# Water-Resources Assessment and Hydrogeologic Report for Cave, Dry Lake, and Delamar Valleys

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Prepared by

SOUTHERN NEVADA
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# Water-Resources Assessment and Hydrogeologic Report for Cave, Dry Lake, and Delamar Valleys

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Pertaining to:
Groundwater Applications 53987 through 53992 in
Cave, Dry Lake, and Delamar Valleys

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# ES.1.0 INTRODUCTION

In 1989, the Las Vegas Valley Water District (LVVWD) filed six applications (53987 through 53992, inclusive) for the appropriation of groundwater resources in Cave, Dry Lake, and Delamar valleys. By agreement with LVVWD, Southern Nevada Water Authority (SNWA) has assumed full interest in these applications. Since filing the applications, LVVWD and SNWA have been actively supporting the applications by establishing hydrologic monitoring networks to acquire groundwater data through the completion of hydrologic and geologic investigations within the three basins. The major work elements have included (1) construction of nine monitor wells for the acquisition of additional geologic, hydrologic and water-chemistry data; (2) geologic mapping and extensive geophysical surveys to define the hydrogeologic framework; (3) vegetation mapping (Cave Valley), and (4) completion of hydrologic site inventories and monitoring, through cooperative agreements with the U.S. Geological Survey (USGS) and Nevada Division of Water Resources (NDWR). Data and information from these programs and previous studies serve as the basis for the analyses and conclusions presented in this report.

This report presents the technical basis and justifications supporting the aforementioned groundwater applications, and is comprised of three parts.

- Part A presents a regional-scale assessment of the natural recharge, groundwater discharge, and interbasin flow of the White River Flow System. This assessment was conducted to estimate the volumes of precipitation recharge for Cave, Dry Lake, and Delamar Valleys using new data and information collected during the more than forty years since the USGS Reconnaissance Series Reports were published for these basins.

- Part B describes the geologic frameworks of Cave, Dry Lake, and Delamar valleys; and the occurrence and movement of groundwater within these three basins.

- Part C presents an analysis of the potential water-related effects of groundwater production associated with SNWA's groundwater applications on senior water-rights and selected points of interest. Also included in this part of the report, is a plan to monitor the effects of pumping and resource management measures to mitigate adverse impacts, should they occur.

The remainder of this executive summary follows the organization of the document. A summary of each part of the document is provided by report section.

# ES.2.0 PART A - REGIONAL ASSESSMENT OF THE GROUNDWATER RESOURCES OF THE WRFS

## ES.2.1 Introduction

This section presents the purpose, scope and objectives of the regional assessment of the groundwater resources of the White River Flow System (WRFS). The purpose of the assessment was to derive updated groundwater budget estimates for the basins of the WRFS, particularly Cave, Dry Lake, and Delamar valleys. The updated groundwater budget estimates incorporate new information produced during the more than 40 years since the USGS Groundwater - Reconnaissance Series Reports for Cave, Dry Lake, and Delamar valleys were first published (Eakin, 1962; 1963a). This information includes meteorologic, hydrologic, and geologic data, and many studies resulting in improved estimates of precipitation distribution and groundwater discharge. This new information warrants a re-evaluation of the groundwater resources for these basins; however, to do so requires adopting a regional approach (i.e., flow system) with respect to precipitation and natural recharge.

## ES.2.2 Previous Investigations

This section provides summary descriptions of numerous studies related to Cave, Dry Lake, and Delamar valleys and the WRFS. These studies have included water-resource investigations, geologic and hydrogeologic investigations, recharge and discharge estimations, and other hydrologic studies relevant to the groundwater-resources assessment presented in this report. The most pertinent of these are as follows:

- Nevada precipitation maps developed by Hardman (1936, 1962, and 1965)
- Reconnaissance Reports for Cave, Dry Lake, and Delamar Valleys (Eakin,1962; 1963a)
- A study of the WRFS by Eakin (1966)
- The U.S Air Force MX-missile siting program
- The Great Basin Regional Aquifer System Analysis study (RASA)
- The LVVWD Cooperative Water Project (CWP)
- An evaluation of the White River and Meadow Valley Wash Flow Systems (LVVWD, 2001)
- Isotopic evaluation of the groundwater budgets derived by LVVWD (2001) (Thomas, 2001)
- Basin and Range Carbonate Aquifer System Study (BARCASS) (Welch and Bright, 2007)

## ES.2.3 Technical Approach

This section describes the technical approach and methods used to complete the groundwater-resources assessment. The groundwater-balance method was selected to derive groundwater budgets for the WRFS and its basins. As applied in this analysis, pre-development conditions were assumed in which the total groundwater inflow to the system (i.e., groundwater recharge and boundary inflow) equals the total groundwater outflow from the system (i.e., groundwater evapotranspiration [ET] and boundary outflow). Given that the volume of boundary outflow constitutes a relatively small component of the WRFS groundwater budget, the scope of the analysis included the entire WRFS in the application of this method to ensure that the typically high uncertainty associated with this budget component was minimized. An optimization approach was implemented using the Excel solver to derive a relationship between recharge efficiencies and precipitation that yielded a balanced groundwater budget for the flow system. This was completed using a spatial distribution of precipitation, estimates of groundwater ET, and external boundary flow. The solution includes recharge efficiencies expressed as a power function of precipitation. The constant and exponent that define this function were determined using the Excel Solver. Independent estimates of boundary flow (internal and external) were used to constrain the solution. The resultant recharge efficiencies were applied to the precipitation distribution to derive a spatial distribution of recharge from which basin recharge estimates could be computed and used to develop basin groundwater budgets. As a final step, uncertainty analyses were conducted to evaluate the effect of the uncertainty associated with the most uncertain variables on the calculated recharge efficiencies and final groundwater budgets.

### *ES.2.4 Data Compilation and Analysis*

This section describes the meteorologic, hydrologic, and geologic data and information that were compiled and analyzed to derive estimates required by the groundwater-balance method applied in this assessment. These include independent estimates of the spatial distribution of precipitation, basin groundwater ET, and boundary flow volumes.

The Precipitation-elevation Regression on Independent Slopes Model (PRISM) was selected as the precipitation distribution for the WRFS. This precipitation source is preferred because precipitation distributions developed using the PRISM method utilize modern tools and incorporate more recent data and information not reflected in previous mapping efforts. More specifically, the most recent normal grid (800-m 1971 to 2000 - Version 2; May 3, 2007) was used as it is considered to be the best quality product to date. It is available online at the following internet address: http://www.prism.oregonstate.edu/products/matrix.phtml. Precipitation-station data were compiled and used to assess the validity of the PRISM-based distribution. Precipitation values extracted from the PRISM precipitation grid were compared to the period of record mean annual precipitation for precipitation stations located within the WRFS and vicinity. The PRISM precipitation values were within 10 percent of the period of record mean annual value for most of these stations, indicating a relatively good model fit with the observed data.

Average annual estimates of pre-development groundwater ET for basin discharge areas were derived as follows:

1. Regional groundwater discharge areas were delineated and ET classes were defined using previous studies, Landsat imagery, aerial photography, other published information, and field work conducted by SNWA.

2. Available ET rate data obtained from the following sources were used in the derivation of basin ET estimates:

    - USGS WRIR 01-4239 (Reiner et al., 2002)
    - USGS SIR 2007-5078 (Moreo et al., 2007)
    - USGS OFR 2007-1156 - Draft Report (Welch and Bright, 2007)

3. ET rates were scaled to reflect basin conditions using potential evapotranspiration (PET) rates calculated using an equation relating PET to latitude and altitude using data from DRI Publication No. 41198 (McCurdy and Albright, 2004).

4. Basin ET volumes were calculated as the sum of the products of ET area multiplied by ET rate for the corresponding ET classes in that basin.

5. Average annual precipitation for the ET areas was derived from the PRISM precipitation distribution and subtracted from the total ET volume to calculate estimates of groundwater ET.

The five defined ET classes and their respective range of ET rates (total ET) are as follows: (1) open water (6.63 to 9.06 ft/yr), (2) wetland/meadow (2.02 to 2.34 ft/yr), (3) dense meadow/riparian (2.82 to 3.89 ft/yr), (4) medium-density phreatophytes (1.03 to 1.18 ft/yr), and (5) bare soil/low-density phreatophytes (1.00 ft/yr). Pre-development maps delineating groundwater discharge areas and the ET classes within, were developed using satellite imagery, aerial photography, and field observations. Irrigated lands within these areas were removed from the maps and replaced with an ET class consistent with the natural vegetation encompassing the irrigated areas. Predevelopment groundwater ET for the WRFS is estimated to be 139,424 afy, which falls within the literature range of 100,600 (Eakin, 1966; Rush, 1968) and 176,305 (LVVWD, 2001). Except for two basins, White River Valley and the Muddy River Springs Area, the estimated groundwater ET volumes compare reasonably well with the estimates reported in the Reconnaissance Series Reports. Estimates of groundwater ET for the three project basins are 1,285 afy for Cave Valley, and zero for Dry Lake and Delamar valleys.

Estimates of spring flow based on spring discharge records were derived for groundwater discharge areas within basins of the WRFS that contain a significant number of gaged springs. These estimates were assumed to constitute lower bounds for the total groundwater discharge volumes (i.e. groundwater ET + outflow). Included in the evaluation were the regional groundwater discharge areas of White River and Pahranagat valleys, and the Muddy River Springs Area. The total spring discharge for the largest springs in White River Valley was estimated to be 34,462 afy, a value that is lower than the estimated groundwater ET, 67,342 afy. For Pahranagat Valley, the total spring discharge estimate of about 25,000 afy (Eakin, 1963b, p. 19-20) is lower than the estimated volume of groundwater ET, 28,516 afy. For the Muddy River Springs Area, the majority of the spring discharge exits the valley in the form of ET and surface water flow in the Muddy River. The estimated average annual flow in the Muddy River near Moapa gage is about 34,000 afy (Wells, 1954, p. 566) and the estimated groundwater ET is 6,000 afy; thus, the total groundwater discharge is estimated at 40,000 afy. This value also constitutes the lower bound for the total groundwater inflow to this basin for predevelopment conditions.

Locations where groundwater flow occurs across basin boundaries were identified based on the prevailing hydrogeology, including rock types and geologic structures. Flow volumes were estimated for selected locations where sufficient information was available. These estimates were applied either in the solver as constraints and their initial conditions, or as additional information for calculating individual basin groundwater budgets. They are as follows:

- Outflow from Cave Valley to White River Valley (through Shingle Pass) at 4,000 afy
- Outflow from White River Valley to Pahroc Valley ranging between 6,300 (Maxey and Eakin, 1949, p. 45) and 40,000 afy (Eakin, 1966, p. 265)
- Inflow to Dry Lake Valley from Pahroc Valley at 2,000 afy
- Minimum total inflow to the Muddy River Springs Area at 40,000 afy
- Maximum outflow from Coyote Spring Valley to Hidden Valley at 15,000 afy.
- Inflow from Lower Meadow Valley Wash at 9,200 afy (4,000 afy to the Muddy River Springs Area, and 5,200 afy to California Wash)
- Minimum outflow to the Colorado River at 25,000 afy

### *ES.2.5 Data Analysis and Results*

This section describes how the estimates of precipitation distribution, groundwater ET, and selected volumes of interbasin flow described in the previous section were used to setup and initialize the Excel solver and derive a solution. Summary descriptions of the analysis and results follow.

For this analysis, the data requirements for the Excel solver included precipitation data (area and rate) for specified intervals, the target value for groundwater ET, initial estimates for the parameters, and values for the constraints. Precipitation data were generated for areas of potential recharge using the PRISM grid. The potential recharge area for a given basin was defined by an area that excluded the valley floor, groundwater ET areas, and areas where precipitation is less than 8 inches. Within this area, 1-in. precipitation bands were defined and used as input to the solver.

The target value for the solver is the estimated value of groundwater ET for the WRFS. The target cell contains a formula expressing groundwater ET as the total recharge volume, plus the total inflow, minus the total outflow. The target value is 139,424 afy. The inflow is 9,200 afy and the outflow is a constrained parameter that is derived as part of the solution.

Parameters represent the unknown variables. For this analysis, the primary parameters are the coefficients of the power function expressing the recharge efficiencies as a function of precipitation. Secondary parameters are outflow from Coyote Spring Valley to Hidden Valley, and the total outflow to the Colorado River. Initial estimates for the power function coefficients were derived from the Maxey-Eakin precipitation-recharge relationship, and are $8.0 \times 10^{-5}$ for the constant and 3.62 for the exponent. To initialize the solver, the parameters representing inter-basin flow were assigned their constraints as initial estimates. Constraints imposed on the solution are as follows:

1. the power function coefficients are positive,
2. the outflow from White River Valley is between 6,300 and 40,000 afy,
3. the outflow from Coyote Spring Valley to Hidden Valley is less than or equal to 15,000 afy,
4. the total inflow to the Muddy River Springs Area is greater than or equal to 40,000 afy,

5. the total outflow to the Colorado River is greater than or equal to 25,000 afy, and
6. the maximum recharge efficiency is less than or equal to 0.63.

Additional fixed constraints were placed on the volumes of underflow at specified locations where flow volumes were estimated. These flow volumes and locations are as follows: (1) 5,200 afy of inflow from Lower Meadow Valley Wash to California Wash, and (2) 4,000 afy of inflow from Lower Meadow Valley Wash to Muddy River Springs Area. This results in a total inflow to the WRFS of 9,200 afy. The solution is derived through an optimization process in which the coefficients of the power function and external boundary flows are adjusted within the constraints, until the formula in the target cell is solved. The solution is defined by the resultant recharge efficiencies and distribution, and a balanced WRFS groundwater budget. The recharge distribution and additional flow routing were then used to derive the basin groundwater budgets external from the solver.

The resulting power function compares relatively well with the work of Faybishenko (2007), Davisson and Rose (2000), and Lichty and McKinley (1995). The recharge efficiencies were computed using the power function derived by the solver, and are summarized here for the following precipitation zones: 45 percent for >20 in. zone, 14 percent for 15 to 20 in. zone, 4 percent for 12 to 15 in. zone, and 0.4 percent for 8 to 12 in. zone. The efficiencies are different from the standard Maxey-Eakin efficiencies because the precipitation distributions and groundwater ET estimates are different. However, the estimated recharge volumes compare well with those reported in the literature. The total recharge calculated for the WRFS is 155,224 afy, which falls within the reported range of values (104,650 [Eakin, 1966; and Rush, 1968] to 201,500 afy [LVVWD, 2001]). Except for two basins, the estimated recharge volumes for all basins with recharge volumes greater than 1,000 afy, fall within the reported ranges. The two exceptions are Garden and Dry Lake valleys. The derived outflow volumes are as follows: (1) 15,000 afy from Coyote Spring Valley to Hidden Valley and, (2) 25,000 afy of total outflow to the Colorado River. A groundwater budget for the WRFS and its individual basins was constructed using the recharge, groundwater ET and boundary flow estimates derived by this analysis. All of the WRFS budget components fall within the ranges of values reported in the literature (Table ES.2-1). The derived groundwater budget components for all basins of the WRFS, including the project basin are presented in Figure ES.2-1.

**Table ES.2-1**
**Estimated Groundwater Budget for the WRFS**

| Budget Component | Estimated Value (afy) | Reported Range (afy) |
|---|---|---|
| Recharge | 155,224 | 104,650 to 201,500 |
| Inflow | 9,200 | 7,000 to 32,000 |
| Groundwater ET | 139,424 | 100,600 to 176,305 |
| Outflow | 25,000 | 11,100 to 49,000 |

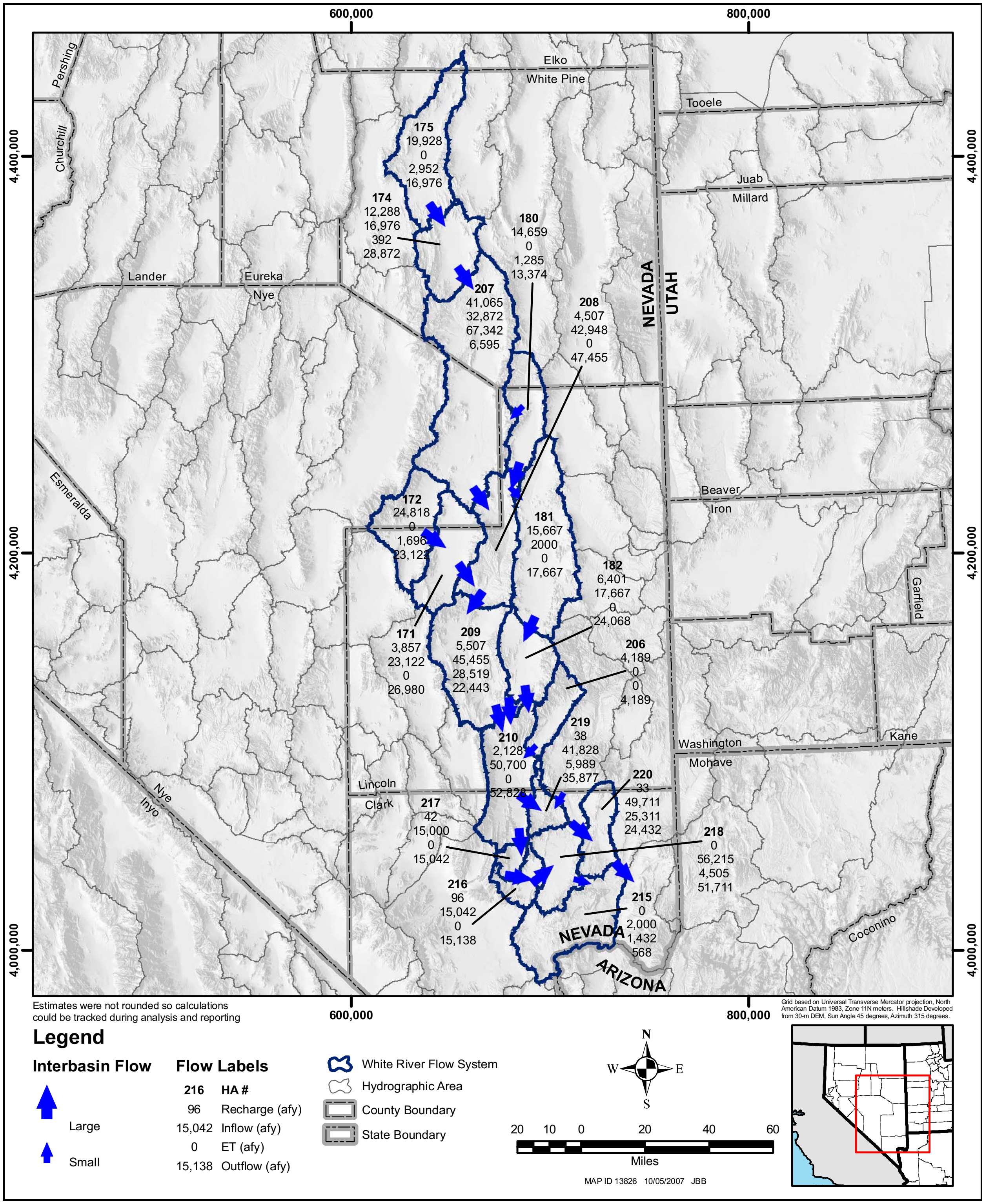


**Figure ES.2-1**
**WRFS Groundwater Budget**

### ES.2.6 Uncertainty Analyses

This section describes uncertainty analyses that were performed to evaluate the estimated budget components of the WRFS and project basins summarized in the previous section. The approach and results are summarized.

The purpose of the uncertainty analyses was to evaluate the effect of the uncertainties associated with selected variables on the calculated recharge efficiencies and final groundwater budgets. The most uncertain variables were selected for these analyses based on the range of their estimated values, and included the following:

1. maximum recharge efficiency,
2. groundwater ET estimate for White River Valley,
3. groundwater ET estimate for the Muddy River Springs Area,
4. the total inflow to WRFS, and
5. the total outflow from WRFS.

Ten alternate scenarios were implemented for each low and high value of the five tested variables. The derived solutions were then compared to the base-case solution. An additional scenario designed to evaluate the BARCASS interpretation (Welch and Bright, 2007) for the northern part of the WRFS was implemented. For this scenario, the BARCASS groundwater ET estimates for Long, Jakes, White River, and Cave valleys were substituted, and the full volume of outflow from Cave Valley was re-directed to the White River Valley.

The results of the analysis may be summarized in terms of the resulting ranges of estimated recharge for the WRFS and the three project basins. The largest uncertainty is related to the estimates of groundwater ET in White River Valley, in which the total recharge for the WRFS ranges from 124,882 to 184,897 afy, as compared to the base-case value of 155,224 afy. For Cave, Dry Lake, and Delamar valleys, the uncertainty for recharge ranges from 28,721 to 44,584 afy, as compared to the base-case value of 36,727 afy. The range of uncertainty is about 20 percent. The scenario designed to evaluate the BARCASS interpretation yields slightly higher values of recharge compared to the base-case, but the results are essentially the same with differences in the total recharge and the recharge in the project basins only 8,367 and 2,214 afy, respectively.

### ES.2.7 Conclusions

The major findings of this study related to the precipitation distribution, the groundwater ET and the recharge distribution of the WRFS and its basins are summarized below.

- The groundwater-balance method used to complete the water-resources assessment described in this report is essentially the same approach used by Maxey and Eakin (1949) almost 60 years ago. While the approach is the same, this analysis incorporates more accurate data of better resolution, and newer technology that allows for more detailed calculations.

- The PRISM precipitation distribution (800-m 1971 to 2000 normals - Version 2; May 3, 2007) best represents the precipitation distribution for the WRFS for the purposes of this assessment.

  - The PRISM grid provides a good representation of the long-term mean annual precipitation distribution for the WRFS. This grid represents, within ten percent, the period of record mean annual value for most precipitation stations within the WRFS and vicinity.

  - The PRISM precipitation grid provides a much better spatial distribution of precipitation than the Hardman precipitation maps (1936, 1965), particularly at the higher precipitation intervals.

- The predevelopment estimates of groundwater ET developed for the WRFS and its basins compare very well with previous estimates. An exception is the estimate for White River Valley which is 30,000 afy higher than Eakin (1966) due to the differences in the mapped acreage. For this study and other more recent studies (e.g. BARCASS), the mapped area for White River Valley is more than four times the acreage relied upon by Eakin (1966).

  - Predevelopment groundwater ET for the WRFS is estimated to be 139,424 afy, which falls within the literature range of 100,600 (Eakin, 1966; Rush, 1968) and 176,305 afy (LVVWD, 2001). Estimates of groundwater ET for the three project basins are as follows: 1,285 afy for Cave Valley, and zero for the other two.

- The solution derived using the groundwater-balance method yielded a recharge-precipitation relationship, recharge efficiencies and a recharge distribution that are believed to be the best to date for the WRFS.

  - The solution incorporates new data and technology, and is calibrated to new and better estimates of discharge.

  - The recharge-precipitation relationship is somewhat different from that of Maxey and Eakin (1949), but very comparable to more recent relationships and field-based data developed by others (Faybishenko, 2007; Davisson and Rose, 2000; Lichty and McKinley, 1995).

  - The derived recharge efficiencies are summarized for the following precipitation zones: 45 percent for >20 in. zone, 14 percent for 15 to 20 in. zone, 4 percent for 12 to 15 in. zone, and 0.4 percent for 8 to 12 in. zone.

  - The calculated groundwater recharge for the WRFS under predevelopment steady-state conditions is about 155,000 afy (rounded to the nearest thousand). The total recharge falls within the reported range of values (104,650 to 201,500 afy).

  - The basin recharge volumes compare well with the recharge estimates reported in the literature for most basins. The exceptions are Garden Valley and Dry Lake Valley which are higher based on this analysis.

  - The total recharge volume calculated for the project basins is 36,727 afy, which is larger than that calculated by Eakin (1962 and 1963a) using the topographic map available at the time. However, it is within about 3,000 afy of the total derived (33,400 afy) by applying the standard Maxey-Eakin recharge efficiencies to the Hardman (1962) precipitation map.

- A groundwater budget for the WRFS and its individual basins was constructed using the recharge, groundwater ET and boundary flow estimates derived by this analysis. All of these components fall within the literature range of values.

- The largest uncertainty is associated with the White River Valley groundwater ET based on the range of estimated values (37,000 to 79,560 afy). This uncertainty results in ranges of recharge of 124,882 to 184,897 afy for the WRFS; and 28,721 to 44,584 afy for the three project basins, or a range of uncertainty of plus or minus about 20 percent.

# ES.3.0 Part B - Hydrogeologic Framework and Groundwater Occurrence and Movement for Cave, Dry Lake, and Delamar Valleys

## ES.3.1 Introduction

Part B of this report describes the geologic framework and the occurrence and movement of groundwater within Cave, Dry Lake, and Delamar valleys. The geologic framework served as the basis from which an understanding of the hydrogeology was developed, particularly the geologic features controlling local and regional groundwater flow in these basins.

The geologic framework is presented as a surface geologic map and a series of geologic cross sections (Plate 1), depth-to-basement maps, and profiles interpreting seismic and audiomagnetotelluric data. Hydraulic data from wells and springs are used in conjunction with the geologic framework to describe the occurrence and movement of groundwater within the basins and vicinity. The hydrogeologic description is relied upon in Part C of this report, which evaluates the potential water-related effects of developing the SNWA applications in these basins.

## ES.3.2 Geologic Framework

This section provides an overview of the geologic information available for Cave, Dry Lake, and Delamar valleys based on a report prepared by SNWA entitled "*Geology of White Pine and Lincoln Counties and Adjacent Areas, Nevada and Utah: The Geologic Framework of Regional Groundwater Flow Systems*" (Dixon et al., 2007).

Cave Valley is bounded in the east by the southern extension of the Schell Creek Range which is comprised of an east-dipping and heavily faulted sequence of Precambrian to Tertiary rocks. The dominant fault is on the western flank of the range, and in the northeast part of the valley, the range is cored by Precambrian to Cambrian quartzite. In the west, Cave Valley is bounded by the Egan Range, which is a complexly faulted, east-dipping horst comprised of Cambrian to Permian rocks overlain by Tertiary volcanic rocks. The basin has been effectively partitioned into two sub-basins by the northeast-striking oblique-slip Shingle Pass Fault, which has displaced a part of the Egan Range, forming an east-dipping fault block that extends northeast across and underneath the valley where it terminates against the west range-front fault of the Schell Creek Range. This fault block contains the Mississippian Chainman Shale formation which, in this area, is considered a confining unit because of its thickness and hydraulic properties. The northern sub-basin is relatively shallow as the depth to basement is typically no greater than 3,300 ft-bgs. The basin fill is comprised of mostly sands and gravels, and occasional cemented strata near the surface. The southern sub-basin is significantly deeper, with the depth to basement extending to almost 20,000 ft-bgs. The basin fill is comprised of mostly sands and gravels, but with greater clay content than the northern sub-basin.

Dry Lake and Delamar valleys are bounded in the west by the North Pahroc Range and the South Pahroc Range, respectively. The North Pahroc Range is a west-dipping horst consisting of upper Paleozoic rocks overlain by Tertiary volcanic rocks. The South Pahroc Range consists of a series of west-dipping volcanic rocks, which extend southward to southern Delamar Valley where they are terminated by the east-northeast trending Pahranagat Shear Zone. To the east, Dry Lake and Delamar valleys are bounded from north to south by the Fairview, Bristol, Highland, and Chief Ranges, and the Delamar Mountains to the south. To the north, the Fairview Range consists of Devonian to Pennsylvanian carbonate rocks, which are interrupted by the Indian Peak Caldera Complex. To the south, the Bristol, Highland and Chief Ranges consist of Cambrian carbonate rocks underlain by Precambrian to Cambrian quartzites. Further south, the Delamar Mountains consist of east-dipping Late Proterozoic to Cambrian rocks and Tertiary volcanic rocks associated with the Caliente and Kane Springs Wash caldera complexes.

The geometry of Dry Lake and Delamar valleys was defined, in part, by gravity surveys and depth to basement estimates which indicate the presence of low saddles to the north adjoining northern Dry Lake Valley (i.e. Muleshoe Valley) and to the south adjoining Delamar Valley. Two grabens are present in Dry Lake Valley, one along the margins of the valley and another along the central axis of the valley. The depth to basement in these areas are estimated to range from about 3,300 to almost 10,000 ft-bgs. In southwest Delamar Valley, a bowl-shaped basin is inferred, and the maximum depth to basement is estimated to be almost 7,000 ft-bgs, with much of the area only about 5,000 ft-bgs. The basin fill underlying these areas consists primarily of sands and gravels, with increasing clay content and thicker sequences of volcanic tuffs to the south. Based on the geologic framework, Dry Lake and Delamar valleys are one contiguous groundwater basin.

### *ES.3.3 Groundwater Occurrence and Movement*

This section describes a conceptualization of the groundwater systems underlying Cave, Dry Lake, and Delamar valleys developed through an inventory of groundwater sites and an assessment of the current and recent water-level conditions for both the basin-fill and carbonate-rock aquifers.

In the northern sub-basin of Cave Valley, depth to water in the basin fill ranges from 2 to 221 ft-bgs, with water-level elevations ranging from 6,896 to 6,119 ft-amsl. Depth to water in the single carbonate well is 1,051 ft-bgs, with a water-level elevation of 5,406 ft-amsl. This carbonate water-level is most likely reflective of the hydraulic head within the Shingle Pass Fault. In the southern sub-basin, depth to water in the basin fill ranges from 8 to 327 ft-bgs, with water-level elevations ranging from 6,221 to 5,704 ft-amsl. Depth to water in the two carbonate wells located on the east and west side of the southern sub-basin ranges from 140 to 220 ft-bgs, respectively, with water level elevations ranging from about 5,850 to 5,790 ft-amsl. There is a north to south hydraulic gradient and direction of groundwater flow in the basin fill. The hydraulic heads in the carbonate rocks appear to be structurally controlled by the fault block associated with the Shingle Pass Fault, as reflected by the water-level elevations north and south of the block. Flow through this fault block is unlikely because of the presence of the Mississippian Chainman Shale formation.

Water-level data indicate a slight increasing trend of about 10 ft since the early 1980s. Because there is virtually no groundwater development within the basin, this trend is most likely reflective of the natural variability of the groundwater system.

Depth to water in Dry Lake and Delamar valleys ranges from 3 to 1,316 ft-bgs, and deepens to the south. Water-level elevations range from 6,630 to 3,486 ft-amsl and indicate a north to south gradient and direction of groundwater flow in both the basin fill and carbonate aquifer. This conceptualization of flow is supported by the data and is consistent with previous investigations by Eakin (1966), Scott et al. (1971), and Harrill et al. (1988).

### *ES.3.4 Conclusions*

This section presents the summary and conclusions of Part B. Based on the geologic framework and groundwater data compiled as part of this effort the following is concluded:

Cave Valley is effectively partitioned into two sub-basins by the northeast-striking oblique-slip Shingle Pass Fault, which has displaced a part of the Egan Range, forming an east-dipping fault block that extends northeast across and underneath the valley where it terminates against the west range-front fault of the Schell Creek Range.

- Based on water-level data, this fault block does not appear to significantly influence flow in the basin fill, but does control water-levels in the carbonate-rock aquifer as evidenced by the gradient defined by two carbonate wells on the north and south side of the block.
- Groundwater flow across this fault block is unlikely due to the presence of the Mississippian Chainman Shale formation which, in this area, is considered a confining unit because of its thickness and hydraulic properties.
- While groundwater flow is unlikely across the fault block, it is likely from north to south along the western range-front fault of the Schell Creek Range based on the elevation of Cave Spring and carbonate wells in the south.
- Interbasin outflow to the southern third of White River likely occurs in small amounts through the Shingle Pass Fault zone, estimated here to be no more than 4,000 afy.
- The remaining interbasin outflow occurs in the southern part of the valley to northern Pahroc Valley. This flow is estimated to be at least 9,400 afy.

- Inflow from southern Steptoe Valley is unlikely due to the lithology and structure of the geologic framework underlying northern Cave Valley and an inferred groundwater divide created by groundwater recharge in this area. The inferred groundwater divide cannot be verified with the presently available water-level data.

Dry Lake and Delamar valleys are one contiguous basin based on the geologic framework as defined by the range-front faults and depth to basement maps, and groundwater water data that indicate north-south gradients in the basin fill and carbonate-rock aquifers.

- All groundwater within the basins is derived from local recharge except for a small amount of interbasin inflow from northern Pahroc Valley at a location coincident with a series of northwest-trending right-lateral faults that form the boundary between southern Cave Valley, northern Pahroc Valley, and northern Dry Lake Valley. This inflow is estimated to be about 2,000 afy or less.

- Groundwater flows from Dry Lake Valley to Delamar Valley where flow is controlled by the Caliente and Kane Springs Wash caldera complexes to the east, and the South Pahroc Range and associated range-front faults to the west. The geologic framework in this area precludes flow to Pahranagat Valley to the west and Lake and Patterson Valleys to the east.

- Interbasin outflow from Delamar occurs along and across the Pahranagat Shear Zone and into northern Coyote Spring Valley and possibly the very southern part of Pahranagat Valley. This outflow is estimated to be about 24,000 afy, and is comprised of inflow from northern Pahroc Valley and recharge derived locally from within the hydrographic area boundaries.

# ES.4.0 Part C - Analysis of Potential Pumping Effects and Monitoring and Management

## ES.4.1 Introduction

Part C of this report presents an analysis of the potential water-related effects associated with the SNWA applications in Cave, Dry Lake, and Delamar valleys, including a description of existing water rights, an analysis of the potential effects, and a description of a program that would be implemented to monitor and manage effects as they occur. The focus of these analyses is primarily limited to Cave, Dry Lake, and Delamar valleys, although some of the data that were used in the analyses are from locations in adjacent valleys.

## ES.4.2 Summary of Water Rights

This section provides descriptions of the existing water rights within Cave, Dry Lake, and Delamar valleys, with emphasis on currently committed underground water rights. Based on abstracts obtained from the NDWR, the majority of the permitted water rights in Cave, Dry Lake, and Delamar valleys are for springs located within the mountain blocks on either side of the valleys. The abstracts also indicate that the manner of use for most of these permits is for stock watering (NDWR, 2007a).

Committed duties for underground rights in these valleys include 46.58 afy in Cave Valley, 56.56 afy in Dry Lake Valley, and 7.24 afy in Delamar Valley (NDWR, 2007b).

### *ES.4.3 Effects Analysis*

This section includes a simplified effects analysis of the groundwater production requested under the SNWA applications in Cave, Dry Lake, and Delamar valleys. The simplified analysis used the Theis (1935) equation to evaluate the effects of continuously pumping the application volume from the points of diversion in each of the three basins for a period of 75 years. The locations of interest for the analysis included existing permits for valley floor springs, underground permits, and areas of environmental concern as identified in SNWA (2007). Although the drawdowns were quantitatively simulated using the Theis (1935) equation, the estimates are still considered qualitative because of the many assumptions that are inherent to this equation.

The conceptual model applied to the Theis analysis involved two separate analyses one for Cave Valley and a combined analysis for Dry Lake and Delamar valleys. This is consistent with the interpretation for Dry Lake and Delamar valleys that these two hydrographic areas are connected geologically and hydrologically, making them one contiguous basin. Simulated flow barriers were placed along the eastern and western margins of southern Cave, Dry Lake, and Delamar valleys to simulate the lack of interbasin flows in those directions. This interpretation is consistent with the flow interpretations presented in Sections 2.0 and 3.0 of Part B of this report. The flow barriers were simulated in the analysis using image wells, which are imaginary discharging wells placed on the opposite side of the flow boundaries from the application points of diversion, at the same distance from, and perpendicular to, the simulated boundary. The resulting drawdown at any point within the boundaries is the algebraic sum of the drawdowns produced at that point by the application point of diversion and its image. In this case, the use of image wells results in greater drawdowns within the valley than would be observed without the simulated flow barriers.

While the alluvial and carbonate-rock aquifers were evaluated separately in this analysis, the drawdowns simulated in each were summed for each location of interest. This is a conservative assumption because it is unlikely that pumping an alluvial point of diversion would have much effect on a location of interest sourced in the carbonate-rock aquifer, and visa versa.

The data required for the Theis analysis included aquifer properties derived from two site specific tests conducted on carbonate rock and alluvial aquifers in Dry Lake Valley, as well as storativity values obtained from a literature review of the properties for the carbonate rock aquifer. The corresponding values for transmissivity and storage coefficient are 170,000 $ft^2$/d and 0.013 for the alluvial aquifer, and 8,690 $ft^2$/d and 0.03 for the carbonate-rock aquifer. Additional assumptions included a 1,000 ft open interval for each well with a radii of 0.83 ft, and the continuous pumping of these wells for a period of 75 years.

The findings of the simplified effects analyses are summarized as follows:

- Simulated drawdowns at the end of 75 years of continuous pumping in Cave Valley ranged from 41 to 50 ft for points of diversion located 3.53 and 5.97 mi away respectively. To further evaluate the effects of the proposed SNWA pumping on underground water rights, the well construction and water-levels must be considered. However, this information is not available for these water-right points of diversion.

- Simulated drawdowns at the end of 75 years of continuous pumping in Dry Lake Valley ranged from 8 ft at water-right number 5936 located in the northern portion of Dry Lake Valley to 48 ft at water-right number 8698 which is located 6.44 mi from the nearest proposed SNWA application point of diversion. Well completion information was available for three of the five underground water right locations and based on an analysis of this information it is unlikely that any adverse effects will occur at these locations. Water-right numbers 8698 and 35771 both have sources identified as springs. Inspection of these points on topographic maps suggests that they may be reservoirs fed by springs located within the mountain block. If they are reservoirs, then pumping the proposed production wells, would not effect these locations. The springs in Dry Lake Valley were unlikely to experience adverse effects due to their nature, geographic location, and the geologic complexity between the springs and the proposed SNWA applications points of diversion.

- Simulated drawdowns at the end of 75 years of continuous pumping in Delamar Valley ranged from 53 to 65 ft. Grassy Spring is the one area of environmental concern in Delamar Valley (SNWA, 2007). The drawdown simulated at Grassy Spring was 61 ft. The spring is located over 450 ft higher in elevation than the nearest proposed pumping well. The discharge measurements and temperatures for Grassy Spring indicate it is derived from local precipitation. These factors suggest a different water source than the source underlying the application point of diversion. Furthermore, the depth to water at the application point of diversion is likely to be on the order of 1,000 ft. Therefore, it is highly unlikely that any effects will occur as a result of pumping the proposed SNWA applications. The remaining water rights in Delamar Valley are associated with springs. Limited water level data in Delamar Valley, as described in Section 2.0 of Part B, indicates a deep water table. This would suggest that the springs are likely derived from a perched system that would be unaffected by pumping from the proposed SNWA application points of diversion.

This scenario is conservative with respect to the evaluation of water-related effects in that the annual production rate is the maximum permitted duty, and the scenario does not incorporate water-resource management strategies that could be invoked to minimize or reduce effects. The simulated drawdowns are believed to be at the upper bounds of what is expected due to the single aquifer assumption in this analysis where drawdowns in the carbonate rock aquifer and the alluvial aquifer were combined. There are several major limitations to the use of the Theis equation to calculate drawdowns over a hydrographic area. Drawdowns simulated using the Theis equation are only approximations of the potential drawdowns. In reality, the magnitude of the drawdowns caused by pumping at a given observation point depends on several factors:

- The distance between the pumping well and the observation point
- The presence of major heterogeneities including barriers to groundwater flow
- The actual aquifer properties in the region of pumping
- The magnitude, length, and continuity of pumping

### ES.4.4 Monitoring and Management

This section describes SNWA's commitment to monitoring and management of the development of these water rights. SNWA will abide by all permit conditions attached to the water-right permits and work within the water-right administrative process set forth by the Nevada State Engineer to (1) manage its use of the water resources, and (2) avoid unreasonable lowering of the water table such that adverse impacts to senior water-right holders do not occur. Additionally, SNWA will seek to manage its use of the permitted water resources in a manner that does not adversely affect environmental resources. SNWA will coordinate the development of a program to monitor long-term fluctuations in water levels and spring discharge at selected monitoring sites in Cave, Dry Lake, and Delamar valleys and vicinity. SNWA installed two monitor wells in each of Cave, Dry Lake, and Delamar valleys in 2005 as well as a monitor well in northern Pahranagat Valley. Additionally, SNWA cooperatively funds USGS monitoring of wells and springs as part of a Joint Funding Agreement between SNWA, USGS, and NDWR. The monitoring sites are regularly evaluated to ensure data adequacy and appropriate spatial coverage. The monitoring of these sites may be included in the permit conditions prescribed by the Nevada State Engineer. Figure ES.4-1 depicts the current monitoring sites within Cave, Dry Lake, and Delamar valleys and vicinity.

### ES.4.5 Conclusions

The major finding of the effects analysis is that it is highly unlikely that any adverse effects will occur to existing permitted underground and spring water-right points of diversion or environmental areas of concern. The monitoring program established as per the permit conditions set forth by the Nevada State Engineer will allow for the management of the water resources to avoid unreasonable effects.

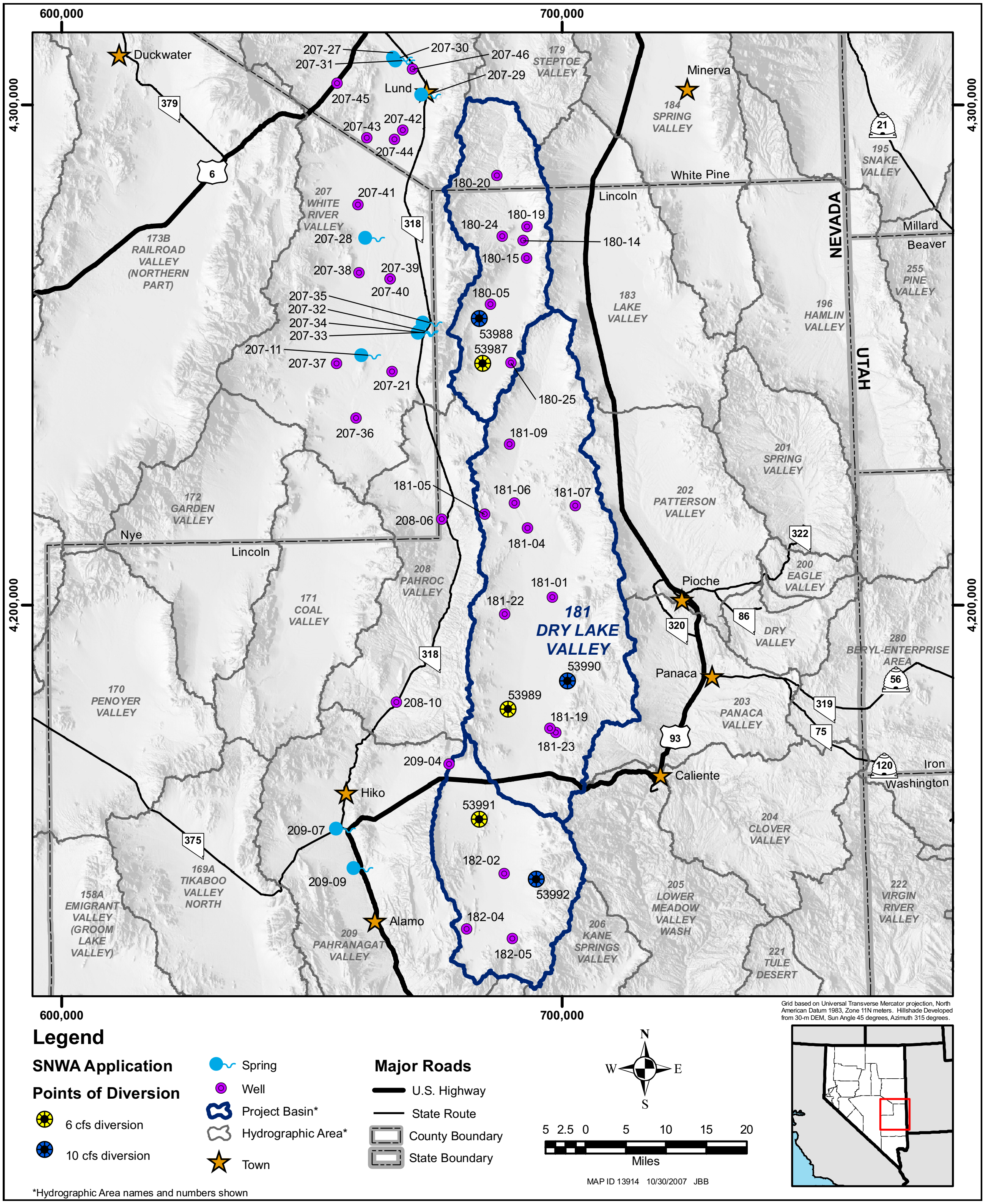


**Figure ES.4-1**
**Current Monitoring Sites**

# ES.5.0 UNAPPROPRIATED GROUNDWATER RESOURCES IN CAVE, DRY LAKE, AND DELAMAR VALLEYS

The unappropriated groundwater resources for Cave, Dry Lake, and Delamar valleys is defined here as the precipitation recharge derived locally within each hydrographic area boundary, minus the existing committed underground rights. An estimate of the unappropriated groundwater resources for each valley based on the analyses presented in this report is presented in Table ES.5-1.

**Table ES.5-1**
**Estimate of Unappropriated Groundwater Resources in Cave, Dry Lake, and Delamar Valleys**

| HA Name | Precipitation Recharge (afy) | Committed Underground Water Rights (afy) | Unappropriated Groundwater (afy) |
|---|---|---|---|
| Cave Valley | 14,659 | 46.58 | 14,612 |
| Dry Lake Valley | 15,667 | 56.56 | 15,610 |
| Delamar Valley | 6,401 | 7.24 | 6,394 |
| **Total** | **36,727** | **110.38** | **36,616** |

Note: Values were not rounded, to allow calculations to be tracked during analysis and reporting.

The total unappropriated groundwater resources estimated for Cave, Dry Lake, and Delamar valleys is sufficient to satisfy the SNWA applications filed in these basins.

SOUTHERN NEVADA
WATER AUTHORITY

# Part A

# Regional-Scale Evaluation of Natural Recharge, Discharge, and Interbasin Flow for the White River Flow System

Prepared by: Andrew G. Burns

November 2007

SOUTHERN NEVADA WATER AUTHORITY
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## TABLES (CONTINUED)

## ACRONYMS

| | |
|---|---|
| BARCAS | Basin and Range Carbonate Aquifer System |
| BARCASS | Basin and Range Carbonate Aquifer System Study |
| BCM | Basin Characterization Model |
| BLM | Bureau of Land Management |
| DCNR | Department of Conservation and Natural Resources |
| DEM | digital elevation model |
| DRI | Desert Research Institute |
| ET | evapotranspiration |
| GAP | Gap Analyses Project |
| GIS | geographic information system |
| HA | hydrographic area |
| LVVWD | Las Vegas Valley Water District |
| MVWD | Moapa Valley Water District |
| NA | not applicable, not available |
| NAD83 | North American Datum of 1983 |
| NAVD88 | North American Vertical Datum of 1988 |
| NCDC | National Climatic Data Center |
| NDWR | Nevada Division of Water Resources |
| NLCD | National Land Cover Data |
| NRCS | Natural Resources Conservation Service |
| PET | potential evapotranspiration |
| PRISM | Precipitation-elevation Regression on Independent Slopes Model |
| RASA | Regional Aquifer-System Analysis |
| SNOTEL | SNOwpack TELemetry |
| SNWA | Southern Nevada Water Authority |
| USAF | U.S. Air Force |
| USFS | U.S. Forest Service |
| USGS | U.S. Geological Survey |
| UTM | Universal Transverse Mercator |
| WRCC | Western Regional Climate Center |
| WRFS | White River Flow System |
| WY | Water Year |

## ABBREVIATIONS

| | |
|---|---|
| afy | acre-feet per year |
| amsl | above mean sea level |
| bgs | below ground surface |
| cfs | cubic feet per second |
| ft | foot |
| gpd | gallons per day |
| gpm | gallons per minute |
| km | kilometer |
| in. | inch |
| m | meter |
| mi | mi |
| yr | year |

# 1.0 INTRODUCTION

The purpose of this report is to present a regional assessment of the precipitation, natural recharge, groundwater discharge, and interbasin flow of the White River Flow System (WRFS) of eastern Nevada (Figure 1-1). This regional assessment was completed in support of water-right hearings related to Southern Nevada Water Authority (SNWA), applications 53987 through 53992, inclusive, in Cave (hydrographic area [HA] 180), Dry Lake (HA 181) and Delamar (HA 182) valleys. Cave, Dry Lake, and Delamar valleys are also referred to as the "project basins" in this report. In Nevada, a hydrographic area is delineated based on topography, has a HA number, and is named after the valley it represents. Even though the groundwater basins underlying the HAs may have different boundaries than the HAs, these are generally unknown. Thus, for the purpose of deriving groundwater budgets, the groundwater basins are assumed to coincide with the HAs. Furthermore, in this report, the terms "HA," "basin," and "valley" are used interchangeably to refer to the individual groundwater basins.

## 1.1 Background

A great amount of new information has been produced during the more than 40 years since the U.S. Geologic Survey (USGS) Groundwater - Reconnaissance Series Reports for Cave, Dry Lake, and Delamar valleys were first published (Eakin, 1962; 1963a). This information includes new meteorologic, hydrologic, and geologic data and many studies resulting in improved estimates of precipitation distribution and groundwater discharge. This new information warrants a re-evaluation of the groundwater resources for these basins; however, to do so requires adopting a regional approach (i.e., flow system) with respect to precipitation and natural recharge.

The Reconnaissance Series Reports (Eakin, 1962 and 1963a) contain estimates of the precipitation and natural recharge for Cave, Dry Lake, and Delamar valleys, based on a version of the precipitation map of Nevada prepared by Hardman (1936) and the standard recharge efficiencies developed by Maxey and Eakin (1949). To form a new assessment of the natural recharge of these basins requires incorporating an improved precipitation distribution. To do so requires, in turn, that new recharge efficiencies be developed so that when applied to the precipitation distribution, the resultant recharge estimate is balanced by estimates of groundwater discharge. For the three basins addressed in this report, the principal component of groundwater discharge is subsurface outflow, which is one of the more uncertain components of any groundwater budget. To minimize the effects of this uncertainty, a regional approach was used to derive the recharge distribution. This ensures that the most uncertain component (i.e., subsurface outflow) of the groundwater discharge represents the smallest portion of the total groundwater discharge. This is the case for the WRFS, as most of the groundwater discharge occurs as groundwater evapotranspiration (ET) rather than subsurface underflow.

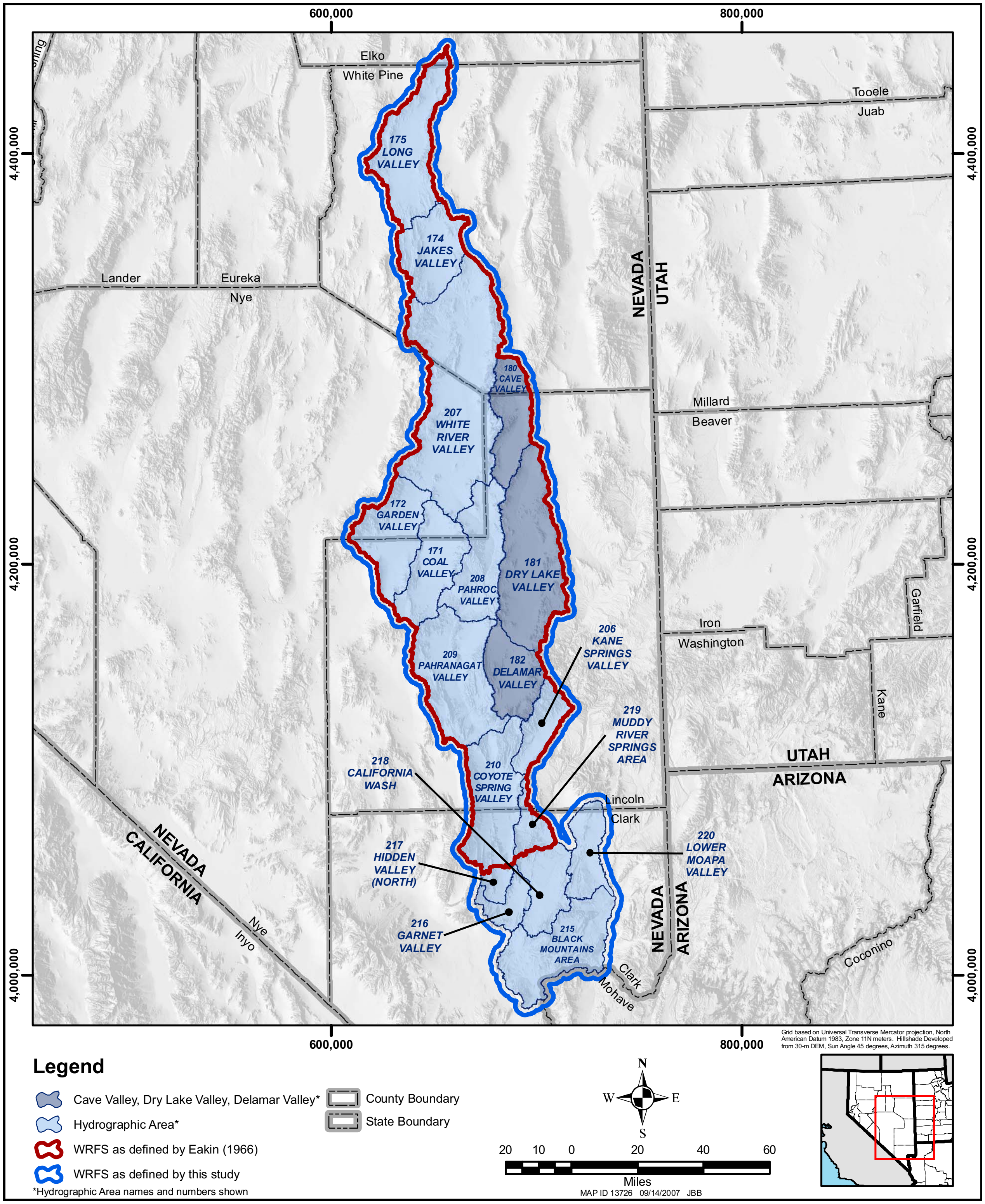


**Figure 1-1**
**Location of the White River Flow System, Cave, Dry Lake, and Delamar Valleys**

### *1.2 Purpose and Scope*

Estimates of precipitation and groundwater discharge for the WRFS were evaluated as part of a regional water-resource assessment to derive natural recharge estimates and groundwater budgets for basins comprising the WRFS. New recharge efficiencies were derived as part of this regional assessment based on the improved estimates of groundwater ET and precipitation distribution. These efficiencies were applied to the precipitation distribution for the purpose of deriving a distribution of natural recharge from which basin recharge estimates could be computed and used in developing basin groundwater budgets.

The WRFS was originally defined by Eakin (1966) as a flow system starting from Long Valley in the north, and ending with the Muddy River Springs Area in the south (Figure 1-1). Eakin's (1966) flow system consisted of thirteen hydrographic areas including Long Valley, Jakes Valley, Cave Valley, White River Valley, Garden Valley, Coal Valley, Pahroc Valley, Pahranagat Valley, Dry Lake Valley, Delamar Valley, Kane Springs Valley, Coyote Spring Valley, and the Muddy River Springs area (also called Upper Moapa Valley). In Eakin's version of the WRFS, the Muddy River Springs Area was assumed to be the terminal discharge area for the flow system. However, more recent studies (Harrill et al., 1988, Figures 3 and 6, Sheet 1; LVVWD, 2001, p. 1-2, Figure 6-1, Errata sheets; Buqo, 2004, p. 57) interpret the Colorado River (now Lake Mead) to be the terminal discharge location of the WRFS. This means that, in addition to the spring water leaving the Muddy River Springs Area along the Muddy River, some groundwater flows past and/or around the Muddy River Springs to basins located downgradient, and discharges to the Colorado River. These basins, which are the California Wash, Lower Moapa Valley, Hidden Valley, Garnet Valley, and Black Mountains Area, were added to Eakin's (1966) interpretation of the WRFS (Figure 1-1). This augmented version of the WRFS was used in this study.

### *1.3 Document Organization*

This report contains eight sections and five appendices. A brief description of each section and appendix follows:

- Section 1.0 is this introduction describing the background, purpose, and scope of the water-resource assessment presented in this report.
- Section 2.0 provides summary descriptions of the previous hydrologic investigations related to the three project basins and to the WRFS.
- Section 3.0 describes the technical approach applied in the data compilation and analysis activities used to complete this water-resources assessment.
- Section 4.0 describes the compilation, processing, and analysis of the available meteorologic, hydrologic, and geologic data used to estimate basin precipitation, groundwater ET, and groundwater outflow.

- Section 5.0 describes the process and results of the analysis used to derive an average annual recharge distribution for the WRFS, and the resultant groundwater budgets for the basins within the WRFS.

- Section 6.0 presents the results of an uncertainty analysis of the recharge distribution and groundwater budgets derived in Section 5.0, based on the uncertainties associated with estimates of selected variables used in the analysis.

- Section 7.0 provides a summary and the conclusions of this water-resources assessment.

- Section 8.0 provides a list of references cited in this report.

- Appendix A provides information about precipitation stations used in this study.

- Appendix B provides descriptions of the groundwater discharge areas of the WRFS and a compilation of ET rates for the study area and vicinity from the literature.

- Appendix C provides spring discharge measurements for selected springs in White River and Pahranagat valleys, and the Muddy River Springs Area.

- Appendix D provides estimates of interbasin flow across selected basin boundaries used as constraints and/or initial conditions in the recharge calculations.

- Appendix E presents details about the calculations performed to derive the recharge efficiencies, the recharge distribution and the basin budgets, including descriptions of the Excel files.

# 2.0 PREVIOUS INVESTIGATIONS

Numerous studies related to Cave, Dry Lake, and Delamar valleys and adjacent basins have been conducted since the late 1930s. These studies have included water-resource investigations, geologic and hydrogeologic investigations, recharge and discharge estimations, and other hydrologic studies. The following sections describe, in general terms, the purpose, objectives, data sources, and conclusions for the most pertinent of these studies.

## 2.1 USGS/DCNR Reconnaissance Investigations

During the late 1940s to the early 1980s, the USGS, in cooperation with the State of Nevada Department of Conservation and Natural Resources (DCNR), completed reconnaissance-level hydrologic evaluations or reevaluations of nearly every valley in Nevada. The purpose of the studies was to provide a general appraisal of the groundwater resources as quickly as possible (Eakin, 1963a, p. 2). The results of these studies are presented in two report series, the USGS Water Resources Bulletin Series and the USGS Ground-Water Resources - Reconnaissance Series.

