	45.9	45.8	44.8	44.7
1954	45.9	45.8	44.4	43.8
1955	46.9	46.6	54.1	47.5
1956	45.7	45.8	43.4	43.1
1957	49.4	48.5	51.0	48.1
1958	48.3	48.0	46.2	44.8
1959	49.8	49.2	45.3	44.8
1960	48.0	47.3	57.9	45.9
1961	44.5	44.2	47.4	45.3
1962	44.2	44.1	43.0	41.9
1963	45.3	45.3	39.9	39.3
1964	43.6	43.7	40.3	40.4
1965	43.3	43.1	44.2	43.2
1966	42.3	41.7	42.3	38.1
1967	45.8	41.7	44.6	41.2
1968	40.9	40.9	43.7	42.5
1969	42.5	42.0	54.4	42.7
1970	39.8	39.8	45.7	43.1
1971	39.3	39.1	42.2	40.9
1972	45.7	42.2	44.1	39.9
1973	43.4	43.4	41.9	40.3
1974	40.1	40.1	39.3	39.1

Table B-5
Stream Flow Measurements for the Moapa and Glendale Gages
 (Page 2 of 2)

Calendar Year	MUDDY RV NR MOAPA, NV Gage		MUDDY RV NR GLENDALE, NV Gage	
	NWIS Calendar Year Discharge (cfs) ^a	Adjusted Calendar Year Discharge (cfs) ^a	NWIS Calendar Year Discharge (cfs) ^a	Adjusted Calendar Year Discharge (cfs) ^a
1975	39.1	39.0	39.6	38.5
1976	41.9	39.1	42.9	39.8
1977	35.6	35.5	35.6	34.3
1978	36.9	36.2	55.7	39.7
1979	39.8	37.8	43.2	37.2
1980	39.5	39.1	45.0	37.8
1981	38.0	37.6	46.0	35.4
1982	37.6	37.3	37.2	36.8
1983	39.8	39.2	NA	NA
1984	39.2	36.1	NA	NA
1985	37.8	37.7	36.2	35.9
1986	36.6	36.5	37.1	37.2
1987	39.2	38.5	38.8	37.4
1988	37.4	37.5	35.6	35.7
1989	33.1	33.1	30.2	30.2
1990	36.7	34.3	41.0	32.3
1991	36.0	35.6	36.5	34.3
1992	37.1	37.0	38.1	36.4
1993	40.5	39.0	53.7	39.7
1994	39.4	39.2	33.6	33.6
1995	33.3	33.3	32.0	32.0
1996	32.9	33.0	30.7	30.5
1997	34.6	34.6	32.1	31.9
1998	34.6	34.0	56.4	38.2
1999	34.2	33.9	36.0	36.0
2000	34.2	33.8	38.4	33.4
2001	31.4	31.4	32.0	32.0
2002	32.5	32.5	31.9	31.9
2003	30.3	30.4	31.4	31.4
2004	31.5	31.4	40.3	32.4

NA = Not available

^a Discharge rounded to the nearest tenth

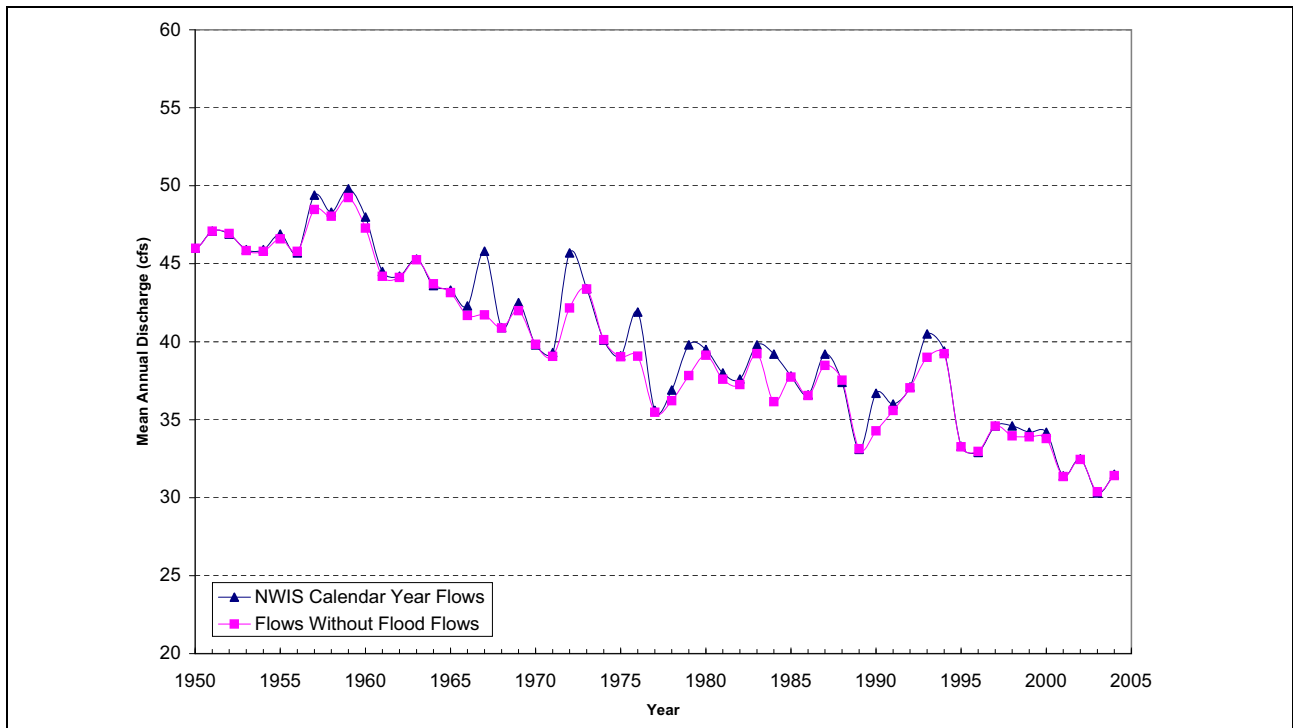


Figure B-2
Annual Flow with and without Flood Flows at USGS Gaging Station
0941600-MUDDY RV NR MOAPA, NV

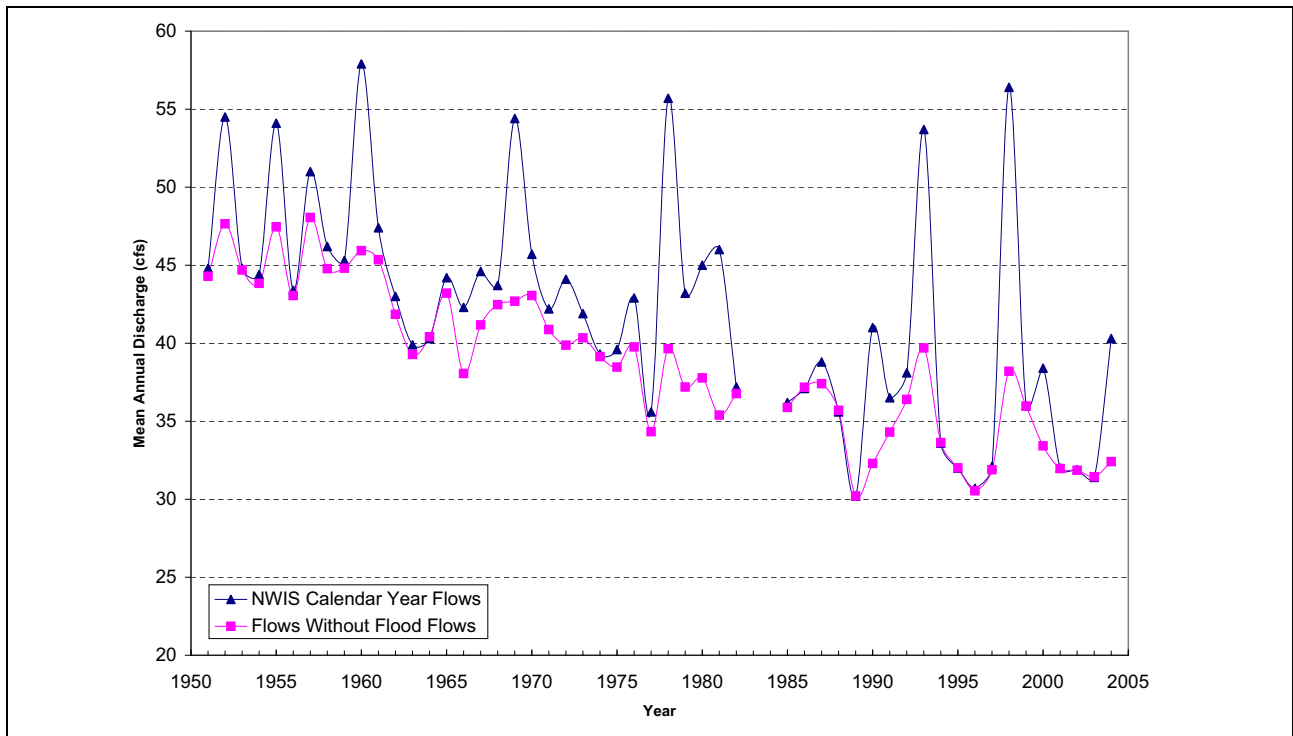


Figure B-3
Annual Flow with and without Flood Flows at USGS Gaging Station
09419000-MUDDY RV NR GLENDALE, NV

2. From the resulting data set in Step 1, calculated yearly average water-level elevations and statistics for each well in the data set.
3. Using the yearly average water-level elevations and statistics, calculated an acceptable range to select water-level elevations for each well for use as observations in the transient model calibration. The acceptable range is defined as the average yearly elevation ± 2 standard deviations.
4. Using the range from Step 3, flagged water-level measurements outside the acceptable range for the well.
5. Excluded the specific water-level measurements from the data set in Step 4 that were flagged as exceeding or being less than the acceptable range.
6. Using the data set from Step 5, recalculated yearly average water-level elevations and statistics for each well in the data set. The resulting data set represents the transient model water-level-elevation data set.

B.3.3.2 Hydrograph Construction

Hydrographs were constructed for each well in the water-level data set. These hydrographs display both the original water-level elevations (i.e., Step 1 results) and the yearly averaged water-level elevations that correspond to the transient model water-level-elevation data set (i.e., Step 6 results). The hydrographs are organized by hydrographic area and station name. For plotting purposes, the yearly averaged water-level elevations were assigned a date of June 15 for every year in the period of record. As a result, for wells with only one water-level elevation, there might be a shift between the two data points. In addition, some hydrographs may appear to be blank; however, the data for the well were likely prior to 1945, and the x-axis was set to encompass the historical development period of the study area. The constructed hydrographs can be found on the DVD included with this report.

The hydrographs were constructed in such a way as to allow for a set elevation to be applied to the maximum and minimum water-level elevations on the hydrograph. This allows for the hydrographs to have more consistent scales in an effort to standardize the overall trends displayed by the hydrographs. This buffer was set to 75 ft.

B.3.3.3 Well Qualification and Data Filtering

Well-qualifier flags were assigned to each well in the transient water-level database so that hydraulic-head and drawdown observations could be derived for the wells. The list of qualifying flags are listed in [Table B-6](#). The flags were assigned to the wells included in the data set by inspection of the data in a Microsoft Access database, spatial querying of the well locations in ArcMap 9.3, and comparison of the well hydrographs in conjunction with a National Climatic Data Center (NCDC) climate index. The assignment of these flags is discussed in greater detail in the following sections. [Figure B-4](#) shows the spatial distribution of the wells and their assigned flags.

Table B-6
Well-Qualifier Flags

Flag	Definition
1	Preliminary flag that is no longer used.
2	Wells with only one yearly averaged water-level-elevation measurement.
3	Wells located in hydrographic areas where no groundwater pumping has occurred during the historical record (e.g., Garden and Coal valleys).
4	Wells located in hydrographic areas where groundwater pumping has occurred during the historical record. Wells are located near a groundwater pumping center.
5	Wells located in hydrographic areas where groundwater pumping has occurred during the historical record. Wells are not located near a groundwater pumping center.
6	Wells located in hydrographic areas where groundwater pumping has occurred during the historical record. Wells appear to be exhibiting fluctuations that can be attributed to climatic factors.

B.3.3.3.1 Inspection of Data in Access

The first step in the assignment of the flags was to perform a query in Microsoft Access that identified wells in the study area that had only one yearly averaged water-level measurement. These wells were assigned a Flag 2.

B.3.3.3.2 Spatial Querying of Transient Water-Level Data Set

The well locations in the updated transient water-level data set were also plotted in ArcMap 9.3. This was done so that spatial queries of the well locations could be made. For example, well locations that fall in hydrographic areas where little to groundwater use occurs (see [Appendix C](#)) were assigned a Flag 3 qualifier (e.g., Garden, Coal, Long, Butte, and Hamlin valleys). The spatial querying was also used to identify well locations that fall in hydrographic areas where a significant amount of groundwater pumping occurs. These wells were assigned Flag 4 or 5 qualifiers. Flag 4 was assigned to well locations that are located in close proximity to groundwater pumping centers. Flag 5 was assigned to well locations that are located in hydrographic areas that have significant pumping but are not located in close proximity to groundwater pumping centers.

B.3.3.3.3 Comparison of Water-Level-Elevation Hydrographs and Climate-Index Data

The last step in assigning the flags was to visually inspect the hydrographs for all well locations that fall in hydrographic areas with groundwater pumping centers. The hydrographs were constructed in conjunction with the creation of a drought index chart for the same time scales as the water-level elevations. Specifically, Palmer Drought Severity Index (PDSI) data were downloaded from the NCDC Climate Monitoring website (<http://lwf.ncdc.noaa.gov/climate-monitoring/>). According to the NCDC website, the PDSI attempts to measure the duration and intensity of the long-term drought-inducing circulation patterns (NCDC, 2009). The PDSI is a monthly value that indicates the severity of a wet or dry spell.

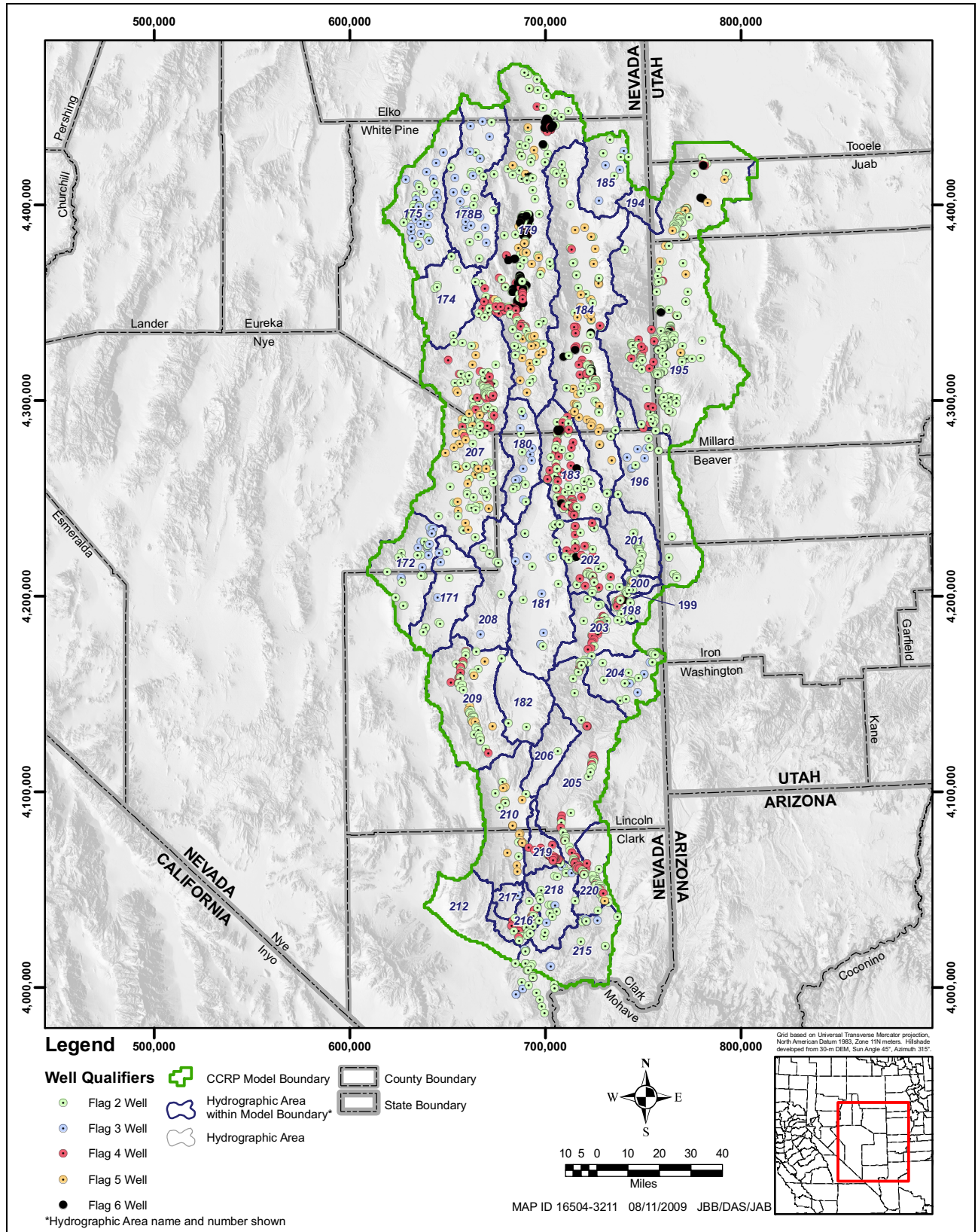


Figure B-4
Well Qualifiers

The downloaded PDSI data are applicable to specific climatological divisions. For the study area, PDSI data were downloaded for Nevada climatological divisions 2, 3, and 4. In addition, PDSI data were downloaded for Utah climatological division 1.

Inspection of the water-level-elevation hydrographs and the PDSI plots allowed for the determination of which wells in the study area might be exhibiting water-level-elevation fluctuations related to climate variability. These wells were assigned a Flag 6. [Figure B-4](#) reflects that most of the wells assigned a Flag 6 were located in Steptoe, Spring, Lake, and Snake valleys.

B.3.3.4 Use-Code Flags

In addition to the assignment of the flags, each well in the transient water-level data set was also assigned a use-code flag. This flag was either a “Y” or an “N.” The wells flagged with an N were ignored (i.e., removed from consideration) in the calibration of the transient model. The wells from the transient water-level data set flagged with an N are listed in [Table B-7](#). This table is organized by hydrographic area and then by station name. The table also explains why a particular well was flagged with an N use code. Some of the reasons for flagging a well with an N included the following:

- Well was incorrectly located.
- Well had no date of measurement associated with the yearly averaged water-level-elevation measurement.
- Well was located in an area that is likely perched or in an area where issues with the framework of the model would prevent the accurate modeling of that particular location.

B.4.0 TRANSIENT MODEL OBSERVATION DATA SETS

Transient model observation data sets were required for calibration of the numerical model. The transient model observation data sets were divided into two main types of observations. The two types of observations include observations prior to 1945 that correspond to the predevelopment period, and observations after 1945 that correspond to the historical period of development in the study area. The observations prior to 1945 were used for the first stress period of the transient calibration. The first stress period corresponds to the steady-state calibration of the numerical model. The observations post 1945 were used as transient observations for the historical development period. The transient model observations are discussed in greater detail in the following sections.

B.4.1 Pre-1945 Transient Model Observations

Hydrologic measurements made prior to 1945 were considered to be part of the predevelopment period in the study area. These measurements were used as steady-state (i.e., stress period 1) observations for the study area. These observations are discussed in greater detail in the following sections.

Table B-7
Wells Flagged as “N” and Not Used in Transient Calibration
 (Page 1 of 5)

HA Number	Site No	Station Name	Reason
171	171 N02 E60 19CA 1	171 N02 E60 19CA 1	DTW measurement has no date associated with it
171	374716115253801	171 S02 E58 11A 2 USBLM	Perched or incorrectly located
171	171 S02 E58 14CB 1	171 S02 E58 14CB 1	Perched or incorrectly located
172	172 N01 E57 20 1	172 N01 E57 20 1	Located on mountain ridge
172	172 N02 E58 14C 1	172 N02 E58 14C 1	Inside perched ET zone
172	172 N02 E58 14CB 1	172 N02 E58 14CB 1	Inside perched ET zone
172	172 N03 E57 10BA 1	172 N03 E57 10BA 1	Perched or incorrectly located
172	172 N03 E57 15CC 1	172 N03 E57 15CC 1	Perched or incorrectly located
172	172 N03 E57 15DC 1	172 N03 E57 15DC 1	Perched or incorrectly located
172	380643115344201	172 N03 E57 16C 1	Perched or incorrectly located
172	381107115251901	172 N04 E58 23D 1 Well (Report R18)	Perched, Garden Valley
172	381123115252001	172 N04 E58 26ABA 1 USBLM	Perched, Garden Valley
172	381339115225501	172 N04 E59 06D 1	Perched, Garden Valley
172	172 N04 E59 08B 1	172 N04 E59 08B 1	Perched, Garden Valley
172	172 N04 E59 08B 2	172 N04 E59 08B 2	Perched, Garden Valley
172	375742115223001	172 N05 E59 32C 1	Perched, Garden Valley
172	381437115214901	172 N05 E59 32D 1	Perched, Garden Valley
172	381829115221601	207 N04 E59 08BCC 1	Perched, Garden Valley
174	390809115134801	174 N14 E60 04DBD 1 USBLM	Well is likely perched
174	174 N17 E59 09 1	174 N17 E59 09 1	Inside perched ET zone
174	174 N17 E59 10BA 1	174 N17 E59 10BA 1	Inside perched ET zone
174	392617115115801	174 N18 E60 10DAA 1 USBLM	Well located in incorrect section
174	174 N19 E60 21CB 1	174 N19 E60 21CB 1	Well is likely perched
175	175 N22 E58 34AD 1	175 N22 E58 34AD 1	DTW measurement has no date associated with it
178B	178B N19 E61 26DAD 1	178B N19 E61 26DAD 1	Well located in incorrect section
178B	178B N20 E61 23AC1	178B N20 E61 23AC1	DTW measurement has no date associated with it
178B	178B N22 E61 21BC 1	178B N22 E61 21BC 1	Perched or incorrectly located
178B	394355115053301	178B N22 E61 33 1	Perched or incorrectly located
178B	395146115014201	178B N23 E61 13 1	Perched or incorrectly located; DTW measurement has no date associated with it
178B	178B N24 E60 33BC 1	178B N24 E60 33BC 1	Perched or incorrectly located
179	179 N14 E63 14BB 1	179 N14 E63 14BB 1	Well located in incorrect section
179	390220114510401	179 N14 E63 36B 1	Perched or incorrectly located
179	179 N15 E63 15DC 1	179 N15 E63 15DC 1	Perched or incorrectly located
179	179 N15 E65 05DB 1	179 N15 E65 05DB 1	Perched or incorrectly located
179	179 N15 E65 07BC 1	179 N15 E65 07BC 1	Perched or incorrectly located
179	391715114574701	179 N16 E62 02A 1	Perched or incorrectly located
179	391546114535501	179 N16 E63 09CC 1	Perched or incorrectly located
179	391548114524301	179 N16 E63 15B 1	Perched or incorrectly located
179	391529114543601	179 N16 E63 17A 1 White Pine County School	Perched or incorrectly located
179	179 N16 E63 28BA 1	179 N16 E63 28BA 1	Perched or incorrectly located
179	391634114484901	179 N16 E64 06CBDC1 USBLM	Inconsistent elevations
179	392055115021501	179 N17 E62 07CDBD1 USBLM	Not likely part of the regional or intermediate flow systems

Table B-7
Wells Flagged as “N” and Not Used in Transient Calibration
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HA Number	Site No	Station Name	Reason
179	391903115021701	179 N17 E62 30A 1	Perched or incorrectly located
179	391749114584601	179 N17 E62 34BDDA1	Inside perched ET zone
179	392131114551401	179 N17 E63 07ABAD1	Inside perched ET zone
179	392112114550501	179 N17 E63 07ADCD1	Inside perched ET zone
179	179 N18 E61 34 1	179 N18 E61 34 1	Not likely part of the regional or intermediate flow systems
179	392343114570601	179 N18 E62 25CCA 1 USBLM	Inside perched ET zone
179	179 N18 E65 10B 1	179 N18 E65 10B 1	Perched or incorrectly located
179	392517114420901	179 N18 E65 18DCDC1	Inside perched ET zone
179	179 N18 E65 19CC 1	179 N18 E65 19CC 1	Inside perched ET zone
179	179 N19 E64 17DDB 1	179 N19 E64 17DDB 1	DTW measurement has no date associated with it
179	179 N19 E64 24DA 1	179 N19 E64 24DA 1	DTW measurement has no date associated with it
179	392952114433401	179 N19 E64 25A 1	Inside perched ET zone
179	392911114425301	179 N19 E64 25ADAD1	Inside perched ET zone
179	179 N19 E65 34CD 1	179 N19 E65 34CD 1	Perched or incorrectly located
179	179 N21 E64 14AC 1	179 N21 E64 14AC 1	Inside perched ET zone
179	179 N22 E64 22CD 1	179 N22 E64 22CD 1	Inside perched ET zone
179	179 N23 E63 06AA 1	179 N23 E63 06AA 1	Inside perched ET zone
179	395117114442601	179 N23 E64 21B 1	Perched or incorrectly located
179	395740114383601	179 N24 E65 17AAD1 USBLM	Well located in incorrect section
179	179 N24 E65 30DC 1	179 N24 E65 30DC 1	Well located in incorrect section
179	400043114481501	179 N25 E63 26A 1	Perched or incorrectly located
179	400504114373101	179 N26 E65 34DABA1	Inconsistent water-level trends in area
179	179 N26 E66 03 1	179 N26 E66 03 1	Perched or incorrectly located
181	181 N04 E65 26DC 1	181 N04 E65 26DC 1	Perched or incorrectly located
181	181 N05 E65 34DC 1	181 N05 E65 34DC 1	Perched or incorrectly located
181	181 N05 E65 35BA 1	181 N05 E65 35BA 1	Perched or incorrectly located
183	381911114235101	183 N05 E68 06C 1	Perched or incorrectly located
183	382336114210301	183 N06 E68 09CAC 1	Well is likely perched
183	382757114414301	183 N07 E65 17DAA 1 USBLM	Framework issues prevent the accurate modeling of this location
184	184 N10 E68 36DA 1	184 N10 E68 36DA 1	Well located in incorrect section
184	390448114274401	184 N14 E67 15C 1	Perched or incorrectly located
184	390952114214401	184 N15 E66 14DBBD1	Well appears to be incorrectly located
184	184 N15 E68 17DD 1	184 N15 E68 17DD 1	Well located in incorrect section
184	395314114373101	184 N23 E65 10D 1	Perched or incorrectly located
184	395234114363601	184 N23 E65 14C 1	Not likely part of the regional or intermediate flow systems
184	394949114331801	184 N23 E66 31AB 1	Not likely part of the regional or intermediate flow systems
184	394942114342001	184 N23 E66 31C 1	Perched or incorrectly located
184	184 N24 E66 31CB 1	184 N24 E66 31CB 1	Not likely part of the regional or intermediate flow systems
185	395606114094401	253 N24 E69 27BAAB1 Goshute Reservation	Well located outside of study area
195	393900113530001	(C-13-18)28ccc- 1	DTW measurement has no date associated with it
195	(C-14-18) 5C	(C-14-18) 5C	DTW measurement has no date associated with it

