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 Project

DRAFT

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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

BLM	Bureau of Land Management
CCRP	Central Carbonate-Rock Province
CSI	Coyote Spring Investment
DEM	digital elevation model
EIS	environmental impact statement
ESA	Endangered Species Act of 1973
ET	evapotranspiration
HA	hydrographic area
HFB	horizontal flow barrier
LCCRDA	Lincoln County Conservation, Recreation, and Development Act
LVVWD	Las Vegas Valley Water District
MNW	Multi-Node Well
NDWR	Nevada Division of Water Resources
NEPA	National Environmental Policy Act of 1969
POD	point of diversion
RMU	regional modeling unit
SNWA	Southern Nevada Water Authority
SoSWR	sum of squared weighted residuals
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator

ABBREVIATIONS

afy	acre-feet per year
amsl	above mean sea level
bgs	below ground surface
cfs	cubic feet per second
ft	foot
km^2	square kilometer
m	meter

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1.0 INTRODUCTION

This report describes the simulation of the groundwater development scenarios associated with the Southern Nevada Water Authority's (SNWA) Clark, Lincoln, and White Pine Counties Groundwater Development Project (hereinafter referred to as the Project). The scenarios were designed and simulated to support the Environmental Impact Statement (EIS) being developed by the Bureau of Land Management (BLM) to satisfy the requirements of the National Environmental Policy Act of 1969 (NEPA). The simulations were performed using the Central Carbonate-Rock Province (CCRP) Model documented in the numerical model report (SNWA, 2009b) and the report's addendum (SNWA, 2010). The extent of the Project study area (i.e., the regional model area) is shown in Figure 1-1. The results of the simulations are part of the environmental analysis for the Project. Summaries of the Project background, purpose and scope, and BLM review process are presented in this section, followed by a description of the contents of this report.

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 additional resources are part of the current water-resource portfolio identified in the SNWA Water Resource Plan (SNWA, 2009c). Some of the information provided in this plan has, however, changed since its last update. The cause is explained in the following text.

In an effort to expand the availability of water resources to Southern Nevada, in 1989, the Las Vegas Valley Water District (LVVWD) filed 147 groundwater applications with the Nevada State Engineer for unallocated groundwater in 30 basins. Some of these applications were subsequently withdrawn because of potential environmental concerns and existing appropriations. Years later, the Nevada State Engineer ruled on some of the applications and issued permits to LVVWD/SNWA. Permits of interest to this EIS are located in Spring, Delamar, Dry Lake and Cave valleys and were issued in 2007 for Spring Valley (NSE, 2007a and b) and in 2008 for the other three valleys (NSE, 2008). On-going appeals by entities wishing to file protests against SNWA's applications/permits in these four valleys eventually reached the Nevada Supreme Court.

On June 17, 2010, the Nevada Supreme Court issued an advance opinion (NSC, 2010) which reversed the Nevada State Engineer's rulings on SNWA's water-rights applications in Spring, Delamar, Dry Lake and Cave valleys. The opinion states:

> Because we determine that the 1989 water appropriation applications were not pending in 2003, we conclude that the State Engineer violated his statutory duty by failing to take action within one year after the final protest date. Based on the State

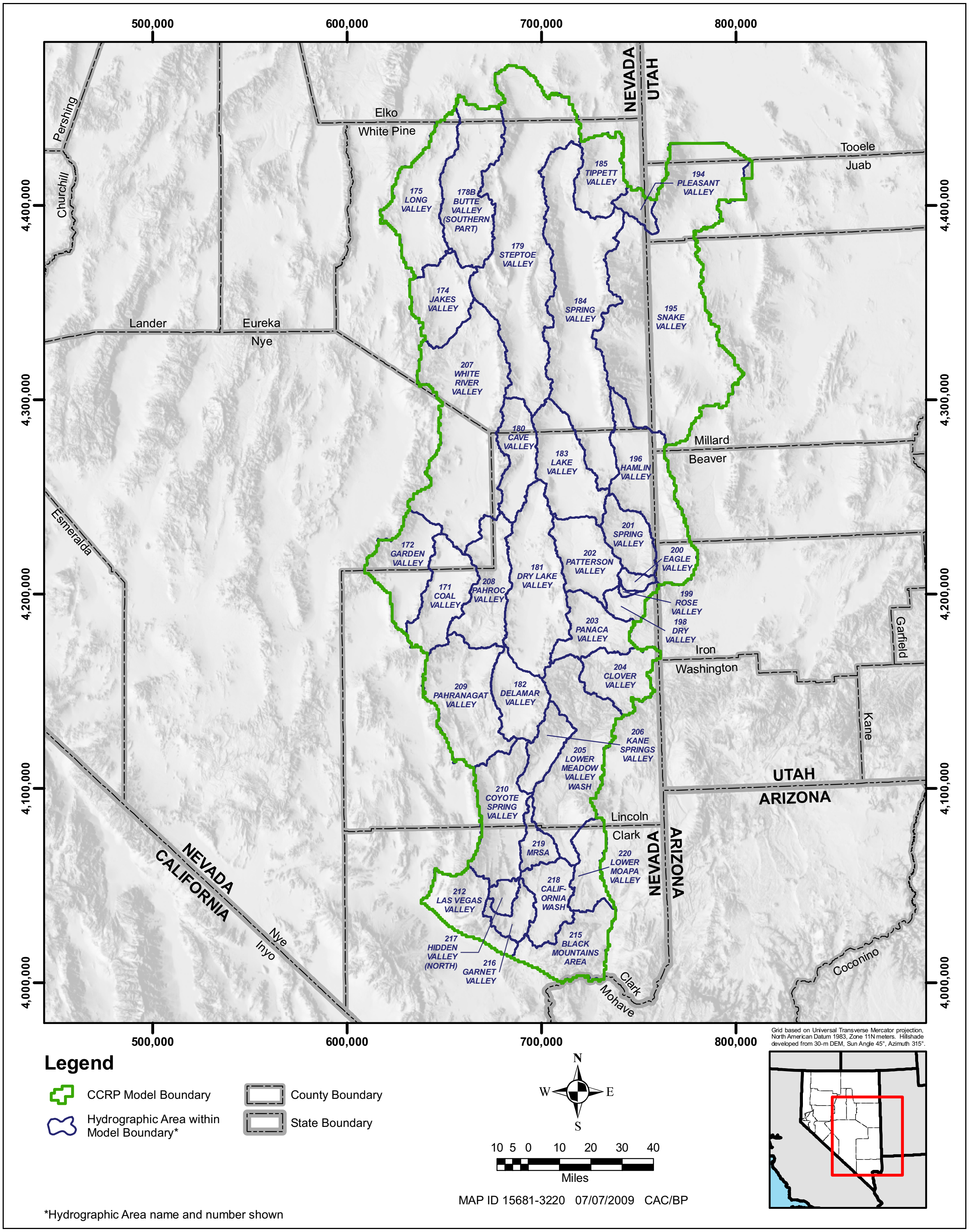


Figure 1-1
Location of Study Area

> Engineer's failure to act on the applications in this case, we further conclude that an equitable remedy is warranted. We determine that the State Engineer must renotice SNWA's 1989 applications and reopen the period during which appellants may file protests. Thus, we reverse the order of the district court and remand the matter to the district court with instructions to remand the matter to the State Engineer for further proceedings consistent with this opinion.

Following the Nevada Supreme Court opinion (NSC, 2010), the Nevada State Engineer stated that: "water rights issued to the Southern Nevada Water Authority under the 1989 applications in Spring Valley, Cave Valley, Dry Lake Valley and Delamar Valley will revert to application status." This allowed the protest period to be reopened and the appellants to submit their protests. The applications of interest are shown in Figure 1-2.

The Project will develop and convey eventually permitted groundwater held by SNWA in these five basins in eastern Nevada. Figure 1-2 shows the project basins and all current points of diversion, including those in Snake Valley. 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 NEPA regulations, the Endangered Species Act of 1973 (ESA), and other Federal regulations. BLM has determined that preparation of an EIS is required to assess the potential effects that may result from permitting the rights-of-way, including the potential indirect effects of the proposed groundwater development. The CCRP groundwater flow model was used in the analysis of potential indirect effects for the EIS.

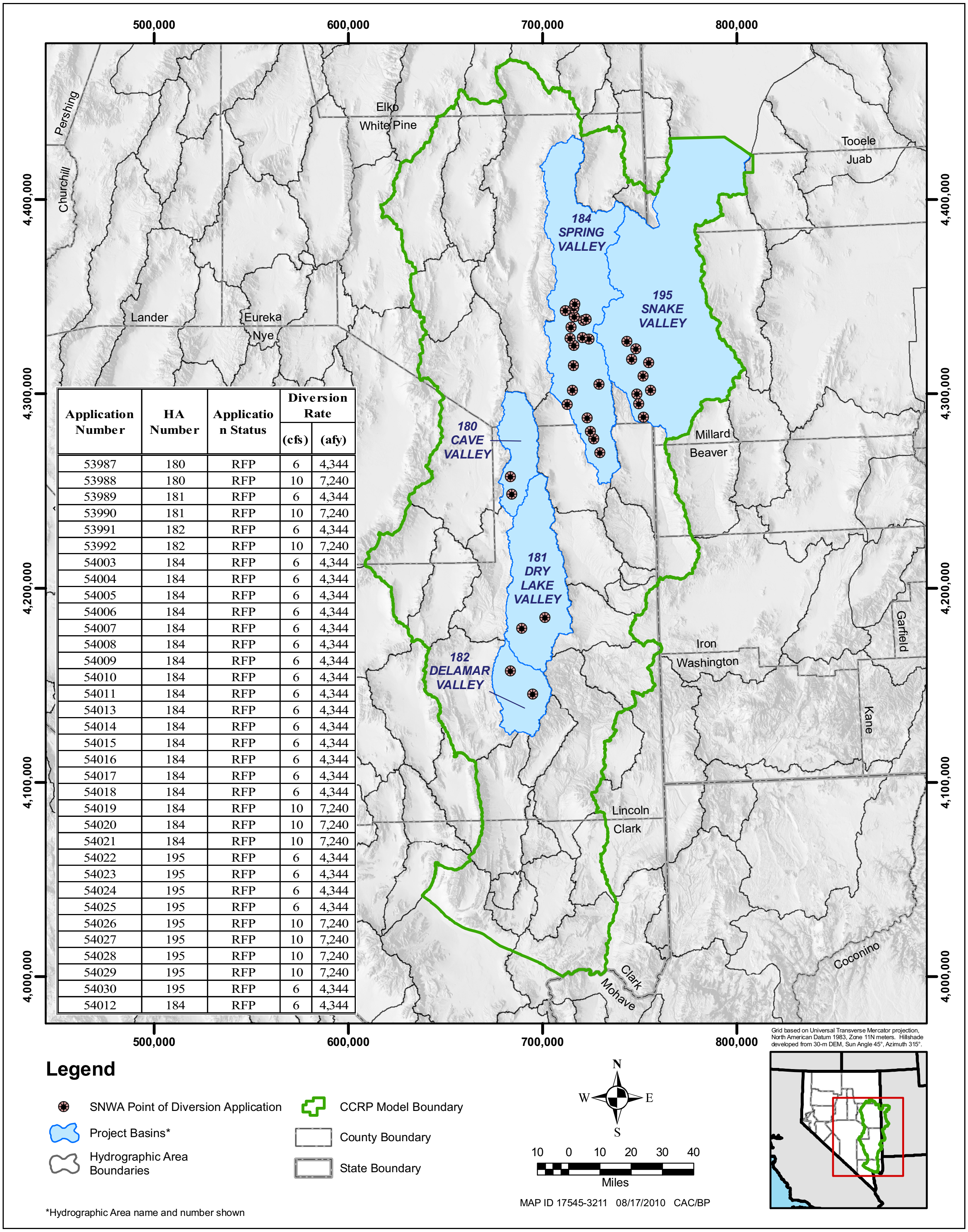
NEPA (1969) regulations for an EIS require the evaluation of the No Action alternative, the Proposed Action and EIS alternatives, and the cumulative pumping effects. In the analysis of potential indirect effects for the EIS, (1) the No Action alternative represents hydrologic conditions that would occur in the future if the pumping associated with the proposed action were not to occur; (2) the Proposed Action represents the groundwater pumping proposed by SNWA; (3) the EIS alternatives represent variations of the Proposed Action; and (4) the Cumulative Pumping includes the effects of the Proposed Action and alternatives and current and reasonably foreseeable, future groundwater uses.

1.2 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 simulation of groundwater development scenarios presented in this report.

1.2.1 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 included the development of a regional three-dimensional numerical model of the flow systems underlying the study area. These



Application Number	HA Number	Application Status	Diversion Rate (cfs)	Diversion Rate (afy)
53987	180	RFP	6	4,344
53988	180	RFP	10	7,240
53989	181	RFP	6	4,344
53990	181	RFP	10	7,240
53991	182	RFP	6	4,344
53992	182	RFP	10	7,240
54003	184	RFP	6	4,344
54004	184	RFP	6	4,344
54005	184	RFP	6	4,344
54006	184	RFP	6	4,344
54007	184	RFP	6	4,344
54008	184	RFP	6	4,344
54009	184	RFP	6	4,344
54010	184	RFP	6	4,344
54011	184	RFP	6	4,344
54013	184	RFP	6	4,344
54014	184	RFP	6	4,344
54015	184	RFP	6	4,344
54016	184	RFP	6	4,344
54017	184	RFP	6	4,344
54018	184	RFP	6	4,344
54019	184	RFP	10	7,240
54020	184	RFP	10	7,240
54021	184	RFP	10	7,240
54022	195	RFP	6	4,344
54023	195	RFP	6	4,344
54024	195	RFP	6	4,344
54025	195	RFP	6	4,344
54026	195	RFP	10	7,240
54027	195	RFP	10	7,240
54028	195	RFP	10	7,240
54029	195	RFP	10	7,240
54030	195	RFP	6	4,344
54012	184	RFP	6	4,344

Figure 1-2
Location of Project Basins and Current Points of Diversion

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 transient numerical model focused on the regional flow system. Intermediate systems were also addressed if they were in contact with the regional flow system. Perched or local flow systems were not modeled. The model was used, along with other analyses, to evaluate the potential water-related effects on the environment and senior water-rights holders. 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 for the following uses:

- Derivation of approximate predevelopment steady-state groundwater budgets for the project basins

- Simulation of preliminary estimates of potential drawdowns in the regional and intermediate portions of the flow system within the model area due to pumping proposed by SNWA and EIS alternatives

- Simulation of the potential effects of pumping proposed by SNWA and EIS alternatives on regional (primarily) and intermediate (secondarily) springs, groundwater evapotranspiration (ET) areas, streams, or wells

- Simulation of the potential effects of pumping proposed by SNWA and EIS alternatives on flow boundaries

- Simulation of the cumulative pumping effects associated with groundwater development within the model area.

The overall scope of work of the hydrologic evaluation included 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 (2009b).

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 two reports. The first one is titled: *Transient Numerical Model of Groundwater Flow for the Central Carbonate-Rock Province–Clark, Lincoln, and White Pine Counties Groundwater Development Project* (SNWA, 2009b). The second report is an

addendum titled: *Addendum to the Groundwater Flow Model for the Central Carbonate-Rock Province: Clark, Lincoln, and White Pine Counties* (SNWA, 2010).

4. Use of the resulting transient model to simulate future water-use scenarios including SNWA's proposed groundwater withdrawals and EIS alternatives as well as the cumulative pumping effects associated with groundwater development in the model area. The simulation of the groundwater development scenarios and the alternatives are documented in this report.

5. Organization and documentation of the CCRP numerical model and scenario simulations files. These files along with their documentation will be provided separately.

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 1.3.

1.2.2 Purpose and Scope of Scenario Simulation

The purpose of the work described in this document is to simulate and describe the potential effects of selected groundwater development scenarios on the flow systems underlying the study area of the Project (Figure 1-1).

The scope of work includes defining the groundwater development scenarios representing the various Project alternatives, simulating their potential effects to satisfy NEPA requirements, and estimating the uncertainty associated with the simulated results. To assess the indirect effects of the Project alternatives, it was necessary to simulate the pumping effects of groundwater development scenarios, which not only included the pumping associated with a given Project alternative but also included the existing pumping associated with the No Action alternative. This was necessary so the effects of the groundwater development scenarios for each alternative could be distinguished from each other as described below.

The modeling scope of work consisted of setting up the water-use schedules associated with each scenario as input to the transient numerical model (SNWA, 2009b), executing the model, and preparing the results for presentation in this report. Given that the simulated results included the combined effects of the existing pumping included in the No Action alternative, the incremental effects of the Proposed Action and other Project alternatives were derived by subtracting the effects of the No Action alternative for the same point in time. This adjustment was not needed in the case of the Cumulative Pumping simulations because, by definition, the groundwater development scenarios representing cumulative pumping include historical, proposed, and reasonably foreseeable, future pumping.

1.3 BLM Review Process

A Hydrology Technical Group was assembled by BLM in the early stages of the technical work performed 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, numerical model development, and simulation of the groundwater development scenarios satisfy the requirements of the EIS analysis.

The BLM Hydrology Technical Group members are as follows:

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

The Hydrology Technical Group review process began in 2006 and 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, analysis, and modeling files and/or results. This group conducted the report reviews and provided review comments 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.

1.4 Document Contents

This report documents groundwater development scenarios representing various Project alternatives in the EIS as required by NEPA. At this time, the scenarios needed to satisfy ESA requirements have not been finalized. This document consists of seven sections. 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 and simulate the groundwater development scenarios, including sensitivity analysis of the most important model parameters.

- Section 3.0 describes the groundwater development scenarios.

- Section 4.0 describes the simulation results of the groundwater development scenarios described in Section 3.0.

- Section 5.0 presents an uncertainty analysis of the simulated effects for a selected modeling scenario presented in Section 4.0.

- Section 6.0 describes the limitations associated with the transient numerical model used to simulate the effects of the groundwater development scenarios.

- Section 7.0 provides a list of references cited in this report.

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2.0 APPROACH

The general approach followed to develop the CCRP model is presented in this section, followed by descriptions of the scenario development and analysis approach, the simulation process, and results presentation.

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 transient numerical model based on the conceptual model.

   - Calibration of the numerical model to transient conditions.

   - Modification of the numerical model following BLM review.

3. Simulation of groundwater development scenarios using the modified numerical model to evaluate:

   - Effects of proposed pumping.

   - Cumulative effects of historical, reasonably foreseeable future and proposed groundwater pumping.

   - Uncertainty analysis of simulated effects.

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 and the development of the transient numerical model are described in SNWA (2009b and 2010). The approach followed to complete Step 3 is described in the remainder of this section. This approach is subdivided into four parts: (1) scenario development, (2) scenario simulation, (3) Uncertainty analysis, and (4) result presentation.

2.2 Groundwater Development Scenarios

A summary listing of the groundwater development scenarios considered is provided, followed by a description of the basis and underlying assumptions applied to derive the corresponding water-use schedules.

2.2.1 Scenario Description

The groundwater development scenarios were constructed in cooperation with BLM in accordance with NEPA, and the Lincoln County Conservation, Recreation, and Development Act (LCCRDA) requirements. Water-use schedules were derived for each of the following identified alternatives:

- No Action
- Proposed Action
- Alternative A (Proposed Action-Reduced Quantity)
- Alternative B (Point of Diversion [POD])
- Alternative C (Intermittent Pumping)
- Alternative D (LCCRDA Corridor)
- Alternative E (Spring, Dry Lake, Delamar, and Cave valleys)

In addition, NEPA cumulative water-use schedules were developed for each of the above alternatives and a proposed pumping cessation for Alternative A was considered for the last case; the Project pumping under Alternative A was ceased 75 years after full development of the Project (year 2125). This simulation was continued until 2250 to observe the recovery.

The production-well locations and water-use schedules are provided in Section 3.0, as part of the descriptions of the groundwater development scenarios, which include groundwater pumping associated with the No Action scenario.

2.2.2 Basis and Assumptions

The water-use schedules are based on: (1) projected schedules of water-resource demand and supply described in the SNWA Water Resource Plan (2009c); and (2) the fact that the status of the groundwater permits included in this plan for Spring Valley, Delamar, Dry Lake and Cave valleys has now been changed to "applications", as described in Section 1.0.

The water-use schedule of the Proposed Action and each alternative reflects the staged development planned for the project basins, including a sequence in which the basins may be developed and the rate of development in each. The difference between SNWA's available Colorado River supply and other nonproject water resources and the projected water-resource demand dictated the annual groundwater volume required from the Project and the time in which it is needed. SNWA's currently available water resources are described in detail in the current Water Resource Plan (SNWA, 2009c). It must also be recognized that while these projections are best estimates, they are subject to the variability of demand and hydrologic conditions on the Colorado River, SNWA's primary water source. Therefore, the anticipated need for groundwater derived from this project may be sooner or later than what is assumed for the schedules.

The water-use schedules associated with the groundwater development scenarios are based on the following assumptions:

- The No Action pumping scenario includes SNWA groundwater rights associated with the SNWA-owned ranches in Spring Valley. SNWA is currently not using the entirety of the 8,000 afy of existing agricultural groundwater rights but is planning to do so within the next two years. Because these 8,000 afy of rights are associated with private property and would be developed regardless of the proposed action, they are included in the No Action scenario.

- The Proposed Action is based on the assumption that the Nevada State Engineer allocates the full application rates in Spring, Delamar, Dry Lake and Cave valleys. This is a reasonable assumption. Given that the permits granted by the State Engineer in these valleys has reverted to "application status," the State Engineer may permit different rates than before, up to the rates specified in the applications.

- SNWA water rights transferred to Lincoln County (3,000 afy) in Delamar and Dry Lake valleys are assigned proportionally in the water-use schedules to the Lincoln County/Vidler application PODs in these basins. The rights are initially developed based on the projected SNWA demands and are assumed to be transferred to Lincoln County at a later time during the simulation period.

- The Project water-use schedules for all groundwater development scenarios are based, in part, on the projections described in the 2009 SNWA Water Resource Plan (SNWA, 2009c). These projections include a resource supply deficit of about 14,000 afy beginning in 2019 and reaching an annual deficit greater than the maximum Project supply by 2050. This schedule is considered the most reasonable based on currently available information and was used to construct the water-use schedules for each groundwater modeling scenario by defining the volume and timing of groundwater development in each of the project basins. However, it is recognized that this schedule assumes normal Colorado River conditions, and groundwater development may be needed sooner if an extended severe drought in the Colorado River basin results in reduced availability of SNWA's other water supplies.

- Deliveries from the Project are required by 2019 to meet projected demands, and pumping in all project basins will reach full capacity by 2050. Pumping for all scenarios, including No Action and Cumulative Pumping scenarios, were simulated for 200 years after full development of the Project.

2.3 Scenario Simulation

The modified version of the transient numerical model (SNWA, 2009b and 2010) was used to simulate the groundwater development scenarios. The simulated pumping effects of the Proposed Action alternative and the other identified alternatives were derived by subtracting the simulated pumping effects of the No Action alternative. The simulated pumping effects of the Cumulative

Pumping scenarios did not require adjustment. A summary description of the transient numerical model and its use in simulating the scenarios is provided.

The modified transient numerical model (SNWA, 2009b and 2010) was developed using a customized version of the finite-difference modeling code, MODFLOW-2000 (Harbaugh et al., 2000). A customized version of UCODE_2005 (Poeter et al., 2005) was used to facilitate the model-calibration and evaluation processes. Two other programs, SIM_ADJUST (Poeter and Hill, 2008) and a customized version of ZONBUD, were also used to support the modeling process. 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 installation and execution of modeling codes and supporting software as well as a description of the model files were provided in SNWA (2009b and 2010). This model was constructed and calibrated using the available information described in SNWA (2008, 2009a and b). The time period of calibration was from January 1, 1945, to December 31, 2004.

All groundwater development scenarios or water-use schedules were set up in the transient numerical model (SNWA, 2009b) in a similar fashion. The following aspects of the model required changes to the model input files:

- Water-use schedules
- Time discretization
- Initial conditions
- Target observations

More details on setting up the numerical model to simulate the scenarios are provided in Section 4.0.

2.4 Uncertainty Analysis

Two types of uncertainty analyses were evaluated. The first one evaluates the effect of parameter uncertainty on the spatial extent of drawdown due to simulated pumping associated with the Proposed Action-Reduced Quantity alternative and the second one examines the effects of using alternate representations of certain features of the conceptual model in the numerical model. The uncertainty analysis is described in Section 5.0.

2.4.1 Effect of Parameter Uncertainty

Sensitivity analyses of selected major groups of model calibration parameters were performed on the calibrated transient model (SNWA, 2009b) and were extended to the simulation of the groundwater development scenarios. Two simulations were performed for each scenario and for each parameter group using the low and high values of the subject group of parameters, representing the uncertainty ranges on the mean (calibrated) values. Model calibration parameters that were perturbed consist of two main groups: hydraulic-conductivity parameters (*K*) and storage parameters, including specific yield (*Sy*) and specific storage (*Ss*). The specific approach, parameter data, simulations, and results are described in Section 5.0.

2.4.2 Effect of Alternate Representation of Big Springs Area

Alternate representation of the Big Springs area in the numerical model (SNWA, 2009a) and the modified numerical model (SNWA, 2010) were evaluated by comparing the simulated pumping effects associated with the Proposed Action-Reduced Quantity alternative.

2.5 Results Presentation

All simulation results including the groundwater development scenarios and the sensitivity analyses are summarized in Section 4.0. The sensitivity analysis results are summarized in Section 5.0. The detailed results are included on the enclosed DVD.

The summary results (Section 4.0) include evaluations of the simulated effects of pumping on the following simulated variables:

- Hydraulic heads
- Spring flow and stream flow
- Interbasin flow
- Groundwater ET

The results are summarized for selected points in time defined as follows:

- Full build-out year: Reflects year when the maximum yearly pumping rate from the SNWA-proposed wells is reached for a given scenario.
- 75 years after full build-out.
- 200 years after full build-out.