The USGS Ground-Water Resources - Reconnaissance Report Series describes estimates of groundwater recharge, groundwater discharge, and perennial yields for each valley or area in Nevada. The reconnaissance-level hydrologic evaluations of Cave Valley were reported by Eakin (1962), and those for Dry Lake and Delamar valleys were reported by Eakin (1963a). The recharge estimates presented in these reports were based on a method developed by Maxey and Eakin (1949), using the water balance method and an empirical relationship between precipitation and groundwater recharge. A more detailed description of the Maxey and Eakin (1949) is provided in Section 3.2.2.1.

Average annual groundwater recharge estimates on the order of 14,000, 5,000, and 1,200 afy were reported for Cave, Dry Lake, and Delamar valleys, respectively (Eakin, 1962, p. 12; 1963a, p. 17). Eakin (1962, p. 12; 1963a, p. 18) also states that groundwater ET in these valleys probably does not exceed a few hundred acre-feet per year and that discharge by subsurface underflow may closely approach the estimated average annual groundwater recharge. In the perennial yield section of these reports, it is stated that the perennial yield for these basins would be limited based, in part, on presumed constraints related to the economic feasibility of pumping sufficient volumes of groundwater to lower water levels so that groundwater discharge is captured.

Eakin (1966) evaluated the potential for a regional interbasin groundwater system based on the results of the reconnaissance groundwater appraisals. The Paleozoic carbonate rocks are reported as the principal means of transmitting groundwater in the interbasin regional system. The probable means of discharge was reported as underflow from Cave Valley to White River Valley (14,000 afy), Dry Lake Valley to Delamar Valley (5,000 afy), and Delamar Valley to southern Pahranagat Valley (6,000 afy) (Eakin, 1966, pp. 261 and 265).

### 2.2 Nevada Water Resources Report No. 3

In this report, Scott et al. (1971) provided a hydrologic summary for the 232 HAs in Nevada. The report was one in a series of reports prepared for the development of a Nevada State Water Plan. The report, titled "Nevada's Water Resources," included precipitation, surface water runoff, and groundwater recharge data in addition to perennial and system yield data for each of the HAs. The sources of most of the data reported by Scott et al. (1971) are the Bulletins and Reconnaissance Series reports. Eakin (1962, 1963a, and 1966) are cited for Cave, Dry Lake, and Delamar valleys; the results of these studies are summarized, consistent with those reported previously, in a series of tables. Perennial yields are reported as 2,000 afy (Cave Valley), 2,500 afy (Dry Lake Valley), and 3,000 afy (Delamar Valley) (Scott et al., 1971, p. 23).

### 2.3 Desert Institute Publication No. 41054

Under contract with the Las Vegas Valley Water District (LVVWD), the Desert Research Institute (DRI) produced DRI Publication No. 41054 (Hess and Mifflin, 1978) describing a feasibility study about groundwater development from the carbonate aquifers of Nevada. The report includes a compilation of information on the carbonate rocks in eastern and southern Nevada and a plan for further studies. Information compiled includes data on large carbonate springs, carbonate caves, wildcat oil and gas wells, and mines found in the study area. Based on this information, Hess and Mifflin (1978) concluded that thick sequences of carbonate rocks occur beneath the alluvial basins and much of the volcanic rocks of eastern Nevada. Information gathered during the drilling of deep petroleum holes indicate that intervals of cavernous carbonate rock exist to depths greater than 10,000 ft (Hess and Mifflin, 1978, p. 19).

### 2.4 U.S. Air Force MX Missile Siting Program

In the late 1970s and early 1980s, hydrogeologic evaluations were conducted in support of the U.S. Air Force (USAF) MX Missile Siting Program. The purpose of these evaluations was to assess the potential for water-supply development in 36 HAs in the Great Basin region that were proposed for the deployment of the MX missile system. This program involved literature reviews, exploratory drilling, aquifer testing, groundwater sampling for water-quality analysis, and the development of groundwater flow models to assist in predicting potential impacts of pumping in some valleys. Development of groundwater from the basin-fill aquifers was the preferred water-supply source; most of the valleys had adequate unappropriated groundwater supplies in the basin fill to meet estimated MX water requirements (Ertec Western, Inc., 1981b, p. 32). These studies are documented in several reports by Ertec Western, Inc. (1981a through e) and summarized by Bunch and Harrill (1984).

Aquifer testing of the basin-fill aquifer was performed in Cave, Delamar, and Dry Lake valleys and of the carbonate-rock aquifer in Dry Lake Valley (Ertec Western, Inc., 1981c, pp. 37, 52, and 60). The potential for the development of the carbonate-rock aquifer was rated as high for Cave and Dry Lake Valleys and as moderate for Delamar Valley (Ertec Western, Inc., 1981b, p. 58). A moderate potential for development of the carbonate-rock aquifer in Delamar Valley was attributed to the lack of thick sequences of carbonate rocks in the valley. Ertec Western, Inc. (1981c, pp. 52–53) stated that Delamar Valley is in a known groundwater flow regime and that areas of high-density faulting were observed.

## 2.5 Great Basin Regional Aquifer System Analysis

The Great Basin Regional Aquifer System Analysis (RASA) study took place in the 1980s and was undertaken as part of the USGS national RASA program. The main purpose of this study was to develop a geologic, hydrologic, and geochemical framework for regional aquifer systems nationwide (Harrill et al., 1988) to support effective future groundwater management (Harrill and Prudic, 1998). The results of the RASA study are described in nearly 60 reports including the USGS Professional Paper 1409 series (1409A through H). The first report of this series, Harrill and Prudic (1998), provides a summary of the RASA study.

Previous RASA reports for the Great Basin region include the USGS Hydrologic Atlas HA-694 series which consists of the following documents:

- USGS Hydrologic Atlas HA-694-A (Plume and Carlton, 1988): This atlas includes one map with a detailed description. The major hydrogeologic units present in the Great Basin region are delineated and described. Hydrogeologic units that constitute regional aquifers or act as barriers to the movement of groundwater are also identified and discussed.

- USGS Hydrologic Atlas HA-694-B (Thomas et al., 1986): This atlas includes two maps with detailed descriptions. The first map (Sheet 1) shows the general distribution of water levels in the basin-fill deposits of the Great Basin Region. The second map (Sheet 2) is a depiction of the potentiometric surface in consolidated rocks of the carbonate rock province.

- USGS Hydrologic Atlas HA-694-C (Harrill et al., 1988): This atlas contains one map with a detailed explanation. The maps depicts interpretations of general groundwater flow directions in basin-fill deposits, and flow directions and magnitudes of interbasin flow in consolidated rocks. Flow through permeable consolidated rock from Cave, Dry Lake, and Delamar valleys to White River, Delamar, and Pahranagat valleys, respectively, are reported. The recharge rates and interbasin flow rates reported by Harrill et al. (1988) are consistent with those reported by Eakin (1962, 1963a, and 1966).

Another RASA report for the Great Basin region is that of Prudic et al. (1995). This report presents a conceptual evaluation of regional groundwater flow based on a numerical groundwater flow model. The two-layer model was used to simulate the concept of numerous shallow flow regions superimposed upon fewer deep-flow regions (Prudic, 1995, p. 95). Cave, Dry Lake, and Delamar valleys were modeled as part of the White River flow subregion of the Colorado River deep-flow region (Prudic, 1995, p. 66). Groundwater flow in the White River subregion was generally north to south in both model layers, and more groundwater flow was simulated in the lower layer than in any other in the study area (Prudic, 1995, p. 71). The Reconnaissance Reports provided the basic estimates of recharge and discharge (Prudic, 1995, p. 6).

## 2.6 LVVWD Cooperative Water Project

LVVWD published a series of 19 reports in support of groundwater applications filed with the Nevada State Engineer’s Office in 1989 and as part of its Cooperative Water Project (CWP). These hydrologic-assessment reports were prepared for valleys in which groundwater applications were filed at the time. The objectives of these reports were (1) to compile, review, and interpret available geologic, hydrologic, and land use data to determine hydrologic characteristics and (2) to develop computer models that simulate steady-state groundwater flow. Brothers et al. (1993) describes the hydrologic assessment conducted for Cave Valley, and Brothers et al. (1996) describes the hydrologic assessment of Dry Lake and Delamar valleys. Two-layer models were developed to simulate groundwater flow in the alluvium and the consolidated rocks. The models were developed to replicate as closely as possible the hydrologic basin budget as defined by Eakin (1962) for Cave Valley and Eakin (1963a) for Dry Lake and Delamar valleys, while attempting to match the existing groundwater levels (Brothers et al., 1993 and 1996).

### *2.7 USGS Open-File Report 96-469*

In cooperation with LVVWD, USGS collected and compiled groundwater data from the 254 wells drilled as part of the MX Missile-Siting Program. Tumbusch and Schaefer (1996) present these data in tables and the well locations on a map. The data include water level, well depth, and site status measured between 1980 and 1996 for four large-diameter production and observation wells in Cave Valley, nine in Dry Lake Valley, and three in Delamar Valley. Groundwater data for two small-diameter monitor wells in Cave Valley were also reported. In addition, digital recording devices were installed in select wells, one in Cave Valley and three in Dry Lake Valley, to monitor detailed changes in groundwater levels. Tumbusch and Schaefer (1996) also report the location, site information, and status of the recording devices.

### *2.8 LVVWD Coyote Spring Valley Report*

In support of groundwater applications in Coyote Spring Valley, LVVWD performed a study to estimate a water-resource budget for the WRFS and Meadow Valley Flow System (LVVWD, 2001). The goal of this study was to define the regional hydrology and geology of the flow systems, estimate their groundwater and surface water budgets, and simulate potential pumping impacts to the regional groundwater and surface water resources related to the LVVWD applications. Additional precipitation data, geologic investigations, geochemistry, and interpretive techniques not previously available were included in the evaluation (LVVWD, 2001, p. 1-1).

The water-resource budget for the area shows a groundwater recharge estimate of 324,000 afy and groundwater ET estimate of about 275,000 afy, leaving about 49,000 afy of discharge from the two flow systems into Lake Mead (LVVWD, 2001, p. 6-2). Estimates of groundwater recharge and ET volumes were greater than those of previous investigators. A modified Maxey-Eakin approach was used to estimate recharge volumes of 20,000, 13,000, and 5,000 afy for Cave, Dry Lake, and Delamar valleys, respectively (LVVWD, 2001, p. 4-25). Volumes of predevelopment ET and groundwater outflow were reported as 5,000 and 15,000 afy (Cave Valley); 1,000 and 12,000 afy (Dry Lake Valley); and 1,000 and 16,000 afy (Delamar Valley), respectively (LVVWD, 2001, pp. 4-37, 4-38, 4-40).

### *2.9 Desert Research Institute Publication No. 41169*

Thomas et al. (2001) describe an approach to evaluate the recharge and ET rates estimated by LVVWD (2001) using a deuterium mass-balance model for water budgets of the regional flow systems in southern Nevada. For this model, groundwater flow paths from Cave Valley to Pahroc Valley, Dry Lake Valley to Delamar Valley, and Delamar Valley to Coyote Valley were evaluated (Thomas et al., 2001, p. 10). A deuterium mass-balance model was produced that was consistent with deuterium values measured in samples collected from the carbonate rock aquifers of the WRFS (Thomas et al., 2001, p. 33). Thomas et al. (2001) pointed out that the model was non-unique and that the modeling results only show that the deuterium data are consistent with the proposed rates and groundwater sources, but does not necessarily confirm that the estimates are correct.

### *2.10 BARCAS Study*

The Basin and Range Carbonate Aquifer System (BARCAS) study is a project created as a result of federal legislation enacted in December 2004 (Section 131 of the Lincoln County Conservation, Recreation, and Development Act of 2004, Public Law 108-424). The purpose of the BARCAS study is to investigate the groundwater flow system underlying White Pine County, Nevada, or Lincoln County, Nevada, and adjacent areas in Utah. The Lincoln County Land Act (U.S. Congress, 2004) states that:

> The study shall–(a) focus on a review of existing data and may include new data; (b) determine the approximate volume of water stored in the aquifers in those areas; (c) determine the hydrogeologic and other controls that govern the discharge and recharge of each aquifer system; and (e) develop maps at consistent scale depicting aquifer systems and the recharge and discharge areas of such systems.

The BARCAS study was conducted by USGS, DRI, and the Utah State Engineer’s Office, in collaboration with Bureau of Land Management (BLM), and included several tasks including data compilation and collection, identification of aquifers present and their hydrologic properties, delineation of groundwater recharge and discharge areas and rates, synthesis of all information into a conceptual model of the regional flow systems including the water budget, and reporting of the study results.

The draft phase of the BARCAS study has been completed, and the reports are currently available in draft form. The main reports are as follows:

- Geophysical framework investigations (Watt and Ponce, 2007)
- Recharge distribution (Flint and Flint, 2007)
- Mapping of ET units (Smith et al., 2007)
- ET rate measurements (Moreo et al., 2007)
- Water-level surface maps (Wilson, 2007)
- Delineated irrigated acreage (Welborn and Moreo, 2007)
- Summary report (Welch and Bright, 2007).

The BARCAS study area includes four of the WRFS basins. They are Long, Jakes, White River and Cave valleys.

# 3.0 TECHNICAL APPROACH

This section includes a review of the various methods used to estimate precipitation recharge for the WRFS, and the rationale for the selection of the groundwater balance method used in this analysis. Also included is a description of the specific technical approach applied in the data compilation and analysis activities used to derive estimates of natural recharge, groundwater discharge, and interbasin flow to assess the water resources of the WRFS.

## 3.1 Objective

The objective of the water-resource assessment was to estimate the components of the groundwater budget of the WRFS and each of its basins. The estimated budget components represent predevelopment, long-term mean annual conditions, and include precipitation recharge, groundwater discharge by ET, and interbasin inflow and outflow. For such conditions, groundwater budgets may be derived by equating the total recharge to the system (precipitation recharge + inflow) to the total discharge from the system (groundwater ET + outflow). Given that precipitation recharge cannot be measured directly, it is estimated as a function of the other components of the budget. The objective of the approach is to derive a relationship between recharge efficiencies and precipitation that yields a balanced water budget for the WRFS. The solution is constrained by a predefined relationship and conditions on interbasin flow where known.

## 3.2 Review and Selection of Recharge Method

Relevant methods of estimation of groundwater recharge are described, followed by the rationale for the method selected.

### 3.2.1 Recharge Methods

Recharge methods that have been used to estimate basin-scale groundwater recharge in the WRFS and vicinity are based on the law of conservation of mass and may be categorized as follows:

- Groundwater balance methods
- Soil water-balance methods
- Chloride mass-balance method.

Brief descriptions of the three methods and their implementation by various authors are provided in the following sections.

### 3.2.2 Groundwater Balance Methods

The groundwater balance method is applied to a groundwater basin, usually under estimated predevelopement steady-state conditions, to derive an estimate of the basin's recharge volume. This volume is calculated as the difference between the total volume of groundwater discharge (i.e., groundwater ET plus subsurface outflow) and the volume of subsurface inflow. A prominent groundwater balance method developed and applied to basins in Nevada is the Maxey-Eakin method (Maxey and Eakin, 1949). This method and its derivatives are summarized, followed by brief descriptions of selected other groundwater balance methods used elsewhere.

#### 3.2.2.1 Maxey-Eakin Method and Derivatives

The Maxey-Eakin method (Maxey and Eakin, 1949; Eakin et al., 1951) was designed to estimate groundwater recharge from precipitation for hydrographic areas of Nevada. Estimates of groundwater recharge based on the Maxey-Eakin method were published by the Nevada Department of Conservation and Natural Resources in the Ground-Water Resources - Reconnaissance Report Series and the Water Resource Bulletins from the mid-1940s through the mid-1970s. Maxey-Eakin methods include the "standard" method and modified versions.

The standard Maxey-Eakin method (Maxey and Eakin, 1949) is based on a precipitation map developed by Hardman (1936). This map, which is described in more detail in Section 4.1.2.1, delineates six precipitation zones, ranging from 0 to over 20 in. of precipitation per year. Using this map, the five precipitation zones above 8 in. in a given hydrographic area are identified as recharge areas. The acreage for each precipitation zone is then measured and multiplied by its average precipitation rate. The resulting precipitation volume is then multiplied by the recharge efficiency for the zone (i.e., the percentage of precipitation that becomes groundwater recharge). The resulting recharge volumes are then summed to yield an estimate of the total recharge volume from precipitation for that hydrographic area, including recharge by direct infiltration and infiltration of runoff. The standard Maxey-Eakin efficiencies were derived by balancing the recharge volume to estimates of discharge volume for 13 basins in Nevada (Maxey and Eakin, 1949). The standard Maxey-Eakin method is not designed to provide a realistic spatial distribution. It does, however, provide first-order approximations of basin recharge volumes (Avon and Durbin, 1994). Also, during the Kane Spring Valley water-rights hearing, it was recognized that the standard Maxey-Eakin efficiencies should only be used with the Hardman precipitation map (Nevada State Engineer, 2007a pp. 12 and 13; Nevada State Engineer, 2007b, pp. 29 and 30).

One major modification of the standard Maxey-Eakin method involves the use of altitude zones on a topographic map to approximate the precipitation zones and calculate their areas. Examples of this variation of the Maxey-Eakin method (1949) are the ones used for Cave, Dry Lake, and Delamar valleys in the Reconnaissance Reports (Eakin 1962; 1963a). Other investigators used variations of the standard Maxey-Eakin method by modifying the precipitation and the recharge efficiencies. They include D'Agnese et al. (1997, pp. 52, 53, and 55), Hevesi et al. (2002, p. 27), Donovan and Katzer (2000, p. 1142), Berger (2000, p. 18), the LVVWD (2001, p. 4-26), Dixon and Katzer (2002, pp. 36-43), and Katzer and Donovan (2003, p. 44). Of particular interest are Hevesi et al. (2002), Donovan and Katzer (2000), and Wilson and Guan (2004), who converted the recharge efficiency step function, defined in the standard Maxey-Eakin method, to similar power functions expressing recharge as a continuous function of precipitation.

### *3.2.2.2 Other Water Balance-Based Methods*

Other selected methods of estimating recharge from precipitation were applied in Idaho and India. They include studies by Contor (2004) and Kumar and Seethapathi (2002), who used power functions to describe the relationship between recharge and precipitation.

#### *Contor (2004)*

In support of the Eastern Snake Plain Aquifer Model Enhancement Project in Idaho, Contor (2004) adapted a relationship used by Rich (1951) to describe a basin's total yield. Contor (2004) simplified the relationship to represent recharge on non-irrigated lands as a function of precipitation as follows:

$$\text{Recharge} = K \times \text{Precipitation}^{N} \qquad \text{(Eq. 3-1)}$$

where,

K = the empirical slope parameter
N = the empirical exponent

Considering that recharge cannot physically be greater than precipitation, the slope of the recharge-precipitation relationship should never be greater than one. At the point at which recharge equals precipitation, the exponential relationship is replaced by a straight line having a slope of 1. Furthermore, for a given relationship, the area between the 1 to 1 straight line extended to zero and the exponential curve represents the portion of precipitation that does not become recharge. This represents the water that is stored in the soil or lost to potential evapotranspiration (PET).

#### *Kumar and Seethapathi (2002)*

Kumar and Seethapathi (2002) derived an empirical relationship to estimate groundwater recharge from rainfall for the Upper Ganga Canal command area using a seasonal groundwater balance spanning over several seasons: 1972-73 to 1983-84. They found that recharge increases with rainfall in a non-linear fashion. The recharge efficiencies they calculated for monsoon season ranged between 0.05 to 0.19. Kumar and Seethapathi (2002) then derived an empirical relationship between recharge and rainfall by fitting the estimated values of recharge and the values of rainfall using the non-linear regression method. The corresponding equation is as follows:

$$R = 0.63(P - 15.28)^{0.76} \qquad \text{(Eq. 3-2)}$$

where,

R = the groundwater recharge from rainfall in monsoon season (in.)
P = the mean rainfall in monsoon season (in.)

The term 15.28 in. represents the magnitude of rainfall below which recharge does not occur. This equation is similar to that of Contor (2004), except that it assumes that recharge only occurs above a certain level of precipitation (15.28 in.).

### *Anderson et al. (1992)*

As part of a RASA study for alluvial basins located in southwest Arizona and vicinity, Anderson et al. (1992) developed an equation for estimating mountain-front recharge as a function of precipitation using the water budget method. Their approach consisted of developing a relationship between the mean annual mountain-front recharge volume and the total annual volume of precipitation for several watersheds when the precipitation is greater than 8 in./yr. They initiated the equation starting with the available data points and adjusted its coefficients until both the individual basin budgets and the total budget for all basins balanced. Their data points include recharge values derived from models and a few basin estimates. They derived two forms of the equation, one using the total precipitation volume for the basins, and a second one using only the precipitation volume for precipitation rates larger than 8 in. The 8 in. cutoff was arbitrary but yielded a better fit to the data, and was therefore, used to estimate recharge for the study area. The volume of precipitation below 8 in. was attributed to losses to soil-moisture deficits and ET. The resulting equation is as follows:

$$\text{Log } R = -1.40 + 0.98 \times \text{Log } P \qquad \text{(Eq. 3-3)}$$

where,

R = Recharge volume in afy
P = Precipitation in afy (where P > 8 in./yr).

Taking the inverse log of each side of the equation yields a power function similar to that of Contor (2004):

$$R = 0.042P^{0.98} \qquad \text{(Eq. 3-4)}$$

where,

R = Mean direct mountain front recharge in afy
P = Mean annual precipitation in afy

## *3.2.3 Soil Water-Balance Methods*

This soil water-balance method focuses on the processes that control net infiltration through the uppermost layers of surficial materials in a given area. These processes include precipitation, snow melt, snow accumulation, and soil water storage. The soil water balance must be successively applied to relatively short time periods for the method to yield reasonable estimates of recharge over long periods of time. This method is used to calculate the amount of water available at each time step, for potential recharge and/or runoff, or water to be carried to the next time step. The soil water balance has been implemented to estimate basin recharge in Nevada using two models: the INFIL code and the Basin Characterization Model (BCM). Brief descriptions of these two models follow.

#### *3.2.3.1 INFIL Code*

The INFIL code (Scanlon et al., 2006) calculates potential groundwater recharge including volume and distribution. INFIL uses a 24-hour (daily) time step to allow for an accurate simulation of the snow accumulation and melting processes. INFIL calculates runoff and distributes it to a stream network, and simulates recharge through the streambeds. An INFIL model may be calibrated to the available streamflow data, or measurements of soil-moisture content. INFIL has been extensively used to estimate recharge for the Yucca Mountain Project (Flint et al., 2002; BSC, 2004). The INFIL code is the most detailed and refined of all the methods discussed here. However, this method requires a tremendous amount of data and intensive computational resources.

#### *3.2.3.2 Basin Characterization Model*

BCM is a geographic information system-based, (GIS) distributed-parameter, water-balance method of estimating basin recharge using monthly climatic boundary conditions (Flint and Flint, 2007). BCM is in essence a simplification of the INFIL code. BCM differs from the INFIL code in that monthly climate data are used, only one soil layer is used, and surface-water is not an explicit parameter. BCM simulates total potential recharge, which is a combination of in-place recharge and runoff. One major shortcoming is the non-inclusion of streams in the code, which renders calibration very difficult, if not impossible. Despite its more simplified form, BCM also requires large amounts of data and significant computational resources. The BCM code has been used by Flint et al. (2004) to derive recharge estimates for basins in the Desert Southwest, and by (Flint and Flint, 2007) for basins in the BARCAS study area. Neither of these BCM models was calibrated to observed conditions, namely groundwater discharge.

### *3.2.4 Chloride Mass-Balance Method*

The chloride mass-balance method is used to estimate groundwater recharge in arid and semiarid environments. Data requirements include the concentration of chloride in pore water, estimates of precipitation volume, and total chloride input to the system from the atmosphere including dry fallout and precipitation. This method has been used in several studies to derive reconnaissance estimates of natural recharge for desert basins in Nevada including those by Dettinger (1989), Maurer and Berger (1997), Russell and Minor (2002), and Mizell et al. (2007).

### *3.2.5 Selection of Recharge Method*

The groundwater-balance method (Section 3.2.2) was selected as the approach for deriving an estimate of natural recharge for the WRFS because it provides the best means of deriving a calibrated recharge estimate by incorporating measurable budget components, namely groundwater ET. As applied in this analysis, a Precipitation-elevation Regression on Independent Slopes Model (PRISM) precipitation distribution was used and a trial-and-error approach taken to solve for a relationship between recharge efficiencies and precipitation that would produce a total recharge estimate that balances with the total groundwater discharge estimate for the flow system. This method also provided an initial spatial distribution of recharge based on the spatial distribution of precipitation.

The application of the standard Maxey-Eakin efficiencies to the PRISM precipitation distribution was rejected because this would result in an over estimation of the natural recharge. As the Maxey-Eakin method (Maxey and Eakin, 1949) is an empirically-derived solution calibrated to the Reconnaissance Reports Series estimates of groundwater discharge using the Hardman (1936) precipitation map, it was concluded that the standard Maxey-Eakin recharge efficiencies should only be applied to the Hardman precipitation map (Nevada State Engineer, 2007a, pp. 12 and 13; Nevada State Engineer, 2007b, pp. 29 and 30). If new recharge estimates are to be derived based on updated precipitation maps, the appropriate recharge efficiencies should be obtained using the water-balance method and updated estimates of groundwater discharge.

The BCM method offers the best approach for distributing recharge as it uses spatial distributions for the parameter datasets considered in the model. However, the recharge values derived by this method are unconstrained by observed data. In addition, BCM-based models have never been calibrated to the groundwater budget components for a basin. For this reason, the BCM method was not used in this analysis.

The chloride mass-balance method offers an alternative method of deriving recharge estimates, but the method was rejected as it was concluded that the chloride concentration observations for precipitation and groundwater are too few to represent the spatial variability of these input parameters for the WRFS.

Other investigators have derived empirical relationships between precipitation and recharge. While these were not used explicitly in this analysis, they do offer insight into alternate ways to relate recharge to precipitation. For this analysis, it was concluded that a nonlinear equation would best reflect the relationship between recharge efficiency and precipitation. Many investigators have expressed this relationship as a non-linear function rather than a linear relationship or a step-wise function such as that defined by the standard Maxey-Eakin method. Hevesi et al. (2002) modified the standard Maxey-Eakin method by developing an exponential curve to define recharge as a continuous function of precipitation. This approach was also used by Donovan and Katzer (2000, p. 1142) and Wilson and Guan (2004, p. 8). Contor (2004, p. 3) adapted a relationship used by Rich (1951) to describe a basin's total yield and simplified the relationship to represent recharge on non-irrigated lands as a nonlinear function of precipitation.

### *3.3 Technical Approach using the Groundwater-Balance Method*

The groundwater-balance method is based on fundamental concepts of hydrology and is a standard approach for estimating unknown groundwater-budget components (i.e., recharge) using estimates of other budget components that can be measured within the bounds of reasonable uncertainty (i.e., precipitation, ET). The water-balance method is more reliable for closed groundwater basins (i.e., basins with no boundary flow). It can, however, yield reasonable results when applied to a basin or flow system where the amount of boundary flow is known to be small relative to the total budget for that basin or flow system. For this assessment, the water-balance method was used to derive a relationship between recharge efficiencies and depth of precipitation that yielded a balanced groundwater budget for the flow system. This was completed using a spatial distribution of precipitation and estimates of groundwater ET and outflow.

### *3.3.1 Method Application*

In applying the groundwater-balance method, predevelopment conditions were assumed in which the total groundwater inflow to the system (i.e., precipitation recharge and boundary inflow) equals the total groundwater outflow from the system (i.e., groundwater ET and boundary outflow). Thus:

$$R_T = ET_{gw} + Outflow - Inflow \qquad \text{(Eq. 3-5)}$$

where,

$R_T$ = the total recharge from precipitation (afy)
$ET_{gw}$ = the total groundwater ET (afy)
Outflow = the total groundwater outflow (afy)
Inflow = the total groundwater inflow (afy)

For a given precipitation zone where precipitation is assumed to be effective and contribute to recharge, the volume of recharge may be expressed as a function of precipitation and recharge efficiency as follows:

$$R_Z = P_Z \times Eff_Z \times A_Z \qquad \text{(Eq. 3-6)}$$

where,

$R_Z$ = the volume of recharge within the precipitation zone (afy)
$P_Z$ = the average precipitation rate for the precipitation zone (ft/yr)
$Eff_Z$ = the recharge efficiency (between 0 and 1.0) for the precipitation zone
$A_Z$ = the surface area of the precipitation zone (acres)

The recharge efficiencies can vary depending on the depth of precipitation that can be partitioned into any number of zones based on the precipitation distribution. The total recharge for the flow system, $R_T$, is the sum of all recharge that falls within each zone ($Z_i$) calculated by Equation 3-6. The total recharge is equal to the total discharge, and can be represented by the following:

$$R_T = \sum_{i=1}^{n} (P_{Z_i} \times Eff_{Zi} \times A_{Zi}) = ET_{gw} + Outflow - Inflow \qquad \text{(Eq. 3-7)}$$

The recharge efficiencies for each zone can be calculated using estimated values for $ET_{gw}$, Outflow, Inflow, $P_Z$, $A_Z$, and the following general assumptions:

- $Eff_Z$ is between 0 and 1 – fraction of precipitation;
- $Eff_Z$ increases with an increase in the depth of precipitation;
- Outflow and Inflow are greater than or equal to zero.

### *3.3.2 Method Implementation*

The process followed to derive a recharge distribution for the WRFS and its basins is outlined in Figure 3-1. The groundwater-balance method was used to derive the recharge efficiencies and was implemented using the Excel Solver.

The Excel Solver is designed to find optimal solutions to numerical problems such as the one defined by Equation 3-7, in which the main variables requiring a solution are the recharge efficiencies for the WRFS. The solver finds an optimal value for a formula in one cell of the worksheet called the target cell. The solver works with a group of cells that are related, either directly or indirectly, to the formula in the target cell. Values in these cells are called parameters, which the solver adjusts to produce the desired result defined by the target cell formula. Constraints can be added to restrict the values of the parameters the solver uses. Worksheet cells containing the constraints can refer to other cells that affect the target cell.

To initialize and run the solver, the target cell, parameters, constraints, and initial parameter estimates must first be defined (Figure 3-1). To do so, the necessary data were compiled and analyzed to estimate values for these inputs. This included compiling the following information and data:

- Precipitation station data and a spatial distribution for the area encompassing the WRFS
- Hydrologic data for the WRFS to assist in defining constraints
- Geologic information and data to assist in identifying likely areas of interbasin flow
- Maps delineating groundwater discharge areas and ET classes
- ET rate data, PET data, and a PET distribution encompassing the groundwater discharge areas
- Estimates of boundary inflow and outflow
- Digital elevation model (DEM).

Additional information on the Excel Solver, including examples, can be found in the Excel 2003 version help menu and/or the "Microsoft Excel 2003 Bible" (Walkenbach, 2003; pp. 518 to 530).

Upon completion of the data compilation and analysis, estimates for the target cell, parameters and constraints were defined, and the solver initialized. The estimated groundwater ET volume was set to be the target. Recharge efficiencies were the primary parameters. Selected volumes of interbasin flow were identified as secondary parameters, some of which were constrained. Constraints on interbasin flow volumes were developed using spring and streamflow gage records, and groundwater elevations. The resultant recharge efficiencies (part of solution) were applied to the precipitation distribution to derive a recharge distribution. Using the recharge distribution, recharge estimates for each basin were calculated and used in developing the groundwater budget for the entire flow system and each of its basins. A groundwater budget for a given basin was defined by the estimates of recharge, groundwater inflow, groundwater ET, and groundwater outflow. Groundwater inflow is equal to the sum of the outflows of the contributing basins, while the groundwater outflow is the difference between the sum of the recharge and inflow, and the groundwater ET.

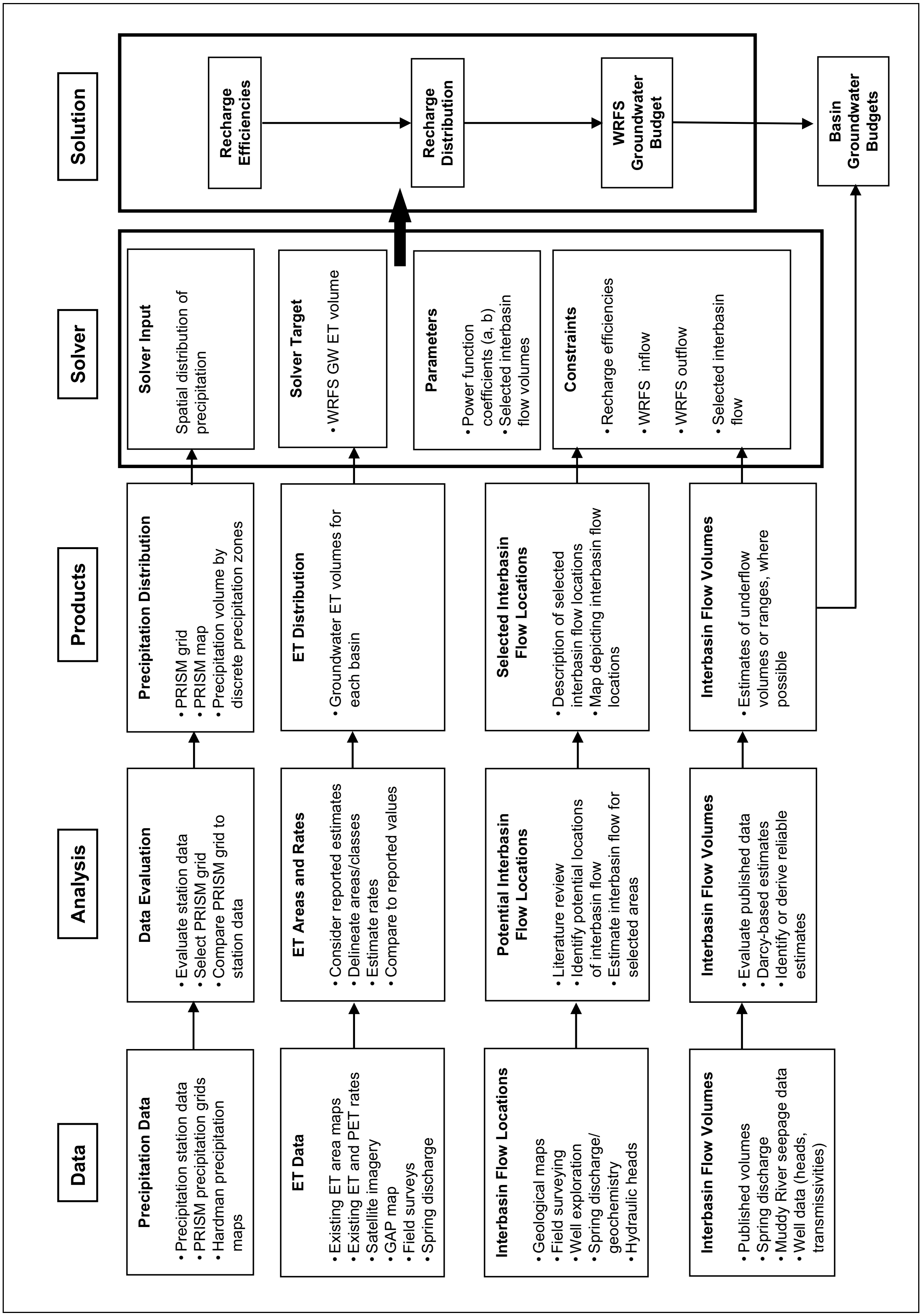


**Figure 3-1**
**Process Used to Derive Groundwater Budget for the WRFS**

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# 4.0 DATA COMPILATION AND ANALYSIS

This section describes the data compilation and analysis effort conducted in support of implementing the technical approach described in Section 3.0. Meteorologic, hydrologic, and geologic data and information were compiled and analyzed to derive estimates and work products required for the water-balance method applied in this water-resource assessment, and are presented in the following sections.

## 4.1 Precipitation Data Analysis

Precipitation is the main, if not the sole, source of groundwater recharge to the WRFS and is one of the important inputs needed to derive the groundwater recharge estimates for the flow system. This section describes the specific objective of the precipitation data analysis, the review of relevant methods and the method selection, and presents the results of the analysis.

### 4.1.1 Objective

The objective of the precipitation data compilation and analysis was to derive a spatial distribution of precipitation for the WRFS that is representative of long-term mean annual conditions. This distribution is needed for the purposes of deriving estimates of groundwater ET and a spatial distribution of recharge.

### 4.1.2 Review and Selection of Precipitation Method

Relevant methods of estimating precipitation are described, followed by the rationale for the method selected.

#### 4.1.2.1 Methods

Methods to derive precipitation distributions in Nevada include maps developed in the past by (Hardman, 1936, 1962, and 1965), the PRISM method (Daly et al., 1994, 1997 and 1998), and other precipitation-altitude regression models that have been developed for local-scale analyses.

##### Precipitation Mapping

A precipitation map for the entire state of Nevada was first produced by Hardman (1936). The map was hand-drawn and was compiled from U.S. Weather Bureau records, USGS topographic maps, and Nevada Experiment Station forage type maps. Six precipitation zones, ranging from 0 to over 20 in. of precipitation per year, were defined as follows: less than 5 in., 5 to 8 in., 8 to 12 in., 12 to 15 in., 15 to 20 in., and over 20 in. The map, also published in Hardman and Mason (1949, p. 10), was later updated by Hardman (1962 and 1965) to provide more detail in the southern Nevada area. This updated map was later revised by the Nevada State Engineer (Scott et al., 1971). The first Hardman map (1936) was used to develop and apply the Maxey-Eakin method (Maxey and Eakin, 1949) for estimating annual groundwater recharge in Nevada.

#### *PRISM*

The PRISM method is a mapping model designed to generate spatial distributions of precipitation, temperature, or other climate variables (Daly et al., 1994, 1997, and 1998). The PRISM method was developed through a partnership between the Natural Resources Conservation Service (NRCS) National Water and Climate Center and the Prism Group at Oregon State University. PRISM is claimed as "*the production of the best and, in many cases, the first high-spatial-resolution climate map products for the United States*" (http://www.wcc.nrcs.usda.gov/climate/prism.html). The basic information used in the model consists of point measurements of precipitation, temperature, or other climate variables made at observation stations. In addition to point data, the PRISM model utilizes a DEM, and incorporates natural phenomena affecting the spatial distributions including rain shadows, coastal effects, and temperature inversions. Products include grids of precipitation, temperature, and other climate variables for a given period of time; and monthly, yearly, and event-based climatic parameters. The PRISM model has been used to estimate precipitation for each state of the United States, including Nevada (Daly et al., 1998).

#### *Precipitation-Altitude Regression Models*

Precipitation-altitude regression models have been developed for many areas of Nevada to derive precipitation distributions and to estimate precipitation volumes, including but not limited to those of Quiring (1965), Daly et al. (1994), Maurer and Halford (2004), and SNWA (2006). In most instances, these relationships were developed to verify estimates derived by other methods or to revise historical estimates by incorporating new data, information, and technology. The regression models are defined by equations that express the relationship between precipitation and altitude based on station data compiled from various sources. The equation can be applied to DEMs to derive precipitation distributions. Typically, the regression models are developed for local-scale (e.g., hydrographic area) analyses where the data density is relatively high.

### *4.1.2.2 Selection of Precipitation Method*

The PRISM method (Daly et al., 1994, 1997, and 1998) was selected for the precipitation distribution of the WRFS. The PRISM datasets including those of precipitation represent state-of-the art distributions at the basin and regional scales and are widely-accepted and recognized world-wide as the highest-quality spatial climate datasets currently available. The U.S. Department of Agriculture, for example, adopted PRISM as their official climatological dataset. Precipitation distributions developed using the PRISM method utilize modern tools and incorporate more recent data and information not reflected in previous mapping efforts. More recent data include additional stations and precipitation records. Development of a separate precipitation-regression model was rejected as it would be limited by the data availability and would be duplicative of the PRISM work.

### 4.1.3 Precipitation Data

Both precipitation station data and PRISM precipitation grids were compiled for this analysis. A PRISM precipitation grid was used to provide a spatial distribution of precipitation, while the station data were used to assess the validity of the PRISM-based distribution.

Precipitation station data were compiled, and the mean annual value for the period of record was derived for each station. Summary data for the stations located within and near the WRFS are listed in Table A.1-1 and presented in Figure 4-1.

Several PRISM precipitation grids are available on the Internet (such as at http://www.ocs.oregonstate.edu/prism/products/). The grids include precipitation distributions for various periods of time and at different resolutions. All PRISM precipitation grids are based on the 1-degree DEM grid at website http://edcwww.cr.usgs.gov/Webglis/glisbin/guide.pl/glis/hyper/guide/usgs_dem. The station precipitation data used to generate the PRISM maps are not available to the public. The most recent normal grid (800-m 1971 to 2000 normals, Version 2; May 3, 2007) is considered to be the best-quality product to date and was deemed appropriate for the purposes of this regional water-resource assessment. Figure 4-2 depicts the PRISM precipitation distribution within the WRFS and vicinity and a relative comparison of the model fit at the precipitation station locations.

## 4.2 Regional Groundwater Discharge

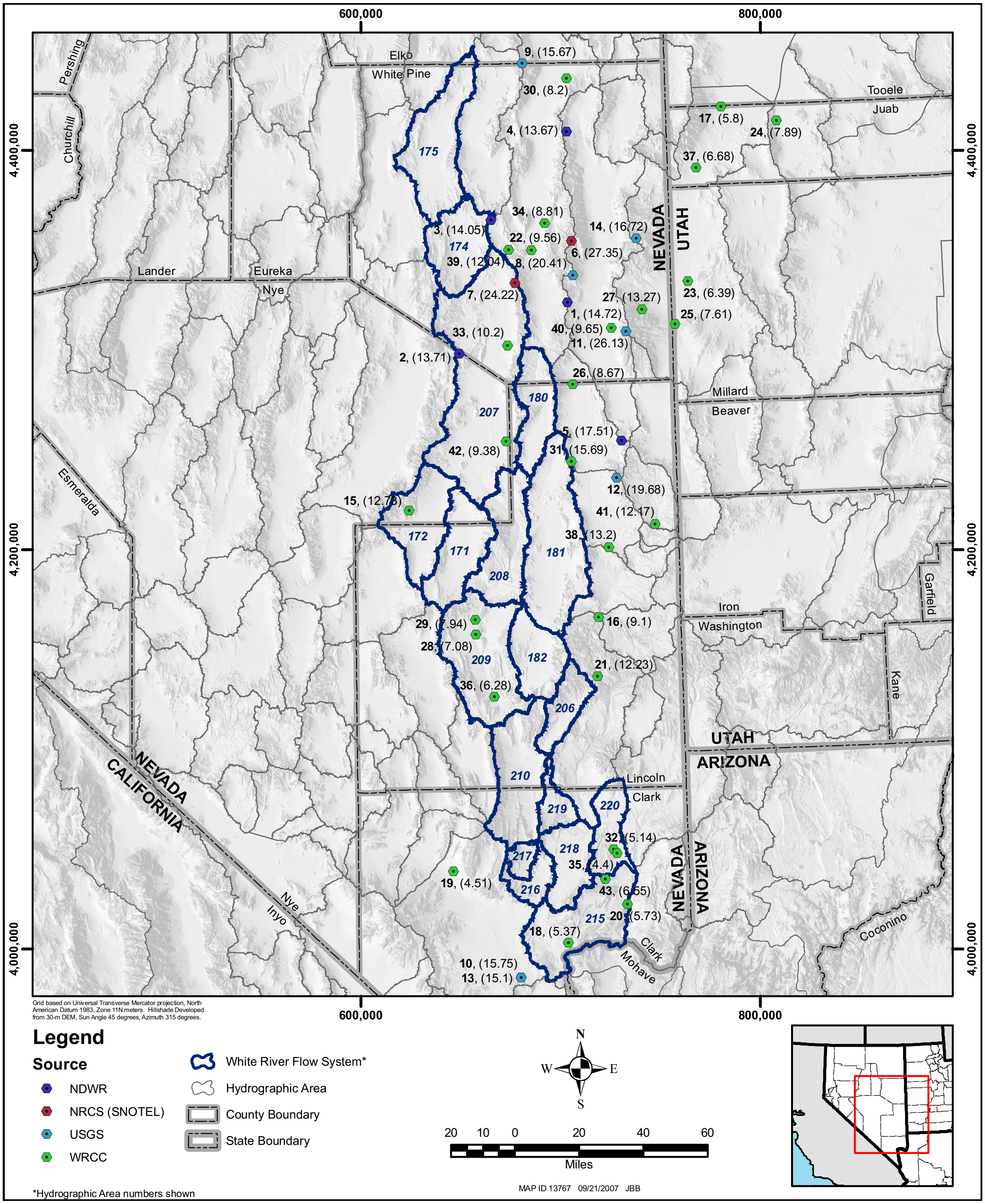
Within the WRFS, regional groundwater discharge occurs in the form of ET, spring discharge, and inter-basin outflow. This section describes the data compilation and analysis that was performed to derive estimates of regional groundwater discharge for the WRFS, including the delineation of regional groundwater discharge areas and ET-class zones, compilation of ET and PET rate data, and derivation of a spatial distribution of PET. Additionally, spring discharge data were compiled for the purpose of constraining the lower bound of groundwater discharge within these areas. The underlying assumption is that the spring discharge is fully consumed by ET within the discharge area or becomes part of the underflow or surface water discharge to the next downgradient basin.

### 4.2.1 Groundwater ET

Groundwater ET within the WRFS is the largest source of groundwater discharge. As such, it plays a prominent role in the water-balance approach used in this water-resource assessment. The objective and technical approach of the data compilation and analysis used to derive groundwater ET estimates are described in the following sections.

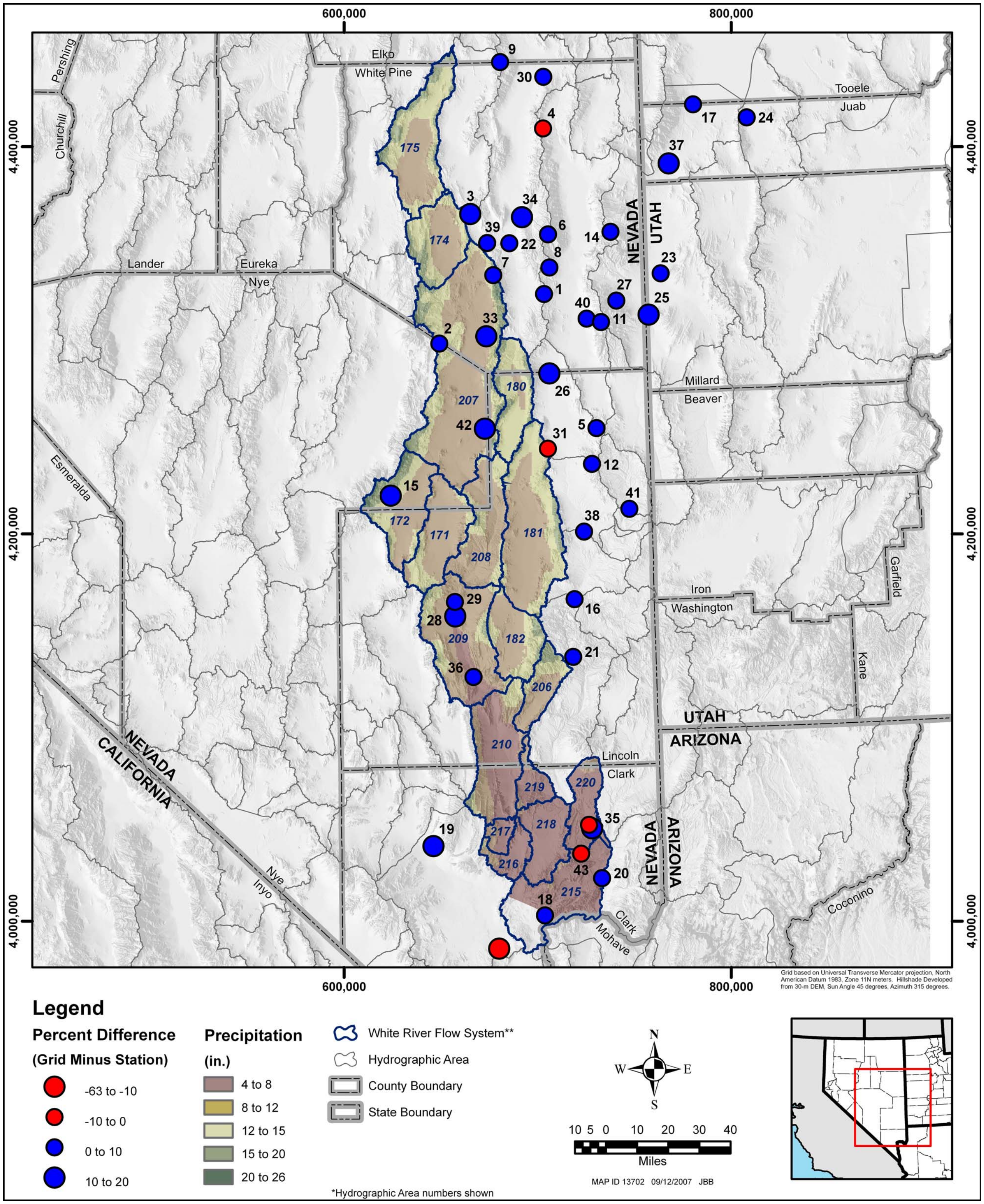
#### 4.2.1.1 Objective

The objective of the ET data compilation and analysis was to derive an estimate of the total groundwater ET volume for the WRFS for use as the target value in the water balance method to estimate groundwater recharge from precipitation.




Note: See Table A.1-1 for names of precipitation stations.

**Figure 4-1**
**Location of Precipitation Stations and Mean Annual Precipitation within the WRFS and Vicinity**




Note: See Table A.1-1 for names of precipitation stations.

**Figure 4-2**
**PRISM Precipitation Distribution within the WRFS and Vicinity, and Percent Difference between PRISM and Precipitation-Station Data**

#### 4.2.1.2 Technical Approach

To estimate the mean annual groundwater ET for the WRFS, it was necessary to estimate mean annual groundwater ET for each of its basins that are representative of predevelopment conditions. Deriving estimates of groundwater ET for the groundwater discharge areas of the WRFS required the compilation and analysis of ET and PET rate data from previous investigations, analysis of satellite imagery, and field investigation. This resulted in interim work products that were used to derive the estimates and included maps delineating the boundaries of the regional groundwater discharge areas and the ET classes within those boundaries, and a spatial distribution of PET. This work included the following steps:

1. Delineate regional groundwater discharge areas and define ET classes.
2. Compile ET rate data from published literature for defined ET classes.
3. Compile PET data and derive spatial distribution of PET.
4. Scale ET rates using PET distribution.
5. Calculate volume of precipitation falling within ET areas.
6. Derive groundwater ET estimates.

#### 4.2.1.3 Regional Groundwater Discharge Areas and ET Classes

Delineation of the regional groundwater discharge areas and ET classes for the WRFS relied upon maps and information from previous investigations including the USGS Reconnaissance Reports Series and Water Resource Bulletins, Nichols (2000), and LVVWD (1994 and 2001). Boundaries were refined through the use of satellite imagery, aerial photography, field investigation, and assumptions used to account for irrigated lands that were nonexistent under predevelopment conditions. The Southwest Regional Gap Analyses Project (GAP) data (USGS, 2004) and the National Land Cover Data (NLCD, 1992) were used in instances where other information was insufficient. The primary use of the GAP and NLCD data was to aid in the identification of playas located in the study area. They were also used to confirm other datasets or flag otherwise undetected potential phreatophytic areas for further investigation. Boundaries of many, but not all of the discharge areas were field-verified during the summer of 2004 and modified as needed using high-resolution global positioning system equipment. Five ET classes were defined and delineated using the Normalized Difference Vegetation Index and Landsat 7 Thematic Mapper 2002 satellite imagery. These classes are presented in Table 4-1.

The groundwater ET areas were then adjusted by determining where agricultural land had likely displaced what would otherwise be phreatophytes under predevelopment conditions. For these agricultural lands, the acreage was reclassified to the ET class reflected in the natural vegetation surrounding the fields. Agricultural lands outside the groundwater discharge areas were not included in the total acreages. Maps depicting the resulting groundwater discharge areas and the spatial distribution of the ET classes were prepared for the HAs that have groundwater discharge areas, including:

- Long Valley (HA 175)
- Jakes Valley (HA 174)
- White River Valley (HA 207)

**Table 4-1**
**ET Classification**

| ET Class | Description |
|---|---|
| Open Water | Bodies of open water fed by groundwater sources (springs, seeps, etc.) |
| Wetland/Meadow | Area of shallow groundwater near bodies of open water consisting of wetland vegetation, marshland, or dense meadows. |
| Dense Meadow/Riparian | Area dominated by dense meadow and woodland vegetation; includes riparian corridors consisting of salt cedar, desert willows, cottonwood, and mesquite trees with underlying shrubs and grasses; includes areas near open water consisting of dense wetland vegetation. |
| Medium-Density Phreatophytes | Area dominated by desert shrubland vegetation, including mixed stands of medium density greasewood, rabbit brush, or other phreatophyte species. |
| Bare Soil/Low-Density Phreatophytes | Area dominated by bare soil and low- to moderate-density desert shrubland, including greasewood, rabbit brush, or other phreatophytic species. |

- Cave Valley (HA 180)
- Garden Valley (HA 172)
- Pahranagat Valley (HA 209)
- Muddy River Springs Area (Upper Moapa Valley) (HA 219)
- California Wash (HA 218)
- Lower Moapa Valley (HA 220)
- Black Mountains Area (HA 215).

These maps and descriptions of the groundwater discharge areas of each valley are provided in Appendix B. The total acreage delineated for the groundwater discharge areas and each ET class are provided in Table 4-2, listed by HA name and from the northern portion of the flow system to the south.

### *4.2.1.4 Compilation of ET and PET Rate Data*

A literature survey for annual ET rates measured in and near the WRFS was conducted, and the rates were compiled into the dataset presented in Table B.1-2. These ET rates were reviewed to select a single most appropriate rate for each of the five ET-unit classes defined for this analysis. The rate selected for each class was based on the similarity between the vegetation types and climate. The selected ET rates are presented Table 4-3, and the measurement sites are depicted in Figure 4-3.

Except for the “Bare Soil/Low Density Vegetation” class, the rates from the ET measurement sites were scaled to the groundwater discharge areas of the WRFS using values of PET extracted from a spatial distribution of PET. A total ET rate of 1.00 ft/yr was assumed for the “Bare Soil/Low Density Vegetation” class for all such areas in the WRFS based on the average rates for sparse and medium dense desert shrubland classes reported in Welch and Bright (2007). The PET distribution was derived from a linear regression model of PET versus latitude Y and altitude Z expressed by the following equation:

$$PET = 104.3531 - 0.82922734Y - 0.004186006Z \qquad \text{(Eq. 4-1)}$$

## Table 4-2
## Groundwater Discharge Areas in Acres, by ET Class for the WRFS

| HA Name | Open Water | Wetland/ Meadow | Dense Meadow/ Riparian | Medium-Density Phreatophytes | Bare Soil/ Low-Density Phreatophytes | Total[a] |
|---|---|---|---|---|---|---|
| Long Valley | -- | 131 | -- | 10,723 | 6,739 | 17,594 |
| Jakes Valley | -- | 346 | -- | 621 | 4 | 971 |
| Cave Valley | -- | 1,084 | -- | 9,651 | 5,914 | 16,648 |
| White River Valley | 313 | 27,958 | -- | 87,786 | 28,636 | 144,692 |
| Garden Valley | -- | -- | 929 | -- | 21 | 950 |
| Pahranagat Valley | 1,296 | -- | 7,101 | -- | 260 | 8,658 |
| Muddy River Springs Area | -- | -- | 1,785 | -- | 166 | 1,951 |
| California Wash | -- | -- | 1,342 | -- | 37 | 1,379 |
| Lower Moapa Valley | 137 | -- | 6,900 | -- | 496 | 7,533 |
| Black Mountains Area | -- | -- | 409 | -- | 54 | 464 |

[a]Values were not rounded, to allow calculations to be tracked during analysis and reporting.