Table B-7
Wells Flagged as “N” and Not Used in Transient Calibration
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HA Number	Site No	Station Name	Reason
195	(C-20-19)21B	(C-20-19)21B	DTW measurement has no date associated with it
195	(C-21-18)10CDD 1	(C-21-18)10CDD 1	DTW measurement has no date associated with it
195	(C-21-18)32ABD 1	(C-21-18)32ABD 1	Perched or incorrectly located
195	(C-21-19)31D	(C-21-19)31D	DTW measurement has no date associated with it
195	(C-22-19)6aad	(C-22-19)6aad	DTW measurement has no date associated with it
195	(C-22-19)6bbb	(C-22-19)6bbb	DTW measurement has no date associated with it
195	(C-22-19)6bbd 1	(C-22-19)6bbd1	DTW measurement has no date associated with it
195	(C-22-19)6bca2	(C-22-19)6bca2	DTW measurement has no date associated with it
195	(C-22-19)6bca3	(C-22-19)6bca3	DTW measurement has no date associated with it
195	(C-22-19)6bca4	(C-22-19)6bca4	DTW measurement has no date associated with it
195	(C-22-19)6ccb	(C-22-19)6ccb	DTW measurement has no date associated with it
195	(C-22-19)6ccd	(C-22-19)6ccd	DTW measurement has no date associated with it
195	(C-22-19)6dab1	(C-22-19)6dab1	DTW measurement has no date associated with it
195	(C-22-19)6dab2	(C-22-19)6dab2	DTW measurement has no date associated with it
195	(C-23-19)13AAB 1	(C-23-19)13AAB 1	DTW measurement has no date associated with it
195	(C-24-19)32ad	(C-24-19)32ad	DTW measurement has no date associated with it
195	(C-24-19)32dd	(C-24-19)32dd	DTW measurement has no date associated with it
195	390126114115701	195 N13 E69 11A 1	Perched or incorrectly located
195	195 N13 E69 11ABC 1	195 N13 E69 11ABC 1	Perched or incorrectly located
195	390028114110401	195 N13 E69 12CCDB1	Well assumed to be perched or the area has framework issues that prevent the modeling of this area correctly
195	390126114075901	195 N13 E70 09B 1 Ranger Station	Perched or incorrectly located
195	195 N13 E70 09BDD 1	195 N13 E70 09BDD 1	Perched or incorrectly located
195	195 N13 E70 09CA 1	195 N13 E70 09CA 1	DTW measurement has no date associated with it
195	390005114080601	195 N13 E70 16C 1	Perched or incorrectly located
195	195 N14 E69 13CD 1	195 N14 E69 13CD 1	Inside perched ET zone
195	390454114111101	195 N14 E69 24A 1	Inside perched ET zone
195	195 N14 E69 24BDD 1	195 N14 E69 24BDD 1	Inside perched ET zone
195	195 N14 E69 24DAB 1	195 N14 E69 24DAB 1	Inside perched ET zone
195	393047114124001	195 N19 E69 15C 1	Perched or incorrectly located
196	(C-30-19)21CAB	(C-30-19)21CAB	DTW measurement has no date associated with it
196	195 N10 E69 08BB 1	195 N10 E69 08BB 1	Perched or incorrectly located
198	375406114171901	198 N01 E69 32CAA 1	Perched or incorrectly located
198	198 S01 E69 02 1	198 S01 E69 02 1	Perched or incorrectly located
198	198 S01 E69 02 2	198 S01 E69 02 2	Perched or incorrectly located
198	198 S01 E69 35DB 1	198 S01 E69 35DB 1	Well located in incorrect section
199	199 N01 E69 16CB 1	199 N01 E69 16CB 1	Perched or incorrectly located
199	199 N01 E69 21AA 1	199 N01 E69 21AA 1	Perched or incorrectly located
201	201 N02 E70 18BB 1	201 N02 E70 18BB 1	Perched or incorrectly located
201	380750114102501	201 N03 E70 07A 1	Perched or incorrectly located
201	381221114121601	201 N04 E69 13CBA 1	Not likely part of the regional or intermediate flow systems
202	202 N01 E67 22AB1	202 N01 E67 22AB1	DTW measurement has no date associated with it
202	202 N01 E69 07CA 1	202 N01 E69 07CA 1	Perched or incorrectly located

Table B-7
Wells Flagged as “N” and Not Used in Transient Calibration
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HA Number	Site No	Station Name	Reason
202	202 N03 E66 20 1	202 N03 E66 20 1	DTW measurement has no date associated with it
202	202 N03 E66 28 1	202 N03 E66 28 1	DTW measurement has no date associated with it
202	202 N04 E67 02 1	202 N04 E67 02 1	Well located in incorrect section
202	202 N04 E67 02 2	202 N04 E67 02 2	Well located in incorrect section
202	202 N04 E67 02 3	202 N04 E67 02 3	Well located in incorrect section
202	202 N04 E67 02BB 1	202 N04 E67 02BB 1	Well located in incorrect section
202	202 N04 E67 02D 1	202 N04 E67 02D 1	Well located in incorrect section
202	202 N05 E65 25DD 1	202 N05 E65 25DD 1	Well located in incorrect section
202	381520114262901	202 N05 E67 35BCB 1	Well located in incorrect section
203	203 N01 E67 32AA1	203 N01 E67 32AA1	Well located in incorrect section; DTW measurement has no date associated with it
203	203 S01 E68 05CC 1	203 S01 E68 05CC 1	Perched or incorrectly located
203	374827114221901	203 S01 E68 33C 1	Perched or incorrectly located
203	374737114240501	203 S02 E68 06D 1	Perched or incorrectly located
203	203 S02 E69 05DB 1	203 S02 E69 05DB 1	Well located in incorrect section
204	204 S03 E70 36BC 1	204 S03 E70 36BC 1	Inside perched ET zone
204	373834114054801	204 S03 E71 31CBBA1 USBLM	Well located in mountain block / caldera
204	373704114285601	204 S04 E67 09AD 1	Perched or incorrectly located
204	373626114075001	204 S04 E70 11CCDD1 USBLM	Inside perched ET zone
204	373637114071101	204 S04 E70 11D 1	Inside perched ET zone
204	373324114095301	204 S04 E70 33BD 1 LA & Salt Lake Railroad	Inside perched ET zone
204	373324114095601	204 S04 E70 33CAB 1 LA & Salt Lake Railroad	Inside perched ET zone
204	373154114230301	204 S05 E68 09B 1 USBLM	Perched or incorrectly located
204	373135114140301	204 S05 E69 11D 1	Inside perched ET zone
204	373049114150701	204 S05 E69 15ADDD1	Inside perched ET zone
204	204 S05 E69 16BD 1	204 S05 E69 16BD 1	Inside perched ET zone
204	204 S05 E70 06DD 1	204 S05 E70 06DD 1	Inside perched ET zone
205	205 S12 E66 04BD 1	205 S12 E66 04BD 1	Perched
206	206 S08 E65 35AD 1	206 S08 E65 35AD 1	Perched
207	207 N06 E61 28DA1	207 N06 E61 28DA1	DTW measurement has no date associated with it
207	207 N06 E62 07AB1	207 N06 E62 07AB1	DTW measurement has no date associated with it
207	207 N07 E61 11AC1	207 N07 E61 11AC1	DTW measurement has no date associated with it
207	207 N08 E61 21AC1	207 N08 E61 21AC1	DTW measurement has no date associated with it
207	383544115173401	207 N09 E59 36 1	Well is volcanic, shallow, and likely perched
207	207 N10 E62 31CB1	207 N10 E62 31CB1	DTW measurement has no date associated with it
207	385400115024001	207 N12 E62 18DDAA1 USGS Well 24	Water levels affected by surface-water irrigation
207	207 N14 E60 01CD1	207 N14 E60 01CD1	DTW measurement has no date associated with it
207	207 N14 E60 04AB 1	207 N14 E60 04AB 1	Well is likely perched
208	380450114594201	208 N03 E62 35B 1 USBLM	Flagged for removal based on hydrograph analysis
208	374525115061801	208 S02 E61 23D 2	Flagged for removal based on hydrograph analysis
209	373808115124301	209 S03 E60 35DABD1	Water levels affected by local structural features
209	209 S04 E61 20DA1	209 S04 E61 20DA1	DTW measurement has no date associated with it
210	210 S11 E62 04AB 1	210 S11 E62 04AB 1	Well has too few measurements

Table B-7
Wells Flagged as “N” and Not Used in Transient Calibration
 (Page 5 of 5)

HA Number	Site No	Station Name	Reason
210	210 S11 E62 13DB 1	210 S11 E62 13DB 1	Perched; DTW measurement has no date associated with it
210	365926114591301	210 S11 E62 13DBC1	Perched
210	210 S11 E62 24BD 1	210 S11 E62 24BD 1	Elevations are extremely inconsistent with surrounding wells
210	210 S11 E62 24DB 1	210 S11 E62 24DB 1	Elevations are extremely inconsistent with surrounding wells
210	365834114590001	210 S11 E62 24DBAD1	Perched
210	210 S11 E62 27DD 1	210 S11 E62 27DD 1	Well located in incorrect section
210	365008114541101	210 S13 E63 11BACD1 USBLM (Dutch Flat)	Elevations are extremely inconsistent with surrounding wells
210	364352114544701	210 S14 E63 10 1	Elevations are extremely inconsistent with surrounding wells
215	360545114563401	212 S21 E63 28ACA 1 USBR LG006	Well located outside of study area
215	360644114563801	212 S21 E63 28ACA 2 USBR LG007	Well located outside of study area
215	362553114322701	215 S17 E67 30ABB 1 NV Division of State Parks	Flagged for removal based on hydrograph analysis
215	362003114341101	215 S19 E66 01ABBB1	Well located in incorrect section
215	215 S20 E63 04 1	215 S20 E63 04 1	Well located outside of study area
215	361349114524401	215 S20 E64 18CB 1	Well located outside of study area
215	BM-LIGHTFOOT-2	215 S20 E64 18CB 1 BM-LIGHTFOOT-2	Well located outside of study area
215	BM-LIGHTFOOT-3	215 S20 E64 18DB 1 BM-LIGHTFOOT-3	Well located outside of study area
215	361044114505601	215 S20 E64 29DADB1	Well located outside of study area
215	BM-HEISEN-2	215 S20 E64 29DD 1 BM-HEISEN-2	Well located outside of study area
215	BM-HEISEN-1	215 S20 E64 32AA 1 BM-HEISEN-1	Well located outside of study area
215	BM-MARTIN	215 S20 E64 32AA 2 BM-MARTIN	Well located outside of study area
215	215 S21 E63 02 1	215 S21 E63 02 1	Well located outside of study area
215	360714114542501	215 S21 E63 14DBD 1 USBR LG004	Well located outside of study area
215	360713114542501	215 S21 E63 14DBD 2 USBR LG005	Well located outside of study area
215	215 S21 E64 07D 1	215 S21 E64 07D 1	Well located outside of study area
215	360725114494301	215 S21 E64 21CC 1	Well located outside of study area
215	360938114434101	215 S21 E65 09DB 1 USNPS	Well located outside of study area
215	215 S21 E65 16CD 1	215 S21 E65 16CD 1	Well located outside of study area
215	215 S22 E64 03DB 1	215 S22 E64 03DB 1	Well located outside of study area
215	360345114482001	215 S22 E64 14CC 1 USNPS	Well located outside of study area
215	215 S22 E64 25CC 1	215 S22 E64 25CC 1	Well located outside of study area
216	CW-Pehlen	216 S17 E64 35BA 1 CW-Pehlen	Well has too few measurements
218	362732114435301	218 S11 E65 21BDAD1 Valley of Fire State Park	Well appears to be incorrectly located
218	MV-4	218 S15 E66 02CA 1 MV-4	DTW measurement has no date associated with it
218	CW-HALL	218 S17 E65 17DD 1 CW-HALL	Well has too few measurements
218	CW-JONES	218 S17 E65 21DC 1 CW-JONES	Well has too few measurements
218	362529114455101	218 S17 E65 31DBCD1	Well has too few measurements
220	MV-10	220 S15 E67 07CD 1 MV-10	Perched or incorrectly located
220	MV-1	220 S16 E66 22CC 1 MV-1	Well has too few measurements

DTW = Depth to Water

B.4.1.1 Spring Discharge Observations

For continuously monitored spring locations in this period in the study area (see [Table B-1](#)), no calendar year average discharge measurements existed prior to 1945. As a result, no continuously monitored spring discharge model observations are available. The spring discharge volumes and variances documented in the Conceptual Model Report (SWNA, 2009, Table G-1), however, were used as observation targets for the steady-state stress period of the transient model. The target flows were assigned a date of December 31, 1944, for identification and plotting purposes, and to indicate the predevelopment nature of the average discharges.

B.4.1.2 Stream Discharge Observations

For continuously monitored stream discharge locations in the study area, only one of the stream gage locations in [Table B-2](#) had calendar year average discharge measurements prior to 1945. Specifically, the USGS MUDDY RV NR MOAPA, NV gage had calendar year average discharge measurements available for 1914 and 1917. Because these measurements preceded the predevelopment period by almost 30 years, no steady-state observation target (stress period 1) was defined or used.

B.4.1.3 Hydraulic-Head and Drawdown Observations

By definition of the development period, water-level-elevation data measured prior to 1945 were considered to be predevelopment observation data. Fifty-seven wells in the transient water-level data set discussed in [Section B.3.3.1](#) had yearly averaged water-level-elevation measurements prior to 1945. Most of these wells had only one yearly averaged measurement prior to 1945, but five of the wells had more than one. For these wells, a mean water-level elevation was calculated using all of the pre-1945 data available for the well. These mean water-level-elevation measurements were then assigned a date of December 31, 1944, for identification and plotting purposes.

The variance associated with the mean water-level elevations was calculated as the sum of the location, land surface, and observation errors. For Flag 2 wells, the observation error was set at zero. For wells assigned Flags 3 and 5, the observation error was defined as the variance of all of the yearly averaged water-level elevations for a given well. For wells assigned Flags 4 and 6, the observation error was defined as the variance of reducing the measurements prior to 1945 to one average value for the predevelopment period. If there was only one measurement prior to 1945, the observation error was set as zero. The predevelopment hydraulic-head-observation data were combined with the post-1945 transient hydraulic-head and drawdown observation data. The combined transient observation data are provided on the DVD included with the report.

B.4.2 Post-1945 Model Observations

Hydrologic measurements made after 1945 were considered to be part of the historical development period for the study area. The hydrologic measurements were used to derive transient discharge, flow, and hydraulic-head observations for the study area. These observations are discussed in greater detail in the following sections.

B.4.2.1 Spring Discharge Observations

Spring discharge observations for the transient stress periods were derived from the spring discharge data set discussed in [Section B.3.1](#). Because of the relatively limited periods of record for the continuously monitored springs (see [Table B-1](#)), there were no obvious declines in spring flows. As a result, it was assumed that the flows were approximately steady for all the springs and that there should be zero change in flow through time. The first yearly averaged spring discharge was treated as the transient flow observation target for a given spring, while the rest of the yearly averaged spring discharges were treated as change in flow observations. The variance associated with the first yearly averaged spring discharge was calculated as the variance associated with the reduction of the multiple yearly measurements to one yearly averaged discharge measurement. The variance associated with the changes in flow for the springs was calculated as the variance of all flows.

[Table B-1](#) shows that for several of the continuously monitored spring locations transient data were available only after 2004. For these spring locations, an average of the spring discharge data after 2004 was applied as a transient spring discharge target for the year 2004. This was done so that the transient model calibration would match the spring flows at the end of the model, close to when measurements were taken, rather than to treat them as predevelopment steady-state targets. The spring discharge observation targets and the changes in flow by spring are provided on the DVD included with this report.

B.4.2.2 Muddy River Observations

Muddy River stream discharge observations were derived from the stream discharge data set discussed in [Section B.3.2](#). Each calendar year average stream discharge measurement was treated as a flow observation for each of the gage locations. As a result, there was no calculation of a reduction in stream flow similar to what was done for the spring discharge measurements. The standard deviation in stream flow for the stream gage locations was defined as 15 percent which means that 95 percent of the daily discharges are within 15 percent of their true values. This was based on the USGS “fair” accuracy rating assumed for the gages. The flow observation data for the transient flow model are provided on the DVD included with this report.

B.4.2.3 Hydraulic-Head and Drawdown Observations

Based on the well qualifiers (flags), hydraulic-head and drawdown observations were derived from the transient water-level data set. [Table B-8](#) provides a summary of the methodologies used to derive the hydraulic-head and drawdown observations for the transient model.

As described in [Table B-8](#), for each flag type, a different methodology to derive the hydraulic-head and drawdown observations was used. For a given well, every yearly averaged water-level elevation represented either a hydraulic-head or drawdown observation. Specifically, the first yearly averaged water-level elevation was considered to be the hydraulic-head observation for a well. The subsequent yearly averaged water-level elevations were considered to be the drawdown observations.

**Table B-8
Hydraulic-Head and Drawdown Observation Calculations
for the Transient Stress Periods**

Flag Type	Hydraulic Heads			Drawdowns		
	Description	Observation Calculation (ft amsl)	Variance Calculation ^{a, b, c} (ft ²)	Description	Observation Calculation (ft)	Variance Calculation ^c (ft ²)
1	Preliminary flag that is no longer used.					
2	Only one head observation	Yearly averaged head elevation	VAR = LOC + GS + OBS (OBS = 0)	No drawdown observations	NA	NA
3	One head observation for first yearly averaged time ^d	Mean elevation of all of the yearly averaged elevations	VAR = LOC + GS + OBS (OBS = variance of all the yearly averaged elevations for the well)	Observations at yearly averaged times ^d following the first yearly average	0	Variance = OBS (OBS = Variance of all the yearly averaged elevations for the well)
4	One head observation for first yearly averaged time ^d	First yearly averaged elevation for a given well	VAR = LOC + GS + OBS (OBS = variance of observations in first yearly averaged calculation; '0' if only 1 observation)	Observations at yearly averaged times ^d following the first yearly average	First yearly average value minus each subsequent yearly average value	Variance = OBS (OBS = Variance of all the yearly averaged elevations for the well)
5	One head observation for first yearly averaged time ^d	Mean elevation of all of the yearly averaged elevations	VAR = LOC + GS + OBS (OBS = variance of all the yearly averaged elevations for the well)	Observations at yearly averaged times ^d following the first yearly average	0	Variance = OBS (OBS = Variance of all the yearly averaged elevations for the well)
6	Head observation for each yearly averaged time	Yearly averaged head elevation for each year	VAR = LOC + GS + OBS (OBS = variance of observations for yearly averaged elevation; '0' if only 1 observation)	No drawdown observations	NA	NA

NA = Not applicable

^aLOC - Location error for the well

^bGS - Land-surface elevation error for the well

^cOBS - Observation error for the well

^dYearly hydraulic-head averages are computed using head value observations falling within a given calendar year (i.e., Jan. 1 through Dec. 31). For plotting purposes, it was assumed that the yearly averaged value fell on June 15 of that year.

The exceptions to this were wells that were assigned Flags 2 or 6. For Flag 2 wells, there was only one yearly averaged water-level elevation. As a result, the water-level measurements for these wells were always hydraulic-head observations. For Flag 6 wells, each yearly averaged water-level-elevation measurement was treated as a hydraulic-head observation, and no drawdown observations were derived. The following sections discuss the calculation of the hydraulic-head and drawdown observations shown on [Table B-8](#) for the transient well type flags in greater detail.

B.4.2.3.1 Flag 2 Hydraulic-Head and Drawdown Observations

Flag 2 wells had only one yearly averaged water-level-elevation measurement. As a result, Flag 2 wells have only a hydraulic-head-observation measurement and no drawdown observation. The hydraulic-head observation for Flag 2 wells was the yearly averaged water-level-elevation measurement. The variance calculated for the hydraulic-head observation was the sum of the location and land-surface-elevation errors for the well.

B.4.2.3.2 Flag 3 Hydraulic-Head and Drawdown Observations

Flag 3 wells were located in hydrographic areas with little to no groundwater pumping during the historical development period. It was assumed that any fluctuations in the water-level elevations for these wells were due to natural factors. As a result, the hydraulic-head observations for these wells were defined as the overall mean elevation of all the yearly averaged water-level elevations. The variance for the hydraulic-head observation was defined as the sum of the location, land surface, and observation errors. For Flag 3 wells, the hydraulic-head-observation error was defined as the variance associated with the reduction of the multiple yearly averaged water-level elevations into the one mean value.

Flag 3 wells have drawdown observations for each yearly averaged water-level elevation after the first one. The drawdown observations for Flag 3 wells were defined as zero. The variance for the drawdown observations for Flag 3 wells was defined as the variance associated with the reduction of the multiple yearly averaged water-level elevations into the one mean value.

B.4.2.3.3 Flag 4 Hydraulic-Head and Drawdown Observations

Flag 4 wells are located in hydrographic areas that have had groundwater pumping during the historical development period and, specifically, are near groundwater pumping centers. As a result, water-level-elevation fluctuations for these wells could be the result of groundwater pumping. These wells have both hydraulic-head and drawdown observations. The first yearly averaged water-level elevation was defined as the hydraulic-head observation, while the subsequent yearly averaged water-level elevations were defined as the drawdown observations. The hydraulic-head observation for Flag 4 wells was defined as the yearly averaged water-level elevation for the first measurement of record. The variance for the hydraulic-head observation was defined as the sum of the location, land surface, and hydraulic-head observation errors. For Flag 4 wells, the hydraulic-head-observation error was defined as the variance associated with the reduction of multiple measurements in a given year into the yearly averaged water-level elevation. If there was only one water-level-elevation measurement in a given year, the hydraulic-head-observation error was defined as zero.

The drawdown observations for Flag 4 wells were defined as the difference between the first yearly averaged water-level-elevation measurement and each subsequent yearly averaged water-level-elevation measurement. The draw down observations were negative for drawups and positive for drawdowns. The variance for the drawdown observations was defined as the variance associated with the reduction of the multiple yearly averaged water-level elevations into one mean value for a given well.

B.4.2.3.4 Flag 5 Hydraulic-Head and Drawdown Observations

Flag 5 wells are located in hydrographic areas that have had groundwater pumping during the historical development period. The wells, however, are not located near groundwater pumping centers. As a result, the hydraulic-head and drawdown observations for these wells are calculated the same as for the Flag 3 wells.

Hydraulic-head observations for Flag 5 wells were defined as the overall mean elevation of all the yearly averaged water-level elevations. The variance for hydraulic-head observation was defined as the sum of the location, land surface, and observation errors. For Flag 5 wells, the hydraulic-head-observation error was defined as the variance associated with the reduction of the multiple yearly averaged water-level elevations into the one mean value.

Flag 5 wells have drawdown observations for each yearly averaged water-level elevation after the first one. The drawdown observations for Flag 5 wells were defined as zero. The variance for the drawdown observations for Flag 5 wells was defined as the variance associated with the reduction of the multiple yearly averaged water-level elevations into the one mean value.

B.4.2.3.5 Flag 6 Hydraulic-Head and Drawdown Observations

Flag 6 wells are located in hydrographic areas where groundwater pumping has occurred during the historical record, but these wells have been identified as exhibiting water-level-elevation fluctuations that can be attributed to climatic factors. As a result, each yearly averaged water-level elevation for Flag 6 wells is treated as a hydraulic-head observation. Flag 6 wells have no drawdown observations.

Hydraulic-head observations for Flag 6 wells were defined as the yearly averaged water-level elevation for each of the years in the period of record for the well. The variance for the hydraulic-head observation was defined as the sum of the location, land surface, and observation errors. For Flag 6 wells, the hydraulic-head-observation error was defined as the variance associated with the reduction of multiple measurements in a given year into the yearly averaged water-level elevation. If there was only one water-level-elevation measurement in a given year, the hydraulic-head-observation error was defined as zero.

B.5.0 SUMMARY

Hydrologic data sets of spring flow, stream flow, and water-level elevations were compiled and analyzed for the purpose of developing observation data sets for inclusion into the transient numerical model that might potentially show a response to groundwater pumping in the study area. This process included updating the data sets documented in the Baseline Report (SNWA, 2008) by adding new well locations and new water-level measurements to existing sites. It also included obtaining daily mean discharge data for both springs and streams in the study area that have continuous measurements.

The hydrologic data sets were processed and analyzed by reducing multiple yearly measurements to one average yearly measurement, deriving calendar year discharges for spring and stream locations, deriving a transient water-level-elevation data set, and assigning well-qualifier and use-code flags to the well locations in the transient water-level data set to guide their use in the model calibration.

Based on the hydrologic data sets and data analysis, observation data sets were constructed for use in calibration of the transient flow model. Model observation data sets were derived for both the pre-1945 and post-1945 time periods.

B.6.0 REFERENCES

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Appendix C
Water-Use Data Analysis

C.1.0 INTRODUCTION

This appendix describes the estimates of historical groundwater use for the study area. Historical records of anthropogenic stresses are very few within the study area. Such information is required, however, to characterize the regional flow system under transient conditions and must be reconstructed using the best estimation methods possible, when actual records do not exist. The most significant anthropogenic activities that generally affect the flow systems of the study area are groundwater withdrawals (i.e., pumping). In addition, stream diversions from the Muddy River may also have a significant impact on the flow system because this river is not only fed by large regional springs, but is also hydraulically connected to the flow system along its stream bed. Muddy River water is, in essence, groundwater. Based on the available potentiometric data provided in SNWA (2008) and [Appendix B](#) of this document, the regional flow system, except for a few localized areas, has essentially remained unaffected by human activities. Nonetheless, estimates of the historical groundwater use in the study area were needed to calibrate the numerical model to transient conditions. The transient model was then used to simulate how the historical groundwater use and the proposed Project pumping might affect groundwater conditions within the study area. A summary of background information is provided, followed by the purpose and scope of the work described in this appendix.

C.1.1 Background

Although groundwater and surface-water uses affect the hydrologic system in different ways, the net effect on the regional flow system is due to the consumptive portion of the total water use. According to NDWR (2008), consumptive water use can be defined as “the portion of water withdrawn from a surface water or groundwater source that is consumed for a particular use, and does not return to its original source or another body of water.”

With respect to groundwater use, after water is pumped from the flow system, some of the pumped water is consumed and some is lost, while the remainder is returned to the flow system. If losses are assumed to be negligible, the net effect on the hydrologic system is caused by the consumptive use. This principle applies to irrigation, domestic, and industry uses. For agricultural water use, the consumptive use is the ET of the irrigated crop. For community water use, the consumptive use is the ET of landscape vegetation and the evaporation loss associated with wastewater disposal.

Regarding surface-water use, only the consumptive portion of water use impacts the hydrologic system. For example, after surface water is diverted from a stream or spring, some of the diverted water is consumed by plant life or lost to infiltration, while the remainder returns to the hydrologic system. Thus, the net water draft from the hydrologic system is the consumptive use. In the absence of a surface-water diversion, a stream flow or spring flow spreads out on the valley floor, where it naturally irrigates phreatophytes, evaporates, or infiltrates into the subsurface. With a diversion, the

ultimate effect is to reduce the consumptive use of the phreatophytes by an amount equal to the consumptive-use part of the diversion. Except for stream diversions from the Muddy River in the southern portion of the study area, the effect of irrigation with surface water is assumed to have equilibrated within the flow system and is, therefore, implicitly accounted for by the groundwater ET estimates. Thus, except for major municipal and industrial and power plant diversions from the Muddy River, stream diversions will not be accounted for explicitly in the consumptive water-use estimates.

C.1.2 Purpose and Scope

Consumptive water-use estimates for the hydrographic areas composing the model domain were needed as input to the numerical model to calibrate the transient numerical model and to simulate the cumulative effects of groundwater pumping and Muddy River diversions.

The consumptive water-use estimates reflect groundwater and surface-water development related to municipal, agricultural, industrial and power plant, and mining and milling uses. The development of water resources from the natural condition represents an increase in the overall consumptive use of the regional flow system from the steady-state condition, in which the only consumptive uses were the transpiration of natural vegetation and evaporation.

The resultant work products are (1) a series of maps that depict the extent of groundwater-irrigated cropland in the study area for nine different time periods, (2) estimated historical consumptive water use for each of the identified time periods, and (3) a series of maps that depict the locations of the groundwater points of diversion or surface-water diversions for each of the time periods.

The remaining sections of this appendix discuss the water-use information available for the study area, the methodology used to estimate historical consumptive water use for the hydrographic areas in the study area, and the distribution of the consumptive water-use estimates to appropriate points of diversion. The consumptive water-use estimates were derived by hydrographic area and manner of use for the period 1945 to 2004.

C.2.0 AVAILABLE INFORMATION

Several agencies, including the USGS, NDWR, Nevada Division of Water Planning, and UDWR, have attempted to quantify water use for select portions of the study area. This section provides a brief summary of the pertinent sources.

The USGS reports data on water withdrawals by state, source of water, and category of use at 5-year intervals for the United States (e.g., Solley et al., 1993, 1998; Hutson et al., 2004). Data files associated with these reports estimate water use by county. In addition to the 5-year water-use estimates, the USGS estimated groundwater pumping and artificial recharge for the year 2000 in SIR 2004-5239 (Lopes and Evetts, 2004). That report provided estimates of groundwater pumping by hydrographic area for the entire state of Nevada for several categories of use, including irrigation, mining, water systems, geothermal, domestic, and miscellaneous. A subset of the data for the model area is provided in [Table C-1](#). More recently, the USGS estimated water use in 2005 for 12 hydrographic areas in White Pine County as part of BARCASS (Welch et al., 2008). Welch et al. (2008) estimated water use for several types of use, including stock watering, mining, public supply, and domestic.

The State of Nevada has also estimated groundwater pumping and water use in Nevada in several reports published by the Department of Conservation and Natural Resources, including those by Smales and Harrill (1971) and the Nevada Division of Water Planning (1992). Groundwater-pumping inventories are also accessible on the NDWR website for some hydrographic areas. Typically, groundwater-pumping inventories are available from 1989 to the present. Available data for select hydrographic areas in the model area are listed in [Table C-2](#). These estimates can be compared to the year 2000 estimates from the USGS. The table reflects that, for most of the hydrographic areas, the total estimated groundwater pumpage has varied very little between 2000 and 2004. Notable increases in groundwater pumpage between 2000 and 2004, however, can be seen in Panaca and Pahranaagat valleys.

The UDWR prepares yearly reports on the groundwater conditions in Utah. These “Cooperative Investigations” reports are available from 1964 to 2007, include estimates of groundwater-use volumes by type of use, and cover the portion of Snake Valley located in Utah. These reports, however, do not include quantified estimates of the extent of the irrigated cropland.