In some instances, results were also included for baseline conditions (January 1, 2005) in the Section 4.0 summary for comparison purposes.

The results of the uncertainty analyses involving the simulated effects associated with the Proposed Action-Reduced Quantity alternative (Alternative A) are presented in Section 5.0 in the form of: (1) maximum drawdown extents corresponding to the most conservative combination of selected groups of parameters, and (2) a comparison of results for Alternative A using the original and modified numerical models.

The detailed results are included in electronic files (see DVD) in the form of tables and graphs showing simulated values for all scenarios and incremental changes from the No Action alternative for all scenarios except the Cumulative Pumping scenarios.

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3.0 DESCRIPTION OF GROUNDWATER MODELING SCENARIOS

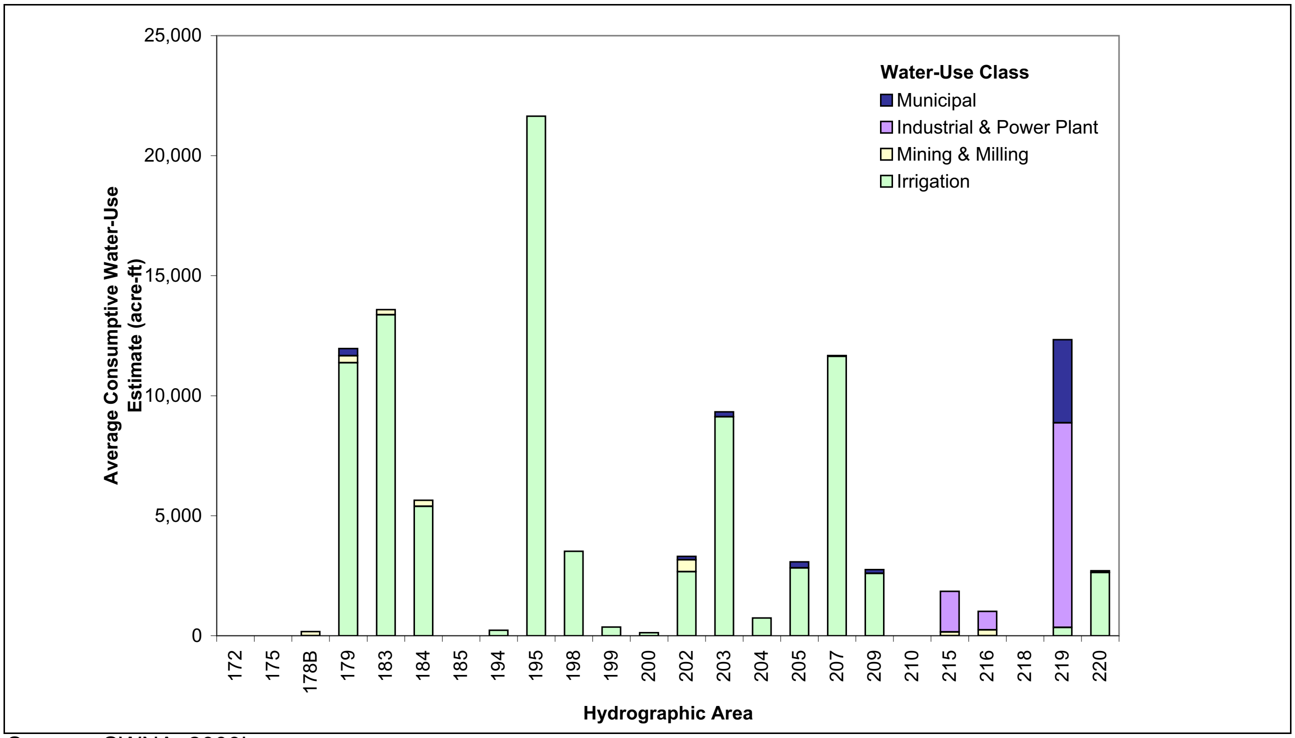
Groundwater modeling scenarios representing anticipated pumping conditions prior to the development of the Project and various Project alternatives were derived in support of the BLM EIS analysis of the Project. Schedules of groundwater consumptive uses defined by these scenarios were developed and then simulated using the transient numerical model to describe the potential, indirect groundwater-related effects of each scenario. Descriptions of the groundwater development scenarios are presented for each alternative in the following order: (1) No-Action scenario, (2) Proposed Action and project alternative scenarios, (3) NEPA cumulative scenarios, and (4) Cessation of pumping scenario. The scenarios are described in detail in the following section. The simulation of these scenarios and associated results are described in Section 4.0.

3.1 No Action

The No Action groundwater development scenario represents the continuation of current groundwater use into the future without pumping from either the proposed wells or additional pumping wells. The simulation results represented by this scenario provide estimates of the pre-Project hydrologic conditions from which the potential, indirect groundwater-related effects of the alternative groundwater development scenarios can be derived.

The water-use schedule for the No Action scenario is based on the estimates of historical consumptive groundwater uses that are documented in the CCRP numerical model report (SNWA, 2009b) for the period 1945 to 2004. More specifically, the consumptive-use rates estimated for the last few years of the historical period (2001 to 2004) (Figure 3-1) were used for the scenario simulation period from 2005 to 2249. The consumptive-use estimates are inclusive of the 11,300 afy of existing Coyote Spring Investment (CSI) groundwater rights in Lake Valley that are expected to be transferred to Coyote Spring Valley using Project facilities and the 8,000 afy of existing SNWA groundwater rights associated with SNWA-owned ranch properties in Spring Valley that will be transferred to southern Nevada. The 11,300 afy of CSI groundwater rights are already in use and are therefore represented in the pre-2005 water-use schedule. All of the SNWA-owned ranch rights have been or will be placed to beneficial uses to support agriculture in the respective basins before Project-related pumping begins. These rights are represented in the water-use schedules as 4,345 afy of current use with the remaining rights, 3,655 afy, being put into production by 2012.

The No Action simulation period starts at the beginning of year 2005 and ends the same year as all other groundwater development scenarios simulated as part of the EIS analysis. The beginning year of 2005 represents the initial hydraulic conditions of the flow system incorporated in the model by using the hydraulic heads simulated by the transient numerical model for the end of 2004 (SNWA, 2009b). This initial hydraulic-head distribution implicitly includes the effects of the historical



Source: SWNA, 2009b

Figure 3-1
Average Consumptive Water Use by Hydrographic Area for Time Period 2001-2004

pumping for the 1945 to 2004 period (SNWA, 2009b). The simulated well distribution and water-use schedule for this scenario is presented in Figure 3-2.

3.2 Project Alternatives

Groundwater development scenarios for project alternatives were derived, constructed and are described in this section. The wa ter-use schedules for e ach of the scenarios include the consumptive-use estimates simulated as the No Action scenario. Any reasonably foreseeable, future nonproject groundwater uses are included and are simulated in the Cumulative Pumping scenarios described in Section 3.3.

3.2.1 Proposed Action

In the Proposed Action s cenario, the full application volume of SNWA's pending applications are simulated. The application volumes per basin are:

- Delamar Valley - 11,584 afy
- Dry Lake Valley - 11,584 afy
- Cave Valley - 11,584 afy
- Spring Valley - 91,224 afy
- Snake Valley - 50,679 afy

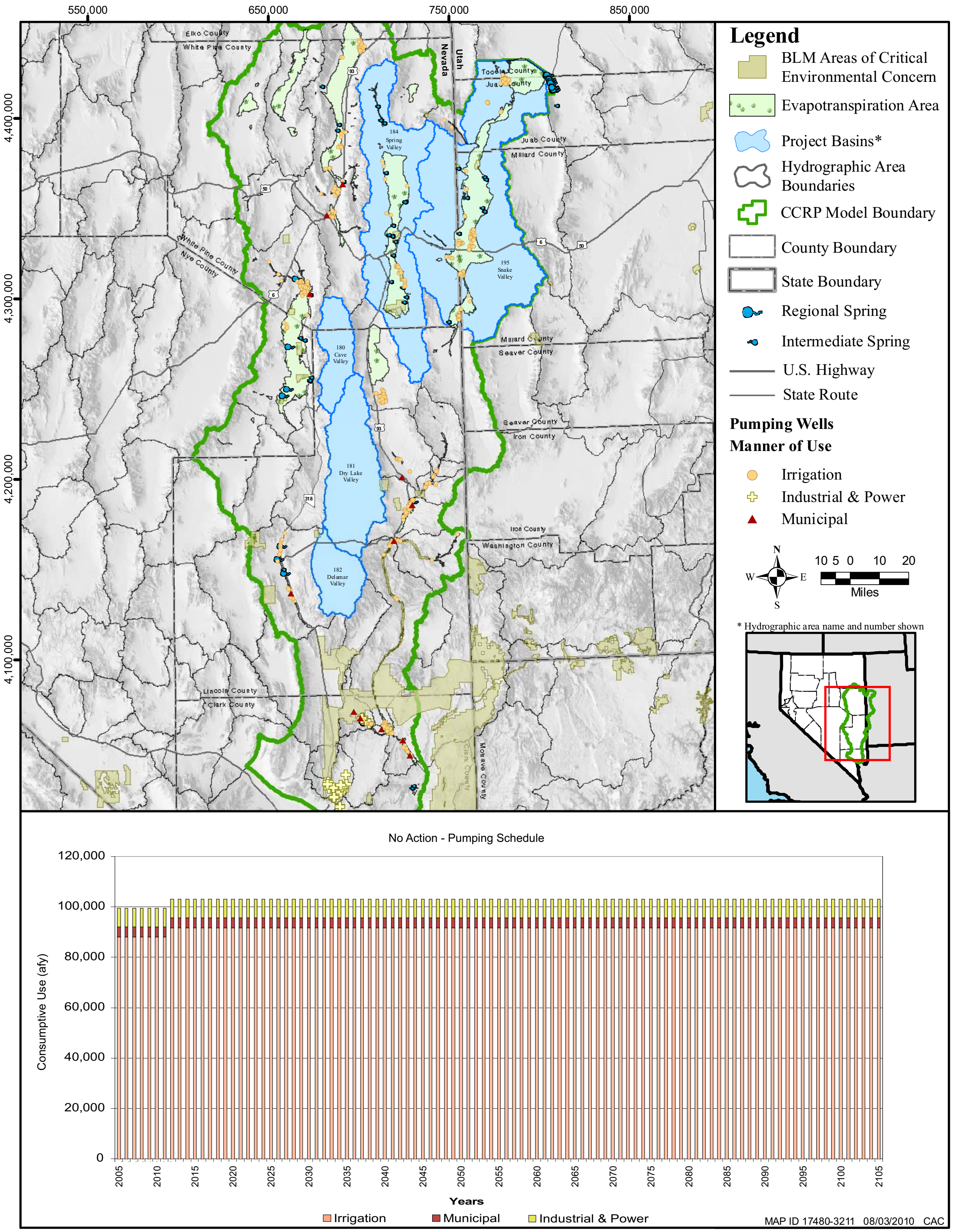


Figure 3-2
No Action - Pumping Distribution

The pumping is distributed spatially within the project basins with the objective of minimizing the pumping effects at (1) PODs associated with senior water rights and (2) areas containing sensitive or listed species and/or their groundwater-related habitat. This distribution reflects the adaptive management strategies that SNWA plans to utilize in managing the resource by redistributing pumping to minimize effects. The total number of wells that are scheduled to pump during a given year is based on the volume required to meet demands for that year (Figure 3-3).

3.2.2 Alternative A - Distributed Pumping - Reduced Quantities

In the Alternative A scenario, the volumes of SNWA's pending applications have been reduced. The volumes per basin have been reduced to:

- Delamar Valley - 2,493 afy
- Dry Lake Valley - 11,584 afy
- Cave Valley - 4,678 afy
- Spring Valley - 60,000 afy
- Snake Valley - 36,000 afy

The pumping is distributed spatially within the project basins with the same purpose as described for the Proposed Action. The total number of wells that are scheduled to pump during a given year is based on the volume required to meet demands for that year (Figure 3-4).

3.2.3 Alternative B - Current Points of Diversion

In the Alternative B - Current PODs scenario, the full application volume of SNWA's pending applications are simulated. The application volumes per basin are:

- Delamar Valley - 11,584 afy
- Dry Lake Valley - 11,584 afy
- Cave Valley - 11,584 afy
- Spring Valley - 91,224 afy
- Snake Valley - 50,679 afy

The pumping in each valley was distributed equally among all the PODs in the valley based on the demand schedule, up to maximum rates equivalent to the diversion rates associated with the individual applications. The total number of wells that are scheduled to pump during a given year is based on the volume required to meet demands for that year (Figure 3-5).

3.2.4 Alternative C - Intermittent Pumping

The Alternative C - Intermittent Pumping scenario reflects a strategy that SNWA would employ based on water availability from the Colorado River. SNWA may be able to reduce deliveries from the Project during times of available surplus Colorado River water but would require full delivery of Project water during times of normal and drought conditions. Because projecting occurrences of drought and surplus on the Colorado River is inherently uncertain due to the variability in climatic

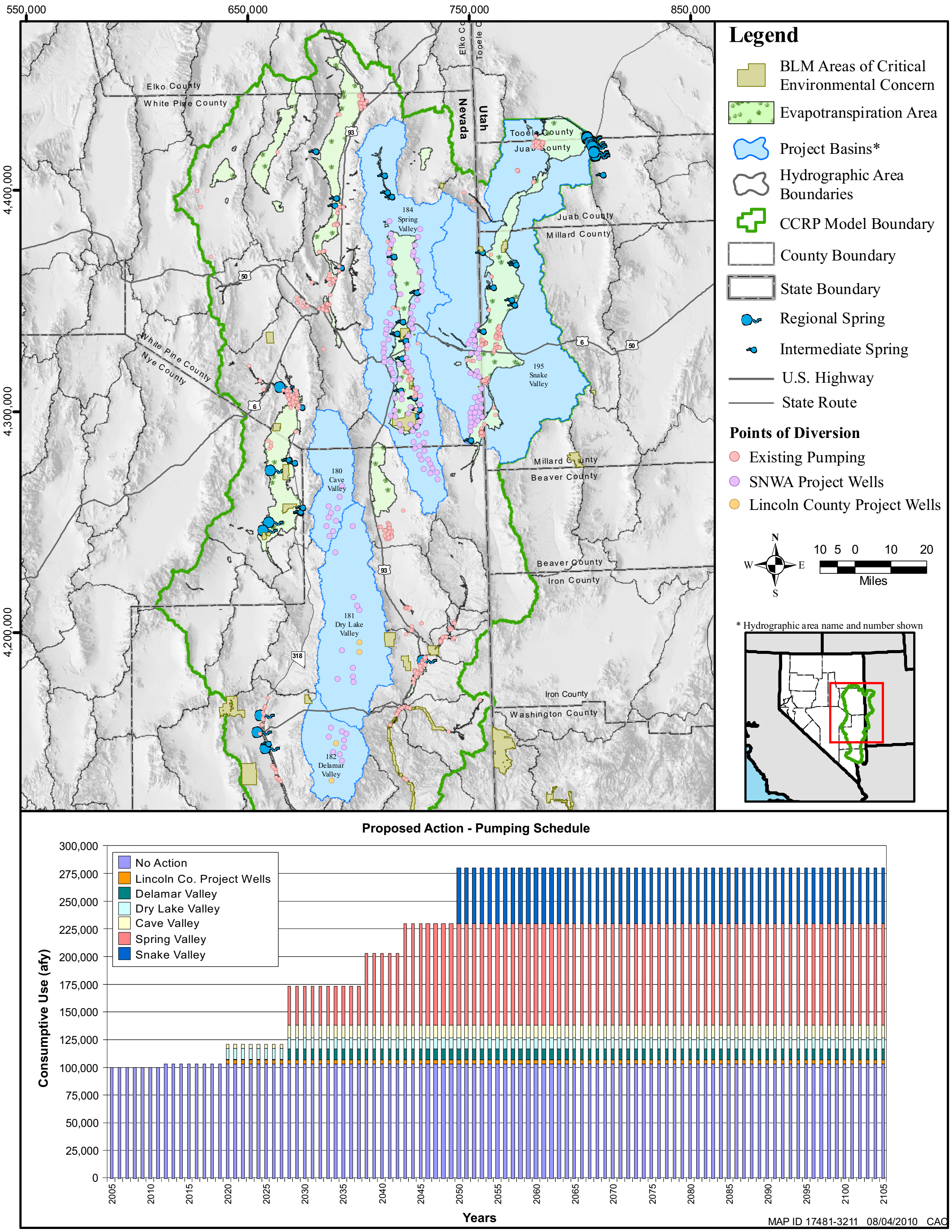


Figure 3-3
Proposed Action - Pumping Distribution

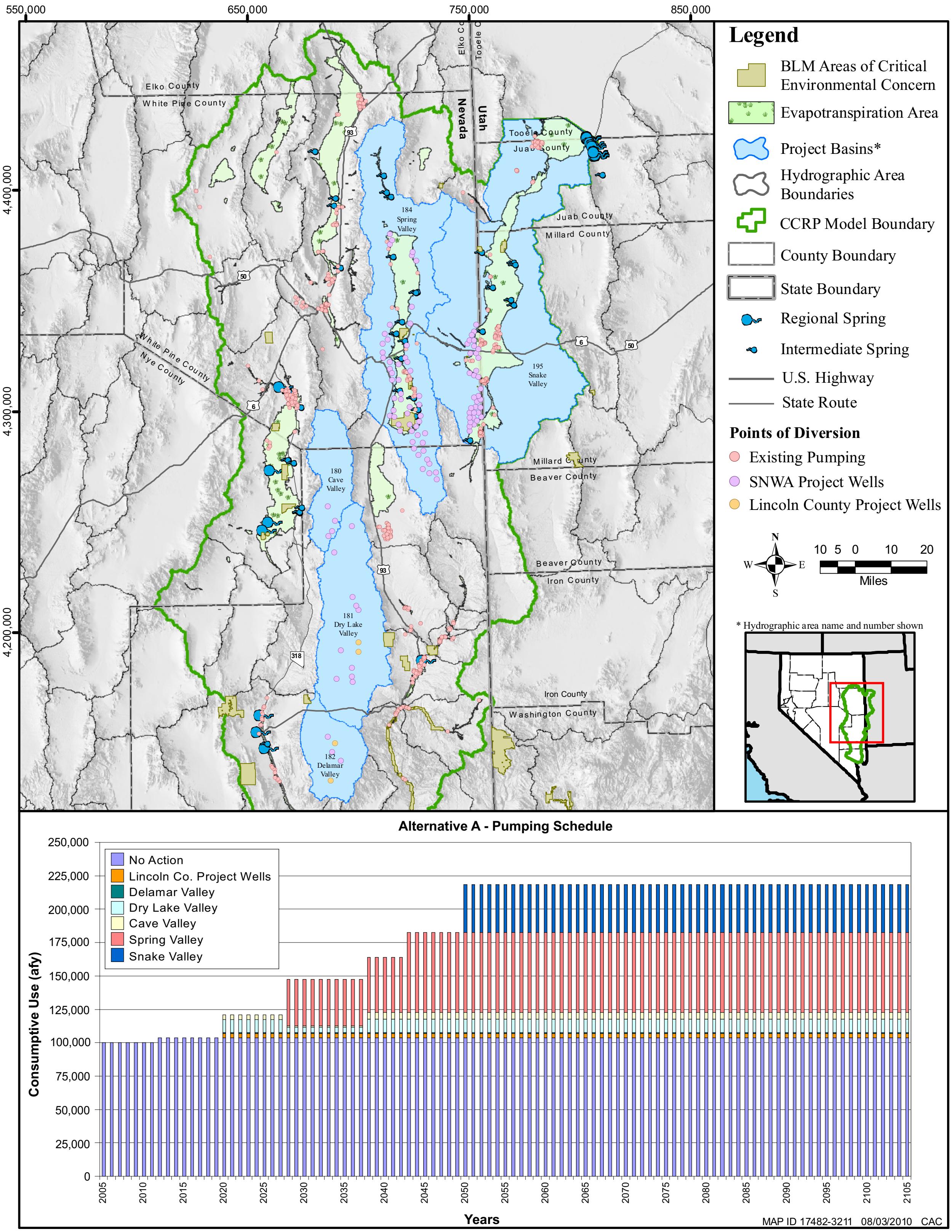


Figure 3-4
Pumping Distribution for Alternative A- Distributed Pumping Reduced Quantities

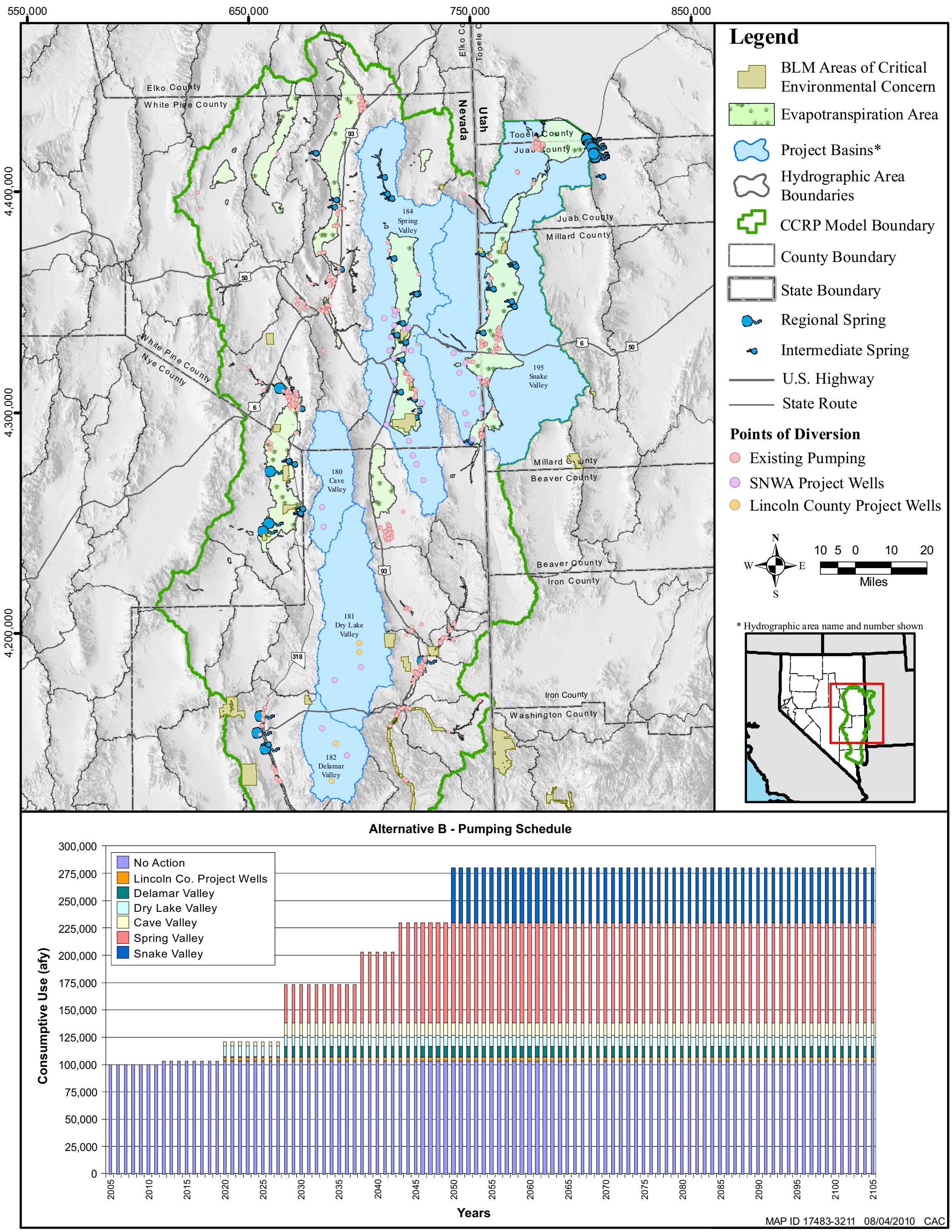


Figure 3-5
Pumping Distribution for Alternative B - Current Points of Diversion

conditions affecting surface-water runoff to the Colorado River, 5-year intermittent periods reflecting occurrences of normal/drought or surplus conditions were assumed in the water-use schedule after the Project reaches full development in 2050. During these periods, the Project water-use schedule is either maintained at the levels described for the Distributed Pumping - Reduced Quantities scenario (Alternative A) or is reduced to a minimum pumping volume of 9,000 afy. The minimum pumping volume in each project basin is projected to be as follows:

- Spring Valley - 3,000 afy
- Snake Valley - 2,000 afy
- Cave Valley - 1,000 afy
- Dry Lake Valley - 2,000 afy
- Delamar Valley - 1,000 afy

The minimum annual volume represents the quantity needed to maintain functionality of pumps, pipelines, and other facilities without major shutdown and startup issues. It is also assumed that pumping the following rights would continue and be conveyed through Project facilities during the intermittent periods of reduced SNWA pumping: (1) 3,000 afy of Lincoln County rights in Dry Lake and Delamar valleys and (2) 11,300 afy of interbasin transfer of groundwater from Lake Valley to Coyote Spring Valley by CSI. Thus, the total volume of groundwater conveyed through the Project facilities during the intermittent periods of reduced SNWA pumping would be approximately 23,000 afy. The simulated well distribution and water-use schedule for this scenario is presented in Figure 3-6.

3.2.5 Alternative D - LCCRDA Corridor

The Alternative D - LCCRDA Corridor scenario assumes that groundwater pumping would only occur in the basins, or portions thereof, located within Lincoln and Clark counties based on the issuance of rights-of-way mandated under LCCRDA. The pumping distribution described here does not include Snake Valley because there is only a very small portion of Snake Valley located within Lincoln County (approximately 1 km^2). The water-use schedules for the other project basins reflect those defined for the Distributed Pumping - Reduced Quantities scenario (Alternative A) and include:

- Delamar Valley - 2,493 afy
- Dry Lake Valley - 11,584 afy
- Cave Valley - 4,678 afy
- Spring Valley - 60,000 afy
- Snake Valley - 0 afy

Under this scenario, the distribution of pumping in Spring Valley is confined to the southern portion of the valley within Lincoln County. The simulated well distribution and water-use schedule for this scenario is presented in Figure 3-7.