## Table 4-3
## ET and PET Rates Used in the Derivation of ET Estimates for the WRFS

| ET-Unit Class | Selected ET Site | Description of Selected ET Site | Total ET or Evaporation Rate (ft/yr) | Source | PET Rate Extracted from PET Grid (ft/yr) |
|---|---|---|---|---|---|
| Open Water | Peterson Reservoir | Open water supplied by spring discharge. | 8.60 | Reiner et al., 2002, Table 4, p. 29 | 5.42 |
| Wetland/ Meadow | SPV-3 | Wetland/meadow land cover surrounding riparian corridors throughout the project area. | 2.25 | Moreo et al., 2007, Table 7, p. 20 | 4.00 |
| Dense Meadow/ Riparian | Springdale | Area dominated by dense meadow and woodland vegetation, primarily trees, meadow and marsh grasses, or mixed trees, shrubs, and grasses; trees, desert ash and cottonwood, with some desert willow and mesquite; water table typically ranging from above land surface to about 20 ft-bgs; soil wet to moist. | 3.30 | Reiner et al., 2002, Table 4, p. 29 | 4.84 |
| Medium Density Phreatophytes | WRV-1, WRV-2, and SPV-2 | Medium-density phreatophytes, greasewood and shrubs like sagebrush. | 1.03[a] | Moreo et al., 2007, Table 7, p. 20 | 4.13 |
| Bare Soil/Low-Density Phreatophytes | Long-Term Mean Rate/ BARCASS Region | Areas within the phreatophytic boundaries that exhibited ground cover densities of less than 20% were considered to be either bare soil or having sparse vegetation cover. | 1.00[b] | Welch and Bright, 2007, Figure 27, p. 58 | 4.11 |

[a]Average ET from WRV-1, WRV-2 and SPV-2
[b]This value is the average of the area-weighted average annual ET for ET Units 7 and 8 reported in Welch and Bright (2007)

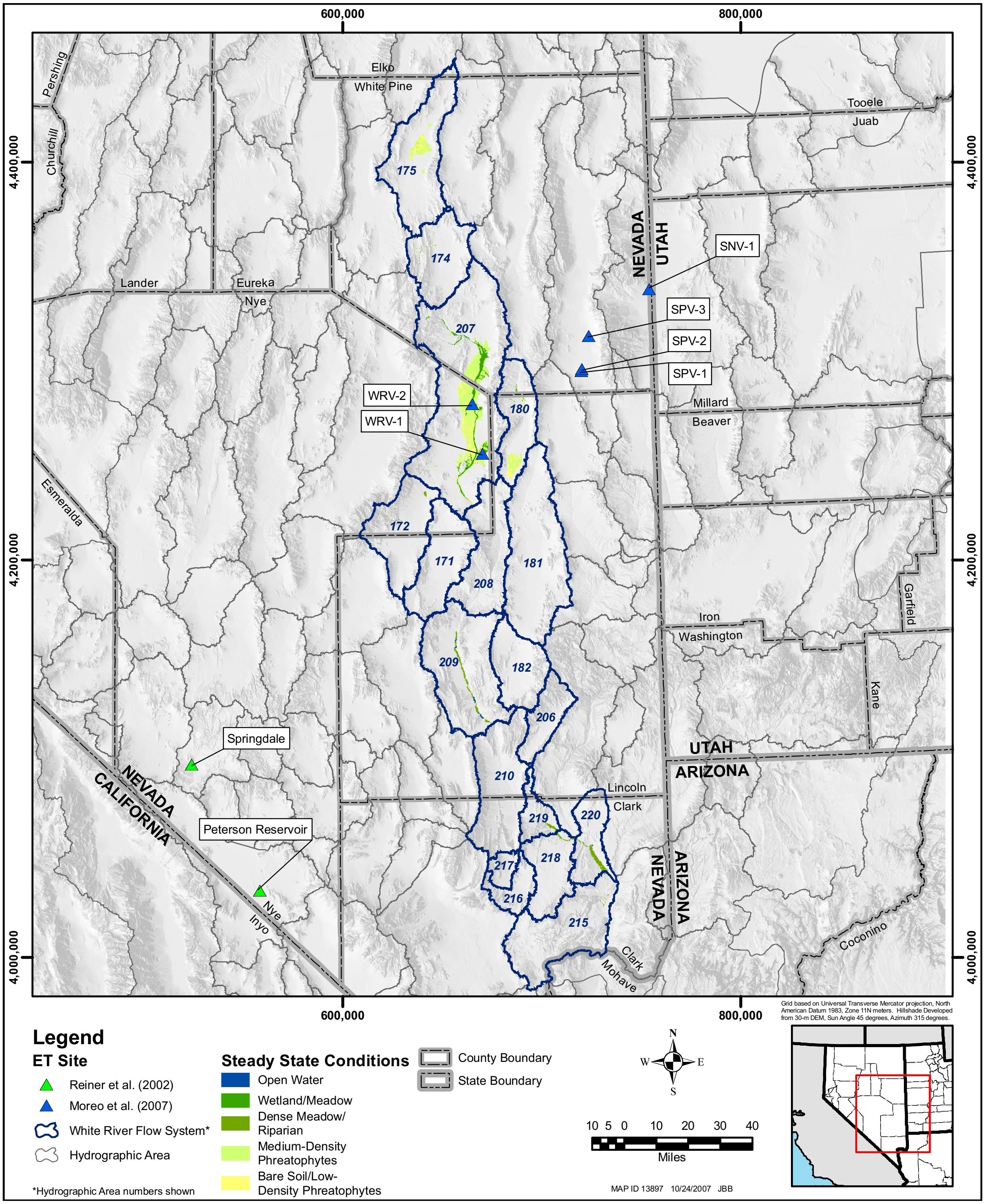



**Figure 4-3**
**ET Measurement Sites within the WRFS and Vicinity**

where,

| | | |
|---|---|---|
| PET | = | potential ET (in./yr) |
| Y | = | latitude (NAD, 1983) |
| Z | = | altitude in ft-amsl (NAVD, 1988) |

The regression model was derived using estimates of PET reported in McCurdy and Albright (2004). McCurdy and Albright (2004) calculated PET for existing meteorological stations within the WRFS and vicinity using the Kimberly-Penman method (Wright, 1982) and the Hargreaves-Saman (1985) equation. Using GIS gridding operations, the spatial distribution of PET was derived by applying Equation 4-1 to a 100-m resolution DEM based on the USGS 30-m DEM (USGS, 2001). The meteorological station locations and their estimated PET values are depicted in Figure 4-4 with the resultant PET distribution that was derived for the WRFS.

Several measurements of ET rates are available for the study area and vicinity (Table 4-3). Prior to assigning these rates to the ET classes in the study area, they were adjusted to the local conditions. The adjustment consisted of scaling them by multiplying their values by the ratio of the average PET for a given groundwater discharge area and the PET at the measurement site. The values used to calculate this ratio were extracted from the PET distribution grid. The resultant scaled ET rates are presented in Table 4-4.

#### *4.2.1.5 Derivation of Groundwater ET Estimates*

Estimates of the annual groundwater discharge for regional discharge areas within the WRFS were derived using the acreages delineated for each of the ET classes, scaled ET rates and the PRISM precipitation grid described in Section 4.1. For a given basin, the total ET for each ET class was calculated by multiplying the acreage by the scaled ET rate. The groundwater ET for each class was calculated by subtracting the volume of precipitation from the total ET. The total groundwater discharge by ET was calculated by summing the groundwater discharge volumes for each class. The estimates of groundwater discharge by ET for each basin are presented in Table 4-5, which also includes the estimates derived by other investigators for comparison.

With the exception of two basins, White River Valley and the Muddy River Springs Area, the estimated groundwater ET volumes compare reasonably well with estimates reported in the Reconnaissance Series Reports (Table 4-5). For White River Valley, the estimated groundwater ET volume of 67,342 afy falls within the range of previous estimates: 37,000 afy (Eakin, 1966; p. 261; Scott et al., 1971, p. 50) and 79,560 afy (LVVWD, 2001; p. 4-35). The large range can be attributed to the different acreages delineated for the groundwater discharge area. These are listed for each basin in Table B.1-1 in Appendix B. The estimate reported by Eakin (1966) is comparatively low, in part, because the delineation of the groundwater discharge area did not include the large area of low-density shrubland that is observed today (Maxey and Eakin, 1949 p. 44). By contrast, all of the more recent studies have included this area, or part of this area. For White River Valley, the total acreage delineated for the groundwater discharge area ranges from about 36,000 (Maxey and Eakin, 1949, p. 44) to 178,000 acres (Smith et al., 2007, p. 15, tbl. 4). The acreage delineated by this study is about 145,000 acres which falls within the range of the three previous estimates. Depth to groundwater is an important a hydrologic factor influencing the distribution of phreatophytes, and

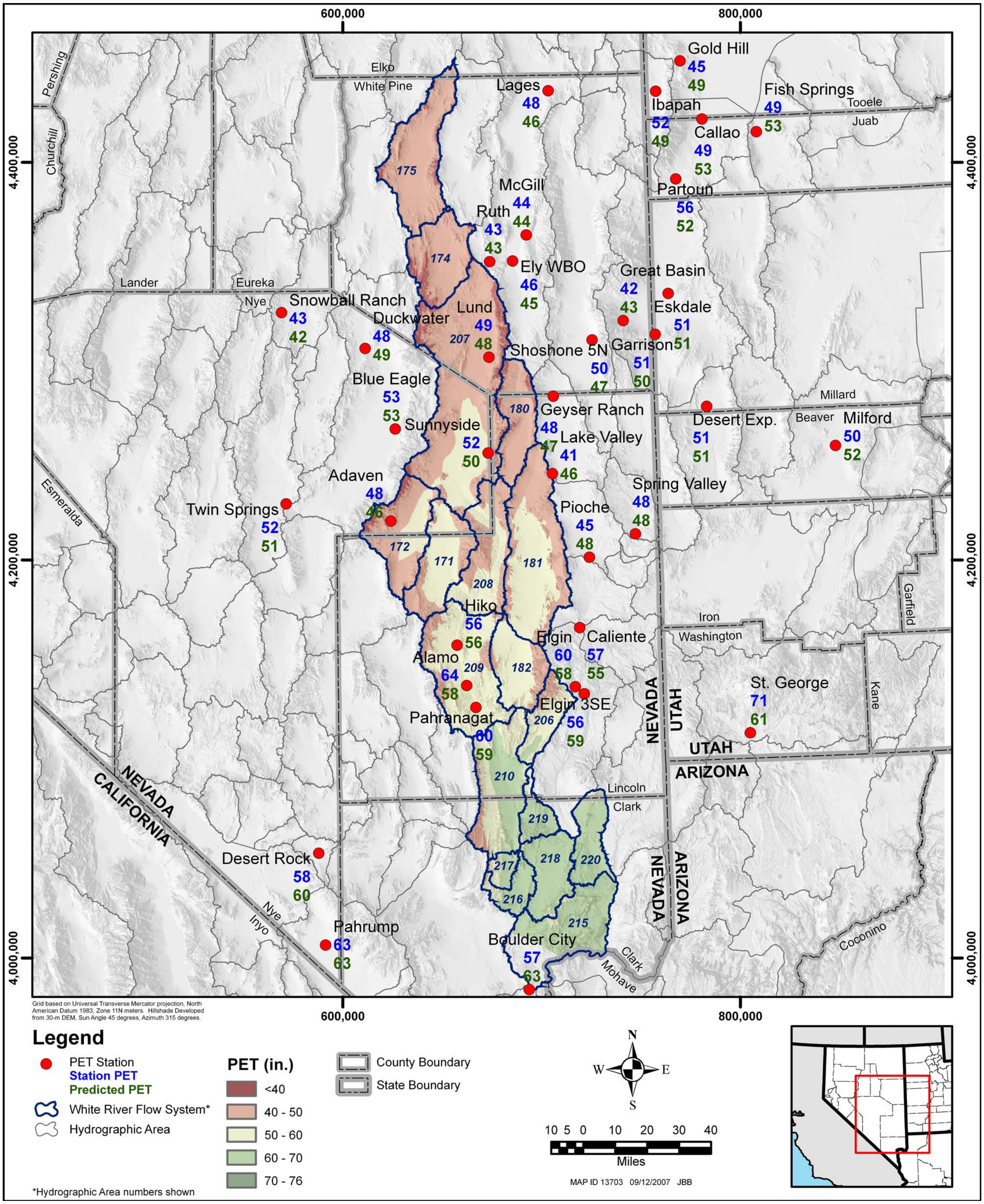



**Figure 4-4**
**Meteorological Station Locations and Distribution of PET within the WRFS**

## Table 4-4
## Average PET Rates for Groundwater Discharge Areas and Scaled ET Rates

| HA Name | Average PET Rate for GW Discharge Area | Open Water | Wetland Meadow | Dense Meadow/ Riparian | Medium Dense Phreatophytes | Bare Soil/Low Density Phreatophytes |
|---|---|---|---|---|---|---|
| Long Valley | 3.82 | -- | 2.14 | -- | 1.18 | 1.00 |
| Jakes Valley | 3.61 | -- | 2.02 | -- | 1.12 | 1.00 |
| Cave Valley | 3.87 | -- | 2.17 | -- | 1.03 | 1.00 |
| White River Valley | 4.18 | 6.63 | 2.34 | -- | 1.04 | 1.00 |
| Garden Valley | 4.13 | -- | -- | 2.82 | -- | 1.00 |
| Pahranagat Valley | 4.84 | 7.68 | -- | 3.30 | -- | 1.00 |
| Muddy River Springs Area | 5.52 | -- | -- | 3.77 | -- | 1.00 |
| California Wash | 5.57 | -- | -- | 3.80 | -- | 1.00 |
| Lower Moapa Valley | 5.71 | 9.06 | -- | 3.89 | -- | 1.00 |
| Black Mountains Area | 5.69 | -- | -- | 3.88 | -- | 1.00 |

## Table 4-5
## Groundwater ET Estimates for the WRFS

| HA Name | SNWA (2007) | | Welch and Bright (2007)[b] (afy) | LVVWD (2001)[b] (afy) | Eakin (1966) & Rush (1968) (afy) |
|---|---|---|---|---|---|
| | Acreage | Groundwater ET[a] (afy) | | | |
| Long Valley | 17,594 | 2,952 | 1,233 | 11,000 | 2,200 |
| Jakes Valley | 971 | 392 | 858 | 600 | 0 |
| Cave Valley | 16,648 | 1,285 | 1,550 | 4,823 | 200 |
| White River Valley | 144,692 | 67,342 | 76,701 | 79,560 | 37,000[c] |
| Garden Valley | 950 | 1,696 | – – | 4,608 | 2,000 |
| Pahranagat Valley | 8,658 | 28,516 | – – | 38,369 | 25,000 |
| Muddy River Springs Area | 1,951 | 5,989 | – – | 5,080 | 2,300 |
| California Wash | 1,379 | 4,505 | – – | 5,760 | 6,700[b] |
| Lower Moapa Valley | 7,533 | 25,311 | – – | 26,505 | 24,000[b] |
| Black Mountains Area | 464 | 1,432 | – – | – – | 1,200 |
| **Total** | **200,840** | **139,424** | – – | **176,305** | **100,600** |

[a]Values were not rounded, to allow calculations to be tracked during analysis and reporting.
[b]Includes areas irrigated by groundwater
[c]Value based on spring discharge estimates (Eakin, 1966; p. 261)

could be used to refine the extent of the groundwater discharge areas; however, the depth to water is not well defined in this area.

The groundwater ET volume for Muddy River Springs Area ranges between 2,300 afy (Eakin, 1966, p. 261) and 5,989 afy (this study). Although the value derived in this study is the maximum, it is essentially the same estimate as the 5,080 afy derived by LVVWD (2001, p. 4-35, tbl. 4-8).

### *4.2.2 Spring Discharge*

For groundwater discharge areas where gaged springs are present, estimates of groundwater discharge based on the spring discharge records can be used to estimate the components of the groundwater budget. As stated previously, the spring discharge is assumed to ultimately be part of the underflow and/or ET. Therefore, the total groundwater discharge from a given basin cannot be lower than the measured spring discharge.

#### *4.2.2.1 Objective*

The objective of the spring data compilation and analysis was to identify springs within groundwater discharge areas of the WRFS that have discharge records reporting mean annual flows or have the necessary records from which mean annual flows can be calculated. This information was not used explicitly in the water-budget calculations.

#### *4.2.2.2 Compilation of Spring Discharge Records*

Many regional springs occur within the basins of the WRFS, particularly within the regional groundwater discharge areas of White River and Pahranagat valleys and the Muddy River Springs Area. Spring data for these areas were compiled from the literature. Maps in Appendix B depict the locations of these springs with respect to the groundwater discharge areas in which they occur.

Available spring discharge records were compiled for springs in the following basins: White River Valley, Pahranagat Valley, and the Muddy River Springs Area. These records are presented in Appendix C. A summary of the spring discharges for the three selected basins follows.

Two relatively important springs occur in the Black Mountains Area hydrographic area (Figure B.1-11), and were accounted for in the estimate of underflow to the Colorado River (see Section 4.3).

##### *White River Valley*

The groundwater discharge area in White River Valley contains a number of springs. Spring discharge measurements for 18 springs are listed in Table C.1-1. The most significant of these springs are Hot Creek Spring, Arnoldson Spring, Preston Big Spring, Lund Spring, Flag Springs, Butterfield Spring, Nicholas Spring, and Moon River Spring. The total average annual discharge measured at these springs is 47.6 cfs or 34,462 afy. This discharge is assumed to represent the lower bound of groundwater discharge, as there are many springs within the area whose flow is not measured. It is lower than the estimated groundwater ET, 67,342 afy. The fact that the estimated volume of groundwater ET is larger than the volume of regional spring flow, is a good indication of the validity of the ET estimate.

### *Pahranagat Valley*

The groundwater discharge area in Pahranagat Valley contains a number of springs. Most notable are the Hiko Springs, Solar Panel Spring, Crystal Springs, Ash Springs, and Brownie Spring. Other smaller springs and seeps occur in the southern portion of the discharge area. Hiko, Crystal, and Ash springs have the most significant discharge and, when combined, produce a total spring discharge of about 35 cfs or about 25,000 afy (Eakin, 1963b, p. 19-20). This value is lower than the estimated volume of groundwater ET, 28,516 afy and is indicative of the validity of the ET estimate.

### *Muddy River Springs Area*

The Muddy River Springs Area contains several large thermal spring groups and seeps. These springs represent the principal source of groundwater discharge in the southern portion of the WRFS and form the headwaters of the Muddy River. The Muddy River near Moapa gage (09416000) measures the combined spring discharge from the Muddy River Springs Area. From 1913 to 1918, the mean daily discharge at this location was 46.8 cfs and the mean annual discharge was approximately 34,000 afy (Wells, 1954, p. 566). From 1914 to 1962, the mean annual discharge was reported (46.5 cfs) as 33,700 afy (Eakin, 1964, p. 14, 15, 16, 18). These measurements account for the flow observed at the gage but not the consumptive uses by the riparian vegetation along the spring channels and river corridor, or by the phreatophytes that likely existed in the area during predevelopment conditions. Eakin (1964) estimated 2,000 to 3,000 afy was being consumed by phreatophytes between the spring area and the gaging station. The analysis conducted for this study estimates that there was approximately 6,000 afy of groundwater ET prior to the extensive groundwater development within the area that exists today. Based on these estimates and the estimated mean annual flow at the Muddy River near Moapa gage, predevelopment groundwater discharge from the Muddy River Springs Area is on the order of 40,000 afy. In this case, the spring flow volume of 34,000 afy is less than the groundwater ET estimate of 6,000 afy, but the total, 40,000 afy, constitutes a lower bound for groundwater inflow to this basin.

## *4.3 Interbasin Flow*

Locations where groundwater flow occurs across basin boundaries were identified based on the prevailing hydrogeology, including lithology and geologic structure. Figure 4-5 depicts their locations using arrows superimposed onto a hydrogeologic map of the WRFS extracted from Dixon et al. (2007). The relative magnitude of the flow volumes is depicted using small or large arrows. Most of the interbasin flow occurs across internal basin boundaries. External interbasin flow occurs at two locations only, as discussed below. Summary descriptions of interbasin flow at the external boundary of the WRFS and through selected internal basin boundaries are also provided below. The detailed descriptions are presented in Appendix D.

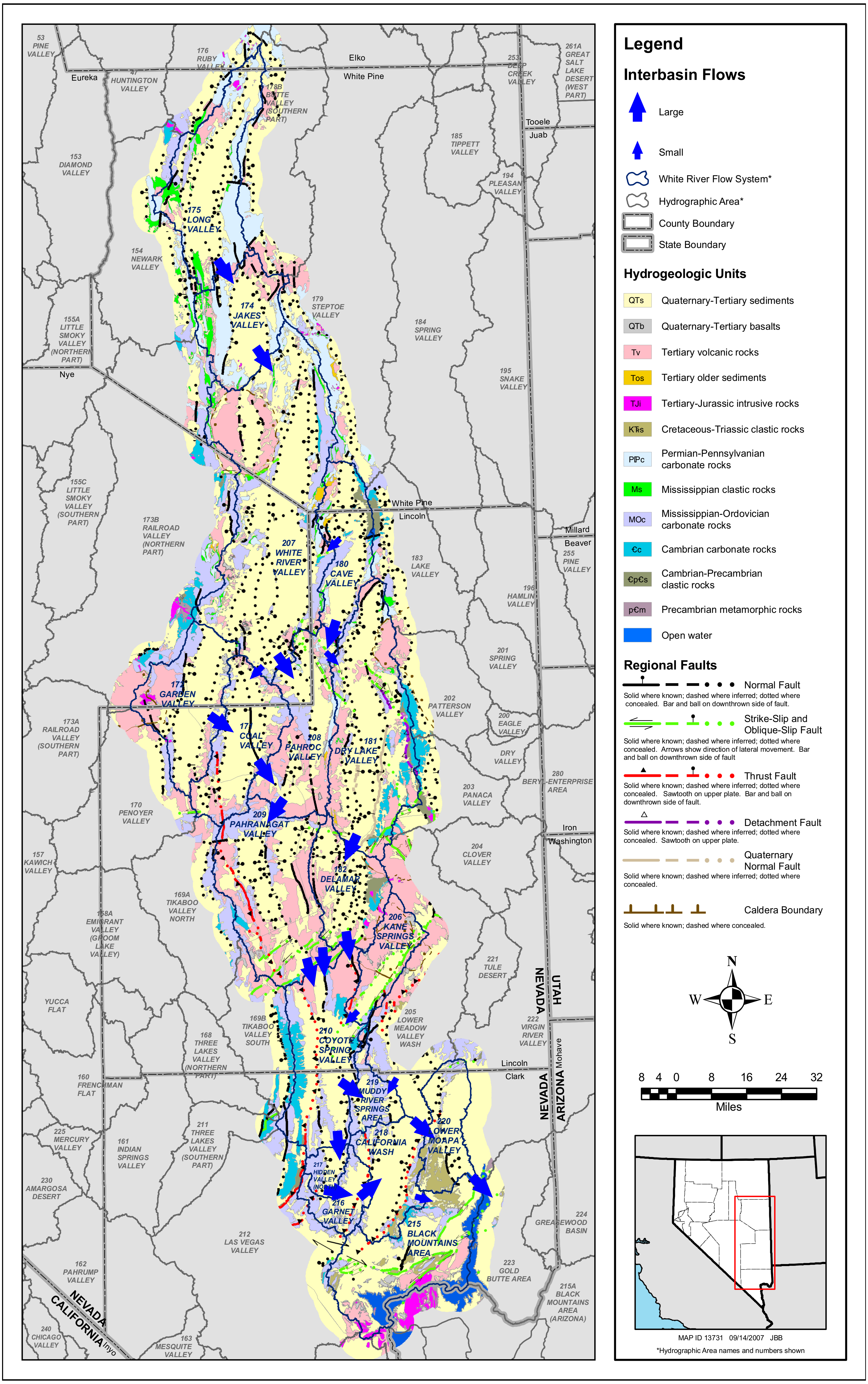



**Figure 4-5**
**Potential Locations of Interbasin Flow Based on the Hydrogeologic Framework**

### *Estimates of External Interbasin Flow*

As shown in Figure 4-5, significant external boundary flow into and out of the WRFS likely occurs by (1) inflow to the WRFS from Lower Meadow Valley Wash and (2) outflow from the WRFS to the Colorado River (currently Lake Mead).

Groundwater inflow to the WRFS originates from Lower Meadow Valley Wash. This inflow occurs through the underlying valley-fill sediments and carbonate rocks. The magnitude of this flow has been estimated by Rush (1968 p. 26), Kirk and Campana (1990 p. 370, 371, 372); Thomas et al. (1996, p. C36), Prudic et al. (1995 p. D71), and Thomas et al. (1996 p. C36) at 7,000 afy, 5,500 to 9,000 afy, 13,000 afy, and 8,000 afy, respectively. The average volume of about 9,200 afy is used in this study. A portion of this inflow, 4,000 afy, was estimated to enter the Muddy River Springs Area. The remainder, 5,200 afy, likely enters the WRFS at the boundary of California Wash basin.

Reported estimates of boundary outflow from the WRFS to the Colorado River range from 11,100 afy (Rush, 1968, p. 24 and 26) to 49,000 afy (LVVWD, 2001, p. 6-3) and include both subsurface outflow and a groundwater component of the surface water flows reaching the Colorado River. For this analysis, groundwater outflow to the Colorado River is estimated to be at least 25,000 afy based on the following components: (1) groundwater component in Muddy River of 7,000 afy, (2) total groundwater outflow from Black Mountains Area of 2,000 afy, and (3) subsurface outflow of 16,000 afy. The estimate of 25,000 afy used in this study falls within the range of reported estimates.

### *Estimates of Internal Interbasin Flow Volumes at Selected Locations*

Several areas of potential interbasin flow within the boundaries of the WRFS have also been identified and are depicted on Figure 4-5. It is necessary to estimate some of these interbasin flow volumes to constrain the recharge solution and to distribute the resulting volume to the individual basins. Interbasin flow locations were selected based on the availability of sufficient information to derive estimates of the expected volumes or bounding values. The following interbasin flow locations were selected for estimation: (1) the outflow volume from White River Valley to Pahroc Valley, (2) the total groundwater inflow to the Muddy River Springs Area, (3) outflow from Coyote Spring Valley to Hidden Valley, and (4) the volumes of interbasin flow across the boundaries of the three project basins, Cave, Dry Lake, and Delamar valleys. Estimates of flow volumes for items (1) and (2) were obtained from the literature and are provided below. Flow volumes for items (3) and (4) were estimated as part of this study (Appendix D) and are summarized in this section.

### *Outflow from White River Valley to Pahroc*

Groundwater outflow from White River Valley to Pahroc Valley was estimated by Maxey and Eakin (1949, p. 45) to be about 19,000 afy. Because of the uncertainty of the estimate, Maxey and Eakin (1949) also estimated a lower bound for the outflow based on (1) the total spring flow of Hot Creek Spring, at the time 11,000 afy, (2) an estimate of ET between this spring and the southern end of the valley of 4,000 afy, and (3) an estimated streamflow of about 700 afy exiting the valley. The groundwater outflow from the valley was estimated by subtracting from the total spring flow, the sum of the estimated ET between the spring and the southern end of the valley and the estimated streamflow exiting the valley. This calculation yielded a groundwater outflow estimate of 6,300 afy (Maxey and Eakin, 1949, p. 45). Considering that several other unmeasured springs contribute to the

ET in this lower section of the valley, it is likely that total volume is somewhat greater than 6,300 afy; therefore, this value was considered the minimum for this study. The maximum volume of outflow was estimated by Eakin (1966, p. 265) at 40,000 afy.

### *Total Inflow to the Muddy River Springs Area*

Groundwater inflow to the Muddy River Springs Area is interpreted to originate mostly from Coyote Spring Valley, with a relatively smaller volume from Lower Meadow Valley Wash (Figure 4-5). Because most of the groundwater outflow from the Muddy River Springs Area occurs as Muddy River streamflow and groundwater ET, the lower bound of the estimate of total inflow to the area can be made using Muddy River gage records and an estimate of ET above the gage. As described in Section 4.2.2, the mean annual streamflow at the Muddy River near Moapa (09416000) gage is about 34,000 afy (based on estimates of 34,000 afy by Wells [1954, p. 566] and 33,700 afy by Eakin [1964, p. 15, 16]). As part of this study, approximately 6,000 afy of groundwater ET was estimated to occur prior to the extensive development of groundwater within the area. Therefore, the total inflow to the Muddy River Springs Area used in this study is assumed to be larger than or equal to 40,000 afy.

### *Outflow from Coyote Spring Valley to Hidden Valley*

Outflow from Coyote Spring Valley to Hidden Valley is likely to occur within the carbonate-rock aquifer. Although no carbonate wells have been drilled in Hidden Valley, carbonate wells where aquifer tests have been conducted exist in Coyote Spring Valley, Garnet Valley, and California Wash. Using carbonate wells located in these valleys located upgradient and downgradient from Hidden Valley, the outflow from Coyote Spring Valley to Hidden Valley has been estimated to be about 15,000 afy, which may constitute a maximum value. These estimates are comparable to the estimates of 16,000 afy derived by LVVWD (2001, p. 6-3). A detailed estimate is provided in Appendix D.

### *Interbasin Flow across the Boundaries of Cave, Dry Lake, and Delamar Valleys*

The majority of the interbasin flow for Cave, Dry Lake, and Delamar valleys occurs as groundwater outflow from Cave Valley to the southern third of White River Valley and northern Pahroc Valley, and from southern Delamar Valley to northern Coyote Spring Valley and perhaps also to the very southern part of Pahranagat Valley. Also, a small amount of groundwater inflow to northern Dry Lake Valley likely occurs from northern Pahroc Valley. Elsewhere among these basins, interbasin flow is limited by geologic structure and lithology.

Groundwater outflow from Cave Valley is thought to occur on the western side of Cave Valley through Shingle Pass to the southern third of White River Valley, and through the southern portion of the valley to northern Pahroc Valley. Total outflow from Cave Valley is estimated to be about 13,400 afy. The outflow from Cave Valley to White River Valley through Shingle Pass is estimated at 4,000 afy, which is considered to be a near maximum value. The remainder, 9,400 afy, flows from Cave Valley to northern Pahroc Valley. A detailed estimate is provided in Appendix D.

For Dry Lake Valley, interbasin flow occurs in the northern portion of the valley as inflow from northern Pahroc Valley and as outflow to Delamar Valley to the south. Inflow from Pahroc Valley is estimated to be no more than 2,000 afy, while the outflow to Delamar Valley is estimated as the sum of the inflow and natural recharge, or about 17,700 afy. A detailed estimate is provided in Appendix D.

For Delamar Valley, interbasin flow occurs as inflow from Dry Lake Valley and as outflow to northern Coyote Spring Valley and possibly the very southern part of southern Pahranagat Valley. The outflow is estimated as the sum of the inflow from Dry Lake Valley and the natural recharge derived from within the hydrographic area boundaries of both basins, or about 24,100 afy. Interbasin flow elsewhere among these basins is precluded by geologic structure and lithology, principally the Caliente and Kane Springs Wash caldera complexes to the east and southeast and the North and South Pahroc ranges and associated range-front faults. A detailed estimate is provided in Appendix D.

# 5.0 DATA ANALYSIS AND RESULTS

This section describes the data analysis conducted to derive recharge efficiencies and estimate the groundwater budget for the WRFS and its basins following the approach described in Section 3.0. Descriptions of the data analysis and the results are provided in the following sections. Details about the calculations conducted in support of the analysis including descriptions of the Excel files are provided in Appendix E.

## 5.1 Data Analysis

Under steady-state conditions, the total recharge for the WRFS is equal to the sum of the estimates of groundwater ET and outflow, less any inflow to the system. To construct groundwater budgets for individual basins within the WRFS, the solver described in Section 3.0 was used in conjunction with the PRISM precipitation grid and boundary flow estimates to calculate recharge efficiencies for 1-in. precipitation intervals and outflow to the Colorado River. The data processing and analyses performed to estimate these efficiencies, including the solver setup, targets, parameters, and constraints, are described in the following sections.

### 5.1.1 Delineation of Areas of Potential Recharge

For the purpose of this report, areas of potential recharge are defined as areas where most of the in-place recharge occurs and mountain-front runoff is generated. This area of potential recharge is used to estimate the recharge distribution at the basin scale, not at the local scale. For example, the recharge that may result from infiltration of mountain-front runoff is not distributed to the actual areas where it may occur. For a given basin, potential recharge is assumed to occur in all areas of a given basin except (1) the valley floor, (2) groundwater discharge areas, and (3) areas where the depth of precipitation is less than 8 in.

The valley floor of a given basin was delineated for each basin of the WRFS using the USGS DEM (USGS, 2001), and subsequently excluded as an area of potential recharge. Land-surface slopes were calculated using the DEM grid, and the relatively flat areas of each basin were identified and excluded if the slopes were less than 2 percent. Alluvial fans were not included in the delineation of the valley floor areas because they are typically comprised of coarse-grained material that can accommodate recharge if the depth of precipitation is significant (i.e., greater than 8 in.).

It is also assumed that groundwater ET areas are not areas of potential recharge. This is consistent with the calculation of estimated groundwater ET where the precipitation is deducted from the total ET estimate. Removing the precipitation volume necessarily leads to the removal of any recharge that may occur there.

It is also assumed that a minimum of 8 in. of precipitation is necessary before groundwater recharge may occur. The first 8 in. of precipitation are assumed to satisfy the soil moisture deficit and losses to the atmosphere (ET) (Anderson et al., 1992, p. B33). This assumption is consistent with the Maxey-Eakin method (1949) which assumes that recharge is zero below 8 in. of precipitation. Thus, areas receiving less than 8 in. of precipitation are not considered to be areas of potential recharge.

The resulting potential recharge areas are depicted in Figure 5-1. The union of the valley floors, groundwater discharge areas, and areas receiving less than 8 in. of precipitation are labeled “areas of no recharge,” for the purpose of this report. As stated before, direct recharge from precipitation may actually occur in these areas, depending on the local conditions.

### 5.1.2 Precipitation Data

The PRISM precipitation distribution serves as the basis for the solver calculations and the derivation of the spatial distribution of recharge. The PRISM grid for the WRFS was contoured to generate 1-in. precipitation intervals starting from a minimum depth of 3 in. to the maximum depth occurring within the flow system. Next, the area corresponding to each interval was calculated, and then adjusted as necessary to exclude the “areas of no recharge,” as defined in the previous section. For each basin, the adjusted areas were then exported to Excel to create a table containing the precipitation rate and corresponding area for each 1-in. interval within the basin. This table forms the basis of the calculations performed by the solver. A map depicting the resulting potential recharge area and the 1-in. precipitation bands is presented in Figure 5-2.

### 5.1.3 Solver Target $ET_{gw}$

In the solver, the target is represented by the estimated value of total groundwater ET for the WRFS. The target cell contains a formula relating groundwater ET to the other components of the budget; this formula is Equation 3-5 rearranged in the following form:

$$ET_{gw} = R_T + Inflow - Outflow \qquad \text{(Eq. 5-1)}$$

where,

$ET_{gw}$ = total groundwater ET for the WRFS (afy)
$R_T$ = total recharge for the WRFS (afy)
Inflow = total groundwater inflow to the WRFS from the Meadow Valley Flow System (afy)
Outflow = total groundwater outflow from the WRFS to the Colorado River (afy)

Based on the data compilation and analysis presented in Section 4.0, the target value for $ET_{gw}$ and the estimate of inflow are 139,424 and 9,200 afy, respectively.

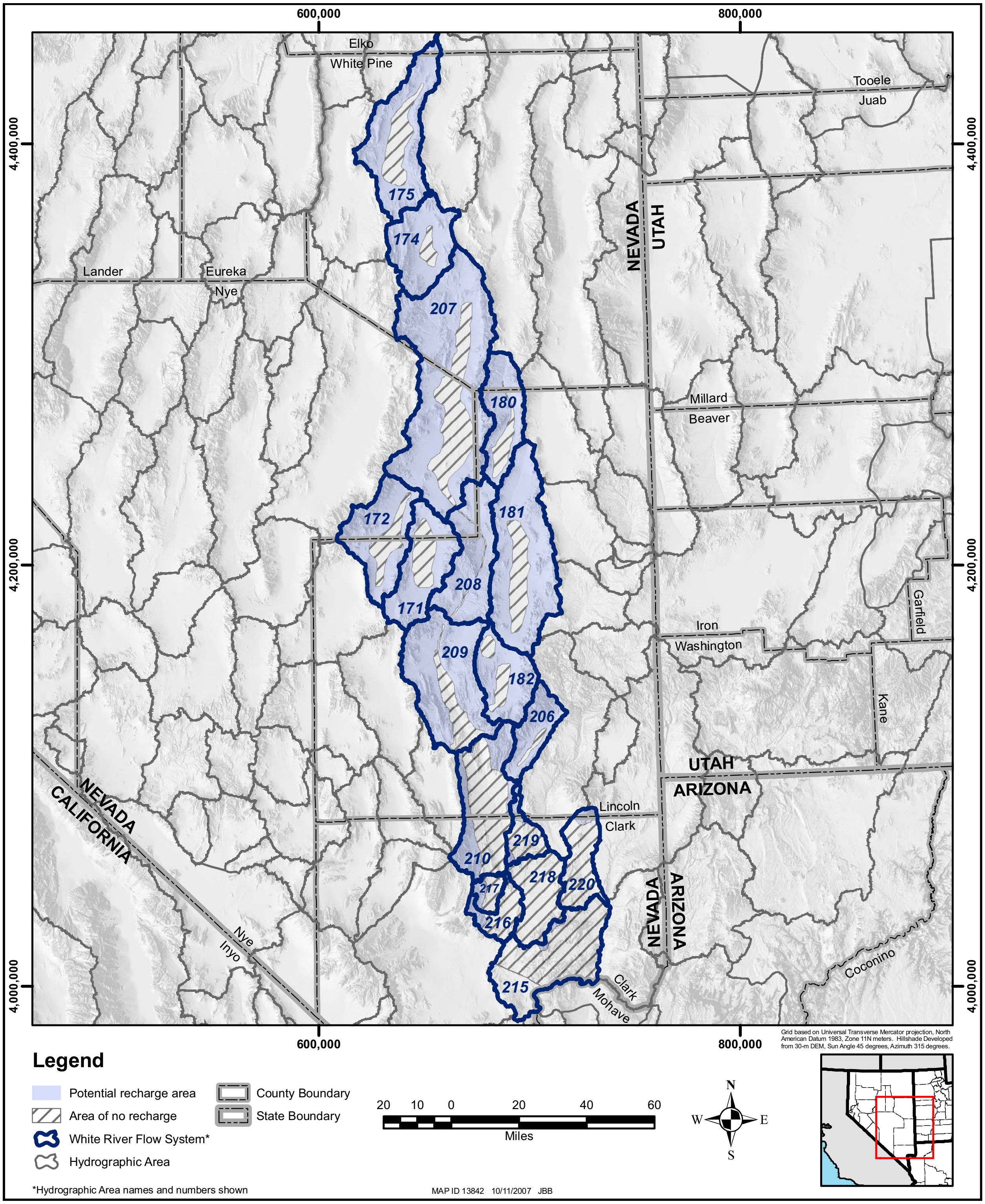



**Figure 5-1**
**Areas of Potential Recharge within the WRFS**

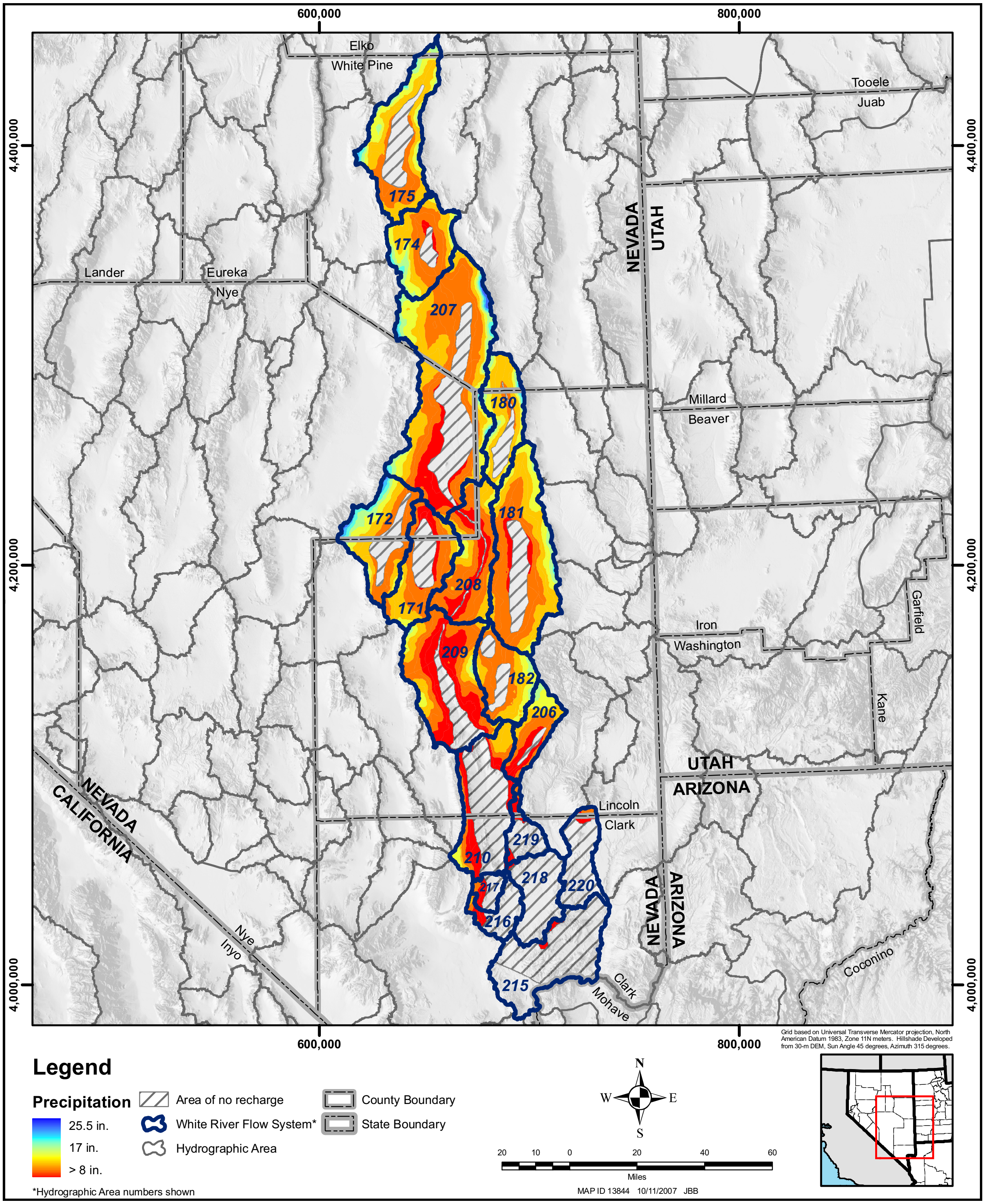



**Figure 5-2**
**Precipitation Distribution within Potential Recharge Areas within the WRFS**

### *5.1.4 Solver Parameters*

Parameters represent the flow system variables that require a solution. For this analysis, the primary parameters are the recharge efficiencies and interbasin flow rates for selected basin boundaries of the WRFS. The parameter solutions are determined through an optimization process in which the recharge efficiencies and boundary flows are adjusted within the predefined constraints described in Section 5.1.5, to ensure that the total recharge is equal to the sum of the total groundwater discharge and outflow, less the groundwater inflow (Equation 3-7).

Considering that the solution to the problem depends on many variables but only a few of them are known within reasonable bounds of uncertainty, the solution is non-unique and many possible representations exist. For example, the solver may identify solutions that are mathematically feasible but not reasonable given what is understood about the physical aspects of the flow system. It is, therefore, important to provide reasonable initial estimates for all parameters as was done in this case.

#### *Recharge Efficiencies*

Recharge efficiency, by definition, is the ratio of recharge to precipitation. Recharge may be expressed as a function of effective precipitation. For this analysis, recharge is assumed to follow a form of the power function of Kumar and Seethapathi (2002) (see Equation 3-2). The equation is as follows:

$$R = a(P - 8)^b \qquad \text{(Eq. 5-2)}$$

where,

R = recharge (in./yr)
a = power function constant
b = power function exponent
P = Precipitation (in./yr)
P – 8 = Effective precipitation (in./yr)

For this analysis, it is assumed that precipitation contributes to recharge (effective precipitation) starting at 8 in./yr where the effective precipitation and recharge are assumed to be zero. The 8 in./yr threshold value is based on the work of Anderson et al. (1992). The volume of precipitation below 8 in./yr is assumed to account for losses to soil-moisture deficits and ET. The effective precipitation and recharge increases with increasing precipitation. This equation is also similar to that of Contor (2004) and Anderson et al. (1992), except that these authors express recharge as a function of total precipitation rather than effective precipitation.

To calculate the recharge efficiencies for use in Equation 3-7, each side of Equation 5-2 is divided by precipitation, P, to yield the following equation expressing recharge efficiency:

$$Eff = \frac{[a(P-8)^b]}{P} \qquad \text{(Eq. 5-3)}$$

where,

| | | |
|---|---|---|
| Eff | = | recharge efficiency or R/P as a fraction |
| a | = | power function constant |
| b | = | power function exponent |
| P | = | Precipitation (in./yr) |
| P – 8 | = | Effective precipitation (in./yr) |

Equation 5-3 was used in the solver for direct calculation of the recharge efficiencies. The primary parameters are the coefficients of Equation 5-3 (i.e., the constant a and the exponent b).

Initial estimates for these two primary parameters were derived from a power function derived from the step-function defined by the standard Maxey-Eakin efficiencies. They are as follows:

- Power function constant: $a = 8.0 \times 10^{-5}$
- Power function exponent: $b = 3.62$

Details on how these initial estimates were derived using the Maxey-Eakin recharge efficiencies are provided in Appendix E.

### *Interbasin Flow Volumes*

Secondary solver parameters are (1) the interbasin flow volume from Coyote Spring Valley (HA 210) to Hidden Valley (HA 217) and (2) the total outflow volume from the WRFS into the Colorado River.

The outflow volumes were assigned their constraints as initial estimates. Initial estimates for these two secondary parameters are as follows:

- Outflow from Coyote Spring Valley to Hidden Valley = 15,000 afy
- Total Outflow from the WRFS = 25,000 afy

## 5.1.5 Constraints

Constraints were placed on the coefficients of the power function, the maximum recharge efficiency, and the two locations of underflow used as secondary parameters in the solver. Additional constraints were placed on underflow out of White River Valley and the total inflow to the Muddy River Springs Area. The constraints are as follows:

- Power Function Constant, a is positive
- Power Function Exponent, b is positive
- Outflow from White River Valley is between 6,300 and 40,000 afy
- Outflow from Coyote Spring Valley to Hidden Valley is less than or equal to 15,000 afy
- Total inflow to Muddy River Springs Area is greater than or equal to 40,000 afy
- Total outflow is greater or equal to 25,000 afy
- Maximum recharge efficiency is less than or equal to 0.63.

The constraint imposed on the recharge efficiency was derived from a literature review of maximum recharge efficiencies estimated for the region of the study area. The maximum reported value of 63 percent or 0.63 was selected as the constraint value (Table E.2-2). The details are located in Appendix E.

Additional constraints imposed on interbasin flow volumes are as follows:

- Inflow to California Wash from Lower Meadow Valley Wash is equal to 5,200 afy
- Inflow to Muddy River Springs Area from Lower Meadow Valley Wash is equal to 4,000 afy.

The information supporting the constraints on flow volumes is described in Section 4.3. A summary of the interbasin flow constraints applied in the solver is presented in Figure 5-3.

### *5.2 Solution Process*

The solution process includes two major steps: (1) use the Excel Solver to derive a recharge distribution, and (2) use the resulting recharge distribution to derive basin budgets.

The solver was used to inversely solve for the recharge efficiencies of the WRFS and the selected underflow volumes using the target ET estimates, the parameters, and the constraints described in Section 5.1.5. Because there is more than one unknown parameter, the derived solution is not unique. To converge to a solution, the solver uses successive values of all parameters while seeking a solution. Values of the primary parameters and the power function coefficients, a and b, are used to calculate recharge for each 1-in. precipitation band. This recharge value is then divided by precipitation to obtain a recharge efficiency, which in turn, is used to calculate recharge volumes. The calculated recharge volumes and values of the secondary parameters are tested in the budget. Once the calculated recharge volumes yield a total groundwater ET value that matches the target value, a solution is reached. The final values of all parameters are part of the solution and are used to estimate the final recharge distribution.

The process of deriving a groundwater budget for each basin in the WRFS is conducted in Excel, but outside of the solver. The solver actually provides a recharge distribution for each basin in the WRFS. Assuming that each basin is under predevelopment steady-state conditions, a groundwater budget may be derived for each basin. The process starts from the most up-gradient basin of the WRFS (Long Valley), and ends at the southernmost basins (Lower Moapa Valley and Black Mountains Area). For each basin, any inflow to the basin is added to the estimate of basin recharge, and the basin's groundwater ET value is then subtracted. The remainder is the outflow to the next contiguous basin(s) located downgradient. For basins having more than one outflow boundary, independent estimates of selected outflow boundaries were made. Such is the case for two basins: Cave Valley and Pahroc Valley. Outflow from Cave Valley is to White River Valley and Pahroc Valley. Outflow from Pahroc Valley is to Pahranagat Valley and Dry Lake Valley. The estimated outflows are as follows:

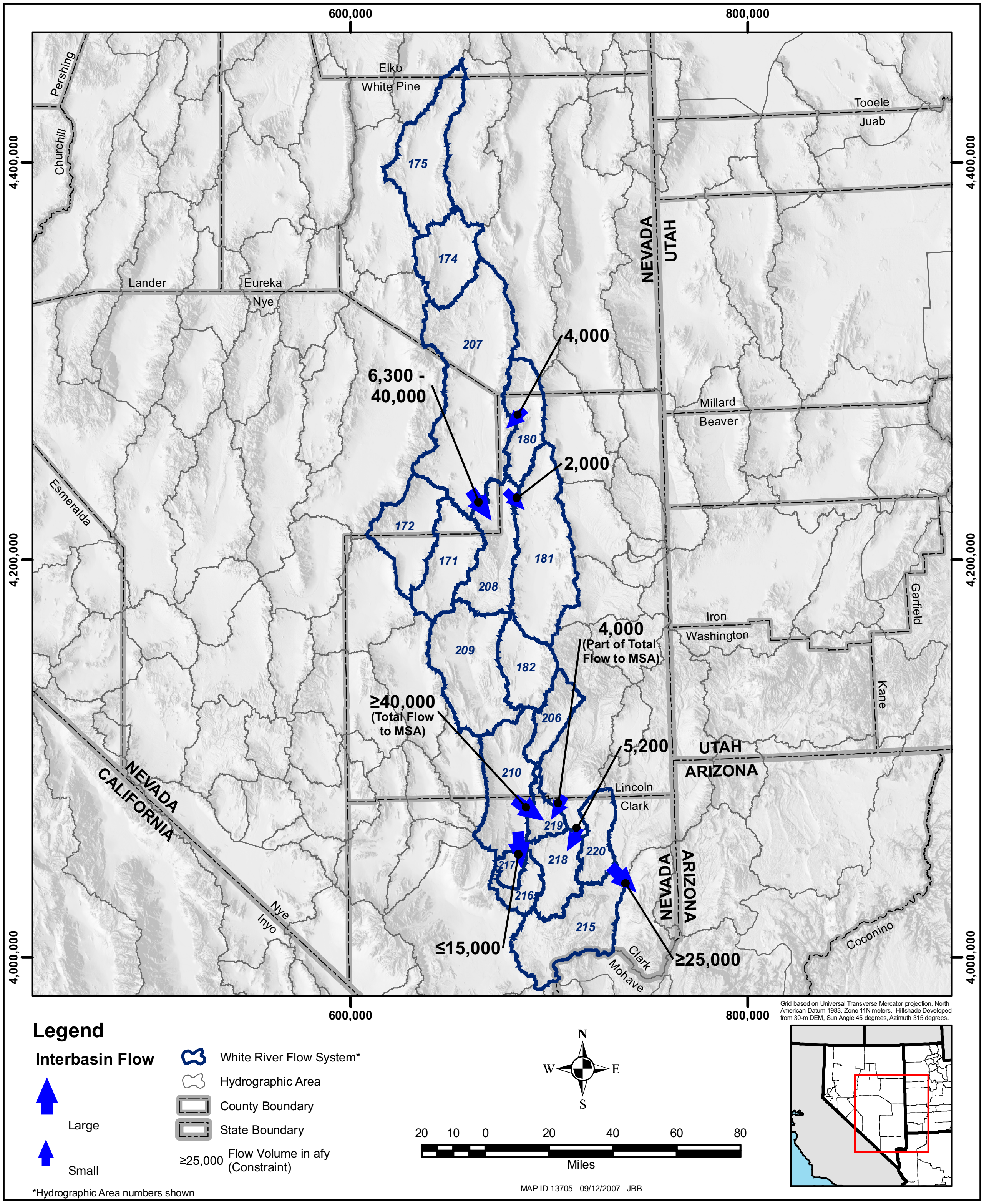



**Figure 5-3**
**Interbasin Flow Constraints Applied in Solver**

- Outflow from Cave Valley to White River Valley of 4,000 afy
- Outflow from Cave Valley to Pahroc Valley of 9,400 afy
- Outflow from Pahroc Valley to Dry Lake Valley of 2,000 afy.

These estimates are discussed in Section 4.0, and the details of the estimates of underflow are presented in Appendix D.

## *5.3 Results and Discussion*

The results of the analysis are presented and discussed in the following order: (1) recharge-precipitation relationship, (2) recharge efficiencies, (3) recharge distribution, and (4) basin groundwater budgets.

### *5.3.1 Recharge-Precipitation Relationship*

The power function computed by the solver is a recharge-precipitation relationship. The corresponding equation is as follows:

$$R = 0.0026(P - 8)^{3.0515} \qquad \text{(Eq. 5-4)}$$

A graph of this relationship is presented in Figure 5-4 which also includes similar relationships and point recharge estimates derived by others for comparison. In addition to precipitation, recharge also depends on soil types and thicknesses, rock types, and climate. Thus, the mathematical relationship between recharge rates and precipitation rates is not uniquely defined and may vary depending on location and the physical characteristics of the terrain. However, as can be seen from Figure 5-4, all relationships shown exhibit similar trends: lower recharge rates at lower precipitation rates, and higher recharge rates at higher precipitation rates. The differences among these relationships could be due to differences in actual precipitation and geology, or different interpretations. A discussion of the relationships shown in Figure 5-4 follows.

The relationship derived by SNWA (green line in Figure 5-4) compares relatively well with the equation reported by Faybishenko (dark purple line) and the data points reported by Davisson and Rose (2000) and Lichty and McKinley (1995). Faybishenko (2007) utilized methods that estimated recharge at the local scale using different types of information. Their estimates constitute point recharge data. The relationship derived by Faybishenko (2007) is a power function of recharge and precipitation similar to the one derived in this analysis. The recharge rates were estimated using precipitation data and PET rates calculated with the Priestley and Taylor formula for selected meteorological stations located in several states including Nevada. Davisson and Rose (2000) estimated the recharge efficiency at selected field observation points in the Fenner Basin in California in an effort to calibrate the Maxey-Eakin efficiency-precipitation curve to the local conditions. Their methods of estimation included the use of a hydrologic mass-balance method and groundwater age dating. Lichty and McKinley (1995) used methods based on the hydrologic mass balance to estimate recharge at specific sites in Central Nevada. Their estimates are in close agreement with the power function derived by this analysis, and are represented by the two datapoints (red triangles in

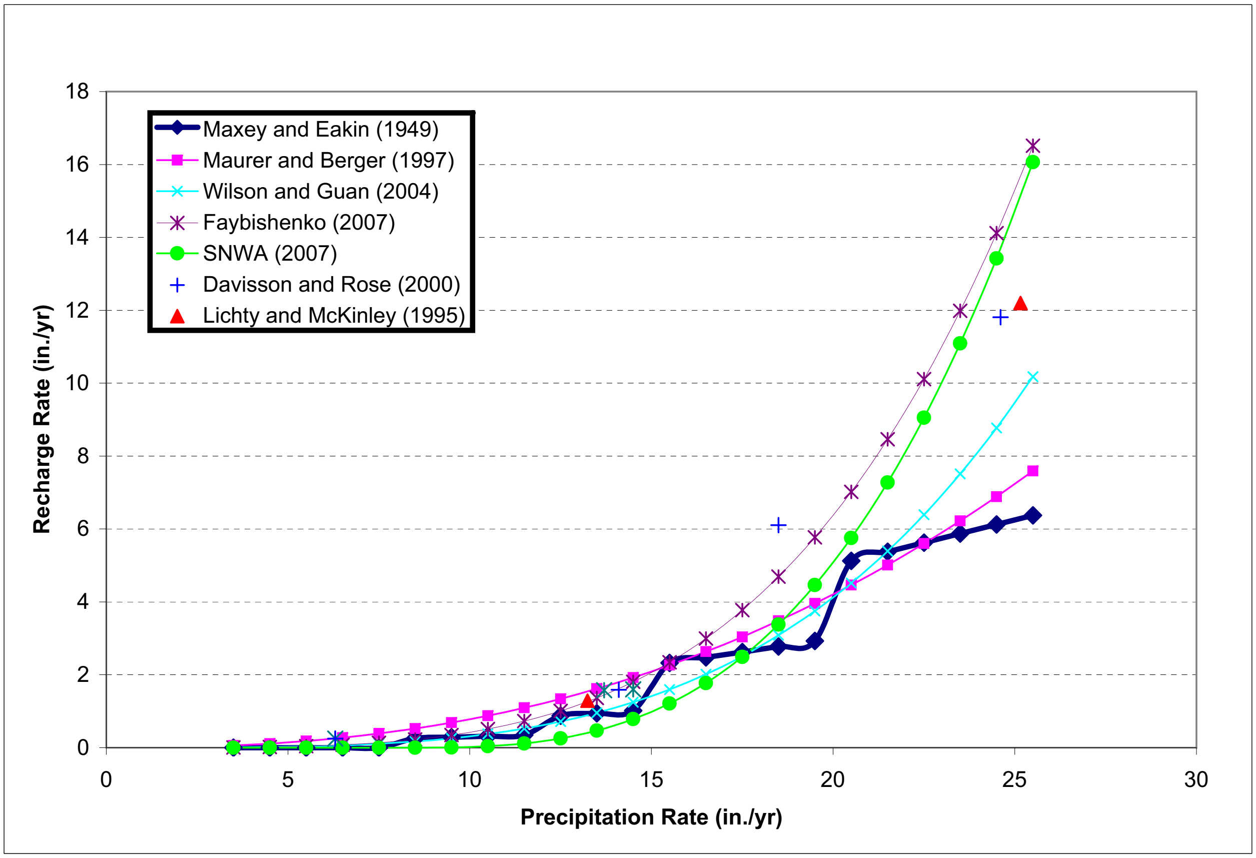



**Figure 5-4**
**Recharge-Precipitation Relationship for the WRFS**

Figure 5-4) located on each side of the green curve representing the power function derived by this analysis (green curve in Figure 5-4).

The power function derived by this analysis is less comparable to the relationships derived by Maxey and Eakin (1949), Wilson and Guan (2004), and Maurer and Berger (1997). The Maxey and Eakin (1949) relationship shown in dark blue in Figure 5-4 was derived from the standard recharge efficiencies estimated by these authors for basins in Nevada. The Maxey-Eakin method is deemed to be an appropriate recharge estimation technique at a reconnaissance level for most HAs in Nevada (Avon and Durbin, 1994). However, the Maxey-Eakin relationship may not reflect the physical nature of groundwater recharge nor its distribution due to the overly simplified precipitation map (Hardman, 1936) on which it is based. More representative maps, such as the one developed later by Hardman (1965) using vegetation distribution and more precipitation data, were not available at the time. Though this map (Hardman, 1965) is better than the previous one (Hardman, 1936), it had few data, if any, controlling the interpretation of precipitation at the higher elevations. The relationship developed by Wilson and Guan (2004) (shown in light blue in Figure 5-4) is a power function fit to the precipitation-recharge points derived from the standard Maxey-Eakin efficiencies. That is why it matches the Maxey-Eakin (1949) relationship in Figure 5-4. Maurer and Berger (1997) derived a power function of recharge versus precipitation for the Carson Basin in Nevada, based on the 4-km PRISM precipitation grid for Nevada. The form of their power function is similar to the power function derived by Wilson and Guan (2004). While the Maurer and Berger (1997) function was developed more recently than the Maxey-Eakin method (1949) and, therefore, uses better data, it does not provide better estimates of recharge. This limitation it due to its ability to distribute recharge to the appropriate locations due to the coarseness of the 4-km PRISM precipitation grid.