Table C-1
Groundwater-Pumpage Estimates (in af)
for Hydrographic Areas in the Model Area in 2000

HA Number	HA Name	Irrigation and Stock Watering	Mining	Water Systems	Geothermal Productions	Self-Supplied Domestic	Misc.	Total Pumpage
171	Coal Valley	0	0	0	0	30	0	30
172	Garden Valley	0	0	0	0	30	0	30
174	Jakes Valley	0	0	0	0	30	0	30
175	Long Valley	0	0	0	0	40	0	40
178	Butte Valley	3,560	0	0	0	80	0	3,640
179	Steptoe Valley	3,560	0	2,800	0	0	0	6,360
180	Cave Valley	0	0	0	0	40	0	40
181	Dry Lake Valley	0	0	0	0	60	0	60
182	Delamar Valley	0	0	0	0	30	0	30
183	Lake Valley	12,990	0	0	0	30	0	13,020
184	Spring Valley	4,170	0	20	0	90	0	4,280
185	Tippett Valley	0	0	0	0	20	0	20
194	Pleasant Valley	0	0	0	0	0	0	0
195	Snake Valley	470	0	30	0	30	0	530
196	Hamlin Valley	0	0	0	0	20	0	20
198	Dry Valley	5,170	0	0	0	10	0	5,180
199	Rose Valley	1,370	0	0	0	0	0	1,370
200	Eagle Valley	0	0	0	0	0	0	0
201	Spring Valley	0	0	0	0	20	0	20
202	Patterson Valley	2,170	0	40	0	0	0	2,210
203	Panaca Valley	9,250	0	470	0	70	0	9,790
204	Clover Valley	0	0	120	0	0	0	120
205	Lower Meadow Valley Wash	330	0	0	0	120	0	450
206	Kane Springs Valley	0	0	0	0	30	0	30
207	White River Valley	3,340	0	50	0	140	0	3,530
208	Pahroc Valley	0	0	0	0	30	0	30
209	Pahranagat Valley	2,320	0	390	0	80	0	2,790
210	Coyote Spring Valley	0	50	150	0	0	0	200
215	Black Mountains Area	0	0	1,700	0	1,090	0	2,790
216	Garnet Valley	0	0	0	0	40	0	40
217	Hidden Valley	0	0	0	0	10	0	10
218	California Wash	0	0	0	0	160	0	160
219	Muddy River Springs Area	0	0	130	0	0	0	130
220	Lower Moapa Valley	0	0	0	0	960	0	960

Source: Lopes and Evetts (2004)

Table C-2
NDWR Groundwater-Pumpage Inventories (in af) for Select Basins in the Model Area
 (Page 1 of 2)

HA Number	HA Name	Year ^a	Irrigation	Recreation	Other ^b	Domestic	Stock Water	Total
198	Dry Valley	1989	5,354	---	---	---	---	5,354
		1990	5,354	---	---	---	---	5,354
		1991	5,230	---	---	---	---	5,230
		1992	4,959	---	---	---	---	4,959
		1993	4,959	---	---	---	---	4,959
		1994	4,959	---	---	---	---	4,959
		1995	4,959	---	---	---	---	4,959
		1996	4,959	---	---	---	---	4,959
		1997	4,959	---	---	---	---	4,959
		1998	4,908.4	1	---	11	---	4920.4
		1999	5,171.4	1	---	10	---	5,182.4
		2000	5,171.4	1	---	10	---	5,182.4
		2001	5,171.4	1	---	10	---	5182.4
		2002	5,171	1	---	14	---	5,186
		2003	5,171	10	---	19	5	5,205
2004	5,171	10	---	21	5	5,207		
199	Rose Valley	1989	590	---	---	---	---	590
		1990	NA	NA	NA	NA	NA	NA
		1991	661	---	---	---	---	661
		1992	1,063.5	---	---	---	---	1,063.5
		1993	1,058.8	---	---	---	---	1,058.8
		1994	1,083.8	---	---	---	---	1,083.8
		1995	1,083.8	---	---	---	---	1,083.8
		1996	1,083.8	---	---	---	---	1,083.8
		1997	1,083.8	---	---	---	---	1,083.8
		1998	1,367.5	---	---	3	---	1,370.5
		1999	1,367.5	---	---	3	---	1,370.5
		2000	1,367.5	---	---	3	---	1,370.5
		2001	1,367.5	---	---	3	---	1,370.5
		2002	1,368	---	---	6	---	1,374
		2003	1,388	---	---	6	---	1,394
2004	1,388	---	---	6	---	1,394		
203	Panaca Valley	1989	7,130	---	150	---	---	7,280
		1990	7,130	---	150	---	---	7,280
		1991	6,431.6	---	150	---	---	6,581.6
		1992	8,462	---	150	---	---	8,612
		1993	7,509	---	150	---	---	7,659

Table C-2
NDWR Groundwater-Pumpage Inventories (in af) for Select Basins in the Model Area
 (Page 2 of 2)

HA Number	HA Name	Year ^a	Irrigation	Recreation	Other ^b	Domestic	Stock Water	Total
203 (Cont.)	Panaca Valley (Cont.)	1994	8,386	---	150	---	---	8,536
		1995	8,048	---	150	---	---	8,198
		1996	10,042	---	300	---	2	10,344
		1997	10,699	---	18	64	14	11,095
		1998	9,819	---	306	68	14	10,207
		1999	9,842	---	442	68	14	10,366
		2000	9,232	---	467	70	14	9,783
		2001	9,232	---	391	74	14	9,711
		2002	11,229	---	359	89	14	11,691
		2003	12,635	---	558	91	14	13,298
		2004	13,236	---	1,142	97	14	14,498
209	Pahranaagat Valley	1989	4,210	---	---	200	---	4,410
		1990	4,197	---	---	200	---	4,397
		1991	4,901	---	---	200	---	5,101
		1992	4,396	---	---	200	---	4,596
		1993	4,198	---	---	200	---	4,398
		1994	4,103	---	---	200	---	4,303
		1995	3,707	---	---	200	---	3,907
		1996	2,151	---	332	73	37	2,593
		1997	2,586	---	331	73	37	3,027
		1998	2,827	---	214	78	35	3,154
		1999	2,310	---	401	80	37	2,828
		2000	2,279	---	390	84	37	2,790
		2001	1,566	---	339	85	38	2,028
		2002	3,334	---	337	89	45	3,805
2003	3,758	---	327	91	45	4,221		
		2004	3,732	---	293	92	47	4,164
215	Black Mountains Area	2001	---	0.12	1,602	---	---	1,602
		2002	---	---	1,915	1	---	1,916
		2003	---	---	1,976	2	---	1,978
		2004	---	---	1,938	---	---	1,938
216	Garnet Valley	2001	---	---	912	--	---	912
		2002	---	---	844	---	---	844
		2003	---	---	885	---	---	885
		2004	---	---	817	---	---	817

^aYearly data from the NDWR website accessed at <http://water.nv.gov/>

^b"Other" includes quasi-municipal, industrial, mining, and commercial manners of use.

NA = Not available

C.3.0 HISTORICAL CONSUMPTIVE WATER-USE ESTIMATES

Based on the development history of the basins in the study area, as documented in the Nevada Ground-Water Resources-Reconnaissance Reports and the NDWR water-rights database, groundwater use by man did not become significant until the mid-1940s. However, prior to that time, Boulder Dam (now Hoover Dam) had been completed (i.e., 1937), and Lake Mead had been filled. Spring flow records at the Muddy, Roger, and Blue Point springs indicate that filling the lake has not significantly affected the majority of the flow system of the study area. Thus, predevelopment conditions are assumed to prevail up to 1945 with a historical mean lake level.

The historical development period is from 1945 to 2004. This period represents a time when significant development by man occurred. The end of this period is assumed to represent “current conditions” but is limited to 2004 because most data-compilation activities supporting the data analysis and model development were completed in 2005. In a report titled *Water-Use Trends in the Desert Southwest—1950–2000* (Konieczki and Heilman, 2004), the authors report that the total number of irrigated acreage in Nevada started to decrease in the mid-1970s and appeared to stabilize in the 1990s. The numbers are reported every 5 years. Considering the large scale of this regional study, both in space and time, year-to-year variations in groundwater-resource development are considered minor and beyond the scope of this study. It is, therefore, appropriate to assume that the conditions of the flow system have been approximately the same over the last few years.

For most of the hydrographic areas in the study area, no groundwater-pumping or surface-water diversion records exist from which historical consumptive water-use estimates can be derived. Derivation of a historical pumping schedule is further complicated by the fact that in many of these areas, water for irrigation is supplied by both surface water and groundwater. For example, groundwater is commonly pumped to supplement surface-water sources used to irrigate crops. This adds another layer of complexity to estimating groundwater use in that supplemental groundwater pumping generally only occurs when conditions warrant it, such as in low runoff years. Nevertheless, estimates of the historical consumptive water use for the model area were made for four different categories of use for the period from 1945 to 2004. The four water-use categories included municipal, agricultural, mining and milling, and industrial and power plant water uses. Stock watering and self-supplied domestic uses were excluded because their consumptive water use is relatively small compared to the other manners of use in the study area.

The consumptive water-use estimates were derived using a combination of reported groundwater-pumping or surface-water diversion data and estimates of consumptive water use based on water-rights information obtained from NDWR and UDWR. The water-rights information was used as a surrogate to estimate consumptive groundwater use because, for the most part, quantifiable groundwater-use data are lacking for most of the study area, especially going back to 1945. Each type of water use will be discussed in greater detail in the following sections.

C.3.1 Municipal Water Use

Estimates of consumptive water use were made for the following municipalities in the study area: Ely, Lund, McGill, Caliente, Alamo, Panaca, Pioche, Moapa, and Moapa Valley. The water use attributed to a community was based on a combination of reported groundwater-pumping or surface-water diversion data and estimates of historical water use. In general, the overall approach consisted of the following steps:

1. Derived historical water-use estimates based on population estimates and per capita water-use rates.
2. Added reported (i.e., known) water-use data, when available, to the historical water-use estimates.
3. Used the reported data along with the population estimates to derive a scaling factor to adjust the population-based, historical water-use estimates. This step ensured that the estimates were consistent with the reported data.
4. Derived historical consumptive water-use estimates from the water-use estimates.

The following sections discuss the estimation of historical consumptive water use by municipalities in greater detail.

C.3.1.1 Water-Use Estimates Based on Population

Historical water-use estimates were derived from population estimates and per capita water-use rates according to the following equation:

$$WU = R \times P \times C \quad (\text{Eq. C-1})$$

where,

- WU = Municipal water-use estimate, in afy
 R = The per capita water-use rate, in gallons per capita per day
 P = The population estimate, dimensionless
 C = A conversion factor used to convert to afy

[Equation C-1](#) was used to derive water-use estimates for each of the municipalities for each year between 1945 and 2004. Estimates of the independent variables in [Equation C-1](#) are discussed in the following sections.

C.3.1.1.1 Per Capita Water-Use Rates

Per capita water-use rates were obtained from data files downloaded from <http://water.usgs.gov/watuse/data/2000/nvco2000.xls>. These data files provide water-use estimates by county for the

United States, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands. These data files support the state-level water-use estimates published in USGS Circular 1268 (Hutson et al., 2004). From the data compiled by Hutson et al. (2004), a per capita water-use rate for municipal water was calculated for each county in Nevada. The per capita water-use rate in gallons per day was 344 for communities in Clark County, 401 for communities in Lincoln County, and 330 for communities in White Pine County.

C.3.1.1.2 Population Estimates

Population data for the communities in Clark, Lincoln, and White Pine counties were obtained from three main sources.

- The first source was a Nevada State Demographer report titled *Nevada County Population Estimates July 1, 1986 to July 1, 2004 Includes Cities and Towns* (Nevada State Demographer, 2004).
- The second source of population data was the Nevada State Library and Archives that can be accessed at <http://nevadaculture.org/nsla/>.
- The last source of population data was the Clark County Comprehensive Planning Group. They provided population data for the communities of Moapa and others in Lower Moapa Valley for the years 1990 to 1995 and 1990 to 2004, respectively.

Population data for cities, towns, or townships are available by decade. These population data go back to 1860 for certain cities. For the years in which actual population data were not available, estimates were made by linear interpolation between the known years. For example, most cities have population data for every ten years, but not for the individual years within a decade. In these instances, the missing records were derived by linear interpolation between the two known values. Population data from the Nevada State Library and Archives is reported sometimes in terms of a “township.” For example, the 1940 U.S. census reports population data for the Alamo township, which includes the actual town of Alamo. The Alamo township included the entire western part of Lincoln County. When possible, these population estimates were scaled to a year in which both the township population and actual town population were both reported. Because each community had a slightly different method to estimate its population, each community is discussed in the following sections explicitly.

C.3.1.1.2.1 Ely

Population data for the city of Ely are available for the years 1940, 1950, 1960, 1970, and 1980 from the Nevada State Library and Archives. Population data for the years 1986 through 2004 are available from the Nevada State Demographer. Population data for the unknown years were estimated by linear interpolation between reported values.

C.3.1.1.2.2 Lund

Population data for “Lund township #4” are available for the years 1940, 1950, and 1960 from the Nevada State Library and Archives. Population data for “Lund township” are also available for the years 1970 and 1980 from the Nevada State Library and Archives. It was assumed that the population of the “Lund township” and “Lund township #4” were the population of the city of Lund for those years. Population data for the “Lund census county division” are available for the year 1990 from the Nevada State Library and Archives. The 1990 population of the “Lund township” was scaled to the year 2000 population of the city of Lund because both were reported for the year 2000. The scaling was not done for the earlier decades because the township boundaries were different prior to 1980. Population data for the city of Lund are available for 1996 to 2004 from the Nevada State Demographer. Population data for the missing years were estimated by linear interpolation between the two decades in which there were reported values.

C.3.1.1.2.3 McGill

Population data for “McGill unincorporated,” “McGill census designated place,” and “McGill precinct” are available for the years 1930, 1950, 1960, 1970, 1980, and 1990 from the Nevada State Library and Archives. It was assumed that these population values represented the population for the city of McGill. Population data for the city of McGill are available for the years 1996 to 2004 from the Nevada State Demographer. Population data for the missing years were estimated by linear interpolation between the two decades in which there were reported values.

C.3.1.1.2.4 Caliente

Population data for the city of Caliente are available for the years 1950, 1960, 1970, and 1980 from the Nevada State Library and Archives. Population data for “Caliente township” are available for the year 1940 from the Nevada State Library and Archives. The 1940 township population was scaled to the 1950 population that reported both the population of the city and the township. Population data for the city of Caliente are available for the years 1986 to 2004 from the Nevada State Demographer. Population data for the missing years were estimated by linear interpolation between the two decades in which there were reported values.

C.3.1.1.2.5 Alamo

Population data for the “Alamo township” are available for the years 1940, 1950, 1960, 1970, and 1980 from the Nevada State Library and Archives. Population data for the “Alamo census county division” are available for year 1990 from the Nevada State Library and Archives. Population data for the city of Alamo are available for the years 1996 to 2004 from the Nevada State Demographer. The “Alamo township” and “Alamo census county division” data were scaled to the population data for the city of Alamo in 2000 because both the census county division and city population data were available for that year. Population data for the missing years were estimated by linear interpolation between the two decades in which there were reported values.

C.3.1.1.2.6 Panaca

Population data for the “Panaca township” are available for the years 1940, 1950, 1960, 1970, and 1980 based on data from the Nevada State Library and Archives. It was assumed that the population of the “Panaca township” was equal to the population of the city of Panaca. Population data for the city of Panaca are available for 1996 to 2004 from the Nevada State Demographer. Population data for the missing years were estimated by linear interpolation between the two decades in which there were reported values.

C.3.1.1.2.7 Pioche

Population data for the “Pioche township” are available for the years 1940, 1950, 1960, 1970, and 1980 from the Nevada State Library and Archives. Population data for the “Pioche census county division” are available for the year 1990 from the Nevada State Library and Archives. Population data for the city of Pioche are available for 1996 to 2004 from the Nevada State Demographer. The “Pioche township” and “Pioche census county division” data were scaled to the population data for the city of Pioche for the year 2000 because both were reported for that year. Population data for the missing years were estimated by linear interpolation between the two decades in which there were reported values.

C.3.1.1.2.8 Moapa

Population data for “Moapa township #6” are available for the years 1940 and 1950 from the Nevada State Library and Archives. Population data for “Moapa township” are available for the years 1960, 1970, and 1980 from the Nevada State Library and Archives. It was assumed that the populations of the townships were equivalent to the population of the city for those decades. Population data for the city of Moapa are available for the years 1990 through 1995 from the Clark County Comprehensive Planning Group. Population data for the city of Moapa are available for the years 1996 to 2004 from the Nevada State Demographer. Population data for the missing years were estimated by linear interpolation between the two decades in which there were reported values.

C.3.1.1.2.9 Moapa Valley

Population data for Moapa Valley were estimated by summing the populations of the “Logan” (or “Logandale”) and “Overton” townships for the years 1940, 1950, 1960, and 1970 from the Nevada State Library and Archives. The population of Moapa Valley was estimated in 1980 by adding the population of the “Logan township” and the “Overton census designated place” from the Nevada State Library and Archives. Population data for Moapa Valley are available for the years 1990 to 2004 from the Clark County Comprehensive Planning Group. Population data for the missing years were estimated by linear interpolation between the two decades in which there were reported values.

C.3.1.2 Groundwater-Pumping and Surface-Water Diversion Data

Municipal groundwater-pumping and surface-water diversion data were obtained from a number of sources including NDWR and the Moapa Valley Water District (MVWD). NDWR reported

groundwater-pumping and surface-water diversion data for the communities of Alamo (1986-2004), Ely (2002-2004), and Panaca (1996-2004). These data were only available, however, for a select numbers of years. The MVWD provided groundwater-pumping and surface-water diversion data for the communities of Moapa, Glendale, Logandale, and Overton. Groundwater-pumping data were available for four wells operated by the MVWD. Surface-water diversion data were available for two spring diversion locations that, when not diverted, contribute water to the Muddy River. The surface-water diversion data are available for Jones Spring since 1959 and for Baldwin Spring since 1975. Groundwater-pumping data for Well MX-6 are available since 1986, while the remainder of the groundwater-pumping data from the MVWD (i.e., Arrow Canyon and Logandale wells) are available since 1992. The reported groundwater-pumping or surface-water diversion data from the MVWD are attributed to the actual well or spring diversion locations as opposed to the municipality locations.

C.3.1.3 Adjustment of Water-Use Estimates Based on Reported Data

The reported groundwater-pumping and surface-water diversion data also provided a means to derive historical water-use estimates based solely on the population. Adjustments were made for the communities of Alamo, Panaca, and Ely.

For those communities, scaling factors were derived from the population estimates and the reported water use in a given year. For example, population data and reported water-use data were available for the years 1996 through 2004 for the town of Panaca. An average scaling factor for those years was derived that relates the population to the reported water use. This average scaling factor was then applied to the population estimates for all of the other years to derive estimates of the municipal water use. These estimates were then used instead of the water-use estimates that were based solely on the population and the per capita water-use rate. These scaling factors produce historical water-use estimates that more closely match the reported data for a particular municipality.

The water-use estimate adjustment for the city of Ely was complicated by the fact that Ely obtains its municipal water from both groundwater and surface-water sources. As a result, an additional scaling factor was necessary to account for the source of the water. Based on three years of data (i.e., 2002, 2003, and 2004), the city of Ely obtains 95.8 per cent of its municipal water from surface-water sources and 4.2 percent of its municipal water from groundwater sources. As a result, a combined scaling factor was derived to estimate the groundwater from the population estimate. The surface-water use by Ely was not accounted for as a net withdrawal from the regional flow system because the surface water originates from Murry Springs and creek, which are not considered to be part of the regional or intermediate groundwater flow system.

C.3.1.4 Derivation of Municipal Consumptive Water Use

For the sake of simplicity, this study assumed that municipal consumptive water use for all communities was equal to 50 percent of the municipal water use. This assumption is consistent with Harrill (1986) and Brothers et al. (1993) who also assumed that 50 percent of municipal water use was consumptively used. Municipal water use reported by MVWD for groundwater and surface-water diversions in the Muddy River Springs Area and Lower Moapa, however, was assumed

to be 100 percent consumptively used because the water is removed from the system and typically transported large distances.

In summary, consumptive water-use estimates for communities in the study area were obtained from a combination of reported groundwater-pumping data, surface-water diversion data, and estimates of water use based on a community's population and a per capita water-use rate. Estimates of water use were obtained by multiplying the per capita water-use rate by the population of a given community or by using the derived scaling factor for a community multiplied by the population. Actual water-use data were used when available. For instance, population data were used to estimate the consumptive use of water for the communities of Alamo and Panaca prior to 1996. After 1996, reported groundwater-pumping data from NDWR were used.

C.3.2 Agricultural Water Use

Most of the consumptive water use in the study area occurs from irrigated croplands. The sources of water for irrigation include precipitation, surface water, and groundwater. Surface water is defined as water that originates as runoff from precipitation, while groundwater includes water that is pumped from underground or water that is discharged from regional springs. A sufficient amount of reported data is not available for the study area to accurately define the agricultural water use for each hydrographic area. As an example, NDWR conducts crop and groundwater-pumpage inventories for select hydrographic areas within the model area, but the data are only available for certain years and not for every hydrographic area. In addition, satellite imagery can be used to delineate agricultural land but is not available for every year back to 1945.

Because of the lack of historical water-use records, estimates of historical consumptive water use for irrigation were derived using a combination of data from the NDWR and UDWR databases, satellite imagery, and crop consumptive-use rates obtained for the study area. The general approach consisted of the following steps:

1. Obtained crop consumptive groundwater-use rates for those hydrographic areas that have agriculture.
2. Derived a series of place-of-use maps that represent the extent of cropland irrigated with groundwater for the years 1945 to 2004.
3. Estimated crop consumptive groundwater-use volumes based on the crop consumptive groundwater-use rates and area of cropland irrigated with groundwater.

The following sections discuss the estimation of crop consumptive groundwater-use volumes in greater detail.

C.3.2.1 Derivation of Crop Consumptive Groundwater-Use Rates

Crop consumptive groundwater-use rates vary based upon the crop type, local climate conditions, and geographic location. For basins in the study area, NDWR has recently updated crop ET and net

irrigation water-requirement estimates for Nevada. Huntington and Allen (2009) stated that the updated estimates of ET and net irrigation water requirements will be used for updating basin water budgets and establishing the amount of irrigation water that is available for water transfers in the future in Nevada. According to Huntington and Allen (2009), the crop ET and net irrigation water-requirement estimates were made for major crops using more than 200 National Weather Service (NWS) stations located throughout the state. Specifically, Huntington and Allen (2009) stated that the net irrigation water requirements for crops were estimated using a dual-crop coefficient and daily soil-water-balance approach.

Huntington and Allen (2009) defined the net irrigation water requirement using the following equation:

$$ET_c = (ET_{act}) - (P) \quad (\text{Eq. C-2})$$

where,

- ET_c = The net irrigation water requirement (a.k.a, the net crop consumptive groundwater-use rate) (ft/yr)
 ET_{act} = The actual crop ET (ft/yr)
 P = The precipitation residing in the root zone (ft/yr)

According to Huntington and Allen (2009), the mean annual net irrigation water requirement of alfalfa for all NWS stations analyzed was computed for the last 30 years of record available, and the results were then spatially distributed and averaged to hydrographic-area boundaries. The net irrigation water requirements of alfalfa for hydrographic areas in this study are provided in [Table C-3](#).

C.3.2.2 Derivation of Groundwater-Irrigation Place-of-Use Maps

The place-of-use maps were derived to delineate the extent of the cropland areas irrigated with groundwater for the period between 1945 and 2004. Because of the lack of historical data, the extents of the croplands irrigated with groundwater were derived using a combination of information from water-right databases from NDWR and UDWR and the overall extent of the irrigated lands as interpreted from 2002 satellite imagery.

In general, the method consisted of the following steps:

1. Subdivided the historical period (1945 to 2004) into discrete time periods to reduce data processing and reporting requirements.
2. Created maps that represent the places of use associated with both surface-water and groundwater irrigation for each time period based on data obtained from NDWR and UDWR.
3. Identified the places of use irrigated exclusively with groundwater rights and the places of use associated with both groundwater and surface-water rights (i.e., commingled or supplemental water rights).

Table C-3
Irrigation Water Requirements for Alfalfa in Study Area

HA Number	HA Name	Alfalfa Net Consumptive Use ^a (ft/yr)
179	Steptoe Valley	2.8
183	Lake Valley	2.9
184	Spring Valley	3.1
194	Pleasant Valley	3.1 ^b
195	Snake Valley	3.1 ^b
198	Dry Valley	3 ^c
199	Rose Valley	3 ^c
200	Eagle Valley	3 ^c
202	Patterson Valley	2.9 ^d
203	Panaca Valley	4
204	Clover Valley	4
205	Lower Meadow Valley Wash	4.1
207	White River Valley	3.3
209	Pahrnagat Valley	4.4
218	California Wash	4.6 ^e
219	Muddy River Springs Area	4.6 ^e
220	Lower Moapa Valley	4.6 ^e

^aSource: Felling (2009)

^bThe net consumptive use is assumed to be the same as for Spring Valley (HA 184)

^cThe net consumptive use is assumed to be the same as for Spring Valley (HA 201)

^dThe net consumptive use is assumed to be the same as for Lake Valley (HA 183)

^eThe net consumptive use is assumed to be the same as for Lower Moapa (HA 220)

- Adjusted the place-of-use maps by limiting their aggregated extents to the agricultural extents identified on the 2002 satellite imagery (i.e., removed areas associated with the water rights that fall outside of the irrigated areas identified from 2002 satellite imagery).

The following sections discuss the derivation groundwater place-of-use maps in greater detail.

C.3.2.2.1 Subdivision of the Historical Period

The historical development period is from 1945 to 2004. This 60-year period represents a time when significant development by man occurred. Because of the lack of reported crop inventories or water use for the study area, it is difficult to derive groundwater-irrigation place-of-use maps for each year of the historical development period. As a result, the historical development period was subdivided into nine discrete time periods. These time periods include 1945 to 1955, 1956 to 1965, 1966 to 1975, 1976 to 1980, 1981 to 1985, 1986 to 1990, 1991 to 1995, 1996 to 2000, and 2001 to 2004. The periods at the beginning of the historical development period correspond to 10-year time intervals,

while the periods at the end of the historical development period correspond to 5-year time intervals. The 5-year time intervals were used to obtain better resolution on the timing of irrigation development activities within the study area when more data to estimate water use are available. The subdivision of the historical development period into fewer discrete periods reduces data processing and reporting requirements from 60 yearly estimates of irrigated cropland to 9 estimates of irrigated cropland.

C.3.2.2.2 Surface-Water and Groundwater Places of Use

Maps that represent surface-water and groundwater places of use were derived from information obtained from NDWR and UDWR. NDWR provided a place-of-use database for the basins in the study area that contained irrigated land identified from the 2002 satellite imagery. The place-of-use database identified the number of acres being irrigated in a particular subdivision of the Public Land Survey System (PLSS). For example, a given water right might state that a farmer is allowed to irrigate 50 acres in Section 10 of Township 19N and Range 63E. These legal description locations were then converted to an x-y coordinate system for plotting purposes. In order to simplify this process, a given place-of-use location was plotted in the center of the smallest part of the legal description. For example, if a given place of use was in Township 19N and Range 63E, the place-of-use point was the center of that particular township. As a result, several degrees of accuracy were attributed to the place-of-use information (e.g., quarter-quarter section, quarter section, section, and Township and Range). A majority of the place-of-use information was located to the nearest quarter-quarter section; however, a number of places of use were only accurate to the nearest section or the nearest Township and Range.

Once each place of use was assigned x-y plotting coordinates, the data were further subdivided based on the status of the water right, the source of the water (i.e., groundwater versus surface water), and the time period (e.g., 1945 to 1955) to which each water right's filing date corresponded. The x-y data were then plotted in ArcGIS®. Only active water rights were used to create the maps representing the surface-water and groundwater places of use. For this study, active water rights included certificated, permitted, vested, reserved, and decreed water rights (along with the corresponding Utah equivalents). After the place-of-use information was subdivided into the appropriate aliquot parts, spatial queries were performed against PLSS shapefiles at the same accuracy as the place-of-use information to identify polygonal areas where irrigation was occurring. The polygonal areas for each accuracy were then combined into one map for each period and source of water. This methodology for identifying irrigation places of use overestimates the actual area of irrigation because, in almost all cases, a given water right is only irrigating a portion of the smallest part of the legal description. For example, a given water right might state that it is irrigating 15 acres of the NW1/4 of the NW1/4 of Section 10 Township 15N and Range 64E, but this methodology would have selected the entire 40 acres of the NW1/4 of the NW 1/4 of Section 10. Nevertheless, this methodology allows for a coarse determination of the locations of irrigation by surface water and groundwater during each of the historical periods. It should be pointed out that an active water right existing in a given time period does not necessarily mean that the water right was actually being used during that time period.

C.3.2.2.3 Identification of Sources of Water for Irrigation Places of Use

The groundwater and surface-water place-of-use maps that were created in the previous step were then used to identify areas where groundwater irrigation occurs. Essentially, the place-of-use maps were used to exclude areas being irrigated solely with surface water. This was done for each of the nine time periods. Surface-water irrigation areas were identified by combining the groundwater and surface-water place-of-use maps for each period. Spatial queries were then performed to identify those places of use that were irrigated solely with groundwater and areas that were irrigated with groundwater and surface water.