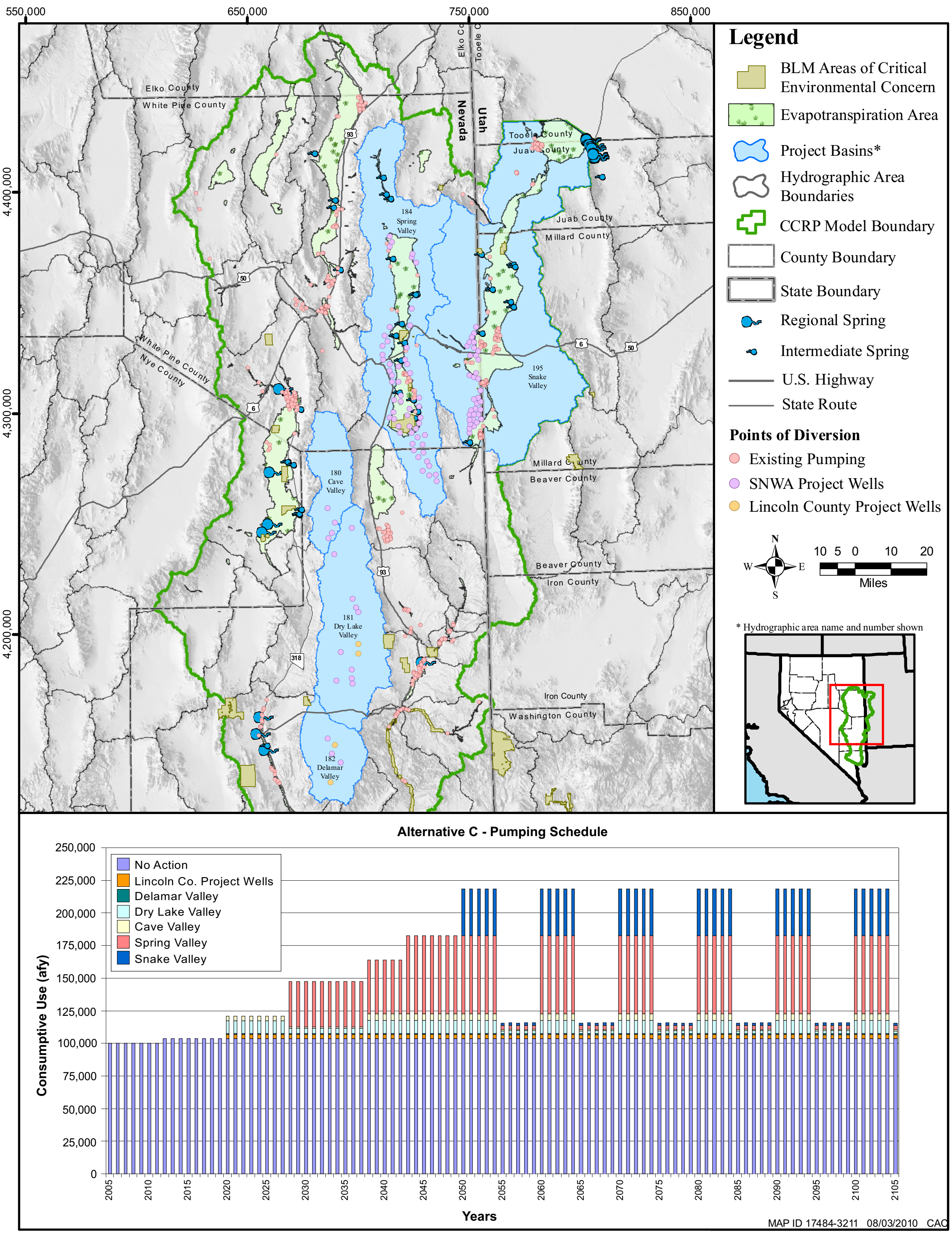


Figure 3-6
Pumping Distribution for Alternative C - Intermittent Pumping

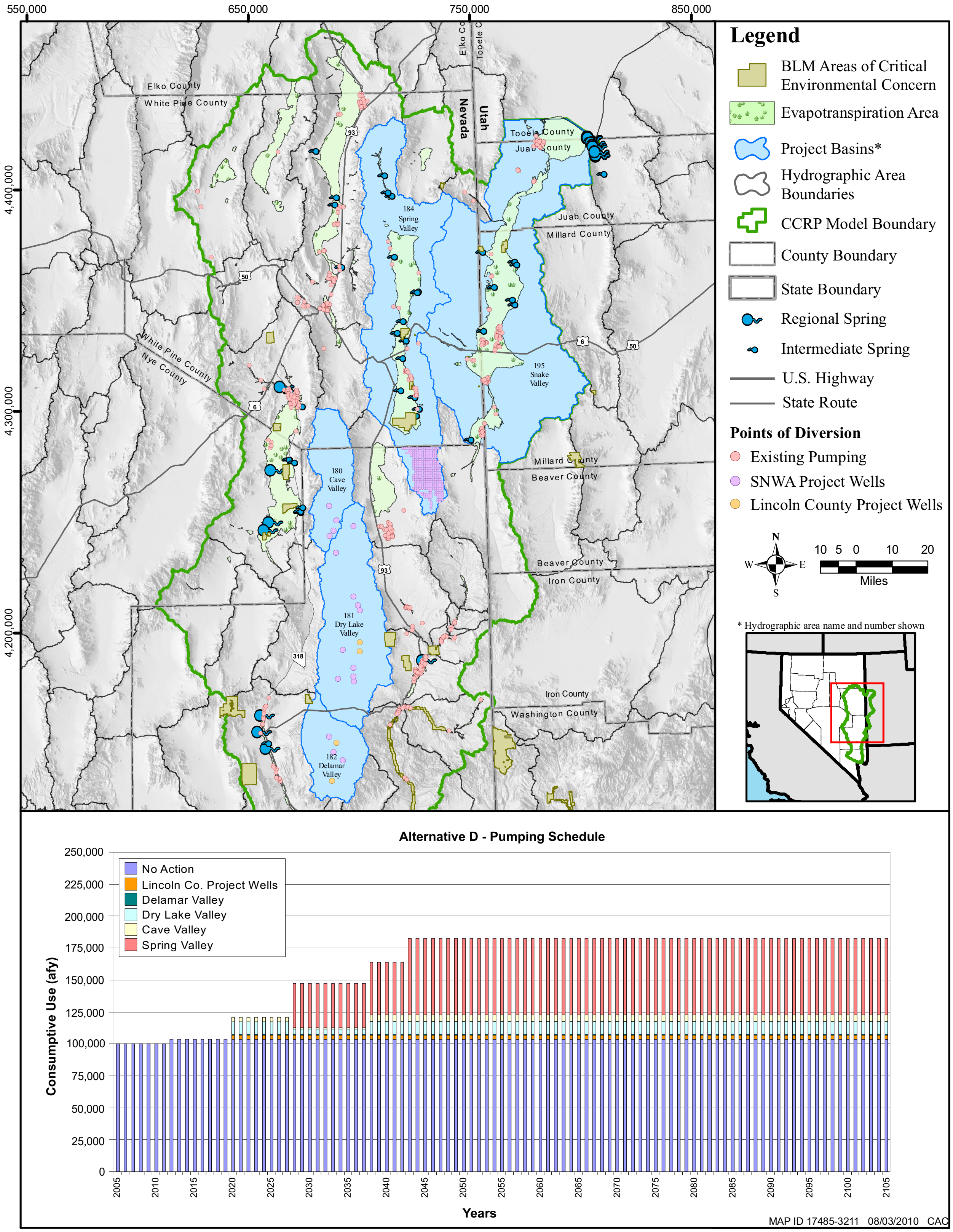


Figure 3-7
Pumping Distribution for Alternative D - LCCRDA Corridor

3.2.6 Alternative E - Delamar, Dry Lake, Cave, and Spring Valleys

Alternative E - Delamar, Dry Lake, Cave, and Spring valleys scenario assumes pumping in Delamar, Dry Lake, Cave, and Spring valleys and not in Snake Valley. This schedule represents a scenario in which a right-of-way is granted in Delamar, Dry Lake, Cave, and Spring valleys, but not in Snake Valley. The volumes and locations of pumping for each valley are the same as those defined for the Distributed Pumping - Reduced Volumes (Alternative A) alternative except for Snake Valley and include:

- Delamar Valley - 2,493 afy
- Dry Lake Valley - 11,584 afy
- Cave Valley - 4,678 afy
- Spring Valley - 60,000 afy
- Snake Valley - 0 afy

The simulated well distribution and water-use schedule for this scenario is presented in (Figure 3-8).

3.3 NEPA Cumulative Pumping Scenarios

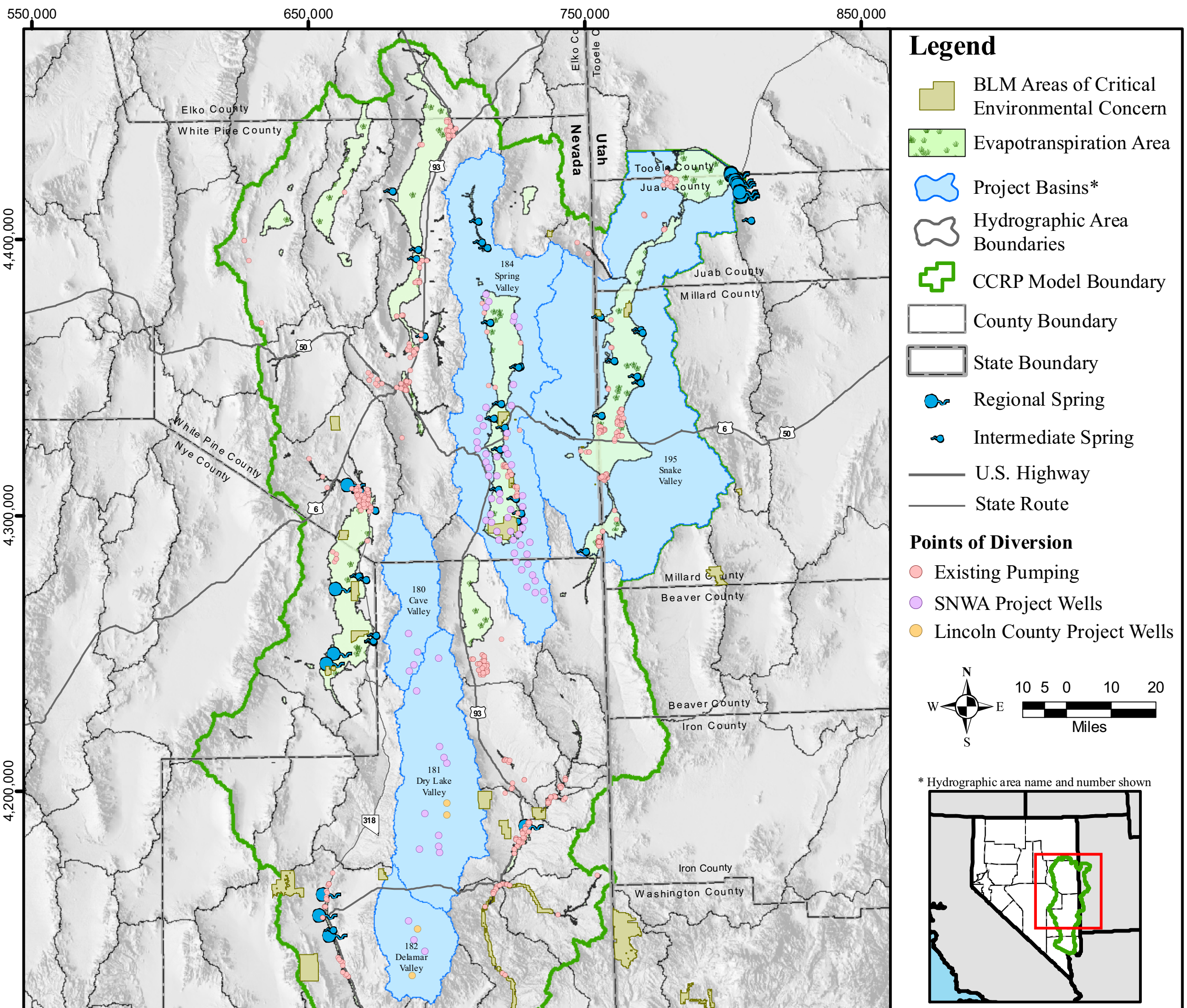
The NEPA cumulative pumping scenarios couple a given project alternative (Proposed Action and Alternatives A through E) with future pumping based on NEPA requirements. NEPA cumulative pumping scenario are as follows:

- No Action and NEPA Cumulative
- No Action, Proposed Action and NEPA Cumulative
- No Action, Alternative A and NEPA Cumulative
- No Action, Alternative B and NEPA Cumulative
- No Action, Alternative C and NEPA Cumulative
- No Action, Alternative D and NEPA Cumulative
- No Action, Alternative E and NEPA Cumulative

For this analysis, the groundwater consumptive uses represented in the cumulative pumping scenarios for NEPA analyses include;

- Existing baseline conditions (No Action pumping)
- Proposed Action or Alternative pumping distributions
- Reasonably foreseeable, future uses (non-Federal)
- Reasonably foreseeable, future uses requiring Federal action

Reasonably foreseeable, future uses include existing permitted groundwater rights that are likely to be developed because they are associated with private lands or a previously authorized project (e.g., irrigation and mining water rights), and/or a project proposal has been developed and submitted to a regulatory agency (e.g., industrial water rights for power plants). These uses are listed in Table 3-1, which does not include past and present uses that are already incorporated as part of the No Action scenario. All of the listed rights are existing permitted groundwater rights, unless otherwise



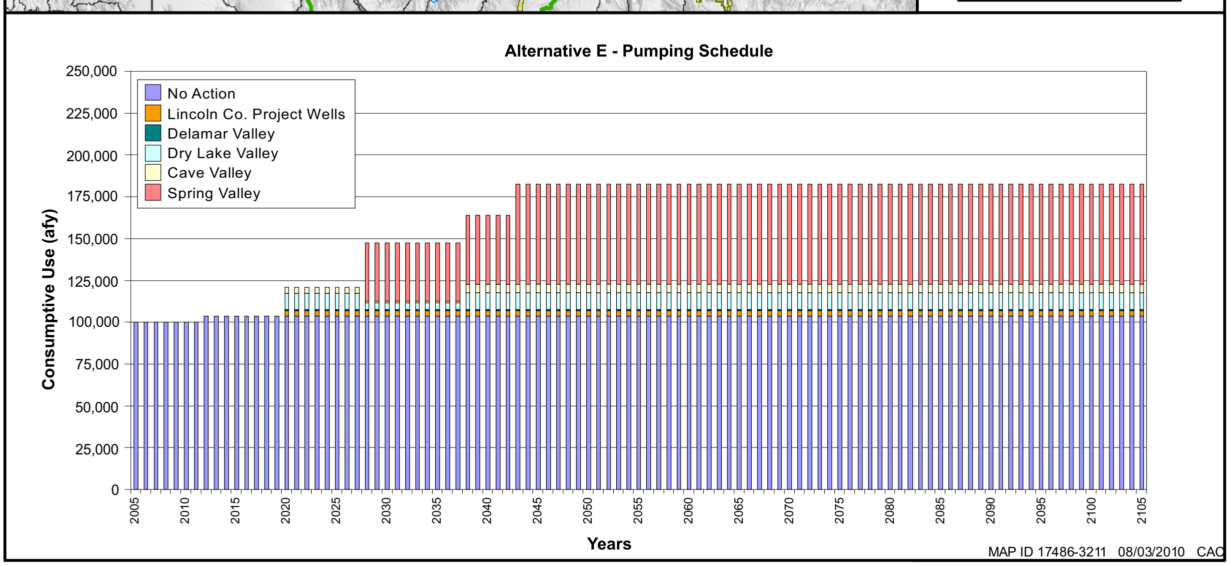


Figure 3-8
Pumping Distribution for Alternative E - Delamar, Dry Lake, Cave, and Spring Valleys

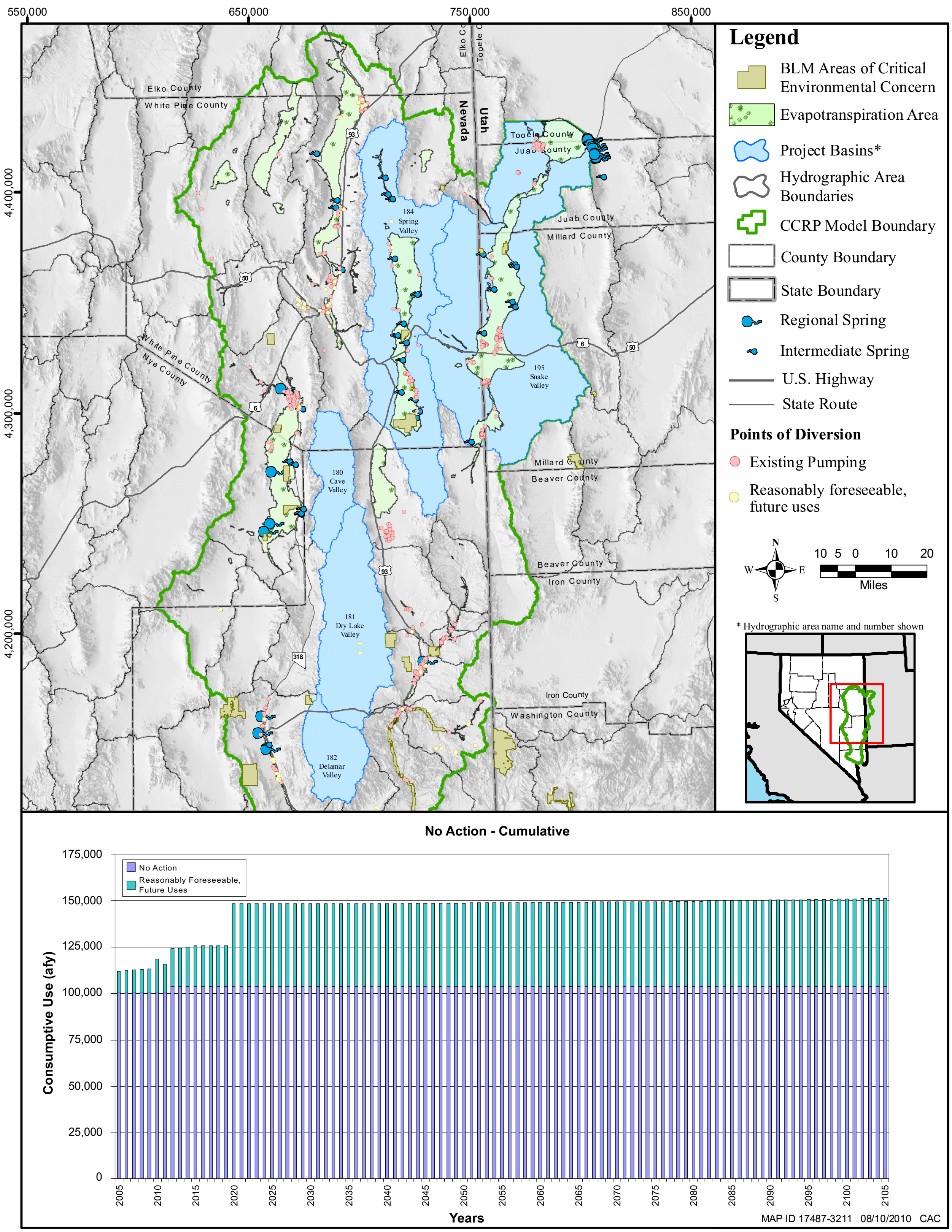


Figure 3-9
No Action - Cumulative Pumping Distribution

noted as pending applications. The simulated well distributions and water-use schedules for these scenarios are presented in Figures 3-9 through 3-15.

3.4 Cessation of Pumping Scenario

The purpose of the cessation of pumping scenario is to estimate how the flow system would respond when and if pumping under the Distributed Pumping - Reduced Quantities scenario (Alternative A) were stopped after 75 years of full production. This scenario is based on the well distribution depicted in Figure 3-3. The water-use schedule shown in Figure 3-3 is applied until the year 2125. All Alternative A pumping is then shut off to allow the flow system to recover until the end of year 2249. In this cessation of pumping scenario, the No Action pumping was continued as scheduled until the end of the simulation period.

Table 3-1
Estimated Reasonably Foreseeable, Future Uses Represented in Cumulative Pumping Scenarios

	Groundwater Consumptive Use[a] (afy)				
Hydrographic Area	**Basin[b] (2001-2004)**	**NEPA**	**Use Type**	**Water-Right Status**	**Comments**
Project Basins					
Delamar Valley	---	---	---	---	No additional reasonably foreseeable, future uses
Dry Lake Valley	---	1,009	IRR	PER	Lincoln County
Cave Valley	---	---	---	---	No additional reasonably foreseeable, future uses
Spring Valley	5,645	1,426	IRR	PER	---
Snake Valley	21,649	---	---	---	2001-2004 basin estimates are for Nevada and Utah combined; No additional reasonably foreseeable, future uses
Other Basins					
Coyote Spring Valley	---	9,000	MUN	PER	SNWA Coyote Spring Pipeline
		4,600		PER	Coyote Spring Investment, Inc.
Steptoe Valley	11,967	2,046	IRR	PER	---
		8,000	IND	PER	White Pine County lease to LS Power Co. (project start assumed in 2020)
		20		PER	Other existing permitted industrial
		2,635	MMD	PER	Robinson Nevada Mining Co.
Garden Valley	---	83	IRR	PER	---
		5	IND	PER	---
Kane Springs Valley	---	1,000	MUN	PER	Lincoln County/Vidler groundwater rights based on NSE Ruling Nos. 5712 and 5987
Panaca Valley	9,325	1,240	IRR	PER	---
Clover Valley	742	37	IRR	PER	---
		14,480	MUN	APP	Lincoln County/Vidler groundwater applications (67964, 67965, 67966, 67967); Lincoln County Land Act Project
Lower Meadow Valley Wash	3,077	380	IRR	PER	---
		580	MUN	PER	Coyote Spring Investment, Inc.
White River Valley	11,671	---	---	---	No additional reasonably foreseeable, future uses
Pahranagat Valley	2,754	924	IRR	PER	---
		216	COM	PER	---

Use Types: COM - commercial; IRR - irrigation; IND - industrial; MMD - mining, milling, and dewatering; MUN - municipal
Status: PER = Permit; APP = Application
[a]Net consumptive use estimates for irrigation are based on crop consumptive-use rates and irrigated acreage obtained from Nevada Division of Water Resources (NDWR).
[b]Total includes all manners of groundwater use for the 2001 to 2004 model stress period.