In summary, the power function representing the recharge-precipitation relationship derived for the WRFS by this study is based on more accurate estimates of precipitation distribution and groundwater ET than the functions previously applied to this area. In addition, this power function agrees better with local recharge estimates than the Maxey-Eakin (1949) and the Maurer and Berger (1997) relationships of recharge with precipitation. Because of this, it is concluded that the relationship derived by this study provides a better assessment of the recharge for individual basins of the WRFS than does the Maxey-Eakin method, or variants thereof, used in the Reconnaissance Report Series.

### *5.3.2 Recharge Efficiencies*

The recharge efficiencies derived by this analysis are computed by the solver and can be expressed by the following equation:

$$Eff = \frac{0.0026(P-8)^{3.0515}}{P} \qquad \text{(Eq. 5-5)}$$

For comparison, Table 5-1 lists the standard Maxey-Eakin precipitation zones and efficiencies as well as the recharge efficiencies derived by this analysis. The efficiency derived by this analysis is higher by 20 percent for the >20 in./yr zone, but is very similar for the middle to lower zones. This places greater volumes of recharge at the higher altitudes, where the depth of precipitation is greater. It was expected that the efficiencies would differ from the standard Maxey-Eakin efficiencies because the precipitation distributions and groundwater ET estimates are significantly different.

**Table 5-1**
**Comparison of Recharge Efficiencies**

| Precipitation Zone (in./yr) | Standard Maxey-Eakin (%) | This Study (%) |
|---|---|---|
| >20 | 25 | 45 |
| 15 to 20 | 15 | 15 |
| 12 to 15 | 7 | 4 |
| 8 to 12 | 3 | 0.4 |
| <8 | 0 | 0 |

Recharge efficiencies derived for each 1-in precipitation zone were used to compute recharge estimates for the individual basins comprising the WRFS. This was accomplished by multiplying the recharge efficiency by the volume of precipitation calculated for each interval. The recharge values were then summed for each basin. Table 5-2 lists those estimates as well as estimates from previous studies. To check the recharge computation, Equation 5-4 was used in conjunction with the PRISM grid to derive a spatial distribution of recharge.

**Table 5-2**
**Comparison of Estimates of Precipitation Recharge Volumes, in Acre-Feet per Year, for Basins in the WRFS**

| HA Name | This Study[a] | Flint and Flint (2007) | Flint et al. (2004) | | LVVWD (2001)[b] | Nichols (2000) | Eakin (1966) and Rush (1968) |
|---|---|---|---|---|---|---|---|
| | | | Mean Year | Time Series | | | |
| Long Valley | 19,928 | 25,000 | 16,289 | 13,536 | 23,000 | 48,000 | 10,000 |
| Jakes Valley | 12,288 | 16,000 | 10,974 | 8,310 | 24,000 | 38,500 | 17,000 |
| White River Valley | 41,065 | 35,000 | 34,925 | 30,759 | 62,000 | – – | 38,000 |
| Cave Valley | 14,659 | 11,000 | 10,264 | 9,380 | 20,000 | – – | 14,000 |
| Garden Valley | 24,818 | – – | 17,974 | 15,559 | 19,000 | – – | 10,000 |
| Coal Valley | 3,857 | – – | 3,839 | 3,110 | 7,000 | – – | 2,000 |
| Pahroc Valley | 4,507 | – – | 4,432 | 4,832 | 8,000 | – – | 2,200 |
| Dry Lake Valley | 15,667 | – – | 10,627 | 11,298 | 13,000 | – – | 5,000 |
| Pahranagat Valley | 5,507 | – – | 7,043 | 7,186 | 7,000 | – – | 1,800 |
| Delamar Valley | 6,401 | – – | 7,764 | 6,404 | 5,000 | – – | 1,000 |
| Kane Springs Valley | 4,189 | – – | 5,421 | 6,328 | 7,000 | – – | 2,600 |
| Coyote Spring Valley | 2,128 | – – | 5,184 | 5,951 | 4,000 | – – | |
| Muddy River Springs Area | 38 | – – | 12 | 207 | 200 | – – | Minor |
| Hidden Valley | 42 | – – | 188 | 571 | 300 | – – | 400 |
| Garnet Valley | 96 | – – | 294 | 1,000 | 300 | – – | 400 |
| California Wash | 0 | – – | 23 | 652 | 300 | – – | <100 |
| Lower Moapa Valley | 33 | – – | – – | 147 | 1,000 | – – | <50 |
| Black Mountains Area | 0 | – – | 54 | 1,470 | 400 | – – | <100 |
| **Total** | **155,224** | **– –** | **135,307** | **126,700** | **201,500** | **– –** | **104,650** |

[a]Values were only rounded to the nearest "ones" to allow calculations to be tracked during analysis and reporting.
[b]Table 6-1, p. 6-3

The recharge for each basin was calculated using the recharge grid derived by Equation 5-4 and depicted in Figure 5-5. These values were then compared to the estimates computed using the efficiencies and precipitation volumes as previously described. The two sets of results were essentially the same, with the difference being about 700 afy for the entire flow system.

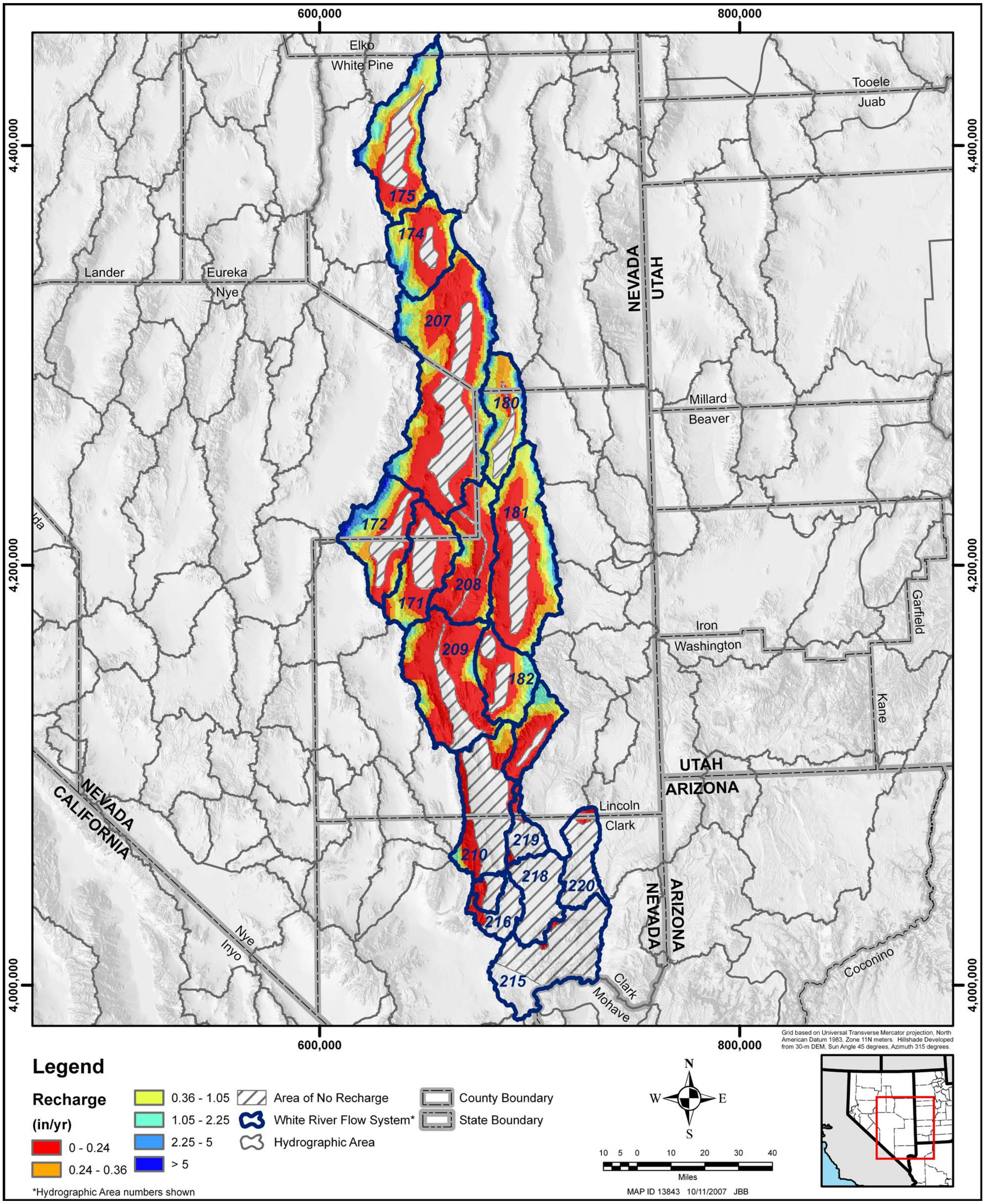



**Figure 5-5**
**Distribution of Precipitation Recharge within the WRFS**

### 5.3.3 Recharge Distribution

The total recharge calculated for the WRFS was 155,224 afy, which exactly matched the sum of the target groundwater ET and outflow, minus the inflow. A discussion of the recharge volumes estimated for the individual basins of the WRFS and the project basins follows.

#### 5.3.3.1 WRFS Basin Recharge Estimates

The estimated basin recharge volumes were compared to those reported in the literature. The recharge volumes of interest are listed in Table 5-2, and are summarized as ranges of reported recharge values by basin in Table 5-3, for comparison with the estimates derived by this study. The total recharge of 155,224 afy estimated for the WRFS by this study falls within the range of previous estimates, which is 104,650 (Eakin, 1966) to 201,500 afy (LVVWD, 2001).

**Table 5-3**
**Comparison of Recharge Volumes,**
**in Acre-Feet per Year, for Basins of the WRFS**

| HA Name | This Study | Range of Previously Reported Volumes |
|---|---|---|
| Long Valley | 19,928 | 10,000 to 48,000 |
| Jakes Valley | 12,288 | 8,310 to 38,500 |
| White River Valley | 41,065 | 30,759 to 62,133 |
| Cave Valley | 14,659 | 9,380 to 19,595 |
| Garden Valley | 24,818 | 10,000 to 19,153 |
| Coal Valley | 3,857 | 2,000 to 7,002 |
| Pahroc Valley | 4,507 | 2,200 to 7,545 |
| Dry Lake Valley | 15,667 | 5,000 to 13,254 |
| Pahranagat Valley | 5,507 | 1,800 to 7,407 |
| Delamar Valley | 6,401 | 1,000 to 7,764 |
| Kane Springs Valley | 4,189 | 600 to 6,757 |
| Coyote Spring Valley | 2,128 | 2,000 to 5,951 |
| Muddy River Springs Area | 38 | 12 to 237 |
| Hidden Valley | 42 | 188 to 571 |
| Garnet Valley | 96 | 294 to 1,000 |
| California Wash | 0 | 23 to 652 |
| Lower Moapa Valley | 33 | 0 to 1,354 |
| Black Mountains Area | 0 | 54 to 1,470 |

Except for two basins, the estimated recharge volumes for all basins with recharge volumes greater than 1,000 afy, fall within the reported ranges. The two exceptions are Garden and Dry Lake valleys. The recharge estimate for Garden Valley is 24,818 afy; which falls outside the 10,000 to 19,153 afy range (Eakin, 1966 and LVVWD, 2001). The recharge estimate for Dry Lake Valley, 15,667 afy, is larger than the maximum reported value of 13,254 afy (LVVWD, 2001). The magnitude of these differences is relatively small and has little bearing on the total groundwater budget for the flow system.

### *5.3.3.2 Recharge in Cave, Dry Lake, and Delamar Valleys*

Eakin (1962; 1963a) estimated recharge in Cave, Dry Lake, and Delamar Valleys by applying the standard Maxey-Eakin recharge efficiencies to estimates of precipitation computed using the areas for precipitation zones defined by land-surface elevation contours (p. 11 and p. 16, respectively). As was done in previous Reconnaissance Series reports, it was assumed that selected elevation contours corresponded to the precipitation zones defined by the Hardman (1936) precipitation map. In the case of Eakin (1962; 1963a), an improved topographical base map (1:250,000 scale topographic map) had been developed and was used to calculate the area for each precipitation zone. Based on this new topographical base and oral communications with Hardman, it was assumed that the 6,000 to 7,000 ft altitude interval corresponded to the 8 to 12 in. precipitation zone, the 7,000 to 8,000 ft interval to the 12 to 15 in. zone, the 8,000 to 9,000 interval to the 15 to 20 in. zone, and for altitudes greater than 9,000 ft, to the >20 in. zone. Below altitudes of 6,000 ft, less than eight inches of precipitation was assumed. Revised versions of the Hardman precipitation map were published in 1962 and 1965, in the same time period the Reconnaissance Series Reports for the project basins were published by Eakin (1962; 1963a). The Hardman (1962) map was used as part of this analysis to evaluate the relationship between precipitation and altitude assumed by Eakin (1962; 1963a), and is described in the following discussion.

To evaluate these assumptions, the Hardman (1962) precipitation map was geo-referenced and digitized for the area encompassing Cave, Dry Lake, and Delamar Valleys (Figure 5-6). Using the digitized map and GIS utilities, the area for each precipitation zone was extracted and multiplied by the average precipitation for the corresponding zone to calculate the volume of precipitation. The standard Maxey-Eakin efficiencies were then applied to compute estimates of recharge. These estimates are compared in Table 5-4 to the estimates reported in Eakin (1962; 1963a) and the estimates derived by this study.

The summary data listed in Table 5-4 highlights an important difference between the estimates reported by Eakin (1962; 1963a) and the estimates derived from the Hardman (1962) precipitation map. The areas calculated for each corresponding precipitation zone are significantly different between the two estimates. This difference is due to the fact that the topographic contours do not correspond to the Hardman (1962) precipitation zones as Eakin (1962; 1963a) assumed they would. In some cases, areas representing the 8 to 12 in. precipitation zone are excluded by the 6,000 ft contour, while other areas representing the 12 to 15 in. zone actually fall within the 6,000 to 7,000 ft contour interval. This is illustrated by Figure 5-6 which overlays the topographic contours derived from the USGS 30-m DEM onto the digitized version of the Hardman (1962) precipitation map. These topographic contours were compared to the 1:250,000 scale topographic maps used by Eakin (1962; 1963a), and only very slight differences between the two were found; therefore, their use in evaluating the altitude-precipitation assumptions of Eakin (1962; 1963a) are appropriate. The inconsistencies between the topographic contours and the Hardman (1962) map are manifested in the estimates of precipitation and recharge. For Cave Valley, the recharge based on the Hardman (1962)

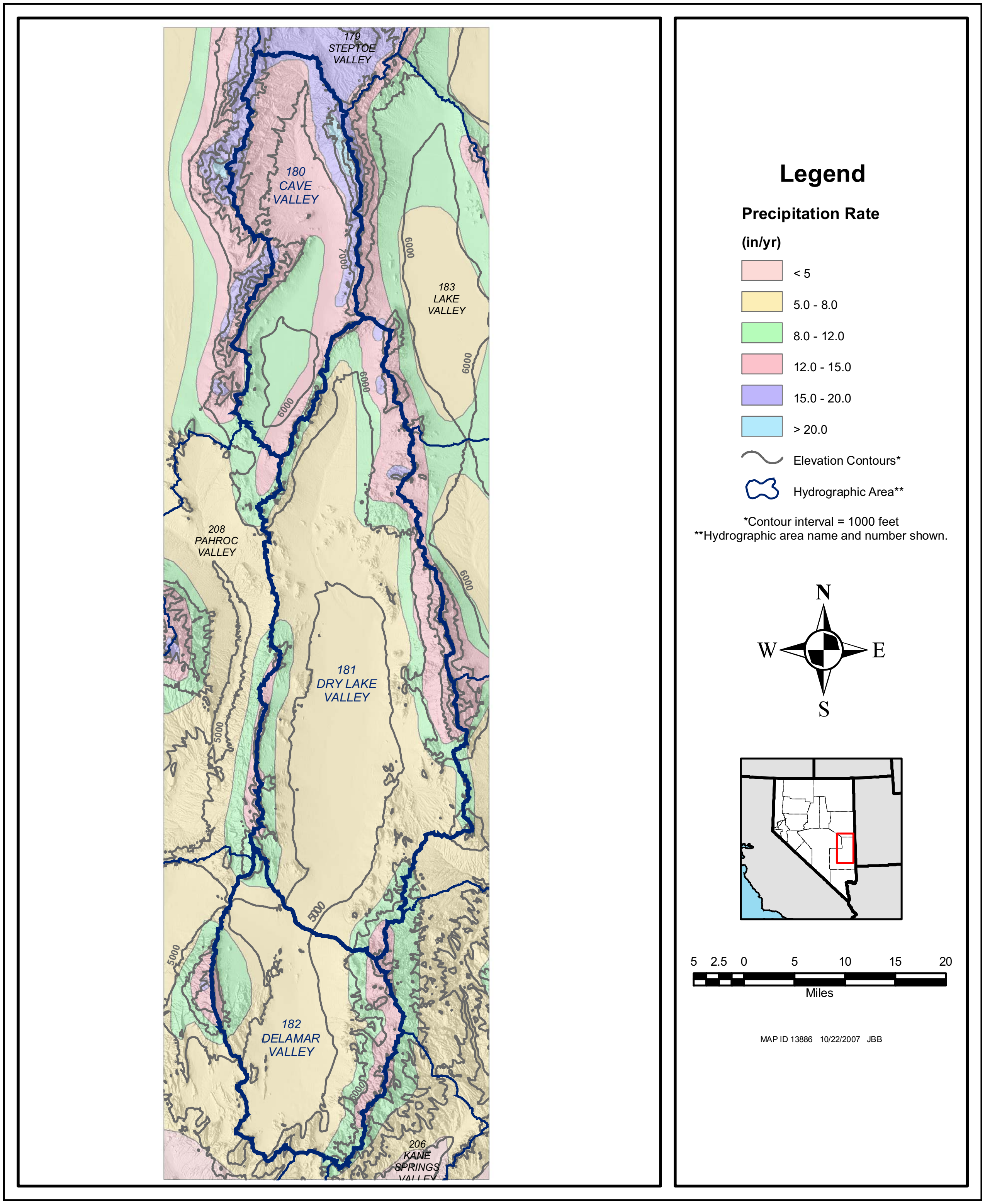



**Figure 5-6**
**Digitized Hardman (1962) Precipitation Map for Cave, Dry Lake, and Delamar Valleys**

## Table 5-4
## Comparison of Precipitation and Recharge Estimates for Cave, Dry Lake, and Delamar Valleys

| HA Name | Precipitation Zone (in.) | Area (acres) | | | Precipitation (afy) | | | Recharge (afy) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Eakin (1962; 1963a) | Hardman (1962) | This Study | Eakin (1962; 1963a) | Hardman (1962) | This Study | Eakin (1962; 1963a) | Hardman (1962) | This Study |
| Cave Valley | > 20 | 3,500 | 4,655 | 3,410 | 6,125 | 8,146 | 6,120 | 1,500 | 2,037 | 2,117 |
| | 15 to 20 | 19,500 | 35,573 | 46,099 | 28,470 | 51,937 | 64,012 | 4,300 | 7,791 | 7,672 |
| | 12 to 15 | 69,000 | 129,990 | 122,302 | 77,280 | 145,589 | 136,231 | 5,400 | 10,191 | 4,742 |
| | 8 to 12 | 114,000 | 58,998 | 12,941 | 94,620 | 48,968 | 12,401 | 2,800 | 1,469 | 128 |
| | **Total** | **206,000** | **229,216** | **184,752** | **206,495** | **254,640** | **218,764** | **14,000** | **21,488** | **14,659** |
| Dry Lake Valley | > 20 | 200 | -- | -- | 350 | -- | -- | 100 | -- | -- |
| | 15 to 20 | 3,200 | 3,380 | 49,434 | 4,672 | 4,935 | 67,122 | 700 | 740 | 7,108 |
| | 12 to 15 | 16,000 | 74,011 | 189,766 | 17,920 | 82,892 | 210,695 | 1,300 | 5,802 | 7,196 |
| | 8 to 12 | 114,000 | 98,686 | 233,143 | 94,620 | 81,909 | 210,006 | 2,700 | 2,457 | 1,363 |
| | **Total** | **133,400** | **176,077** | **472,343** | **117,562** | **169,736** | **487,823** | **5,000** | **8,999** | **15,667** |
| Delamar Valley | > 20 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | 15 to 20 | -- | -- | 22,170 | -- | -- | 29,717 | -- | -- | 2,871 |
| | 12 to 15 | 4,000 | 22,292 | 75,122 | 4,480 | 24,967 | 83,539 | 300 | 1,748 | 2,891 |
| | 8 to12 | 35,000 | 45,648 | 86,183 | 29,050 | 37,888 | 79,816 | 900 | 1,137 | 639 |
| | **Total** | **39,000** | **67,940** | **183,475** | **33,530** | **62,855** | **193,072** | **1,200** | **2,885** | **6,401** |
| **GRAND TOTAL** | | **378,400** | **473,233** | **840,570** | **357,587** | **487,231** | **899,659** | **20,200** | **33,372** | **36,727** |

Note: Estimates derived using the Hardman (1962) precipitation map and SNWA (2007) were not rounded so calculations could be tracked during analysis and reporting map is about 7,500 afy greater than the value estimated by Eakin (1962), and about 4,000 afy and 1,700 afy greater for Dry Lake and Delamar Valleys, respectively. In total, for the three basins, the difference is about 13,200 afy.

The recharge estimates derived by this study compare more favorably to the estimates derived using the Hardman (1962) precipitation map, with the total recharge for the three basins about 3,400 afy greater for this study. The biggest difference between the two estimates is observed in the distribution of the recharge. In Cave Valley, the recharge derived using the Hardman (1962) precipitation map is about 21,500 afy while the estimate derived by this study is about 14,700 afy, a difference of about 6,800 afy. In Dry Lake and Delamar Valleys, the estimates derived by this study are about 6,700 afy and 3,500 afy greater than the estimates derived from Hardman (1962). The difference between these estimates are mostly due to the spatial distribution of precipitation interpreted by Hardman (1962) and that derived by PRISM (2007). Recharge efficiencies contribute to some of the difference, but have less effect on the results because the Maxey-Eakin efficiencies and the efficiencies derived by this study are very similar for the mid-range precipitation zones (i.e., 12 to 15 in.; 15 to 20 in.) where most of the precipitation occurs in these basins.

In summary, the recharge estimates of Eakin (1962; 1963a) are less than those derived using the Hardman (1962) precipitation map. This difference is significant, and occurs due to the fact that the elevation contours assumed to represent the precipitation zones defined by Hardman (1962) do not match the precipitation map. The estimates derived by this study are comparable to estimates derived using the Hardman (1962) precipitation map. However, the estimates derived using the Hardman (1962) map are greater for Cave Valley, and less for Dry Lake and Delamar Valleys. These differences are mostly due to differences observed in the precipitation distributions; the PRISM precipitation distribution generates more precipitation at the mid-range altitudes for this area than does the Hardman (1962) precipitation map.

### *5.3.4 Groundwater Budgets*

A groundwater budget for the WRFS and its individual basins was constructed using the recharge, groundwater ET, and boundary flow estimates derived by this analysis as described in Section 5.2.

The groundwater budget for the WRFS is presented in Table 5-5. As listed in Table 5-5, all components of the groundwater budget for the WRFS fall within the ranges of values reported in the literature.

The groundwater budget for the WRFS and individual basins is presented in Figure 5-7. Figure 5-7 provides the individual basin budgets, and presents interbasin flow arrows depicting the general direction of flow. The outflow for a given basin is listed as a total, even for basins with more than one outflow arrow. The groundwater budgets for the three project basins are described in the following section:

For Cave Valley, no inflow is presumed to occur based on the lithology and structure comprising the surrounding mountain ranges and the hydraulic head potential across basin boundaries. Recharge is estimated to be about 14,700 afy, while groundwater ET is estimated to be about 1,300 afy. The

**Table 5-5**
**Estimated Groundwater Budget for the WRFS**

| Budget Component | Estimated Value (afy) | Reported Range (afy) | Reference |
|---|---|---|---|
| Recharge | 155,224 | 104,650 to 201,500 | Eakin, 1966 (min); LVVWD, 2001 (max) |
| Inflow | 9,200 | 7,000 to 32,000 | Rush, 1968 (min)[a]; LVVWD, 2001 (max) |
| Groundwater ET | 139,424 | 100,600 to 176,305 | Eakin, 1966 (min); LVVWD, 2001 (max) |
| Outflow | 25,000 | 11,100 to 49,000 | Rush, 1968 (min); LVVWD, 2001 (max) |

[a]This is the minimum inflow reported by Rush (1968); Thomas et al. (1996) report a range of 5,500 to 9,000 afy

difference between the two is assumed to be interbasin outflow to southern White River Valley and northern Pahroc Valley, which is estimated to be 4,000 and 9,400 afy, respectively.

For Dry Lake Valley, interbasin flow occurs in the northern portion of the valley as inflow from northern Pahroc Valley in some amount less than 2,000 afy. Recharge is estimated to be about 15,700 afy. The sum of the inflow and recharge, about 17,700 afy, constitutes the total outflow from Dry Lake Valley to Delamar Valley as there is no other significant source of groundwater discharge elsewhere within the valley.

For Delamar Valley, the recharge is estimated to be about 6,400 afy. Interbasin inflow is equated to the volume of outflow from Dry Lake Valley, or about 17,700 afy. Like Dry Lake Valley, Delamar Valley has no other significant source of groundwater discharge, so the combined estimates of inflow and recharge constitute the total outflow from Delamar Valley to northern Coyote Spring Valley, or about 24,100 afy.

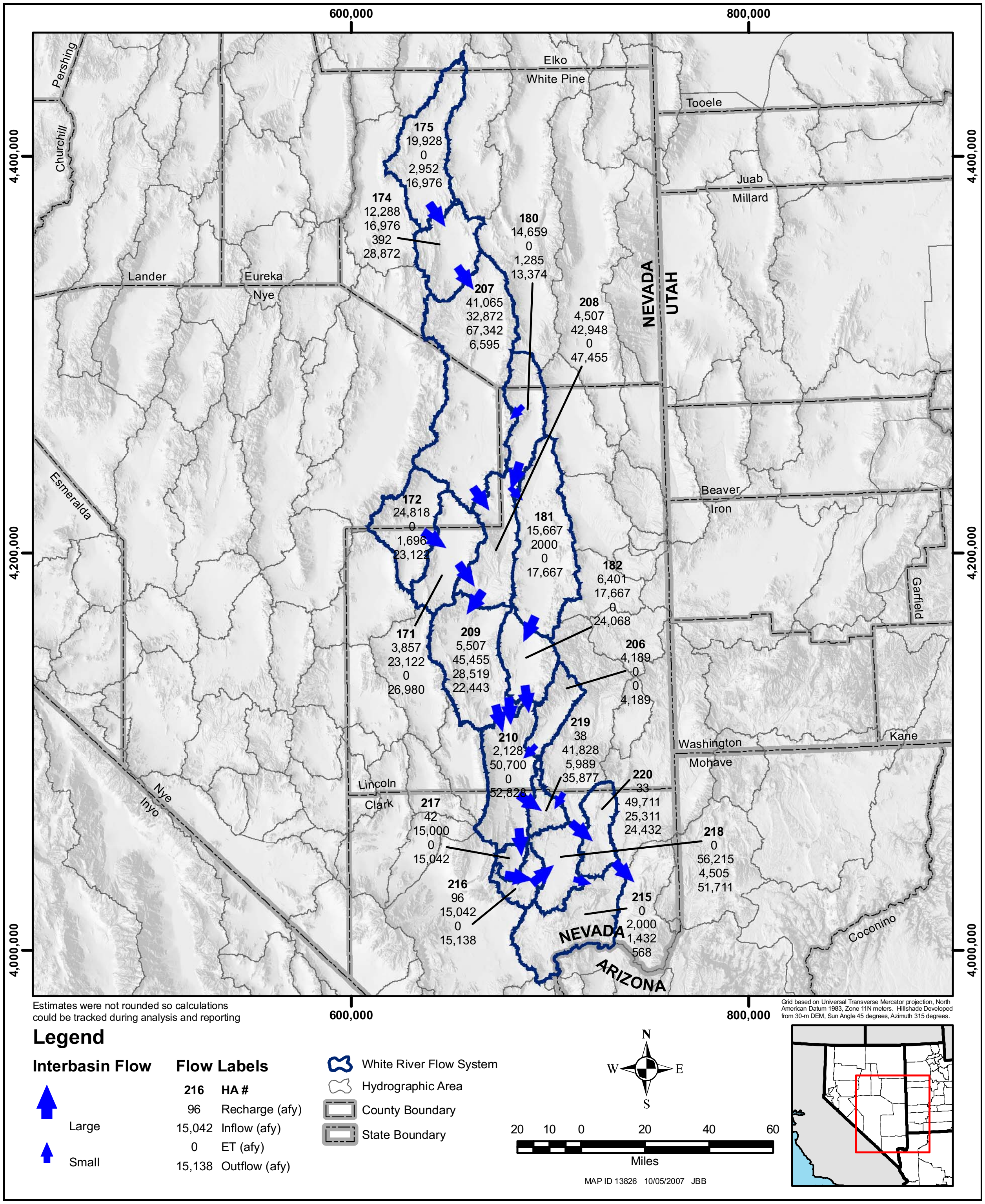



**Figure 5-7**
**Estimated Groundwater Budgets for Basins within the WRFS**

# 6.0 UNCERTAINTY ANALYSES

Uncertainty analyses were conducted to evaluate the estimated budget components of the WRFS and the three project basins described in Section 5.0. Descriptions of the objectives, approach, are results of the uncertainty analyses are provided, followed by a summary. Analysis details are provided in Appendix E.

## 6.1 Objective

The objective of the uncertainty analyses is to develop an understanding of the uncertainties associated with estimated variables, including groundwater budget components and recharge efficiencies, and their effect on the calculated recharge efficiencies and final groundwater budgets.

## 6.2 Approach

The approach consists of considering alternative scenarios to evaluate the effect of the uncertainty associated with the target value and the constraints placed on the most uncertain variables of the base-case solution. The base-case solution in this uncertainty analysis is the solution described in Section 5.0. An additional special scenario was also considered to evaluate the effect of incorporating the BARCASS ET estimates, where available, into the calculations.

For all scenarios, except the last one, the specific steps are as follows:

1. Identify the constraints with the largest uncertainty based on the range of estimated values.
2. Starting with the Excel base-case solution file, create an uncertainty file by replacing the appropriate variable with the low or high value.
3. Execute the solver to derive a new solution and basin groundwater budgets.
4. Compare the results of the new solution to the results of the base-case solution.

Comparisons between the base-case and new solutions were made to determine the effects of the uncertainty with respect to the following parameters: (1) recharge efficiencies, (2) the WRFS budget components, and (3) the budget components for Cave, Dry Lake, and Delamar valleys. The effects on selected interbasin flow volumes were also examined in some cases.

Constrained variables involved in estimating the recharge distribution for the WRFS are as follows:

- Groundwater ET estimates for each basin in the WRFS

- Total inflow to the WRFS from the Meadow Valley Wash flow system
- Total outflow from the WRFS to the Colorado River
- Maximum recharge efficiency

Based on the groundwater ET estimates presented in Section 4.0 and summarized in Table 4-5, most of the groundwater ET estimates independently derived by SNWA are very similar to previously reported values. Because the differences between these estimates are small, it is assumed that uncertainty associated with the estimates is also small. However, there are relatively large differences between the estimates for White River Valley and the Muddy River Springs Area. Therefore, it is assumed that the ET estimates for these two basins are the most uncertain. Another constrained variable that plays a major role in the distribution of recharge is the maximum recharge efficiency.

The effect of the uncertainty associated with these variables (groundwater ET, WRFS inflow, WRFS outflow, and maximum recharge efficiency) was evaluated with respect to their affect on the recharge distribution and associated basin groundwater budgets. A set of ten alternate scenarios was implemented separately for the low and high values of each variable (Table 6-1). The derived solutions and the comparisons to the base-case solution are presented and discussed in the next section.

**Table 6-1**
**Range of Uncertainty for Selected Variables**

| Variable | Low Value | High Value | Sources |
|---|---|---|---|
| White River Valley Groundwater ET (afy) | 37,000[a] | 79,560 | Eakin, 1966; LVVWD, 2001 |
| Muddy River Springs Area ET (afy) | 2,300 | 5,989 | Eakin, 1966; this study |
| Total Inflow to the WRFS (afy) | 7,000 | 32,000 | Rush, 1968; LVVWD, 2001 |
| Total Outflow from the WRFS (afy) | 11,100 | 49,000 | Rush, 1968; LVVWD, 2001 |
| Maximum Recharge Efficiency (percent of precipitation) | 0.25 | 1 | Maxey and Eakin, 1949 |

[a]Based on spring discharge estimates (Eakin, 1966, p. 261; Scott et al., 1971, p. 50).

The special scenario, referred to as the “SNWA/BARCASS” scenario, was designed to evaluate the effects of using the groundwater ET estimates derived by BARCASS for Long, Jakes, White River, and Cave valleys, instead of those derived by this study. The principal elements of the BARCASS interpretation were incorporated in the SNWA solution file (base-case) as follows:

- The groundwater ET estimates derived by this study for the four subject basins were replaced with the BARCASS estimates (see Table 4-5 for the BARCASS estimates)

- Groundwater flow routing from Cave Valley was changed to the BARCASS interpretation, in which all flow is routed to White River Valley (Welch and Bright, 2007, p. 6), instead of White River and Pahroc valleys.

## 6.3 Analysis and Results

Descriptions of the analysis and results for the scenarios tested for each of the variables listed in Table 6-1 are provided in Table 6-2 and discussed in the following subsections. Analysis details are provided in Appendix E.

### 6.3.1 Groundwater ET Estimates

The effects of the uncertainty associated with the groundwater ET estimates of White River Valley and the Muddy River Springs Area are described below.

#### White River Valley Groundwater ET

Estimated volumes of groundwater ET from White River Valley range between 37,000 afy (Eakin, 1966; Scott et al., 1971) and 79,560 afy (LVVWD, 2001). The effects of these two values on the recharge efficiencies and groundwater budgets are presented in Table 6-2.

The effects on the recharge efficiencies are relatively small, especially for the case of the high ET value. However, the effects on recharge are significant for both cases. As can be seen in Table 6-2, a decrease in the groundwater ET of White River Valley causes a decrease in recharge. Inversely, an increase in the groundwater ET of White River Valley causes an increase in recharge. The resulting total recharge volumes for the WRFS are 124,882 and 184,897 afy, as compared to the base case volume of 155,224 afy. The resulting recharge volumes for the three project basins are 28,721 and 44,584 afy, as compared to the base case value of 36,727 afy.

In the case where the ET value was decreased to the low value of 37,000 afy (Eakin, 1966; Scott et al., 1971), the total outflow from the WRFS remained the same. In the case where the ET value was increased to the high value of 79,560 afy (LVVWD, 2001), the total outflow from the flow system increases from 25,000 to 40,063 afy. The effect of the uncertainty of this variable is rather large.

#### Muddy River Springs Area Groundwater ET

Estimated volumes of groundwater ET from the Muddy River Springs Area range between 2,300 afy (Eakin, 1966, p. 261) and 5,989 afy (this study). Solutions were derived for each of these values.

In the case of the low value of 2,300 afy (Eakin, 1966), the target value of total ET was adjusted to 135,735 afy to reflect the lower ET value for the Muddy River Springs Area. Since the largest groundwater ET value was derived as part of this study, the high value case is identical to the base case. The results are presented in Table 6-2. The case of the low value causes a small decrease in the total recharge from 155,224 to 154,705 afy. The total WRFS outflow increases from 25,000 to 28,169 afy. The effect of the uncertainty of this variable is small.

### 6.3.2 Total Inflow from the Lower Meadow Valley Wash Flow System

As described in Section 4.0, the inflow from Lower Meadow Valley Wash has been estimated by several authors. The lowest volume was estimated by Rush (1968, p. 26, 27) at 7,000 afy, and the

## Table 6-2
## Results of Uncertainty Analysis for Scenarios Listed in Table 6-1

| Variable | Base Case | Recharge Efficiency | | White River Valley Groundwater ET | | Muddy River Springs Area Groundwater ET | | WRFS Inflow | | WRFS Outflow | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Value (0.25) | High Value (1.0) | Low Value (37,000 afy) | High Value (79,560 afy) | Low Value (2,300 afy) | High Value (5,989 afy) | Low Value (7,000 afy) | High Value (32,000 afy) | Low Value (11,100 afy) | High Value (49,000 afy) |
| **Recharge Efficiency as a Percentage of Precipitation** | | | | | | | | | | | |
| Precipitation Zone: 8 to 12 in. (% of precipitation) | 0.38 | 1.10 | 0.22 | 0.24 | 0.56 | 0.38 | 0.38 | 0.39 | 0.38 | 0.20 | 0.52 |
| Precipitation Zone: 12 to 15 in. (% of precipitation) | 3.64 | 4.98 | 2.98 | 2.67 | 4.61 | 3.62 | 3.64 | 3.71 | 3.62 | 2.72 | 4.42 |
| Precipitation Zone: 15 to 20 in. (% of precipitation) | 14.79 | 11.12 | 16.53 | 12.64 | 16.69 | 14.75 | 14.79 | 14.94 | 14.75 | 15.05 | 16.34 |
| Precipitation Zone: >20 in. (% of precipitation) | 44.52 | 20.55 | 63.77 | 42.96 | 45.78 | 44.50 | 44.52 | 44.62 | 44.50 | 58.06 | 45.56 |
| **WRFS Budget Components** | | | | | | | | | | | |
| Recharge (afy) | 155,224 | 168,241 | 155,224 | 124,882 | **184,897** | 154,705 | 155,224 | 157,424 | 154,690 | 141,324 | 179,224 |
| Inflow (afy) | 9,200 | 9,200 | 9,200 | 9,200 | **9,200** | 9,200 | 9,200 | 7,000 | 32,000 | 9,200 | 9,200 |
| ET (afy) | 139,424 | 139,424 | 139,424 | 109,082 | **151,642** | 135,735 | 139,424 | 139,424 | 139,424 | 139,424 | 139,424 |
| Outflow (afy) | 25,000 | 38,018 | 25,000 | 25,000 | **42,455** | 28,169 | 25,000 | 25,000 | 47,266 | 11,100 | 49,000 |
| **Cave Valley** | | | | | | | | | | | |
| Recharge (afy) | 14,659 | 14,360 | 14,944 | 11,932 | 17,250 | 14,613 | 14,659 | 14,854 | 14,612 | 13,606 | 16,760 |
| Inflow (afy) | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| ET (afy) | 1,285 | 1,285 | 1,285 | 1,285 | 1,285 | 1,285 | 1,285 | 1,285 | 1,285 | 1,285 | 1,285 |
| Outflow (afy) | 13,374 | 13,074 | 13,658 | 10,647 | 15,965 | 13,328 | 13,374 | 13,568 | 13,326 | 12,320 | 15,475 |
| **Dry Lake Valley** | | | | | | | | | | | |
| Recharge (afy) | 15,667 | 20,017 | 13,962 | 11,945 | 19,380 | 15,603 | 15,667 | 15,940 | 15,601 | 12,712 | 18,666 |
| Inflow (afy) | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 |
| ET (afy) | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| Outflow (afy) | 17,667 | 22,017 | 15,962 | 13,945 | 21,380 | 17,603 | 17,667 | 17,940 | 17,601 | 14,712 | 20,666 |
| **Delamar Valley** | | | | | | | | | | | |
| Recharge (afy) | 6,401 | 8,294 | 5,610 | 4,844 | 7,954 | 6,374 | 6,401 | 6,515 | 6,373 | 5,108 | 7,656 |
| Inflow (afy) | 17,667 | 22,017 | 15,962 | 13,945 | 21,380 | 17,603 | 17,667 | 17,940 | 17,601 | 14,712 | 20,666 |
| ET (afy) | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| Outflow (afy) | 24,068 | 30,310 | 21,572 | 18,789 | 29,334 | 23,977 | 24,068 | 24,456 | 23,974 | 19,819 | 28,321 |

largest by the LVVWD (2001, p. 6-2, 6-3) at 32,000 afy. These two values were substituted to the estimate of 9,200 afy used in the base case. The flow volume was subdivided between the Muddy River Springs Area and the California Wash in the same proportions as in the base case; a fraction of 0.43 is routed to the Muddy River Springs Area, the remaining fraction, 0.57, is routed to California Wash.

The effects on the recharge efficiencies and groundwater budgets are presented in Table 6-2. The results indicate that, despite the large relative changes in the inflow amounts, the recharge volumes changed very little. The resulting volumes for the WRFS recharge for the low and high values of inflow are 157,424 and 154,690 afy, respectively, as compared to a base case value of 155,224 afy. The resulting recharge volumes for the project basins are 37,309 and 36,586 afy, respectively, as compared to the base case value of 36,727 afy. In the case of the high value of inflow, the total outflow increases by a relatively large amount, from 25,000 to 47,266 afy.

### *6.3.3 Total Outflow to the Colorado River*

As described in Section 4.0, outflow from the WRFS to the Colorado River occurs as Muddy River streamflow (of groundwater origins), spring discharge from Rogers and Blue Point springs, and subsurface outflow from Lower Moapa Valley. The low and high values for the reported range of outflow are 11,100 afy (Rush, 1968; Wells, 1954, p. 570) and 49,000 afy (LVVWD, 2001, p. 6-3). The two values were tested in the solution by changing the constraint on the outflow to the Colorado River from being greater than or equal to the estimated 25,000 afy, to being equal to each of these two values (Table 6-2). The constraint for total outflow was set equal to each of these two values one at the time.

The case where the outflow is constrained to equal 11,100 afy does not yield a solution, unless other constraints are changed. The constraints placed on outflow from White River Valley and the total inflow to the Muddy River Springs Area were changed to allow the solver to converge to a solution. The lower bound for the White River Valley outflow was changed from greater than or equal to 6,300 afy to a positive number (i.e., >0). The total inflow to the Muddy River Springs Area was changed from greater than or equal to 40,000 afy to a positive number. Interbasin flow volumes calculated by the solver are 2,085 afy for the outflow from White River Valley, and 28,022 afy for the total inflow to the Muddy River Springs Area. The constraint imposed on the maximum recharge efficiency was increased from 0.63 to the absolute maximum of 1. The derived solution exhibits notable changes in the recharge efficiencies and the water budgets (Table 6-2). The maximum calculated recharge efficiency increased from 0.63 in the base case to 0.88. The WRFS recharge decreased from 155,224 afy in the base case to 141,324 afy. The total recharge for the three project basins decreased from 36,727 afy in the base case to 31,426 afy. Although the underflow out of White River Valley is believed to be significant, the volume derived for this case is very low (2,085 afy). Hydrologic conditions prevailing along the boundary between White River Valley and Pahroc Valley dictate that at least 6,300 afy (Maxey and Eakin, 1949, p. 45; Welch and Bright, 2007 p. 6) of outflow occurs through this boundary. This volume may be higher and has previously been estimated to be about 40,000 afy (Eakin, 1966, p. 265). Also, the calculated volume of total inflow to the Muddy River Springs Area (28,022 afy) is much lower than the absolute minimum of about 34,000 afy corresponding to the spring discharge of the Muddy Springs (Eakin, 1964, p. 24; Wells, 1954, p. 566). This case is, therefore, highly unlikely, if not impossible.

The case where the total outflow is constrained to equal the maximum reported value of 49,000 afy yields a solution without any changes to the constraints. The effects on the recharge efficiencies are relatively small (Table 6-2). A notable increase occurs in the recharge efficiencies in the lower part of the precipitation levels (more than 20 percent for the 12-to-15-inch zone). The effects on the recharge estimates and interbasin flow volumes are also large (Table 6-2). The total recharge increased from 155,224 to 179,224 afy, reflecting the increase in the outflow. The total recharge to the three project basins increased from 36,727 to 43,082 afy. The outflow from White River Valley increased from 6,595 to 17,078 afy. The inflow to the Muddy River Springs Area increased from 41,828 to 65,757 afy. Although this volume seems large, it is within the realm of possibilities.

### 6.3.4 Maximum Recharge Efficiency

The maximum recharge efficiency of 0.25 reported by Maxey and Eakin (1949) was used as the low value to be tested in this uncertainty analysis. The value of 0.25 is associated with a large precipitation interval and does not, therefore, represent a maximum recharge efficiency for narrow 1-in. intervals such as the ones used in this analysis. Thus, the value of 0.25 most probably represents the lowest possible value for a maximum recharge efficiency. The absolute maximum recharge efficiency is 1, which represents a situation where all precipitation becomes recharge. Given the same altitude and climatic conditions, the maximum efficiency depends on the geology, specifically, the vertical hydraulic conductivity of the receiving medium. In highly fractured media such as karstic carbonate-rock aquifers, the absolute maximum efficiency may be reached at the local scale. However, at the regional and basin scales, it is highly unlikely that this maximum is reached. Although both of these values represent the extremes, they were used in two alternate scenarios to gage how the uncertainty associated with this variable might effect the solution.

The results of the two tests are presented in Table 6-2. Although the effects on the recharge efficiencies seem drastic, the recharge volumes for the WRFS as a whole and the individual basins do not change appreciably. The total flow system recharge is 168,241 afy for the low value as compared to the base case value of 155,224 afy. To balance the larger recharge of 168,241 afy in the low value case, the total outflow had to increase. The total recharge corresponding to the high efficiency value remained unchanged. The recharge for the three project basins was, however, effected by both values. The recharge is 42,671 afy for the low value and 34,516 afy for the high value, as compared to the base case value of 36,727 afy.

### 6.3.5 SNWA/BARCASS Scenario

The effects of using the BARCASS groundwater ET estimates and their interpretation of flow routing out of Cave Valley are presented in Table 6-3. The calculated recharge efficiencies are very close to the base-case efficiencies. The total WRFS recharge for this case increased from 155,224 to 163,591 afy. The difference is the result of the increase in the groundwater ET estimate of the four basins that are common to the two studies. Most of it is due to the larger groundwater ET estimates for White River Valley, 76,701 afy as compared to the estimate derived by this study, 67,342 afy. The total recharge for Cave, Dry Lake, and Delamar valleys increases from 36,727 to 38,941 afy; whereas, the total ET for these three basins is 1,285 afy for this study and 1,550 afy for BARCASS

**Table 6-3**
**Results of SNWA/BARCASS Scenario**

| Variable | Base Case | SNWA/BARCASS Scenario |
|---|---|---|
| **Recharge Efficiency as a Percent of Precipitation** | | |
| Precipitation Zone: 8 to 12 in. | 0.38 | 0.43 |
| Precipitation Zone: 12 to 15 in. | 3.64 | 3.91 |
| Precipitation Zone: 15 to 20 in. | 14.79 | 15.34 |
| Precipitation Zone: >20 in. | 44.52 | 44.90 |
| **White River Valley Flow System** | | |
| Recharge (afy) | 155,224 | 163,591 |
| Inflow (afy) | 9,200 | 9,200 |
| ET (afy) | 139,424 | 147,791 |
| Outflow (afy) | 25,000 | 25,000 |
| **Cave Valley** | | |
| Recharge (afy) | 14,659 | 15,397 |
| Inflow (afy) | 0 | 0 |
| ET (afy) | 1,285 | 1,550 |
| Outflow (afy) | 13,374 | 13,847 |
| **Dry Lake Valley** | | |
| Recharge (afy) | 15,667 | 16,708 |
| Inflow (afy) | 2,000 | 2,000 |
| ET (afy) | 0 | 0 |
| Outflow (afy) | 17,667 | 18,708 |
| **Delamar Valley** | | |
| Recharge (afy) | 6,401 | 6,836 |
| Inflow (afy) | 17,667 | 18,708 |
| ET (afy) | 0 | 0 |
| Outflow (afy) | 24,068 | 25,544 |

(Welch and Bright, 2007; Appendix A, Excel file named "ofr20071156_appendixa.xls" - Sheet named "Discharge").

## *6.4 Summary*

A summary of the results for all scenarios used in the uncertainty analysis is presented in Table 6-4. The table lists the minimum and maximum effects of changing the specified variable in the solution in terms of the difference between the base-case and the new solution. There is a relatively large range for the recharge efficiencies, with the efficiency associated with the >20 in. precipitation zone ranging from about 20 and 64 percent of precipitation. Although this range appears to be significant, when expressed in terms of recharge volume, the differences are less dramatic. The range of uncertainty for the WRFS recharge ranges from 124,882 to 184,897 afy as compared to the base-case value of 155,224 afy. This represents a maximum uncertainty of 20 percent. For Cave, Dry Lake, and Delamar valleys, the uncertainty for recharge ranges from 28,721 to 44,584 afy as compared to the base-case value of 36,727 afy. This also represents an uncertainty range of about 20 percent. The maximum uncertainty associated with the recharge volume estimates is caused by the uncertainty in the estimate of groundwater ET for White River Valley.

**Table 6-4**
**Summary of Uncertainty Analysis Results**

| Variable | Base Case | Minimum Value | Maximum Value |
|---|---|---|---|
| **Recharge Efficiency as a Percentage of Precipitation** | | | |
| Precipitation Zone: 8 to 12 in. | 0.38 | 0.20 | 1.10 |
| Precipitation Zone: 12 to 15 in. | 3.64 | 2.67 | 4.98 |
| Precipitation Zone: 15 to 20 in. | 14.79 | 11.12 | 16.53 |
| Precipitation Zone: >20 in. | 44.52 | 20.55 | 63.77 |
| **White River Valley Flow System** | | | |
| Recharge (afy) | 155,224 | 124,882 | 184,897 |
| Inflow (afy) | 9,200 | 7,000 | 32,000 |
| ET (afy) | 139,424 | 109,082 | 151,642 |
| Outflow (afy) | 25,000 | 11,100 | 49,000 |
| **Cave Valley** | | | |
| Recharge (afy) | 14,659 | 11,932 | 17,250 |
| Inflow (afy) | – – | – – | – – |
| ET (afy) | 1,285 | 1,285 | 1,285 |
| Outflow (afy) | 13,374 | 10,647 | 15,965 |
| **Dry Lake Valley** | | | |
| Recharge (afy) | 15,667 | 11,945 | 20,017 |
| Inflow (afy) | 2,000 | 2,000 | 2,000 |
| ET (afy) | – – | – – | – – |
| Outflow (afy) | 17,667 | 13,945 | 22,017 |
| **Delamar Valley** | | | |
| Recharge (afy) | 6,401 | 4,844 | 8,294 |
| Inflow (afy) | 17,667 | 13,945 | 22,017 |
| ET (afy) | – – | – – | – – |
| Outflow (afy) | 24,068 | 18,789 | 30,310 |

# 7.0 SUMMARY AND CONCLUSIONS

This report presents a regional assessment of the precipitation, natural recharge, groundwater discharge, and interbasin flow of the WRFS. This assessment and was completed in support of water-right hearings related to SNWA applications 53987 through 53992, inclusive, in Cave, Dry Lake, and Delamar valleys.

The objectives of this assessment were to estimate the groundwater recharge distribution for the WRFS and derive predevelopment groundwater budgets for the flow system and for the individual basins, specifically Cave, Dry Lake, and Delamar valleys. To achieve these objectives, new recharge efficiencies were derived for the WRFS using the water-balance method, improved estimates of groundwater ET and precipitation distribution, and other hydrologic information collected since the Reconnaissance Series Reports were published. The water-balance method was implemented using the Excel Solver. These efficiencies were then applied to the precipitation distribution to generate a distribution of recharge from which basin recharge estimates were then computed and used to develop basin groundwater budgets. Finally, an uncertainty analysis was conducted to evaluate the effect of the most uncertain variables on the solution. The major findings of this study related to the precipitation distribution, the groundwater ET and the recharge distribution of the WRFS and its basins and are summarized below.

### *Precipitation Distribution*

The PRISM grid (800-m 1971 to 2000 normals - Version 2; May 3, 2007) provides a good representation of the long-term mean annual precipitation distribution for the WRFS. The PRISM grid represents, within ten percent, the period of record mean annual value for most stations within the WRFS and vicinity (Figure 4-2). The PRISM precipitation distribution appears to overestimate precipitation at the station locations, but with little spatial correlation (i.e., overestimates regardless of location and altitude). If in fact PRISM overestimates the “true” values of precipitation, then the “true” values of groundwater ET are underestimated and, therefore, the “true” value of the total recharge of the WRFS is underestimated. This is because the groundwater ET was computed by subtracting precipitation from the total ET estimate; therefore, a larger value of precipitation would yield a smaller value of groundwater ET. Because groundwater ET is used as the target value in the water-balance method (as applied here), a smaller value would yield a corresponding smaller value of recharge.

The PRISM precipitation grid provides a much better spatial distribution of precipitation than the Hardman precipitation maps (1936, 1965), particularly at the higher precipitation intervals, where the resolution of the PRISM grid is much better than the Hardman maps. This is because (1) PRISM incorporates more data (e.g., high-altitude precipitation stations), (2) PRISM has greater topographical resolution (800 meter versus 1:250,000 scale), and (3) PRISM incorporates natural phenomena affecting the spatial precipitation distributions such as rain shadows and coastal effects.

Therefore, it was concluded that for the purposes of this regional-scale evaluation, the PRISM precipitation distribution best represents the precipitation distribution for the WRFS.

For Cave, Dry Lake, and Delamar valleys, Eakin (1962; 1963a) had assumed through personal communication with Hardman, that the elevation contours from an improved topographical base correlated to the precipitation zones defined by Hardman (1936). Based on this assumption, Eakin (1962; 1963a) equated the 6,000 to 7,000 ft elevation interval to the 8 to 12 in. precipitation zone, the 7,000 to 8,000 ft interval to the 12 to 15 in. zone, the 8,000 to 9,000 interval to the 15 to 20 in. zone, and for altitudes greater than 9,000 ft, to the >20 in. zone. Below altitudes of 6,000 ft, less than eight inches of precipitation was assumed. This assumption was tested for Cave, Dry Lake, and Delamar valleys by comparing a digitized version of the Hardman (1962) map and superposing elevation contours that were generated from 30 m DEM (USGS, 2001). The results of this comparison revealed that the assumption was erroneous for much of the area of these basins. This is a very important as these assumptions were used in the derivation of the recharge estimates for these basins using the standard Maxey-Eakin recharge efficiencies. The comparison indicates that the Hardman precipitation map yields about 130,000 afy more precipitation for the three project basins for precipitation zones greater than 8-in. (Table 5-4).

### *Groundwater ET*

Predevelopment groundwater ET for the WRFS is estimated to be 139,424 afy, which falls within the literature range of 100,600 (Eakin, 1966; Rush, 1968) and 176,305 (LVVWD, 2001) (Table 4-5). Estimates of groundwater ET for the three project basins are as follows: 1,285 afy for Cave Valley, and zero for the other two. The estimated basin groundwater ET volumes compare reasonably well with previous estimates, except for two basins: White River Valley and the Muddy River Springs Area.

For White River, more recent estimates, including this study, reflect newer mapping and utilize data from ET measurement sites. These estimates all fall within a range of about 10,000 afy (Table 4-5) of each other but are at least 30,000 afy greater than the early estimate of Eakin (1966, p. 261). The disparity between these estimates and Eakin's (1966) can be traced to the total acreage delineated for the groundwater discharge area (Table B.1-1). Only 36,000 acres were delineated for the area used in the Eakin (1966) estimate (Maxey and Eakin, 1949), while the other studies delineated more than four times this acreage. Because of the similarity between the more recent measurements and the difference in the acreage delineated for the groundwater discharge area, it is concluded that the groundwater estimate reported by Eakin (1966) is low and not representative of the long-term mean annual conditions.

For the Muddy River Springs Area, the groundwater ET estimate of 5,989 afy derived by this study represents the highest reported value, and is about 3,700 afy greater than the lowest estimate derived by Eakin (1966), which is 2,300 afy. The acreage delineating this groundwater discharge area was estimated by this study to be 1,951 acres. The area was not delineated or reported by Eakin (1966). While the percent difference between the estimates is seemingly large, the difference in terms of volume is insignificant with respect to its influence on the outcome of the analyses described in this report.

### *Natural Recharge*

The Excel solver was used to derive a recharge solution using the groundwater balance approach. The solution is an estimate of the total groundwater discharge and recharge distribution for the WRFS. The recharge distribution was used in conjunction with the groundwater ET estimates to construct the groundwater budget for the WRFS and its individual basins. The results of this analysis are summarized below:

- The total groundwater recharge for the WRFS under predevelopment steady-state conditions was calculated to be about 155,000 afy (rounded). The total recharge falls within the reported range of values (104,650 to 201,500 afy).

- Recharge efficiencies were derived for 1-in precipitation intervals, and are summarized by the precipitation zones defined by Maxey and Eakin (1949) for comparison purposes. They are as follows: 45 percent for >20 in. zone; 15 percent for 15 to 20 in. zone; 4 percent for 12 to 15 in. zone, and 0.4 percent for 8 to 12 in. zone (Equation 5-5). The relationship between recharge and precipitation is somewhat different from that of Maxey and Eakin (1949) because the precipitation distributions and groundwater ET estimates are significantly different. However, the method by which the relationships were derived are essentially the same. The relationship derived by this analysis is very comparable to more recent relationships developed by others (Figure 5-4).

- The recharge efficiencies were applied to the PRISM precipitation distribution to derive a spatial distribution of recharge, yielding basin recharge volumes that compare well with the recharge estimates reported in the literature for most basins. The exceptions are Garden Valley and Dry Lake Valley which are higher based on this analysis, and Coyote Spring Valley which is lower (Table 5-2).

- As discussed previously, the altitude-precipitation assumptions of Eakin (1962; 1963a) yield much different estimates of precipitation than the Hardman (1962) precipitation map. These differences also translate into significantly different estimates of recharge for Cave, Dry Lake, and Delamar valleys (Table 5-4). Applying the standard Maxey-Eakin recharge efficiencies to the Hardman (1962) precipitation map yields over 13,000 afy more recharge in these basins than Eakin (1962; 1963a). For Cave Valley the difference is about 7,500 afy more, in Dry Lake Valley about 4,000 afy more, and in Delamar Valley about 1,700 afy more. The recharge was estimated to be about 21,500, 9,000, and 2,900 afy, respectively, or 33,400 afy in total. This is only about 3,300 afy less than the total for the three basins estimated by this study, although the distribution is somewhat different.