The identification of the sources of water for irrigation on the Utah side of Snake and Pleasant valleys was done in a slightly different manner than that used for the places of use in Nevada because a place-of-use database was not available for download. The UDWR website, however, has an online tool that allows for the querying of place-of-use information by section, township, and range. The query results indicate which water rights are being used in a particular aliquot of a section and the source of the water. This tool allowed for the determination of the source of water for the irrigated areas that were delineated from the 2002 satellite image for the Utah side of Snake and Pleasant valleys.

C.3.2.2.4 Adjustment of Place-of-Use Maps

The final step in the delineation of groundwater-irrigated croplands was to adjust the place-of-use maps by limiting their aggregated maximum extents to the actual cropland extents identified on the 2002 satellite imagery. This was done to reduce the irrigated cropland acreage that was obtained from the creation of the place-of-use maps, which overestimate the irrigation acreage. The study assumed that the irrigated areas interpreted from the 2002 satellite imagery represent the maximum extent of croplands irrigated in the study area.

This process consisted of using the place-of-use maps for each time period in conjunction with the delineated agricultural areas from the 2002 satellite imagery. When the places of use in a given time period corresponded to an agricultural area delineated from the 2002 satellite imagery, the delineated agricultural areas were then considered to have been present in that particular time period (see [Figures C-1 through C-9](#) for the place-of-use maps). This build-out process allows for an estimation of the historical agricultural areas found in the study area. Several assumptions are implicit in this estimation methodology including:

- Once a groundwater right becomes active, it is assumed to stay active indefinitely.
- The extents of the irrigated areas interpreted from the 2002 satellite imagery represent the maximum extent.

The resulting estimates of the historical cropland acreages are listed in [Table C-4](#) by basin and time period.

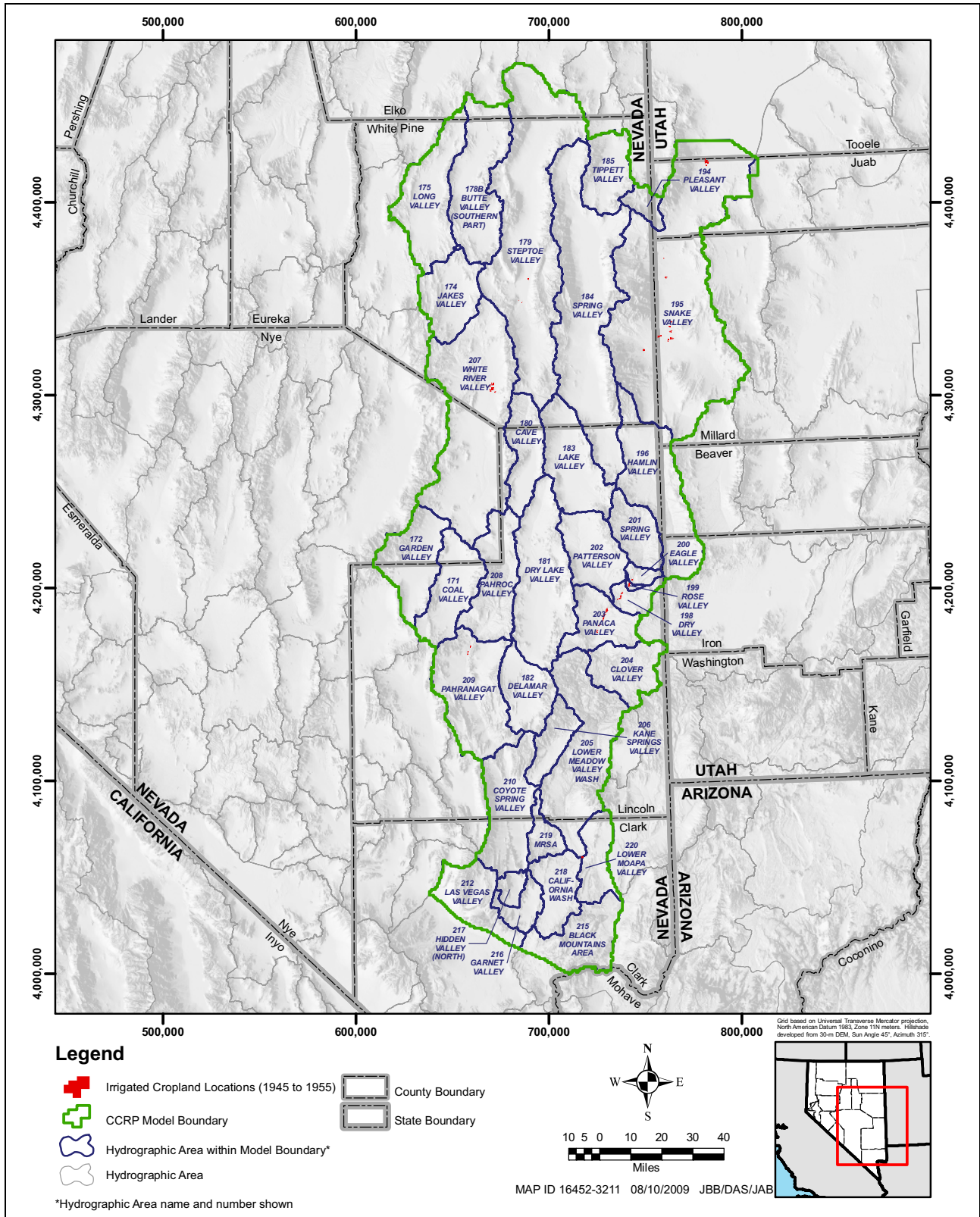


Figure C-1
Spatial Distribution of Groundwater-Irrigated Cropland
for the 1945 to 1955 Time Period

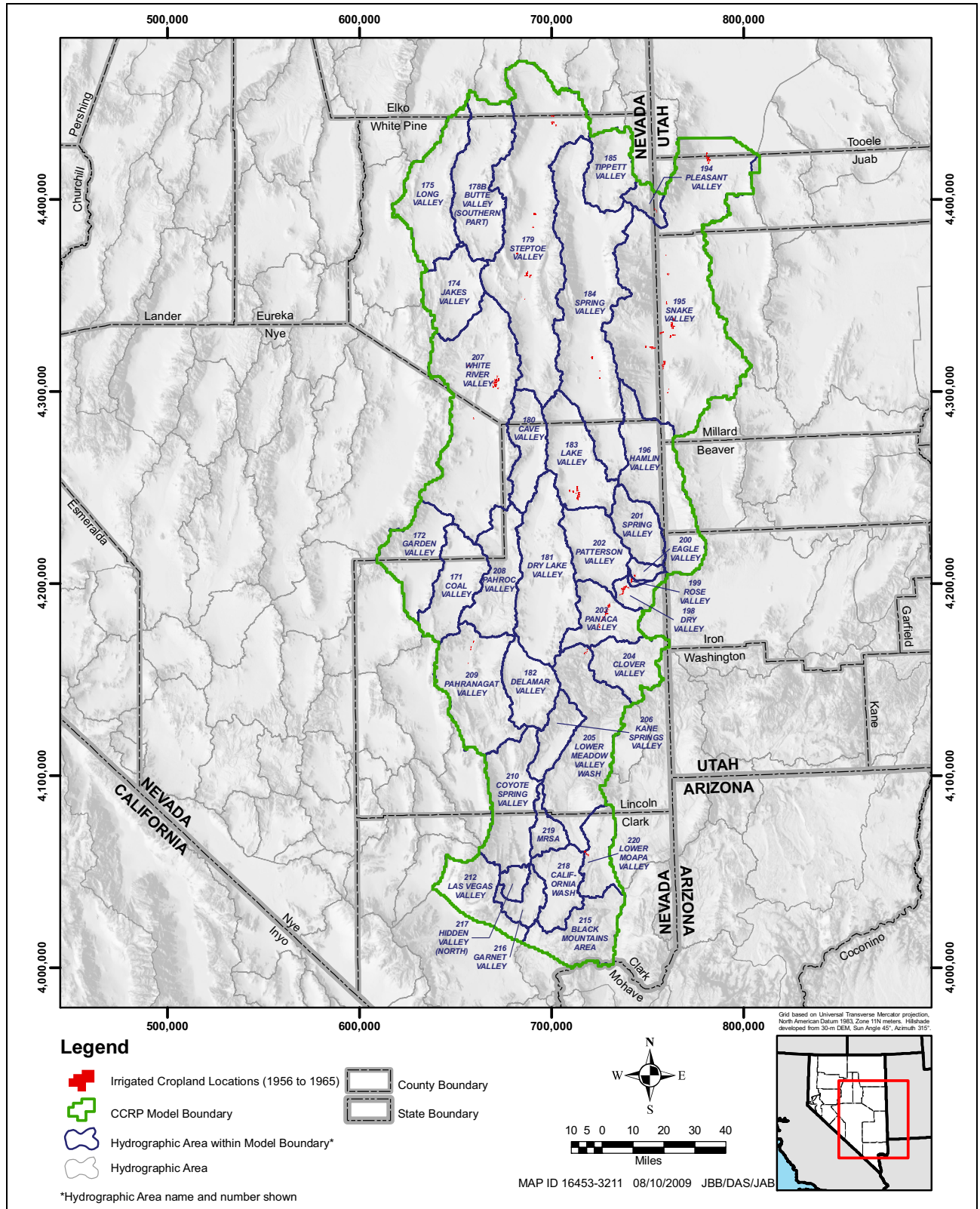


Figure C-2
Spatial Distribution of Groundwater-Irrigated Cropland
for the 1956 to 1965 Time Period

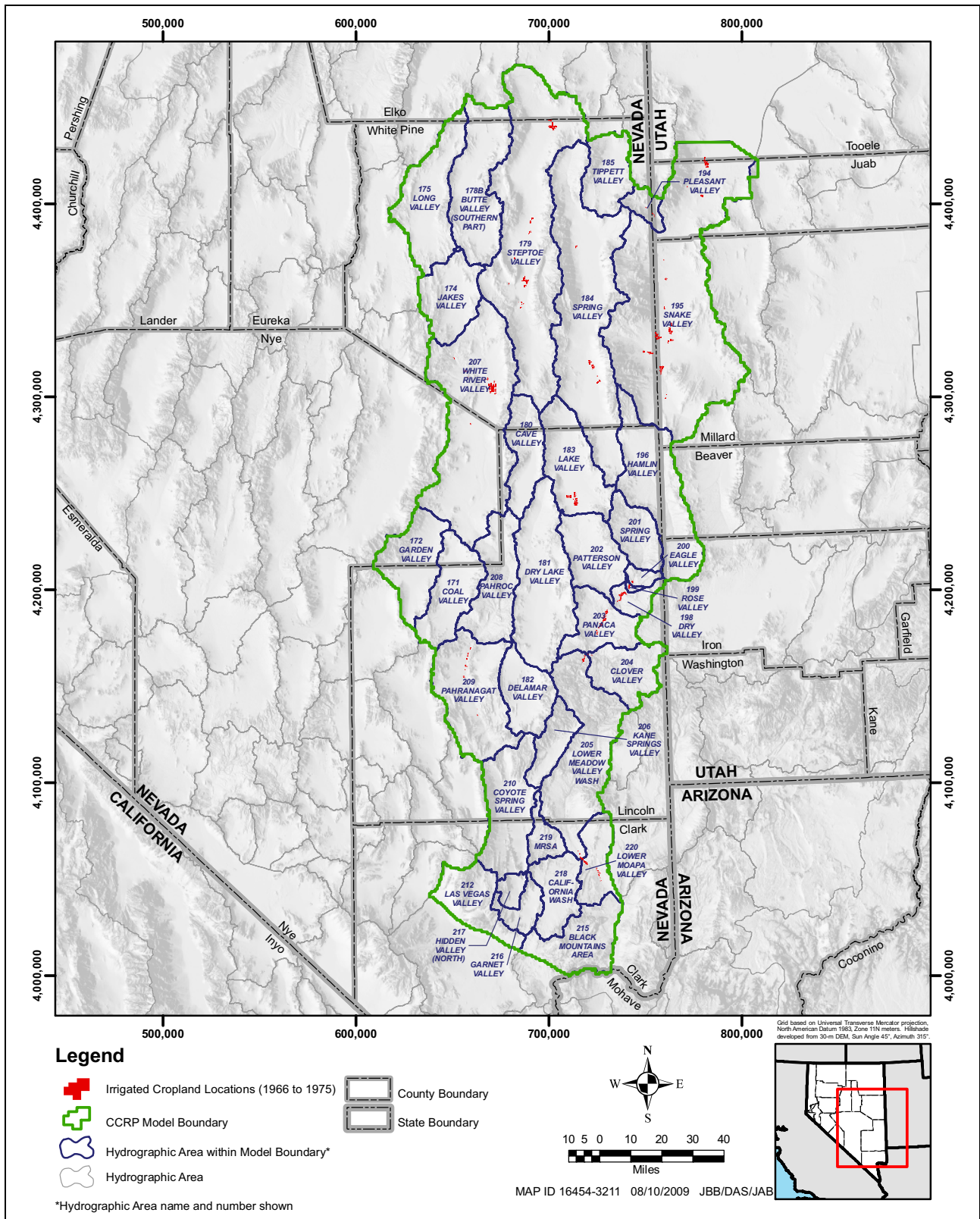


Figure C-3
Spatial Distribution of Groundwater-Irrigated Cropland
for the 1966 to 1975 Time Period

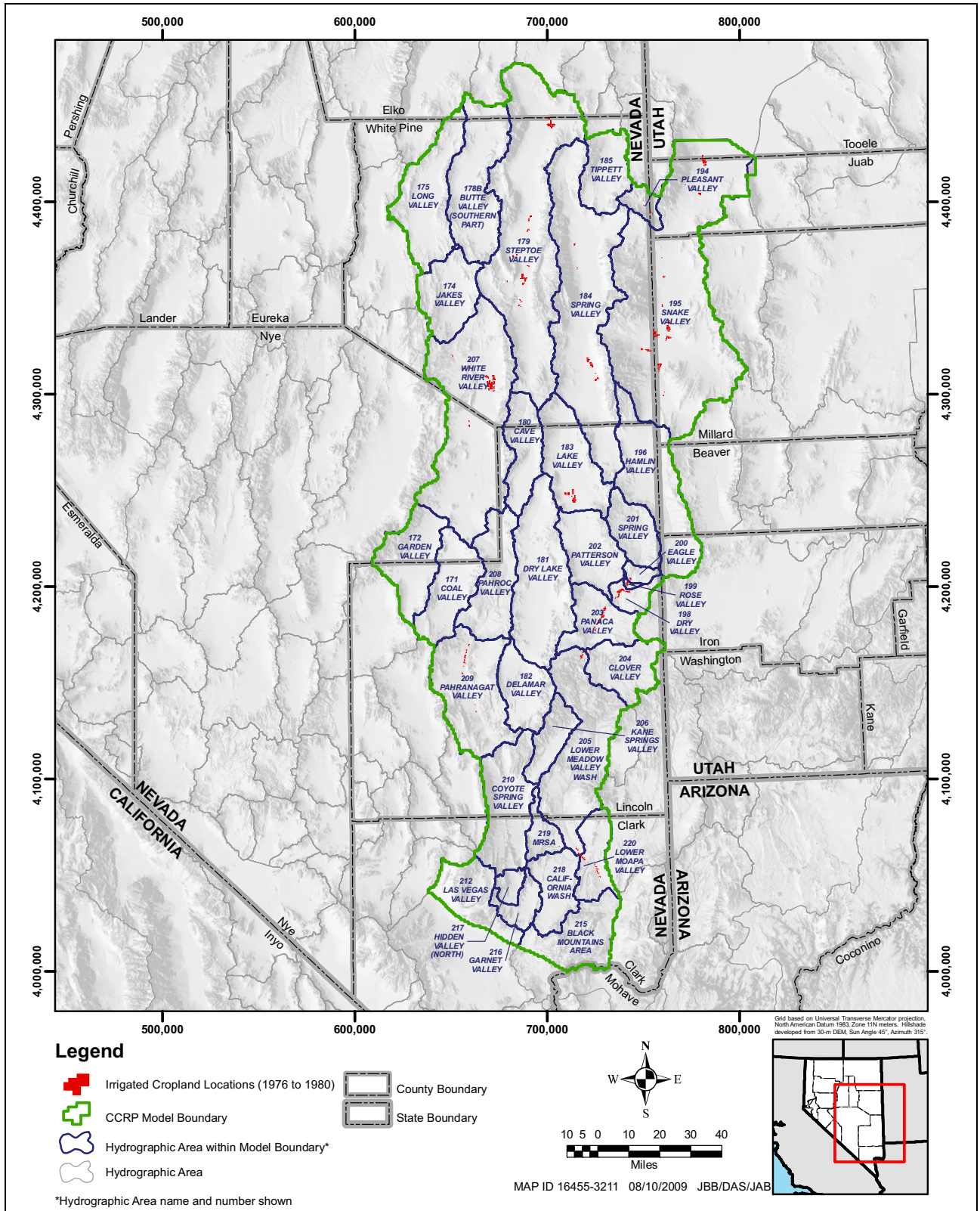


Figure C-4
Spatial Distribution of Groundwater-Irrigated Cropland
for the 1976 to 1980 Time Period

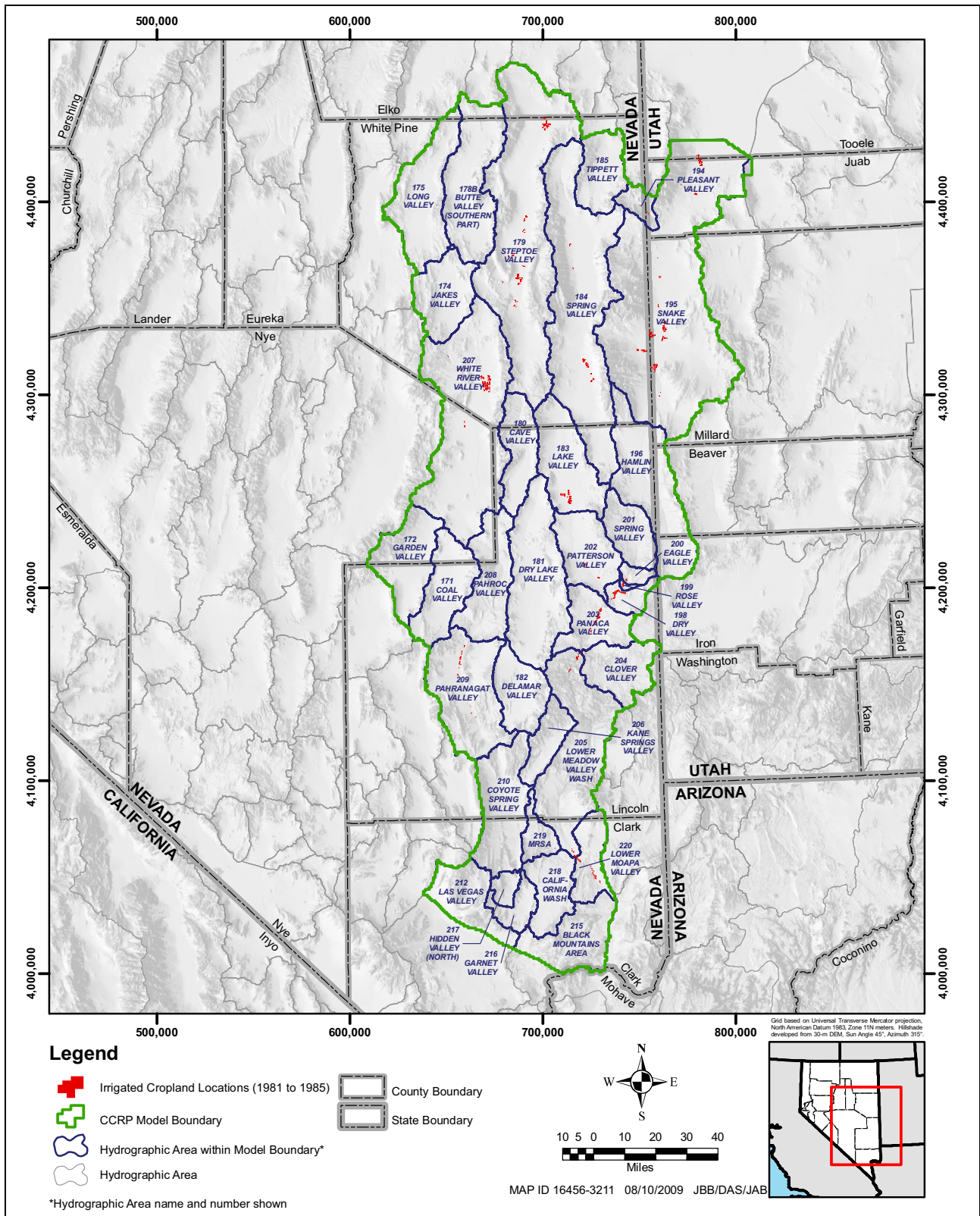


Figure C-5
Spatial Distribution of Groundwater-Irrigated Cropland
for the 1981 to 1985 Time Period

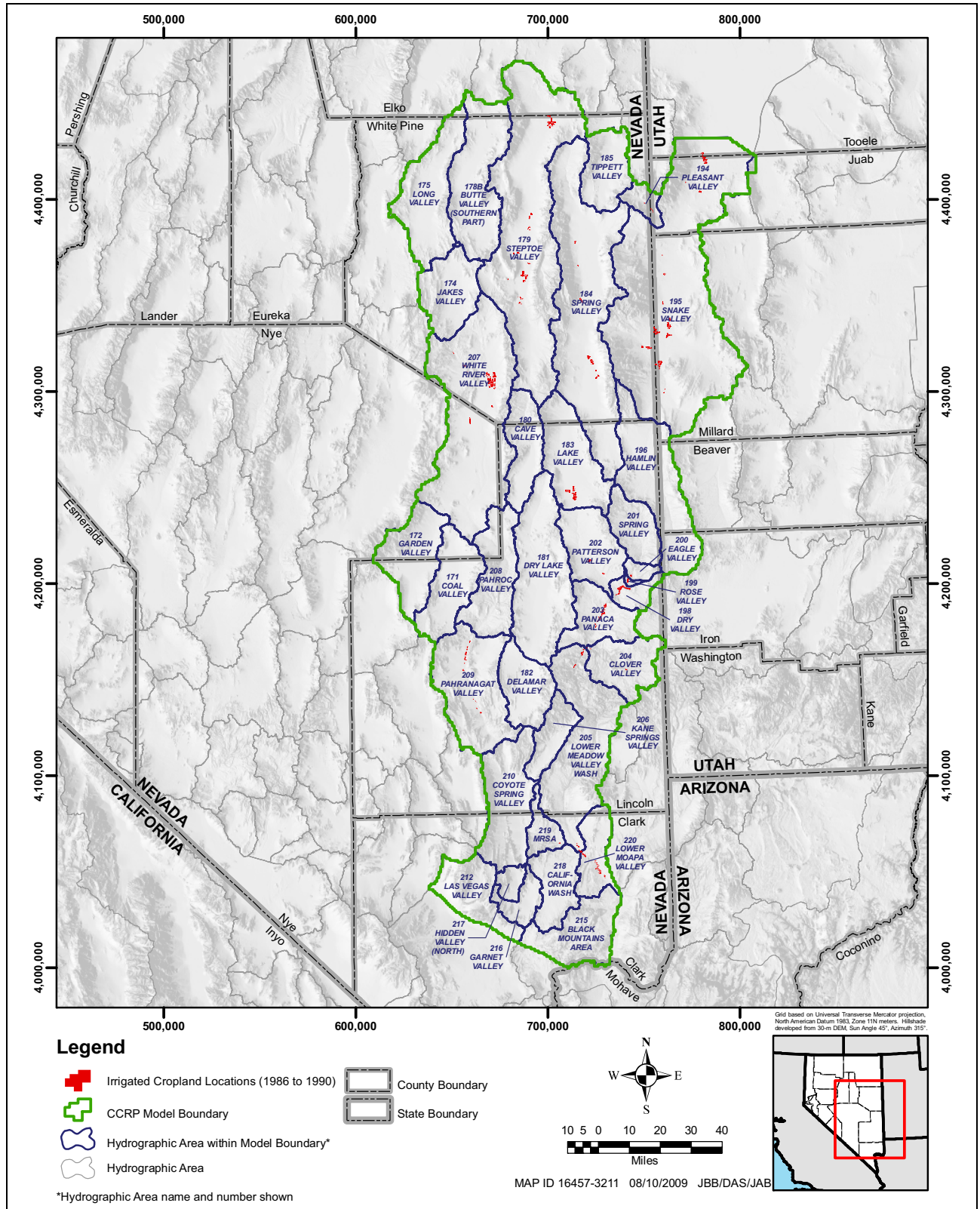


Figure C-6
Spatial Distribution of Groundwater-Irrigated Cropland
for the 1986 to 1990 Time Period

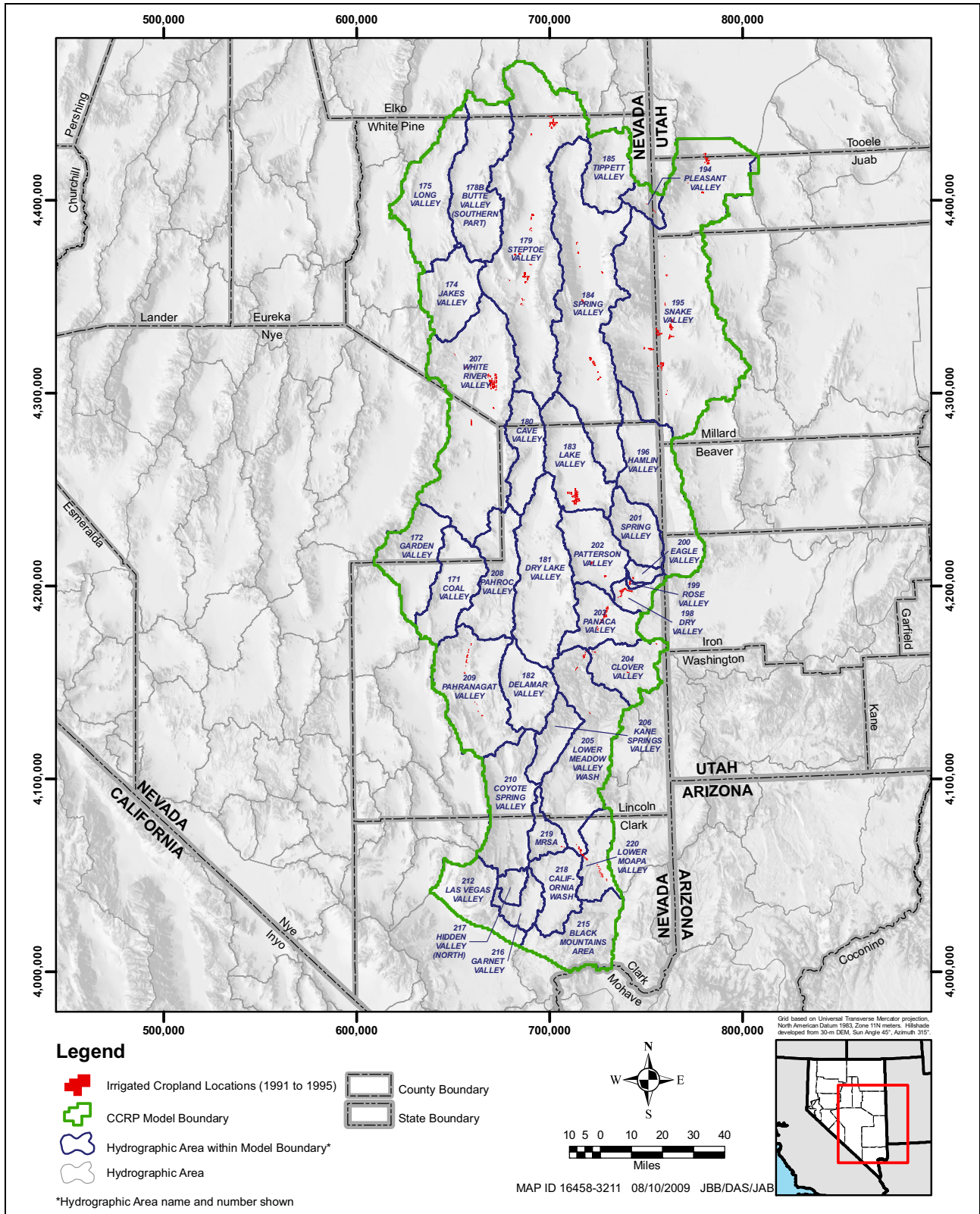


Figure C-7
Spatial Distribution of Groundwater-Irrigated Cropland
for the 1991 to 1995 Time Period