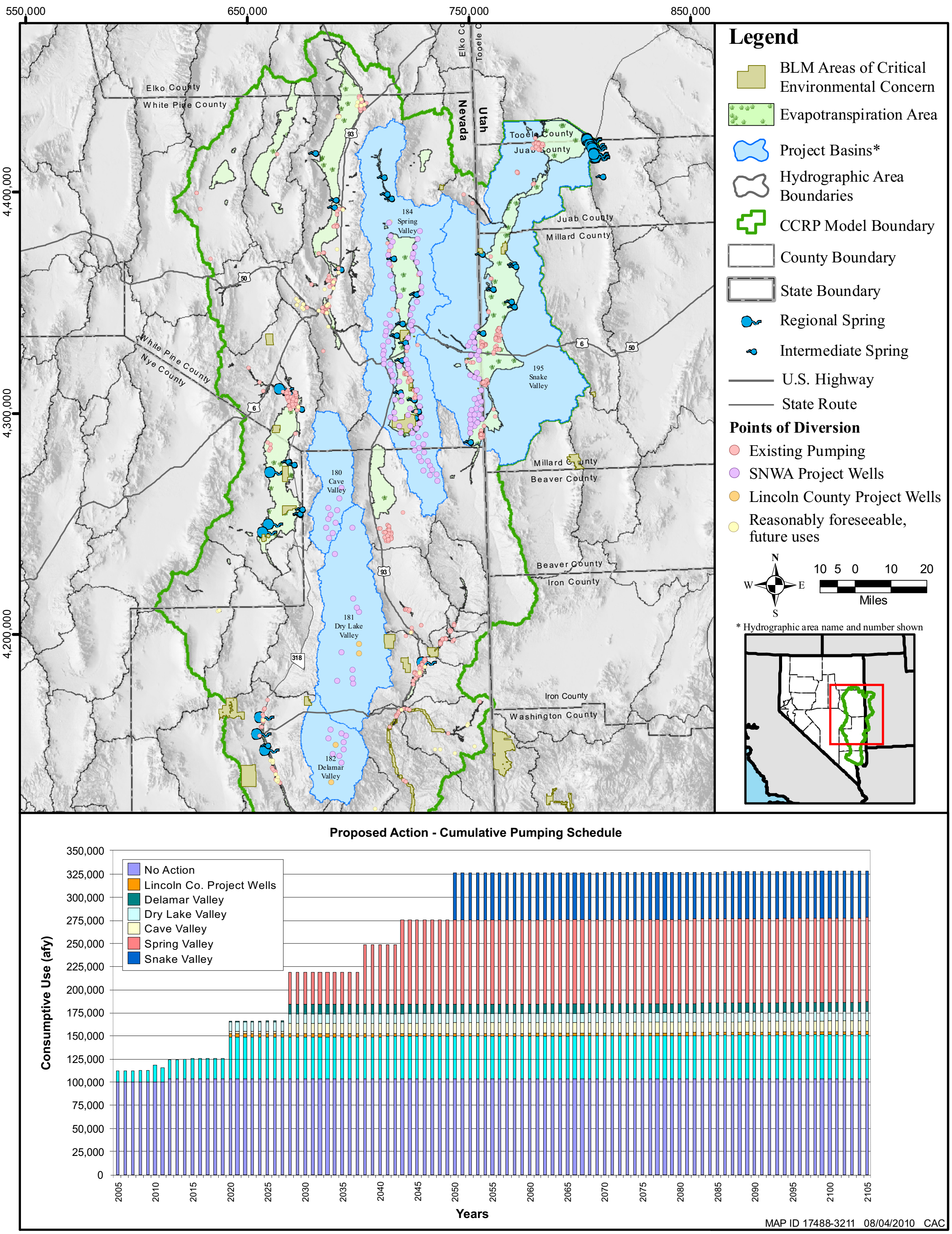


Figure 3-10
Proposed Action - Cumulative Pumping Distribution

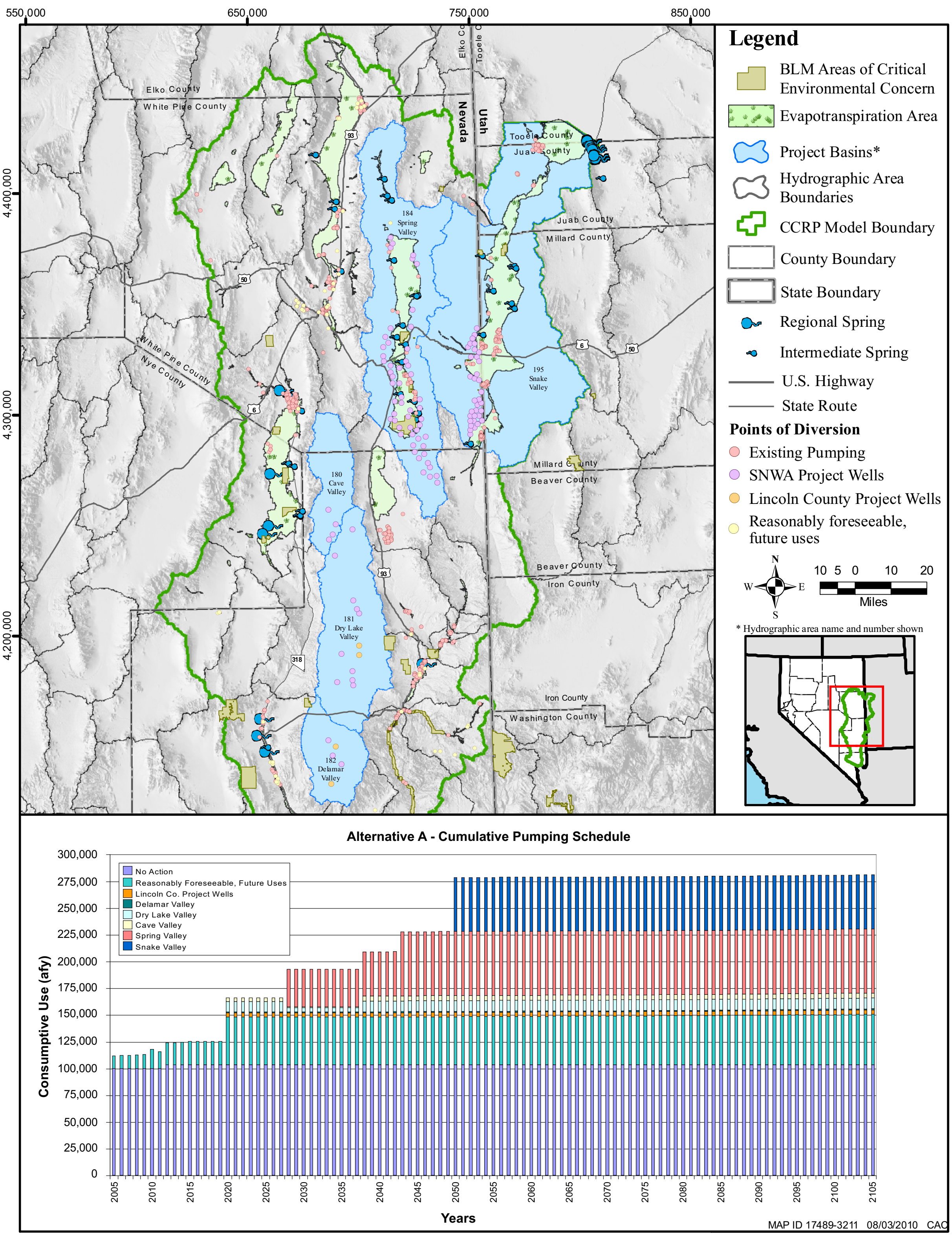
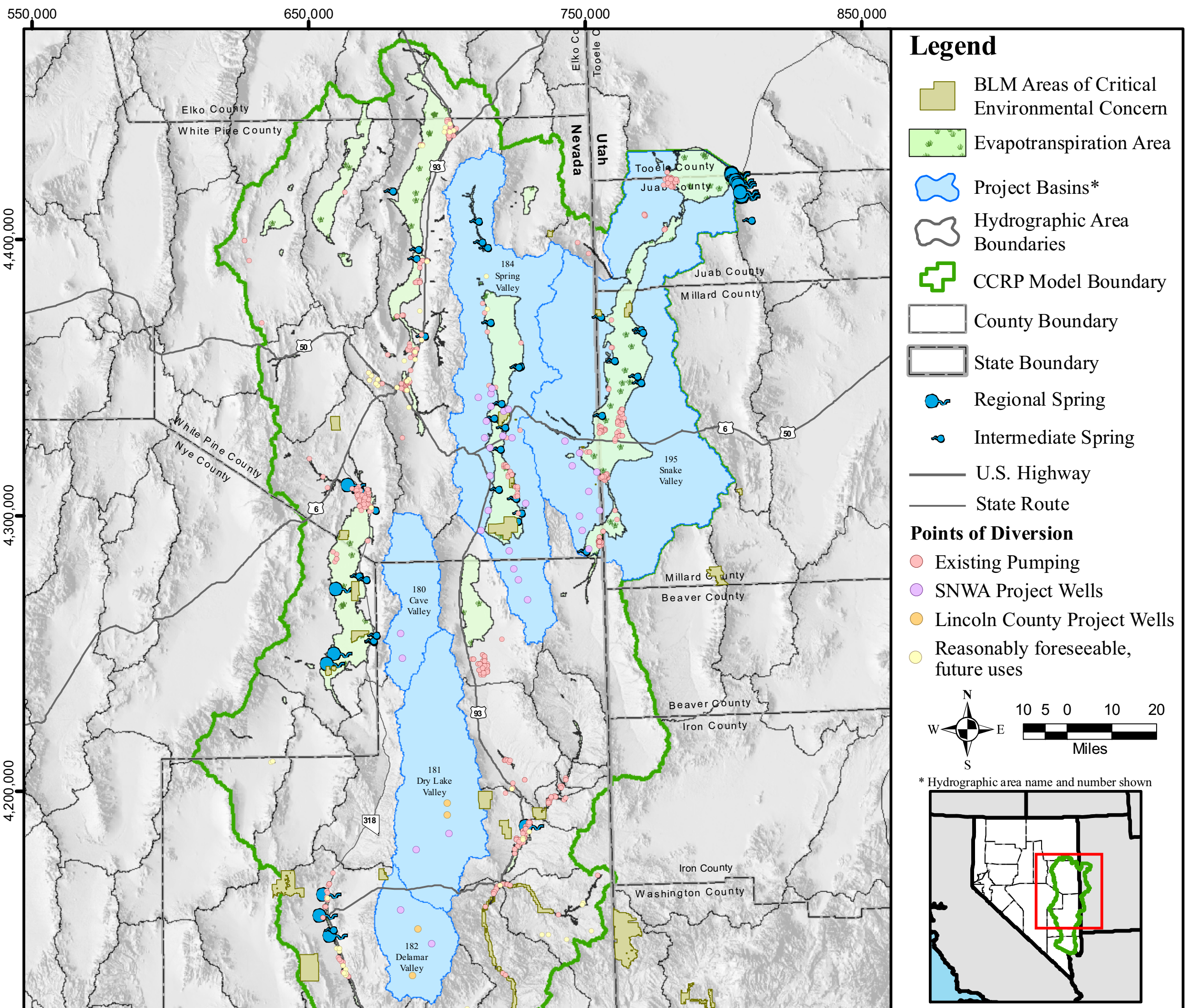


Figure 3-11
Cumulative Pumping Distribution for Alternative A - Distributed Pumping-Reduced Quantities



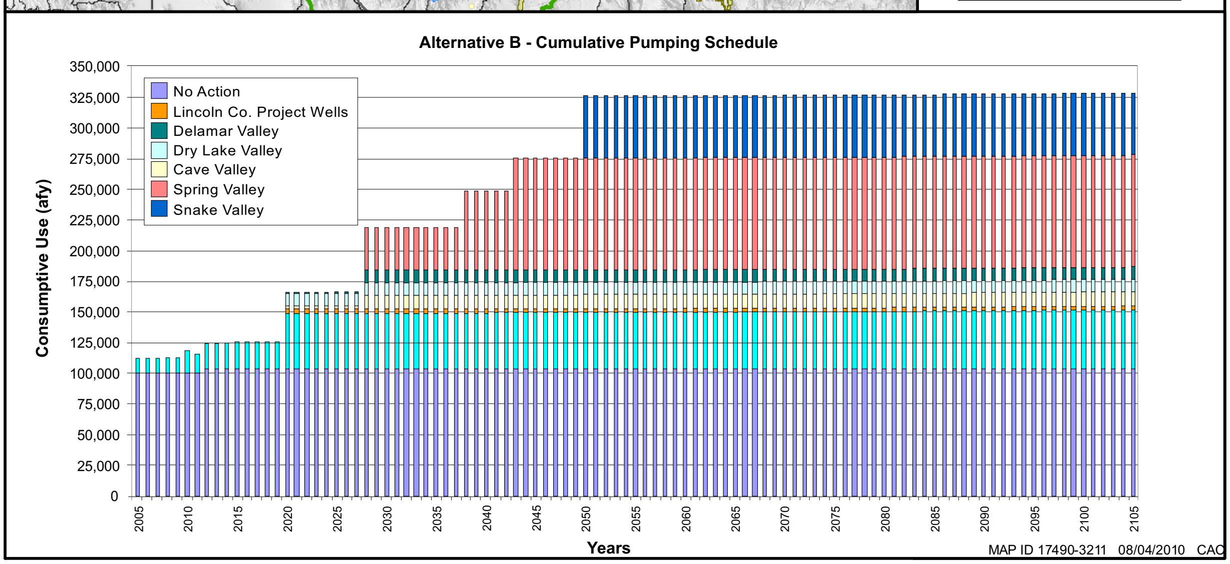


Figure 3-12
Cumulative Pumping Distribution for Alternative B - Current Points of Diversion

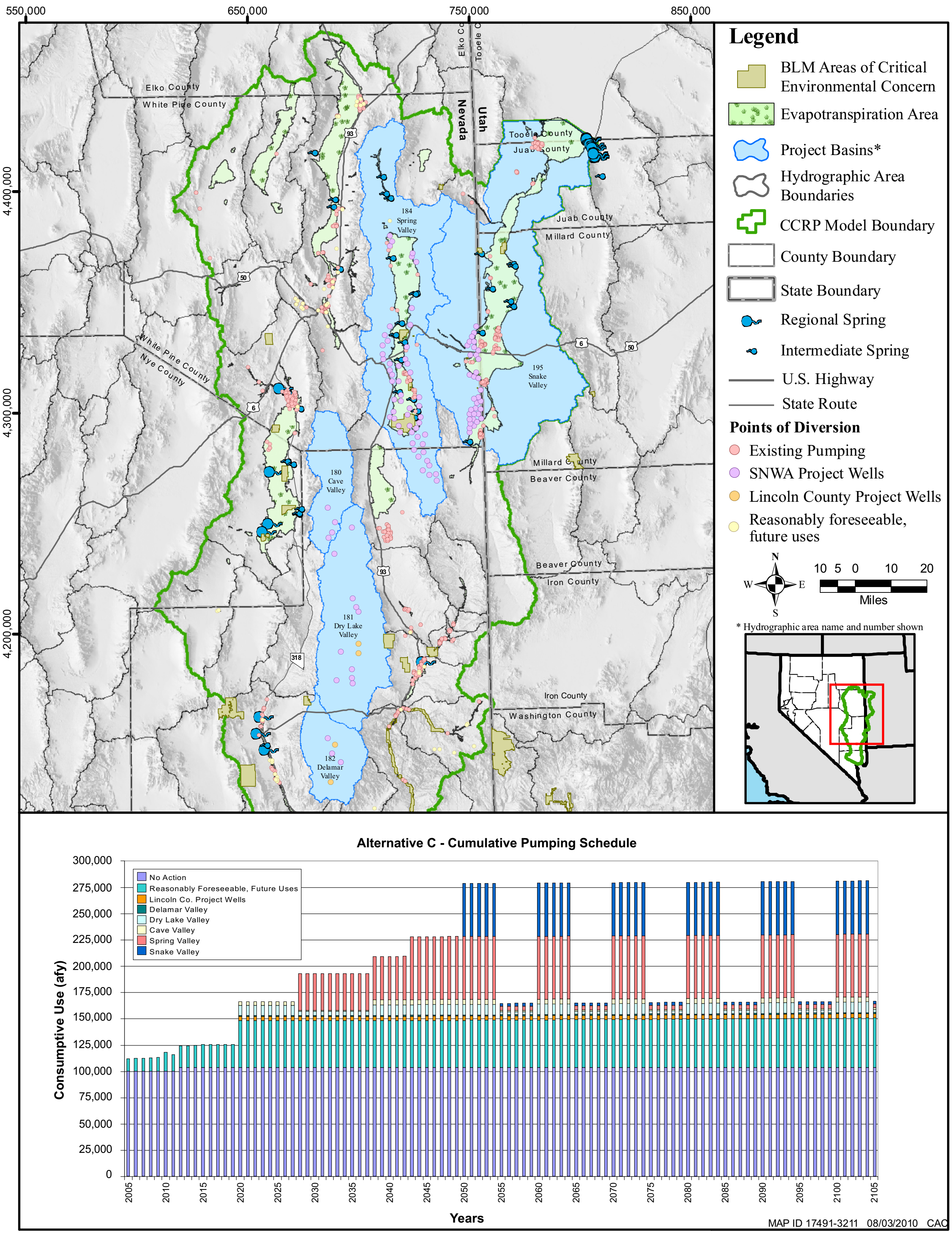


Figure 3-13
Cumulative Pumping Distribution for Alternative C - Intermittent Pumping

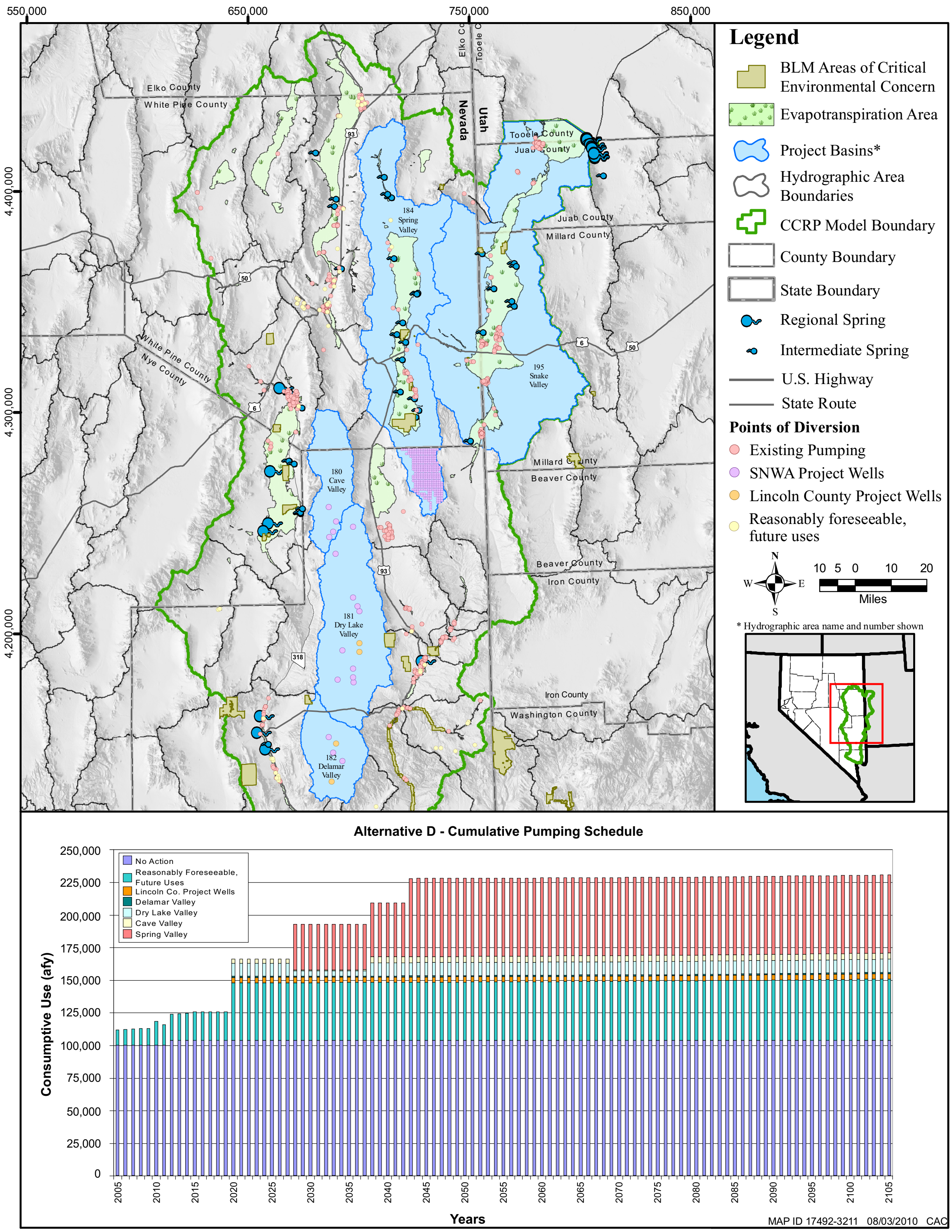


Figure 3-14
Cumulative Pumping Distribution for Alternative D - LCCRDA Corridor

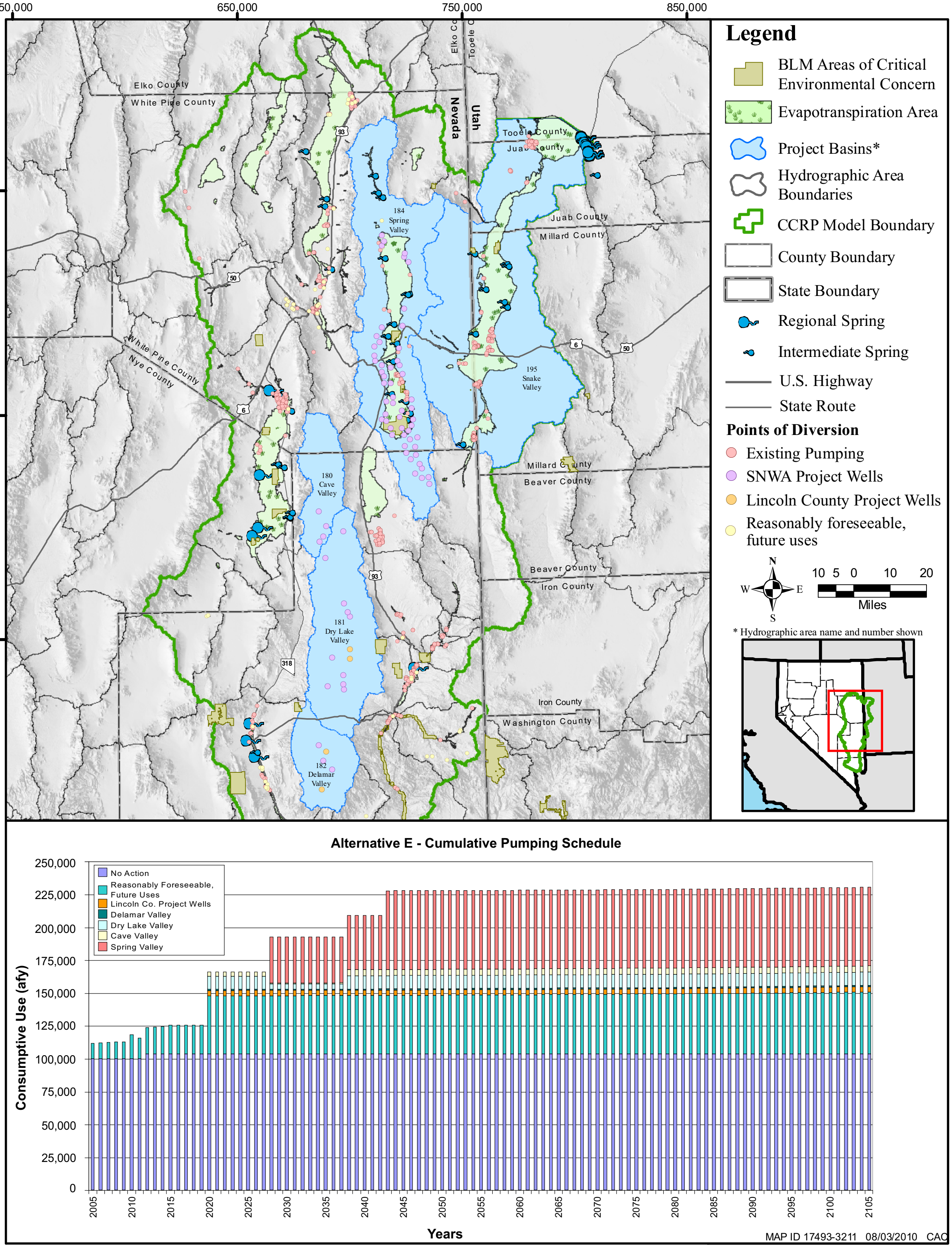


Figure 3-15
Cumulative Pumping Distribution for Alternative E - Delamar, Dry Lake, Cave, and Spring Valleys

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4.0 SCENARIO SIMULATION AND RESULTS

A description of the scenario modeling and the results of the groundwater development scenario simulations introduced in Section 3.0 are summarized in this section. Detailed simulation results are provided in electronic form for each scenario on the DVD set provided separately.

4.1 Scenario Modeling

All groundwater modeling scenarios described in Section 3.0 were simulated with the modified numerical model (SNWA, 2009b and 2010). The specific scenario simulations are presented in this section.

4.1.1 Simulations

A total of 17 simulations were performed using the calibrated modified numerical model (SNWA, 2009b and 2010) to estimate the potential pumping effects of the alternatives described in Section 3.0. Each scenario simulation is listed in Table 4-1. The 17 simulations consist of 16 groundwater development scenarios corresponding to the 7 alternatives described in Section 3.0. Eight of these simulations represent the alternatives and the other eight, their NEPA cumulative scenarios. The last simulation (Scenario A-Cessation) was performed to simulate a cessation of SNWA pumping after pumping 75 years beyond full build-out under Alternative A.

Two additional simulations of the No Action scenario were necessary to accommodate the LCCRDA scenarios (Alternative D and the cumulative pumping for Alternative D) (Table 4-1). The two No Action simulations (ucpd955 and ucpd966) represent the same No Action scenario described in Section 3.0, with the only differences being the definition of the stress periods selected to match the timing of the pumping in the LCCRDA scenarios and the smaller time steps needed for the MODFLOW-2000 solutions to converge.

The cessation of pumping simulation (ucpd951) (Table 4-1) was conducted to evaluate the effects to the system after pumping under the Distributed Pumping-Reduced Quantities scenario (Alternative A) stops. The well distribution and water-use schedule is identical to that of Alternative A described in Section 3.0 (Table 3-3) from the start of pumping until December 31, 2124. After the end of 2124, all Project pumping was shut off. In this simulation, the No Action pumping continued as scheduled until the end of the simulation period, December 31, 2249.

4.1.2 Model Setup

All modeling scenarios were set up starting with the calibrated modified transient numerical model files (SNWA, 2009b) in a similar fashion. The setup of the water-use schedules (pumping wells and

Table 4-1
Scenario Simulations

Alternative Name	Alternative Description	Simulation Number	NEPA Cumulative Simulation Number	Full Build-Out
No Action	No Action	ucpd949 ucpd955 (LCCRDA)	ucpd960 ucpd966 (LCCRDA)	2050 2043
Proposed Action	Distributed Pumping – Full Application Quantities	ucpd999	ucpd1001	2050
Alternative A	Distributed Pumping – Reduced Quantities[a]	ucpd950	ucpd998	2050
Alternative B	Points of Diversion – Full Application Quantities	ucpd1000	ucpd1003	2050
Alternative C	Intermittent Pumping[a]	ucpd954	ucpd1004	2050
Alternative D	LCCRDA Corridor[a]	ucpd956	ucpd967	2043
Alternative E	Spring, Dry Lake, Delamar, Cave (acronym: Spring/DDC)[a]	ucpd970	ucpd969	2050
Alternative A - Cessation	Cessation of Pumping --Distributed Pumping – Reduced Quantities[a]	ucpd951	NA	2050

[a]Reduced pumping rates

stream diversions), the time discretization, the initi al conditions, and the obser vations in the numerical model are described in the following text.

4.1.2.1 Water-Use Schedules

The water-use schedules corresponding to the scena rios were summarized in Section 3.0 and ar e provided in electronic form (DVD set).