### *Groundwater Budgets*

A groundwater budget for the WRFS and its individual basins was constructed using the recharge, groundwater ET, and boundary flow estimates derived by this analysis. All of these components fall within the literature range of values. The budget components for Cave, Dry Lake, and Delamar valleys are listed in Table 7-1.

**Table 7-1**
**Groundwater Budget Components for Cave, Dry Lake, and Delamar Valleys**

| Basin Name | Recharge | Inflow | Groundwater ET | Outflow |
|---|---|---|---|---|
| Cave Valley | 14,659 | 0 | 1,285 | 13,374 |
| Dry Lake Valley | 15,667 | 2,000 | 0 | 17,667 |
| Delamar Valley | 6,401 | 17,667 | 0 | 24,068 |
| **TOTAL** | **36,727** | | **1,285** | |

### *Uncertainty Analysis*

An uncertainty analysis was conducted to evaluate the effect of the most uncertain variables on the calculated recharge efficiencies and final groundwater budgets:

- The uncertainty on the constraint placed on the maximum recharge efficiency is significant for the low value (0.25), and not significant for the high value (1.0). For the case of the low value, the total WRFS recharge increases from 155,224 afy to 168,241 afy, and remains unchanged for the case of the high value (1.0). The total recharge for the three project basins ranges from 34,516 afy (high value) to 42,671 (low value).

- The largest uncertainty is associated with the White River Valley groundwater ET based on the range of estimated values (37,000 to 79,560 afy). For the case of the low value, the total WRFS recharge decrease from 155,224 afy to 124,882 afy, and increases to 184,897 afy for the high value. The total recharge for the three project basins ranges from 28,721 (low value) to 44,584 afy (high value).

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# Appendix A

# Precipitation Station Data

# A.1.0 PRECIPITATION STATION DATA

Precipitation station data were compiled and the period of record mean annual value was derived for each station. Data were compiled from the following sources:

- Nevada Division of Water Resources (NDWR)
- USGS
- Western Regional Climate Center (WRCC)
- National Climatic Data Center (NCDC)
- NRCS - SNOwpack TELemetry (SNOTEL).

Precipitation stations selected from these sources included stations qualified as climate normals by the NCDC (Note: the average annual precipitation as reported by WRCC was used for these stations). Other stations, except for the “Sheep Peak” and “Hayford Peak” stations, have more than 20 “non-zero” years of reported annual precipitation (i.e., years in which the reported annual precipitation was greater than zero).

Summary data for the stations located within and near the WRFS are listed in Table A.1-1. The fields in the table are as follows:

- Station Number
- Station Name
- UTM Easting
- UTM Northing
- Altitude (ft-amsl)
- Annual Precipitation, Mean (inches)
- Annual Precipitation, Minimum (inches)
- Annual Precipitation, Maximum (inches)
- Period of Record
- Period of Record Duration
- NCDC Normal
- Source

## Table A.1-1
## Precipitation Station Information
(Page 1 of 2)

| Station No.[a] | Station Name | UTM Easting[b] (m) | UTM Northing[b] (m) | Altitude (ft-amsl) | Annual Precipitation | | | Period of Record | Period of Record (Number of Years) | NCDC Normal | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Mean (in.) | Min (in.) | Max (in.) | | | | |
| 1 | Connors Pass | 703,315 | 4,323,835 | 7,732 | 14.72 | 2.90 | 26.30 | 1954 to 2005 | 52 | No | NDWR |
| 2 | Current Creek | 649,245 | 4,298,199 | 5,999 | 13.71 | 6.00 | 24.49 | 1954 to 2005 | 52 | No | NDWR |
| 3 | Robinson Summit | 665,201 | 4,365,136 | 7,800 | 14.05 | 0.55 | 27.30 | 1954 to 2005 | 52 | No | NDWR |
| 4 | Schellbourne Pass | 702,800 | 4,409,348 | 7,100 | 13.67 | 0.00 | 26.80 | 1954 to 2005 | 52 | No | NDWR |
| 5 | Wilson Creek Summit | 730,436 | 4,254,601 | 7,200 | 17.51 | 6.50 | 33.00 | 1954 to 2005 | 52 | No | NDWR |
| 6 | Berry Creek | 705,390 | 4,354,622 | 9,100 | 27.35 | 19.00 | 40.80 | 1981 to 2005 | 25 | No | NRCS (SNOTEL) |
| 7 | Ward Mountain | 677,114 | 4,333,562 | 9,200 | 24.22 | 13.30 | 38.80 | 1981 to 2005 | 25 | No | NRCS (SNOTEL) |
| 8 | Cave Mountain | 706,108 | 4,337,547 | 10,650 | 20.41 | 12.00 | 32.16 | 1984 to 2005 | 22 | No | USGS |
| 9 | Cherry Creek Range | 680,594 | 4,443,655 | 9,700 | 15.67 | 9.00 | 26.25 | 1984 to 2005 | 22 | No | USGS |
| 10 | Hayford Peak | 680,192 | 3,985,798 | 9,840 | 15.75 | 7.25 | 29.00 | 1986 to 2003 | 18 | No | USGS |
| 11 | Mt. Washingon | 732,764 | 4,309,377 | 10,440 | 26.13 | 12.00 | 46.00 | 1984 to 2005 | 22 | No | USGS |
| 12 | Mt. Wilson | 728,118 | 4,236,086 | 9,200 | 19.68 | 0.00 | 47.00 | 1984 to 2005 | 22 | No | USGS |
| 13 | Sheep Peak | 680,192 | 3,985,794 | 9,600 | 15.10 | 3.00 | 28.25 | 1986 to 2003 | 18 | No | USGS |
| 14 | Unnamed Peak NW of Mt. Moriah | 737,695 | 4,355,941 | 9,300 | 16.72 | 0.00 | 28.50 | 1984 to 2005 | 22 | No | USGS |
| 15 | Adaven | 624,110 | 4,219,700 | 6,250 | 12.73 | 4.42 | 23.64 | 1928 to 1982 | 55 | No | WRCC |
| 16 | Caliente | 719,105 | 4,166,179 | 4,400 | 9.10 | 1.84 | 18.73 | 1928 to 2007 | 80 | 30 yr | WRCC |
| 17 | Callao | 780,345 | 4,421,801 | 4,330 | 5.80 | 0.94 | 10.59 | 1948 to 2007 | 60 | 30 yr | WRCC |
| 18 | Callville Bay | 703,844 | 4,002,962 | 1,270 | 5.37 | 3.18 | 11.85 | 1989 to 2007 | 19 | 10 yr | WRCC |
| 19 | Desert Game Range | 646,235 | 4,038,794 | 2,920 | 4.51 | 0.69 | 14.78 | 1948 to 2007 | 60 | No | WRCC |
| 20 | Echo Bay | 733,343 | 4,022,206 | 1,250 | 5.73 | 3.35 | 12.96 | 1989 to 2007 | 19 | 10 yr | WRCC |
| 21 | Elgin | 718,409 | 4,136,549 | 3,420 | 12.23 | 3.72 | 24.98 | 1951 to 2007 | 57 | 10 yr | WRCC |
| 22 | Ely WBO | 685,372 | 4,350,044 | 6,250 | 9.56 | 4.22 | 16.16 | 1897 to 2007 | 111 | No | WRCC |
| 23 | Eskdale | 763,613 | 4,334,515 | 4,980 | 6.39 | 3.18 | 12.57 | 1966 to 2007 | 42 | 30 yr | WRCC |

**Table A.1-1**
**Precipitation Station Information**
(Page 2 of 2)

| Station No.[a] | Station Name | UTM Easting[b] (m) | UTM Northing[b] (m) | Altitude (ft-amsl) | Annual Precipitation | | | Period of Record | Period of Record (Number of Years) | NCDC Normal | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Mean (in.) | Min (in.) | Max (in.) | | | | |
| 24 | Fish Springs Refuge | 808,023 | 4,415,084 | 4,340 | 7.89 | 3.89 | 12.64 | 1960 to 2007 | 48 | 30 yr | WRCC |
| 25 | Garrison | 757,384 | 4,313,196 | 5,260 | 7.61 | 4.59 | 14.69 | 1951 to 1990 | 40 | 10 yr | WRCC |
| 26 | Geyser Range | 706,113 | 4,282,815 | 6,020 | 8.67 | 1.65 | 15.49 | 1948 to 2002 | 55 | No | WRCC |
| 27 | Great Basin National Park | 740,673 | 4,320,446 | 6,830 | 13.27 | 7.37 | 21.20 | 1948 to 2007 | 60 | 10 yr | WRCC |
| 28 | Hiko | 657,455 | 4,157,377 | 3,940 | 7.08 | 1.45 | 13.68 | 1989 to 2007 | 19 | 10 yr | WRCC |
| 29 | Key Pittman WMA | 657,315 | 4,164,774 | 3,950 | 7.94 | 4.64 | 11.94 | 1964 to 1989 | 26 | No | WRCC |
| 30 | Lages | 702,945 | 4,436,011 | 5,960 | 8.20 | 4.83 | 13.20 | 1984 to 2007 | 24 | 10 yr | WRCC |
| 31 | Lake Valley Steward | 705,365 | 4,243,927 | 6,350 | 15.69 | 9.39 | 28.29 | 1971 to 1998 | 28 | No | WRCC |
| 32 | Logandale | 726,628 | 4,049,785 | 1,410 | 5.14 | 3.23 | 9.81 | 1968 to 1992 | 25 | No | WRCC |
| 33 | Lund, Nevada | 673,483 | 4,302,024 | 5,570 | 10.20 | 4.99 | 18.83 | 1957 to 2007 | 51 | 30 yr | WRCC |
| 34 | Mcgill | 691,944 | 4,363,530 | 6,300 | 8.81 | 3.76 | 16.21 | 1914 to 2007 | 94 | 30 yr | WRCC |
| 35 | Overton | 728,168 | 4,047,975 | 1,290 | 4.40 | 0.71 | 8.94 | 1948 to 2007 | 60 | No | WRCC |
| 36 | Pahranagat Wildlife Refuge | 666,918 | 4,126,112 | 3,400 | 6.28 | 2.23 | 11.54 | 1964 to 2007 | 44 | 30 yr | WRCC |
| 37 | Partoun | 767,708 | 4,391,336 | 4,780 | 6.68 | 2.03 | 12.21 | 1950 to 2007 | 58 | 30 yr | WRCC |
| 38 | Pioche | 724,042 | 4,201,109 | 6,180 | 13.20 | 3.81 | 27.29 | 1948 to 2006 | 59 | 30 yr | WRCC |
| 39 | Ruth | 673,938 | 4,350,154 | 6,840 | 12.04 | 6.68 | 19.46 | 1958 to 2007 | 50 | 10 yr | WRCC |
| 40 | Shoshone 5 N | 725,336 | 4,311,105 | 5,930 | 9.65 | 5.48 | 14.56 | 1988 to 2007 | 20 | 10 yr | WRCC |
| 41 | Spring Valley State Park | 747,440 | 4,212,891 | 5,950 | 12.17 | 5.05 | 23.48 | 1974 to 2007 | 34 | 10 yr | WRCC |
| 42 | Sunnyside | 672,777 | 4,254,266 | 5,300 | 9.38 | 5.73 | 17.11 | 1948 to 2007 | 60 | 30 yr | WRCC |
| 43 | Valley of Fire State Park | 722,534 | 4,034,875 | 2,000 | 6.55 | 1.66 | 16.90 | 1972 to 2007 | 36 | 30 yr | WRCC |

[a]Used in Figures 4-2 and 4-3.
[b]North American Datum of 1983, Zone 11

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# Appendix B

# Groundwater Discharge Areas and Evapotranspiration Rates

# B.1.0 INTRODUCTION

This appendix contains maps of the groundwater discharge areas for basins comprising the WRFS, and ET rates reported in the literature and used in this study to derive estimates of predevelopment groundwater discharge. A list of references used is also provided.

### *B.1.1 Groundwater Discharge Areas*

Groundwater discharge occurs as ET and as spring flow from springs located on the valley floor, usually within or near the groundwater ET areas.

Maps depicting groundwater ET distribution under predevelopment conditions and selected spring locations were developed for the following basins:

- Long Valley (HA 175)
- Jakes Valley (HA 174)
- White River Valley (HA 207) and four inset maps for added detail
- Cave Valley (HA 180)
- Garden Valley (HA 172)
- Pahranagat Valley (HA 209)
- Muddy River Springs Area (Upper Moapa Valley) (HA 219)
- California Wash (HA 218)
- Lower Moapa Valley (HA 220)
- Black Mountains Area (HA 215)

The total acreage delineated for the groundwater discharge areas for each of these basins is listed in Table B.1-1, including the estimates derived as part of this study and those of previous investigations. The discharge areas and the distribution of ET classes within the areas are depicted in Figures B.1-1 through B.1-11. It should be noted that the discharge area of White River Valley is presented in five maps. Figure B.1-3 shows the whole valley and the locations of four subareas for which more details are provided in the next four maps (Figures B.1-4 through B.1-7).

### *B.1.2 ET Rates*

A literature survey for annual ET rates measured in the WRFS region was conducted and the rates were compiled into the dataset presented in Table B.1-2. Descriptions of the fields contained in the table are as follows:

- Report: reference to report containing information. Consists of author(s) and date. Full citation is in the reference list.

- Location: Name of valley where ET rate was measured
- ET Unit Description: Description of vegetation present in area where ET rate was measured.
- DTW: Depth to water in area where ET rate was measured.
- Total ET: Total ET rate measured. Includes groundwater ET and precipitation.
- Precipitation: Precipitation rate in area where ET rate was measured.
- Groundwater ET: Measured groundwater ET rate.

**Table B.1-1**
**Total Acreage of Groundwater Discharge Areas**

| HA Name | SNWA (2007) | Smith et al. (2007)[a] | LVVWD (2001)[a] | Nichols (2000) | USGS Reconnaissance Series Reports and Water Resource Bulletins | |
|---|---|---|---|---|---|---|
| | | | | | Estimate | Author |
| Long Valley | 17,594 | 18,283 | 21,822 | 21,882 | 11,000 | Eakin (1961) |
| Jakes Valley | 971 | 1,224 | 416 | 416 | NR[b] | Eakin (1966) |
| White River Valley | 144,692 | 178,096 | 163,922 | | 36,000 | Maxey and Eakin (1949) |
| Cave Valley | 16,648 | 13,348 | 10,293 | | NR[b] | Eakin (1962) |
| Garden Valley | 950 | | 6,144 | | 2,000 to 3,000 | Eakin (1963c) |
| Pahranagat Valley | 8,658 | | 8,976 | | 9,000 | Eakin (1963b) |
| Muddy River Springs Area | 1,951 | | 1,016 | | NR[b] | Eakin (1964) |
| California Wash | 1,379 | | 1,152 | | 1,700[c] | Rush (1968) |
| Lower Moapa Valley | 7,533 | | 5,301 | | 5,600[c] | Rush (1968) |
| Black Mountains Area | 464 | | NR | | 200 | Rush (1968) |

[a]Area includes irrigated lands within the groundwater discharge area.
[b]Phreatophyte area was not delineated.
[c]Does not include 1,000 and 3,400 acres of irrigated land in California Wash and Lower Moapa Valley, respectively.

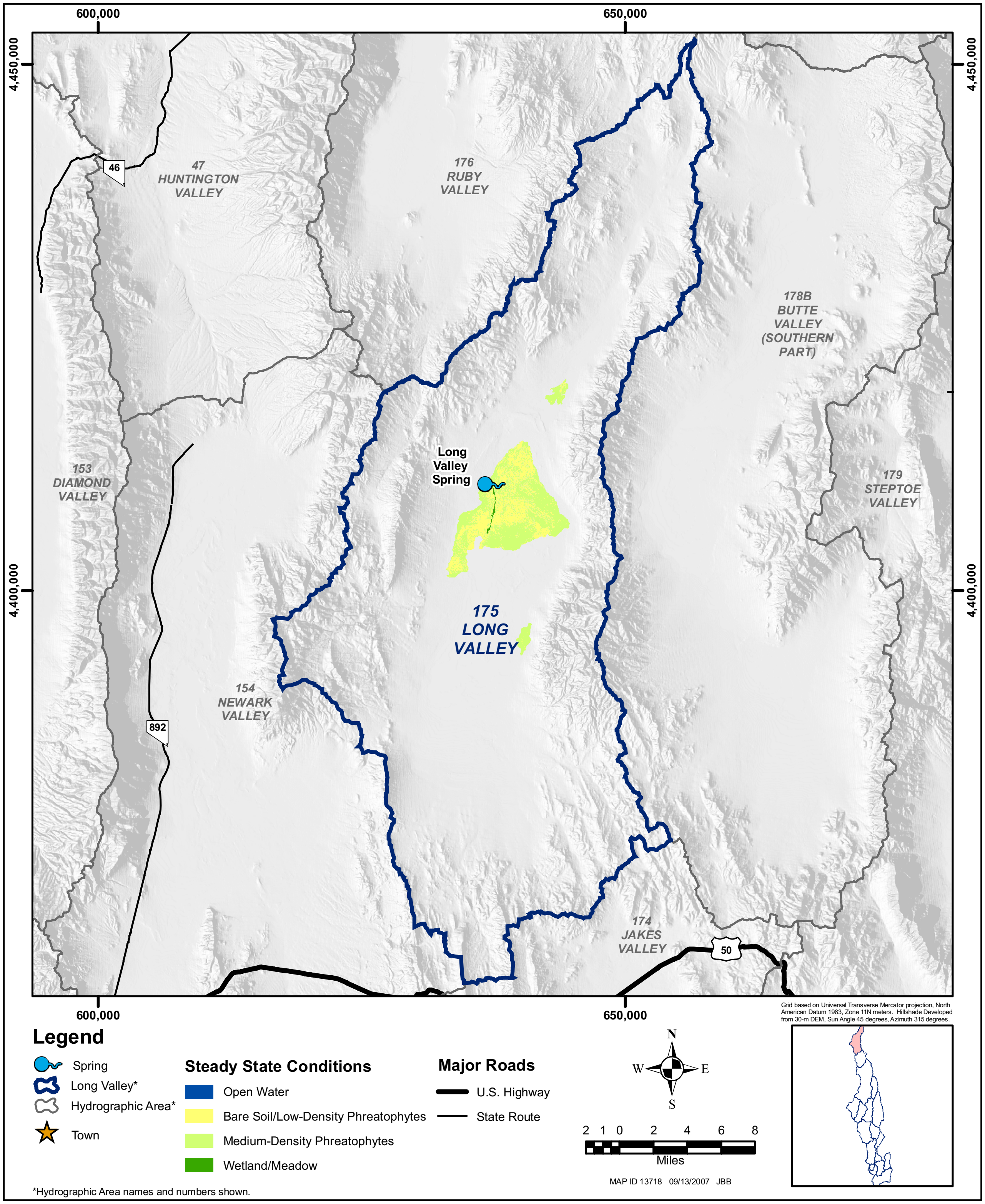
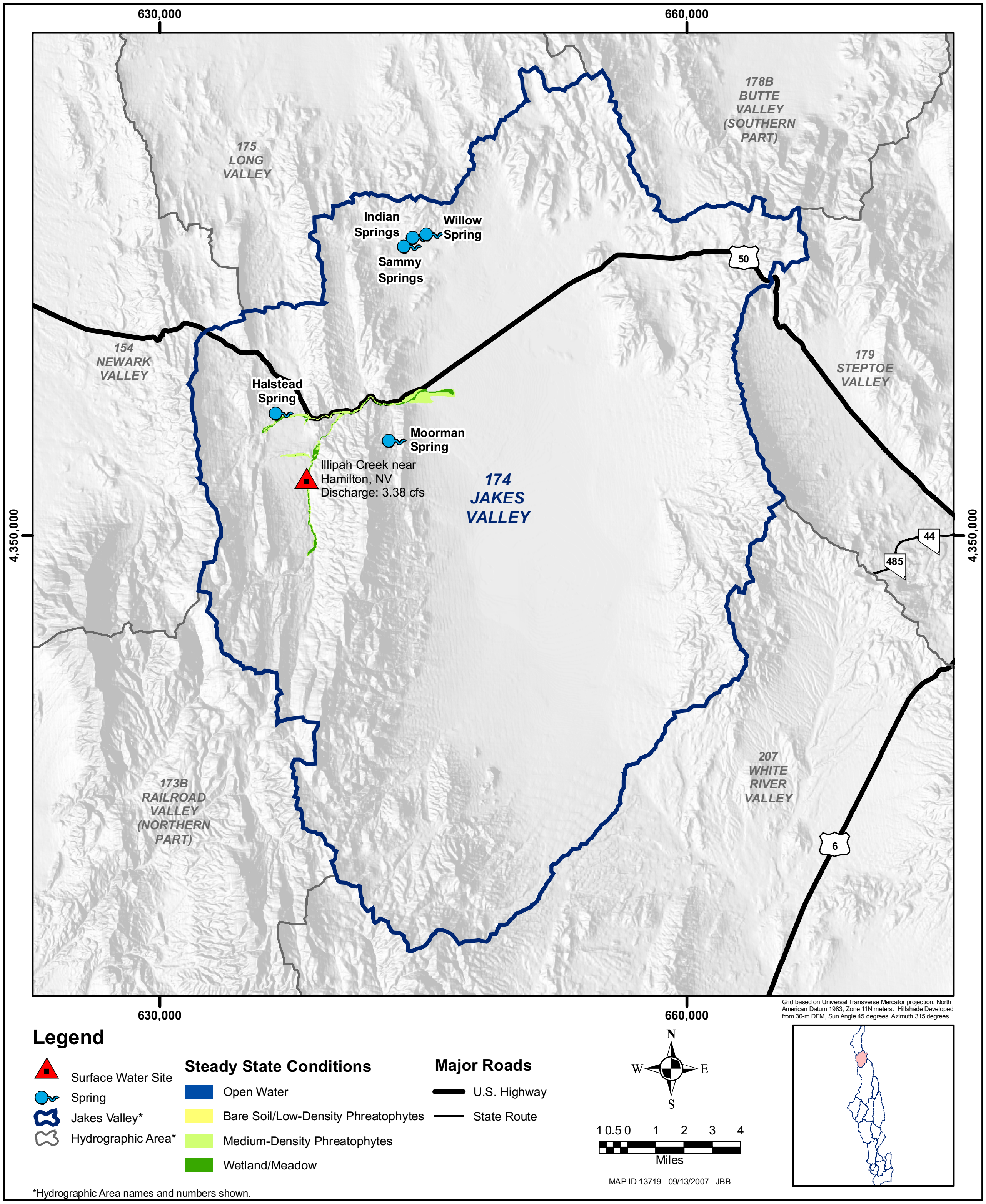
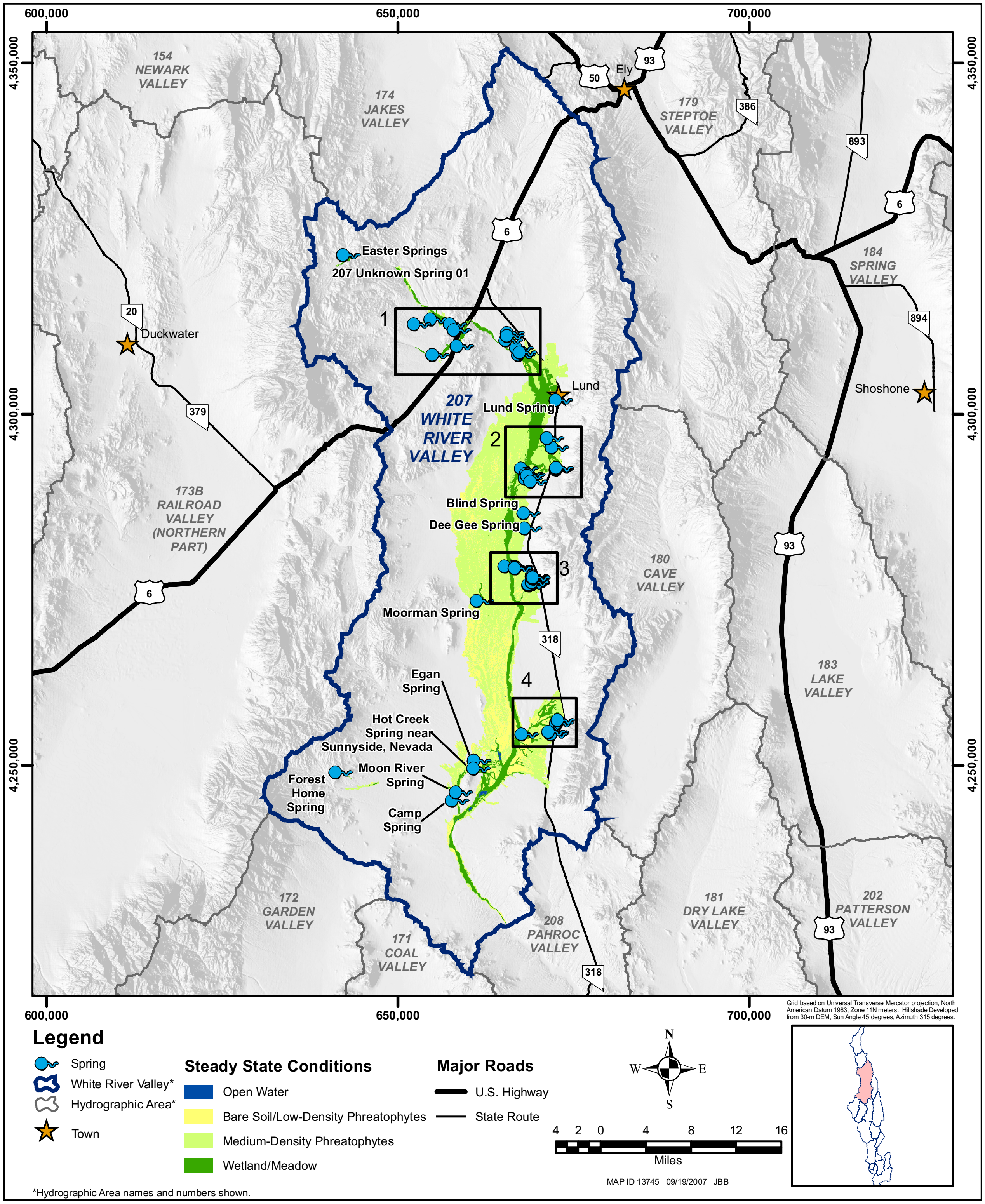



**Figure B.1-1**
**Distribution of Predevelopment Groundwater Evapotranspiration and Location of Selected Springs in Long Valley**




Note: Illipah Creek Discharge reported in USGS, 2006.

**Figure B.1-2**
**Distribution of Predevelopment Groundwater Evapotranspiration and Location of Selected Springs in Jakes Valley**




Note: Also shown are four subareas for which more details are provided in Figures B.1-4 through B.1-7

**Figure B.1-3**
**Distribution of Predevelopment Groundwater Evapotranspiration and Location of Selected Springs in White River Valley**

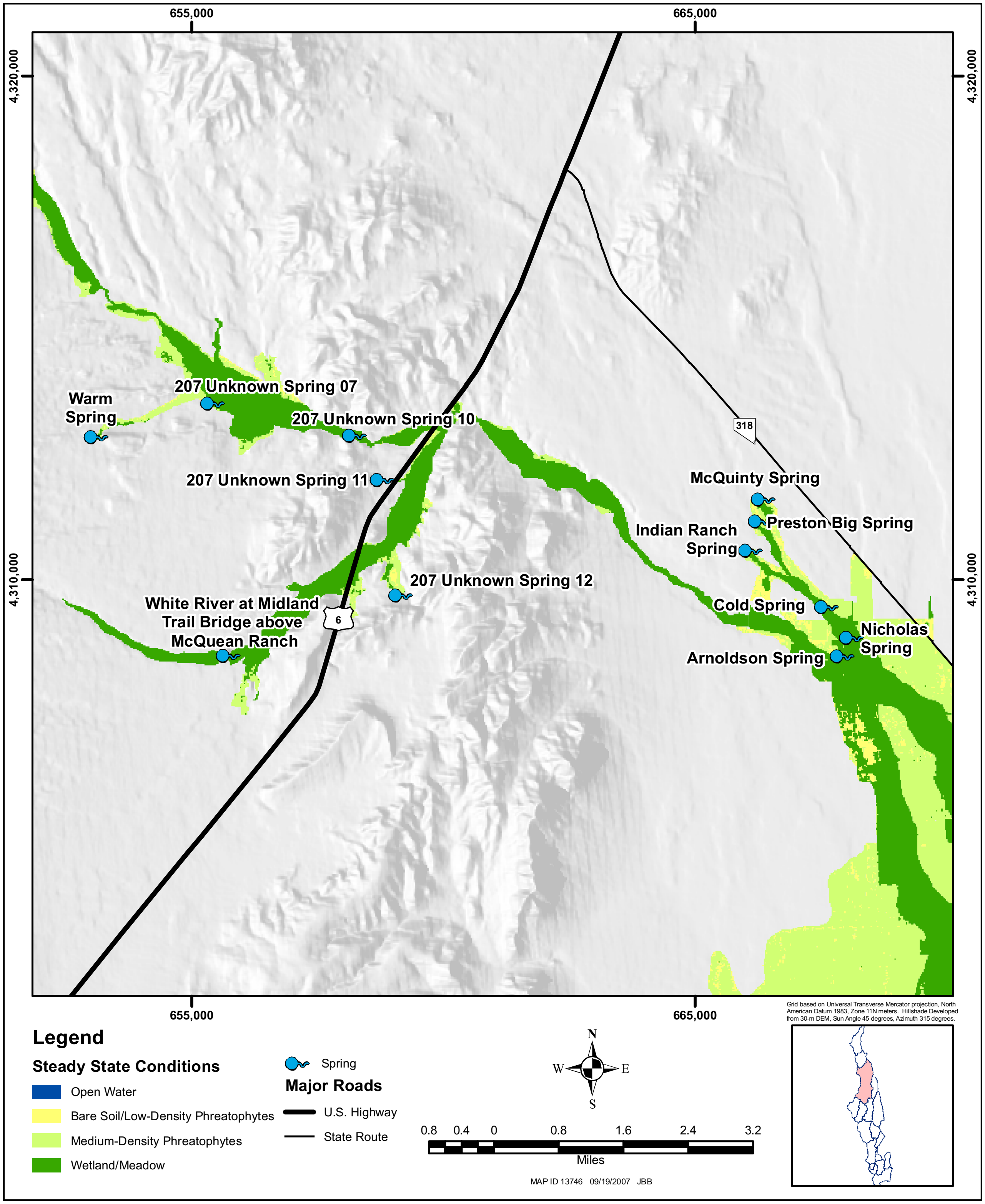



**Figure B.1-4**
**White River Valley Discharge Area - Inset 1**

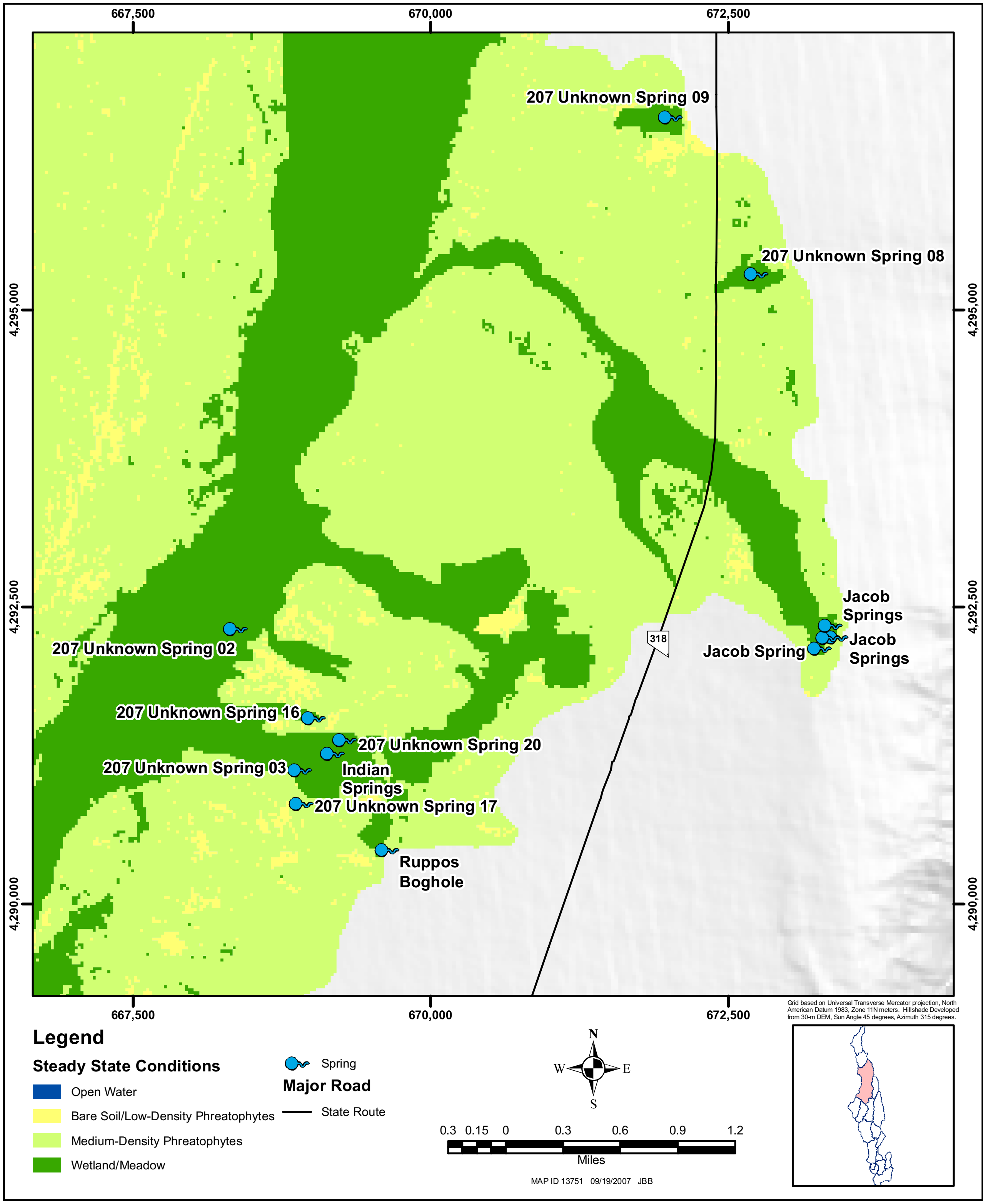



**Figure B.1-5**
**White River Valley Discharge Area - Inset 2**

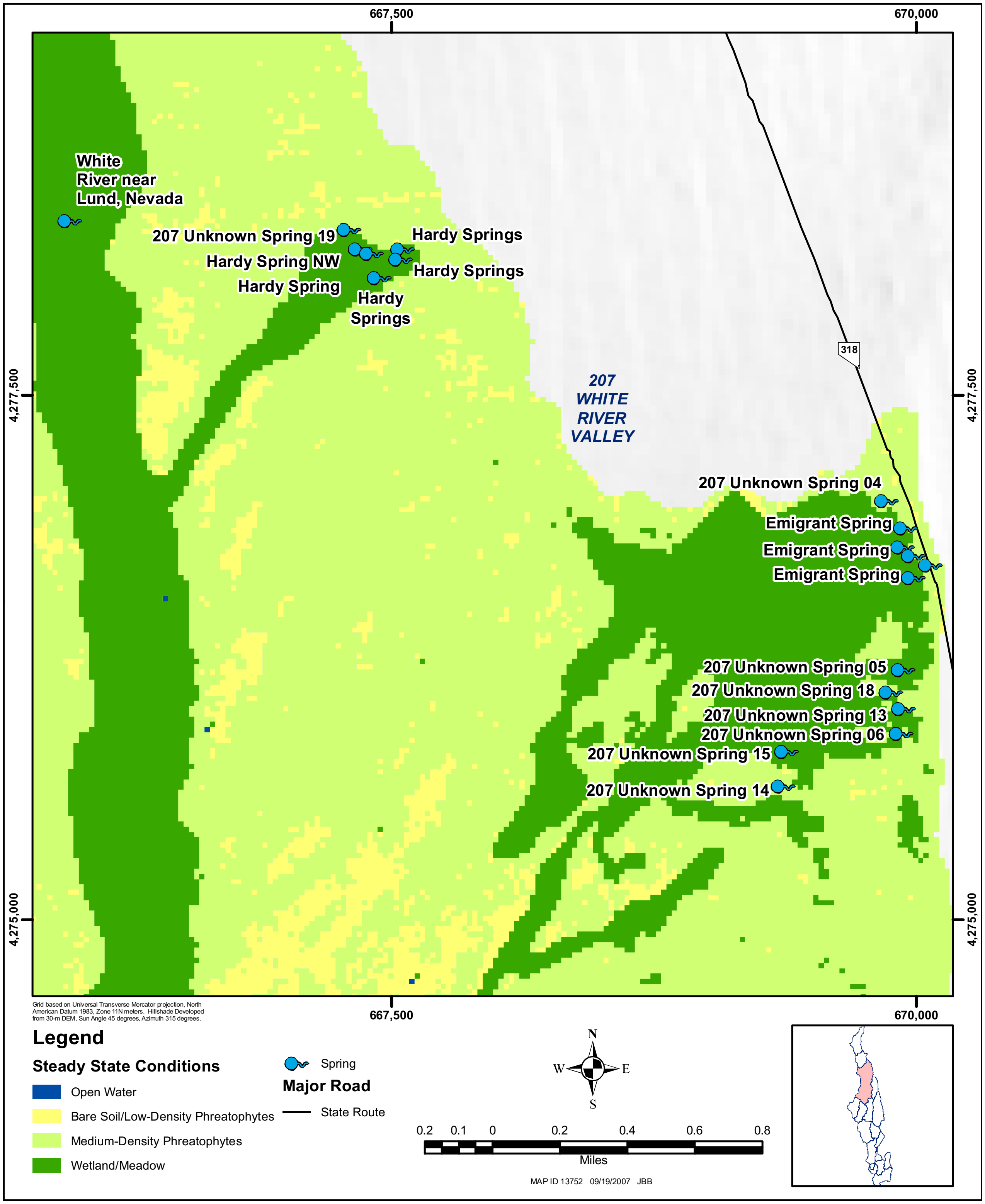



**Figure B.1-6**
**White River Valley Discharge Area - Inset 3**

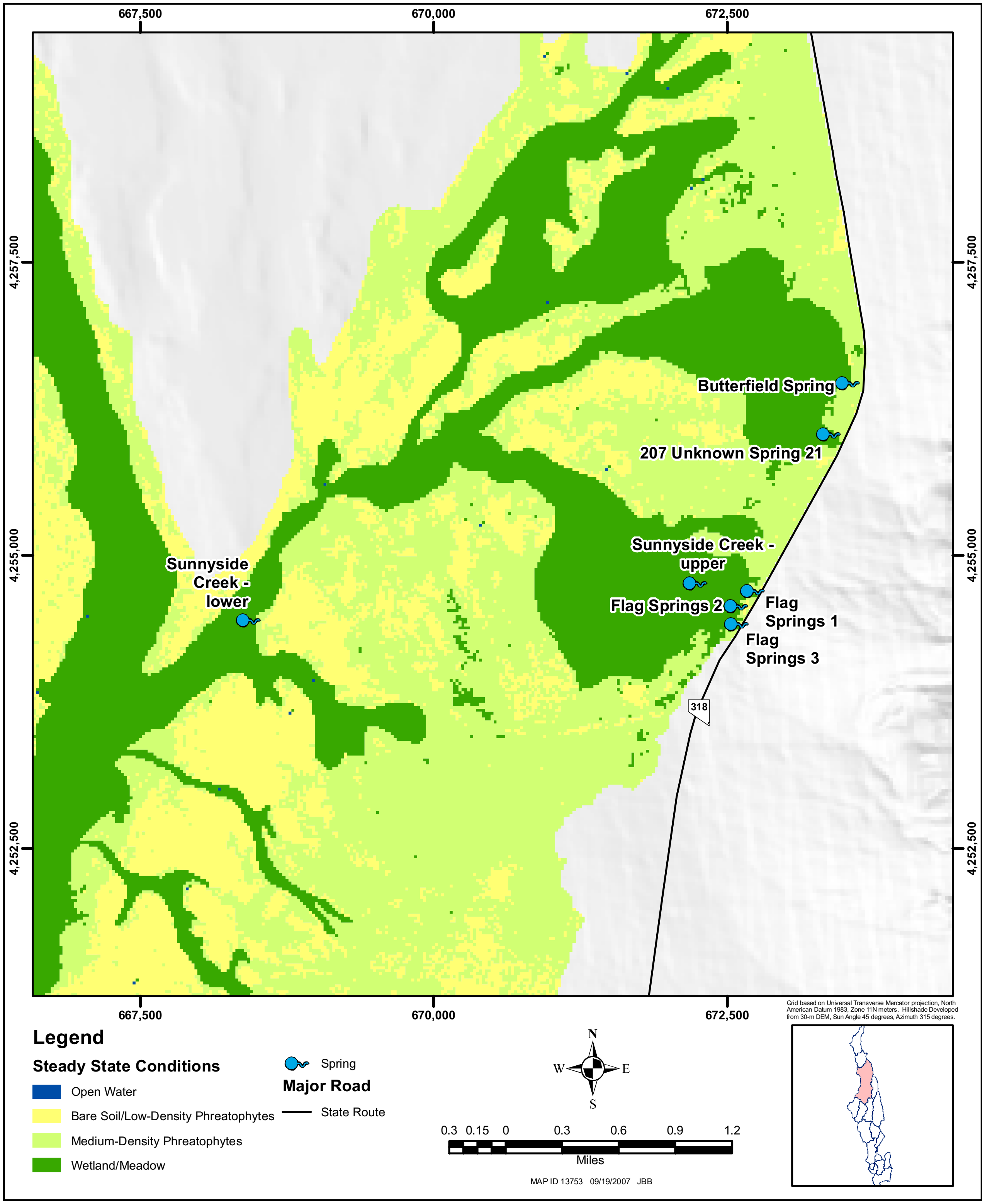



**Figure B.1-7**
**White River Valley Discharge Area - Inset 4**

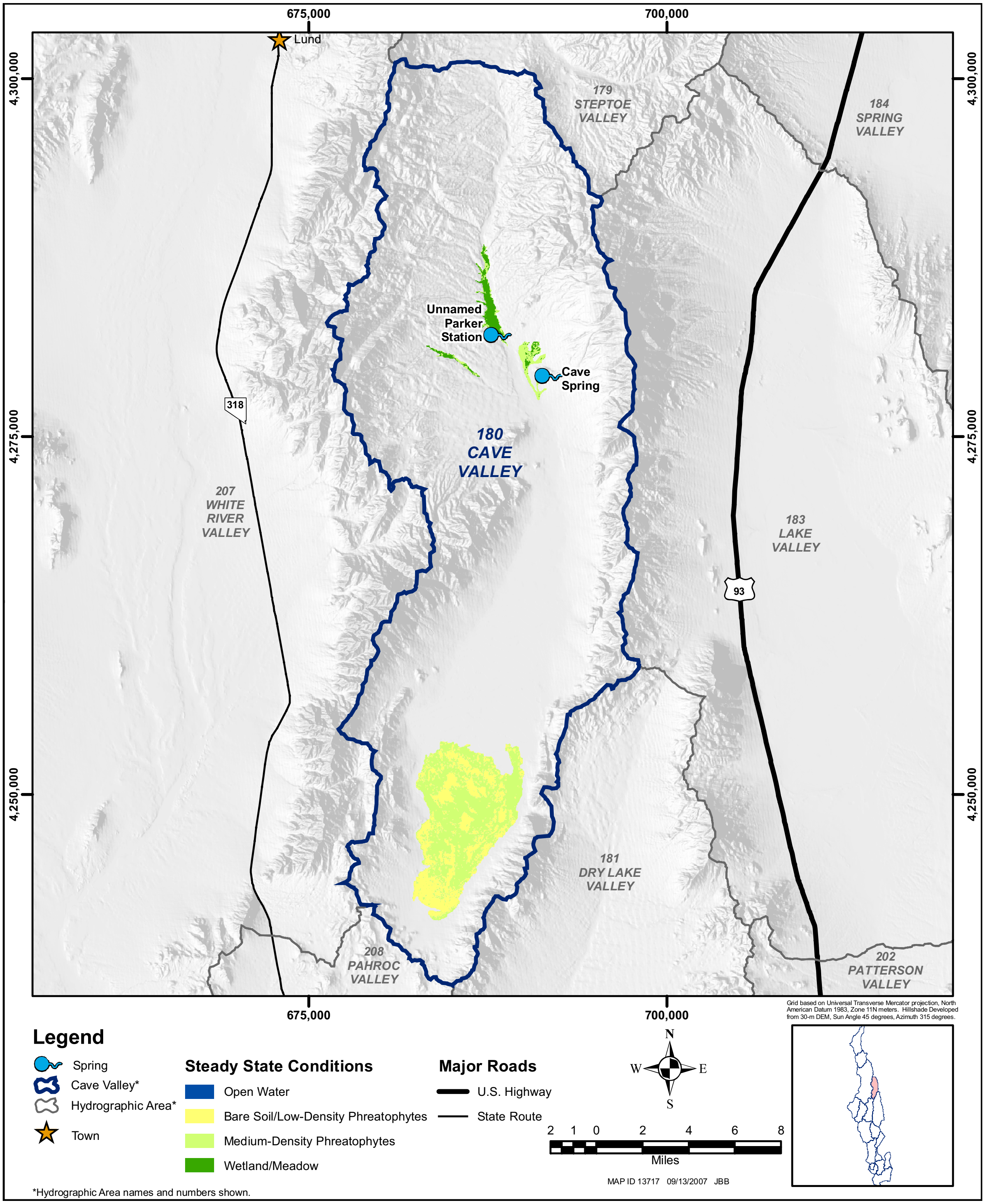



**Figure B.1-8**
**Distribution of Predevelopment Groundwater Evapotranspiration and Location of Selected Springs in Cave Valley**

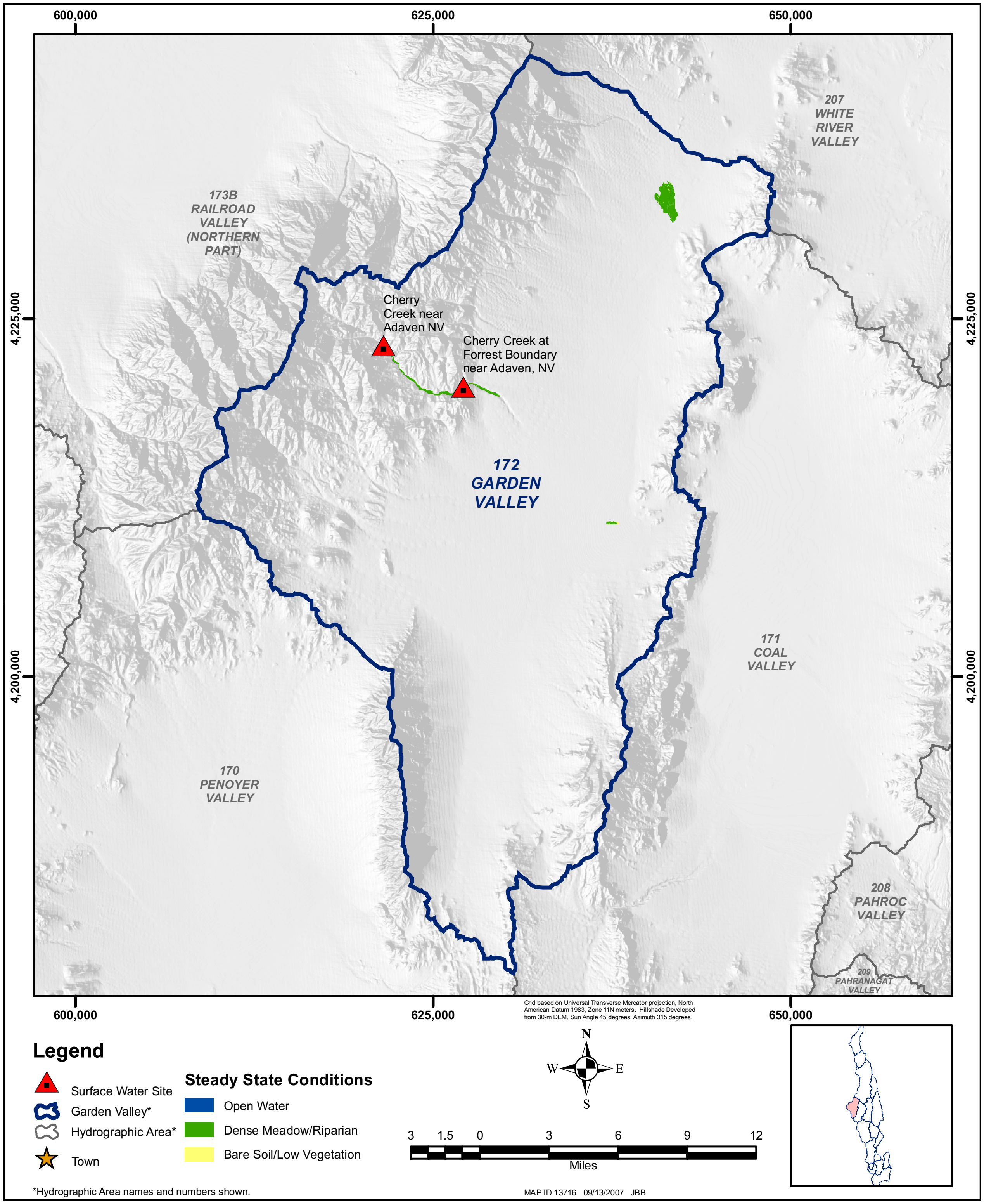



**Figure B.1-9**
**Distribution of Predevelopment Groundwater Evapotranspiration and Location of Selected Springs in Garden Valley**

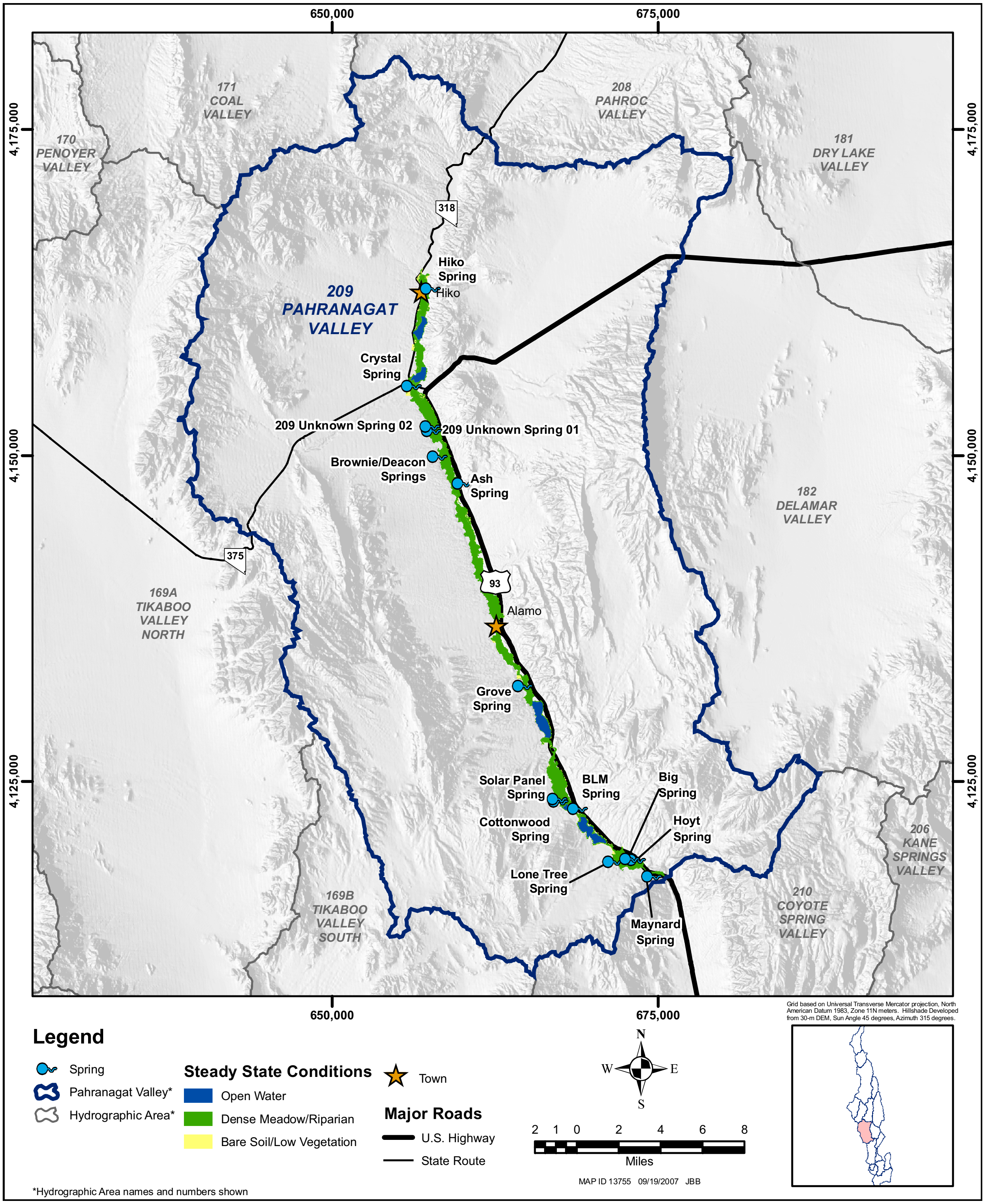



**Figure B.1-10**
**Distribution of Predevelopment Groundwater Evapotranspiration and Location of Selected Springs in Pahranagat Valley**

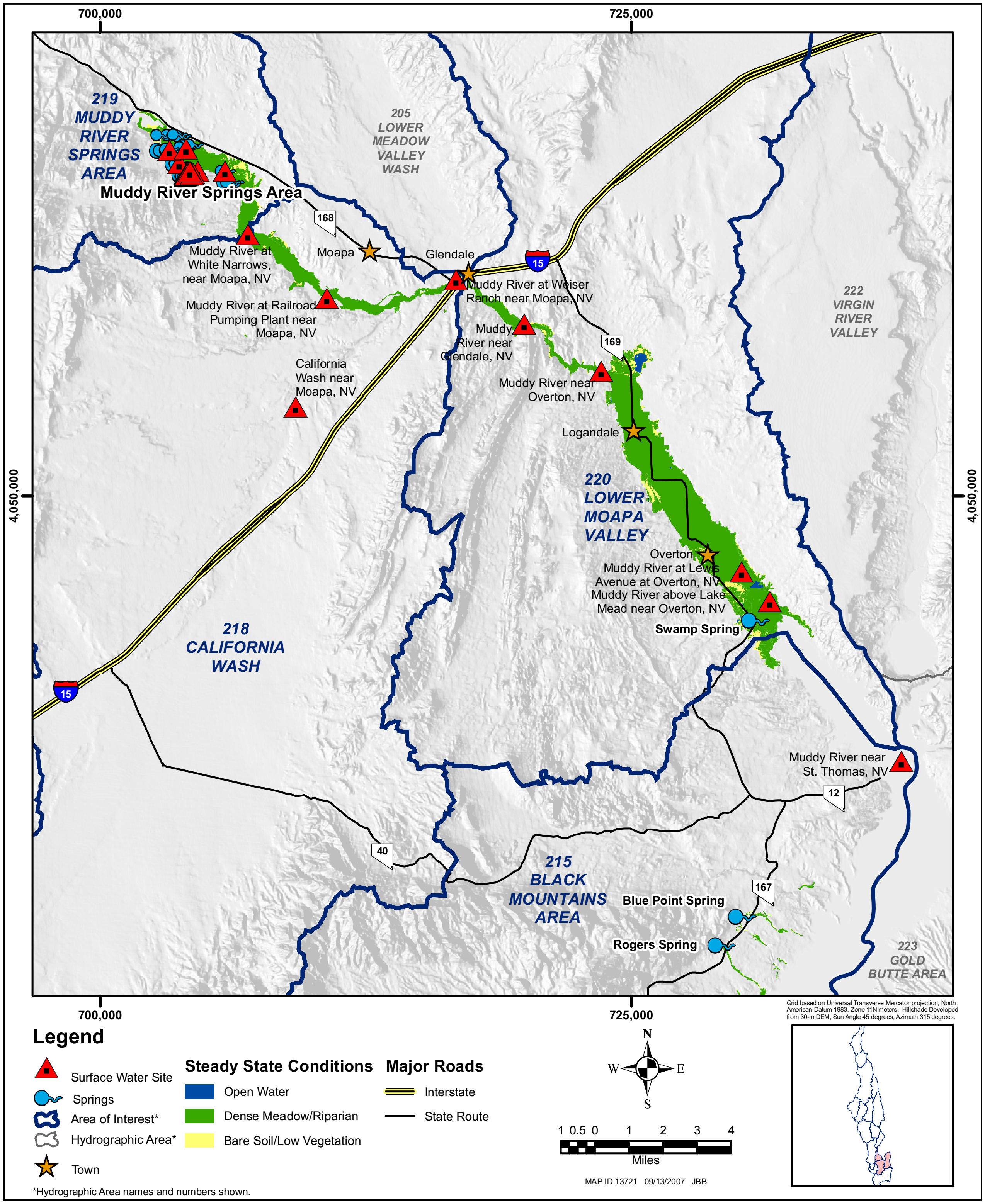



**Figure B.1-11**
**Distribution of Predevelopment Groundwater ET and Location of Selected Springs in Muddy River Springs Area, California Wash, Lower Moapa Valley, and Black Mountains Area**