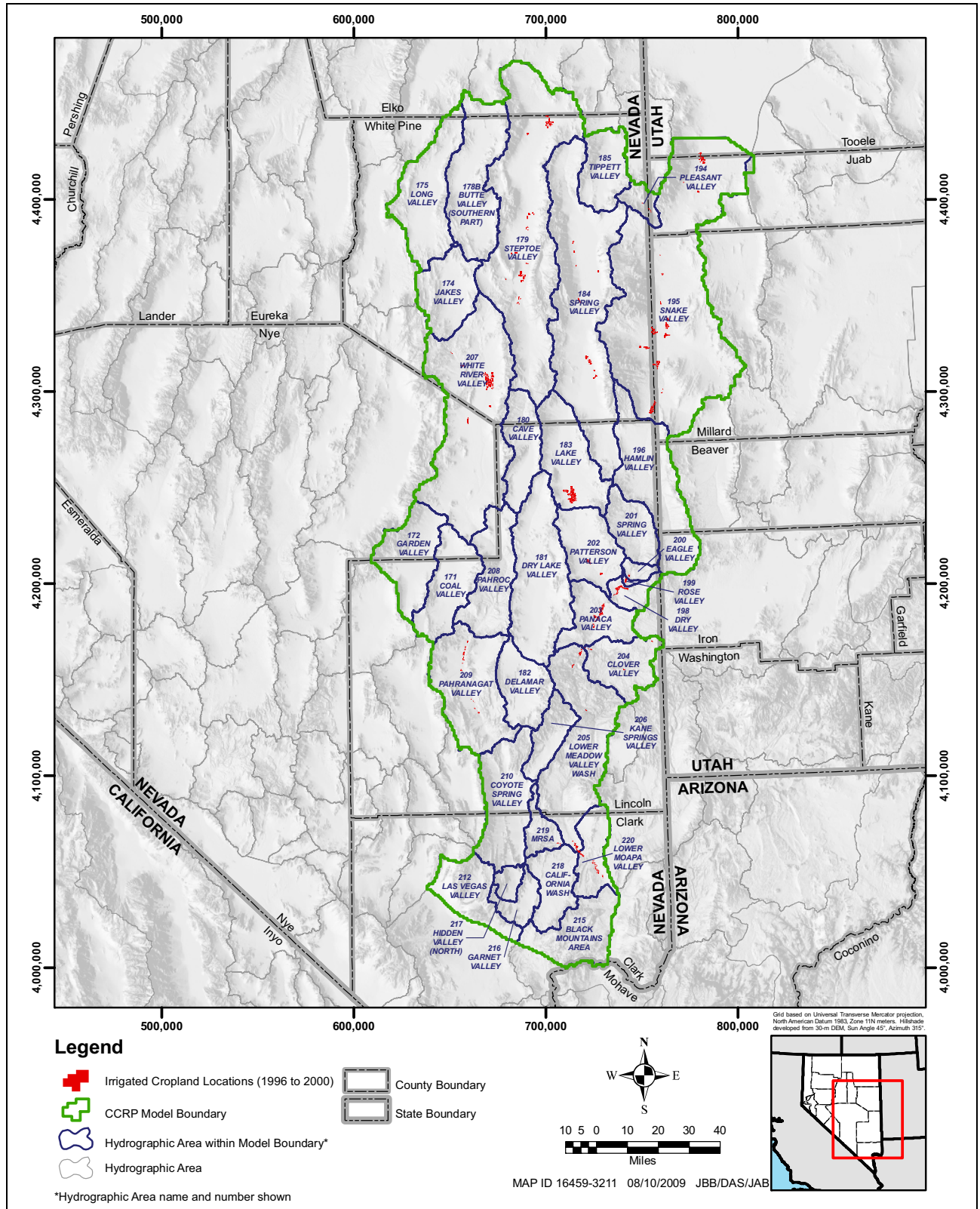


Figure C-8
Spatial Distribution of Groundwater-Irrigated Cropland
for the 1996 to 2000 Time Period

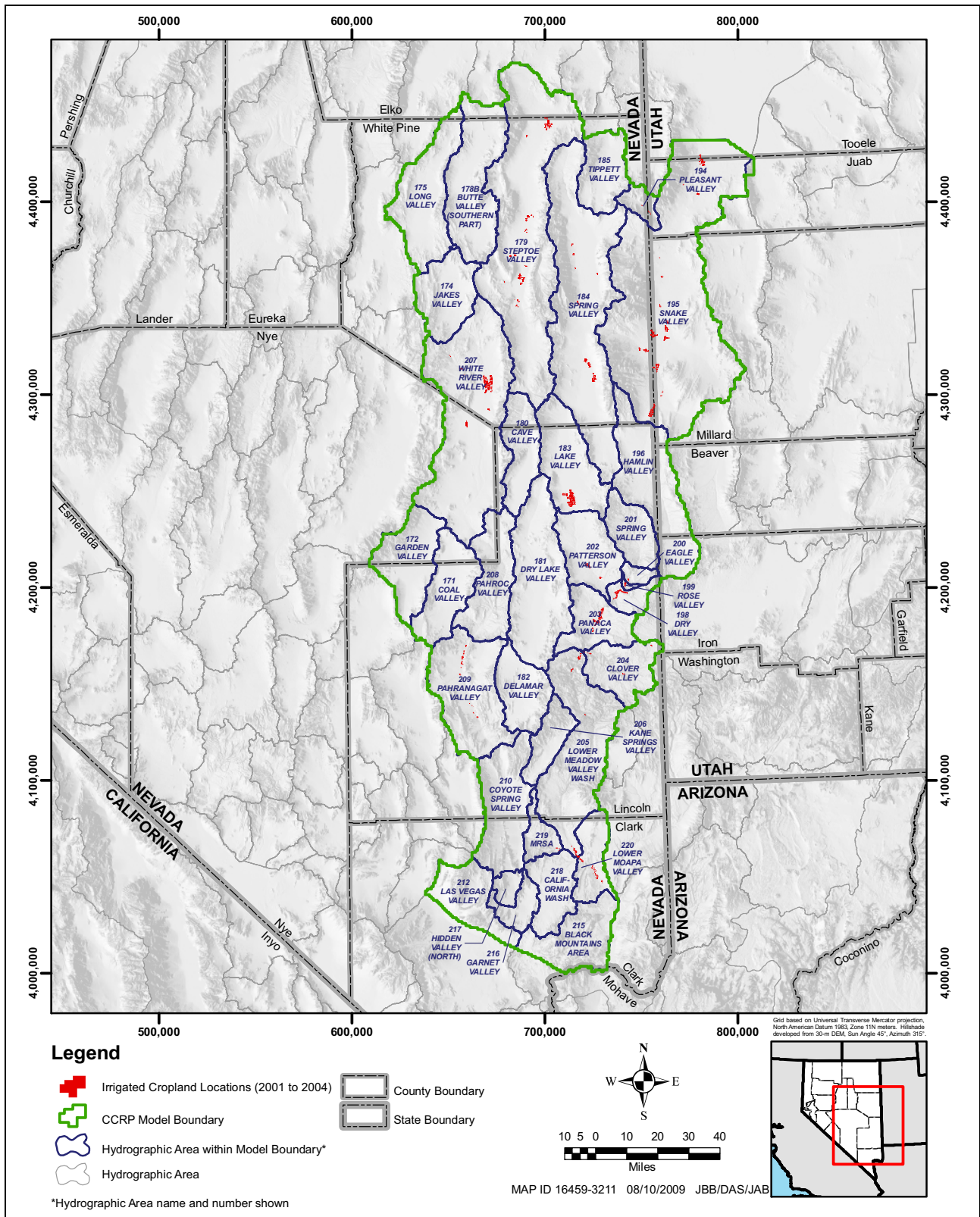


Figure C-9
Spatial Distribution of Groundwater-Irrigated Cropland
for the 2001 to 2004 Time Period

**Table C-4
Historical Cropland Acreages by Time Period**

HA Number	HA Name	Area (acres)								
		1945-1955	1956-1965	1966-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001-2004
179	Steptoe Valley	138	1,714	3,336	3,630	4,023	4,023	4,118	4,249	4,249
183	Lake Valley	0	1,603	2,080	2,080	2,080	2,223	3,915	4,611	4,611
184	Spring Valley	0	251	1,100	1,500	1,527	1,780	2,014	2,014	2,568
194	Pleasant Valley	0	95	122	122	122	122	122	122	122
195	Snake Valley	1,890	4,408	5,684	5,928	6,089	6,229	6,251	8,052	8,222
198	Dry Valley	319	904	960	1,129	1,205	1,225	1,225	1,225	1,225
199	Rose Valley	223	231	231	231	231	231	231	231	231
200	Eagle Valley	25	43	43	43	43	43	43	43	43
202	Patterson Valley	0	0	0	71	496	496	569	921	921
203	Panaca Valley	811	1,187	1,495	1,495	1,495	1,495	1,872	2,213	2,393
204	Clover Valley	18	18	35	35	35	104	190	190	190
205	Lower Meadow Valley Wash	97	212	413	416	489	489	708	708	708
207	White River Valley	1,170	2,170	3,470	4,468	4,527	5,009	5,182	5,540	5,542
209	Pahrnagat Valley	304	314	503	607	613	644	648	648	648
219	Muddy River Springs Area	0	34	34	58	58	81	87	91	91
220	Lower Moapa Valley	0	128	449	564	852	852	852	893	893
Total Area		4,995	13,311	19,954	22,376	23,886	25,047	28,027	31,750	32,657

Note: The sum of the areas in a given time period may not match the "Total Area" value because of independent rounding.

C.3.2.3 Crop Consumptive Groundwater-Use Estimates

Crop consumptive groundwater-use estimates were derived for the hydrographic areas in the study area for each of the nine time periods using the crop consumptive groundwater-use rates and the estimated cropland acreages. In general, the crop consumptive groundwater-use volumes were derived in the following manner:

1. For places of use where only groundwater irrigation is assumed to occur, the area of the irrigated cropland (Table C-4) was multiplied by the NDWR crop consumptive groundwater-use rate for a particular hydrographic area and a factor of 1 to reflect the groundwater-only use of the water (Table C-3).
2. For places of use where both surface water and groundwater (i.e., supplemental or commingled) are used to irrigate the cropland, the area of irrigated cropland (Table C-4) was

multiplied by the NDWR crop consumptive groundwater-use rate (Table C-3) for a particular hydrographic area and a factor of 0.5 to reflect the intermittent use of supplemental water. This adjustment factor was chosen for several reasons including the Nevada State Engineer's Ruling #5726 (Spring Valley) that stated the maximum supplemental use in Spring Valley was 49.8 percent of the regular annual duty (Nevada State Engineer, 2007). In addition, groundwater-pumping inventories for Pahrnagat Valley in the southern portion of the study area show that supplemental groundwater rights have duties assigned to them that are half the duty of nonsupplemental groundwater rights.

The crop consumptive groundwater-use volumes are presented in Table C-5. The table contains the groundwater consumptive use for the acreages and volumes of cropland irrigated solely with groundwater and the acreages and volumes of cropland irrigated by groundwater and surface water by hydrographic area for the selected 10- and 5-year periods. The total acreages and estimated consumptive groundwater-use volumes are plotted against time in Figure C-10.

C.3.3 Mining and Milling Water Use

Consumptive groundwater use in the study area as a result of mining and milling activities was estimated using a combination of groundwater-pumping data obtained from NDWR and estimates of consumptive groundwater use based on mining and milling water rights. Because of the lack of historical data, water-right abstracts were the main source of information for the estimation of mining and milling water use in the study area. In general, the procedure to estimate mining and milling consumptive groundwater use consisted of the following:

1. Derived historical mining and milling groundwater-use estimates for basins in the study area based on the duties associated with the water rights.
2. Added reported (i.e., known) groundwater-use data, when available, to the historical groundwater-use estimates.
3. Derived historical consumptive groundwater-use estimates from the historical groundwater-use estimates.

The following sections discuss the estimation of mining and milling historical water use in greater detail.

C.3.3.1 Derivation of Mining and Milling Groundwater-Use Estimates

Mining and milling groundwater-use estimates were derived by querying the water-right databases for certificated mining and milling water rights. The resulting data sets were then organized by hydrographic area and filtered for groundwater rights. The filtered data were then examined, and supplemental rights were excluded from the resulting data sets. Mining and milling groundwater-use estimates were based on the duty associated with the water right. It was assumed that water-right duties became active two years after the filing date of the water-right application. Presumably, this would allow a sufficient amount of time to begin proving beneficial use on a certificated water right.

Table C-5
Estimates of Groundwater-Irrigated Areas
and Consumptive Groundwater-Use Volumes
 (Page 1 of 4)

HA Number	Time Period	NDWR Rate (ft/yr)	Groundwater Irrigation			Supplemental Groundwater Irrigation			Total Consumptive Groundwater-Use Volume ^a (afy)
			Area (acre)	Factor (-)	Volume ^a (afy)	Area (acre)	Factor (-)	Volume ^a (afy)	
179	1945 to 1955	2.8	107	1	301	31	0.5	43	344
	1956 to 1965	2.8	1,613	1	4,515	101	0.5	142	4,657
	1966 to 1975	2.8	3,227	1	9,035	110	0.5	154	9,188
	1976 to 1980	2.8	3,425	1	9,591	205	0.5	286	9,877
	1981 to 1985	2.8	3,813	1	10,675	210	0.5	294	10,970
	1986 to 1990	2.8	3,813	1	10,675	210	0.5	294	10,970
	1991 to 1995	2.8	3,817	1	10,688	301	0.5	421	11,109
	1996 to 2000	2.8	3,875	1	10,849	374	0.5	523	11,373
	2001 to 2004	2.8	3,875	1	10,849	374	0.5	523	11,373
183	1945 to 1955	2.9	0	1	0	0	0.5	0	0
	1956 to 1965	2.9	1,603	1	4,647	0	0.5	0	4,647
	1966 to 1975	2.9	2,080	1	6,033	0	0.5	0	6,033
	1976 to 1980	2.9	2,080	1	6,033	0	0.5	0	6,033
	1981 to 1985	2.9	2,080	1	6,033	0	0.5	0	6,033
	1986 to 1990	2.9	2,223	1	6,448	0	0.5	0	6,448
	1991 to 1995	2.9	3,915	1	11,353	0	0.5	0	11,353
	1996 to 2000	2.9	4,611	1	13,373	0	0.5	0	13,373
	2001 to 2004	2.9	4,611	1	13,373	0	0.5	0	13,373
184	1945 to 1955	3.1	0	1	0	0	0.5	0	0
	1956 to 1965	3.1	212	1	658	39	0.5	60	718
	1966 to 1975	3.1	705	1	2,186	394	0.5	611	2,798
	1976 to 1980	3.1	633	1	1,962	867	0.5	1,344	3,306
	1981 to 1985	3.1	633	1	1,962	895	0.5	1,387	3,348
	1986 to 1990	3.1	633	1	1,962	1,148	0.5	1,779	3,740
	1991 to 1995	3.1	779	1	2,413	1,235	0.5	1,914	4,328
	1996 to 2000	3.1	779	1	2,413	1,235	0.5	1,914	4,328
	2001 to 2004	3.1	910	1	2,820	1,658	0.5	2,570	5,390
194	1945 to 1955	3.1	0	1	0	0	0.5	0	0
	1956 to 1965	3.1	0	1	0	95	0.5	146	146
	1966 to 1975	3.1	27	1	85	95	0.5	146	232
	1976 to 1980	3.1	27	1	85	95	0.5	146	232
	1981 to 1985	3.1	27	1	85	95	0.5	146	232
	1986 to 1990	3.1	27	1	85	95	0.5	146	232
	1991 to 1995	3.1	27	1	85	95	0.5	146	232
	1996 to 2000	3.1	27	1	85	95	0.5	146	232
	2001 to 2004	3.1	27	1	85	95	0.5	146	232

Table C-5
Estimates of Groundwater-Irrigated Areas
and Consumptive Groundwater-Use Volumes
 (Page 2 of 4)

HA Number	Time Period	NDWR Rate (ft/yr)	Groundwater Irrigation			Supplemental Groundwater Irrigation			Total Consumptive Groundwater-Use Volume ^a (afy)
			Area (acre)	Factor (-)	Volume ^a (afy)	Area (acre)	Factor (-)	Volume ^a (afy)	
195	1945 to 1955	3.1	1,639	1	5080	251	0.5	389	5,469
	1956 to 1965	3.1	2,354	1	7297	2,053	0.5	3,183	10,480
	1966 to 1975	3.1	3,246	1	10,063	2,438	0.5	3,778	13,841
	1976 to 1980	3.1	3,490	1	10,820	2,438	0.5	3,778	14,598
	1981 to 1985	3.1	3,652	1	11,320	2,438	0.5	3,778	15,099
	1986 to 1990	3.1	3,791	1	11,753	2,438	0.5	3,778	15,531
	1991 to 1995	3.1	3,814	1	11,823	2,438	0.5	3,778	15,601
	1996 to 2000	3.1	5,587	1	17,320	2,465	0.5	3,821	21,141
	2001 to 2004	3.1	5,745	1	17,809	2,478	0.5	3,840	21,649
198	1945 to 1955	3.0	267	1	800	52	0.5	79	879
	1956 to 1965	3.0	852	1	2,555	52	0.5	79	2,633
	1966 to 1975	3.0	908	1	2,724	52	0.5	79	2,803
	1976 to 1980	3.0	1,026	1	3,079	103	0.5	154	3,233
	1981 to 1985	3.0	1,102	1	3,307	103	0.5	154	3,461
	1986 to 1990	3.0	1,122	1	3,366	103	0.5	154	3,520
	1991 to 1995	3.0	1,122	1	3,366	103	0.5	154	3,520
	1996 to 2000	3.0	1,122	1	3,366	103	0.5	154	3,520
	2001 to 2004	3.0	1,122	1	3,366	103	0.5	154	3,520
199	1945 to 1955	3.0	10	1	31	212	0.5	319	350
	1956 to 1965	3.0	10	1	31	221	0.5	331	362
	1966 to 1975	3.0	10	1	31	221	0.5	331	362
	1976 to 1980	3.0	10	1	31	221	0.5	331	362
	1981 to 1985	3.0	10	1	31	221	0.5	331	362
	1986 to 1990	3.0	10	1	31	221	0.5	331	362
	1991 to 1995	3.0	10	1	31	221	0.5	331	362
	1996 to 2000	3.0	10	1	31	221	0.5	331	362
	2001 to 2004	3.0	10	1	31	221	0.5	331	362
200	1945 to 1955	3.0	25	1	76	0	0.5	0	76
	1956 to 1965	3.0	43	1	129	0	0.5	0	129
	1966 to 1975	3.0	43	1	129	0	0.5	0	129
	1976 to 1980	3.0	43	1	129	0	0.5	0	129
	1981 to 1985	3.0	43	1	129	0	0.5	0	129
	1986 to 1990	3.0	43	1	129	0	0.5	0	129
	1991 to 1995	3.0	43	1	129	0	0.5	0	129
	1996 to 2000	3.0	43	1	129	0	0.5	0	129
	2001 to 2004	3.0	43	1	129	0	0.5	0	129

Table C-5
Estimates of Groundwater-Irrigated Areas
and Consumptive Groundwater-Use Volumes
 (Page 3 of 4)

HA Number	Time Period	NDWR Rate (ft/yr)	Groundwater Irrigation			Supplemental Groundwater Irrigation			Total Consumptive Groundwater-Use Volume ^a (afy)
			Area (acre)	Factor (-)	Volume ^a (afy)	Area (acre)	Factor (-)	Volume ^a (afy)	
202	1945 to 1955	2.9	0	1	0	0	0.5	0	0
	1956 to 1965	2.9	0	1	0	0	0.5	0	0
	1966 to 1975	2.9	0	1	0	0	0.5	0	0
	1976 to 1980	2.9	71	1	206	0	0.5	0	206
	1981 to 1985	2.9	496	1	1,439	0	0.5	0	1,439
	1986 to 1990	2.9	496	1	1,439	0	0.5	0	1,439
	1991 to 1995	2.9	569	1	1,651	0	0.5	0	1,651
	1996 to 2000	2.9	921	1	2,671	0	0.5	0	2,671
	2001 to 2004	2.9	921	1	2,671	0	0.5	0	2,671
203	1945 to 1955	4.0	722	1	2,889	89	0.5	178	3,067
	1956 to 1965	4.0	1,021	1	4,086	166	0.5	331	4,417
	1966 to 1975	4.0	1,329	1	5,317	166	0.5	331	5,649
	1976 to 1980	4.0	1,329	1	5,317	166	0.5	331	5,649
	1981 to 1985	4.0	1,329	1	5,317	166	0.5	331	5,649
	1986 to 1990	4.0	1,329	1	5,317	166	0.5	331	5,649
	1991 to 1995	4.0	1,649	1	6,597	223	0.5	445	7,042
	1996 to 2000	4.0	1,990	1	7,961	223	0.5	445	8,406
	2001 to 2004	4.0	2,170	1	8,679	223	0.5	447	9,126
204	1945 to 1955	4.0	8	1	33	9	0.5	19	52
	1956 to 1965	4.0	8	1	33	9	0.5	19	52
	1966 to 1975	4.0	25	1	100	10	0.5	19	119
	1976 to 1980	4.0	25	1	100	10	0.5	19	119
	1981 to 1985	4.0	25	1	100	10	0.5	19	119
	1986 to 1990	4.0	95	1	380	10	0.5	19	399
	1991 to 1995	4.0	181	1	723	10	0.5	19	742
	1996 to 2000	4.0	181	1	723	10	0.5	19	742
	2001 to 2004	4.0	181	1	723	10	0.5	19	742
205	1945 to 1955	4.1	97	1	399	0	0.5	0	399
	1956 to 1965	4.1	187	1	768	25	0.5	51	819
	1966 to 1975	4.1	388	1	1,590	25	0.5	51	1,641
	1976 to 1980	4.1	391	1	1,602	25	0.5	51	1,653
	1981 to 1985	4.1	464	1	1,904	25	0.5	51	1,954
	1986 to 1990	4.1	464	1	1,904	25	0.5	51	1,955
	1991 to 1995	4.1	669	1	2,744	38	0.5	79	2,823
	1996 to 2000	4.1	669	1	2,744	38	0.5	79	2,823
	2001 to 2004	4.1	669	1	2,744	38	0.5	79	2,823

Table C-5
Estimates of Groundwater-Irrigated Areas
and Consumptive Groundwater-Use Volumes
 (Page 4 of 4)

HA Number	Time Period	NDWR Rate (ft/yr)	Groundwater Irrigation			Supplemental Groundwater Irrigation			Total Consumptive Groundwater-Use Volume ^a (afy)
			Area (acre)	Factor (-)	Volume ^a (afy)	Area (acre)	Factor (-)	Volume ^a (afy)	
207	1945 to 1955	3.3	0	1	0	1,170	0.5	1,930	1,930
	1956 to 1965	3.3	262	1	864	1,908	0.5	3,148	4,012
	1966 to 1975	3.3	282	1	931	3,188	0.5	5,260	6,191
	1976 to 1980	3.3	1,011	1	3,337	3,457	0.5	5,704	9,041
	1981 to 1985	3.3	1,011	1	3,337	3,516	0.5	5,801	9,138
	1986 to 1990	3.3	1,391	1	4,590	3,618	0.5	5,969	10,559
	1991 to 1995	3.3	1,391	1	4,590	3,791	0.5	6,256	10,845
	1996 to 2000	3.3	1,515	1	4,999	4,025	0.5	6,642	11,641
	2001 to 2004	3.3	1,515	1	4,999	4,027	0.5	6,645	11,644
209	1945 to 1955	4.4	304	1	1,339	0	0.5	0	1,339
	1956 to 1965	4.4	304	1	1,339	10	0.5	22	1,361
	1966 to 1975	4.4	439	1	1,931	64	0.5	140	2,071
	1976 to 1980	4.4	496	1	2,184	111	0.5	244	2,427
	1981 to 1985	4.4	503	1	2,212	111	0.5	244	2,455
	1986 to 1990	4.4	534	1	2,348	111	0.5	244	2,592
	1991 to 1995	4.4	534	1	2,348	114	0.5	252	2,600
	1996 to 2000	4.4	534	1	2,348	114	0.5	252	2,600
	2001 to 2004	4.4	534	1	2,348	114	0.5	252	2,600
219	1945 to 1955	4.6	0	1	0	0	0.5	0	0
	1956 to 1965	4.6	34	1	157	0	0.5	0	157
	1966 to 1975	4.6	34	1	157	0	0.5	0	157
	1976 to 1980	4.6	34	1	157	24	0.5	54	211
	1981 to 1985	4.6	34	1	157	24	0.5	54	211
	1986 to 1990	4.6	49	1	225	32	0.5	74	299
	1991 to 1995	4.6	55	1	253	32	0.5	74	327
	1996 to 2000	4.6	59	1	271	32	0.5	74	344
	2001 to 2004	4.6	59	1	271	32	0.5	74	344
220	1945 to 1955	4.6	0	1	0	0	0.5	0	0
	1956 to 1965	4.6	128	1	588	0	0.5	0	588
	1966 to 1975	4.6	191	1	879	257	0.5	592	1,471
	1976 to 1980	4.6	191	1	879	373	0.5	857	1,736
	1981 to 1985	4.6	253	1	1,164	599	0.5	1,378	2,541
	1986 to 1990	4.6	253	1	1,164	599	0.5	1,378	2,541
	1991 to 1995	4.6	253	1	1,164	599	0.5	1,378	2,541
	1996 to 2000	4.6	253	1	1,164	640	0.5	1,472	2,636
	2001 to 2004	4.6	253	1	1,164	640	0.5	1,472	2,636

^aThe sum of the groundwater and supplemental groundwater irrigation volumes may not match the "Total" volume because of independent rounding of the values. Also, the significant figures do not imply a specific degree of accuracy. They were included for tracking/accounting purposes.

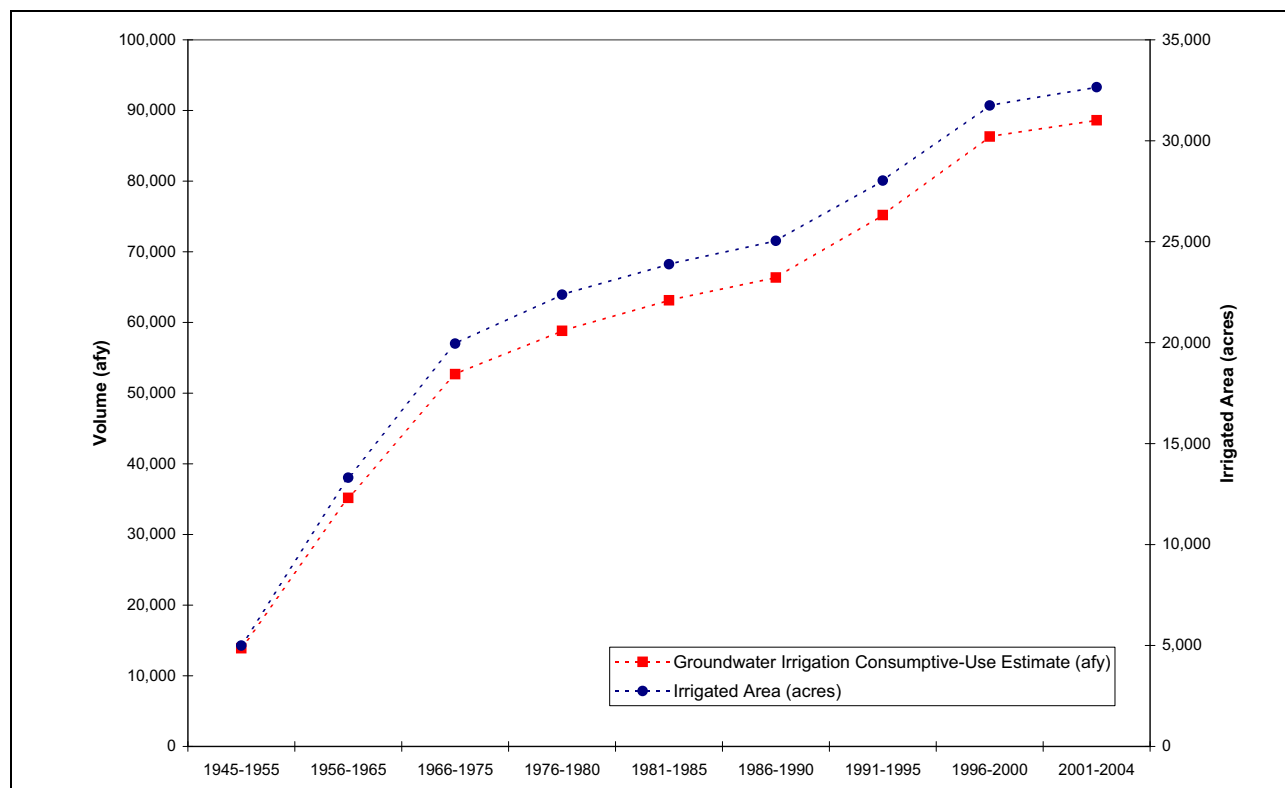


Figure C-10
Final Estimated Groundwater-Irrigated Acreages and
Consumptive Groundwater-Use Volumes for the Study Area

Another assumption was that once a given water right became active, it was always active, unless shown to be otherwise. Using these assumptions as a guide, a yearly historical build-out was constructed for each basin in the study area that contained mining and milling water rights for the period 1945 to 2004.