The water-use schedules were set up in the numerical model by modifying the input files for the well and stream flow packages according to each modeling scenario. The stream diversions were set up as described in the numerical model re port (SNWA, 2009b). The MOD FLOW Multi-Node Well (MNW) module (Halford and Hanson, 2002) was used to simulate all pumping wells, including historical pumping. The MNW module was use d so that pumping from a single well could be distributed over multiple model layers in a realistic manner. The MNW module apportions pumping to each model layer based on the layer's material properties and relative saturated thickness. The setup for historical pumping was described in the numerical model report as well (SNWA, 2009b). Additional pumping wells were added to represent either the Project wells or wells that are part of the Cumulative Pumping scenarios (not historical wells used in calibration) as described in the following text.

- For the Proposed Action and all Project alternatives, other than for the LCCRDA scenarios, the top of the open interval was set to the initial water table (January 1, 2005) or to the top of the regional modeling unit (RMU) as follows:

  - If a well is completed in the Upper Valley Fill (UVF) RMU, the open interval was extended from the water table to the bottom of the UVF RMU. Although no depth limit was imposed on UVF wells, the MNW module automatically limits the length of the interval from which a given well draws water to the most transmissive model layers. Because of the decrease of hydraulic conductivity with depth implemented in the numerical model (SNWA, 2009b), the most transmissive layers correspond to the upper model layers.

  - If a well is completed in the Lower Carbonate (LC3) RMU, the open interval was extended from the top of the LC3 RMU (or water table, if lower) toward the bottom of the LC3 RMU. However, the total open interval was not allowed to exceed 1,000 m.

  - If a well is completed in the Lower Valley Fill (LVF) RMU, the open interval was extended from the top of the LVF RMU (or water table, if lower) toward the bottom of the LVF RMU. However, the total screened interval was not allowed to exceed 1,000 m.

- For the NEPA Cumulative Pumping scenarios, except for wells used to extract reasonably foreseeable, future uses, all wells were set up as in the Proposed Action scenario. The wells representing reasonably foreseeable, future uses were open to single RMUs, the preferential order being UVF, LC3, and LVF.

- For the LCCRDA scenarios, the completion depths and open intervals of the proposed pumping wells were extended to greater depths to allow the model to maintain stability while simulating the removal of large volumes of water from limited areas.

It is noted that estimating screened intervals for the CCRP model is relatively unimportant because only a limited number of the pumping wells intersect more than one model layer. In addition, most of the multi-node wells likely resulted from the arbitrary vertical discretization of the model with flat-lying layers that arbitrarily range between 0 and 300 m thick at the water table rather than being wells with more than 300 m of screen.

4.1.2.2 Time Discretization

Two primary time-discretization schedules used in the scenario simulations were as follows: (1) the 2050 schedule which included the period from January 1, 2005 through December 31, 2249, 200 years after full SNWA production is reached; (2) the 2043 schedule which included the period from January 1, 2005 through December 31, 2242, 200 years after full SNWA production is reached. The 2050 schedule was used for all scenarios, except the LCCRDA scenario and its corresponding No Action scenarios.

The period of interest in the 2050 schedule (2005 to 2250) was subdivided into 85 stress periods while the period of interest in the 2043 schedule was subdivided into 78 stress periods (2005 to 2243). Two additional stress periods are defined in the scenario model files and were reserved for testing purposes only during the modeling activities. These stress periods were left in the scenario model files to avoid problems during pre- and post-processing because the corresponding scripts had previously been designed to handle 87 stress periods. These 2 stress periods (86 and 87) will not be discussed any further in this document.

The discretization of the stress periods was different depending on the scenario. For all scenarios, except the LCCRDA scenarios, the simulation period was discretized as follows:

- One-year stress periods with 12 time steps were used from January 1, 2005, through the stress period just before full build-out of Project pumping was reached (stress periods 1 through 45).
- Five-year stress periods with five time steps were then used for 200 years (stress periods 46 through 85).
- The Proposed Action (ucpd999) required more refined time steps for the last 6 stress periods of interest (80 to 85) because of the larger pumping rates. For this case, ten time steps were used instead of five.

For the LCCRDA scenarios, the time discretization was adjusted to match the different evaluation times (Table 4-1) and to achieve model convergence. Initially, the time steps in the LCCRDA scenario (ucpd956) were also the same as in the No Action scenario (ucpd955). However, during modeling of the LCCRDA scenarios, it was necessary to further refine selected stress periods into smaller time steps for MODFLOW-2000 to converge. The finer discretization of the stress periods makes the model simulate slightly different results for the same stress conditions; however, these differences are negligible. In these two cases, the following changes were made:

- For the three stress periods starting at the beginning of full build-out of Project pumping, 60 equal-length time steps were used instead of 5 variable-length (1.1 multiplier) time steps.
- For the subsequent stress periods, 20 equal-length time steps were used instead of 5 variable-length (1.1 multiplier) time steps.

The LCCRDA scenario required a second version of the No Action scenario simulation (ucpd955) with the same stress periods and output times, so the incremental effects of this scenario could be evaluated.

4.1.2.3 Initial Conditions

Initial conditions were set to be the same as the conditions simulated by the calibrated transient numerical model for the end of 2004 (SNWA, 2009b). Initial conditions are represented in the calibrated transient numerical model by the hydraulic-head distribution of each model layer. This initial hydraulic-head distribution, together with the calibrated distributions of all model parameters, produces initial values for all other simulated variables, such as groundwater ET rates, spring flow, and boundary flow.

4.1.2.4 Observations

Observation wells were originally set to those used in the transient numerical model calibration (SNWA, 2009b). To reduce the number of observation wells, control memory requirements, and allow the simulation of a significant number of transient observations, the number of hydraulic-head observations was reduced from 1,815 to 424, using the following criteria:

- If more than one observation well occurred in a model cell, the first listed well was retained, and the remaining wells were discarded.
- If many observation wells occurred in more than five model cells in a hydrographic area (HA), up to 50 percent of the remaining wells were removed (every other listed well). The final number of hydraulic-head observation wells was not allowed to drop below five in a given hydrographic area.
- In large hydrographic areas where the remaining number of wells was still large, another 50 percent of these wells were removed, but geographic distribution was considered during removal to ensure a relatively-even spatial distribution.

4.2 Effects of Proposed Action and Alternatives

The simulated effects of pumping under the Proposed Action and Project alternatives are summarized in terms of changes in water levels, external boundary flows, groundwater ET, and spring and stream flows. In some instances, the incremental hydraulic effects attributable to the Proposed Action and each alternate groundwater development scenario were calculated by subtracting the effects due to the No Action scenario for selected points in time. In other instances, these incremental effects were presented graphically without subtracting the corresponding values of the No Action scenario. The simulated effects of these scenarios on interbasin flow and the details on all groundwater-budget components are provided in electronic form (DVD set).

4.2.1 Effects on Water Levels

The simulated effects of pumping on the water table within the model area are summarized in this section in the form of drawdown maps and hydrographs for selected observation wells. The simulated effects on all selected observation points (see Section 4.1.2.4) are provided on the DVD.

4.2.1.1 Extent of Drawdown

The extents of the simulated drawdowns of the water table from its levels on January 1, 2005, are presented in the form of maps on Plate 1. Plate 1 shows the net drawdowns caused by Project pumping only. Another plate provided in electronic form shows the total simulated drawdowns caused by Project and No Action pumping combined (DVD set).

The simulated drawdown maps are arranged in three rows and seven columns. Each row of maps represents a year of particular interest, i.e., full build-out year, 75 years after full build-out, and 200 years after full build-out. Each column of maps represents one scenario. The drawdown maps for the No Action scenario are placed in the first column, followed by maps for the Proposed Action scenario and the alternatives pumping scenarios. The maps shown on Plate 1 for the No Action and Proposed

Action scenarios and the alternatives are described in this section, while those of the Cumulative Pumping scenarios are presented in Section 4.3.

The No Action scenario drawdowns are those calculated by the model as the differences between the initial hydraulic heads, (those simulated at the end of 2004 by the calibrated modified numerical model) reduced by the simulated hydraulic heads. The drawdowns (Plate 1) for the Proposed Action and Project alternatives (A through E), were further reduced by the No Action scenario drawdowns to depict the extent of incremental drawdown due to Project pumping alone.

Under the No Action scenario, most of the large drawdowns in the water table (larger than 10 ft) simulated for the beginning of full build-out occur in southern Lake Valley (HA 183) and northern Patterson Valley (HA 202) (Plate 1). At the same time, smaller areas of large drawdowns are also simulated for some basins located south and north: Dry Valley (198), Panaca Valley (203), Clover Valley (204), Lower Meadow Valley Wash (205) to the south, and southern Spring Valley (HA 184) to the north. By 75 years after full build-out, the extents of these cones of depression are more extensive, and new areas of large drawdowns appear in northern White River Valley and in the southern end of the model area, in an area straddling Las Vegas Valley (HA 212) and the Black Mountains Area (HA 215). By the end of the simulation period, the cone of depression centered on southern Lake Valley (HA 183) and northern Patterson Valley (HA 202) is deeper (more than 80 ft) and extends over a larger area joining all drawdown cones located immediately to the south. This cone of depression is also simulated to extend into Cave and Dry Lake valleys and to Hamlin Valley (HA 196) by this time. The other cones of depression are simulated to extend over slightly-larger areas and are shallower. Although, relatively large volumes of groundwater are withdrawn for irrigation from Lake Valley, larger groundwater withdrawals occur in other basins (Snake Valley, for example) (Figure 3-1). And yet, drawdowns simulated in southern Lake Valley are the largest because all groundwater withdrawn from this basin originates from storage. This causes the relatively-large drawdowns, as no groundwater ET area is present to capture like in White River, Spring, or Snake valleys.

For the Proposed Action and Project alternatives, small areas of relatively-large incremental drawdowns (larger than 10 ft) occur in Spring (HA 184), Cave, Dry Lake and Delamar valleys (HAs 180, 181, and 182) by full build-out (Plate 1). No drawdowns appear in Snake Valley, as Project pumping from this basin has just been initiated. By 75 years after full-build out, as expected, the simulated drawdowns caused by Project pumping occur in all project basins and are greatest in the vicinity of the pumping centers. By this time, the cones of depression in Cave, Dry Lake, and Delamar valleys overlap, as do the cones of depression caused by Project pumping from southern Spring and Snake valleys. By 200 years after full build-out, the cones of depression due to Project pumping extend over most of Delamar, Dry Lake, and Cave valleys and slightly into neighboring basins, such as Pahroc and Pahranagat valleys. The largest drawdowns occur in the southern parts of Spring, Snake, and Cave valleys. The drawdown cones are the largest and deepest in areas of little or no groundwater ET for the same reasons as for the No Action scenario. As expected, the Intermittent Pumping scenarios (Scenarios 4 and 6) appear to cause the smallest drawdowns.

4.2.1.2 Simulated Water Levels at Selected Wells

As shown on Plate 1, the magnitude of drawdown is a function of location relative to the Project pumping centers. The greater the distance the observation point is from the pumping centers, the lesser the drawdown. Thus, wells were selected within the Project basins to illustrate how the water table might decline close to the pumping centers under the Proposed Action and Project alternatives. Six observation wells located in the project basins were selected, and their locations are shown in Figure 4-1. The simulated drawdowns for each groundwater development scenario and all selected hydraulic-head observation points are provided in the enclosed DVD.

The effects of pumping under each groundwater development scenario are reflected in the hydrographs that depict changes in hydraulic head at selected observation points represented in the model. The simulated water-level hydrographs for Cave, Dry Lake, and Delamar valleys are presented in Figure 4-2. The simulated water-level hydrographs for the wells selected for Spring and Snake valleys are shown in Figure 4-3. An interval of 300 ft was used for the y-axis to represent the change in water-level elevation for all six hydrographs to facilitate comparisons. An observed water level was added to the hydrographs where possible to also aid comparison.

All selected hydrographs (Figures 4-2 and 4-3) exhibit declining water-level trends. The most pronounced declining trends are simulated in the Cave Valley observation well, and the least pronounced trend is simulated in the Snake Valley observation well located in Eskdale.

4.2.2 Effects on External Boundary Flows

External flow boundaries that exhibit effects of simulated pumping were selected for presentation in this summary. Their locations are shown in Figure 4-4.

The simulated flows across these boundaries are presented in Table 4-2 for all groundwater development scenarios and for each year of interest. Flows simulated by the model for the No Action scenario are included for comparison. Flows simulated for the Proposed Action scenario and the alternatives are presented as incremental changes from the No Action scenario. Pumping associated with the Proposed Action and Project alternatives only affected flow across external boundaries that are located near the project basins.

The effects are considered to be negligible for all scenarios. The largest relative decrease occurs at the flow boundary between Snake Valley and Pine Valley under the Proposed Action scenario and Alternative B at the end of the simulation period. Although the decrease in simulated outflow at this boundary (-1,141 afy) is large relative to the calibrated value of outflow (1,414 afy), it is still considered unconsequential given the limited flow across this boundary and the uncertainty associated with the available interpretations (SNWA, 2009a). The outflow decrease for the Proposed Action scenario at this boundary after 200 years represents only about 2 percent of the annual groundwater pumped in Snake Valley. Also, the direction of flow is uncertain at this boundary, as some authors interpreted inflow rather than outflow to occur across this boundary (Harrill et al., 1988).

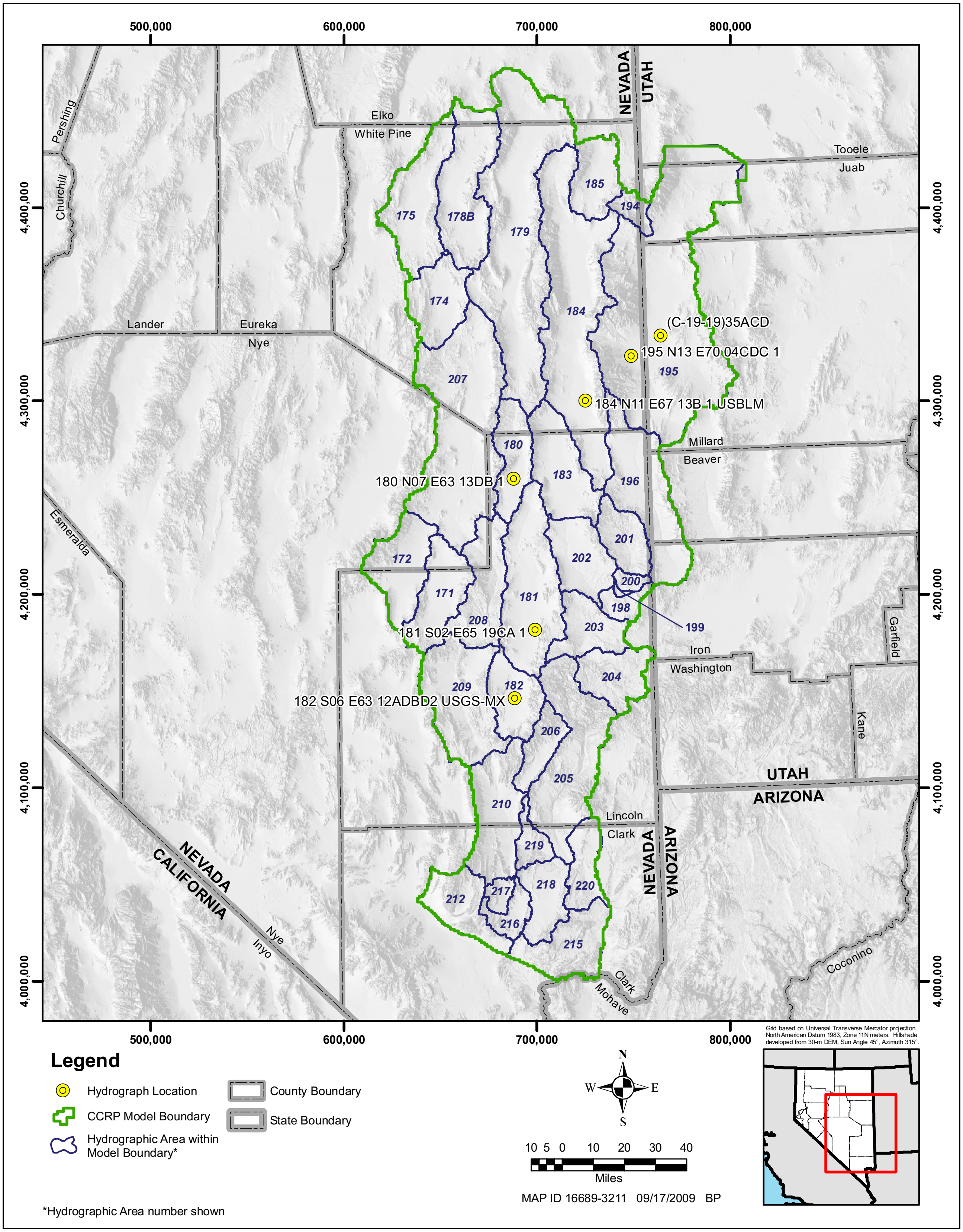
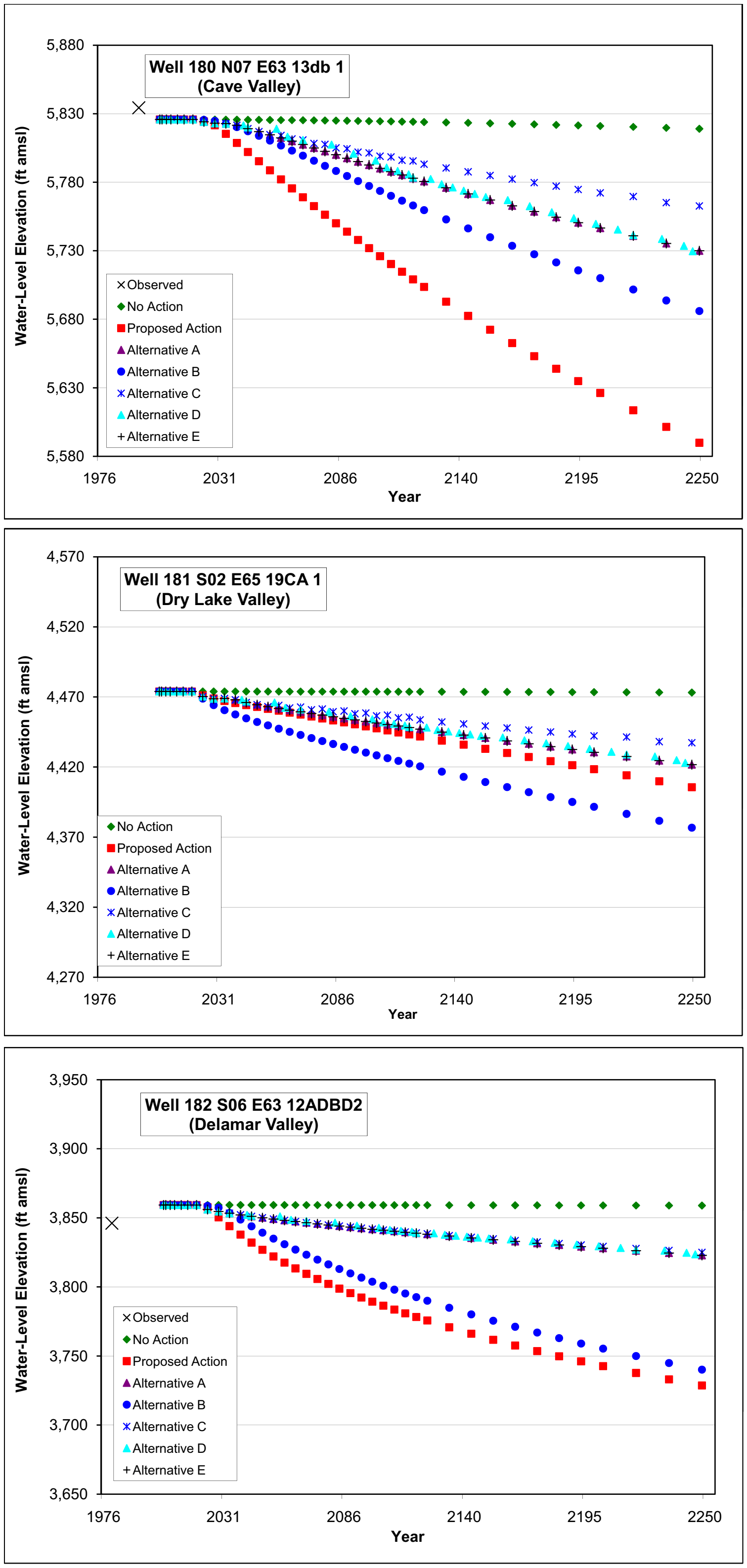
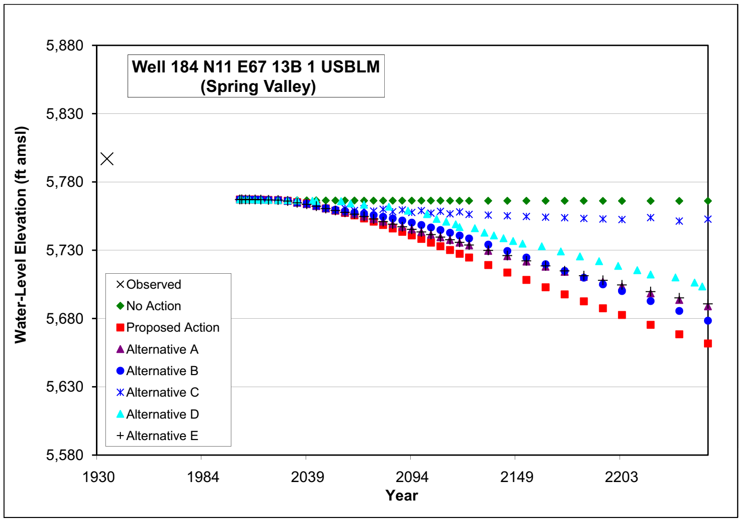


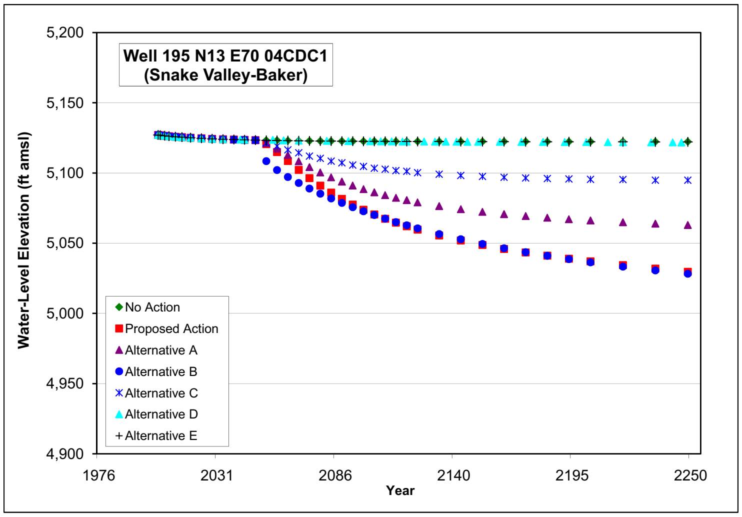
Figure 4-1
Location of Selected Observation Wells

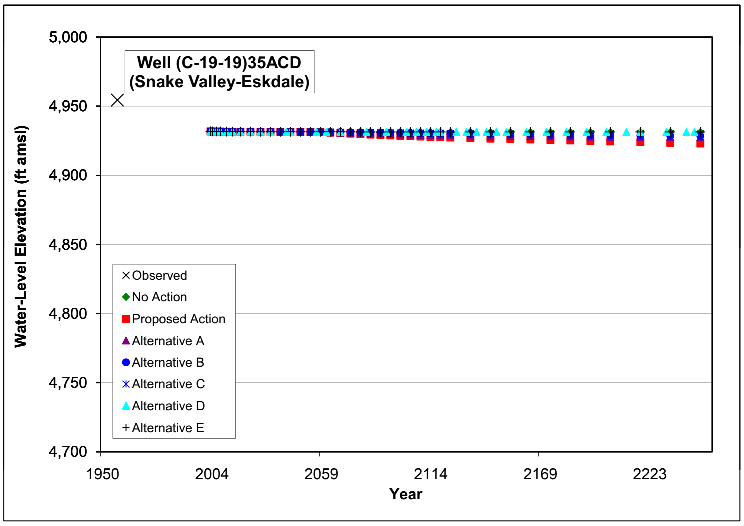


Note: See Figure 4-1 for well locations.

Figure 4-2
Simulated Water Levels at Selected Wells in Cave, Dry Lake, and Delamar Valleys







Note: See Figure 4-1 for well locations.