## Table B.1-2
## ET Rates Reported in the Literature
(Page 1 of 6)

| Report | Location | ET Unit Description | Depth to Water (ft) | Total ET (ft/yr) | Precipitation (ft/yr) | Groundwater ET (ft/yr) |
|---|---|---|---|---|---|---|
| Lee (1912) p. 56, and 119-122 | Independence area of Owens Valley, CA | Alfalfa | – – | 4.3 | – – | – – |
| | | Bare Soil (Tank 1) | 5.7 to 5.9 | 3.33 | – – | – – |
| | | Saltgrass (Tanks 2-7) | 0.1 to 6.0 | 0.66 to 3.59 | – – | – – |
| White (1932) p. 99 and 100 | Escalante Valley, UT | Greasewood | 1.3 to 3.3 | 0.99 to 2.1[a] | 0.13 to 0.37[a] | – – |
| | | Alfalfa | 2.3 to 3.3 | 1.92 to 2.16[a] | 0.13 to 0.43[a] | – – |
| | | Saltgrass | 0.92 to 2.3 | 0.76 to 1.88[a] | 0.01 to 0.37[a] | – – |
| Maxey and Eakin (1949) p. 44 | White River Valley | Native phreatophytes | – – | – – | – – | 0.8 |
| | | Cultivated crops | – – | – – | – – | 1.25 |
| Gatewood et al. (1950) p. 123 -128 | Safford Valley, AZ | Saltcedar | 0.26 to 0.65 | 3.3 to 8.6 | 0.0 to 0.22 | – – |
| | | Cottonwood | 0.42 to 0.57 | 3.4 to 8.7 | 0.0 to 0.22 | – – |
| | | Baccharis | 0.14 to 0.51 | 2.9 to 7.1 | 0.0 to 0.22 | – – |
| Eakin (1961) p. 23 | Long Valley | Mixed rabbitbrush and greasewood | 10 to 40 | – – | – – | 0.2 |
| Eakin (1962) p. 9 | Cave Valley | Main drainage channel | – – | – – | – – | – – |
| Eakin (1963a) p. 1 and 18 | Dry Lake/Delamar valleys | No phreatophytes, discharge from springs | – – | – – | – – | – – |
| Eakin (1963c) p. 19 | Garden/Coal valleys | Along stream channels and spring areas | – – | – – | – – | – – |
| Eakin (1963b) p. 19, 20 | Pahranagat/Pahroc valleys | Phreatophytes, agriculture, and lakes | – – | – – | – – | 1.0 to 4.8 |
| Rush and Eakin (1963) p. 13 | Lake Valley | Saltgrass and wetland meadow | <5 | – – | – – | 1.5 |
| | | Saltgrass and mod wet meadow | <5 | – – | – – | 1.25 |
| | | Saltgrass and dry meadow | 5 to 20 | – – | – – | 0.5 |
| | | Greasewood | 20 to 25 | – – | – – | 0.25 |
| | | Greasewood and rabbitbrush mixed with big sage | 25 to 50 | – – | – – | 0.1 |
| Rush (1964) p. 22 | Clover Valley | Dry meadow | 5 to 10 | – – | – – | 0.5 |
| | | Rabbitbrush | 10 to 25 | – – | – – | 0.2 |
| | Dry Valley | Rabbitbrush and big sage | 15 to 40 | – – | – – | 0.1 |
| | Eagle Valley | Dry meadow | – – | – – | – – | 0.5 |
| | | Rabbitbrush and big sage | 10 to 15 | – – | – – | 0.3 |
| | Lower Meadow Valley | Saltbush | 20 to 60 | – – | – – | 0.1 |
| | | Greasewood and rabbitbrush | 20 to 50 | – – | – – | 0.1 |
| | | Greasewood, rabbitbrush, and creosote bush | – – | – – | – – | 0.1 |
| | | Cottonwood, willow, and saltcedar | 0 to 5 | – – | – – | 3.0 |
| | Panaca Valley | Greasewood and rabbitbrush | 10 to 20 | – – | – – | 0.1 |
| | | Rabbitbrush | 15 to 25 | – – | – – | 0.2 |
| | Patterson Valley | Greasewood, rabbitbrush | 20 to 30 | – – | – – | 0.1 |
| | Rose Valley | Rabbitbrush and big sage | 20 to 25 | – – | – – | 0.1 |

**Table B.1-2**
**ET Rates Reported in the Literature**
(Page 2 of 6)

| Report | Location | ET Unit Description | Depth to Water (ft) | Total ET (ft/yr) | Precipitation (ft/yr) | Groundwater ET (ft/yr) |
|---|---|---|---|---|---|---|
| Rush (1964) p. 22 cont. | Spring Valley | Rabbitbrush | 5 to 25 | – – | – – | 0.1 |
| | | Wetland meadow (very wet meadow and dry meadow) | 0 to 10 | – – | – – | 0.5 to 1.5 |
| Eakin (1964)) p. 24 and 25 | Coyote Spring | Not delineated | – – | – – | – – | – – |
| | Kane Spring | Not delineated | – – | – – | – – | – – |
| | Muddy River Springs | Springs area | – – | – – | – – | – – |
| Rush and Kazmi (1965) p. 23 | Spring Valley | Wetland meadow and saltgrass | 0 to 5 | – – | – – | 1.5 |
| | | Saltgrass, rabbitbrush, and moderately wet meadow | 0 to 10 | – – | – – | 1.0 |
| | | Greasewood, saltgrass, meadow grass, and swamp cedar | 5 to 15 | – – | – – | 0.5 |
| | | Greasewood and rabbitbrush | 10 to 50 | – – | – – | 0.2 |
| | | Bare soil and sparse vegetation | 5 to 15 | – – | – – | 0.1 |
| | | Cottonwood, willow, and wildrose | 0 to 5 | – – | – – | 2.0 |
| Hood and Rush (1965) p. 25 | Snake Valley | Wetland meadow | 0 to 5 | – – | – – | 1.75 |
| | | Meadow grass and rabbitbrush | 2 to 10 | – – | – – | 0.5 |
| | | Greasewood and rabbitbrush | 10 to 50 | – – | – – | 0.2 |
| | | Playas (flooded part of year) | 0 to 15 | – – | – – | 0.75 |
| | | Playas (rarely flooded, but shallow water table) | 0 to 30 | – – | – – | 0.1 |
| Eakin (1966) p. 261 | Jakes Valley | Not delineated | – – | – – | – – | – – |
| Eakin, Hughes and Moore (1967) p. 25 | Steptoe Valley | Wetland meadow and saltgrass, including lowland spring areas | 0 | – – | – – | 1.5 |
| | | Saltgrass, rabbitbrush, greasewood, and Goshute Lake Playa | <10 | – – | – – | 0.5 |
| | | Greasewood, rabbitbrush, and saltgrass | <20 | – – | – – | 0.3 |
| | | Saltgrass, rabbitbrush, and greasewood | <12 | – – | – – | 0.1 |
| Glancy (1968) p. 28 | S. Butte Valley | Open water | – – | – – | – – | 3.5 |
| | | Saltgrass | 0 to 10 | – – | – – | 0.5 |
| | | Rabbitbrush and greasewood | 10 to 35 | – – | – – | 0.2 |
| | | Greasewood | 30 to 50+ | – – | – – | 0.1 |
| Rush (1968) p. 35 | Hidden Valley | None | – – | – – | – – | – – |
| | Garnet Valley | None | – – | – – | – – | – – |
| | California Wash Area | Saltbush, saltgrass, saltcedar, mesquite, and cottonwood | 2 to 50 | – – | – – | 1.0 |
| | Lower Moapa Valley | Saltbush, saltgrass, saltcedar, mesquite, cottonwood, and tules | 2 to 50 | – – | – – | 2.0 |
| | Black Mountains Area | Tules, mesquite (LV Wash and Rogers Spring) | 0 to 5 | – – | – – | 6.0 |
| Robinson (1970) p. D28 | Humboldt River Valley, NV | Greasewood | 5.0 to 7.8 | 1.14 to 1.81[a] | 0.14 to 0.44[a] | – – |
| | | Rabbitbrush | 5.0 to 6.2 | 1.07 to 2.19[a] | 0.14 to 0.44[a] | – – |
| | | Bare soil | 1.9 to 4.0 | 0.36 to 1.00[a] | 0.14 to 0.44[a] | – – |
| | | Willow | 3.5 to 5.8 | 2.07 to 3.94[a] | 0.14 to 0.44[a] | – – |

**Table B.1-2**
**ET Rates Reported in the Literature**
(Page 3 of 6)

| Report | Location | ET Unit Description | Depth to Water (ft) | Total ET (ft/yr) | Precipitation (ft/yr) | Groundwater ET (ft/yr) |
|---|---|---|---|---|---|---|
| Harrill (1971) p. 21 | Tippet Valley | No phreatophytes | >50 | – – | – – | – – |
| Duell (1990) p. E26 | Owens Valley, CA | Alkali meadow (sacaton and thistle) | 10 to 15 | 2.71 | – – | – – |
| | | Alkali meadow (saltgrass, sacaton, and rabbitbrush) | 7 to 9 | 2.05 | – – | – – |
| | | Alkali meadow (NV saltbush, sacaton, and rabbitbrush) | 5 to 7 | 2.69 | – – | – – |
| | | Desert sink scrub (rabbitbrush, sacaton, and ephedra) | 10 to 11 | 1.99 | – – | – – |
| | | Desert sink scrub (saltgrass and greasewood) | 8 to 9 | 1.26 | 0.52 | – – |
| | | Rabbitbrush meadow (saltgrass, rabbitbrush, sacaton, and greasewood) | 10 to 11 | 1.55 | 0.49 | – – |
| | | Rush and sedge meadow (saltgrass, sacaton, and rush) | ≤4 | 3.24 | 0.26 | – – |
| Carman (1993) p. 2 and 18 | Smith Creek Valley and Carson Desert, NV | Soda Lake (greasewood) | 25 to 30 | 0.59 | 0.49 to 0.66 | – – |
| | | Smith Creek (rabbitbrush) | 10 to 15 | 1.05 | 0.66 to 0.98 | – – |
| Nichols (1994) from Nichols (2000) p. A5 and A7 | Northern Great Basin, NV | Smoke Creek desert (greasewood, salt brush, and sagebrush) | 8.9 | – – | – – | 0.82[a] |
| | | Smith Creek Valley (greasewood and rabbitbrush) | 5.9 | – – | – – | 1.2[a] |
| | | Railroad Valley (greasewood, salt brush, and sagebrush) | 5.9 | – – | – – | 0.2[a] |
| Nichols (1997) from Nichols (2000) p. A5 and A7 | Ash Meadows, NV | Ash Meadows 1 (salt grass) | 1.6 | – – | – – | 2.45 |
| | | Ash Meadows 2 (salt grass and wiregrass) | 0 | – – | – – | 2.52 |
| Devitt et al. (1998) p. 2,407 and 2,410 | Virgin River, NV | Riparian (mostly tamarix) | – – | 2.5 to 4.8 | – – | – – |
| Laczniak et al. (1999) p. 18 and 47 | Ash Meadows, NV | Open water body | – – | 8.6 | – – | – – |
| | | Submerged aquatic vegetation (shallow part of open water areas, includes sparse emergent vegetation) | – – | 8.6 | – – | – – |
| | | Dense grassland vegetation (grasses, short rushes, and trees) | – – | 3.5 | – – | – – |
| | | Sparse grassland vegetation (grasses) | – – | 1.3 | – – | – – |
| | | Moist bare soil (grasses) | – – | 2.6 | – – | – – |
| | | Dense wetland vegetation (reedy and rushy marsh plants) | – – | 3.9 | – – | – – |
| | | Dense meadow vegetation (trees, grasses, and shrubs) | – – | 3.4 | – – | – – |
| Nichols (2000) p. C16 | 16 valleys in Great Basin, NV | Open water | – – | – – | – – | – – |
| | | Playa / bare soil | – – | – – | – – | 0.15 |
| | | <10 percent plant cover | – – | – – | – – | 0.29 to 0.41 |
| | | 10 to <20 percent plant cover | – – | – – | – – | 1.28 to 1.35 |
| | | 20 to < 35 percent plant cover | – – | – – | – – | 2.14 to 2.15 |
| | | 35 to < 50 percent plant cover | – – | – – | – – | 2.50 |
| | | 50 percent plant cover | – – | – – | – – | 2.58 |

## Table B.1-2
## ET Rates Reported in the Literature
(Page 4 of 6)

| Report | Location | ET Unit Description | Depth to Water (ft) | Total ET (ft/yr) | Precipitation (ft/yr) | Groundwater ET (ft/yr) |
|---|---|---|---|---|---|---|
| Laczniak et al. (2001)[b] p. 13 and 29 | Death Valley Regional Flow System, primarily Ash Meadows and Oasis Valley | Open water | 0 | 8.4 to 8.8 | – – | – – |
| | | Submerged aquatic vegetation (shallow part of open water areas, includes sparse emergent vegetation) | 0 | 8.1 to 8.5 | – – | – – |
| | | Sparse grassland vegetation (grasses and very low density shrubs) | few to 12 | 0.6 to 2.3 | – – | – – |
| | | Sparse woodland vegetation (mesquite) | 10 to 40 | 0.7 to 1.8 | – – | – – |
| | | Dense meadow / forested vegetation (trees, grasses, and shrubs) | few to 20 | 3.0 to 4.0 | – – | – – |
| | | Sparse to moderately dense shrubland vegetation (greasewood, rabbitbrush, wolfberry, and seepweed) | 5 to 20 | 0.7 to 2.5 | – – | – – |
| | | Dense wetland vegetation (reedy and rushy marsh plants) | 0 | 3.7 to 4.3 | – – | – – |
| | | Dense to moderately dense grassland vegetation (saltgrass and/or short rushes with occasional tree or shrub) | < 5 | 2.5 to 3.7 | – – | – – |
| | | Moist Bare Soil (very sparse grasses) | < 5 | 2.2 to 3.0 | – – | – – |
| | | Open Playa (bare soil) | 5 to 40 | 0.1 to 0.7 | – – | – – |
| Berger et al. (2001) p. 8, 16, 23, and 24 see footnotes | Ruby Lake National Wildlife Refuge Area, Ruby Valley | Open water (submerged aquatic vegetation) | – – | 5.31[a] | 0.65[a] | – – |
| | | Greasewood, rabbitbrush, wild rye, sagebrush (sparse to moderate) | 17 | 1.33[a] | 0.65[a] | 0.68[a] |
| | | Rabbitbrush, wildrye, greasewood, sagebrush (moderate) | 5 | 1.33[a] | 0.65[a] | 0.68[a] |
| | | Rabbitbrush, wildrye, greasewood, and sagebrush (moderate) | 10 | 1.33[a] | 0.65[a] | 0.68[a] |
| | | Saltgrass, rabbitbrush, wildrye, and greasewood (moderate) | <5 | 1.33[a] | 0.65[a] | 0.68[a] |
| | | Desert shrub upland (moderate sagebrush and rabbitbrush) | >80 | 0.99[a] | 0.65[a] | 0.34[a] |
| | | Bulrush marsh (moderate to dense bulrush and cattails) | 1 to 3 | 4.19[a] | 0.65[a] | 3.54[a] |
| | | Meadow (dense mixed sedges, rushes, and grasses) | <2 | 3.19[a] | 0.65[a] | 2.54[a] |
| | | Saltgrass, rabbitbrush, wildrye, and greasewood (moderate) | <5 | 1.32[a] | 0.65[a] | 0.67[a] |
| | | Grasslands | – – | 2.36[a] | 0.65[a] | 1.71[a] |
| | | Playa/bare soil | – – | 0.80[a] | 0.65[a] | 0.15[a] |
| Reiner et al. (2002) p. 17 and 30 | Oasis Valley, NV | Open water body | – – | 8.6 | 0.50 | 8.1 |
| | | Submerged and sparse aquatic vegetation (shallow part of open water areas, includes sparse emergent vegetation) | 0 | 8.6 | 0.50 | 8.1 |
| | | Dense wetland vegetation (Reedy and rushy marsh plants) | 0 | 3.9 | 0.50 | 3.4 |
| | | Dense meadow and woodland vegetation (trees, grasses, shrubs) | 0 to 20 | 3.3 | 0.50 | 2.8 |
| | | Moderately dense to dense grassland (grasses, short rushes, occasional scattered trees.) | <10 | 3.2 | 0.50 | 2.7 |
| | | Sparse to moderately dense grassland (grasses) | few to 10 | 2.0 | 0.50 | 1.5 |
| | | Moist bare soil (grasses) | ≤5 | 2.6 | 0.50 | 2.1 |
| | | Sparse to moderately dense shrubs (greasewood, rabbitbrush, and wolfberry) | 5 to 20 | 1.2 | 0.50 | 0.7 |

# Table B.1-2
## ET Rates Reported in the Literature
(Page 5 of 6)

| Report | Location | ET Unit Description | Depth to Water (ft) | Total ET (ft/yr) | Precipitation (ft/yr) | Groundwater ET (ft/yr) |
|---|---|---|---|---|---|---|
| Harrington & Steinwand (2003, 2004) | Owens Valley, CA | Nev. saltbush scrub | 13 to 14 | 0.59 | 0.35 | 0.25 |
| | | Rabbitbrush scrub | >16 | 0.31 | 0.11 | 0.19 |
| | | Nev. saltbush meadow | 6.9 to 7.9 | 0.71 to 1.06 | 0.10 to 0.30 | 0.61 to 0.74 |
| | | Desert sink scrub | >13 | 0.49 to 0.80 | 0.10 | 0.31 to 0.38 |
| | | Rabbitbrush meadow | 8.5 to 11 | 1.68 | 0.23 | 1.44 |
| | | Alkali meadow (sacaton, saltgrass, and wildrye) | 6.6 to 11 | 1.37 to 2.25 | 0.11 to 0.99 | 0.87 to 2.18 |
| DeMeo et al. (2003) p. 8, 20, and 24 | Death Valley, CA | Bare to soil playa | ≤10 | 0.21 to 0.37 | 0.06 to 0.35 | 0.15 to 0.01 |
| | | Low density vegetation (salt grass, pickleweed, and shrub mesquite) | 5 to 20 | 0.60 | 0.06 | 0.54 |
| | | Moderate density vegetation (grasses, arrowweed, mesquite, and pickleweed) | 2 to 20 | 2.0 | 0.23 | 1.8 |
| | | High density vegetation (grasses and mesquites) | ≤20 | 2.9 | 0.16 | 2.7 |
| | | High density vegetation (grasses and mesquites) | ≤20 | 3.9 | 0.25 | 3.6 |
| | | Salt to encrusted playa | ≤5 | 0.17 to 0.39 | 0.04 to 0.28 | -1.40 to 0.13 |
| Maurer et al. (2006) p. 9, 10, and 22 | Carson Valley and Douglas County, NV, and Alpine County, CA | Rabbitbrush and greasewood | 3 to 5 | 1.9 | – – | – – |
| | | Flood irrigated alfalfa | 3 to 6 | 3.1 | – – | – – |
| | | Flood irrigated pasture | 2 to 5 | 3.2 | – – | – – |
| | | Flood irrigated pasture | 3 to 4 | 2.8 | – – | – – |
| | | Flood irrigated alfalfa | 40 | 3.0 | – – | – – |
| | | Non irrigated pasture | 6 to 7 | 1.7 | – – | – – |
| | | Bitterbrush and sage | 60 | 1.5 | – – | – – |
| | | Flood irrigated pasture | 0 to 2 | 4.4 | – – | – – |
| Westenburg et al. (2006) p. 10 and 21 | Topock Wash, Havasu area, Lower Colorado River, AZ | High density saltcedar (saltcedar) | 8 | 3.53 | – – | – – |
| | | Medium density, mixed vegetation (mesquite, saltcedar, salt grass, arrowweed, baccharis, rush) | 4 to 8 | 2.39 | – – | – – |
| | | Low to medium density arrowweed (Arrowweed) | 8 | 2.35 | – – | – – |
| Cooper et al. (2006) p. 21 | San Luis Valley, CO | Greasewood and rabbitbrush | 3.0 | 1.34 | – – | 0.74 |
| | | Greasewood and rabbitbrush | 8.2 | 0.91 | – – | 0.28 |
| Laczniak et al., (2006) p. 12 and 30 | Death Valley, CA | saltgrass, grass, yerba mansa, arrowweed, desert baccharis, mesquite | 0 to 15 | 2.28 to 2.68 | 0.05 to 0.49 | 2.1 to 2.3 |
| Devitt et. al (2006 data, unpublished) | Spring Valley | Bare soil/low vegetation (greasewood and sage) | – – | 1.28 | 0.51 | 0.77 |
| | White River Valley | Medium vegetation (greasewood) | – – | 1.77 | 0.87 | 0.90 |

**Table B.1-2**
**ET Rates Reported in the Literature**
(Page 6 of 6)

| Report | Location | ET Unit Description | Depth to Water (ft) | Total ET (ft/yr) | Precipitation (ft/yr) | Groundwater ET (ft/yr) |
|---|---|---|---|---|---|---|
| LCRAS (BOR, 1995-2005) Fort Mohave Reservation | Lower Colorado River, AZ | Marsh (cattail, bullrush, phragmites [bamboo]) | – – | 5.93 | – – | – – |
| | | Desert Vegetation | – – | 1.34 | – – | – – |
| | | Barren (≤10% vegetation) | – – | 1.66 | – – | – – |
| | | Saltcedar (11 to 60%), arrowweed (≤25%) | – – | 4.36 | – – | – – |
| | | Saltcedar (61 to 100%), arrowweed (≤25%) | – – | 5.12 | – – | – – |
| | | Saltcedar (11 to 60%), mesquite (11 to 60%), arrowweed (≤25%) | – – | 5.45 | – – | – – |
| | | Saltcedar (≤75%), arrowweed (≤25%) | – – | 5.29 | – – | – – |
| | | Saltcedar (15 to 45%), mesquite (15 to 45%), arrowweed (20 to 40%) | – – | 5.43 | – – | – – |
| | | Screwbean/honey mesquite (11 to 60%), arrowweed (≤25%) | – – | 3.99 | – – | – – |
| | | Screwbean/honey mesquite (61 to 100%), arrowweed (≤25%) | – – | 4.99 | – – | – – |
| | | Mesquite (21 to 60%), arrowweed (31 to 60%), saltcedar (≤20%) | – – | 4.76 | – – | – – |
| | | Arrowweed (51 to 100%), trees (≤10%) | – – | 4.69 | – – | – – |
| | | Cottonwood and willow trees (61 to 100%) | – – | 4.96 | – – | – – |
| | | Low Veg (phreatophyte vegetation >10% to ≤30%) | – – | 4.29 | – – | – – |
| | | Moist Soil Unit (flooded in winter and irrigated in summer) | – – | 5.03 | – – | – – |
| | | Seasonal Wetland (flooded in winter and not irrigated in summer) | – – | 3.65 | – – | – – |
| Moreo et al. (2007) p. 13, 15, and 20 | Snake, Spring, and White River valleys | Moderately dense desert shrubland (greasewood) | 17.16 | 0.836 | 0.52 | 0.32 |
| | | Sparse desert shrubland (greasewood and rabbitbrush) | 9.78 | 0.835 | 0.72 | 0.12 |
| | | Moderately dense desert shrubland (greasewood and rabbitbrush) | 7.24 | 1.01 | 0.76 | 0.24 |
| | | Grassland/Meadowland (mixed grasses/meadow) | 3.89 | 2.25 | 0.66 | 1.58 |
| | | Dense desert shrubland (greasewood) | 32.39 | 1.06 | 0.74 | 0.32 |
| | | Moderately dense desert shrubland (greasewood) | 23.58 | 1.02 | 0.95 | 0.06 |

[a]Rates reflect growing season only or less.
[b]Laczniak et al. (2001) relies on rates from previously published literature.

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# Appendix C

# Spring Data

# C.1.0 SPRING DISCHARGE

For groundwater discharge areas where there are gaged springs, estimates of groundwater discharge based on the spring discharge records can be used to estimate the lower bound of groundwater discharge from the area.

Table C.1-1 lists the historical averages of groundwater discharge for gaged springs in White River Valley, Pahranagat Valley, and the Muddy River Springs Area.

Table C.1-2 lists the individual discharge measurements of these springs for their periods of record.

Table C.1-3 lists the annual average discharge of these springs based on the available data.

Note that spring discharge measurements for the Muddy River Springs Area are actually reported as stream flow measurements on the Muddy River.

# Table C.1-1
## Mean Annual Estimates of Spring Discharge for Three Basins of the WRFS
(Page 1 of 2)

| Site Number | Spring Name | Data Collection Frequency | HA | UTM Easting | UTM Northing | Elevation (ft-amsl)[a] | Local Number | Mean Average Annual Discharge (cfs) | Period of Record (WY) | Period of Record Duration (No. of Years)[b] | No. of Discharge Measurements Used in Analysis[c] | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **White River Valley** | | | | | | | | | | | | |
| 2070401 | Forrest Home Creek near Forrest Home, NV | Miscellaneous | 207 | 643,629 | 4,247,921 | 6,213 | 207 N06 E59 21BC | 1.79[d] | 2003 | 1 | – – | |
| 2070501 | Hot Creek Spring near Sunnyside, Nevada | Continuous | 207 | 661,573 | 4,249,541 | 5,229 | 207 N06 E61 18AADA | 11.30 | 1935-2006 | 72 | 41 | |
| 2070601 | Arnoldson Spring | Miscellaneous | 207 | 667,919 | 4,308,473 | 5,625 | 207 N12 E61 12DCCD | 3.66 | 1911-2006 | 97 | 64 | |
| 2070701 | Cold Spring | Miscellaneous | 207 | 66,7609 | 4,309,454 | 5,653 | 207 N12 E61 12BDAD | 1.30 | 1911-2006 | 97 | 57 | |
| 2070901 | Preston Big Spring | Continuous | 207 | 666,296 | 4,311,153 | 5,732 | 207 N12 E61 02ACAB | 7.86[e] | 1983-2006 | 8 | – – | |
| 2071001 | Lund Spring | Miscellaneous | 207 | 673,266 | 4,302,019 | 5,608 | 207 N11 E62 04AABA | 7.94 | 1911-2006 | 97 | 47 | |
| 2071101 | Moorman Spring | Miscellaneous | 207 | 662,053 | 4,273,440 | 5,299 | 20 N09 E61 32DABC | 0.500 | 1935-2006 | 72 | 38 | |
| 2071201 | Shingle Spring | Miscellaneous | 207 | 679,925 | 4,267,716 | 6434 | 207 N08 E63 19AA | 0.003 | 1979-2004 | 26 | 2 | |
| 2071301 | Flag Springs 3 | Miscellaneous | 207 | 672,579 | 4,254,416 | 5,294 | 207 N07 E62 33BCCC | 2.16 | 1949-2006 | 58 | 39 | |
| 2071302 | Flag Springs 2 | Miscellaneous | 207 | 672,576 | 4,254,570 | 5,285 | 20 N07 E62 33BCCB | 2.94 | 1982-2006 | 25 | 34 | |
| 2071303 | Flag Springs 1 | Miscellaneous | 207 | 672,719 | 4,254,697 | 5,294 | 207 N07 E62 33BCAB | 2.29 | 1982-2006 | 25 | 35 | |
| 2071401 | Butterfield Spring | Miscellaneous | 207 | 673,530 | 4,256,472 | 5,324 | 207 N07 E62 28ABDC | 2.73 | 1949-2006 | 58 | 39 | |
| 2071501 | Hardy Springs | Miscellaneous | 207 | 667,553 | 4,278,196 | 5,354 | 207 N09 E61 13CB | 0.450 | 1967-2004 | 39 | 2 | |
| 2071502 | Hardy Spring NW | Miscellaneous | 207 | 667,352 | 4,278,196 | 5,349 | 207 N09 E61 13CB | 0.010 | 2004 | 1 | 1 | |
| 2071601 | Nicholas Spring | Miscellaneous | 207 | 668,104 | 4,308,847 | 5,635 | 207 N12 E61 12DBDD | 2.71 | 1911-2006 | 97 | 66 | |
| 2071801 | Williams Hot Spring | Miscellaneous | 207 | 653,089 | 4,312,874 | 6,300 | 207 N13 E60 33AB | 0.16 | 1935-2005 | 71 | 3 | |
| 2071901 | Moon River Spring | Miscellaneous | 207 | 658,908 | 4,246,394 | 5,223 | 207 N06 E60 25BDAD | 4.01 | 1979-1990 | 16 | 8 | |
| 2072001 | Emigrant Springs | Miscellaneous | 207 | 669,895 | 4,276,841 | 5,480 | 207 N09 E62 19DB | 1.63 | 1985-1994 | 10 | 14 | |

## Table C.1-1
## Mean Annual Estimates of Spring Discharge for Three Basins of the WRFS
(Page 2 of 2)

| Site Number | Spring Name | Data Collection Frequency | HA | UTM Easting | UTM Northing | Elevation (ft-amsl)[a] | Local Number | Mean Average Annual Discharge (cfs) | Period of Record (WY) | Period of Record Duration (No. of Years)[b] | No. of Discharge Measurements Used in Analysis[c] | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Pahranagat Valley** | | | | | | | | | | | | |
| 2090101 | Hiko Springs | Miscellaneous | 209 | 657,549 | 4,162,744 | 3,878 | 209 S04 E60 14DBAB | 5.76 | 1913-2004 | 95 | 26 | |
| 2090201 | Solar Panel Spring | Miscellaneous | 209 | 667,262 | 4,123,643 | 3,238 | 209 S08 E61 23BABD | 0.001 | 2004 | 1 | 1 | |
| 2090401 | Crystal Springs | Continuous | 209 | 656,165 | 4,155,348 | 3,803 | 209 S05 E60 10AD | 12.7[e] | 2005-2006 | 2 | – – | Based on Crystal Spring and Diversion gages (2005-2006) |
| 2090501 | Ash Springs | Continuous | 209 | 659,684 | 4,147,460 | 3,622 | 209 S06 E61 01AD | 16.5[e] | 2005-2006 | 2 | – – | Based on Ash Springs and Diversion gages (2005-2006) |
| 2090701 | Brownie Spring | Miscellaneous | 209 | 658,088 | 4,149,897 | 3,695 | 209 S05 E60 26DAD 1 | 0.50 | 1963 | 1 | 1 | Estimate from Eakin, 1963 0.5-1.0 cfs |
| **Muddy River Springs Area** | | | | | | | | | | | | |
| 2150101 | Muddy River near St. Thomas, NV | Continuous | 215 | 737,700 | 4,037,477 | 1,100 | 220 S17 E68 13C | 19.3[f] | 1913-1916 | 1 | 1 | Water Year 1914 is only complete water year. |
| 09416000 | Muddy River near Moapa, NV | Continuous | 219 | 705,855 | 4,065,298 | 1,712 | 219 S14 E65 15DD | 41.0[e] | 1913-2006 | 66 | – – | |
| 09419000 | Muddy River near Glendale, NV | Continuous | 220 | 719,946 | 4,058,093 | 1,460 | 220 S15 E67 07CA | 42.6[e] | 1950-2006 | 55 | – – | |

[a]Elevations are in North American Vertical Datum of 1988
[b]Only complete years for gaging stations were used in the calculation of annual averages.
[c]The number of discharge measurements applies only to ungaged sites.
[d]SNWA, 2006
[e]USGS, 2006
[f]Wells, 1954

## Table C.1-2
## Miscellaneous Discharge Measurements of Selected Springs in the WRFS
(Page 1 of 19)

| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 4/6/1935 | 6,885 | 15.3 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 12/7/1961 | 6,000 | 13.4 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 7/23/1982 | 6,000 | 13.4 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 7/26/1982 | 4,847 | 10.8 | – – | USGS, 1982 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 1/16/1985 | 4,143 | 9.23 | – – | USGS, 1985 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 2/1/1985 | 11,000 | 24.5 | – – | USGS-NWIS, 2004 | Discharge appears high cfs may have been entered in the gpm column (11.0) | No |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 2/3/1986 | 4,143 | 9.23 | – – | USGS, 1986 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 2/11/1987 | 6,328 | 14.1 | – – | USGS, 1987 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 8/12/1987 | 3,519 | 7.84 | – – | USGS, 1987 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 2/23/1988 | 7,002 | 15.6 | – – | USGS, 1988 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 3/14/1989 | 3,999 | 8.91 | – – | USGS, 1989 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 3/23/1990 | 6,400 | 14.3 | – – | USGS, 1990 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 11/8/1990 | 5,000 | 11.1 | – – | USGS, 1991 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 3/4/1991 | 6,001 | 13.4 | – – | USGS, 1991 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 10/23/1991 | 2,783 | 6.20 | – – | USGS, 1992 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 3/18/1992 | 4,197 | 9.35 | – – | USGS, 1992 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 10/14/1992 | 4,084 | 9.10 | – – | USGS, 1993 | – – | Yes |

**Table C.1-2**
**Miscellaneous Discharge Measurements of Selected Springs in the WRFS**
(Page 2 of 19)

| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 5/3/1993 | 3,950 | 8.80 | – – | USGS, 1993 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 10/19/1993 | 494 | 1.10 | – – | USGS-NWIS, 2004 | Discharge appears low. | No |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 3/29/1994 | 1,257 | 2.80 | – – | USGS, 1994 | Discharge appears low. | No |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 10/19/1994 | 5,386 | 12.0 | – – | USGS, 1995 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 4/17/1997 | 6,330 | 14.1 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 9/25/1997 | 5,430 | 12.1 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 4/29/1998 | 4,578 | 10.2 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 9/22/1998 | 4,670 | 10.4 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 4/7/1999 | 4,760 | 10.6 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 9/13/1999 | 6,910 | 15.4 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 4/20/2000 | 3,480 | 7.75 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 9/14/2000 | 3,520 | 7.84 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 4/17/2001 | 4,850 | 10.8 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 9/13/2001 | 4,800 | 10.7 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 4/16/2002 | 4,940 | 11.0 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 9/17/2002 | 4,940 | 11.0 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 4/24/2003 | 4,420 | 9.85 | – – | USGS-NWIS, 2004 | – – | Yes |

**Table C.1-2**
**Miscellaneous Discharge Measurements of Selected Springs in the WRFS**
(Page 3 of 19)

| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 8/5/2003 | 6,150 | 13.7 | P | This Study | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 9/11/2003 | 4,760 | 10.6 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 4/23/2004 | 4,670 | 10.4 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 9/24/2004 | 4,580 | 10.2 | – – | USGS, 2004 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 6/30/2005 | 4,246 | 9.46 | – – | USGS, 2005 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 9/22/2005 | 4,847 | 10.8 | – – | USGS, 2005 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 4/28/2006 | 6,284 | 14.0 | – – | USGS, 2006 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 8/2/2006 | 6,418 | 14.3 | – – | USGS, 2006 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 8/15/2006 | 6,104 | 13.6 | – – | USGS, 2006 | – – | Yes |
| 207 | 2070501 | Hot Creek Spring near Sunnyside, Nevada | 9/14/2006 | 6,284 | 14.0 | – – | USGS, 2006 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 10/27/1910 | 1,409 | 3.14 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 6/15/1913 | 1,643 | 3.66 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 6/15/1922 | 1,580 | 3.52 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 5/7/1935 | 1,459 | 3.25 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 3/6/1936 | 1,732 | 3.86 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 3/29/1936 | 1,728 | 3.85 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 3/30/1936 | 1,728 | 3.85 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 4/7/1936 | 1,719 | 3.83 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 4/29/1936 | 1,706 | 3.80 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 5/5/1936 | 1,706 | 3.80 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 5/7/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 5/12/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 5/16/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |

**Table C.1-2**
**Miscellaneous Discharge Measurements of Selected Springs in the WRFS**
(Page 4 of 19)

| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2070601 | Arnoldson Spring | 5/19/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 5/23/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 5/26/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 5/30/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 6/2/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 6/5/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 6/9/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 6/16/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 6/19/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 6/23/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 6/27/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 7/7/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 7/12/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 7/19/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 7/26/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 8/4/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 8/15/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 8/25/1936 | 1,715 | 3.82 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 5/9/1947 | 1,400 | 3.12 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 11/13/1966 | 1,380 | 3.07 | – – | Hess and Mifflin, 1978 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 1/19/1982 | 1,804 | 4.02 | – – | USGS, 1982 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 7/30/1984 | 1,499 | 3.34 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 1/21/1985 | 1,822 | 4.06 | – – | USGS, 1985 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 2/1/1986 | 1,580 | 3.52 | – – | USGS, 1986 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 2/23/1988 | 1,800 | 4.01 | – – | USGS, 1988 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 3/14/1989 | 1,499 | 3.34 | – – | USGS, 1989 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 4/4/1990 | 1,499 | 3.34 | – – | USGS, 1990 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 11/6/1990 | 498 | 1.11 | – – | USGS, 1991 | Discharge appears low. | No |
| 207 | 2070601 | Arnoldson Spring | 3/3/1991 | 399 | 0.89 | – – | USGS, 1991 | Discharge appears low. | No |
| 207 | 2070601 | Arnoldson Spring | 10/24/1991 | 1,786 | 3.98 | – – | USGS, 1992 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 3/19/1992 | 1,854 | 4.13 | – – | USGS, 1992 | – – | Yes |

## Table C.1-2
## Miscellaneous Discharge Measurements of Selected Springs in the WRFS
(Page 5 of 19)

| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2070601 | Arnoldson Spring | 10/15/1992 | 1,885 | 4.20 | – – | USGS, 1993 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 5/4/1993 | 1,571 | 3.50 | – – | USGS, 1993 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 10/19/1993 | 1,436 | 3.20 | – – | USGS, 1994 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 3/30/1994 | 1,571 | 3.50 | – – | USGS, 1994 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 10/20/1994 | 1,706 | 3.80 | – – | USGS, 1995 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 5/20/1997 | 1,490 | 3.32 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 9/24/1997 | 1,630 | 3.63 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 4/30/1998 | 2,410 | 5.37 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 9/23/1998 | 1,800 | 4.01 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 4/8/1999 | 1,830 | 4.08 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 9/14/1999 | 1,540 | 3.43 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 4/19/2000 | 1,600 | 3.56 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 9/13/2000 | 1,360 | 3.03 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 4/18/2001 | 1,450 | 3.23 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 9/12/2001 | 1,580 | 3.52 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 4/17/2002 | 1,480 | 3.30 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 9/18/2002 | 1,320 | 2.94 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 4/23/2003 | 1,130 | 2.52 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 9/10/2003 | 1,850 | 4.12 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 4/22/2004 | 1,250 | 2.79 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 4/27/2006 | 1,481 | 3.30 | – – | USGS, 2006 | – – | Yes |
| 207 | 2070601 | Arnoldson Spring | 9/13/2006 | 1,548 | 3.45 | – – | USGS, 2006 | – – | Yes |
| 207 | 2070701 | Cold Spring | 10/27/1910 | 462 | 1.03 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 5/7/1935 | 588 | 1.31 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 3/6/1936 | 601 | 1.34 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 3/29/1936 | 628 | 1.40 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 3/30/1936 | 628 | 1.40 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 4/7/1936 | 633 | 1.41 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 4/29/1936 | 633 | 1.41 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 5/5/1936 | 619 | 1.38 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 5/7/1936 | 619 | 1.38 | – – | Maxey and Eakin, 1949 | – – | Yes |

**Table C.1-2**
**Miscellaneous Discharge Measurements of Selected Springs in the WRFS**
(Page 6 of 19)

| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2070701 | Cold Spring | 5/12/1936 | 624 | 1.39 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 5/16/1936 | 646 | 1.44 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 5/19/1936 | 624 | 1.39 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 5/23/1936 | 619 | 1.38 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 5/26/1936 | 583 | 1.30 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 5/30/1936 | 601 | 1.34 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 6/2/1936 | 669 | 1.49 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 6/5/1936 | 628 | 1.40 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 6/9/1936 | 628 | 1.40 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 6/16/1936 | 628 | 1.40 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 6/19/1936 | 619 | 1.38 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 6/23/1936 | 633 | 1.41 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 6/27/1936 | 615 | 1.37 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 7/7/1936 | 619 | 1.38 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 7/12/1936 | 619 | 1.38 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 7/18/1936 | 619 | 1.38 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 7/19/1936 | 628 | 1.40 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 7/26/1936 | 619 | 1.38 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 8/4/1936 | 624 | 1.39 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 8/15/1936 | 624 | 1.39 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 8/25/1936 | 628 | 1.40 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 5/9/1947 | 781 | 1.74 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2070701 | Cold Spring | 11/13/1966 | 780 | 1.74 | – – | Hess and Mifflin, 1978 | – – | Yes |
| 207 | 2070701 | Cold Spring | 1/19/1982 | 768 | 1.71 | – – | USGS, 1982 | – – | Yes |
| 207 | 2070701 | Cold Spring | 7/30/1984 | 440 | 0.98 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070701 | Cold Spring | 1/17/1985 | 404 | 0.90 | – – | USGS, 1985 | – – | Yes |
| 207 | 2070701 | Cold Spring | 1/21/1985 | 440 | 0.98 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070701 | Cold Spring | 2/1/1986 | 498 | 1.11 | – – | USGS, 1986 | – – | Yes |
| 207 | 2070701 | Cold Spring | 2/23/1988 | 1,000 | 2.23 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070701 | Cold Spring | 3/14/1989 | 1,499 | 3.34 | – – | USGS, 1989 | – – | Yes |
| 207 | 2070701 | Cold Spring | 4/4/1990 | 911 | 2.03 | – – | USGS, 1990 | – – | Yes |

## Table C.1-2
## Miscellaneous Discharge Measurements of Selected Springs in the WRFS
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| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2070701 | Cold Spring | 11/9/1990 | 382 | 0.85 | – – | USGS, 1991 | – – | Yes |
| 207 | 2070701 | Cold Spring | 3/5/1991 | 601 | 1.34 | – – | USGS, 1991 | – – | Yes |
| 207 | 2070701 | Cold Spring | 10/24/1991 | 1,005 | 2.24 | – – | USGS, 1992 | – – | Yes |
| 207 | 2070701 | Cold Spring | 3/19/1992 | 799 | 1.78 | – – | USGS, 1992 | – – | Yes |
| 207 | 2070701 | Cold Spring | 10/15/1992 | 148 | 0.33 | – – | USGS, 1993 | – – | Yes |
| 207 | 2070701 | Cold Spring | 5/4/1993 | 18 | 0.04 | – – | USGS, 1993 | – – | Yes |
| 207 | 2070701 | Cold Spring | 10/19/1993 | 103 | 0.23 | – – | USGS, 1994 | – – | Yes |
| 207 | 2070701 | Cold Spring | 3/30/1994 | 135 | 0.30 | – – | USGS, 1994 | – – | Yes |
| 207 | 2070701 | Cold Spring | 10/20/1994 | 108 | 0.24 | – – | USGS, 1995 | – – | Yes |
| 207 | 2070701 | Cold Spring | 4/23/2003 | 380 | 0.85 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070701 | Cold Spring | 4/23/2003 | 350 | 0.78 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070701 | Cold Spring | 9/10/2003 | 680 | 1.52 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070701 | Cold Spring | 4/22/2004 | 260 | 0.58 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2070701 | Cold Spring | 7/1/2005 | 633 | 1.41 | – – | USGS, 2005 | – – | Yes |
| 207 | 2070701 | Cold Spring | 9/21/2005 | 660 | 1.47 | – – | USGS, 2005 | – – | Yes |
| 207 | 2070701 | Cold Spring | 4/27/2006 | 503 | 1.12 | – – | USGS, 2006 | – – | Yes |
| 207 | 2070701 | Cold Spring | 9/13/2006 | 355 | 0.79 | – – | USGS, 2006 | – – | Yes |
| 207 | 2071001 | Lund Spring | 10/27/1910 | 2,406 | 5.36 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071001 | Lund Spring | 10/26/1912 | 2,406 | 5.36 | – – | Carpenter, 1915 | – – | Yes |
| 207 | 2071001 | Lund Spring | 3/16/1935 | 4,574 | 10.2 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071001 | Lund Spring | 3/16/1935 | 4,192 | 9.34 | – – | Maxey and Eakin, 1949 | Spring orifice lowered. | No |
| 207 | 2071001 | Lund Spring | 3/6/1936 | 2,868 | 6.39 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071001 | Lund Spring | 1/23/1937 | 3,241 | 7.22 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071001 | Lund Spring | 5/17/1944 | 3,653 | 8.14 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071001 | Lund Spring | 5/9/1947 | 4,259 | 9.49 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071001 | Lund Spring | 5/9/1947 | 4,300 | 9.58 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 6/15/1966 | 2,800 | 6.24 | – – | Hess and Mifflin, 1978 | – – | Yes |
| 207 | 2071001 | Lund Spring | 1/18/1982 | 3,137 | 6.99 | – – | USGS, 1982 | – – | Yes |
| 207 | 2071001 | Lund Spring | 1/17/1985 | 5,296 | 11.8 | – – | USGS, 1985 | – – | Yes |
| 207 | 2071001 | Lund Spring | 2/1/1986 | 2,473 | 5.51 | – – | USGS, 1986 | – – | Yes |
| 207 | 2071001 | Lund Spring | 2/11/1987 | 4,937 | 11.0 | – – | USGS, 1987 | – – | Yes |

**Table C.1-2**
**Miscellaneous Discharge Measurements of Selected Springs in the WRFS**
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| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2071001 | Lund Spring | 2/23/1988 | 2,500 | 5.57 | – – | USGS, 1988 | – – | Yes |
| 207 | 2071001 | Lund Spring | 3/14/1989 | 2,002 | 4.46 | – – | USGS, 1989 | – – | Yes |
| 207 | 2071001 | Lund Spring | 3/22/1990 | 2,101 | 4.68 | – – | USGS, 1990 | – – | Yes |
| 207 | 2071001 | Lund Spring | 11/9/1990 | 3,200 | 7.13 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071001 | Lund Spring | 3/3/1991 | 4,399 | 9.80 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071001 | Lund Spring | 10/24/1991 | 3,294 | 7.34 | – – | USGS, 1992 | – – | Yes |
| 207 | 2071001 | Lund Spring | 3/19/1992 | 2,837 | 6.32 | – – | USGS, 1992 | – – | Yes |
| 207 | 2071001 | Lund Spring | 10/14/1992 | 4,533 | 10.1 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071001 | Lund Spring | 5/4/1993 | 3,501 | 7.80 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071001 | Lund Spring | 10/19/1993 | 3,860 | 8.60 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071001 | Lund Spring | 3/30/1994 | 3,860 | 8.60 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071001 | Lund Spring | 10/19/1994 | 2,873 | 6.40 | – – | USGS, 1995 | – – | Yes |
| 207 | 2071001 | Lund Spring | 5/20/1997 | 2,990 | 6.66 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 9/24/1997 | 2,580 | 5.75 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 4/29/1998 | 3,240 | 7.22 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 9/23/1998 | 4,340 | 9.67 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 4/8/1999 | 3,830 | 8.53 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 9/14/1999 | 4,310 | 9.60 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 4/19/2000 | 4,010 | 8.93 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 9/13/2000 | 4,890 | 10.9 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 4/18/2001 | 3,280 | 7.31 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 9/13/2001 | 4,120 | 9.18 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 4/17/2002 | 3,670 | 8.18 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 9/18/2002 | 3,830 | 8.53 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 4/23/2003 | 3,070 | 6.84 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 8/6/2003 | 2,805 | 6.25 | G | This Study | – – | Yes |
| 207 | 2071001 | Lund Spring | 8/8/2003 | 2,805 | 6.25 | G | This Study | – – | Yes |
| 207 | 2071001 | Lund Spring | 9/10/2003 | 3,160 | 7.04 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 4/22/2004 | 3,190 | 7.11 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071001 | Lund Spring | 6/24/2004 | 2,805 | 6.25 | G |  | – – | Yes |
| 207 | 2071001 | Lund Spring | 6/30/2005 | 4,412 | 9.83 | – – | USGS, 2005 | – – | Yes |

## Table C.1-2
## Miscellaneous Discharge Measurements of Selected Springs in the WRFS
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| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2071001 | Lund Spring | 9/21/2005 | 5,206 | 11.6 | – – | USGS, 2005 | – – | Yes |
| 207 | 2071001 | Lund Spring | 4/27/2006 | 4,250 | 9.47 | – – | USGS, 2006 | – – | Yes |
| 207 | 2071001 | Lund Spring | 9/13/2006 | 5,431 | 12.1 | – – | USGS, 2006 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 3/16/1935 | 4,574 | 10.2 | – – | Maxey and Eakin, 1949 | Spring orifice lowered | No |
| 207 | 2071101 | Moorman Spring | 9/15/1945 | 100 | 0.22 | – – | Miller et al., 1953 | Possibly only half the flow | No |
| 207 | 2071101 | Moorman Spring | 6/15/1949 | 1,900 | 4.23 | – – | Stearns et al., 1937 | Measurement is probably .422 cfs | No |
| 207 | 2071101 | Moorman Spring | 11/15/1966 | 1,900 | 4.23 | – – | Hess and Mifflin, 1978 | This is probably the wrong discharge, and is the same measurement as 6/15/1949. | No |
| 207 | 2071101 | Moorman Spring | 1/1/1968 | 225 | 0.50 | – – | Mifflin, 1968 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 7/23/1982 | 265 | 0.59 | – – | USGS, 1982 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 1/17/1985 | 256 | 0.57 | – – | USGS, 1985 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 2/1/1986 | 240 | 0.53 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 2/11/1987 | 274 | 0.61 | – – | USGS, 1987 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 2/23/1988 | 251 | 0.56 | – – | USGS, 1988 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 3/14/1989 | 301 | 0.67 | – – | USGS, 1989 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 3/22/1990 | 229 | 0.51 | – – | USGS, 1990 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 11/8/1990 | 301 | 0.67 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 3/5/1991 | 310 | 0.69 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 10/24/1991 | 202 | 0.45 | – – | USGS, 1992 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 3/19/1992 | 260 | 0.58 | – – | USGS, 1992 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 10/15/1992 | 193 | 0.43 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 5/4/1993 | 171 | 0.38 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 10/19/1993 | 193 | 0.43 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 3/29/1994 | 206 | 0.46 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 10/19/1994 | 211 | 0.47 | – – | USGS, 1995 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 4/17/1997 | 170 | 0.38 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 9/24/1997 | 234 | 0.52 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 4/29/1998 | 255 | 0.57 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 4/8/1999 | 248 | 0.55 | – – | USGS-NWIS, 2004 | – – | Yes |

**Table C.1-2**
**Miscellaneous Discharge Measurements of Selected Springs in the WRFS**
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| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2071101 | Moorman Spring | 9/15/1999 | 175 | 0.39 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 4/20/2000 | 230 | 0.51 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 9/13/2000 | 222 | 0.49 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 4/17/2001 | 207 | 0.46 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 9/13/2001 | 156 | 0.35 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 4/18/2002 | 221 | 0.49 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 4/24/2003 | 211 | 0.47 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 9/10/2003 | 220 | 0.49 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 4/22/2004 | 260 | 0.58 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 6/23/2004 | 231 | 0.51 | P | SNWA | – – | Yes |
| 207 | 2071101 | Moorman Spring | 9/22/2004 | 211 | 0.47 | – – | USGS, 2004 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 6/30/2005 | 192 | 0.43 | – – | USGS-NWIS, 2007 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 6/30/2005 | 192 | 0.43 | – – | USGS, 2005 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 9/21/2005 | 189 | 0.42 | – – | USGS-NWIS, 2007 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 9/21/2005 | 189 | 0.42 | – – | USGS, 2005 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 4/27/2006 | 238 | 0.53 | – – | USGS, 2006 | – – | Yes |
| 207 | 2071101 | Moorman Spring | 9/13/2006 | 206 | 0.46 | – – | USGS, 2006 | – – | Yes |
| 207 | 2071201 | Shingle Spring | 8/1/1979 | 2 | 0.004 | – – | Bunch and Harrill, 1984 | – – | Yes |
| 207 | 2071201 | Shingle Spring | 9/14/2004 | 0.35 | 0.001 | E | SNWA | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 1/1/1949 | 1,122 | 2.50 | – – | Maxey and Eakin, 1949 | Reported as 7/62-32D1 | Yes |
| 207 | 2071301 | Flag Springs 3 | 7/24/1982 | 1,046 | 2.33 | – – | USGS, 1982 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 1/16/1985 | 983 | 2.19 | – – | USGS, 1985 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 2/4/1986 | 759 | 1.69 | – – | USGS, 1986 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 2/11/1987 | 907 | 2.02 | – – | USGS, 1987 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 2/23/1988 | 902 | 2.01 | – – | USGS, 1988 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 3/14/1989 | 902 | 2.01 | – – | USGS, 1989 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 3/22/1990 | 938 | 2.09 | – – | USGS, 1990 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 11/8/1990 | 799 | 1.78 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 3/4/1991 | 902 | 2.01 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 10/23/1991 | 853 | 1.90 | – – | USGS, 1992 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 3/18/1992 | 754 | 1.68 | – – | USGS, 1992 | – – | Yes |

## Table C.1-2
## Miscellaneous Discharge Measurements of Selected Springs in the WRFS
(Page 11 of 19)

| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2071301 | Flag Springs 3 | 10/14/1992 | 718 | 1.60 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 5/3/1993 | 808 | 1.80 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 10/19/1993 | 539 | 1.20 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 3/29/1994 | 673 | 1.50 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 10/19/1994 | 763 | 1.70 | – – | USGS, 1995 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 4/17/1997 | 1,460 | 3.25 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 5/21/1997 | 978 | 2.18 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 9/29/1997 | 1,020 | 2.27 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 4/29/1998 | 1,140 | 2.54 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 9/23/1998 | 1,260 | 2.81 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 4/8/1999 | 754 | 1.68 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 9/13/1999 | 1,180 | 2.63 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 4/4/2000 | 1,180 | 2.63 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 9/14/2000 | 1,640 | 3.65 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 4/17/2001 | 1,000 | 2.23 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 9/13/2001 | 1,320 | 2.94 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 4/16/2002 | 1,000 | 2.23 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 5/30/2002 | 890 | 1.98 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 9/19/2002 | 1,300 | 2.90 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 4/24/2003 | 930 | 2.07 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 9/11/2003 | 800 | 1.78 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 4/23/2004 | 825 | 1.84 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 9/11/2004 | 810 | 1.80 | – – | USGS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 9/24/2004 | 785 | 1.75 | – – | USGS, 2004 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 6/30/2005 | 1,109 | 2.47 | – – | USGS, 2005 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 9/22/2005 | 1,073 | 2.39 | – – | USGS, 2005 | – – | Yes |
| 207 | 2071301 | Flag Springs 3 | 4/28/2006 | 983 | 2.19 | – – | USGS, 2006 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 7/24/1982 | 1,153 | 2.57 | – – | USGS, 1982 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 1/16/1985 | 1,284 | 2.86 | – – | USGS, 1985 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 2/4/1986 | 1,203 | 2.68 | – – | USGS, 1986 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 2/11/1987 | 1,584 | 3.53 | – – | USGS, 1987 | – – | Yes |

**Table C.1-2**
**Miscellaneous Discharge Measurements of Selected Springs in the WRFS**
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| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2071302 | Flag Springs 2 | 2/23/1988 | 1,598 | 3.56 | – – | USGS, 1988 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 3/14/1989 | 1,302 | 2.90 | – – | USGS, 1989 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 3/22/1990 | 220 | 0.49 | – – | USGS, 1990 | Discharge appears low. | No |
| 207 | 2071302 | Flag Springs 2 | 11/8/1990 | 1,001 | 2.23 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 3/4/1991 | 1,001 | 2.23 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 10/23/1991 | 1,257 | 2.80 | – – | USGS, 1992 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 3/18/1992 | 1,333 | 2.97 | – – | USGS, 1992 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 10/14/1992 | 1,302 | 2.90 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 5/3/1993 | 1,436 | 3.20 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 10/19/1993 | 1,302 | 2.90 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 3/29/1994 | 1,391 | 3.10 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 10/19/1994 | 1,302 | 2.90 | – – | USGS, 1995 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 4/17/1997 | 1,460 | 3.25 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 9/29/1997 | 1,440 | 3.21 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 4/29/1998 | 1,570 | 3.50 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 9/23/1998 | 1,020 | 2.27 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 4/8/1999 | 1,280 | 2.85 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 9/13/1999 | 1,430 | 3.19 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 4/4/2000 | 1,400 | 3.12 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 9/14/2000 | 1,520 | 3.39 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 4/17/2001 | 1,440 | 3.21 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 9/13/2001 | 1,380 | 3.07 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 4/16/2002 | 1,390 | 3.10 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 9/16/2002 | 1,250 | 2.79 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 4/24/2003 | 1,380 | 3.07 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 9/11/2003 | 1,320 | 2.94 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 4/23/2004 | 1,095 | 2.44 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 9/24/2004 | 1,400 | 3.12 | – – | USGS, 2004 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 6/30/2005 | 1,212 | 2.70 | – – | USGS, 2005 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 9/22/2005 | 1,203 | 2.68 | – – | USGS, 2005 | – – | Yes |
| 207 | 2071302 | Flag Springs 2 | 4/28/2006 | 1,189 | 2.65 | – – | USGS, 2006 | – – | Yes |

## Table C.1-2
## Miscellaneous Discharge Measurements of Selected Springs in the WRFS
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| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2071303 | Flag Springs 1 | 7/25/1982 | 1,005 | 2.24 | – – | USGS, 1982 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 1/16/1985 | 1,059 | 2.36 | – – | USGS, 1985 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 2/4/1986 | 857 | 1.91 | – – | USGS, 1986 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 2/11/1987 | 1,041 | 2.32 | – – | USGS, 1987 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 2/23/1988 | 902 | 2.01 | – – | USGS, 1988 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 3/14/1989 | 1,400 | 3.12 | – – | USGS, 1989 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 3/22/1990 | 691 | 1.54 | – – | USGS, 1990 | Discharge appears low. | No |
| 207 | 2071303 | Flag Springs 1 | 11/9/1990 | 1,001 | 2.23 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 3/4/1991 | 1,302 | 2.90 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 10/23/1991 | 907 | 2.02 | – – | USGS, 1992 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 3/18/1992 | 996 | 2.22 | – – | USGS, 1992 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 10/14/1992 | 898 | 2.00 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 5/3/1993 | 898 | 2.00 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 10/19/1993 | 1,077 | 2.40 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 3/29/1994 | 943 | 2.10 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 10/19/1994 | 853 | 1.90 | – – | USGS, 1995 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 4/17/1997 | 1,070 | 2.38 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 9/25/1997 | 1,090 | 2.43 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 4/29/1998 | 952 | 2.12 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 9/23/1998 | 1,570 | 3.5 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 4/8/1999 | 956 | 2.13 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 9/15/1999 | 1,010 | 2.25 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 4/4/2000 | 1,160 | 2.58 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 9/14/2000 | 1,180 | 2.63 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 4/17/2001 | 826 | 1.84 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 9/13/2001 | 1,080 | 2.41 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 4/16/2002 | 970 | 2.16 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 4/16/2002 | 960 | 2.14 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 9/19/2002 | 1,390 | 3.10 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 4/24/2003 | 871 | 1.94 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 9/11/2003 | 915 | 2.04 | – – | USGS-NWIS, 2004 | – – | Yes |