C.3.3.2 Addition of Reported Mining and Milling Data

In addition to the water-right databases, NDWR provided groundwater-pumping reports for several active mines in Steptoe, Long, and White River valleys. Unfortunately, data were only available for years after 1992. The reported data for a particular water right replaced the estimated groundwater-use estimate that was derived in the previous section. In some instances, the groundwater-pumping data obtained from NDWR corresponded to certificated water rights listed as being “supplemental” or permitted rights. In those instances, the water rights that corresponded to the reported data were also added to the groundwater-use estimates from the previous section.

C.3.3.3 Derivation of Mining and Milling Consumptive Groundwater Use

Once the water-right estimates and reported groundwater-pumping data were assembled for the 1945 to 2004 time frame, the consumptive groundwater use for mining and milling was assumed to be 100 percent of the duty from the certificated water rights or from the known groundwater-pumping

volumes. The 100 percent consumptive-use factor was based, in part, on Nevada Division of Water Planning (1992). This report stated that, in 1990, White Pine County withdrew 2,930 af of water for mining uses and consumptively used 2,828 af. This resulted in a 96 percent consumptive-use ratio for mining use. For Lincoln County, there was a 97 percent consumptive-use ratio, and for Clark County, there was a 74 percent consumptive-use factor. The 100 percent consumptive-use factor chosen for the model area represents a more conservative bound from the literature data. Mining and milling groundwater consumptive uses were deemed to be insignificant when they did not exceed 150 af in any year. In those cases, the historical groundwater-use estimates for those basins were removed from further consideration.

C.3.4 Industrial and Power Plant Water Use

Consumptive water use in the study area as a result of industrial and power plant use is limited to a relatively few hydrographic areas. The hydrographic areas in the study area with any significant industrial or power plant use are Lower Meadow Valley Wash, Muddy River Springs Area, Garnet Valley, and the Black Mountains Area. The consumptive water-use estimates for these hydrographic areas were based on groundwater and surface-water production data from Nevada Power Co., groundwater-pumping data from NDWR, groundwater-pumping estimates from LVVWD (2001), and groundwater-use estimates based on water-right abstracts. In general, the procedure to estimate industrial and power plant consumptive water use consisted of the following:

1. Derived historical industrial and power plant groundwater-use estimates for basins in the study area based on the duties associated with groundwater rights.
2. Added reported (i.e., known) water-use data, when available, to the historical water-use estimates.
3. Derived historical consumptive water-use estimates from the historical water-use estimates.

The following sections discuss the estimation of industrial and power plant historical water use in greater detail.

C.3.4.1 Derivation of Industrial and Power Plant Groundwater-Use Estimates

Industrial and power plant groundwater-use estimates were derived by querying the water-right databases for certificated industrial and power plant water rights. This was done because certificated rights have shown proof of beneficial use, and the water, at some point in the past, was actually used and theoretically is still in use for the stated volumes. The resulting data sets were then organized by hydrographic area and filtered for groundwater rights. The filtered data were then examined, and supplemental rights were excluded from the resulting data sets. Industrial and power plant groundwater-use estimates were based on the duty associated with a given water right. It was assumed that water-right duties became active two years after the filing date of the water-right application. Presumably, this would allow a sufficient amount of time to begin proving beneficial use on a certificated water right. Another assumption was that once a given water right became active, it was always active unless shown to be otherwise. Using these assumptions as a guide, a historical

build-out was constructed for each basin in the study area that contained industrial and power plant water rights for the period 1945 to 2004.

C.3.4.2 Addition of Reported Industrial and Power Plant Data

In addition to the water-right databases, groundwater-pumping and surface-water diversion data were obtained from Nevada Power Co. and NDWR. Unfortunately, data were only available for a select number of years. The reported data for a particular water right replaced the estimated water use that was derived by the methods described in the previous section. It should be noted that in some instances the groundwater-pumping data obtained from NDWR or Nevada Power Co. corresponded to certificated water rights listed as being supplemental or permitted rights. In those instances, the water rights that corresponded to the reported data were also added to the groundwater-use estimates from the previous section. These data were included in the historical groundwater-use estimates because the information represented actual data. In addition, some of the reported data could not be correlated to a NDWR water-right number. These reported production data were attributed to the known well location instead. Surface-water diversions for two locations on the Muddy River were also reported by Nevada Power Co. These data were included in the historical water-use estimate because the information represents a withdrawal of water from the regional flow system. The surface-water diversion data were available after 1997. Using the reported data, groundwater-pumping and surface-water diversion data were added to the consumptive water-use estimates for the appropriate years. This combination of estimated water use and known groundwater and surface-water production data allows for a tabulation of water use for the period 1945 to 2005.

C.3.4.3 Derivation of Industrial and Power Plant Groundwater Consumptive Use

After the water-use estimates were tabulated for the time frame of interest, the consumptive use for industrial and power plant use was assumed to be 100 percent of the water-right duties or known groundwater-pumping data. The 100 percent consumption factor was appropriate because these types of water use tend to consume most of the available water and leave very little secondary recharge. Industrial and power plant groundwater consumptive uses were deemed to be insignificant when they did not exceed 150 af in any year. In those cases, the historical groundwater-use estimates for those basins were removed from further consideration.

C.3.5 Historical Consumptive Water-Use Data Set

All estimates of water uses identified in the model area were combined and distributed to points of diversion. These processes are described, followed by a description of the combined data set.

C.3.5.1 Combination of Historical Consumptive Water Uses

The municipal, mining and milling, and industrial and power plant consumptive water-use estimates were derived on a yearly basis from 1945 to 2004. The agricultural consumptive water-use estimates, however, were derived for the nine time periods identified in [Section C.3.2.2.1](#). As a result, the municipal, mining and milling, and industrial and power plant consumptive water-use estimates were averaged for the same nine time periods used for the creation of the irrigation place-of-use maps.

This allowed for the combination of all the manners of use into one average consumptive water-use estimate for each time period.

The time-period-average annual consumptive water-use estimates for all the hydrographic areas basins in the study area can be seen in Figure C-11. This figure shows that irrigation accounts for the majority of the consumptive water use in each time period. The average consumptive water-use estimate for the period 1945 to 1955 was approximately 20,000 afy, while the average consumptive water-use estimate increased to slightly over 100,000 afy for the 2001 to 2004 time period. Figures C-12 through C-20 illustrate the average consumptive water-use estimates by hydrographic area and manner of use for each of the nine time periods. It can be seen from the figures that for almost every hydrographic area, irrigation water use accounts for the majority of the water use. The notable exceptions are in the far southern portion of the study area in the Muddy River Springs Area, Black Mountains Area, and Garnet Valley hydrographic areas.

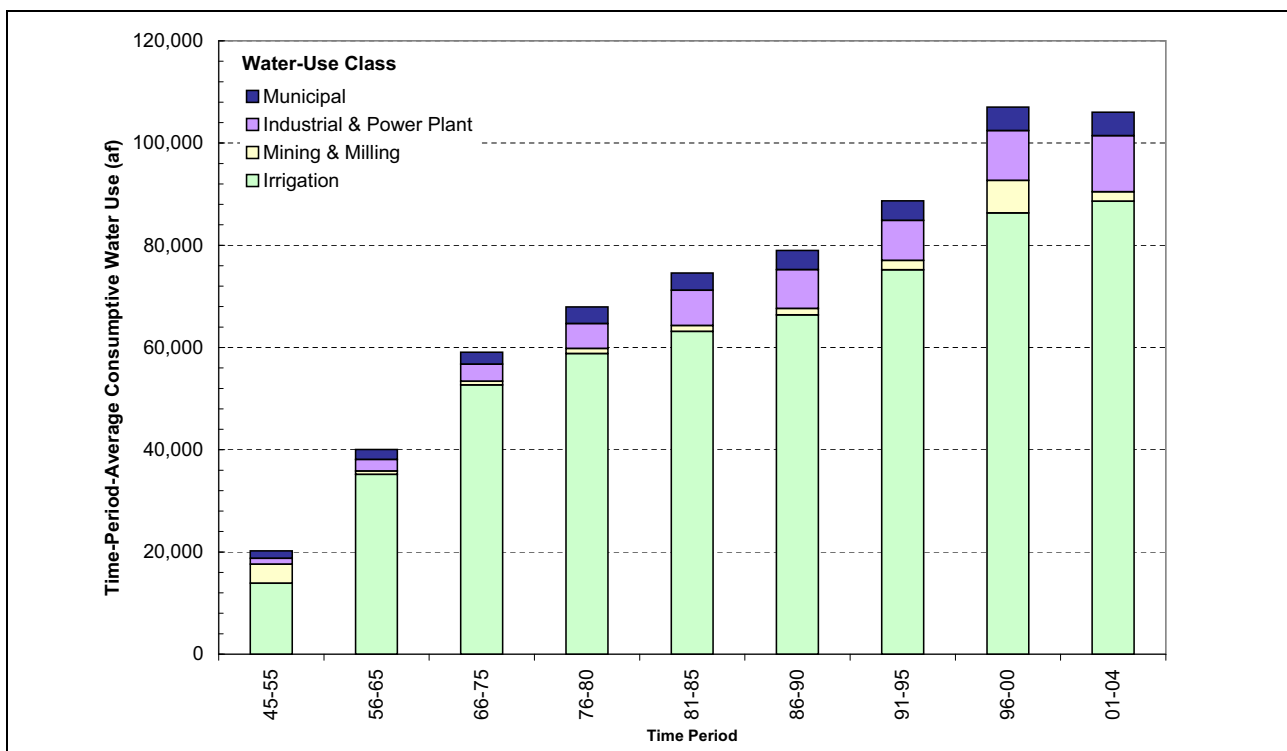


Figure C-11
Average Consumptive Water Use by Time Period for the Study Area

C.3.5.2 Distribution of Consumptive Water-Use Volumes to Points of Diversion

The average estimated consumptive water-use volumes were distributed by time period to various water-right points of diversion, wells, surface-water diversions, and town locations, depending on the type of water use. This section discusses the spatial distribution of the estimated consumptive water-use volumes in greater detail.

The municipal consumptive water-use volumes were spatially distributed to either the town locations responsible for the water use or to the known locations of water-supply wells or surface-water