Figure 4-3
Simulated Water Levels at Selected Wells in Spring and Snake Valleys

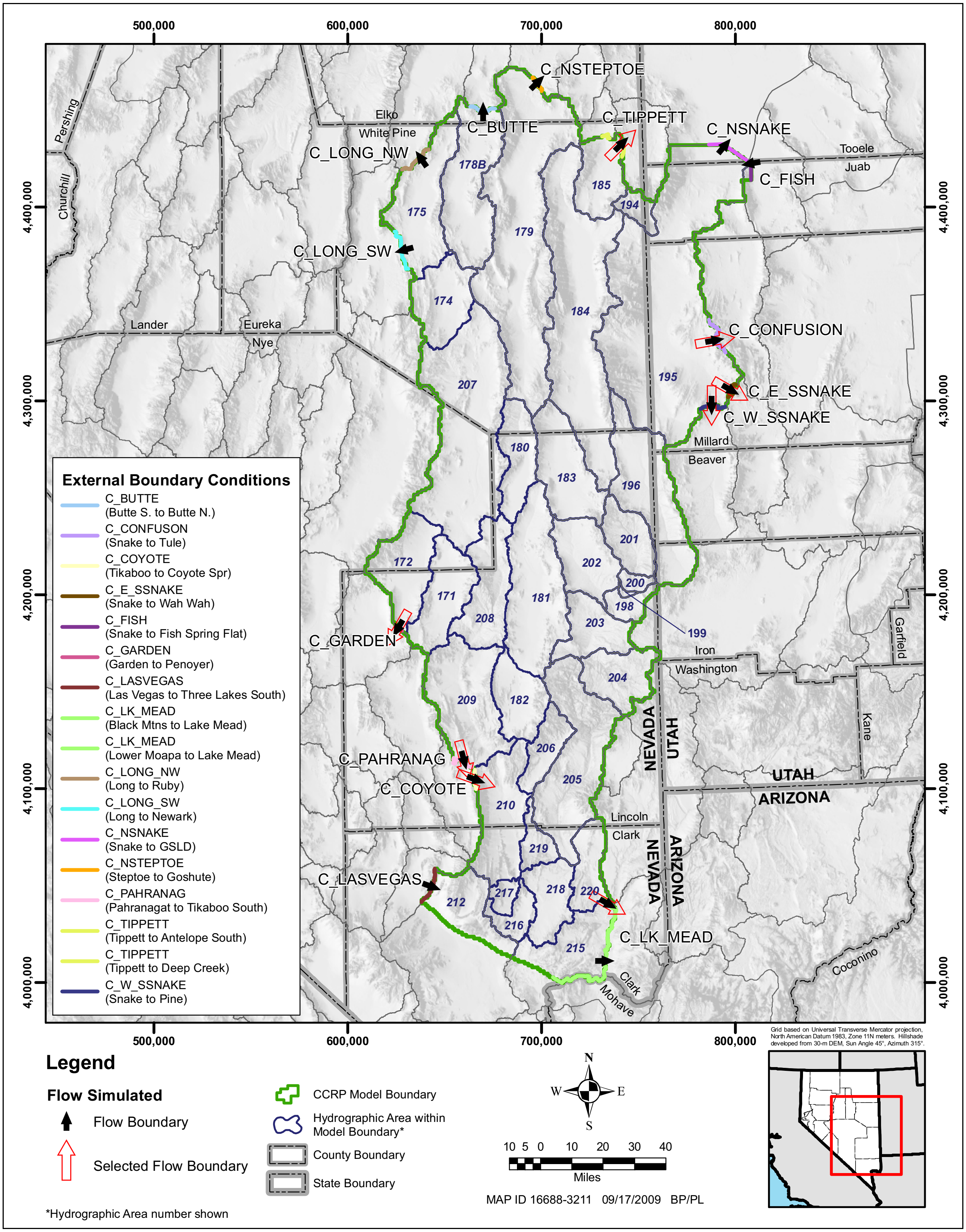


Figure 4-4
Location of Selected External Flow Boundaries

4.2.3 Effects on Groundwater ET

The simulated effects of pumping on groundwater ET are summarized in this section in the form of incremental changes from the No Action scenario in the model area and in the project basins.

The simulated effects of pumping under the Proposed Action and Project alternatives on the annual groundwater ET rates for the entire model area as well as the project basins are presented in Table 4-2.

The simulated effects of pumping under the Proposed Action and Project alternatives on the annual groundwater ET rate within the modeled area are largest under the Proposed Action and least under the Intermittent LCCRDA scenario (Alternative D) (Table 4-2). Most of the reduction in groundwater ET occurs in Spring Valley at the end of the simulation period (Table 4-2).

4.2.4 Effects on Spring and Stream Flow

The simulated effects of pumping on the flow of selected springs and streams are summarized in Table 4-2. The simulated effects on all springs and stream gages represented in the transient numerical model are provided on the DVD.

The selected spring and stream gages (Figure 4-5) represent a spatially distributed sample of the springs and stream gages represented in the transient numerical model (SNWA, 2009b). The Muddy River near Moapa gage is represented as a spring on the map (Figure 4-5) because this stream gage actually measures the combined spring flow from the Muddy River Springs.

The flow rates simulated for the No Action scenario and the reduction in flow rates simulated for the Proposed Action and Project alternatives at the selected spring and stream gages are presented in Table 4-2. The effects of pumping under these alternate groundwater development scenarios cause only negligible effects at the regional springs. The simulated effects on intermediate springs, such as Big Springs are large but much more uncertain than for regional springs. Note that in the modified numerical model, the simulated groundwater discharge from Big Springs was only about half of the observed value (SNWA, 2010). The numerical model is designed to simulate flow from springs that are believed to be connected to the regional groundwater flow system and may not accurately simulate flow from springs that are controlled by local structures not represented in the model (e.g., Warm Springs at Gandy and Big Springs).

4.3 Effects of Cumulative Pumping

The simulated effects of the cumulative pumping described in Section 3.3 on the flow system of the model area are summarized in this section (Table 4-1). The effects are presented in terms of cumulative changes in the water table (drawdowns from January 1, 2005), external boundary flows, groundwater ET, and spring and stream flow for the Cumulative Proposed Action scenario. The simulated effects for all cumulative scenarios, as well as the effects on interbasin flow and other groundwater-budget components are provided on the DVD.

Table 4-2
Simulated Changes in Discharge for External Boundaries, ET, and Spring and Stream Flows due to the Proposed Action and Alternative Scenarios
(Page 1 of 2)

Time[a]	Observation	No Action Simulated Value (afy)	Proposed Action	Alternative A	Alternative B	Alternative C	Alternative D	Alternative E
			Incremental Change from No Action (afy)					
Selected External Flow Boundaries[b]								
2005	Garden Valley to Penoyer Valley (C_GARDEN)	2,242	0	0	0	0	0	0
Full Build-Out		2,230	0	0	0	0	0	0
+ 75 years		2,217	-3	-2	-7	-1	-2	-2
+ 200 years		2,202	-19	-11	-32	-8	-2	-11
2005	Lower Moapa Valley to Colorado River (C_LK_MEAD)	13,563	0	0	0	0	0	0
Full Build-Out		13,430	0	0	0	0	0	0
+ 75 years		13,338	-6	-3	-6	-3	-2	-3
+ 200 years		13,288	-20	-5	-20	-5	-5	-5
2005	Pahranagat Valley to Tikaboo Valley South (C_PAHRANAG)	9,503	0	0	0	0	0	0
Full Build-Out		9,476	-184	-86	-207	-86	-53	-86
+ 75 years		9,454	-904	-285	-926	-282	-256	-285
+ 200 years		9,434	-1,703	-533	-1,762	-503	-500	-533
2005	Snake Valley to Tule Valley (C_CONFUSION)	15,117	0	0	0	0	0	0
Full Build-Out		15,099	0	0	0	0	0	0
+ 75 years		15,084	-166	-111	-98	-55	6	-1
+ 200 years		15,074	-457	-278	-316	-117	-12	-5
2005	South Snake Valley to Pine Valley (C_W_SSNAKE)	1,414	0	0	0	0	0	0
Full Build-Out		1,394	0	0	0	0	-2	0
+ 75 years		1,378	-441	-294	-320	-143	-50	-9
+ 200 years		1,365	-1,141	-703	-913	-272	-202	-38
2005	South Snake Valley to Wah Wah Valley (C_E_SSNAKE)	2,060	0	0	0	0	0	0
Full Build-Out		2,056	0	0	0	0	0	0
+ 75 years		2,051	-54	-36	-38	-17	0	0
+ 200 years		2,047	-188	-117	-144	-48	-15	-4
2005	Tikaboo Valley South to Coyote Springs Valley (C_COYOTE)	2,016	0	0	0	0	0	0
Full Build-Out		2,048	14	8	16	8	4	7
+ 75 years		2,083	109	37	111	37	32	37
+ 200 years		2,115	258	81	263	78	76	81
2005	Tippett Valley to Antelope Valley (C_TIPPETT)	4,172	0	0	0	0	0	0
Full Build-Out		4,165	-13	-2	0	-2	0	-2
+ 75 years		4,152	-265	-80	0	-51	-4	-80
+ 200 years		4,135	-721	-239	-2	-118	-13	-238
Regional ET								
2005	Model Domain ET	425,200	0	0	0	0	0	0
Full Build-Out		412,800	-32,000	-21,200	-27,200	-21,200	-1,400	-21,200
+ 75 years		406,300	-83,400	-59,700	-68,300	-41,800	-17,700	-37,000
+ 200 years		401,500	-95,300	-68,000	-81,100	-43,800	-29,200	-42,900

Table 4-2
Simulated Changes in Discharge for External Boundaries, ET, and Spring and Stream Flows due to the Proposed Action and Alternative Scenarios
(Page 2 of 2)

Time[a]	Observation	No Action Simulated Value (afy)	Proposed Action	Alternative A	Alternative B	Alternative C	Alternative D	Alternative E
			Incremental Change from No Action (afy)					
Project Basin ET								
2005	Spring Valley	74,100	0	0	0	0	0	0
Full Build-Out	Spring Valley	69,900	-31,700	-21,100	-25,300	-21,100	-800	-21,100
+ 75 years	Spring Valley	68,700	-52,900	-35,300	-45,200	-25,900	-12,300	-35,300
+ 200 years	Spring Valley	68,300	-57,400	-38,700	-49,600	-25,000	-19,200	-38,600
2005	Snake Valley	104,700	0	0	0	0	0	0
Full Build-Out	Snake Valley	103,500	0	0	-100	0	-300	0
+ 75 years	Snake Valley	102,800	-28,700	-23,500	-18,800	-15,300	-4,300	-800
+ 200 years	Snake Valley	102,500	-34,000	-27,700	-25,100	-17,600	-8600	-2700
Selected Spring and Stream Flow Observations[c]								
2005	Big Springs	3,182	0	0	0	0	0	0
Full Build-Out	Big Springs	2,910	-55	-56	-190	-56	-450	-56
+ 75 years	Big Springs	2,771	-2,771	-2,771	-2,771	-2,424	-2,792	-733
+ 200 years	Big Springs	2,665	-2,665	-2,665	-2,665	-2,665	-2,672[d]	-2,076
2005	Crystal Springs	7,482	0	0	0	0	0	0
Full Build-Out	Crystal Springs	7,414	-1	-1	-2	-1	0	-1
+ 75 years	Crystal Springs	7,376	-18	-9	-23	-7	-7	-9
+ 200 years	Crystal Springs	7,353	-75	-38	-90	-31	-34[d]	-38
2005	Flag Spring 3	902	0	0	0	0	0	0
Full Build-Out	Flag Spring 3	898	-11	-4	-170	-4	-2	-4
+ 75 years	Flag Spring 3	891	-65	-31	-258	-22	-28	-31
+ 200 years	Flag Spring 3	879	-151	-74	-325	-47	-76	-74
2005	Hot Creek Spring	11,108	0	0	0	0	0	0
Full Build-Out	Hot Creek Spring	11,082	-23	-10	-316	-10	-5	-10
+ 75 years	Hot Creek Spring	11,044	-137	-65	-522	-46	-54	-65
+ 200 years	Hot Creek Spring	10,992	-344	-167	-731	-107	-159	-167
2005	Moorman Spring	569	0	0	0	0	0	0
Full Build-Out	Moorman Spring	566	-1	0	-12	0	0	0
+ 75 years	Moorman Spring	564	-6	-3	-23	-2	-2	-3
+ 200 years	Moorman Spring	561	-14	-7	-32	-4	-7	-7
2005	Muddy River near Moapa	24,767	0	0	0	0	0	0
Full Build-Out	Muddy River near Moapa	23,727	-4	-2	-4	-2	-2	-2
+ 75 years	Muddy River near Moapa	23,169	-81	-30	-83	-30	-29	-30
+ 200 years	Muddy River near Moapa	22,614	-282	-91	-286	-88	-83[d]	-91

[a]Full Build-out for all but the LCCRDA scenarios occurs in 2050. For the LCCRDA scenarios, Full Build-out occurs in 2043.
[b]See Figure 4-4 for selected external flow boundary locations.
[c]See Figure 4-5 for selected spring and stream flow observation locations.
[d]Result represents 191 years after full production as no 200-year value was available.

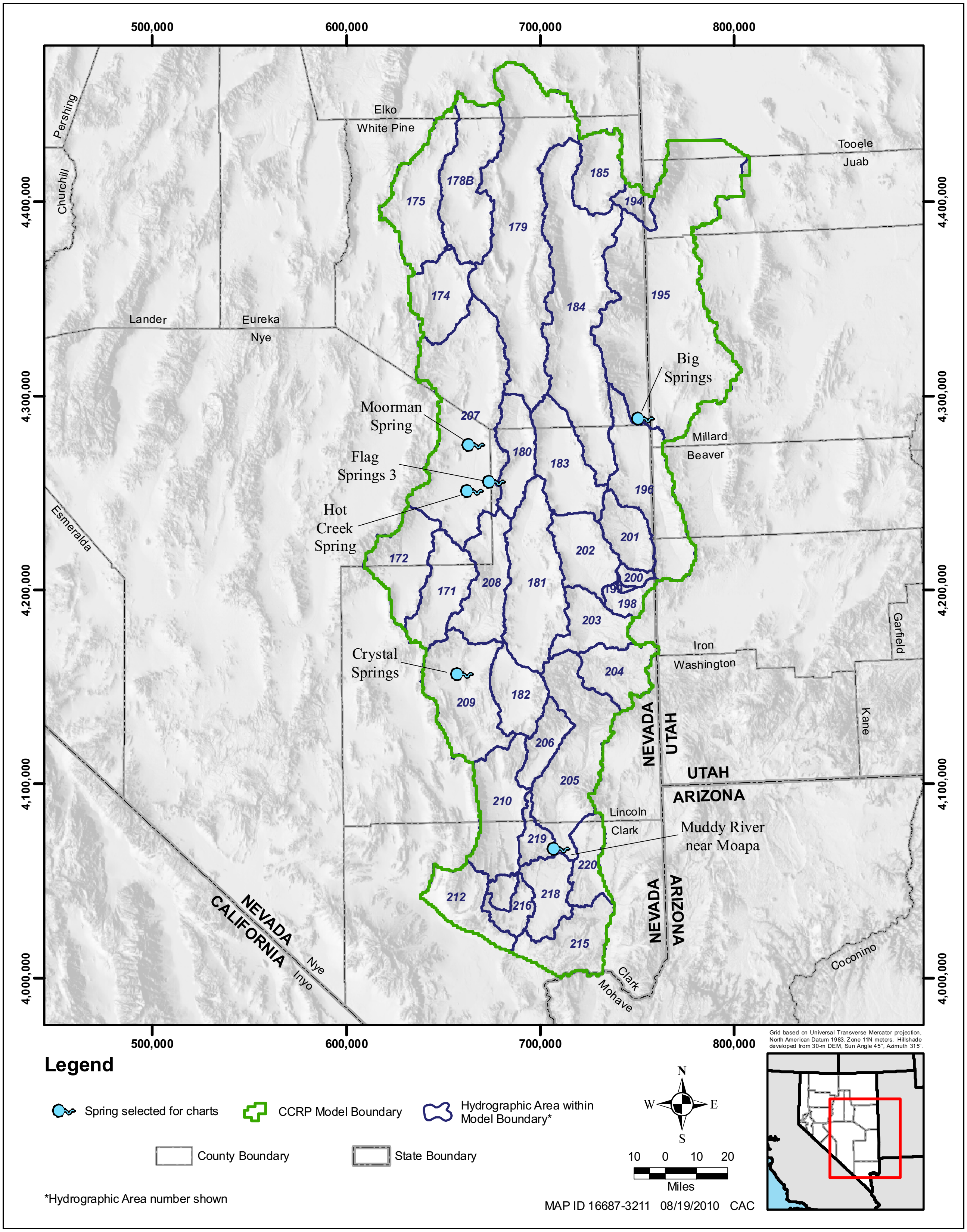


Figure 4-5
Location of Selected Springs and Stream Gages

4.3.1 Extent of Drawdown

The cumulative effects of pumping on water levels are shown as drawdown maps on Plate 2. The simulated drawdowns associated with the Cumulative Pumping scenarios are shown on maps located in Plate 2. As Cumulative Pumping scenarios include both the Project and No Action pumping, the effects of these scenarios are larger than those of the Project pumping alone. The effects are greater for the Cumulative Pumping scenarios because additional reasonably foreseeable, future groundwater withdrawals were included in their water-use schedules, as described in Section 3.0. These large drawdowns occur in the southern part of the model area and cause maximum drawdowns in Clover Valley (HA 204).

The drawdowns in Spring and Snake valleys appear to be similar to those caused by the Proposed Action scenario. This is because groundwater pumping from existing wells in Spring and Snake valleys and associated drawdowns are insignificant. However, simulated drawdowns are larger over Cave and Dry Lake valleys. These two valleys are located near Lake Valley where significant groundwater withdrawals from wells are simulated. These withdrawals cause substantial drawdowns in Lake Valley, which propagate to Cave and Dry Lake valleys.

4.3.2 Effects on External Boundary Flows

The cumulative effects of pumping on flows across the external model boundaries are presented in Table 4-3. As was the case for the Proposed Action and Project alternatives, the simulated flow rates across the external boundaries of the numerical model are not significantly affected by the cumulative pumping. The maximum relative decrease in flow occurs at the boundary between Snake Valley and Pine Valley at the end of the simulation period under the Cumulative Proposed Action Pumping scenario. This was also the case for the Proposed Action and Project alternatives.

4.3.3 Effects on Groundwater ET

The cumulative pumping effects on annual groundwater ET rates are presented in Table 4-3 for the entire model area and the Project basins. Again, as expected for these larger-pumping scenarios, the effects are larger.

4.3.4 Effects on Spring and Stream Flows

The simulated flow rates due to cumulative pumping at the selected springs and stream gages are presented in Table 4-3. The largest simulated effects are associated with the Cumulative Pumping scenarios and affect mostly the Muddy River near Moapa Gage. All other springs are either not affected or only minimally affected by the cumulative pumping as compared to pumping under the No Action scenario. The simulated effect of the Proposed Action and Project alternatives on the Muddy River near Moapa Gage is negligible, therefore the simulated large reductions in flow at the Muddy River near Moapa Gage is caused by future pumping simulated under the Cumulative Pumping scenarios.

Table 4-3
Simulated Discharge for External Boundaries, ET, and Spring and Stream Flows due to the Proposed Action and Alternative Scenarios
(Page 1 of 2)

Time[a]	Observation	No Action Simulated Value (afy)	Proposed Action	Cumulative Proposed Action
			Includes No Action (afy)	
Selected External Flow Boundaries[b]				
2005	Garden Valley to Penoyer Valley (C_GARDEN)	2,242	2,242	2,242
Full Build-Out		2,230	2,230	2,222
+ 75 years		2,217	2,214	2,201
+ 200 years		2,202	2,183	2,164
2005	Lower Moapa Valley to Colorado River (C_LK_MEAD)	13,563	13,563	13,564
Full Build-Out		13,430	13,430	12,904
+ 75 years		13,338	13,332	12,737
+ 200 years		13,288	13,268	12,618
2005	Pahranagat Valley to Tikaboo Valley South (C_PAHRANAG)	9,503	9,503	9,502
Full Build-Out		9,476	9,292	9,145
+ 75 years		9,454	8,550	8,297
+ 200 years		9,434	7,731	7,388
2005	Snake Valley to Tule Valley (C_CONFUSION)	15,117	15,117	15,117
Full Build-Out		15,099	15,099	15,099
+ 75 years		15,084	14,918	14,918
+ 200 years		15,074	14,617	14,617
2005	South Snake Valley to Pine Valley (C_W_SSNAKE)	1,414	1,414	1,414
Full Build-Out		1,394	1,394	1,394
+ 75 years		1,378	937	937
+ 200 years		1,365	224	224
2005	South Snake Valley to Wah Wah Valley (C_E_SSNAKE)	2,060	2,060	2,060
Full Build-Out		2,056	2,056	2,056
+ 75 years		2,051	1,997	1,997
+ 200 years		2,047	1,859	1,859
2005	Tikaboo Valley South to Coyote Springs Valley (C_COYOTE)	2,016	2,016	2,016
Full Build-Out		2,048	2,062	2,286
+ 75 years		2,083	2,192	2,677
+ 200 years		2,115	2,373	3,024
2005	Tippett Valley to Antelope Valley (C_TIPPETT)	4,172	4,172	4,172
Full Build-Out		4,165	4,152	4,142
+ 75 years		4,152	3,887	3,830
+ 200 years		4,135	3,414	3,278
Regional ET				
2005	Model Domain ET	425,200	425,200	425,200
Full Build-Out		412,800	380,800	365,500
+ 75 years		406,300	322,900	297,300
+ 200 years		401,500	306,200	275,300

Table 4-3
Simulated Discharge for External Boundaries, ET, and Spring and Stream Flows due to the Proposed Action and Alternative Scenarios
(Page 2 of 2)

Time[a]	Observation	No Action Simulated Value (afy)	Proposed Action	Cumulative Proposed Action
			Includes No Action (afy)	
Project Basin ET				
2005	Spring Valley	74,100	74,100	74,100
Full Build-Out		69,900	38,200	37,900
+ 75 years		68,700	15,800	15,300
+ 200 years		68,300	10,900	10,300
2005	Snake Valley	104,700	104,700	104,700
Full Build-Out		103,500	103,500	103,500
+ 75 years		102,800	74,100	74,100
+ 200 years		102,500	68,500	68,500
Selected Spring and Stream Flow Observations[c]				
2005	Big Springs	3,182	3,182	3,182
Full Build-Out		2,910	2,855	2,855
+ 75 years		2,771	0	0
+ 200 years		2,665	0	0
2005	Crystal Springs	7,482	7,482	7,482
Full Build-Out		7,414	7,413	7,405
+ 75 years		7,376	7,358	7,345
+ 200 years		7,353	7,278	7,260
2005	Flag Spring 3	902	902	902
Full Build-Out		898	887	887
+ 75 years		891	826	825
+ 200 years		879	728	727
2005	Hot Creek Spring	11,108	11,108	11,108
Full Build-Out		11,082	11,059	11,056
+ 75 years		11,044	10,907	10,901
+ 200 years		10,992	10,648	10,638
2005	Moorman Spring	569	569	569
Full Build-Out		567	567	565
+ 75 years		564	558	558
+ 200 years		561	547	546
2005	Muddy River near Moapa	24,767	24,767	24,767
Full Build-Out		23,727	23,723	15,531
+ 75 years		23,169	23,088	11,400
+ 200 years		22,614	22,332	9,448

[a]Full Build-out for all but the LCCRDA scenarios occurs in 2050. For the LCCRDA scenarios, Full Build-out occurs in 2043.
[b]See Figure 4-4 for selected external flow boundary locations.
[c]See Figure 4-5 for selected spring and stream flow observation locations.

4.4 Effects of Alternative A Pumping Cessation

The simulated effects of the Alternative A Cessation scenario on the flow system of the modeled area are summarized in this section. The effects are presented in terms of changes in water levels, external boundary flows, groundwater ET, and spring and stream flow. The simulated effects of these scenarios on interbasin flow and groundwater-budget components are provided on the DVD.

4.4.1 Effects on Water Levels

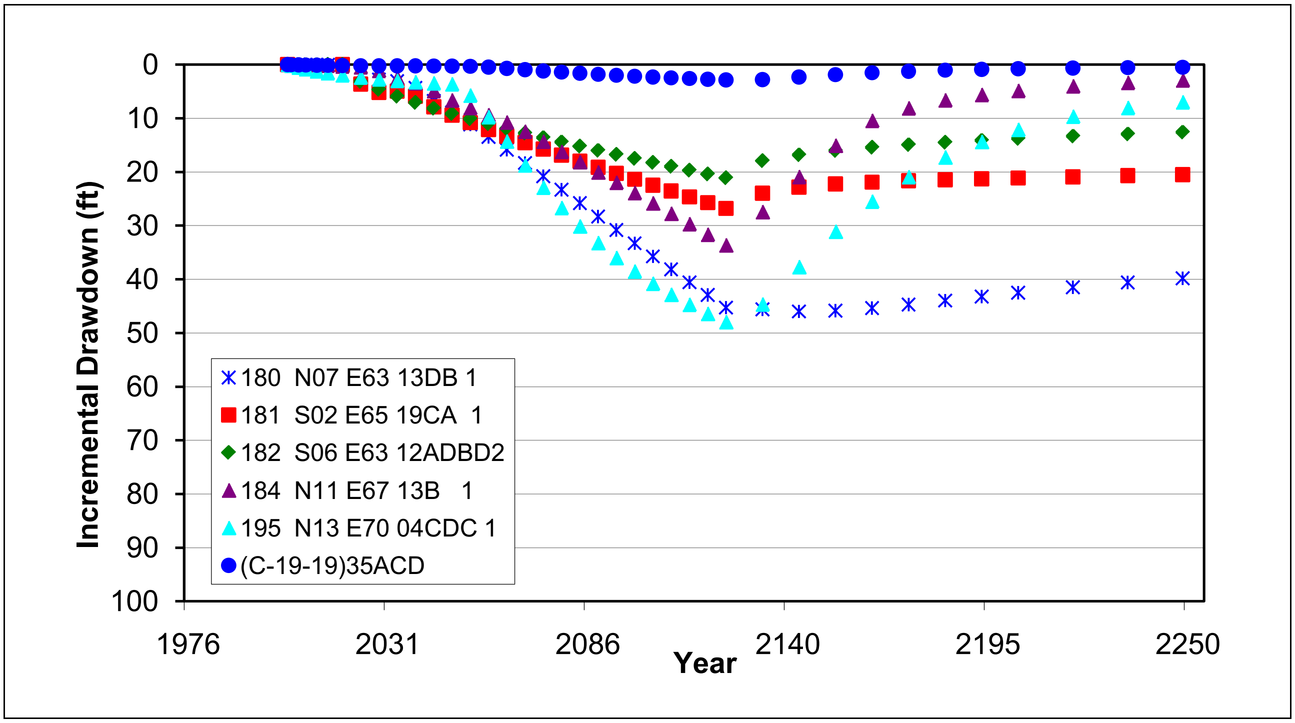
In the Alternative A Pumping Cessation scenario, pumping is ceased 75 years after full build-out, on December 21, 2124. The effects of this scenario on the water table at the selected observation wells (Figure 4-1) are shown in Figure 4-6. A map showing the drawdown contours for this scenario is included on the DVD. The effects are presented in terms of incremental drawdown that is additional to the drawdown caused by the No Action scenario.