**Table C.1-2**
**Miscellaneous Discharge Measurements of Selected Springs in the WRFS**
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| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2071303 | Flag Springs 1 | 4/23/2004 | 950 | 2.12 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 9/24/2004 | 950 | 2.12 | – – | USGS, 2004 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 6/30/2005 | 965 | 2.15 | – – | USGS, 2005 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 9/22/2005 | 907 | 2.02 | – – | USGS, 2005 | – – | Yes |
| 207 | 2071303 | Flag Springs 1 | 4/28/2006 | 1,077 | 2.40 | – – | USGS, 2006 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 1/1/1949 | 1,122 | 2.50 | – – | USGS-NWIS, 2004 | Reported as 7/62-28B1 | Yes |
| 207 | 2071401 | Butterfield Spring | 3/9/1966 | 900 | 2.01 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 7/25/1982 | 1,127 | 2.51 | – – | USGS, 1982 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 1/16/1985 | 1,423 | 3.17 | – – | USGS, 1985 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 2/4/1986 | 1,477 | 3.29 | – – | USGS, 1986 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 2/11/1987 | 1,028 | 2.29 | – – | USGS, 1987 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 8/12/1987 | 1,872 | 4.17 | – – | USGS, 1987 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 2/23/1988 | 1,001 | 2.23 | – – | USGS, 1988 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 3/14/1989 | 1,400 | 3.12 | – – | USGS, 1989 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 3/22/1990 | 902 | 2.01 | – – | USGS, 1990 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 11/8/1990 | 1,100 | 2.45 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 3/4/1991 | 1,100 | 2.45 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 10/23/1991 | 1,517 | 3.38 | – – | USGS, 1992 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 3/18/1992 | 1,369 | 3.05 | – – | USGS, 1992 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 10/14/1992 | 1,257 | 2.80 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 5/3/1993 | 1,257 | 2.80 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 10/19/1993 | 1,481 | 3.30 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 3/29/1994 | 1,481 | 3.30 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 10/19/1994 | 1,167 | 2.60 | – – | USGS, 1995 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 4/17/1997 | 1,001 | 2.23 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 9/25/1997 | 1,300 | 2.90 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 4/29/1998 | 1,530 | 3.41 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 9/23/1998 | 1,500 | 3.34 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 4/8/1999 | 1,240 | 2.76 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 9/15/1999 | 1,210 | 2.70 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 4/20/2000 | 1,450 | 3.23 | – – | USGS-NWIS, 2004 | – – | Yes |

# Table C.1-2
## Miscellaneous Discharge Measurements of Selected Springs in the WRFS
(Page 15 of 19)

| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2071401 | Butterfield Spring | 9/13/2000 | 1,490 | 3.32 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 4/17/2001 | 1,180 | 2.63 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 10/2/2001 | 1,330 | 2.96 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 4/16/2002 | 1,090 | 2.43 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 9/19/2002 | 1,250 | 2.79 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 4/24/2003 | 978 | 2.18 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 9/11/2003 | 978 | 2.18 | – – | USGS, 2003 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 4/23/2004 | 1,020 | 2.27 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 9/24/2004 | 942 | 2.10 | – – | USGS, 2004 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 6/30/2005 | 853 | 1.90 | – – | USGS, 2005 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 9/22/2005 | 1,001 | 2.23 | – – | USGS, 2005 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 4/27/2006 | 1,275 | 2.84 | – – | USGS, 2006 | – – | Yes |
| 207 | 2071401 | Butterfield Spring | 9/14/2006 | 1,176 | 2.62 | – – | USGS, 2006 | – – | Yes |
| 207 | 2071501 | Hardy Springs | 11/14/1966 | 200 | 0.45 | – – | Hess and Mifflin, 1978 | Reported as West Immigrant Spring | Yes |
| 207 | 2071501 | Hardy Springs | 9/14/2004 | 200 | 0.45 | F | SNWA | Discharge is confluence of five springs | Yes |
| 207 | 2071502 | Hardy Spring NW | 9/14/2004 | 5 | 0.01 | E | SNWA | 200 yds. West of Hardy Springs | Yes |
| 207 | 2071601 | Nicholas Spring | 10/27/1910 | 1,023 | 2.28 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 5/7/1935 | 1,180 | 2.63 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 3/6/1936 | 1,203 | 2.68 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 3/29/1936 | 1,189 | 2.65 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 3/30/1936 | 1,189 | 2.65 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 4/7/1936 | 1,234 | 2.75 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 4/29/1936 | 1,230 | 2.74 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 5/5/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 5/7/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 5/12/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 5/16/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |

**Table C.1-2**
**Miscellaneous Discharge Measurements of Selected Springs in the WRFS**
(Page 16 of 19)

| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2071601 | Nicholas Spring | 5/19/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 5/23/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 5/26/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 5/30/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 6/2/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 6/5/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 6/9/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 6/16/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 6/19/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 6/23/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 6/27/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 7/7/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 7/12/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 7/18/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 7/19/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 7/26/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 8/4/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 8/15/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 8/25/1936 | 1,212 | 2.70 | – – | Maxey and Eakin, 1949 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 5/9/1947 | 1,100 | 2.50 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 11/13/1966 | 1,125 | 2.51 | – – | Hess and Mifflin, 1978 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 1/19/1982 | 1,068 | 2.38 | – – | USGS, 1982 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 7/30/1984 | 1,200 | 2.67 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 1/21/1985 | 965 | 2.15 | – – | USGS, 1985 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 2/1/1986 | 1,086 | 2.42 | – – | USGS, 1986 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 2/23/1988 | 1,598 | 3.56 | – – | USGS, 1988 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 3/14/1989 | 301 | 0.67 | – – | USGS, 1989 | Discharge appears low | No |
| 207 | 2071601 | Nicholas Spring | 4/4/1990 | 1,100 | 2.45 | – – | USGS, 1990 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 11/6/1990 | 1,302 | 2.90 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 3/3/1991 | 1,499 | 3.34 | – – | USGS, 1991 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 10/24/1991 | 1,167 | 2.60 | – – | USGS, 1992 | – – | Yes |

# Table C.1-2
## Miscellaneous Discharge Measurements of Selected Springs in the WRFS
(Page 17 of 19)

| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2071601 | Nicholas Spring | 3/19/1992 | 108 | 0.24 | – – | USGS, 1992 | Discharge appears low | No |
| 207 | 2071601 | Nicholas Spring | 10/15/1992 | 1,346 | 3.00 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 5/4/1993 | 1,346 | 3.00 | – – | USGS, 1993 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 10/19/1993 | 1,257 | 2.80 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 3/30/1994 | 898 | 2.00 | – – | USGS, 1994 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 10/20/1994 | 1,302 | 2.90 | – – | USGS, 1995 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 5/20/1997 | 1,190 | 2.65 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 9/24/1997 | 1,320 | 2.94 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 4/30/1998 | 1,360 | 3.03 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 9/23/1998 | 1,230 | 2.74 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 4/8/1999 | 1,310 | 2.92 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 9/14/1999 | 1,130 | 2.52 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 4/19/2000 | 1,260 | 2.81 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 9/13/2000 | 1,550 | 3.45 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 4/18/2001 | 952 | 2.12 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 9/12/2001 | 1,240 | 2.76 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 4/17/2002 | 1,270 | 2.83 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 9/18/2002 | 1,220 | 2.72 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 4/23/2003 | 1,260 | 2.81 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 9/10/2003 | 1,120 | 2.50 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 4/22/2004 | 1,200 | 2.67 | – – | USGS-NWIS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 9/23/2004 | 1,185 | 2.64 | – – | USGS, 2004 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 7/1/2005 | 1,207 | 2.69 | – – | USGS, 2005 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 9/21/2005 | 1,207 | 2.69 | – – | USGS, 2005 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 4/27/2006 | 1,145 | 2.55 | – – | USGS, 2006 | – – | Yes |
| 207 | 2071601 | Nicholas Spring | 9/13/2006 | 1,297 | 2.89 | – – | USGS, 2006 | – – | Yes |
| 207 | 2071801 | Williams Hot Spring | 1/1/1935 | 50 | 0.11 | – – | Stearns et al., 1937 | No date given, listed as un-published record, by Stearns et al., 1935 | Yes |
| 207 | 2071801 | Williams Hot Spring | 12/16/1947 | 135 | 0.30 | – – | Maxey and Eakin, 1949 | – – | Yes |

**Table C.1-2**
**Miscellaneous Discharge Measurements of Selected Springs in the WRFS**
(Page 18 of 19)

| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 207 | 2071801 | Williams Hot Spring | 7/26/2005 | 30 | 0.07 | F | SNWA | Measured Q at 6-in. ABS pipe below the reservoir outside the fence. | Yes |
| 207 | 2071901 | Moon River Springs | 8/1/1979 | 700 | 1.60 | – – | Ertec, 1981 | – – | Yes |
| 207 | 2071901 | Moon River Springs | 1/16/1985 | 1,800 | 4.01 | – – | USGS, 1985 | – – | Yes |
| 207 | 2071901 | Moon River Springs | 2/3/1986 | 1,854 | 4.13 | – – | USGS, 1986 | – – | Yes |
| 207 | 2071901 | Moon River Springs | 2/11/1987 | 1,777 | 3.96 | – – | USGS, 1987 | – – | Yes |
| 207 | 2071901 | Moon River Springs | 8/11/1987 | 1,840 | 4.1 | – – | USGS, 1987 | – – | Yes |
| 207 | 2071901 | Moon River Springs | 2/23/1988 | 2,199 | 4.9 | – – | USGS, 1988 | – – | Yes |
| 207 | 2071901 | Moon River Springs | 3/14/1989 | 2,298 | 5.12 | – – | USGS, 1989 | – – | Yes |
| 207 | 2071901 | Moon River Springs | 3/22/1990 | 1,899 | 4.23 | – – | USGS, 1990 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 1/17/1985 | 1,752 | 2.25 | – – | USGS, 1985 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 2/1/1986 | 2,422 | 3.11 | – – | USGS, 1986 | Discharge appears high | No |
| 207 | 2072001 | Emigrant Springs | 3/26/1987 | 1,379 | 1.77 | – – | USGS, 1987 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 8/12/1987 | 1,464 | 1.88 | – – | USGS, 1987 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 2/23/1988 | 1,386 | 1.78 | – – | USGS, 1988 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 3/14/1989 | 1,044 | 1.34 | – – | USGS, 1989 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 3/22/1990 | 1,495 | 1.92 | – – | USGS, 1990 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 11/8/1990 | 779 | 1.00 | – – | USGS, 1991 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 3/8/1991 | 1,558 | 2.00 | – – | USGS, 1991 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 10/24/1991 | 1,449 | 1.86 | – – | USGS, 1992 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 3/18/1992 | 1,433 | 1.84 | – – | USGS, 1992 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 10/14/1992 | 584 | 0.75 | – – | USGS, 1993 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 5/4/1993 | 1,636 | 2.10 | – – | USGS, 1993 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 10/19/1993 | 1,012 | 1.30 | – – | USGS, 1994 | – – | Yes |
| 207 | 2072001 | Emigrant Springs | 3/29/1994 | 857 | 1.10 | – – | USGS, 1994 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 11/15/1912 | 4,039 | 9.00 | – – | Carpenter, 1915 | Discharge could be confused with Crystal Springs | No |
| 209 | 2090101 | Hiko Springs | 1/1/1931 | 5,368 | 12.0 | – – | Hardman and Miller, 1934 | Discharge could be confused with Crystal Springs | No |

# Table C.1-2
## Miscellaneous Discharge Measurements of Selected Springs in the WRFS
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| HA | Station Number | Station Name | Date | Discharge (gpm) | Discharge (cfs) | Measurement Rating[a] (E, G, F, P) | Data Source | Remarks | Measurement Used in this Study Analysis |
|---|---|---|---|---|---|---|---|---|---|
| 209 | 2090101 | Hiko Springs | 1/1/1934 | 2,949 | 6.57 | – – | Smith, 1938 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 1/1/1941 | 2,926 | 6.52 | – – | Smith, 1942 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 1/1/1943 | 2,873 | 6.40 | – – | Smith, 1944 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 6/15/1963 | 2,406 | 5.36 | – – | USGS, 1963 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 2/7/1965 | 2,877 | 6.41 | – – | USGS, 1965 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 5/19/1965 | 2,886 | 6.43 | – – | USGS, 1965 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 7/13/1965 | 2,953 | 6.58 | – – | USGS, 1965 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 10/12/1965 | 2,832 | 6.31 | – – | USGS, 1966 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 7/29/1982 | 2,935 | 6.54 | – – | USGS, 1982 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 1/21/1985 | 3,034 | 6.76 | – – | USGS, 1985 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 1/28/1986 | 2,729 | 6.08 | – – | USGS, 1986 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 3/25/1987 | 2,590 | 5.77 | – – | USGS, 1987 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 2/12/1988 | 2,801 | 6.24 | – – | USGS, 1988 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 3/14/1990 | 1,930 | 4.30 | – – | USGS, 1990 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 11/5/1990 | 2,998 | 6.68 | – – | USGS, 1991 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 4/3/1991 | 2,199 | 4.90 | – – | USGS, 1991 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 11/4/1991 | 1,903 | 4.24 | – – | USGS, 1992 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 3/25/1992 | 2,370 | 5.28 | – – | USGS, 1992 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 10/14/1992 | 2,873 | 6.40 | – – | USGS, 1993 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 4/20/1993 | 1,975 | 4.40 | – – | USGS, 1993 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 10/19/1993 | 1,795 | 4.00 | – – | USGS, 1994 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 3/29/1994 | 2,065 | 4.60 | – – | USGS, 1994 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 10/18/1994 | 2,693 | 6.00 | – – | USGS, 1995 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 4/16/1997 | 2,150 | 4.79 | – – | USGS, 1997 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 9/23/1997 | 2,730 | 6.08 | – – | USGS, 1997 | – – | Yes |
| 209 | 2090101 | Hiko Springs | 7/19/2004 | 2,693 | 6.00 | P | This Study | – – | Yes |
| 209 | 2090201 | Solar Panel Spring | 5/24/2004 | 0.45 | 0.001 | P | SNWA | – – | Yes |
| 209 | 2090701 | Brownie Spring | 6/1/1963 | 224 | 0.5 | | Eakin, 1963 | – – | Yes |

[a]Note: E = Excellent, G = Good, F = Fair, P = Poor

## Table C.1-3
## Annual Discharge of Spring Gaging Stations in the WRFS
(Page 1 of 4)

| Station Number | Station Name | HA | Year | Discharge (cfs) | Data Source |
|---|---|---|---|---|---|
| 09415510 | Preston Big Spring near Preston, NV | 207 | 1984 | 7.24 | USGS-NWIS, 2007 |
| 09415510 | Preston Big Spring near Preston, NV | 207 | 1985 | 7.98 | USGS-NWIS, 2007 |
| 09415510 | Preston Big Spring near Preston, NV | 207 | 2001 | 7.7 | USGS-NWIS, 2007 |
| 09415510 | Preston Big Spring near Preston, NV | 207 | 2002 | 7.45 | USGS-NWIS, 2007 |
| 09415510 | Preston Big Spring near Preston, NV | 207 | 2003 | 7.61 | USGS-NWIS, 2007 |
| 09415510 | Preston Big Spring near Preston, NV | 207 | 2004 | 7.92 | USGS-NWIS, 2007 |
| 09415510 | Preston Big Spring near Preston, NV | 207 | 2005 | 7.61 | USGS-NWIS, 2007 |
| 09415510 | Preston Big Spring near Preston, NV | 207 | 2006 | 9.38 | USGS-NWIS, 2007 |
| 2150101[a] | Muddy River near St. Thomas, NV | 215 | 1914 | 19.3 | Wells, 1954 |
| 09415589 | Crystal Springs Diversion near Hiko, NV | 209 | 2005 | 1.7 | USGS, 2005 |
| 09415589 | Crystal Springs Diversion near Hiko, NV | 209 | 2006 | 1.28 | USGS, 2006 |
| 09415590 | Crystal Spring near Hiko, NV | 209 | 2005 | 11.2 | USGS, 2005 |
| 09415590 | Crystal Spring near Hiko, NV | 209 | 2006 | 11.3 | USGS, 2006 |
| 09415639 | Ash Springs Diversion at Ash Springs, NV | 209 | 2005 | 3.03 | USGS, 2005 |
| 09415639 | Ash Springs Diversion at Ash Springs, NV | 209 | 2006 | 3.88 | USGS, 2006 |
| 09415640 | Ash Springs Creek below Hwy. 93 at Ash Springs, NV | 209 | 2005 | 13.9 | USGS, 2005 |
| 09415640 | Ash Springs Creek below Hwy. 93 at Ash Springs, NV | 209 | 2006 | 12.1 | USGS, 2006 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1914 | 47.2 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1915 | 47.6 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1917 | 46.7 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1918 | 47 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1945 | 45.7 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1946 | 46.9 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1947 | 47.7 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1948 | 46.3 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1949 | 47 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1950 | 46.2 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1951 | 46.9 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1952 | 46.6 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1953 | 46 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1954 | 46 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1955 | 47.2 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1956 | 45.8 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1957 | 47.7 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1958 | 49.6 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1959 | 48.9 | USGS-NWIS, 2007 |

# Table C.1-3
## Annual Discharge of Spring Gaging Stations in the WRFS
(Page 2 of 4)

| Station Number | Station Name | HA | Year | Discharge (cfs) | Data Source |
|---|---|---|---|---|---|
| 09416000 | Muddy River near Moapa, NV | 219 | 1960 | 47.8 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1961 | 46.3 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1962 | 44.5 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1963 | 44.7 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1964 | 44.9 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1965 | 43.4 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1966 | 41.8 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1967 | 46 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1968 | 40.6 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1969 | 42.7 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1970 | 40.9 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1971 | 38.1 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1972 | 43.5 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1973 | 45.5 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1974 | 40.5 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1975 | 39.9 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1976 | 41.2 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1977 | 37.5 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1978 | 36.2 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1979 | 39.2 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1980 | 39.8 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1981 | 37.9 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1982 | 37.8 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1983 | 39.4 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1984 | 39.4 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1985 | 38.2 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1986 | 36.6 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1987 | 37.6 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1988 | 39.7 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1989 | 33.7 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1990 | 36.6 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1991 | 36.1 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1992 | 36.4 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1993 | 39.6 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1994 | 39.4 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1995 | 35.6 | USGS-NWIS, 2007 |

## Table C.1-3
## Annual Discharge of Spring Gaging Stations in the WRFS
(Page 3 of 4)

| Station Number | Station Name | HA | Year | Discharge (cfs) | Data Source |
|---|---|---|---|---|---|
| 09416000 | Muddy River near Moapa, NV | 219 | 1996 | 33.5 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1997 | 32.5 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1998 | 34.9 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 1999 | 34.8 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 2000 | 34.5 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 2001 | 32.2 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 2002 | 31.4 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 2003 | 31.7 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 2004 | 30.4 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 2005 | 33.2 | USGS-NWIS, 2007 |
| 09416000 | Muddy River near Moapa, NV | 219 | 2006 | 33.2 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1951 | 44.1 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1952 | 53.6 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1953 | 46 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1954 | 43.8 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1955 | 54.8 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1956 | 43.6 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1957 | 48.3 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1958 | 48.3 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1959 | 45 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1960 | 44.2 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1961 | 60.7 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1962 | 44.8 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1963 | 40.1 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1964 | 40 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1965 | 44.2 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1966 | 41.9 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1967 | 45.2 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1968 | 43.9 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1969 | 54.5 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1970 | 45.1 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1971 | 42.5 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1972 | 41.9 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1973 | 44.3 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1974 | 38.5 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1975 | 40.6 | USGS-NWIS, 2007 |

## Table C.1-3
## Annual Discharge of Spring Gaging Stations in the WRFS
(Page 4 of 4)

| Station Number | Station Name | HA | Year | Discharge (cfs) | Data Source |
|---|---|---|---|---|---|
| 09419000 | Muddy River near Glendale, NV | 220 | 1976 | 41.6 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1977 | 38.2 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1978 | 55.4 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1979 | 42.3 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1980 | 46.6 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1981 | 44.8 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1982 | 37.1 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1983 | 55 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1985 | 36.7 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1986 | 36.8 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1987 | 37.3 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1988 | 38.4 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1989 | 30.8 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1990 | 41.3 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1991 | 35.9 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1992 | 36.6 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1993 | 54.2 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1994 | 34.7 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1995 | 32.8 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1996 | 31.2 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1997 | 30.4 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1998 | 54.9 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 1999 | 37.3 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 2000 | 39.8 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 2001 | 31.6 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 2002 | 31.7 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 2003 | 31.7 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 2004 | 32 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 2005 | 72.2 | USGS-NWIS, 2007 |
| 09419000 | Muddy River near Glendale, NV | 220 | 2006 | 34.6 | USGS-NWIS, 2007 |

[a]SNWA Station Number

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# Appendix D

# Interbasin Groundwater Flow through Selected Boundaries

# D.1.0 INTRODUCTION

This appendix presents the assumptions, data, and calculations used to approximate interbasin groundwater flow through selected boundaries of the WRFS. These estimates were used as the basis for some of the Excel Solver constraints discussed in Section 5.0 and to partition groundwater outflow for selected basins.

# D.2.0 INTERBASIN FLOW WITHIN THE WRFS

This section includes estimates of the groundwater outflow from Coyote Spring Valley to Hidden Valley and the interbasin flow for Cave, Dry Lake, and Delamar valleys.

## D.2.1 Outflow From Coyote Spring Valley to Hidden Valley

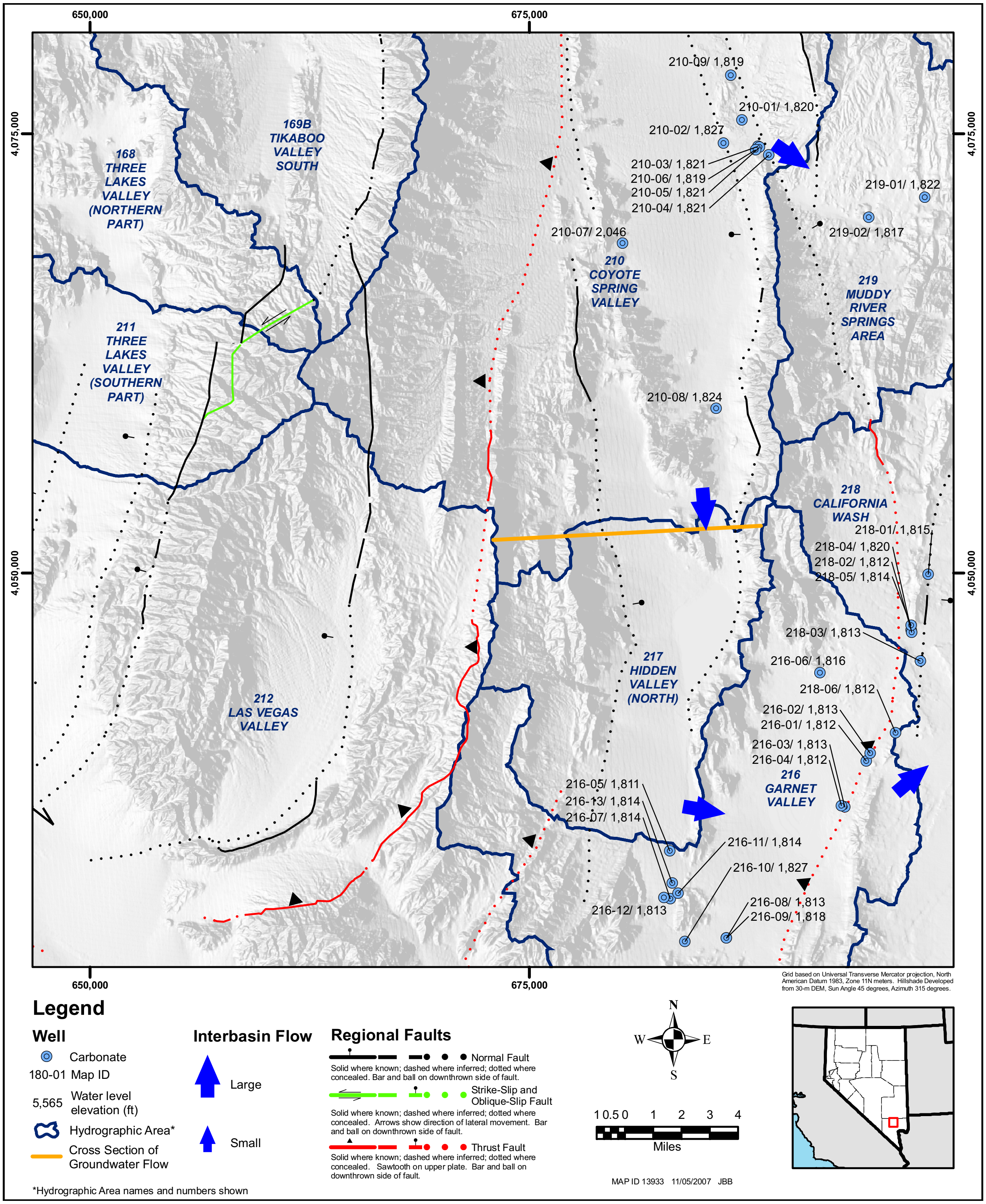
Outflow from Coyote Spring Valley to Hidden Valley is likely to occur through the carbonate-rock aquifer. The outflow volume may be estimated using the available water-level and hydraulic property data, and Darcy's Law expressed in the form of the following equation:

$$Q = TIW \times \left(\frac{365}{43{,}560}\right) \qquad \text{(Eq. D.2-1)}$$

where,

Q = the groundwater flow (afy)
T = the transmissivity ($ft^2$/day)
I = the hydraulic gradient (ft/ft)
W = the estimated width of the section of flow (ft)

Although most of the groundwater from Coyote Spring Valley flows to the southeast into the Muddy Springs River Area (Eakin, 1966; Harrill et al., 1988), the hydrogeology of the valley supports a portion of this groundwater flowing south to Hidden Valley. No carbonate-rock wells have been drilled in Hidden Valley to date. However, carbonate-rock wells for which hydraulic data are available exist in Coyote Spring Valley and California Wash, the two valleys located upgradient and downgradient from Hidden Valley, respectively (Figure D.2-1 and Table D.2-1). An estimate of this groundwater flux may be derived using Equation D.2-1 and water levels and transmissivities measured in these carbonate-rock wells.




Note: For an index of springs names and well IDs, see Table D.2-1.

**Figure D.2-1**
**Interbasin Outflow and Water-Level Elevations of Selected Wells in Southern Coyote Spring Valley and Vicinity**

# Table D.2-1
## Water Level Data for Selected Wells and Springs
(Page 1 of 4)

| Map-ID | Station Number | Station Name | Location | | Ref. Pt. Elev.[b] (ft-amsl) | Site Type | Well Depth (ft-bgs) | Open Interval (ft-bgs) | Last Water Level Measurement Date | Last Depth to Water (ft-bgs)[c] | Water Level Elevation[d] (ft-amsl) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | UTM Easting[a] (m) | UTM Northing[a] (m) | | | | | | | |
| 180-01 | 382223114502501 | 180 N06 E64 18CC 1 Sidehill Pass Well | 688,678 | 4,249,221 | 5,975 | Well-Basin Fill | -- | -- | 7/25/2005 | 158 | 5,817 |
| 180-02 | 180 N07 E63 13DB 1 | 180 N07 E63 13DB 1 | 687,817 | 4,259,662 | 6,014 | Well-Basin Fill | 250 | 200 to 240 | 12/15/1995 | 180 | 5,834 |
| 180-03 | 382822114515301 | 180 N07 E63 14AB 1 USGS-MX | 685,674 | 4,260,043 | 6,012 | Well-Basin Fill | 273 | 200 to 263 | 3/15/1994 | 223 | 5,789 |
| 180-04 | 382822114515302 | 180 N07 E63 14AB 2 USGS-MX | 685,674 | 4,260,043 | 6,012 | Well-Carbonate | 422 | 380 to 422 | 10/25/1980 | 231 | 5,781 |
| 180-05 | 382810114521501 | 180 N07 E63 14BADB1 USAF | 685,674 | 4,260,043 | 6,013 | Well-Basin Fill | 269 | 50 to 269 | 5/29/2007 | 219 | 5,794 |
| 180-06 | 382810114521502 | 180 N07 E63 14BADB2 USAF | 685,674 | 4,260,043 | 6,013 | Well-Carbonate | 418 | 50 to 418 | 7/15/2002 | 221 | 5,792 |
| 180-07 | 382807114521001 | 180 N07 E63 14BADD1 USGS-MX (Cave Valley) | 685,797 | 4,259,954 | 6,012 | Well-Carbonate | 460 | 210 to 250/ 375 to 435 | 5/29/2007 | 220 | 5,792 |
| 180-08 | 382747114525701 | 180 N07 E63 15DBAD1 USBLM | 684,672 | 4,259,311 | 6,026 | Well-Basin Fill | -- | -- | 8/4/2003 | 15 | 6,011 |
| 180-09 | 180 N07 E63 27CD 1 | 180 N07 E63 27CD 1 | 684,288 | 4,255,971 | 5,988 | Well-Basin Fill | 245 | 200 to 240 | 5/15/1998 | 157 | 5,831 |
| 180-10 | 180 N07 E63 27DD 1 | 180 N07 E63 27DD 1 | 685,088 | 4,255,990 | 5,988 | Well-Basin Fill | 290 | 240 to 280 | 5/15/1998 | 168 | 5,820 |
| 180-11 | 180 N07 E63 27DD 2 | 180 N07 E63 27DD 2 | 685,088 | 4,255,990 | 5,988 | Well-Basin Fill | 320 | 260 to 300 | 7/15/1998 | 183 | 5,805 |
| 180-12 | 180 N07 E63 33D 1 | 180 N07 E63 33D 1 | 683,325 | 4,254,561 | 5,982 | Well-Basin Fill | 300 | 198 to 300 | 1/15/2000 | 192 | 5,790 |
| 180-13 | 382640114492801 | 180 N07 E64 19 1 Gulf Oil Corp | 689,787 | 4,257,364 | 6,005 | Well-Basin Fill | 265 | 240 to 265 | 3/15/1980 | 215 | 5,790 |
| 180-14 | 383458114473601 | 180 N08 E64 04ABDD1 USBLM | 692,206 | 4,272,813 | 6,224 | Well-Basin Fill | 200 | 160 to 200 | 2/21/2007 | 131 | 6,093 |
| 180-15 | 383307114471001 | 180 N08 E64 15BCBC1 USBLM | 692,846 | 4,269,374 | 6,163 | Well-Basin Fill | -- | -- | 5/29/2007 | 262 | 5,901 |
| 180-16 | 383056114501501 | 180 N08 E64 30CDBC1 USBLM | 688,462 | 4,265,229 | 6,087 | Well-Basin Fill | 352 | 50 to 352 | 7/11/1999 | 327 | 5,760 |
| 180-17 | 383501114504801 | 180 N09 E63 01A 1 | 687,559 | 4,283,005 | 6,536 | Well-Basin Fill | -- | -- | 10/16/1962 | 2 | 6,534 |
| 180-18 | 383828114474501 | 180 N09 E64 16ACB 1 Cave Spring | 691,761 | 4,279,249 | 6,488[e] | Spring | -- | -- | -- | -- | 6,488 |
| 180-19 | 383632114465801 | 180 N09 E64 27BCDD1 USBLM | 692,983 | 4,275,700 | 6,414 | Well-Basin Fill | 315 | 277 to 315 | 5/29/2007 | 221 | 6,193 |
| 180-20 | 384207114505601 | 180 N10 E63 25A 1 | 686,984 | 4,285,891 | 6,604 | Well-Basin Fill | 20 | -- | 9/22/2006 | 14 | 6,590 |
| 180-21 | 384534114495301 | 180 N10 E64 06BDA 1 Robbers Roost Well | 688,337 | 4,292,295 | 6,848 | Well-Basin Fill | -- | -- | 7/26/2005 | 140 | 6,708 |
| 180-22 | 180 N11 E63 25DD 1 | 180 N11 E63 25DD 1 | 687,670 | 4,294,728 | 6,987 | Well-Basin Fill | 140 | 100 to 140 | 4/15/1998 | 91 | 6,896 |
| 180-23 | 382458114474301 | 180 S07 E64 33 1 Sidehill Spring | 692,408 | 4,254,280 | 6,531[e] | Spring | -- | -- | -- | -- | 6,531 |
| 180-24 | 180W501M | 180W501M | 688,048 | 4,273,716 | 6,457 | Well-Carbonate | 1,212 | 788 to 1,192 | 9/7/2007 | 1,051 | 5,406 |
| 180-25 | 180W902M | 180W902M | 689,805 | 4,248,363 | 5,987 | Well-Carbonate | 903 | 196 to 882 | 9/26/2007 | 138 | 5,849 |
| 180-26 | 382738114525601 | 180 N07 E63 15C 1 | 684,703 | 4,259,034 | 6,004 | Well-Basin Fill | -- | -- | 1/1/1900 | 300 | 5,704 |
| 180-27 | 381624114540302 | 180 N05 E63 34BBCC2 USBLM | 683,551 | 4,238,220 | 6,229 | Well-Basin Fill | -- | -- | 8/25/2003 | 8 | 6,221 |
| 181-01 | 375624114444501 | 181 N01 E62 24ABB 1 USBLM | 698,010 | 4,201,548 | 4,695 | Well-Basin Fill | 515 | 400 to 515 | 11/13/2006 | 48 | 4,648 |
| 181-02 | 181 N01 E65 02AA 1 | 181 N01 E65 02AA 1 | 706,529 | 4,206,411 | 5,663 | Well-Volcanic | -- | -- | 6/15/1960 | 10 | 5,653 |
| 181-03 | 181 N02 E63 13CA 1 | 181 N02 E63 13CA 1 Coyote Spring | 687,693 | 4,211,513 | 5,224[e] | Spring | -- | -- | -- | -- | 5,224 |
| 181-04 | 380336114473501 | 181 N02 E64 03B 1 USBLM | 693,124 | 4,215,351 | 4,972 | Well-Basin Fill | 742 | 702 to 742 | 5/9/2006 | 658 | 4,314 |
| 181-05 | 380531114534201 | 181 N03 E63 27CAA 1 USGS-MX (N. Dry Lake) | 684,519 | 4,218,103 | 5,391 | Well-Carbonate | 2,395 | No perforations | 7/25/2007 | 846 | 4,545 |
| 181-06 | 380616114494101 | 181 N03 E64 20BD 1 USBLM - Coyote Well | 690,486 | 4,220,368 | 5,071 | Well-Basin Fill | 380 | 50 to 380 | 5/29/2007 | 269 | 4,801 |
| 181-07 | 380550114412301 | 181 N03 E65 21D 1 Bristol Well | 702,610 | 4,219,921 | 5,464 | Well-Basin Fill | 80 | 20 to 80 | 5/29/2007 | 20 | 5,444 |
| 181-08 | 181 N03 E65 22 1 | 181 N03 E65 22 1 | 703,867 | 4,220,163 | 5,593 | Well-Basin Fill | 240 | 60 to 240 | 1/15/1966 | 3 | 5,590 |
| 181-09 | 381256114500701 | 181 N04 E64 07DC 1 USGS-MX (Muleshoe Valley) | 689,481 | 4,232,096 | 5,534 | Well-Basin Fill | 1,190 | 1,050 to 1,190 | 5/29/2007 | 253 | 5,280 |
| 181-10 | 381256114500702 | 181 N04 E64 07DC 2 USGS-MX | 689,526 | 4,232,282 | 5,539 | Well-Basin Fill | 672 | 50 to 672 | 8/27/2003 | 269 | 5,270 |
| 181-11 | 381256114500703 | 181 N04 E64 07DC 3 USGS-MX | 689,526 | 4,232,282 | 5,539 | Well-Basin Fill | 1,134 | 50 to 1,134 | 3/10/1990 | 253 | 5,285 |

# Table D.2-1
## Water Level Data for Selected Wells and Springs
(Page 2 of 4)

| Map-ID | Station Number | Station Name | Location: UTM Easting[a] (m) | Location: UTM Northing[a] (m) | Ref. Pt. Elev.[b] (ft-amsl) | Site Type | Well Depth (ft-bgs) | Open Interval (ft-bgs) | Last Water Level Measurement Date | Last Depth to Water (ft-bgs)[c] | Water Level Elevation[d] (ft-amsl) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 181-12 | 381358114412201 | 181 N04 E65 04DBD 1 Little Field Spring | 701,112 | 4,233,949 | 6,150[e] | Spring | -- | -- | -- | -- | 6,150 |
| 181-13 | 181 N04 E65 26DC 1 | 181 N04 E65 26DC 1 | 705,540 | 4,227,429 | 6,319 | Well-Volcanic | 81 | 60 to 80 | 10/15/1954 | 50 | 6,268 |
| 181-14 | 381029114430701 | 181 N04 E65 29CB 1 Spring | 699,080 | 4,227,795 | 6,090[e] | Spring | -- | -- | -- | -- | 6,090 |
| 181-15 | 381506114421801 | 181 N05 E65 32AD 1 Spring | 700,888 | 4,236,201 | 6,178[e] | Spring | -- | -- | -- | -- | 6,178 |
| 181-16 | 181 N05 E65 34DC 1 | 181 N05 E65 34DC 1 | 703,684 | 4,235,544 | 6,549 | Well-Volcanic | 28 | 10 to 28 | 5/1/1972 | 10 | 6,539 |
| 181-17 | 181 N05 E65 35BA 1 | 181 N05 E65 35BA 1 | 704,865 | 4,236,789 | 6,642 | Well-Volcanic | 22 | 12 to 22 | 7/15/1972 | 12 | 6,630 |
| 181-18 | 374536114443001 | 181 S02 E65 19CA 1 | 698,859 | 4,181,583 | 4,672 | Well-Basin Fill | 156 | 50 to 156 | 4/28/1994 | 49 | 4,623 |
| 181-19 | 374215114453101 | 181 S03 E64 12AC 1 USGS-MX(S. Dry Lake Well) | 697,515 | 4,175,351 | 4,643 | Well-Basin Fill | 1,000 | 600 to 970 | 7/30/2007 | 394 | 4,249 |
| 181-20 | 374215114453102 | 181 S03 E64 12AC 2 USGS-MX | 697,515 | 4,175,351 | 4,643 | Well-Basin Fill | 1,300 | 1,270 to 1,290 | 7/30/2007 | 382 | 4,262 |
| 181-21 | 374215114453103 | 181 S03 E64 12AC 3 USGS-MX | 697,515 | 4,175,351 | 4,643 | Well-Basin Fill | 798 | 768 to 788 | 3/10/1990 | 382 | 4,261 |
| 181-22 | 181M-1 | 181M-1 | 688,537 | 4,198,181 | 4,966 | Well-Carbonate | 1,472 | 765 to 1,471 | 9/4/2007 | 675 | 4,291 |
| 181-23 | 181W909M | 181W909M | 698,688 | 4,174,479 | 4,804 | Well-Basin Fill | 1,260 | 637 to 1,240 | 9/4/2007 | 497 | 4,307 |
| 181-24 | 181 S03 E63 22AB 1 | 181 S03 E63 22AB 1 | 684,620 | 4,172,308 | 5,313 | Well-Basin Fill | -- | -- | 3/15/1966 | 3 | 5,310 |
| 181-25 | 181 S04 E64 07AC 1 | 181 S04 E64 07AC 1 Jacob 7B | 689,759 | 4,165,424 | 4,810 | Well-Basin Fill | -- | 50 to 1,000 | 5/26/2003 | 515 | 4,295 |
| 182-01 | 182 S05 E64 02CB 1 | 182 S05 E64 02CB 1 Grassy Spring | 695,124 | 4,157,193 | 5,786[e] | Spring | -- | -- | -- | -- | 5,786 |
| 182-02 | 372639114520901 | 182 S06 E63 12AD 1 USGS-MX (Delamar Well) | 688,422 | 4,146,273 | 4,713 | Well-Basin Fill | 1,195 | 920 to 980/ 1,040 to 1,180 | 7/30/2007 | 863 | 3,850 |
| 182-03 | 372639114520902 | 182 S06 E63 12ADBD2 USGS-MX | 688,422 | 4,146,273 | 4,713 | Well-Basin Fill | 981 | 540-630/816-847/ 877-940/950-971 | 4/1/1981 | 867 | 3,846 |
| 182-04 | 182M-1 | 182M-1 | 680,874 | 4,135,306 | 4,582 | Well-Volcanic | 1,321 | 1,000 to 1,300 | 9/4/2007 | 827 | 3,755 |
| 182-05 | 182W906M | 182W906M | 690,078 | 4,133,299 | 4,802 | Well-Volcanic | 1,702 | 1,274 to 1,677 | 9/4/2007 | 1,316 | 3,486 |
| 183-01 | 183 N07 E65 17D 1 | 183 N07 E65 17D 1 | 700,785 | 4,259,596 | 6,364 | Well-Basin Fill | 229 | 50 to 229 | 8/15/1963 | 212 | 6,152 |
| 183-02 | 183 N07 E65 17DA 1 | 183 N07 E65 17DA 1 | 700,984 | 4,259,800 | 6,344 | Well-Basin Fill | 264 | 50 to 264 | 6/15/1966 | 200 | 6,144 |
| 183-03 | 382757114414301 | 183 N07 E65 17DAA 1 USBLM | 701,001 | 4,260,012 | 6,320 | Well-Basin Fill | 230 | 50 to 230 | 7/25/2005 | 177 | 6,143 |
| 183-04 | 183 N07 E65 11CC 1 | 183 N07 E65 11CC 1 | 704,604 | 4,261,398 | 6,047 | Well-Basin Fill | 220 | 147 to 210 | 6/15/1967 | 147 | 5,900 |
| 207-01 | 207 N07 E61 07DD 1 | 207 N07 E61 07DD 1 | 660,917 | 4,260,101 | 5,249 | Well-Basin Fill | 100 | 50 to 100 | 7/15/1979 | 13 | 5,236 |
| 207-02 | 207 N07 E61 10B 1 | 207 N07 E61 10B 1 | 664,739 | 4,260,344 | 5,246 | Well-Carbonate | -- | 50 to 6,305 | 6/15/1981 | 55 | 5,191 |
| 207-03 | 207 N07 E61 11AC1 | 207 N07 E61 11AC1 | 666,829 | 4,260,940 | 5,240 | Well-Carbonate | -- | -- | 1986 | 29 | 5,211 |
| 207-04 | 207 N07 E62 21AC 1 | 207 N07 E62 21AC 1 | 673,421 | 4,258,166 | 5,327 | Well-Basin Fill | 55 | 30 to 55 | 10/15/2001 | 35 | 5,292 |
| 207-05 | 382718115094901 | 207 N07 E61 19BDDC1 USGS-MX | 660,169 | 4,257,489 | 5,249 | Well-Basin Fill | 101 | 50 to 101 | 9/4/1991 | 49 | 5,199 |
| 207-06 | 207 N06 E61 06BB 1 | 207 N06 E61 06BB 1 | 659,866 | 4,253,191 | 5,224 | Well-Basin Fill | 456 | 50 to 456 | 7/15/1979 | 39 | 5,185 |
| 207-07 | 207 N07 E61 36CC 1 | 207 N07 E61 36CC 1 | 667,912 | 4,253,734 | 5,187 | Well-Basin Fill | 110 | 50 to 110 | 1/15/2003 | 16 | 5,171 |
| 207-08 | 207 N07 E61 36CCD 1 | 207 N07 E61 36CCD 1 | 668,003 | 4,253,623 | 5,184 | Well-Basin Fill | 79 | 50 to 79 | 7/15/1979 | 19 | 5,165 |
| 207-09 | 207 N07 E61 36DD 1 | 207 N07 E61 36DD 1 | 669,105 | 4,253,753 | 5,204 | Well-Basin Fill | 100 | 50 to 100 | 8/15/1970 | 9 | 5,195 |
| 207-10 | 207 N06 E61 06CC 1 | 207 N06 E61 06CC 1 | 659,812 | 4,252,240 | 5,219 | Well-Basin Fill | 6 | 6 to 513 | 7/15/1966 | 33 | 5,186 |
| 207-11 | 382259115090801 | 207 N06 E61 18AADA1 NDW - Hot Creek Spring | 661,290 | 4,249,926 | 5,229[e] | Spring-Regional | -- | -- | -- | -- | 5,229 |
| 207-12 | 207 N06 E61 09CCB 1 | 207 N06 E61 09CCB 1 | 663,011 | 4,250,517 | 5,219 | Well-Basin Fill | 400 | 50 to 400 | 7/15/1979 | 5 | 5,214 |
| 207-13 | 207 N06 E62 07AB1 | 207 N06 E62 07AB1 | 670,126 | 4,251,495 | 5,284 | Well-Carbonate | -- | -- | 1986 | 200 | 5,084 |
| 207-14 | 207 N06 E62 07CD 1 | 207 N06 E62 07CD 1 | 670,034 | 4,250,846 | 5,284 | Well-Basin Fill | 117 | 40 to 117 | 5/15/1968 | 25 | 5,259 |
| 207-15 | 207 N06 E62 07CD 2 | 207 N06 E62 07CD 2 | 669,947 | 4,250,478 | 5,285 | Well-Carbonate | -- | 50 to 3,980 | 6/22/1966 | 142 | 5,143 |

# Table D.2-1
## Water Level Data for Selected Wells and Springs
(Page 3 of 4)

| Map-ID | Station Number | Station Name | Location | | Ref. Pt. Elev.[b] (ft-amsl) | Site Type | Well Depth (ft-bgs) | Open Interval (ft-bgs) | Last Water Level Measurement Date | Last Depth to Water (ft-bgs)[c] | Water Level Elevation[d] (ft-amsl) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | UTM Easting[a] (m) | UTM Northing[a] (m) | | | | | | | |
| 207-16 | 207 N06 E61 31AA 1 | 207 N06 E61 31AA 1 | 661,137 | 4,245,452 | 5,143 | Well-Basin Fill | 152 | 70 to 152 | 3/15/2001 | 27 | 5,116 |
| 207-17 | 207 N06 E61 32BA 1 | 207 N06 E61 32BA 1 | 662,019 | 4,245,179 | 5,149 | Well-Basin Fill | 50 | -- | 3/15/1979 | 18 | 5,131 |
| 207-18 | 207 N06 E61 33DC 1 | 207 N06 E61 33DC 1 | 664,040 | 4,243,999 | 5,208 | Well-Basin Fill | -- | -- | 10/14/1968 | 6 | 5,202 |
| 207-19 | 207 N06 E61 33D 1 | 207 N06 E61 33D 1 | 664,251 | 4,244,203 | 5,207 | Well-Basin Fill | 200 | 50 to 200 | 8/15/1979 | 100 | 5,107 |
| 207-20 | 207 N06 E61 28DA1 | 207 N06 E61 28DA1 | 664,334 | 4,245,971 | 5,195 | Well-Carbonate | -- | -- | 1986 | 53 | 5,142 |
| 207-21 | 382111115055901 | 207 N06 E61 27AADC1 USGS-MX | 666,042 | 4,246,692 | 5,214 | Well-Basin Fill | 96 | 50 to 96 | 9/21/1994 | 70 | 5,144 |
| 207-22 | 207 N06 E61 27DD 1 | 207 N06 E61 27DD 1 | 666,042 | 4,245,663 | 5,204 | Well-Basin Fill | 250 | 50 to 250 | 6/15/1970 | 98 | 5,106 |
| 207-23 | 207 N06 E62 31AD 1 | 207 N06 E62 31AD 1 | 670,827 | 4,244,903 | 5,434 | Well-Basin Fill | 250 | 50 to 250 | 7/15/1979 | 145 | 5,289 |
| 207-24 | 382005115023701 | 207 N06 E62 31ADD 1 | 670,987 | 4,244,822 | 5,454 | Well-Basin Fill | 300 | 50 to 300 | 3/9/1990 | 123 | 5,331 |
| 207-25 | 207 N05 E61 31CB 1 | 207 N05 E61 31CB 1 Murphy Meadows 2 | 660,306 | 4,234,215 | 5,104 | Well-Basin Fill | 100 | 50 to 100 | 7/25/2005 | 11 | 5,093 |
| 207-26 | 373614115083701 | 207 N04 E61 16D 1 | 663,950 | 4,230,089 | 5,140 | Well-Basin Fill | -- | -- | 5/10/1963 | 84 | 5,056 |
| 208-01 | 208 N05 E63 34BBCC 1 | 208 N05 E63 34BBCC 1 Griswald Well | 683,428 | 4,236,136 | 6,255 | Well-Basin Fill | -- | -- | 7/12/1998 | 3 | 6,252 |
| 208-02 | 380914115044101 | 208 N04 E61 36C 1 USBLM | 668,322 | 4,224,628 | 5,044 | Well-Basin Fill | -- | -- | 7/23/2000 | 69 | 4,975 |
| 208-03 | 374218115031501 | 208 N03 E62 08C 1 USBLM | 671,468 | 4,222,073 | 5,063 | Well-Basin Fill | -- | -- | 5/1/1963 | 217 | 4,847 |
| 208-04 | 208 N03 E62 17AB 1 | 208 N03 E62 17AB 1 | 672,041 | 4,221,499 | 5,053 | Well-Basin Fill | 350 | 150 to 350 | 3/15/1974 | 252 | 4,801 |
| 208-05 | 208 N03 E62 27 1 | 208 N03 E62 27 1 | 674,898 | 4,217,767 | 4,976 | Well-Basin Fill | 357 | 320 to 357 | 8/15/1958 | 260 | 4,716 |
| 208-06 | 380505114593501 | 208 N03 E62 35BBB 1 USBLM | 675,936 | 4,217,111 | 4,960 | Well-Basin Fill | 315 | 50 to 315 | 3/9/1985 | 251 | 4,710 |
| 208-07 | 208 N03 E62 35BBB 2 | 208 N03 E62 35BBB 2 Pahroc MX | 675,845 | 4,217,088 | 4,965 | Well-Basin Fill | -- | -- | 7/26/2004 | 268 | 4,698 |
| 208-08 | 380450114594201 | 208 N03 E62 35B 1 USBLM | 675,775 | 4,216,645 | 4,979 | Well-Basin Fill | 270 | 50 to 270 | 9/21/1994 | 250 | 4,729 |
| 208-09 | 373924115003101 | 208 N03 E62 35B 2 USBLM | 676,045 | 4,216,558 | 4,956 | Well-Basin Fill | -- | -- | 5/8/1963 | 252 | 4,704 |
| 209-01 | 374058115113501 | 209 S03 E60 13DACD1 | 659,265 | 4,172,123 | 4,060 | Well-Carbonate | 479 | 213 to 479 | 8/25/2003 | 209 | 3,851 |
| 209-02 | 209 S03 E61 22BB 1 | 209 S03 E61 22BB 1 | 664,606 | 4,171,854 | 5,005 | Well-Carbonate | 1,427 | 35 to 1427 | 6/15/1965 | 860 | 4,145 |
| 209-03 | 209 S03 E62 25AB 1 | 209 S03 E62 25AB 1 Pahroc Spring | 678,091 | 4,170,481 | 5,403[e] | Spring | -- | -- | -- | -- | 5,403 |
| 209-04 | 209M-1 | 209M-1 | 677,377 | 4,168,166 | 5,123 | Well-Carbonate | 1,616 | 1,273 to 1,595 | 9/4/2007 | 1,200 | 3,923 |
| 209-05 | 373554115125201 | 209 S04 E60 14DBAB1 Hiko Spring | 657,549 | 4,162,744 | 3,878[e] | Spring-Regional | -- | -- | -- | -- | 3,878 |
| 209-06 | 373158115141601 | 209 S05 E60 10ABCC1 | 655,626 | 4,155,431 | 3,841 | Well-Basin Fill | 140 | 50 to 140 | 1/1/1988 | 30 | 3,811 |
| 209-07 | 09415590 | 209 S05 E60 10 1 Crystal Spring near Hiko, NV | 656,168 | 4,155,349 | 3,803[e] | Spring-Regional | -- | -- | -- | -- | 3,803 |
| 209-08 | 372857115124001 | 209 S05 E60 26DAD 1 Brownie Spring | 658,088 | 4,149,897 | 3,695[e] | Spring | -- | -- | -- | -- | 3,695 |
| 209-09 | 372749115113401 | 209 S06 E61 06BBBB1 Ash Springs | 659,848 | 4,147,834 | 3,622[e] | Spring-Regional | -- | -- | -- | -- | 3,622 |
| 209-10 | 209 S07 E61 21DA 1 | 209 S07 E61 21DA 1 Grove Spring | 664,633 | 4,132,301 | 3,395[e] | Spring | -- | -- | -- | -- | 3,395 |
| 209-11 | 209 S08 E61 23BABD 1 | 209 S08 E61 23BABD 1 Solar Panel Spring | 667,261 | 4,123,643 | 3,238[e] | Spring | -- | -- | -- | -- | 3,238 |
| 209-12 | 209 S07 E62 21AC 1 | 209 S07 E62 21AC 1 | 674,019 | 4,133,040 | 4,123 | Well-Basin Fill | -- | -- | 8/15/2001 | 31 | 4,092 |
| 209-13 | 209 S08 E61 32BD 1 | 209 S08 E61 32BD 1 | 662,530 | 4,119,798 | 4,525 | Well-Basin Fill | -- | -- | 5/15/1976 | 25 | 4,500 |
| 209-14 | Maynard Spring | Maynard Spring | 674,523 | 4,117,711 | 3,098[e] | Spring | -- | -- | -- | -- | 3,133 |
| 210-01 | CSI-2 | 210 S13 E63 14CD 1 CSI-2 | 687,083 | 4,075,781 | 2,209 | Well-Carbonate | 1,015 | 523.8 to 644/ 684.1 to 844.4/ 884.5 to 1,004.7 | 6/15/2006 | 389 | 1,820 |
| 210-02 | CSI-1 | 210 S13 E63 22DC 1 CSI-1 | 686,043 | 4,074,459 | 2,266 | Well-Carbonate | 920 | 520 to 600/640 to 760/800 to 880 | 5/30/2005 | 439 | 1,827 |
| 210-03 | 364743114533101 | 210 S13 E63 23DDDC1 USGS-MX CE-DT-4 | 688,003 | 4,074,277 | 2,175 | Well-Carbonate | 669 | 50 to 669 | 7/10/2007 | 354 | 1,821 |

# Table D.2-1
## Water Level Data for Selected Wells and Springs
(Page 4 of 4)

| Map-ID | Station Number | Station Name | Location | | Ref. Pt. Elev.[b] (ft-amsl) | Site Type | Well Depth (ft-bgs) | Open Interval (ft-bgs) | Last Water Level Measurement Date | Last Depth to Water (ft-bgs)[c] | Water Level Elevation[d] (ft-amsl) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | UTM Easting[a] (m) | UTM Northing[a] (m) | | | | | | | |
| 210-04 | 210 S13 E63 25AD 1 | 210 S13 E63 25AD 1 CSVM-1 | 688,602 | 4,073,793 | 2,161 | Well-Carbonate | 1,040 | 320 to 1,020 | 7/10/2007 | 340 | 1,821 |
| 210-05 | 364741114532801 | 210 S13 E63 26AAAA1 USGS-MX CE-DT-5 | 688,084 | 4,074,219 | 2,173 | Well-Carbonate | 628 | 121 to 628 | 7/10/2007 | 352 | 1,821 |
| 210-06 | 210 S13 E63 26AB 1 | 210 S13 E63 26AB 1 CSV-RW2 | 687,862 | 4,074,082 | 2,200 | Well-Carbonate | 710 | 460 to 700 | 9/20/2006 | 381 | 1,819 |
| 210-07 | 210 S14 E62 01AA 1 | 210 S14 E62 01AA 1 CSVM-5 | 680,295 | 4,068,774 | 3,131 | Well-Carbonate | 1,780 | 1,020 to 1,760 | 7/9/2007 | 1085 | 2,046 |
| 210-08 | 210 S15 E63 03BB 1 | 210 S15 E63 03BB 1 CSVM-2 | 685,625 | 4,059,370 | 2,573 | Well-Carbonate | 1,400 | 720 to 1,380 | 7/9/2007 | 748 | 1,824 |
| 210-09 | 210 S13 E63 11BC 1 | 210 S13 E63 11BC 1 CSVM-6 | 686,453 | 4,078,333 | 2,252 | Well-Carbonate | 1,160 | 420 to 1,160 | 7/10/2007 | 433 | 1,819 |
| 210-10 | 210 S10 E62 25AD 1 | 210 S10 E62 25AD 1 CSVM-3 | 679,319 | 4,102,600 | 2,651 | Well-Carbonate | 1,200 | 380 to 1,180 | 7/9/2007 | 443 | 2,207 |
| 216-01 | 362846114495501 | 216 S17 E64 09DD 1 CRYSTAL WELL 2 | 694,146 | 4,039,284 | 2,069 | Well-Carbonate | 565 | 510 to 560 | 9/20/2006 | 257 | 1,812 |
| 216-02 | 216 S17 E64 10CC 1 | 216 S17 E64 10CC 1 Crystal Well 1 | 694,389 | 4,039,716 | 2,073 | Well-Carbonate | 497 | 442 to 492 | 9/20/2006 | 260 | 1,813 |
| 216-03 | 216 S17 E64 21CB 1 | 216 S17 E64 21CB 1 GV-RW1 | 692,928 | 4,036,645 | 2,069 | Well-Carbonate | 833 | 553 to 833 | 6/20/2006 | 257 | 1,813 |
| 216-04 | 362723114505401 | 216 S17 E64 21CBBD1 | 692,740 | 4,036,717 | 2,072 | Well-Carbonate | 575 | 510 to 575 | 6/12/1958 | 260 | 1,812 |
| 216-05 | GV-1 | GV-1 | 682,983 | 4,034,143 | 2,691 | Well-Carbonate | 1,400 | 1,040 to 1,380/ 1,140 to 1,180/ 1,240 to 1,280/ 1,340 to 1,380 | 7/11/2007 | 880 | 1,811 |
| 216-06 | Paiutes-M3 | Paiutes-M3 | 691,536 | 4,044,302 | 2,238 | Well-Carbonate | 670 | 630 to 670 | 10/15/2000 | 422 | 1,816 |
| 216-07 | GV-PW-WS1 | 216 S18 E63 05DA 1 GV-PW-WS1 | 683,007 | 4,031,434 | 2,498 | Well-Carbonate | 2,000 | 1,240 to 1,980 | 7/15/2002 | 684 | 1,814 |
| 216-08 | GV-DUKE-WS1 | GV-DUKE-WS1 | 686,197 | 4,029,178 | 2,248 | Well-Carbonate | 685 | 537 to 685 | 7/11/2007 | 435 | 1,813 |
| 216-09 | GV-DUKE-WS2 | GV-DUKE-WS2 | 686,185 | 4,029,177 | 2,249 | Well-Carbonate | 1,965 | 877 to 1944 | 7/11/2007 | 431 | 1,818 |
| 216-10 | GV-KERR | GV-KERR | 683,838 | 4,028,991 | 2,405 | Well-Carbonate | 1,145 | 700 to 1,145 | 2/15/1990 | 578 | 1,827 |
| 216-11 | GV-PW-MW1 | GV-PW-MW1 | 683,460 | 4,031,730 | 2,502 | Well-Carbonate | 1,500 | 900 to 1,500 | 7/11/2007 | 688 | 1,814 |
| 216-12 | GV-PW-MW2 | GV-PW-MW2 | 682,652 | 4,031,488 | 2,525 | Well-Carbonate | 1,500 | 940 to 1,500 | 7/11/2007 | 712 | 1,813 |
| 216-13 | 362507114572701 | 216 S18 E63 05AADB1 | 683,115 | 4,032,318 | 2,568 | Well-Carbonate | 1,979 | 1,197 to 1,979 | 6/13/2007 | 754 | 1,814 |
| 217-01 | 217 S17 E63 21DC 1 | 217 S17 E63 21DC 1 | 684,324 | 4,035,393 | 2,728 | Well-Carbonate | 1,434 | 1,434 to 2,480 | 6/15/2000 | 882 | 1,846 |
| 218-01 | 363427114472301 | 218 S16 E64 02ABCD1 TH-2 | 697,684 | 4,049,916 | 2,341 | Well-Carbonate | 0 | 50 to 1,200 | 8/21/2000 | 526 | 1,815 |
| 218-02 | 363245114480501 | 218 S16 E64 15AADD1 ECP-2 | 696,723 | 4,046,742 | 2,228 | Well-Carbonate | 139 | 139 to 1,228 | 8/21/2000 | 416 | 1,812 |
| 218-03 | 363147114474601 | 218 S16 E64 23BDBB1 TH-1 | 697,234 | 4,044,959 | 2,168 | Well-Carbonate | 0 | 50 to 1,100 | 8/21/2000 | 354 | 1,813 |
| 218-04 | PAIUTES-ECP1 | PAIUTES-ECP1 | 696,729 | 4,046,590 | 2,234 | Well-Carbonate | 1,125 | 600 to 701/ 701 to 1,125 | 7/15/2000 | 414 | 1,820 |
| 218-05 | PAIUTES-ECP3 | PAIUTES-ECP3 | 696,714 | 4,046,984 | 2,243 | Well-Carbonate | 74 | 74 to 1500 | 10/15/2000 | 429 | 1,814 |
| 218-06 | PAIUTES-M2 | PAIUTES-M2 | 695,836 | 4,040,876 | 2,109 | Well-Carbonate | 680 | 640 to 680 | 10/15/2000 | 297 | 1,812 |
| 219-01 | 364604114471301 | 219 S13 E64 35ACAA1 USGS-MX CE-DT-6 | 697,482 | 4,071,381 | 2,278 | Well-Carbonate | 325 | 325 to 937 | 11/1/2002 | 456 | 1,822 |
| 219-02 | UMVM-1 | UMVM-1 | 694,305 | 4,070,248 | 2,062 | Well-Carbonate | 1,780 | 960 to 1,760 | 7/10/2007 | 245 | 1,817 |

[a]Coordinates are in Universal Transverse Mercator, Zone 11, North American Datum of 1983.
[b]Elevations are in North American Vertical Datum of 1988.
[c]Sources: Ertec, 1981; Johnson, 2005; Luzier, 2003; McKay and Kepper, 1988; NDWR, 2004; SNWA Field Measurements; Thomas et al., 1986; USGS, 2004; USGS, 2007
[d]Calculated using last depth-to-water measurement.
[e]USGS, 2001 DEM

Carbonate wells located in the area of interest and where aquifer tests have been conducted include: test wells MX-4 (Map-ID 210-03) and MX-5 (Map ID 210-05), RW-1 (Map ID 216-03) and its observation well, Harvey Well, Well ECP-2 (Map ID 218-02), and Well TH-2 (Map ID 218-01). Tests wells MX-4 and MX-5 are located in Coyote Spring Valley within about 300 ft of each other. Transmissivities at test wells MX-4 and MX-5 have been reported by several authors (Bunch and Harrill, 1984, p. 119; IT Corporation, 1996, Appendix A; Dettinger et al., 1995, Table 5, p. 33). The average T values are 290,516 and 400,055 $ft^2$/day for MX-4 and MX-5, respectively. At the RW-1 test location, SRK Consulting, Inc., (2001, tbl 4) reports the following transmissivities: 326,900 $ft^2$/day (pumping) and 411,400 $ft^2$/day (recovery) using the observation data collected from Harvey Well; and 64,090 $ft^2$/day using data collected at the pumping well, RW-1. The mean transmissivity at this location is 267,456 $ft^2$/day. Transmissivities calculated for Well ECP-2 and Well TH-2 are 109,500 and 53,820 $ft^2$/day, respectively (Mifflin and Associates, 2001, Appendix A, p. 3-5). The average transmissivity for the area based on the five test sites is 224,269 $ft^2$/day.