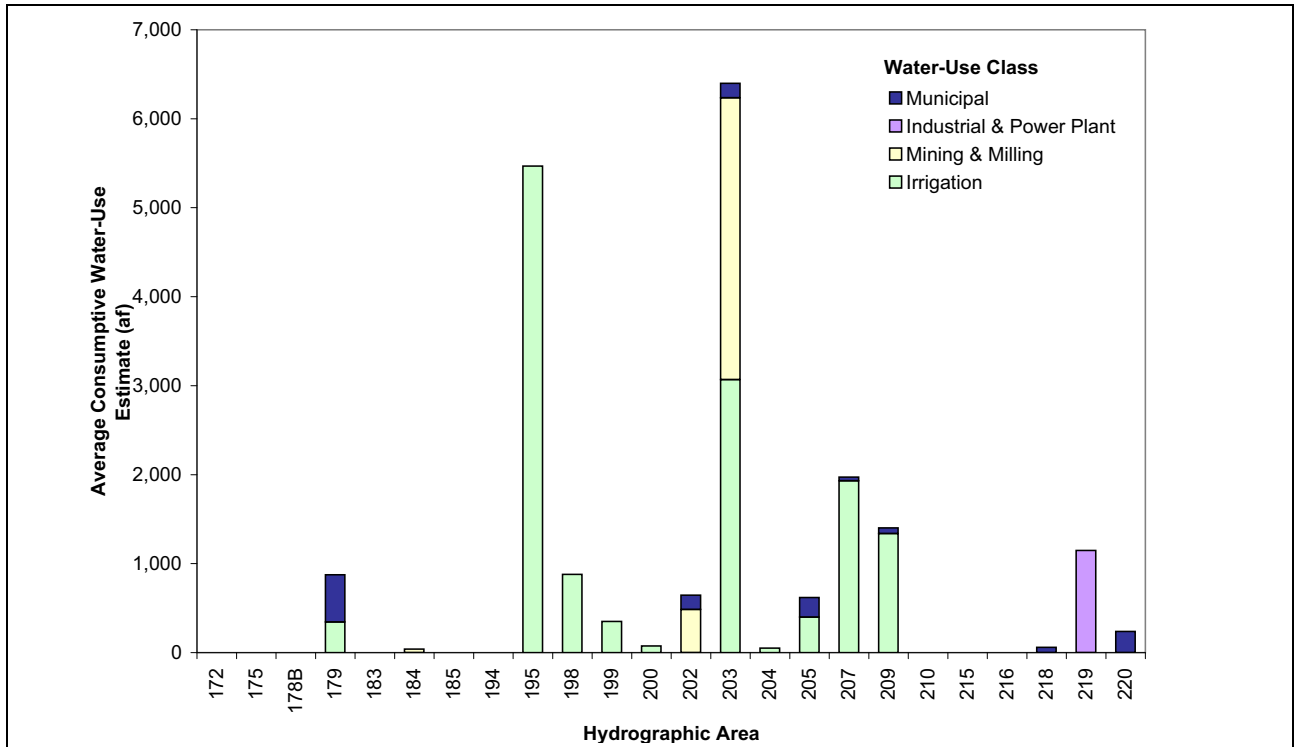


Figure C-12
Average Consumptive Water Use by HA for Time Period 1945-1955

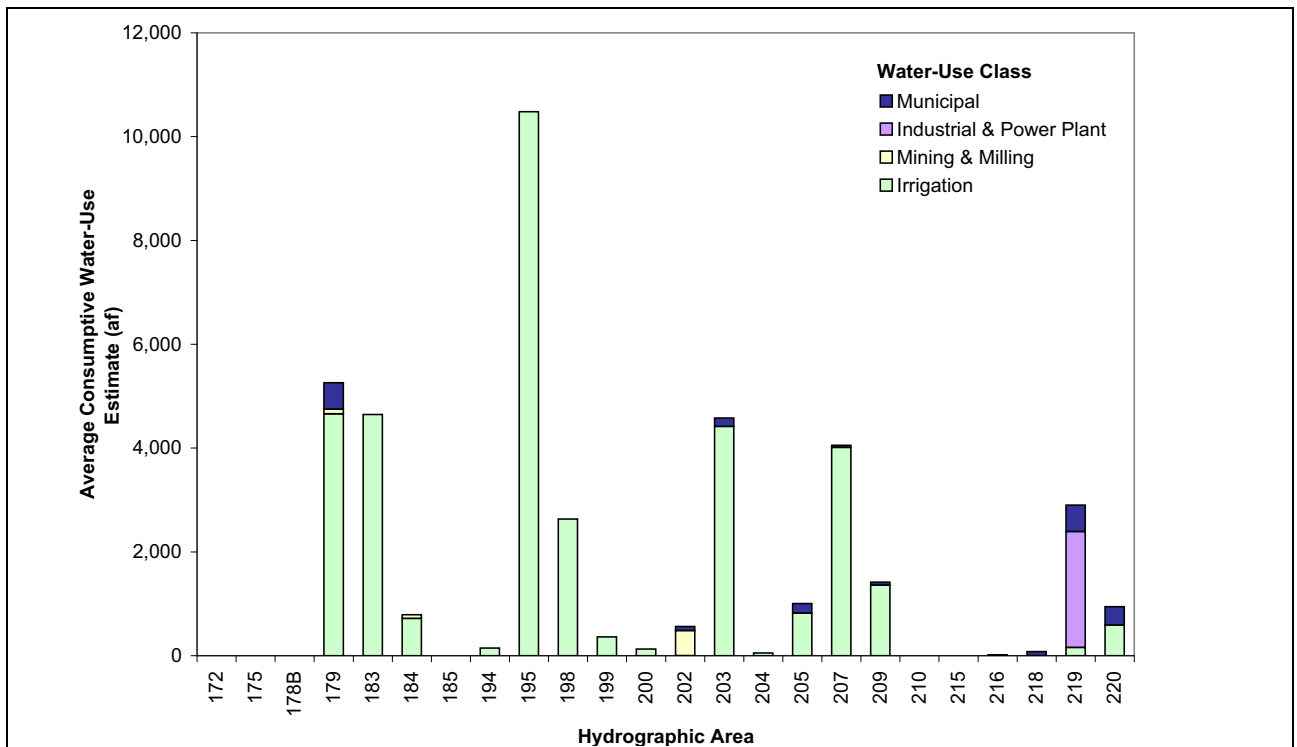


Figure C-13
Average Consumptive Water Use by HA for Time Period 1956-1965

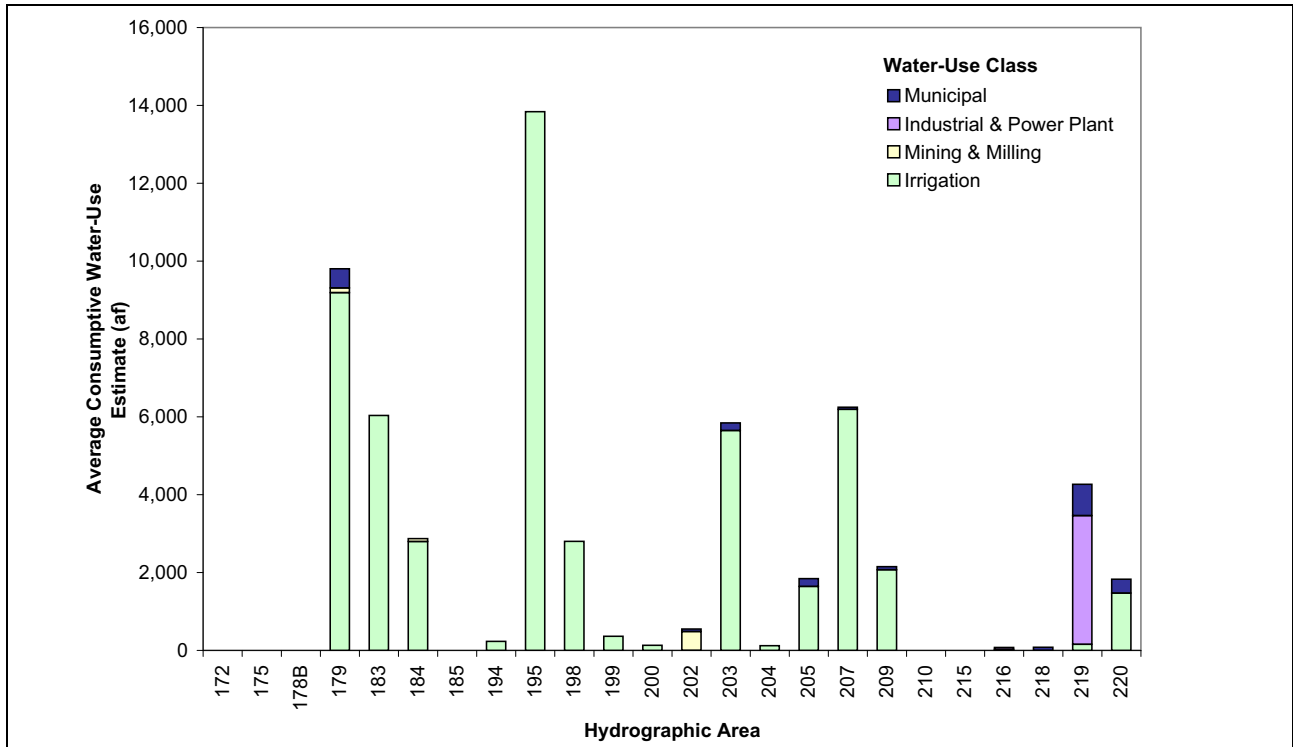


Figure C-14
Average Consumptive Water Use by HA for Time Period 1966-1975

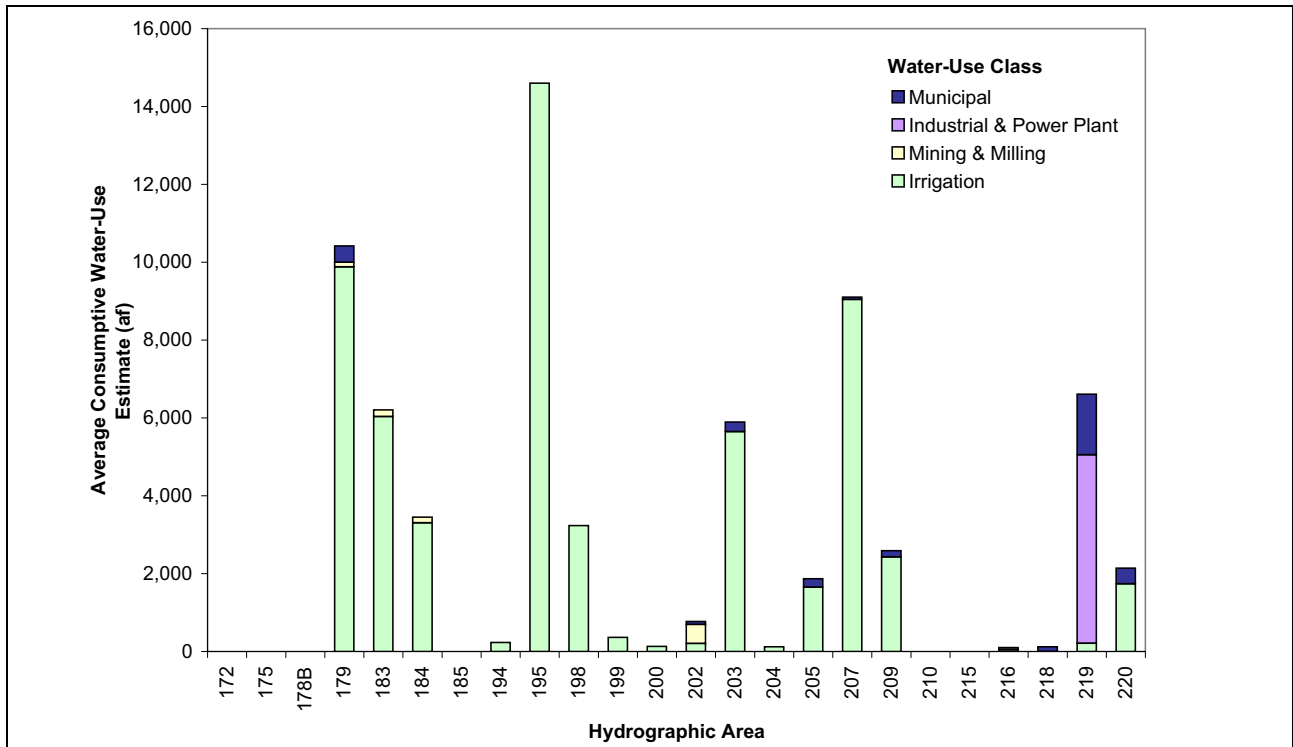


Figure C-15
Average Consumptive Water Use by HA for Time Period 1976-1980

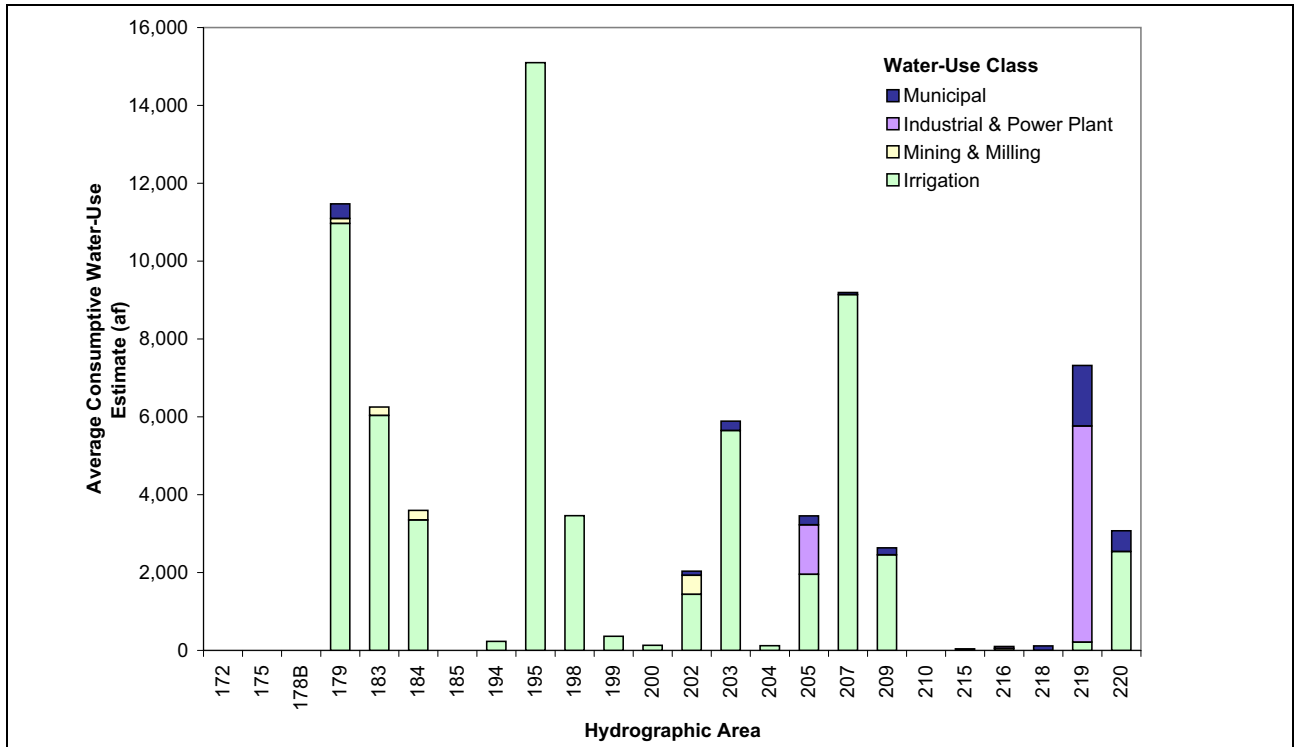


Figure C-16
Average Consumptive Water Use by HA for Time Period 1981-1985

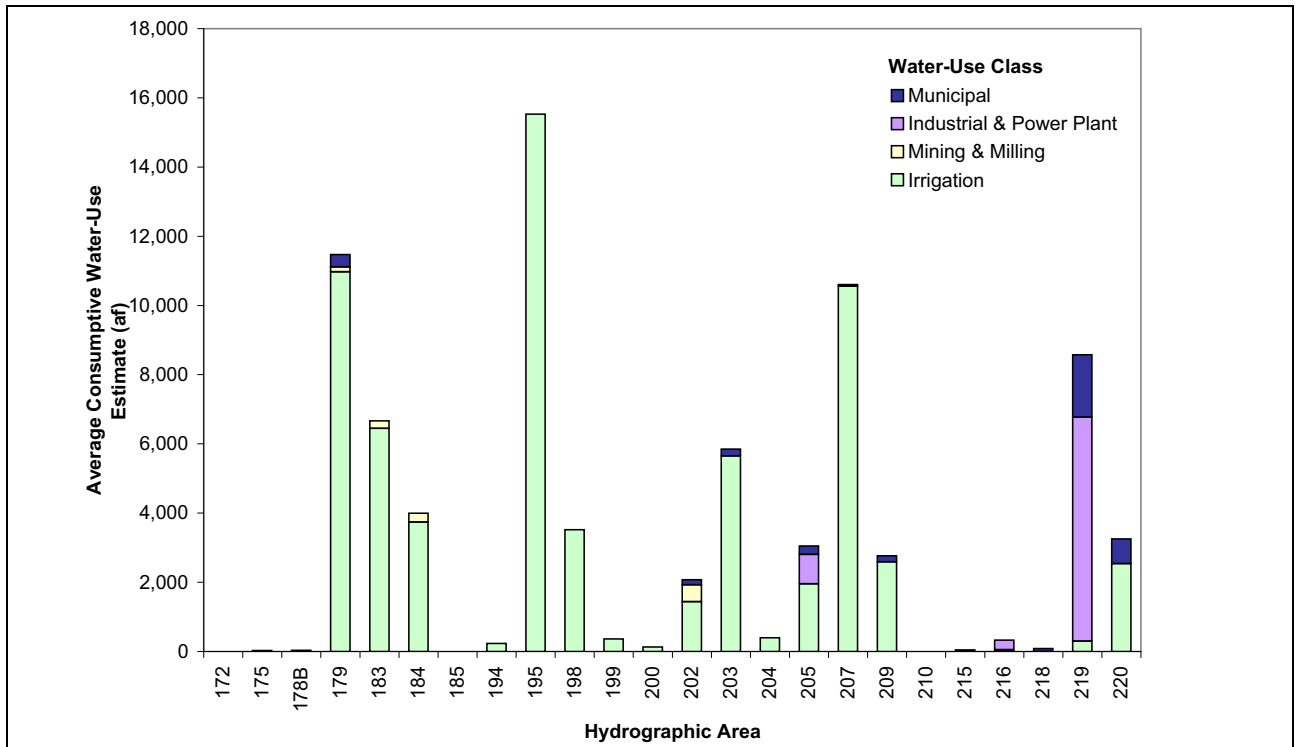


Figure C-17
Average Consumptive Water Use by HA for Time Period 1986-1990

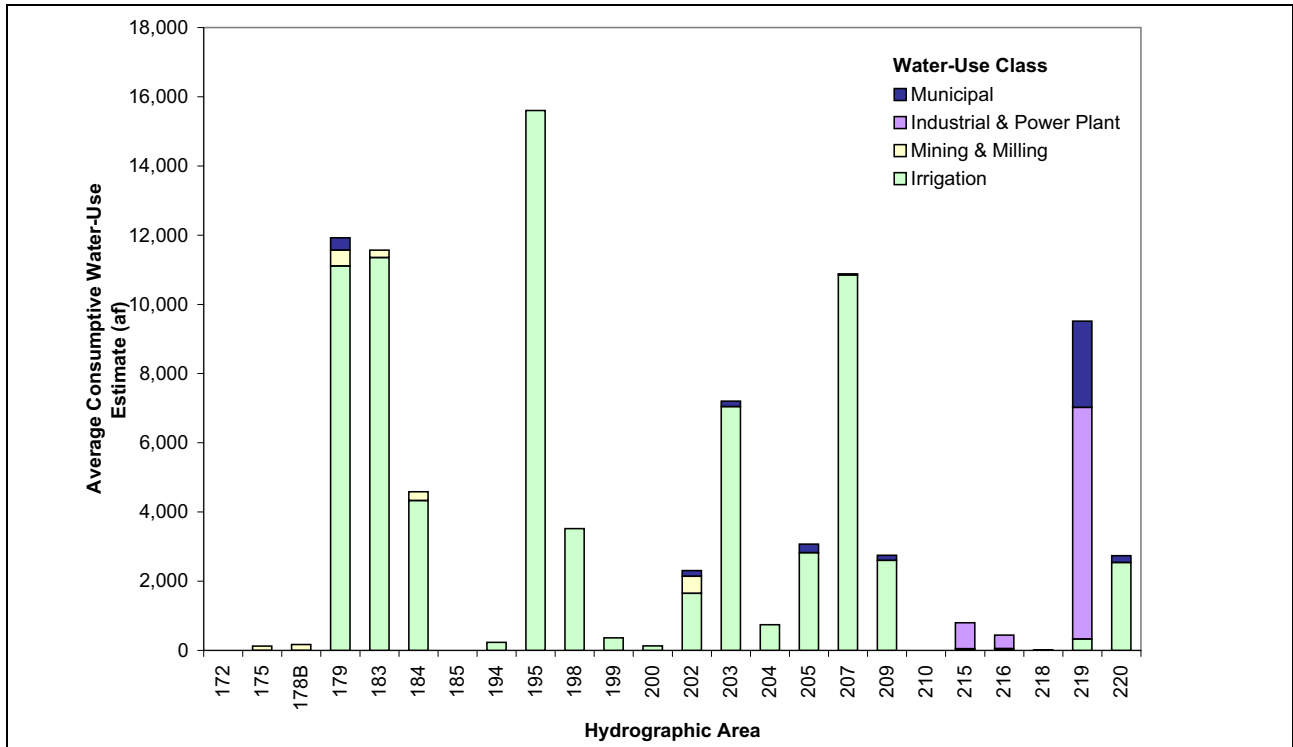


Figure C-18
Average Consumptive Water Use by HA for Time Period 1991-1995

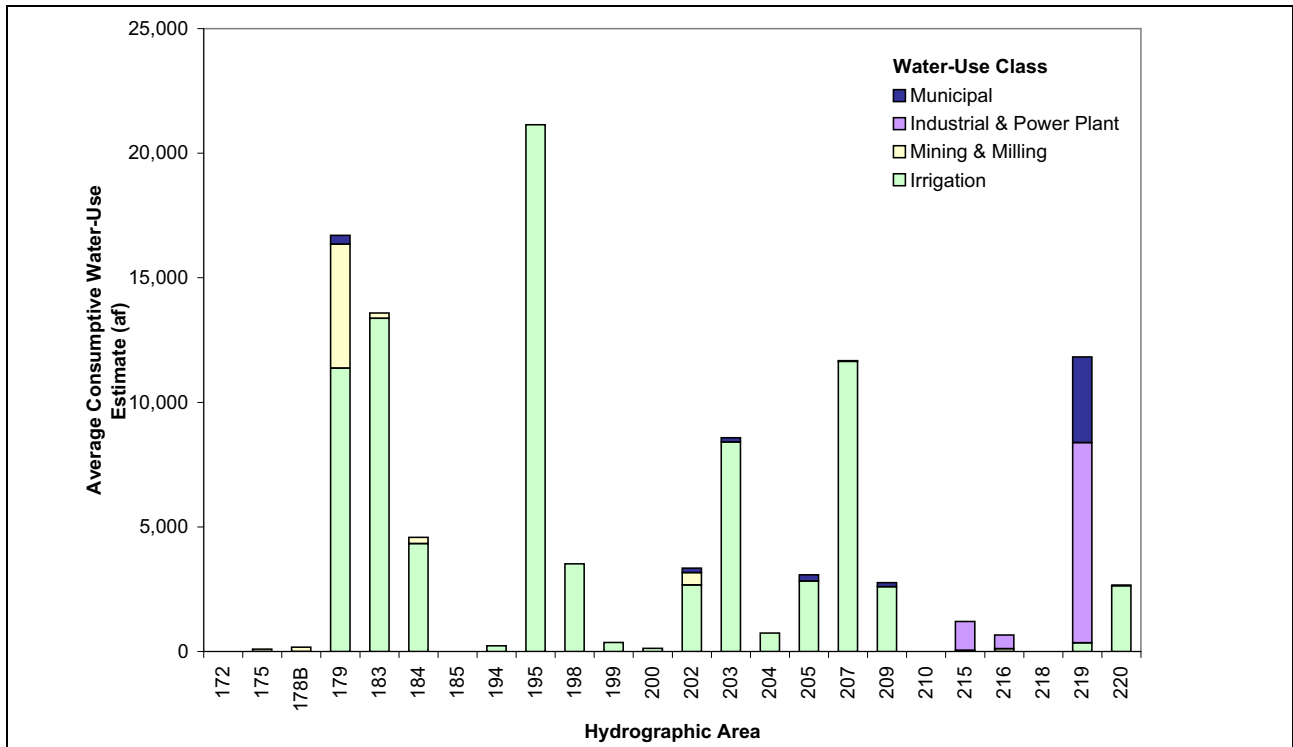


Figure C-19
Average Consumptive Water Use by HA for Time Period 1996-2000

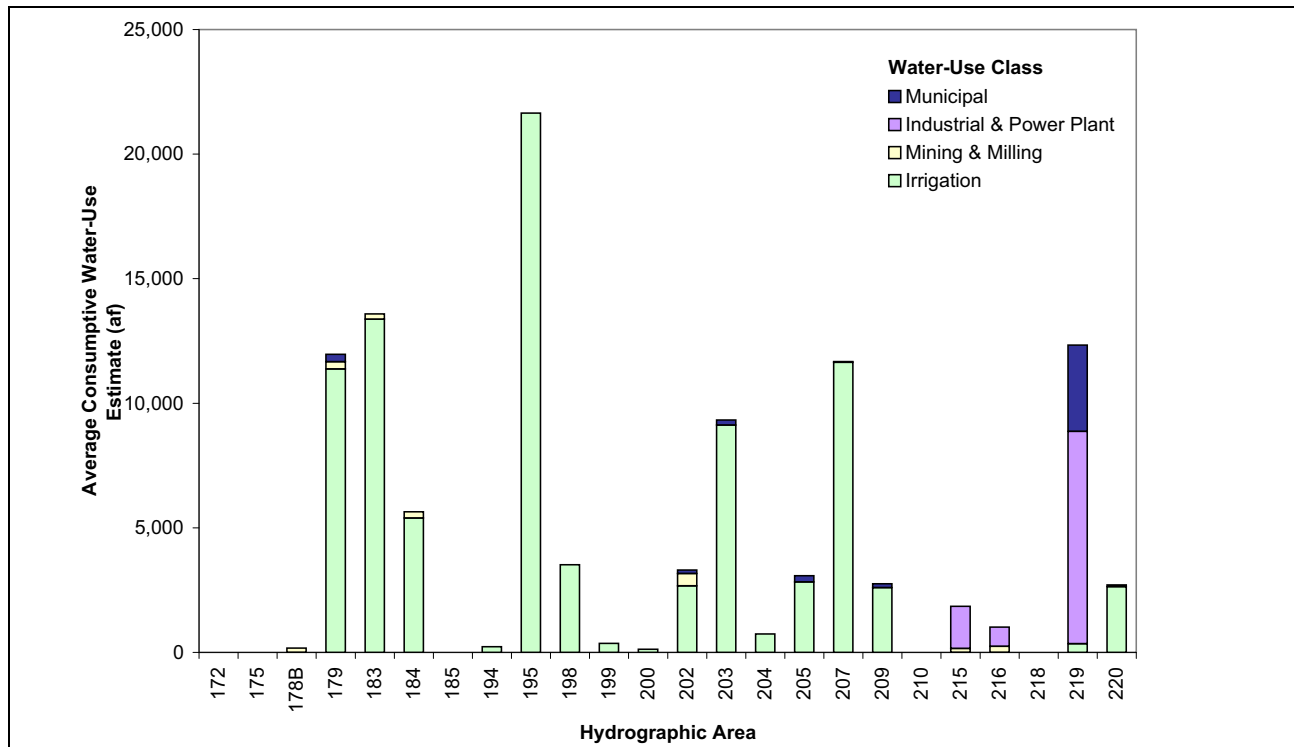


Figure C-20
Average Consumptive Water Use by HA for Time Period 2001-2004

diversions. For example, well locations are unknown for the consumptive water-use estimates based on population. As a result, the estimated consumptive water use was assumed to be withdrawn from a point that corresponds to the location of the town with the assumption that the water was supplied from an underground source. For the towns of Moapa, Logandale, Glendale, and Overton, municipal water is supplied by MVWD. As a result, the known locations of MVWD water-supply wells and surface-water diversions are used, instead of the town locations, to represent the withdrawal or diversion of water from the regional flow system.

The agricultural consumptive groundwater-use volumes were spatially distributed to the water-right points of diversion. The points of diversion were correlated with the groundwater-irrigation places of use used to create the irrigated cropland maps in [Section C.3.2.2.4](#). Specifically, the consumptive groundwater-use volume for each delineated, irrigated cropland was equally distributed to the water-right points of diversion that were most likely used for the irrigation of the cropland. This is a simplification of what is actually occurring because it is unknown which wells, and which specific intervals, would be used for irrigation. In addition, for areas with numerous irrigated crops, it is difficult to resolve which point of diversion is actually responsible for a particular parcel of irrigation. For example, numerous points of diversion were used to equally distribute the crop consumptive water-use volumes for the irrigated croplands in northern White River Valley near Lund, Nevada, and in northern Snake Valley near Callao, Utah.

The mining and milling consumptive groundwater-use volumes were spatially distributed to either water-right points of diversion or known well locations, when available. Most of the mining and milling consumptive groundwater-use volumes were derived using the water-right duties. In those

instances, the consumptive groundwater-use volumes were spatially distributed to the water-right points of diversion. For several of the hydrographic areas, however, it was possible to correlate known well locations with the mining and milling water rights. In those instances, the actual well locations were used to represent the withdrawal of groundwater.

The industrial and power plant consumptive groundwater-use volumes were spatially distributed to either water-right points of diversion or known well and surface-water diversion locations, when available. Most of the industrial and power plant consumptive groundwater-use volumes were derived using the water-right duties. In those instances, the consumptive groundwater-use volumes were spatially distributed to the water-right points of diversion. For several of the hydrographic areas, however, it was possible to correlate known well and surface-water diversion locations with the industrial and power plant water rights. In those instances, the actual well and surface-water diversion locations were used to represent the withdrawal of water.

The spatial distribution of the points of diversion, where groundwater and surface-water diversions are assumed to occur for the nine time periods, are depicted on [Figure C-21](#) (1945 to 1955), [Figure C-22](#) (1956 to 1965), [Figure C-23](#) (1966 to 1975), [Figure C-24](#) (1976 to 1980), [Figure C-25](#) (1981 to 1985), [Figure C-26](#) (1986 to 1990), [Figure C-27](#) (1991 to 1995), [Figure C-28](#) (1996 to 2000), and [Figure C-29](#) (2001 to 2004).

C.3.5.3 Data Set Description

The combined consumptive water-use data set is provided in electronic form on the DVD included with this report. The data set contains the following fields along with their respective definitions:

- Timeperiod - Identifier to indicate the time period for the point of diversion.
- id - Unique identifier for the point of diversion used to link with the transient model input data sets.
- use - The manner of use for the point of diversion.
- site_name - The more common name for a particular well or diversion location.
- app - The NDWR water-right application number.
- cert - The NDWR water-right certificate number.
- app_status - The status of the water right.
- basin - The hydrographic area for the point of diversion.
- source - The NDWR source of water for the water right.
- src - A more simplistic flag to indicate the source of water (e.g., Groundwater or surface-water).

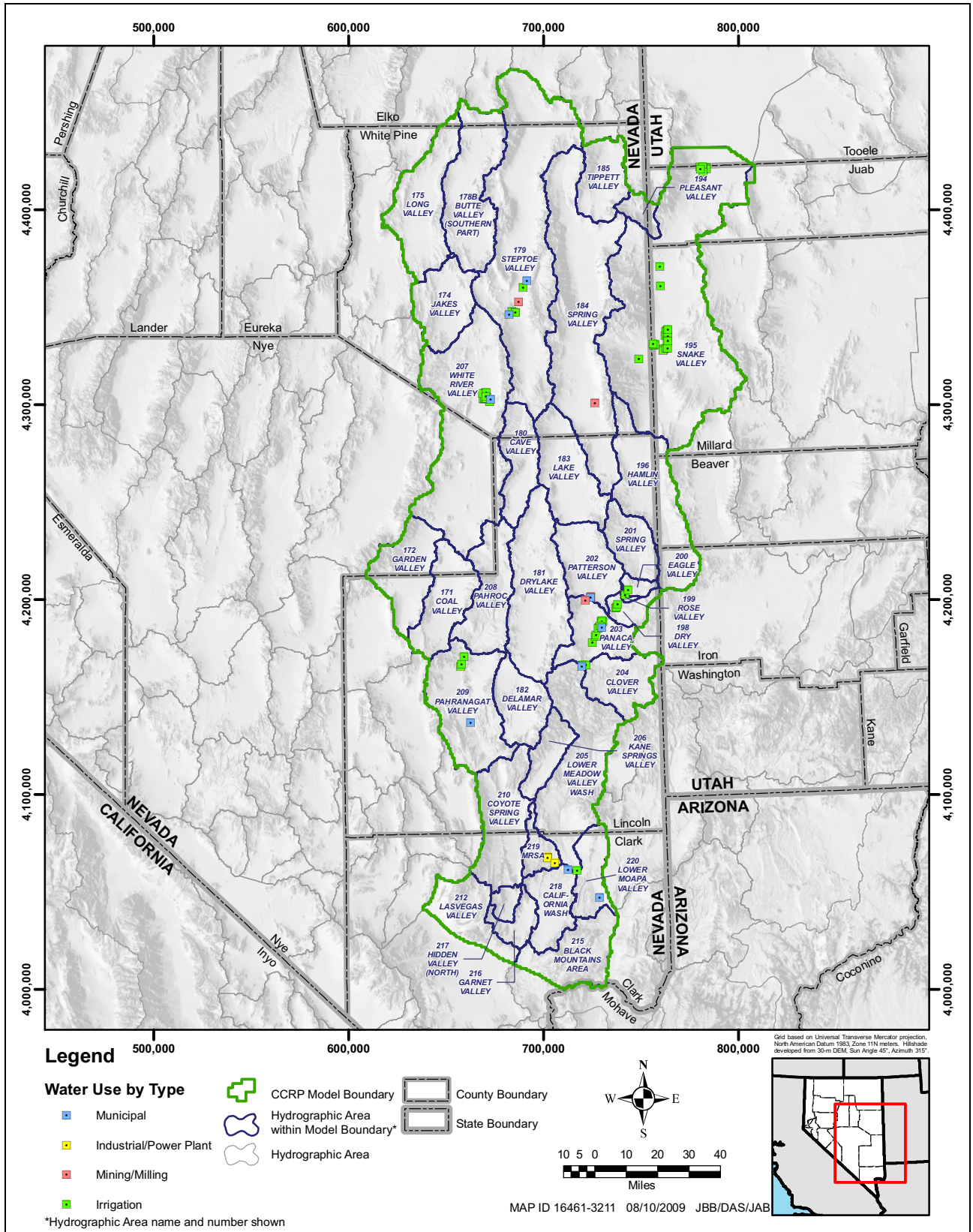


Figure C-21
Spatial Distribution of Diversion Locations for the 1945 to 1955 Time Period

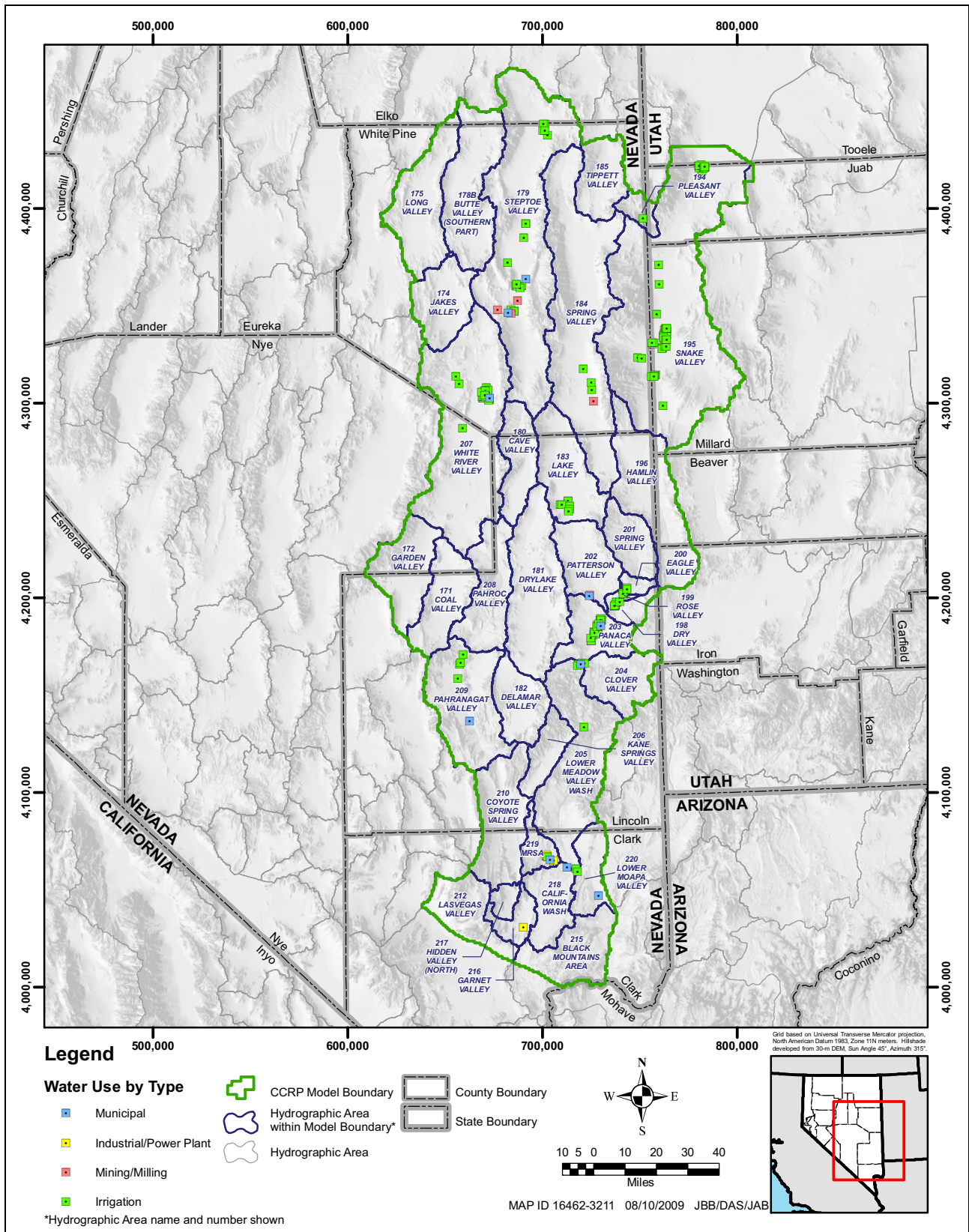


Figure C-22
Spatial Distribution of Diversion Locations for the 1956 to 1965 Time Period

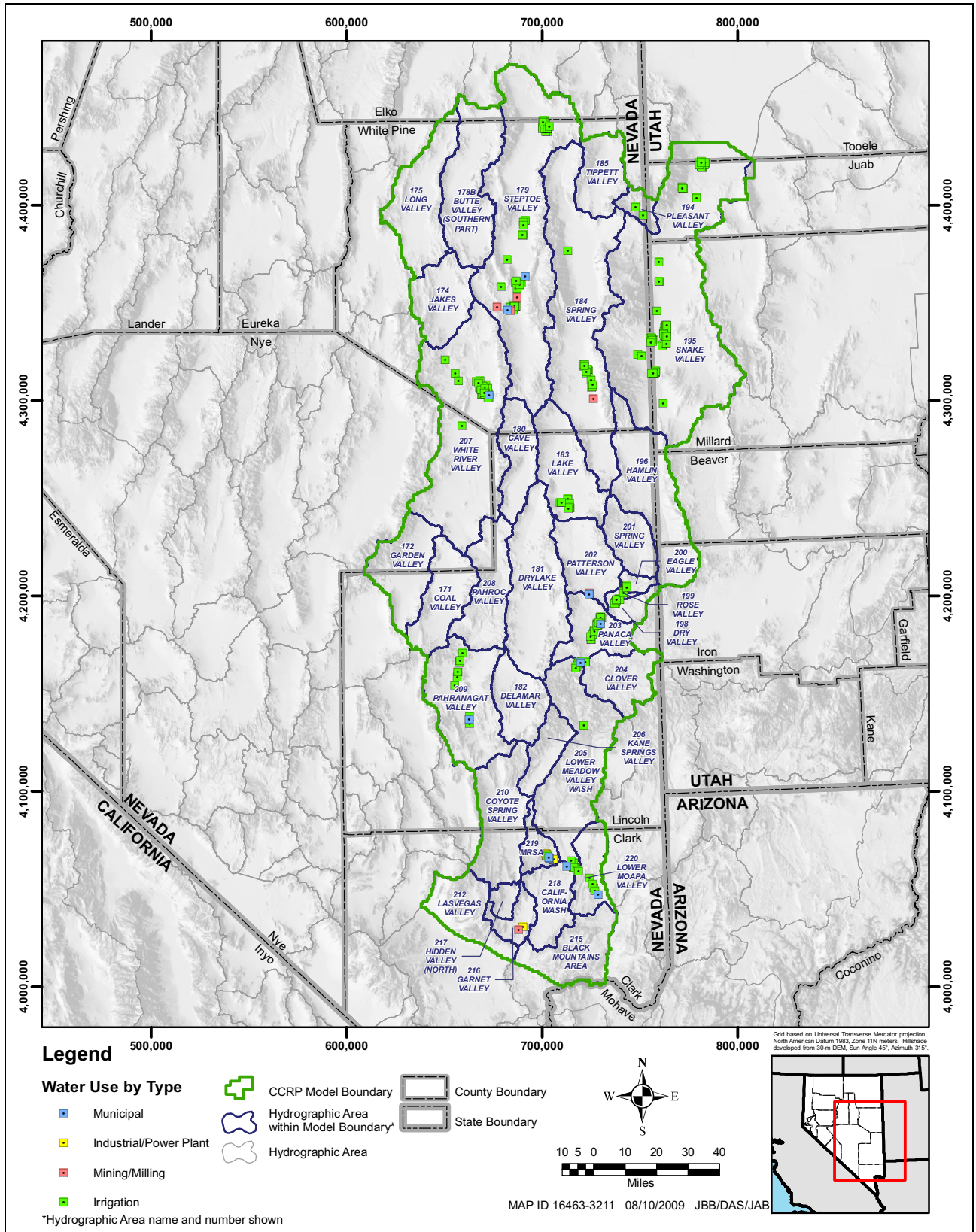


Figure C-23
Spatial Distribution of Diversion Locations for the 1966 to 1975 Time Period

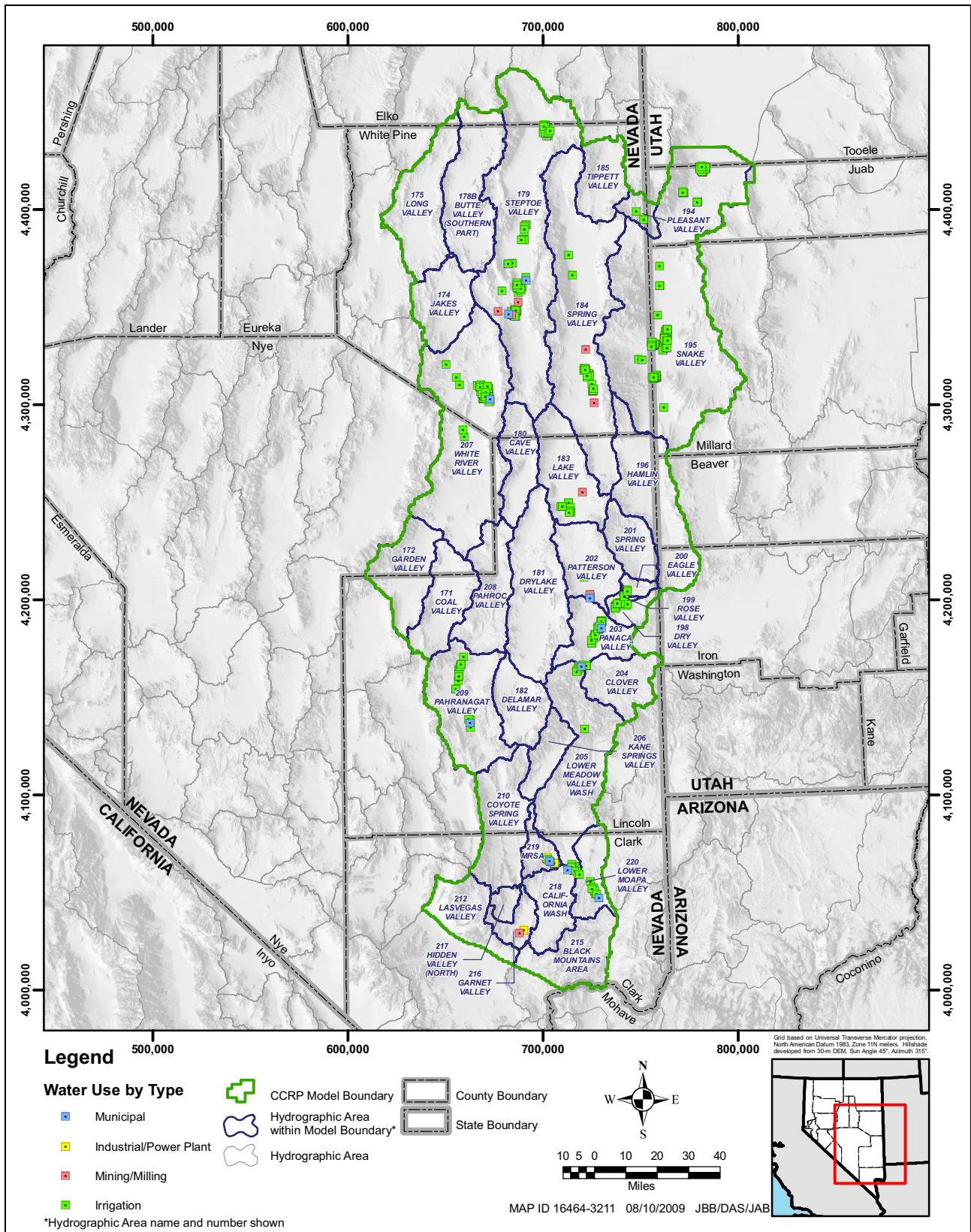


Figure C-24
Spatial Distribution of Diversion Locations for the 1976 to 1980 Time Period