The maximum incremental drawdown on the selected hydrographs shown in Figure 4-6 is about 49 ft and occurs at Well 195 N13 E70 04CDC 1 in Snake Valley. The incremental drawdown curves shown in Figure 4-6 display ascending trends for all selected wells. By the end of the simulation period (200 years after full build-out), the wells in Spring and Snake valleys have an incremental drawdown of less than 10 ft, or nearly the same drawdowns as would occur under the No Action scenario. The wells in Dry Lake and Delamar valleys have incremental drawdowns of about 20 ft or less, and the well in Cave Valley has an incremental drawdown of about 40 ft. Therefore, the simulated flow system in Dry Lake, Delamar, and Cave valleys exhibits a different hydraulic behavior than in other portions of the modeled area.

Reasons for the different flow-system behaviors in the areas of Dry Lake, Delamar, and Cave valleys may be related to the following:

- The lesser magnitude of local recharge
- The proximity to recharge outside of the area
- The presence of structural features near the edges of the valleys

The simulated annual recharge rate from precipitation in Cave, Delamar, and Dry Lake valleys is about one-fifth to one-tenth that of Spring and Snake valleys. The pumping areas are centered on nonrecharge areas within the UVF RMU and little direct recharge is simulated into the UVF in these valleys. In addition, several structural features simulated as horizontal flow barriers (HFBs) isolate the deep UVF sequences from small-magnitude recharge sources in Cave, Delamar, and Dry Lake valleys. The presence of these structures have an attenuating effect on the simulated velocity of groundwater flow from the recharge areas to the valley fill after the Proposed Action pumping was stopped. This behavior is dictated by this version of the calibrated numerical model and may be different if other assumptions were made about the role of the HFBs in this area.



Note: See Figure 4-1 for well locations.

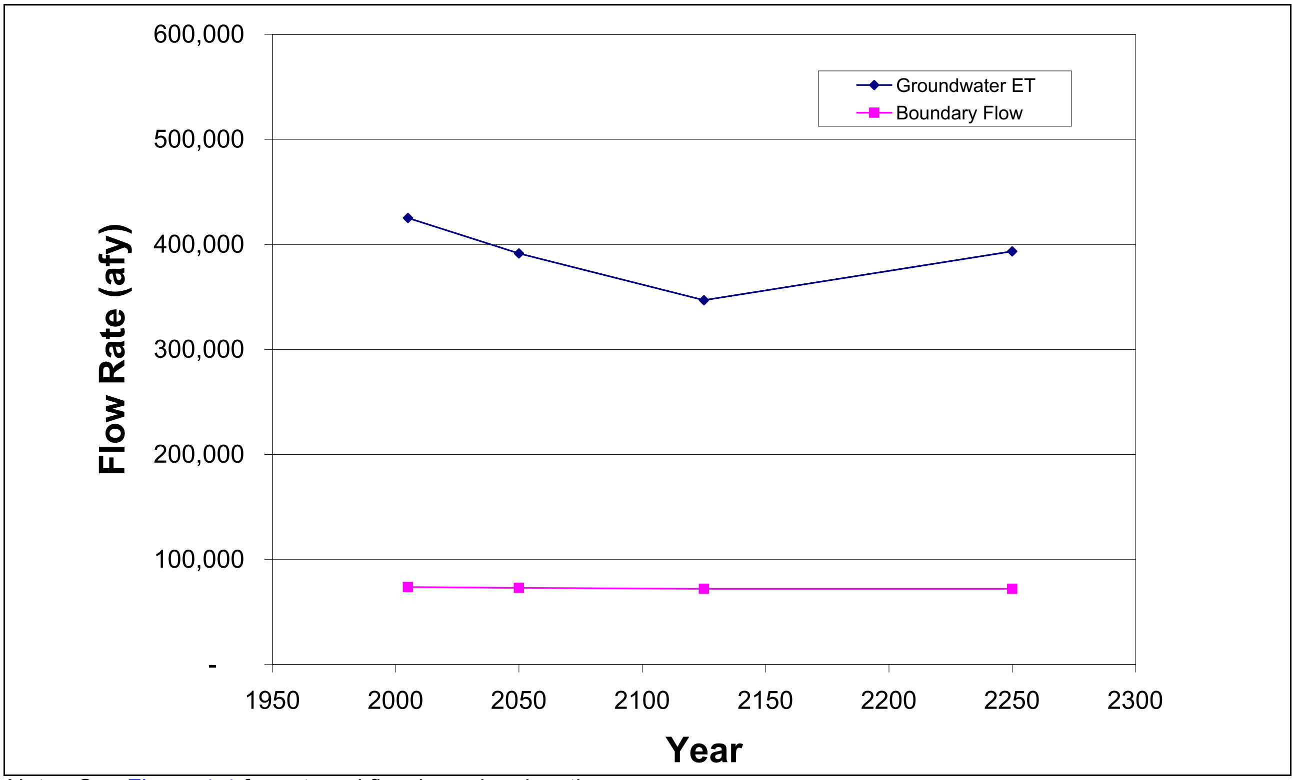
Figure 4-6
Incremental Drawdowns to No Action Levels Simulated Under Alternative A Pumping Cessation Scenario at Selected Wells in Project Basins

4.4.2 Effects on External Boundaries and Groundwater ET

The effects of the Alternative A Pumping Cessation scenario on external boundary flow and groundwater ET are shown in Figure 4-7 for the model area. The effects of pumping of the project wells under the Alternative A Pumping Cessation scenario from 2005 to 2125 on boundary flow is negligible. By the end of the simulation period, the flows have recovered to greater than 99 percent of the No Action boundary flow in the same year. The response to pumping cessation on groundwater ET in the project basins is presented in Table 4-4. Groundwater ET in the project basins was simulated to occur only in Spring and Snake valleys. By the end of the simulation period, the annual discharge by groundwater ET from the project basins is at 164,100 afy, a recovery to within 96 percent of the 170,800 afy that would discharge under the No Action scenario in that same year.

4.4.3 Effects on Spring and Stream Flow

The effects of the water-use schedule under the Alternative A Pumping Cessation scenario, 200 years after full build-out, on spring and stream flow are negligible as compared to the effects of pumping under the No Action scenario for all selected springs except Big Springs (Table 4-4). For Big Springs, the discharge drops to zero in year 2086 but recovers to 55 percent of No Action by the end of the simulation.



Note: See Figure 4-4 for external flow boundary locations.

Figure 4-7
Groundwater ET and Boundary Flow Simulated Under Alternative A Pumping Cessation for Model Area

Table 4-4
Simulated Discharge for External Boundaries, ET, and Spring and Stream Flows due to the Alternative A Pumping Cessation
(Page 1 of 2)

Time[a]	Observation	No Action Simulated Value (afy)	Alternative A	Alternative A Pumping Cessation
			Includes No Action (afy)	
Selected External Flow Boundaries[b]				
+ 200 years	Garden Valley to Penoyer Valley (C_GARDEN)	2,202	2,191	2,194
+ 200 years	Lower Moapa Valley to Colorado River (C_LK_MEAD)	13,288	13,283	13,285
+ 200 years	Pahranagat Valley to Tikaboo Valley South (C_PAHRANAG)	9,434	8,901	9,234
+ 200 years	Snake Valley to Tule Valley (C_CONFUSION)	15,074	14,796	15,011
+ 200 years	South Snake Valley to Pine Valley (C_W_SSNAKE)	1,365	662	1,249
+ 200 years	South Snake Valley to Wah Wah Valley (C_E_SSNAKE)	2,047	1,930	2,016
+ 200 years	Tikaboo Valley South to Coyote Springs Valley (C_COYOTE)	2,115	2,196	2,151
+ 200 years	Tippett Valley to Antelope Valley (C_TIPPETT)	4,135	3,896	4,035

Table 4-4
Simulated Discharge for External Boundaries, ET, and Spring and Stream Flows due to the Alternative A Pumping Cessation
(Page 2 of 2)

Time[a]	Observation	No Action Simulated Value (afy)	Alternative A	Alternative A Pumping Cessation
			Includes No Action (afy)	
Regional ET				
+ 200 years	Model Domain ET	401,500	335,500	394,000
Project Basin ET				
+ 200 years	Spring Valley	68,300	29,600	64,100
+ 200 years	Snake Valley	102,500	74,800	100,000
Selected Spring and Stream Flow Observations[c]				
+ 200 years	Big Springs	2,665	0	1,739
+ 200 years	Crystal Springs	7,353	7,315	7,327
+ 200 years	Flag Spring 3	879	805	847
+ 200 years	Hot Creek Spring	10,992	10,825	10,915
+ 200 years	Moorman Spring	561	554	558
+ 200 years	Muddy River Moapa	22,614	22,523	22,562

[a]Full Build-out occurs in 2050.
[b]See Figure 4-4 for selected external flow boundary locations.
[c]See Figure 4-5 for selected spring and stream flow observation locations.

5.0 UNCERTAINTY USING SENSITIVITY ANALYSES

This section contains an analysis of the effect of parameter uncertainty and the alternate representation of the Big Springs Area on the results of the Alternative A - Distributed Pumping-Reduced Quantities scenario.

5.1 Effect of Parameter Uncertainty

The objective of this uncertainty analysis is to quantify the effects of the uncertainty associated with the input parameters on the variables simulated by the modified transient numerical model (SNWA, 2009b and 2010). A formal method of uncertainty analysis using the transient numerical model and the capabilities of UCODE_2005 is not feasible primarily because it was not possible to optimize all model parameters (SNWA, 2009b). Secondarily, such an analysis would require a large number of model simulations, including calibration, which is not feasible at this time, given the available resources. Although sensitivity analysis is typically used to rank the model input parameters based on their influence on the simulated results, it can also be used to derive approximate uncertainty ranges of simulated results. This method does not require model calibration.

In this case, only the maximum extents of the drawdown cones will be estimated and compared to the base case (Alternative A). Input parameters were grouped to reduce the number of simulations. Criteria were applied to ensure (1) the input parameters were set within reasonable uncertainty ranges, and (2) the model would be valid within those ranges. This simplified method of uncertainty analysis was applied to the Alternative A scenario. The analysis approach is described, followed by a discussion of the results.

5.1.1 Approach

The process followed to conduct the sensitivity analyses is generally based on the *Standard Guide for Conducting a Sensitivity Analysis for a Ground-Water Flow Model Application* (ASTM, 1998). Sensitivity analysis simulations require (1) the selection of model parameters to perturb and their reasonable low and high values, (2) execution of calibration and prediction simulations for each low and high value of each selected parameter, and (3) processing of the results to derive uncertainty ranges.

5.1.1.1 Selection of Parameters and Ranges

Two major groups of parameters were selected to conduct the sensitivity simulations. The first group includes all hydraulic conductivity (*Kh*) parameters, and the second group includes all aquifer storage properties defined in the numerical model (SNWA, 2009b). Aquifer storage parameters include specific yield (*Sy*) and specific storage (*Ss*).

The ranges of parameter values represent the uncertainty on the mean values for large zones of RMUs defined in the numerical model, not the ranges of spatial variability. If sufficient data were available for a given parameter within a given RMU zone, a realistic mean value and the corresponding uncertainty range could be derived statistically. The uncertainty on the mean value may be statistically expressed by the variance of the mean, which is calculated as the variance of the sample divided by the sample size (Davis, 2002, p. 59). Given that the data available for the study area are limited and insufficient, such an analysis could not be conducted. Rather, the uncertainty ranges on the mean parameter values were estimated. In addition, because BLM reviewers believed that the mean parameter values used in the numerical model yielded minimum extents, rather than means, they requested that parameters be perturbed to only estimate the maximum extent of the drawdown cones.

Nonetheless, the available aquifer-property data were used as guides in the estimation of reasonable ranges of uncertainty for the mean parameter values. The upper bound for the uncertainty range of hydraulic conductivity values is about 1.5 times the calibrated values. As most of the existing wells (No Action) and the proposed pumping wells (Alternative A) are in the UVF, only the Sy value of the UVF was perturbed in the uncertainty analysis. A lower bound for the mean Sy for the valley-fill aquifer of 0.12 was derived from aquifer-test analysis results using irrigation pumping and historical water-level data (SNWA, 2009b). However, the BLM requested that a low value of 0.1 be used. The combination of the maximum *Kh* values and minimum *Sy* value for the UVF aquifer yields a maximum value of hydraulic diffusivity for the UVF aquifer. Using this maximum diffusivity, the maximum extents of drawdown cones for Alternative A were simulated.

5.1.1.2 Execution of Simulations

The sensitivity analyses of the selected parameter groups were performed on the calibrated modified transient numerical model, as well as the No Action, Alternative A, and Cumulative Alternative A Pumping scenarios. The No Action scenario was needed because it serves as the basis for deriving the incremental changes caused by a given groundwater development scenario.

The sensitivity analyses were performed first using the calibrated transient numerical model. All simulations are listed in Table 5-1. For the calibration uncertainty (ucpd971), the simulation period spans January 1, 1945, to December 31, 2004, and includes historical groundwater use during that period. Simulations were performed using the calibrated model for each parameter group using the low and high values of the appropriate parameter as described in the previous section. The main products of interest from these simulations are the hydraulic-head distributions generated for the end of the simulation period (December 31, 2004) for each perturbed parameter group's low and high values. These hydraulic-head distributions served as the initial, spatial hydraulic-head distributions in the corresponding scenario's sensitivity analysis simulations.

Table 5-1
Sensitivity Simulations Using Calibrated Transient Numerical Model

Alternative Name	Simulation Number	Description	Comment
Calibration Uncertainty	ucth971	Uncertainty simulation using calibrated modified numerical model files and perturbed parameters.	Used maximum *Kh* values (calibrated *Kh* x 1.5) and minimum storage property values (*Sy* = 0.1 for UVF)
No-Action Uncertainty	ucpd972	Uncertainty simulation using No Action scenario model files and perturbed parameters.	Same as above
Alternative A Uncertainty	ucpd973	Uncertainty simulation using Alternative A scenario model files and perturbed parameters.	Same as above

Simulations were performed using each of the three selected groundwater development scenarios and the perturbed parameter set (Table 5-1). The initial hydraulic-head distributions corresponded to the appropriate spatial-head distributions reflecting the particular *K* and *S* values being simulated for December 31, 2004, using the calibrated transient numerical model (ucth971).

5.1.1.3 Processing of Results

The results of the sensitivity simulations for the calibrated transient numerical model and the groundwater development scenarios were processed separately. The selection of the simulated variable of interest for evaluation is described, followed by descriptions of the evaluation of model validity and the quantification of prediction uncertainty.

5.1.1.3.1 Selection of Simulated Variable of Interest

The extents of the cones of depression are of particular interest in this EIS. A cone of depression corresponds to areas where the hydraulic heads have decreased as a result of the stresses imposed by the pumping wells. In this case, pumping wells would be the Project wells for the Alternative A scenario. Hydraulic head is the main control variable on all other simulated variables, such as spring flow, groundwater ET rates, boundary fluxes, and stream-aquifer interactions. Hydraulic head was therefore selected as the variable of interest for evaluation in this uncertainty analysis.

5.1.1.3.2 Evaluation of Model Validity

The validity of the model within the tested ranges of parameter uncertainty was evaluated by classifying the types of sensitivities (ASTM, 1998) of the model to the tested parameters.

The sensitivity types are described in ASTM (1998) as follows:

- Type I sensitivity: In this case, the perturbed parameter minimally affects the calibration residuals and the model's conclusions. Type I sensitivity means that the model simulates approximately the same response for this perturbation of the parameter value and therefore leads to the same conclusion.

- Type II sensitivity: In this case, the perturbed parameter greatly affects the calibration residuals but minimally affects the model's conclusions. Type II sensitivity means that the model's conclusion is the same even if the input parameter value changes.

- Type III sensitivity: In this case, the perturbed parameter greatly affects both the calibration residuals and the model's conclusions. Type III sensitivity means that the model is not calibrated anymore and the conclusion is changed. Therefore, the perturbed value is outside of the reasonable range of possibilities, but the calibrated model is still valid.

- Type IV sensitivity: In this case, the perturbed parameter minimally affects the calibration residuals but changes the model's conclusions. Type IV sensitivity means that the model may not be calibrated over the range selected for the perturbed parameter and the model results may be invalid.

Type IV sensitivity would invalidate the results of the calibrated transient numerical model. Type III sensitivity would invalidate the selected ranges of uncertainty of the perturbed parameters. Sensitivity types I and II would support the use of the sensitivity analyses to approximate the simulated ranges of uncertainty for output variables.

The sum of squared weighted residuals (SoSWR) values were used to evaluate model fit. The conclusion of the transient numerical model is that the model simulates the spatial distribution of hydraulic heads realistically. This conclusion can be tested by comparing the fit of the hydraulic heads for a given sensitivity run to the fit of the calibrated transient numerical model.

If the transient numerical model is determined to be valid over the range of uncertainty of the selected parameters, approximate ranges of uncertainty for hydraulic heads or drawdowns can be processed from the sensitivity simulation results.

5.1.2 Results

The results are discussed in terms of the model validity evaluation and the uncertainty on the simulated drawdowns.

5.1.2.1 Model Validity Evaluation

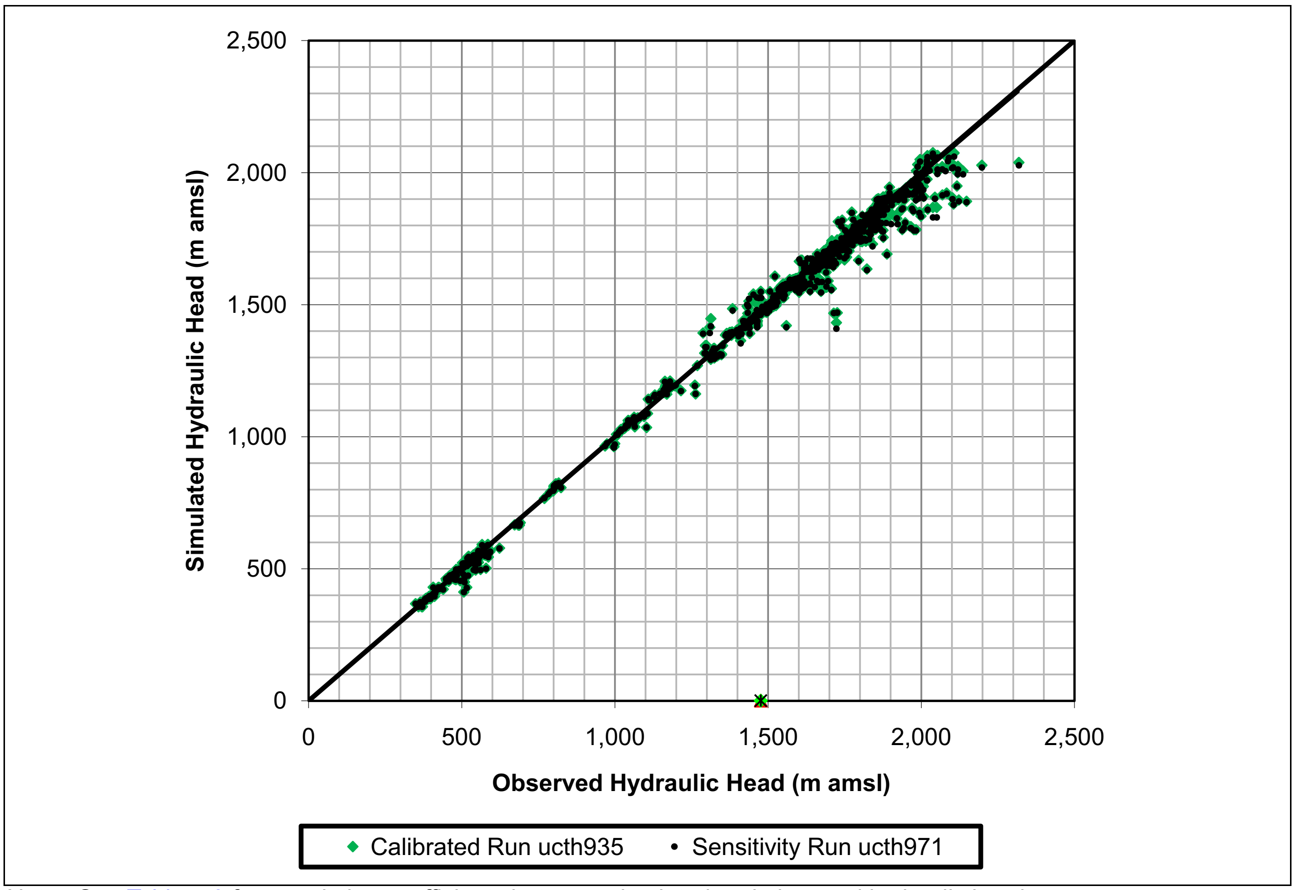
Model validity in the sensitivity analysis was evaluated using the calibration residuals, represented by the SoSWR, and the conclusion of the model, which may be defined as minimal change in the simulated target hydraulic heads. This conclusion may be evaluated by comparing the fit of the simulated hydraulic heads to the observed hydraulic heads of each sensitivity run to the fit of the calibrated transient numerical model. This comparison is made visually and comparatively using the correlation coefficients between simulated and observed hydraulic heads for all simulations.

A comparison of the SoSWR values are shown in Table 5-2. The effect of perturbing the horizontal hydraulic conductivities and the UV F specific yield on the SoSWR is apparently significant. The SoSWR value increased from 41,464 to 75,877.

Table 5-2
Evaluation of Residuals for Base Model

Model Number	Description	SoSWR
ucth935	Calibrated	41,464
ucth971	High *Kh*/Low UVF *Sy*	75,877

The conclusion reached for the calibrated modified numerical model (ucth935) was that a relatively good fit was achieved between the simulated and observed hydraulic heads. The question then is: Was this fit maintained when the parameters were perturbed (ucth971)? A graph comparing the fits of the calibrated model and sensitivity run is shown in Figure 5-1.



Note: See Table 5-3 for correlation coefficients between simulated and observed hydraulic heads.

Figure 5-1
Comparison of Simulated to Observed Hydraulic Heads for Calibrated Modified Numerical Model and Sensitivity Simulation

Based on a visual inspection of Figure 5-1, the simulated hydraulic heads for both the calibrated numerical model (ucth935) and the sensitivity run (ucth971) appear close to the 1:1 line, which indicates the simulated hydraulic heads are close to the observed hydraulic heads. An additional test of these fits was conducted by comparing the correlations between the simulated heads and the observed heads for the two simulations. Linear regressions were performed to derive these correlation coefficients and related statistics (Table 5-3). The correlation coefficient values (multiple R) are very high and are comparable for the two simulations, indicating relatively-small changes in the simulated hydraulic heads at the observation points.

Table 5-3
Comparison of Regression Statistics

Regression Statistics	Modified Calibrated Model (ucth935)	Sensitivity Run (ucth971)
Multiple *R*	0.99766	0.99755
R Square	0.99533	0.99510
Adjusted *R* Square	0.99533	0.99510
Standard Error (m)	27.35	27.99
Observations	2707	2707

Considering that the changes in parameter values in the sensitivity simulation (ucth971) did not significantly alter the model fit, particularly the fit of the hydraulic heads (model conclusion), the type of sensitivity that the model has with respect to all tested parameters is Type I. This means that the modified numerical model is valid across the range of parameter uncertainty considered. Therefore, the results of the sensitivity analyses may be used to derive the upper bound of the range of uncertainty on the results of the selected groundwater development scenario (i.e., Alternative A).

5.1.2.2 Simulated Drawdown Uncertainty

The resulting hydraulic heads were processed in terms of changes in the top model layers from the start of the simulations (2005), i.e., as drawdowns in the water table.

The effects of the uncertainty associated with the hydraulic conductivity and storage parameters on the simulated hydraulic heads are expressed in terms of ranges of uncertainty of the 10-ft drawdown contour line. Maps showing the net 10-ft drawdown contour lines for the Alternative A scenario and the corresponding uncertainty simulation (ucpd973) are presented in Figure 5-2.

The maximum extents of the 10-ft drawdown contour line is spatially variable. In some areas, the two lines are very close to each other. In other areas, the maximum extents of the 10-ft contour line cover a significantly-larger area than the line derived from the calibrated modified numerical model.

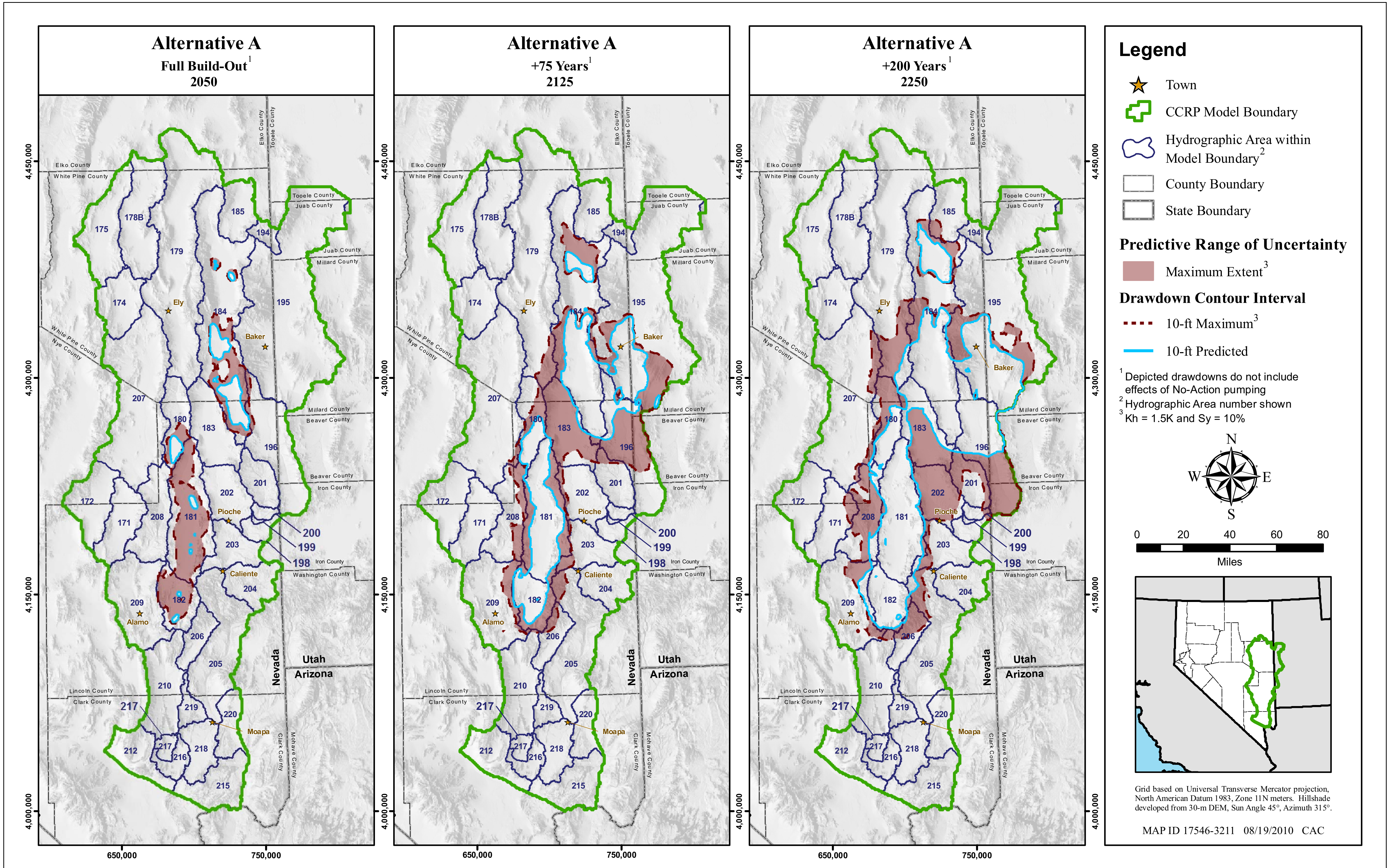


Figure 5-2
Uncertainty of 10-ft Drawdown Simulated for Alternative A

5.2 *Effect of Uncertainty in Big Springs Area Representation*

The effects of alternate representations of the Big Springs area in the numerical model is evaluated through the simulation of the Alternative A scenario using the original and modified versions of the numerical model (SNWA, 2009b and 2010).

As described in the addendum report, the calibrated transient models were essentially the same everywhere, except in the Big Springs area. The most prominent difference occurs in the Big Springs discharge. Therefore, the relative simulated discharge for this spring is compared for the two versions of the CCRP numerical model. Figure 5-3 shows a comparison of the springflow hydrograph of Big Springs using the two models. As previously discussed, the spring discharge simulated by the modified numerical model is about half that simulated by the original numerical model. Because of this difference and the different representation of the spring in the two models, the decrease in springflow caused by pumping is different. The spring discharge simulated by the original model decreases following a gentle slope. By the end of the simulation period, spring discharge has been reduced by less than a third of the rate in 2005. The spring discharge simulated by the modified numerical model decreases following approximately the same rate of decrease as the one simulated by the original model until about the year 2050. After that time, the rate of decrease increases drastically causing the spring to stop flowing.

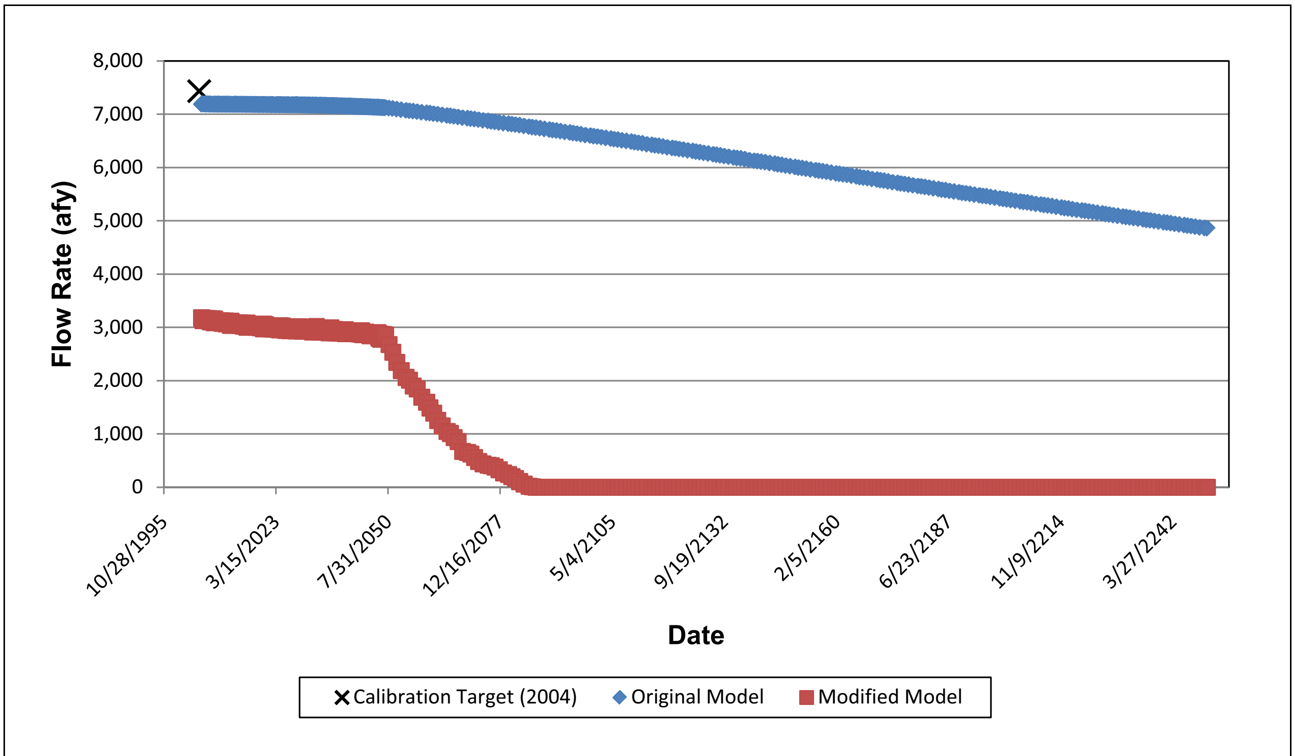


Figure 5-3
Comparison of Spring Discharge Simulated for Big Springs by Original and Modified Model

6.0 LIMITATIONS

The results of the groundwater development scenario simulations using the CCRP model are uncertain. The uncertainties in the simulated responses to each of the pumping scenarios stem from the following: (1) limited knowledge of the aquifer system including its history, (2) the oversimplications of the system in the numerical model.

6.1 Knowledge of Aquifer System

The most up-to-date representation of hydrogeologic data available for the Great Basin region was used to develop the CCRP model. However, the model area covers a vast portion of remote Nevada and Utah where data are generally lacking. This lack of data causes limitations and uncertainties in the conceptual and numerical models and in the simulation of the groundwater development scenarios. These limitations and uncertainties are common for models developed for this region, as the Death Valley Regional Flow System Model describes many of the same (Belcher, 2004). These limitations are (1) interpretations of the hydrogeologic framework, (2) estimates of the recharge from precipitation, (3) records of the historical anthropogenic data, (4) the observation data set. These limitations are disclosed below.

6.1.1 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.

6.1.1.1 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 Pahranagat 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 Pahranagat shear zone give rise to hydrogeologic features that contribute to a generally-southward stair-stepping to 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 Pahranagat Valley.

East and northeast of the Pahranagat 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.

6.1.1.2 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 CCRP 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.

6.1.2 Precipitation Recharge

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. Its distribution is affected by many factors, including precipitation, topography and the hydrogeology of the unsaturated zone as well as the saturated zone.

The initial yearly rates and spatial distribution of the mean recharge were estimated using the groundwater budget method and the final distribution 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 natural fluctuations cannot be simulated. Climate change is discussed in more detail at the end of this section.

6.1.3 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 the NDWR and the Utah Division of Water Rights. 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.

6.1.4 Historical Aquifer Response-Observations

The availability and quality of the historical aquifer system response data are paramount in understanding the flow system and calibrating the numerical model. These data constitute the observations used as targets during model calibration.

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, and (2) the appropriateness of the hydrogeologic interpretations.

6.1.5 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.

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.

6.2 Flow System Representation in Numerical Model

Representing the various components of a flow system into a numerical model requires numerous simplifications. The most influential are described below.

- 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.

- The representation of groundwater recharge process in the numerical model is affected by the coarse discretization and several simplifications used to distribute recharge over the model area. 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 natural fluctuations cannot be simulated.

- Although the uncertainties associated with the water-use data set were assumed to be negligible in the model, they most probably add to the uncertainty of the model and the scenario simulation results.

- 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 Pahranagat 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.

- Generally, simulating spring discharge was difficult because of several factors, including the source depth, the drain elevation and the hydraulic head at the spring. The elevations assigned to define the drains in the numerical model particularly affect the ability to simulate groundwater conditions more accurately. Also, simulating intermediate springs was particularly difficult in this regional-scale numerical model. An example of the large uncertainties associated with the simulation of these springs is Big Springs in Snake Valley. As described in Section 5.0, this spring is most probably controlled by local structural features that were either simplified or ignored in the two alternate models. The two representations yielded much different results.

- 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.

- Incised drainages and other focused discharge areas are difficult to simulate accurately. This is particularly noticeable along Meadow Valley Wash and Pahranagat 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 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.

6.3 Climate Change

Ongoing scientific research has identified a trend of increasing global average air and ocean temperatures. Climate change, whether natural or anthropogenic, can effect hydrologic systems through changes in key weather patterns. Changes in either temperature or precipitation, or both, can have hydrologic consequences, particularly in the amount, the seasonal timing, and the elevation of snow accumulation and melt. Snowfall and snowpack are crucial components of the hydrologic system in the study area.

The Intergovernmental Panel on Climate Change (IPCC, 2007a, 2007b) has performed the most recent assessment of the current status of climate research and of model projections. Increasing temperatures are predicted, with the northern portion of the western continental U.S. generally becoming wetter annually, and the southern portion of the western continental U.S. becoming drier. Spring and Snake Valley are near the nodal line of no change for annual precipitation (Redmond, 2009).

Redmond (2009) compared the output from fifteen different climate models to develop more specific information about climate variability and change within the central Great Basin. He concluded that:

- Annual mean temperature is expected to rise for the next several decades.
- Annual precipitation is expected to remain similar to present values as the century progresses.
- Cooler precipitation is more effective at soil moisture recharge than warmer precipitation, and snow is more effective than rain.
- The spatial and seasonal details of temperature and precipitation changes on soil moisture and groundwater have not been definitively or even approximately quantified, and are the subject of ongoing research.

While there have been studies and modeling of the projected effects of climate change on temperature, precipitation, and surface water systems, there is currently insufficient information currently to reasonably predict potential effects on groundwater systems. The assumption that temperature, precipitation, and surface water changes would manifest into lower infiltration and recharge has not been substantiated. Moreover, potential effects would likely vary by geographic area. According to the U.S. Climate Change Science Program: "In contrast to the many studies that have been conducted over the last 20 years of surface water vulnerability to climate change...few studies have examined the sensitivity of groundwater systems to a changing climate" (USCCSP, 2008, p. 43). In this report the authors present work that has shown both increases and decreases to recharge as a result of climate change and then conclude:

> these studies suggest that the ability to predict the effects of climate and climate change on groundwater systems is nowhere near advanced as for surface water systems...The interaction of groundwater recharge with climate is an area that requires further research. The papers reviewed have used a variety of approaches, some of them physically based, but others have essentially "tuned" recharge in ways that do not represent the full range of mechanisms through which climate change might affect groundwater systems (USCCSP, 2008b, p. 145).

The numerical model uses a constant average recharge from precipitation rates averaged over 30 years of historical records (PRISM normal precipitation grid). This precipitation grid was used because it has a relatively fine resolution (800 m) and is recognized as the best quality spatial climate data available. The 30-year PRISM data was also used by CBO (2009) to represent historical climate patterns in the U.S. There is a coarser scale (4 km) PRISM precipitation grid with a longer historical record, however, these grids do not have as much data resolution and were determined to be lesser quality for this numerical modeling. The 30-year historical record represents the best available data, and there is no other suitable quality data that could represent a long-term climatic average.

Since current climate change modeling suggests annual precipitation in the study area may remain similar to present conditions, and given the uncertainties of potential effects of climate change on groundwater systems, no separate climate change modeling simulations were performed. Potential climate change variability would only further increase uncertainties associated with modeling outputs from the regional groundwater model.

There are efforts underway to downscale the regional climate change models in east central Nevada by the Nevada System of Higher Education, under a National Science Foundation five-year grant (Experimental Program to Stimulate Competitive Research). This study is not anticipated to be completed until 2013. Information from this study could be incorporated into future updates of this groundwater model.

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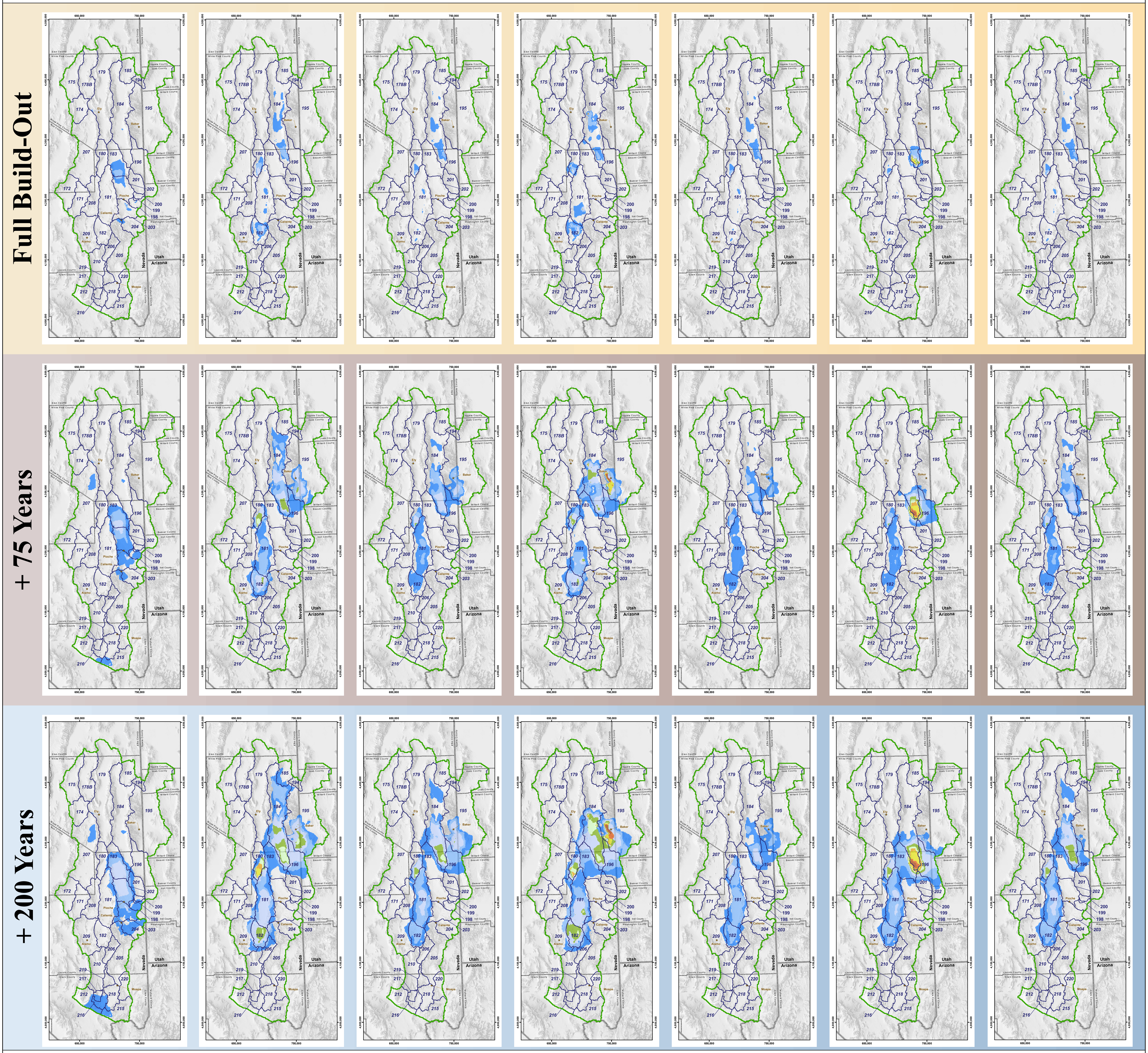
Plates

No Action	Proposed Action Distributed Pumping Application Quantities[1]	A Distributed Pumping Reduced Quantities[1]	B Current Points of Diversion Application Quantities[1]	C Intermittent Pumping[1]	D LCCRDA Corridor[1]	E Spring, Dry Lake, Delamar, and Cave Valleys[1]



Legend

Town

CCRP Model Boundary

Hydrographic Area within Model Boundary[2]

County Boundary

State Boundary

[1] Depicted drawdowns do not include effects of No-Action pumping.
[2] Hydrographic Area number shown.

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Drawdown (feet)

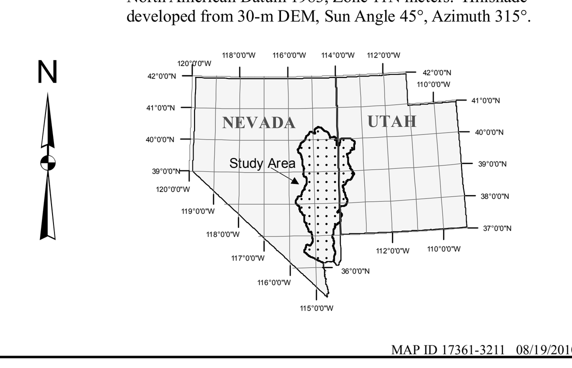
0 - 10 | 10 - 25 | 25 - 50 | 50 - 100 | 100 - 150 | 150 - 200 | 200 - 250 | 250 - 500 | 500 - 750 | > 750

Year	Groundwater Development Alternative						
	No Action	Proposed Action	A	B	C	D	E
Model Run Number	ucpd949	ucpd999	ucpd950	ucpd1000	ucpd954	ucpd956	ucpd970
Full Build-Out	2050	2050	2050	2050	2050	2043	2050
+ 75 years	2125	2125	2125	2125	2125	2118	2125
+200 years	2250	2250	2250	2250	2250	2243	2250

0 10 20 40 60 80 100 Kilometers

0 10 20 40 60 80 100 Miles

Grid based on Universal Transverse Mercator projection, North American Datum 1983, Zone 11N meters. Hillshade developed from 30-m DEM, Sun Angle 45°, Azimuth 315°.



MAP ID 17361-3211 08/19/2010 CAC

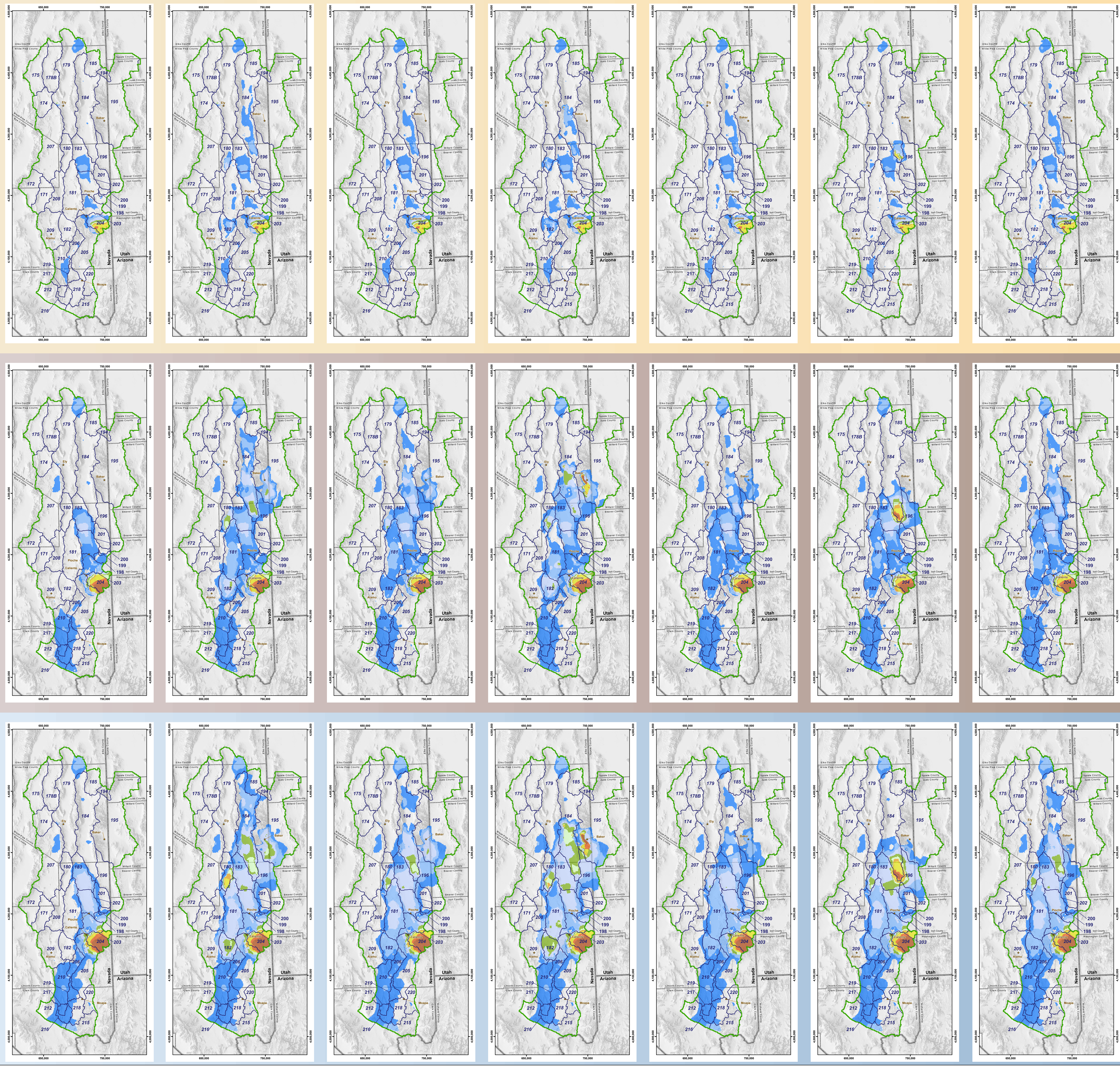
PLATE 1 - SIMULATED NET[1] DRAWDOWN FROM BASELINE CONDITIONS FOR PROJECT ALTERNATIVES, AT FULL BUILD-OUT, 75 YEARS AFTER FULL BUILD-OUT, AND 200 YEARS AFTER FULL BUILD-OUT OF SNWA GROUNDWATER DEVELOPMENT

	No Action	Proposed Action Distributed Pumping Application Quantities [1]	A Distributed Pumping Reduced Quantities [1]	B Current Points of Diversion Application Quantities [1]	C Intermittent Pumping [1]	D LCCRDA Corridor [1]	E Spring, Dry Lake, Delamar, and Cave Valleys [1]

Full Build-Out

+ 75 Years

+ 200 Years



Legend

- Town
- CCRP Model Boundary
- Hydrographic Area within Model Boundary [2]
- County Boundary
- State Boundary

[1] Depicted drawdowns include cumulative effects of No Action coupled with Reasonably Foreseeable, Future Action pumping.
[2] Hydrographic Area number shown.

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Drawdown (feet)

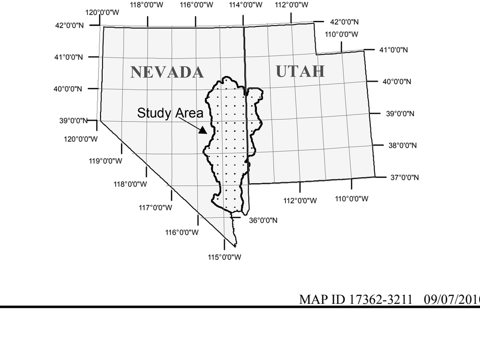
0 - 10 | 10 - 25 | 25 - 50 | 50 - 100 | 100 - 150 | 150 - 200 | 200 - 250 | 250 - 500 | 500 - 750 | > 750

Year	Groundwater Development Alternative						
	No Action	Proposed Action	A	B	C	D	E
Model Run Number	ucpd960	ucpd1001	ucpd998	ucpd1003	ucpd1004	ucpd967	ucpd969
Full Build-Out	2050	2050	2050	2050	2050	2043	2050
+ 75 years	2125	2125	2125	2125	2125	2118	2125
+200 years	2250	2250	2250	2250	2250	2243	2250

0 10 20 40 60 80 100 Kilometers

0 10 20 40 60 80 100 Miles

Grid based on Universal Transverse Mercator projection, North American Datum 1983, Zone 11N meters. Hillshade developed from 30-m DEM, Sun Angle 45°, Azimuth 315°.



MAP ID 17362-3211 09/07/2010 BP

PLATE 2 - SIMULATED DRAWDOWN FROM BASELINE CONDITIONS FOR ALL CUMULATIVE SCENARIOS, AT FULL BUILD-OUT, 75 YEARS AFTER FULL BUILD-OUT, AND 200 YEARS AFTER FULL BUILD-OUT OF SNWA GROUNDWATER DEVELOPMENT