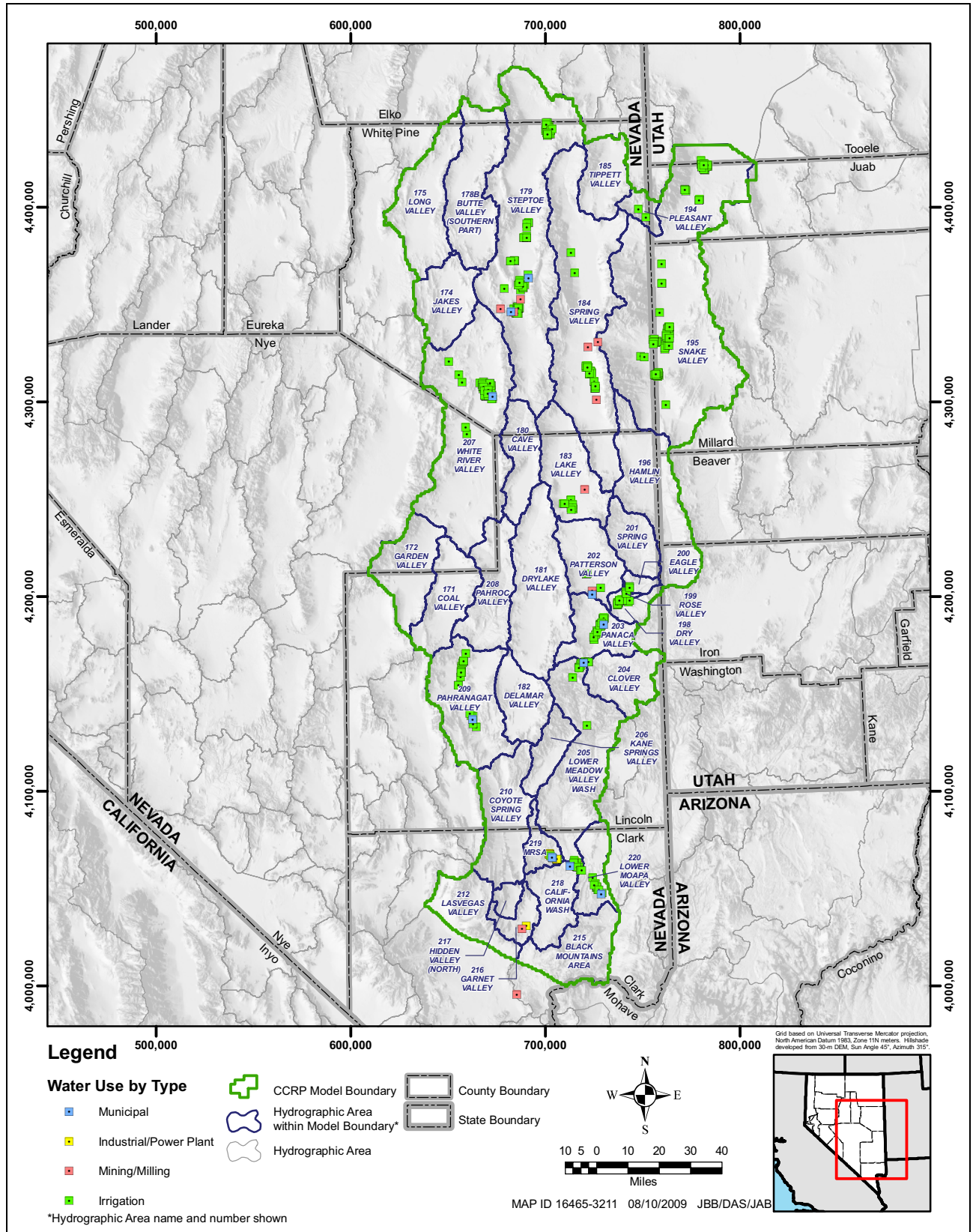


Figure C-25
Spatial Distribution of Diversion Locations for the 1981 to 1985 Time Period

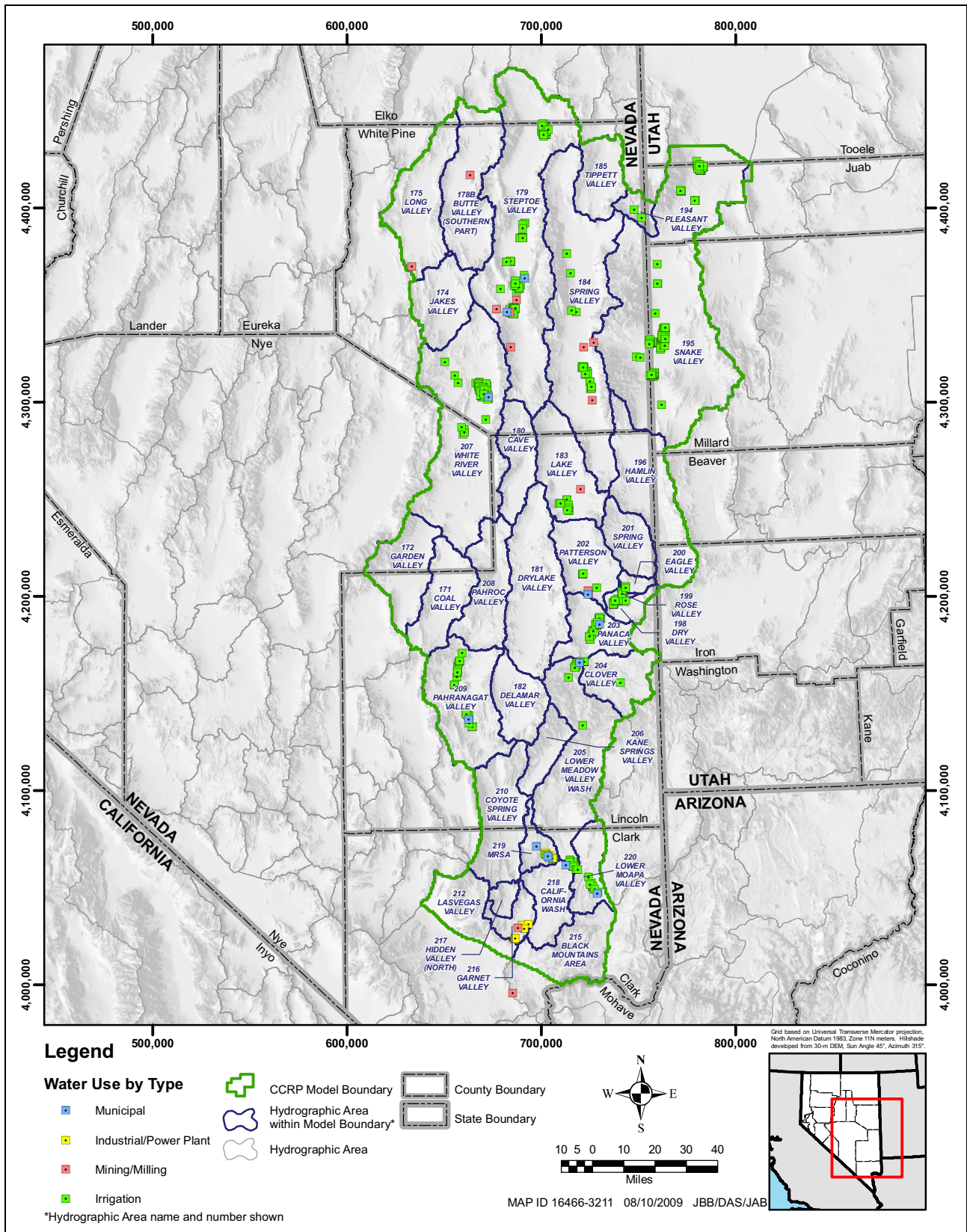


Figure C-26
Spatial Distribution of Diversion Locations for the 1986 to 1990 Time Period

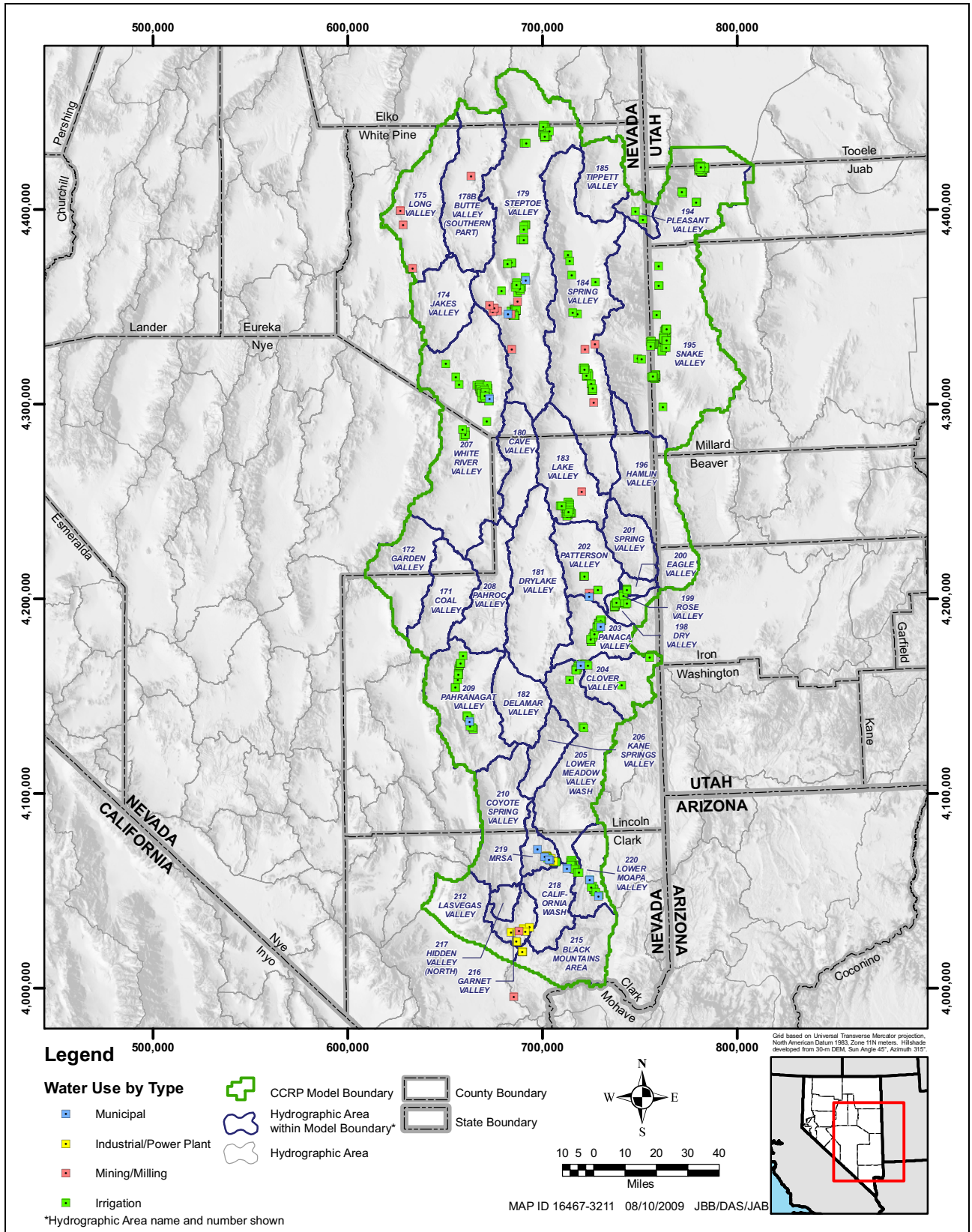


Figure C-27
Spatial Distribution of Diversion Locations for the 1991 to 1995 Time Period

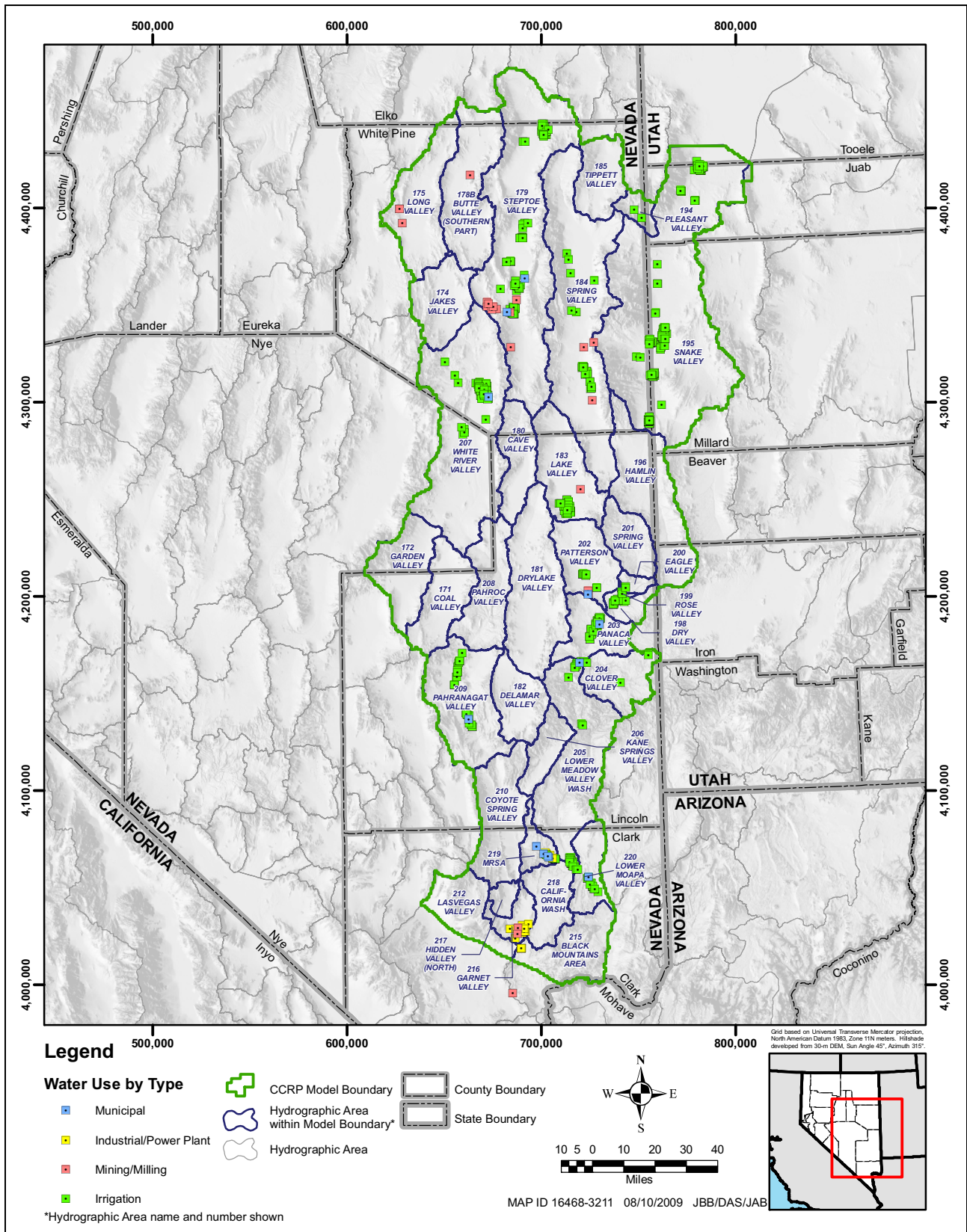


Figure C-28
Spatial Distribution of Diversion Locations for the 1996 to 2000 Time Period

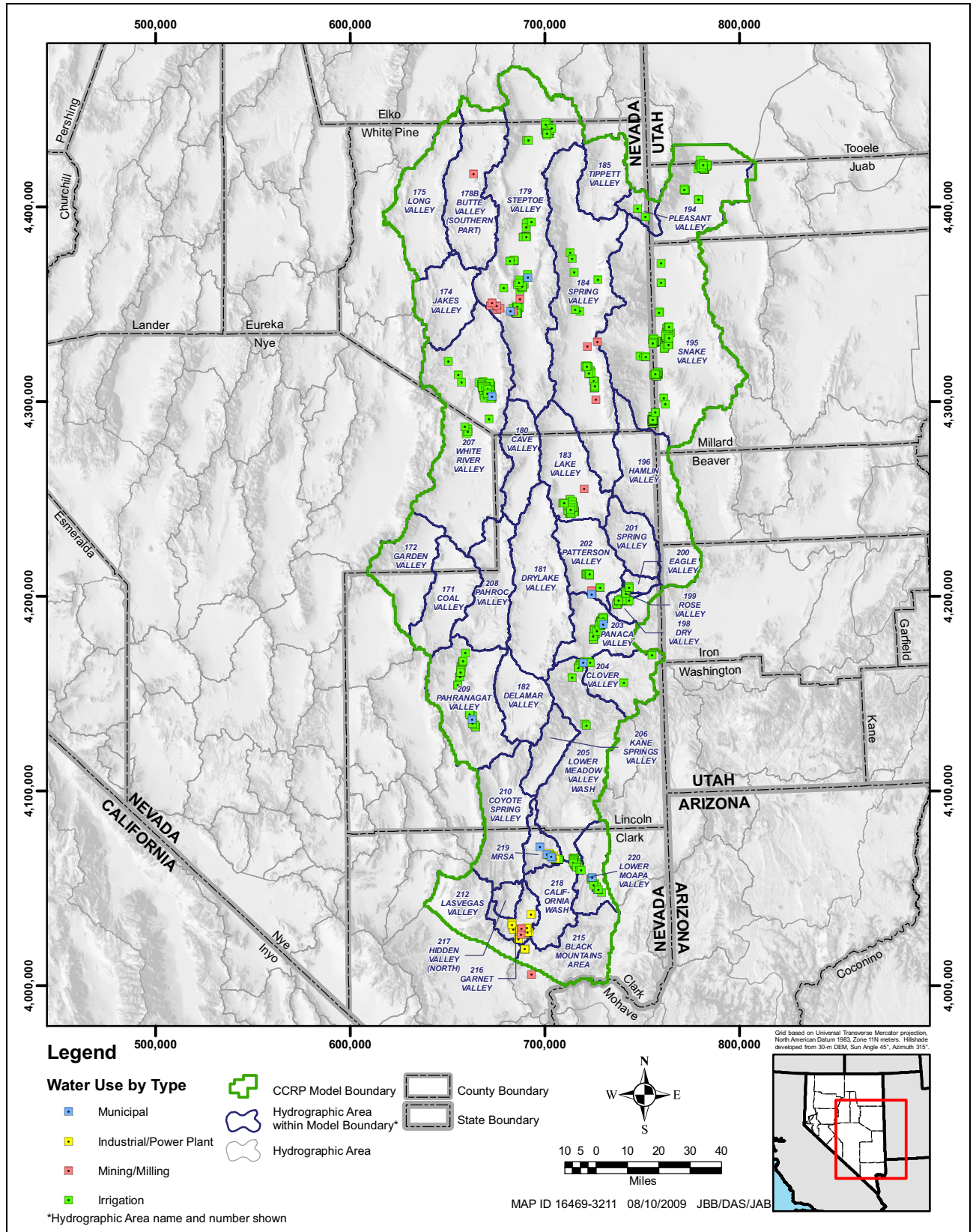


Figure C-29
Spatial Distribution of Diversion Locations for the 2001 to 2004 Time Period

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- mou - The NDWR manner of use associated with the water right.
 - well_log1 - The well log (NDWR) or well identification (Utah) number associated with the water right.
 - file_dt - The filing date for the water-right application.
 - prior_dt - The priority date for the water-right application.
 - UTM_N_N83 - The UTM northing coordinates for the point of diversion.
 - UTM_E_N83 - The UTM easting coordinates for the point of diversion.
 - Open_Interval - The perforated or open interval for the well.
 - Match_ID - Unique identification used to link the points of diversion to specific irrigated croplands.
 - Final_Volume - The volume in afy associated with the point of diversion in a particular time period.

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Plates

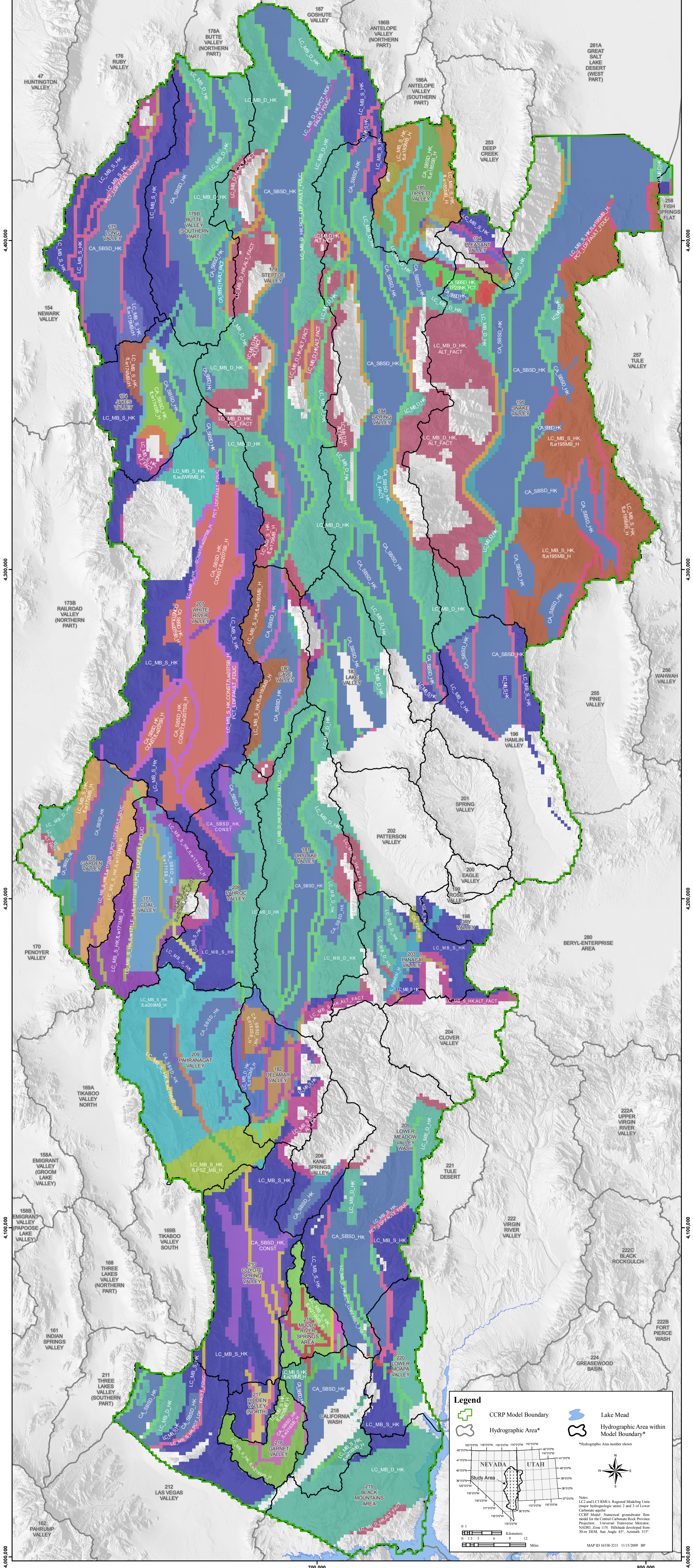


PLATE 1: PARAMETER ZONES DEFINED FOR THE LC2 AND LC3 RMUS IN THE CCRP MODEL

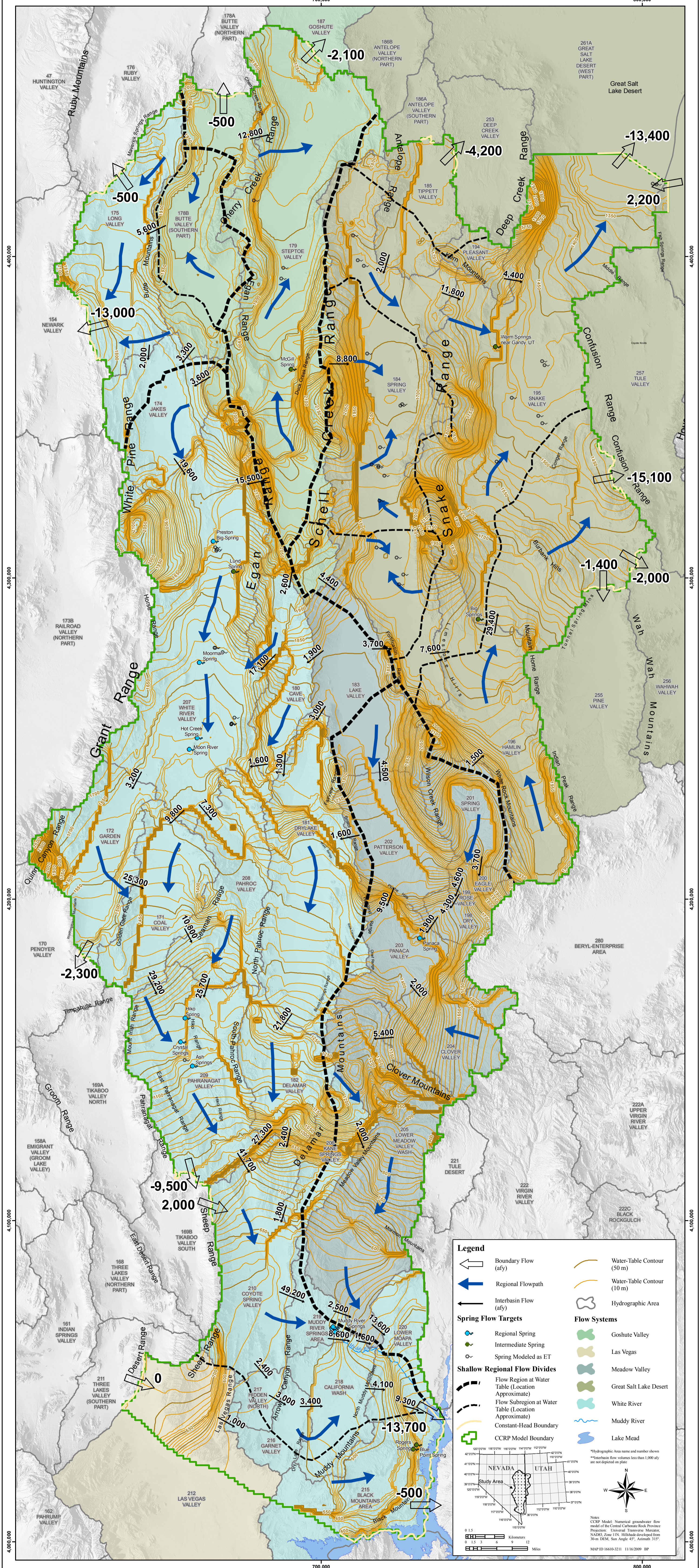


PLATE 2 - GROUNDWATER FLOW REGIONS AND FLOWPATHS AT THE WATER TABLE SIMULATED FOR STEADY-STATE CONDITIONS BY THE CCRP TRANSIENT MODEL

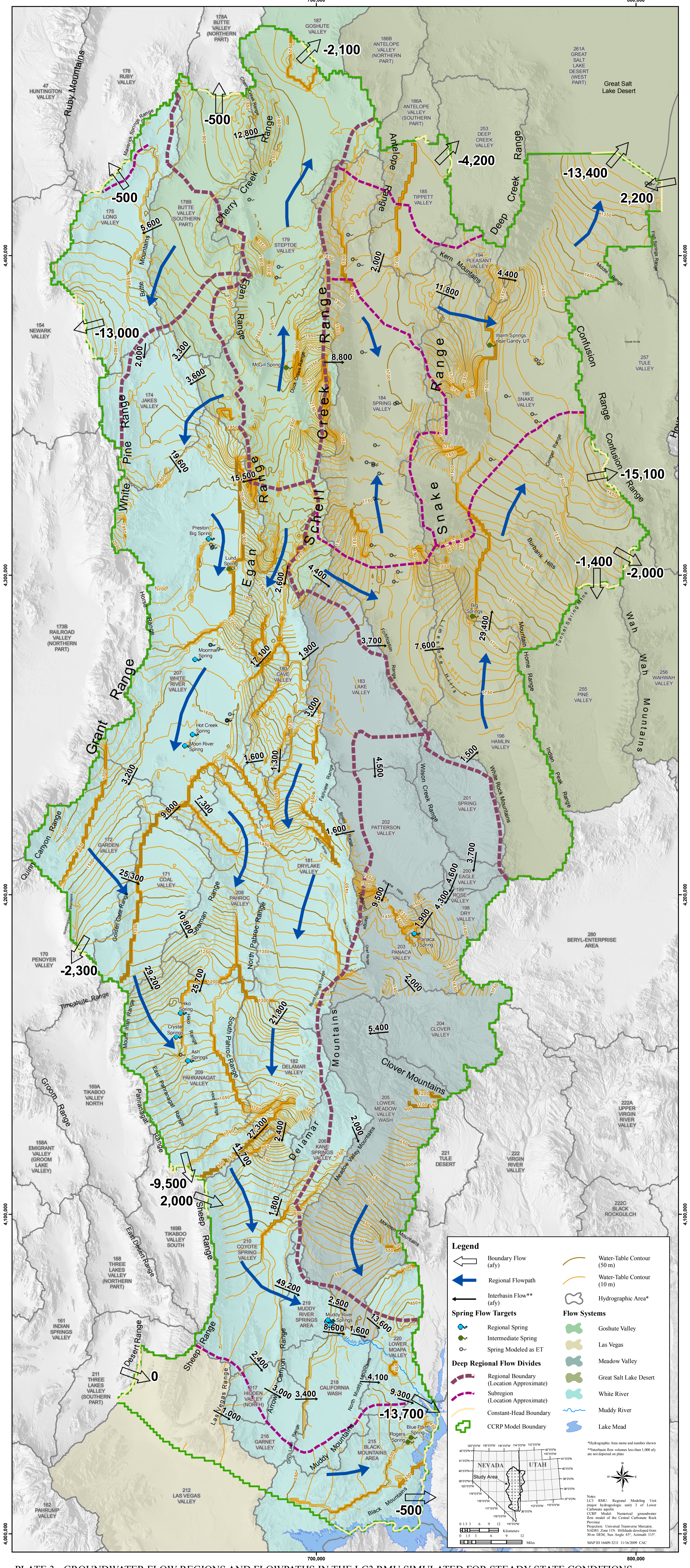


PLATE 3 - GROUNDWATER FLOW REGIONS AND FLOWPATHS IN THE LC3 RMI SIMULATED FOR STEADY-STATE CONDITIONS BY THE CCRP TRANSIENT MODEL