A hydraulic gradient was calculated between monitor well CSVM-2 (Map ID 210-08) located in southern Coyote Spring Valley and monitor well GV-1 (Map ID 216-05), located in northern Garnet Valley. The wells have average potentiometric heads of 1,823.82 and 1,810.85 ft, respectively; based on more than 40 depth-to-water measurements each. The distance between the two wells is about 15.76 mi or 83,213 ft. Based on this information, a hydraulic gradient of 0.00016 ft/ft was calculated.

Outflow is assumed to occur across the southern boundary of Coyote Spring Valley. This boundary is crossed by several range-front faults, but the exact locations where flow occurs may not be identified with the available information. The length of the flow section was measured along a line that is approximately perpendicular to the north-to-south direction of flow hydraulic. Its length is estimated to be about 9.5 mi or 50,160 ft.

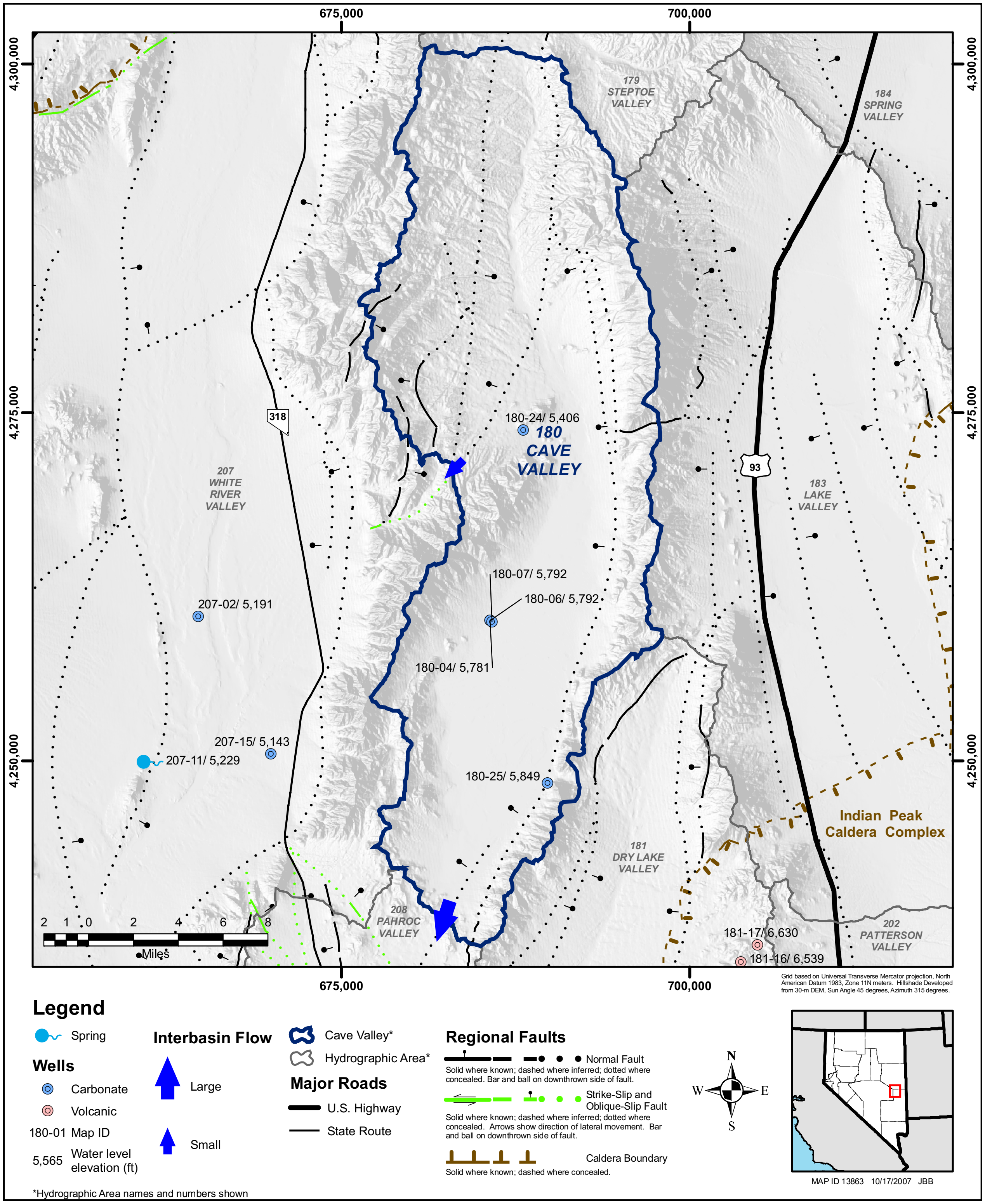
The groundwater outflow volume was calculated as the product of transmissivity, the hydraulic gradient and the flow width. The resulting estimated outflow volume is about 15,000 afy.

### D.2.2 Interbasin Flow among Cave, Dry Lake, and Delamar Valleys

The majority of the interbasin flow for Cave, Dry Lake, and Delamar valleys occurs as groundwater outflow from Cave Valley to the southern third of White River Valley and northern Pahroc Valley, and from southern Delamar Valley to northern Coyote Spring Valley and perhaps also to the very southern part of Pahranagat Valley. Also, a small amount of groundwater inflow to northern Dry Lake Valley likely occurs from northern Pahroc Valley. Elsewhere among these basins, interbasin flow is limited by geologic structure and lithology. The following sections describe the interbasin flow among these areas.

#### D.2.2.1 Cave Valley

Groundwater outflow from Cave Valley is thought to occur on the western side of Cave Valley through Shingle Pass to the southern third of White River Valley, and through the southern portion of the valley to northern Pahroc Valley (Figure D.2-2). Total outflow from Cave valley, which for this analysis is estimated to be about 13,400 afy, is estimated as the difference between natural recharge




Note: For an index of springs names and well IDs, see Table D.2-1.

**Figure D.2-2**
**Interbasin Flows and Water-Level Elevations of Selected Wells and Springs in Cave Valley and Vicinity**

and groundwater ET. The following sections describe the assumptions, data, and method by which this volume was partitioned to the interbasin flow locations.

### *D.2.2.1.1 Outflow to White River Valley through Shingle Pass*

Outflow from Cave Valley to the southern third of White River Valley occurs through fractured carbonate rock associated with the Shingle Pass Fault. The volume of outflow was approximated by equating it to the downgradient spring discharge minus the recharge from the contributing watersheds in White River Valley. The springs selected to derive this downgradient spring discharge volume are listed in Table D.2-2 and are depicted in Figure D.2-3. These springs were selected because they are cold-water springs (i.e., local springs) and have similar isotopic composition to springs in the Egan Range and Cave Valley. These are indications that the sources of their respective discharges are derived from local recharge. The total discharge from these springs is about 7,330 afy.

**Table D.2-2**
**Discharge Data for Selected Springs in White River Valley**

| Spring Name | Location | | Elevation (ft-amsl) | No. of Measurements[b] | Mean Annual Discharge (cfs)[b] | $\delta$D (‰)[c] |
|---|---|---|---|---|---|---|
| | UTM Easting[a] (m) | UTM Northing[a] (m) | | | | |
| Flag Springs 3 | 672,579 | 4,254,416 | 5,294 | 39 | 2.16 | -105 |
| Flag Springs 2 | 672,576 | 4,254,570 | 5,285 | 34 | 2.94 | NA |
| Flag Springs 1 | 672,719 | 4,254,697 | 5,294 | 35 | 2.29 | NA |
| Butterfield Spring | 673,530 | 4,256,472 | 5,324 | 39 | 2.73 | -105 |
| Shingle Spring | 679,925 | 4,267,716 | 6,434 | 2 | 0.003 | -104 |
| | | | | **Total** | **10.12 (7,327 afy)** | |

[a]North American Datum of 1983, Zone 11
[b]Data from Table C.1-1
[c]USGS, 2004

Based on the recharge analysis presented in Section 5.0, a recharge grid was derived and used as the basis to calculate the total recharge of the contributing watersheds in White River Valley. The recharge was calculated to be about 3,240 afy for the watersheds depicted in Figure D.2-3. It is assumed that the spatial distribution of recharge derived as part of the recharge analysis is sufficiently accurate for the purpose for which it is used here. However, it is acknowledged that the actual value for this area could be more or less, depending on the accuracy of the precipitation-recharge relationship defined in Section 5.0. The outflow from Cave Valley to White River Valley through Shingle Pass, calculated as the difference of the spring discharge and the recharge from the contributing watersheds, is estimated to be about 4,000 afy.

To check the validity of this approximation, the transmissivity value of the rocks comprising the presumed flow path was calculated by re-arranging Equation D.2-1 in the form:

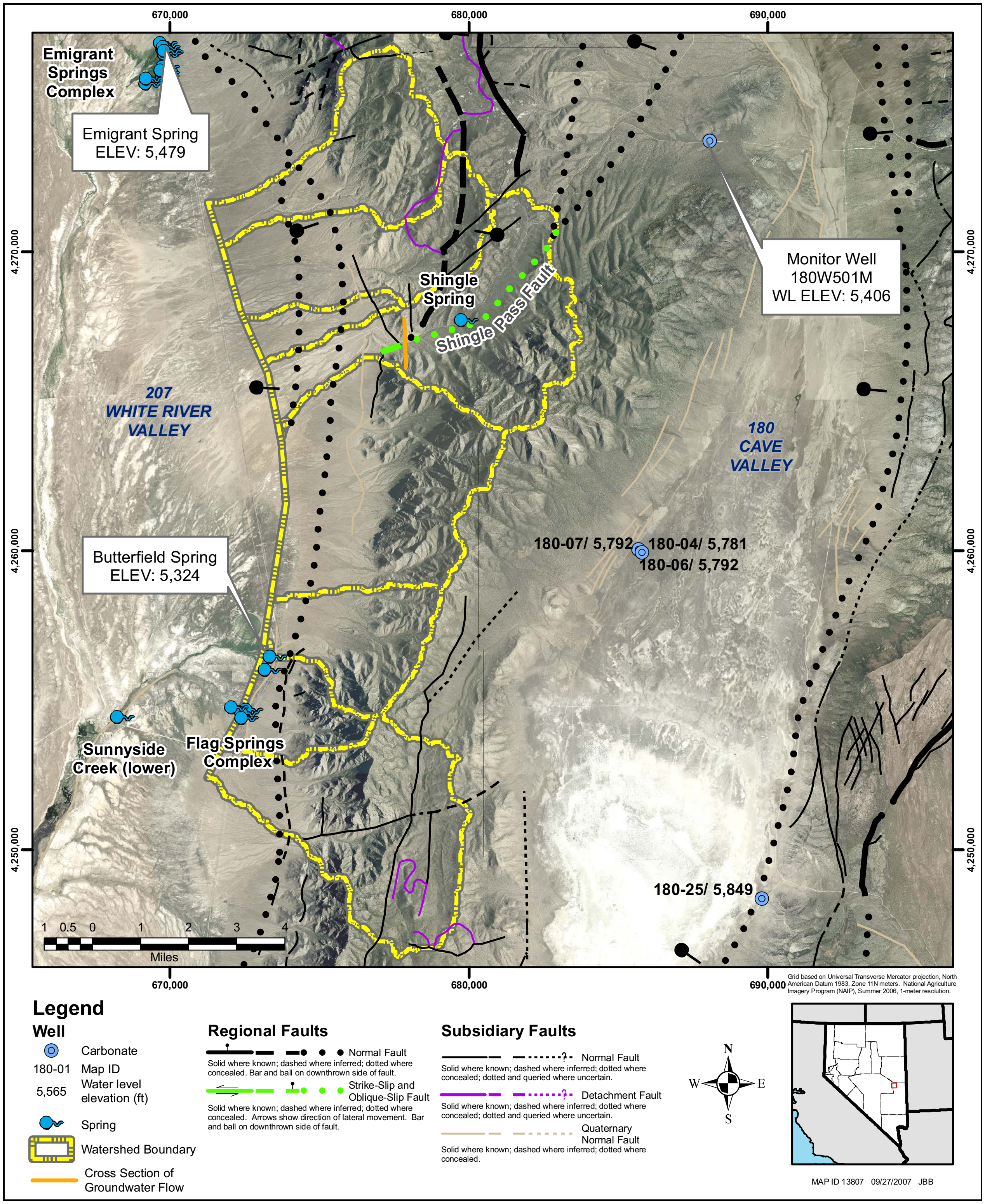



**Figure D.2-3**
**Watershed for Selected Springs in White River Valley**

$$T = \frac{Q}{IW} \times \frac{43,560}{365} \quad \text{(Eq. D.2-2)}$$

where,

Q = the groundwater flow (afy)
T = the transmissivity ($ft^2$/day)
I = the hydraulic gradient (ft/ft)
W = the estimated width of the section of flow (ft)

The hydraulic gradient was calculated using the following data: (1) the water-level elevation (5,406 ft-amsl) of Monitor Well 180W501M, recently drilled by SNWA and completed in carbonate bedrock east of Shingle Pass, (2) the elevation of Butterfield Spring (5,324 ft-amsl), and (3) the distance between the two locations of about 14 mi or about 74,000 ft (Figure D.2-3). The hydraulic gradient between these two locations was calculated to be 0.00111. The estimated length of the cross section of flow measured along the west entrance to Shingle Pass in White River Valley (Figure D.2-3) was estimated to be about one mile or 5,280 ft. Using these values, a transmissivity of 81,451 $ft^2$/day was calculated. This transmissivity value falls within the range of reported values. Dettinger et al. (1995) had reported a range of 10 to 250,000 $ft^2$/d for the carbonate wells of the region. Larger transmissivity values, as high as 410,000 $ft^2$/d (SRK Consulting, Inc., 2001, tbl 4), have been reported since, making the range wider. The calculated transmissivity calculated for the Shingle Pass is, however, on the high side of the range, which suggests that the estimated interbasin flow of 4,000 afy may also be on the high side.

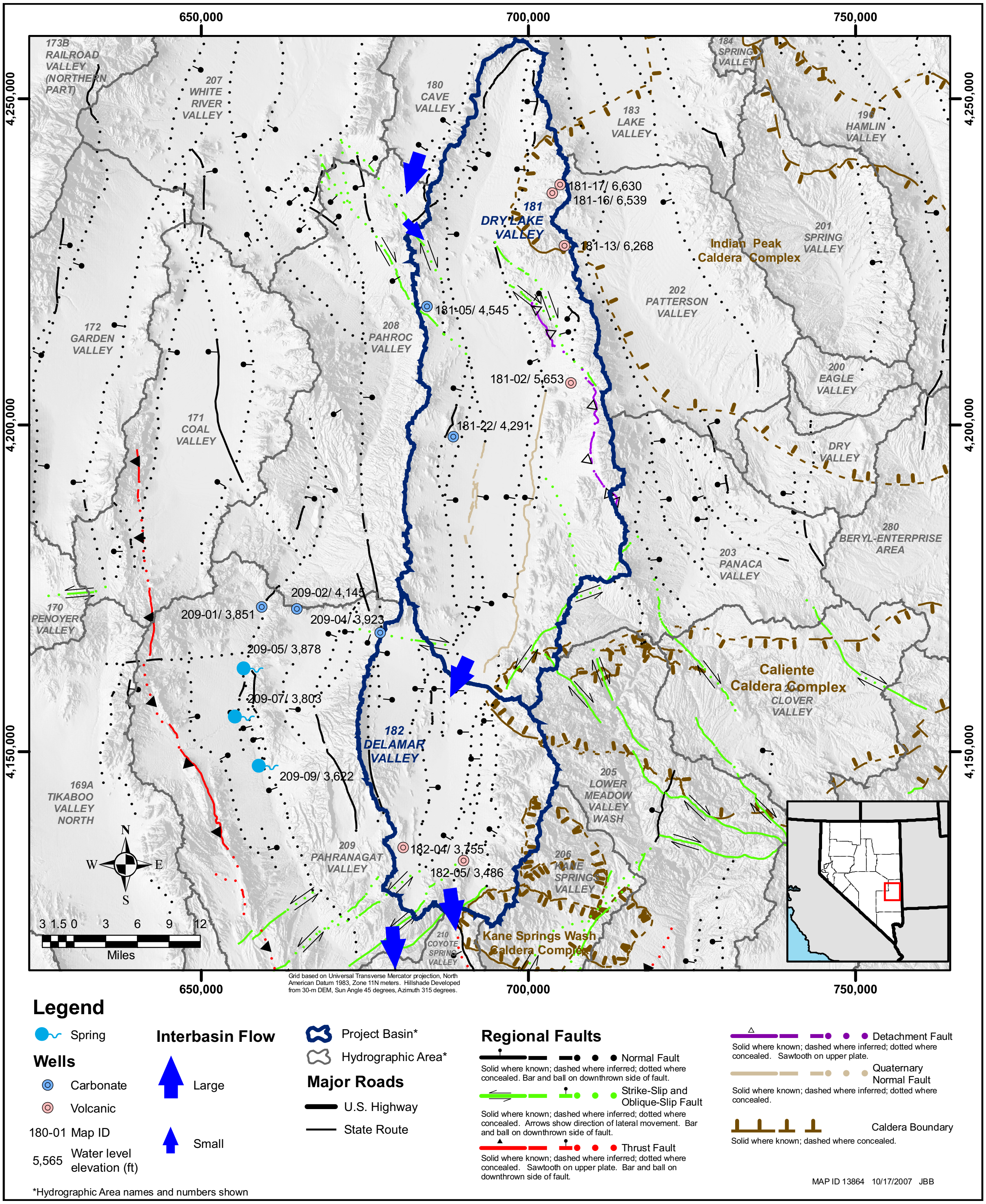
#### *D.2.2.1.2 Outflow to Northern Pahroc Valley*

Outflow from southern Cave Valley to the northeastern portion of Pahroc Valley occurs through fractured carbonate rock and along fault zones associated with the west range-front fault of the southern Schell Creek Range. With about 4,000 afy of the total 13,400 afy of Cave Valley outflow occurring through Shingle Pass, the outflow from southern Cave Valley is estimated to be the difference, or 9,400 afy.

### *D.2.3 Dry Lake and Delamar Valleys*

For Dry Lake Valley, interbasin flow occurs in the northern portion of the valley as inflow from northern Pahroc Valley and as outflow to Delamar Valley to the south (Figure D.2-4). Inflow from Pahroc Valley is estimated to be no more than 2,000 afy, while the outflow to Delamar Valley is estimated as the total of the inflow and natural recharge, or about 17,700 afy.

For Delamar Valley, interbasin flow occurs as inflow from Dry Lake Valley and as outflow to northern Coyote Spring Valley and possibly the very southern part of southern Pahranagat Valley (Figure D.2-4). The outflow is estimated as the sum of the inflow from Dry Lake Valley and the natural recharge derived from within the hydrographic area boundaries of both basins, or about 24,100 afy. Interbasin flow elsewhere among these basins is precluded by geologic structure and lithology, principally the Caliente and Kane Springs Wash caldera complexes to the east and




Note: For an index of springs names and well IDs, see Table D.2-1.

**Figure D.2-4**
**Interbasin Flows and Water-Level Elevations of Selected Wells and Regional Springs for Dry Lake and Delamar Valleys and Vicinity**

southeast and the North and South Pahroc ranges and associated range-front faults. The following sections describe the interbasin flow approximations in greater detail.

#### D.2.3.1 Inflow from Pahroc Valley

The approximate location of inflow from Pahroc Valley to Dry Lake Valley is depicted in Figure D.2-5 and is coincident with a series of northwest-trending, right-lateral faults that form the boundary between southern Cave Valley, northern Pahroc Valley, and northern Dry Lake Valley. These faults extend from southeastern White River Valley through northeastern Pahroc Valley and into Dry Lake Valley, where they transition into the east range-front fault of the North Pahroc Range.

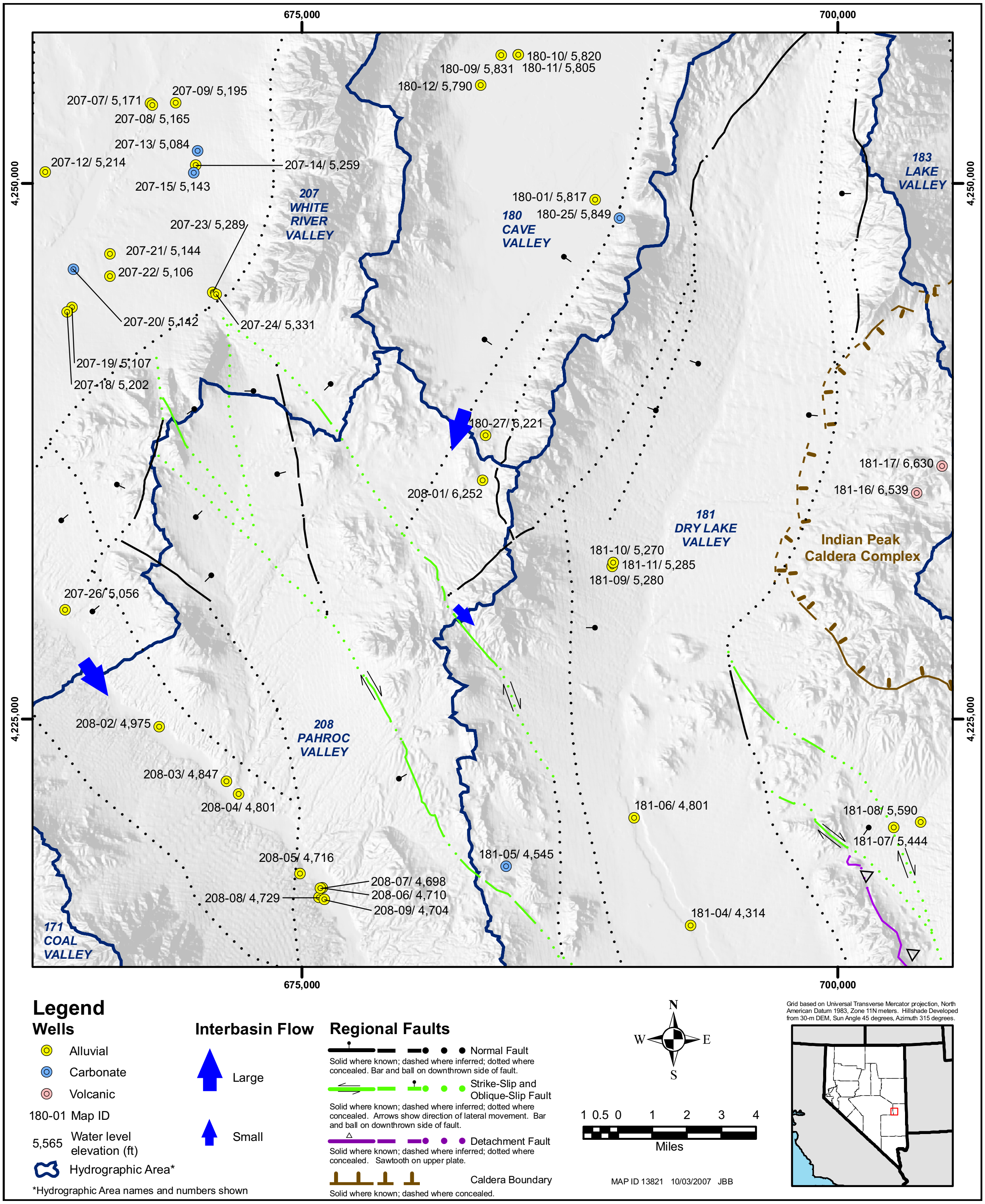
Water-level data are sparse in this area and are limited to shallow basin-fill wells in northern Pahroc Valley and the North Dry Lake MX Well (Table D.2-1). Based on water-level elevation data for the northern Pahroc Valley alluvial wells (about 4,800 ft-amsl) and the North Dry Lake MX well (about 4,540 ft-amsl) (Ertec Western, Inc., 1981), there is a difference in water-level elevation of about 200 to 300 ft between the two areas and groundwater systems. No carbonate-rock well data exists for this area of Pahroc Valley; however, nearby Well 207 N6E61 28DA1 in southeastern White River Valley (Map ID 207-20) is completed in the carbonate-rock aquifer and has a reported water-level elevation of 5,142 ft-amsl based on shut-in pressures from drill-stem testing (Thomas, 1986). This water-level elevation and that of the North Dry Lake MX well are indicative of a gradient in the carbonate-rock aquifer from southeastern White River Valley to northern Pahroc and Dry Lake valleys. However, groundwater flow is complicated by the local right-lateral fault structures, and given the lack of data, it is difficult to estimate how much groundwater might flow into northern Dry Lake Valley. Because there is a significant hydraulic gradient and accommodating structures, it is assumed that about 2,000 afy of groundwater flows from Pahroc Valley to northern Dry Lake Valley (Figure D.2-5).

#### D.2.3.2 Outflow from Dry Lake Valley to Delamar Valley

Outflow from Dry Lake Valley to northern Delamar Valley occurs through fractured carbonate rocks and valley-fill sediments. These two hydrographic areas are topographically separated by a low alluvial divide but are connected geologically and hydrologically, making them one contiguous basin. Based on water-level elevations from wells located within Dry Lake and Delamar Valleys, there is a north-south gradient, thus indicating outflow from Dry Lake Valley to Delamar Valley. Because there is no significant groundwater ET in Dry Lake Valley, the outflow is calculated as the sum of the inflow from Pahroc Valley and the locally derived natural recharge. This value is estimated to be about 17,700 afy. As in Dry Lake Valley, no significant groundwater ET occurs in Delamar Valley, and the outflow is calculated as the sum of the inflow from Dry Lake Valley, 17,700 afy, and the locally-derived natural recharge, about 6,400 afy, for a total of about 24,100 afy.

#### D.2.3.3 Outflow from Delamar Valley

Groundwater outflow from Delamar Valley is controlled by the Kane Springs Wash caldera complex underlying the Delamar Mountains to the southeast, the South Pahroc Range and western Delamar Mountains and associated range-front faults, and the southwest trending Pahranagat Shear Zone (Figure D.2-6). Regional flow through the caldera complex is unlikely, as the majority of flow occurs




Note: For an index of springs names and well IDs, see Table D.2-1.

**Figure D.2-5**
**Inflow from Pahroc Valley to Northern Dry Lake Valley**

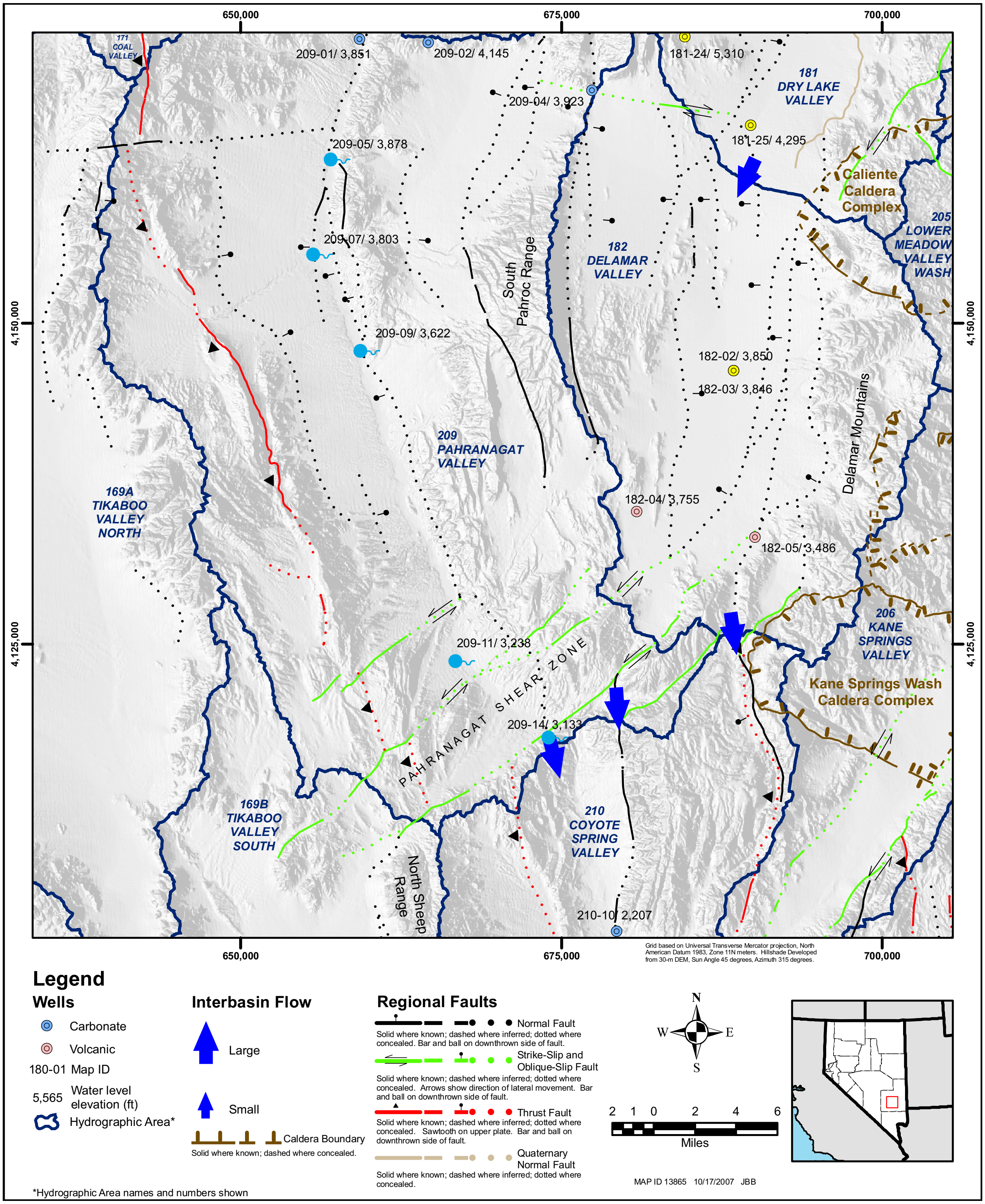



**Figure D.2-6**
**Delamar and Pahranagat Valleys and the Pahranagat Shear Zone**

along the range-front faults and the northeast extension of the Pahranagat Shear Zone to areas of lower potential in northern Coyote Spring Valley and possibly the very southern part of Pahranagat Valley. The range-front faults transition into right-lateral shear zones as they pass through southern Pahranagat Valley and become normal faults on the eastern side of the Sheep Range. Water-level elevation data from the few wells and springs in Delamar Valley and the adjacent areas of southern Pahranagat and northern Coyote Spring valleys indicate a hydraulic gradient to the southwest and south along and across the Pahranagat Shear Zone and into northern Coyote Spring Valley.

SNWA monitor wells 182M-1 and 182W906M, recently drilled to depths of 1,345 and 1,735 ft-bgs, respectively, in southern Delamar Valley, have water-level elevations of 3,755 and 3,486 ft-amsl, respectively (Figure D.2-6). Both wells are completed in volcanic rocks (Hiko Tuff) comprising the valley fill. Monitor Well 182M-1 is located north of the Pahranagat Shear Zone on the southwest side of the valley, while Monitor Well 182W906M is located near the west range-front fault of the Delamar Mountains and within the trace of the Pahranagat Shear Zone. Water levels in both wells are most likely representative of the local groundwater system rather than the regional potential of the carbonate-rock aquifer. A comparison of their water-level elevations with elevations of the springs in southern Pahranagat Valley and wells in Coyote Spring Valley completed in the carbonate-rock aquifer, reveals a significant hydraulic potential between these areas. Spring elevations in southern Pahranagat Valley range in elevation from about 3,240 ft-amsl at Solar Panel Spring to about 3,133 ft-amsl at Maynard Spring. This represents a hydraulic potential of at least 350 ft from southern Delamar Valley to southern Pahranagat Valley.

SNWA's monitor well CSVM-3 in northern Coyote Spring Valley is completed to 1,230 ft-bgs in the carbonate-rock aquifer and has a water-level elevation of 2,207 ft-amsl (Figure D.2-6). The nearest location reflecting the potentiometric level the carbonate-rock aquifer is the elevation of Ash Springs, in central Pahranagat Valley, which emerges from carbonate rocks (Sevy Dolomite) coincident with the north-trending range front. Ash Springs is about 30 mi from Monitor Well CSVM-3 at an elevation of 3,622 ft-amsl. This represents a potential in the carbonate-rock aquifer of about 1,400 ft from central Pahranagat Valley to northern Coyote Spring Valley. When compared to the SNWA monitor wells in Delamar Valley, the hydraulic potential is even greater, ranging from about 1,550 to 1,280 ft.

Based on the conceptualization of flow and the supporting hydraulic head data, groundwater flow is to the south and southwest from Delamar Valley along the strike of the Pahranagat Shear Zone. The large hydraulic head differences between Delamar and Pahranagat valleys and Coyote Spring Valley suggest that there is potential for significant flow from these areas and across the shear zone to Coyote Spring Valley. The flow is controlled principally by the shear zone, for which hydraulic properties are unavailable making an estimate of the flow using Darcy's Law unrealistic. However, a transmissivity value representing the hydraulic properties across the shear zone was calculated using Equation D.2-2 and the estimated outflow to Coyote Spring Valley derived in Section 5.0. This value was compared to the range of transmissivity values compiled for the carbonate-rock aquifer to determine where within the range the value falls. Values used in the calculation are as follows: (1) 46,500 afy of total outflow from Pahranagat and Delamar valleys to Coyote Spring Valley, (2) a hydraulic gradient of 0.00893 ft/ft based on the water-level elevations for Ash Springs and Monitor Well CSVM-3, and (3) a cross section of flow of about 125,000 ft (23.7 mi), equal to the length of the shear zone from the northeast Sheep Range to the west range-front fault of the Delamar Mountains.

The calculated transmissivity value is 4,972 $ft^2$/day, or about 5,000 $ft^2$/day. As expected, this value falls at the low end of the range (10 to 419,000 $ft^2$/day [Dettinger, 1995, p 15-17; SRK Consulting Inc., 2001, tbl. 4]), and represents a reasonable average transmissivity for flow across the shear zone. It is likely that transmissivity is locally substantially higher or lower given the geologic variability within the shear zone.

# D.3.0 WRFS BOUNDARY FLOW

The majority of the WRFS boundary inflow and outflow occurs in the southern portion of the flow system as inflow from Lower Meadow Valley Wash and as outflow to the Colorado River. Minor amounts of outflow from southwestern Long Valley to Newark Valley (Harrill et al., 1988; Thomas et al., 1986) and from Garden Valley to Penoyer Valley might occur based on hydraulic head potential (San Juan et al., 2004; Chapter C, p. 119). Elsewhere, boundary flow is limited by geologic structure and lithology. The boundary flow in the southern portion of the flow system is discussed in the following sections.

## D.3.1 Inflow from Lower Meadow Valley Wash

Groundwater inflow from Lower Meadow Valley Wash occurs through the underlying valley-fill sediments and carbonate rocks. The magnitude of this flow has been estimated by Rush (1968, p. 24), Kirk and Campana (1990, p. 372; Thomas et al., 1996, p. C36), Prudic et al. (1995, p. D71), and Thomas et al. (1996, p. C36) at 7,000 afy, 5,500 to 9,000 afy, 13,000 afy, and 8,000 afy respectively. For this analysis, it was assumed that about 9,200 afy of groundwater inflow from Lower Meadow Valley Wash enters California Wash and the Muddy River Springs Area. This value represents the average of the estimates.

### D.3.1.1 Inflow to California Wash

Gage records and miscellaneous discharge measurements for the Muddy River support groundwater inflow from Lower Meadow Valley Wash. Two synoptic discharge measurement studies indicate an apparent 2 to 2.5 cfs increase in streamflow along the river reach extending from the White Narrows to Jackman Narrows (Figure D.3-1). Rush (1968, p. 13 and 15) reports measurements from a February 5, 1968, study in which the gage flow above White Narrows was 46.6 cfs, while a measurement made minutes later above Jackman Narrows near Glendale was 48.3 cfs. On February 6, 1968, measurements were made at three sites: near Glendale, at Jackman Narrows, and at a site about 1 mi below Jackman Narrows. Flow rates of 48, 54, and 47.8 cfs, respectively, were recorded at these sites. Based on this study, the net gain from above White Narrows to Jackman Narrows is about 7.4 cfs, or 5,350 afy. Rush (1968) suggests that the observed increase in flow is likely due to inflow from alluvial sediments and/or underlying consolidated rocks, namely the carbonate-rock aquifer.

A second and more recent study corroborates the findings of Rush (1968). Beck and Wilson (2006) describe the results of a synoptic discharge study for the same river reaches described by Rush (1968). This study was conducted during February 7, 2001 and involved many of the same

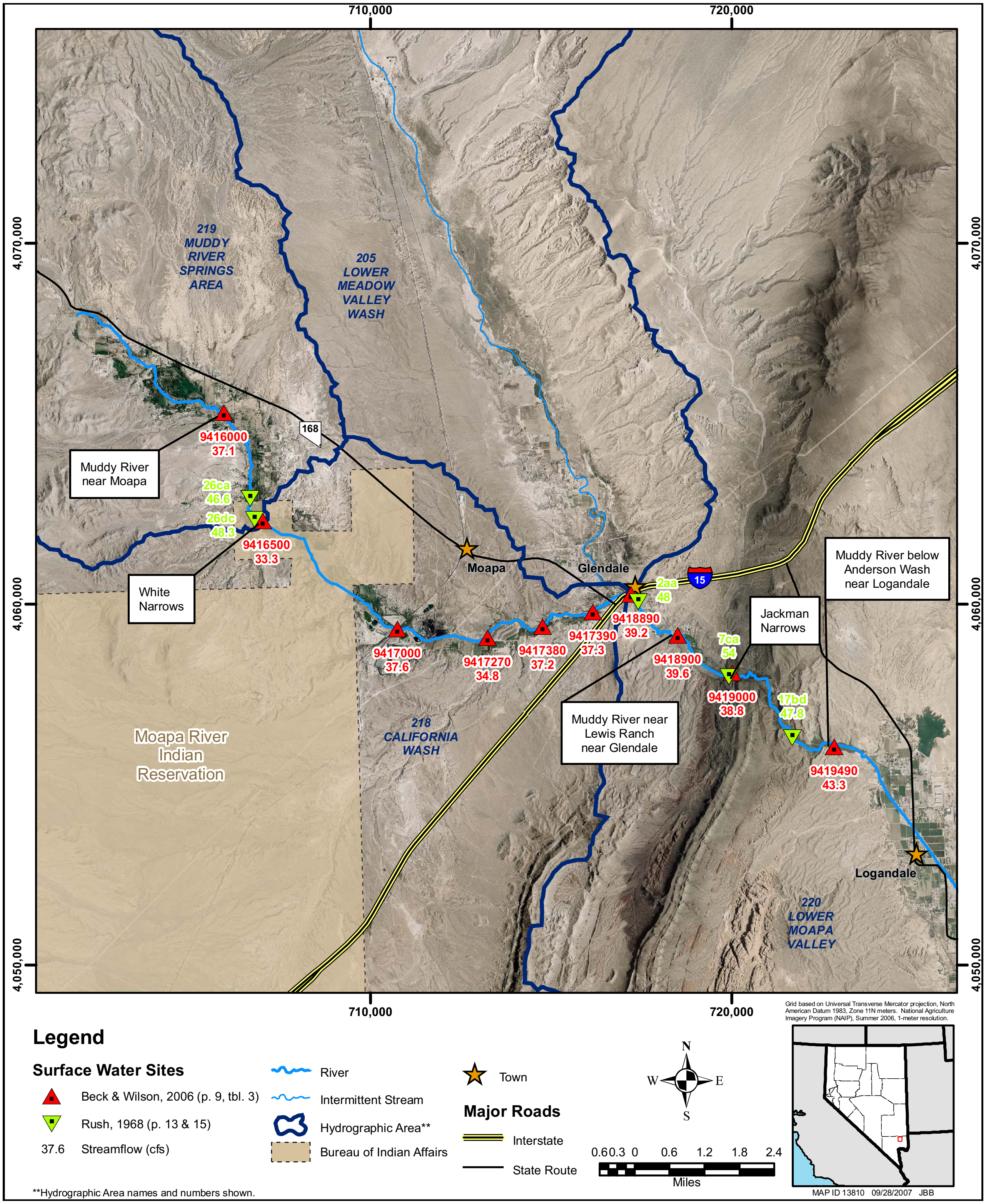



**Figure D.3-1**
**Two Sets of Synoptic Discharge Measurements along Muddy River**

measurement sections. For essentially the same reach (from White Narrows to Jackman Narrows near Glendale), the river gained about 2.5 cfs based on the maximum values of the gage record for the Muddy River near Moapa gage (09416000) and the measurement section at Muddy River near Lewis Ranch near Glendale (09418900). Maximum flow rates at these sites were measured at 37.1 cfs and 39.6 cfs, respectively (Beck and Wilson, 2006 p. 9, Tbl. 3). From station 09418900 to the Muddy River below Anderson Wash near Logandale gage (09419490), an apparent increase in flow of 3.7 cfs was observed. In total, from the Muddy River near Moapa gage to the Muddy River below Anderson Wash near Logandale gage, an apparent increase in flow of 6.2 cfs was observed, or about 4,500 afy.

Based on these studies and because of the location of the gaining reaches, the increases in flow observed in the river are, in part, a result of groundwater outflow from Lower Meadow Valley Wash to California Wash. For this study, this flow is estimated to be about 5,200 afy.

#### *D.3.1.2 Inflow to Muddy River Springs Area*

The remaining outflow from Lower Meadow Valley Wash of about 4,000 afy flows to the Muddy River Springs Area through fractured carbonate rocks and accommodating structures associated with the east range-front fault of the Meadow Valley Mountains. This water is mostly consumed by local ET in the Muddy River Springs Area. Total groundwater discharge (spring discharge, groundwater ET, and underflow) from this area during predevelopment conditions is estimated to be at least 40,000 afy based on (1) the average annual flow of the Muddy River (adjusted for precipitation runoff events) of 33,700 afy at the Muddy River near Moapa gage (09416000) (Eakin, 1964, p. 24), and (2) an estimate of predevelopment groundwater ET of 6,000 afy.

### *D.3.2 Outflow to Colorado River*

Outflow from the WRFS to the Colorado River occurs as spring discharge from the Muddy Springs, Rogers and Blue Point springs, and subsurface outflow from Lower Moapa Valley. The outflow to the Colorado River from Lower Moapa Valley has been estimated to be between 11,100 afy (Rush, 1968, p. 24 tbl. 5, p. 26 tbl 7) and 49,000 afy (LVVWD, 2001). The estimate of Rush (1968) includes an estimate of Muddy River streamflow that represents the total flow, including some unquantified contribution of surface runoff from precipitation events. Estimates for this study are based on gage records of Muddy River discharge, including miscellaneous discharge measurements and the Muddy River near St. Thomas, Nevada, gage, and an estimate of subsurface outflow from Lower Moapa Valley. For this analysis, it is estimated that groundwater outflow from the WRFS to the Colorado River, including the groundwater component of the measured flows at the Muddy River near St. Thomas gage, is less than 25,000 afy.

#### *D.3.2.1 Black Mountains Area/Rogers and Blue Point Springs*

The Black Mountains Area is bounded by the Colorado River (Lake Mead) in the east, the Black Mountains in the southwest, and the Muddy Mountains in the northwest. The most dominant features are the Muddy Mountains, Bitter Spring Valley, and the large washes of Gypsum, Callville, Echo, and Valley of Fire. Rogers and Blue Point springs are located in the eastern portion of the hydrographic area and discharge to the Colorado River (Figure D.3-2). From water year (WY) 1986 to WY2006,

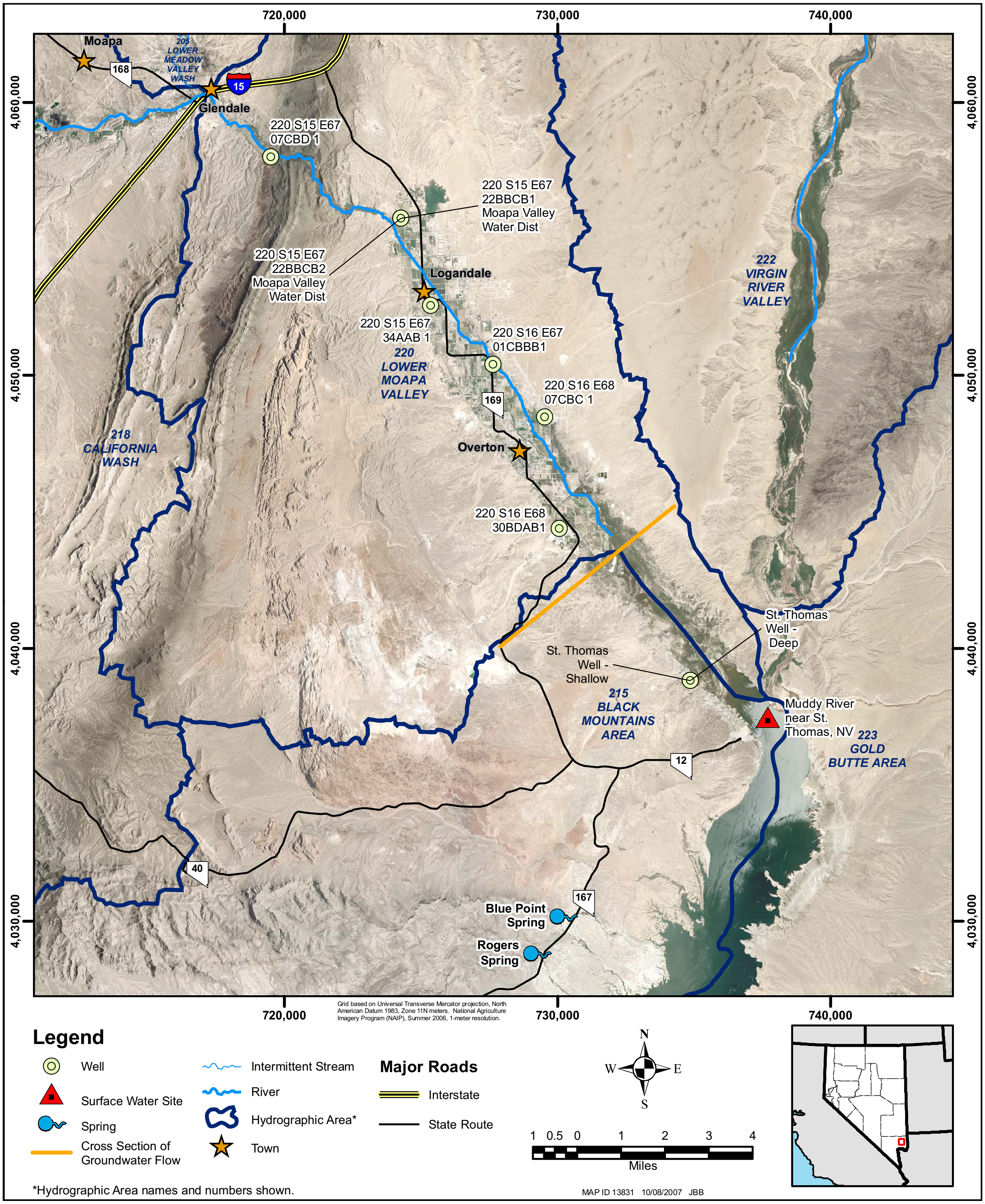



**Figure D.3-2**
**Measurement Sites along the Muddy River in Lower Moapa Valley**

the mean annual discharge of Rogers Spring was 1.66 cfs (USGS, 2006). The mean annual discharge reported for Blue Point Springs for the period of WY 2000 to WY 2006 was 0.55 cfs. The combined average annual discharge for the two springs is about 2.21 cfs, or about 1,600 afy. An additional 400 afy of groundwater outflow to the Colorado River from the Black Mountains Area is assumed to account for any underflow or additional spring discharge in the area. Therefore, the total groundwater discharge from the Black Mountains Area is estimated to be about 2,000 afy.

### *D.3.2.2 Outflow from Lower Moapa Valley*

#### *Muddy River at St. Thomas, Nevada (1913 to 1916)*

The Muddy River near St. Thomas gaging station was located just upstream from the confluence of the Muddy and Virgin Rivers. Because of its early record and location with respect to the Colorado River, the gage records for this station were most representative of predevelopment conditions of flow from the Muddy River to the Colorado River. The flow at this location during the period of record had flow contributions from (1) surface-water runoff related to precipitation events, (2) groundwater discharge from the Muddy River Springs Area, and (3) inflow from California Wash.

The gage records began in June of WY 1913 and ended in September of WY 1916, during which time there was a 7-month period of missing records (June of WY 1915 to December of WY 1916) (Wells, 1954, p. 570). The mean-annual flow for the only complete year (WY 1914) was 19.3 cfs, or about 14,000 afy (Wells, 1954, p. 570). The period of record mean annual flow was calculated to be 19.6 cfs based on the mean monthly values; however, this value reflects large flood events during February of WY 1914 (136 cfs). If this value is excluded, the period of record mean annual discharge is 17.5 cfs, or almost 13,000 afy. Rush (1968, p. 24, tbl. 5) estimated this flow to be 10,000 afy, but qualified the estimate as a rough approximation based on few data gathered in 1967. This flow most likely represented agricultural return flows.

At the confluence with the Virgin River, discharge from the Muddy River was observed during this period; however, it is impossible to determine the magnitude of the groundwater component given the limitations of the gage records. For this analysis, it is estimated that about half of the flow was groundwater discharge, or 7,000 afy.

#### *Subsurface Outflow from Lower Moapa Valley to the Colorado River*

Groundwater outflow via the subsurface from Lower Moapa Valley to the Colorado River has the greatest uncertainty of the outflow components due to the lack of hydraulic information related to the basin-fill aquifer(s) underlying the valley floor. Rush (1968) estimated an outflow of 1,100 afy from the alluvial basin but did not report an estimate for the consolidated rocks. Specific capacity data for wells within the valley indicate that the underlying materials are transmissive. Moapa Valley Water District (MVWD) constructed a production well (Well No. 1) completed in bedrock (sandy limestone) to 154 ft-bgs near Logandale, Nevada. This well had a specific capacity of 105 gpm/ft (Rush, 1968, Table 19). A second MVWD well (Well No. 2) was constructed and completed in bedrock (porous limestone) to a depth of 154 ft-bgs and had a specific capacity of 24 gpm/ft (Figure D.3-2). An estimate of groundwater outflow to the Colorado River was derived using Equation D.2-1.

The transmissivity value was approximated by multiplying the specific capacity by 2,000 (Driscoll, 1986). Using the average for the two MVWD wells, a transmissivity value of 129,000 gpd/ft, or 17,000 $ft^2$/day was calculated. This value falls within the reported range of 0.02 to 64,600 $ft^2$/day for the basin-fill aquifer in the region (Belcher et al., 2001, Appendix A).

An average hydraulic gradient between Lower Moapa Valley and the Colorado River was estimated using the available water-level data. Well data selected for use in this calculation are presented in Table D.3-1.

**Table D.3-1**
**Selected Wells Located in Lower Moapa Valley and Black Mountains Area near the Muddy River**

| Site ID | Well Name | Land Surface Elevation (ft-amsl) | Depth-to-Water Measurements | | | Mean Head Elevation (ft-amsl) |
|---|---|---|---|---|---|---|
| | | | Date | Depth (ft-bgs) | Mean Depth (ft-bgs) | |
| 363832114323801 | 220 S15 E67 07CBD 1 | 1,502.2 | 3/14/1985 | 21.20 | 21.6 | 1,480.6 |
| | | | 3/28/1990 | 21.90 | | |
| 363715114292901 | 220 S15 E67 22BBCB1 MVWD | 1,412.1 | 4/10/1967 | 22.00 | 22.0 | 1,390.1 |
| 363531114284801 | 220 S15 E67 34AAB 1 | 1,357.1 | 12/11/1966 | 6.00 | 7.2 | 1,349.9 |
| | | | 3/14/1985 | 8.36 | | |
| 363419114271901 | 220 S16 E67 01CBBB1 | 1,312.1 | 11/09/1949 | 9.00 | 8.0 | 1,304.1 |
| | | | 5/11/1950 | 7.82 | | |
| | | | 11/10/1967 | 5.70 | | |
| | | | 3/14/1985 | 9.26 | | |
| 363315114260501 | 220 S16 E68 07CBC 1 | 1,282.1 | 1/01/1950 | 9.00 | 9.9 | 1,272.2 |
| | | | 3/14/1985 | 10.82 | | |
| 363102114254801 | 220 S16 E68 30BDAB1 | 1,252.1 | 2/08/1948 | 23.00 | 21.4 | 1,230.7 |
| | | | 3/14/1985 | 19.88 | | |
| St. Thomas Well - Shallow | St. Thomas Well - Shallow | 1,174.0 | 1915 | 30.00 | 30.0 | 1,144.0 |
| St. Thomas Well - Deep | St. Thomas Well - Deep | 1,174.0 | 1915 | 284.00 | 284.0 | 890.0 |
| St. Thomas Well - Average | St. Thomas Well - Average | 1,174.0 | 1915 | 157.00 | 157.0 | 1,017.0 |

Sources: Carpenter (1915, p. 63); NDWR Driller's Logs; USGS NWIS Database

Water-level data available for the Lower Moapa Valley and the Black Mountains Area near the confluence of the Muddy River with the Colorado River were compiled and evaluated. Data for 49 wells are available for Lower Moapa Valley but only 6 of the 49 wells have more than one depth-to-water measurement. The six wells with at least two measurements were extracted from the dataset and sorted from north to south along the main direction of flow. Two of the six wells had exactly the same coordinates and virtually the same water level, so one (220 S16E6830BDAB1) of these two wells was eliminated from the hydraulic gradient computation. The well used to estimate the transmissivity (MVWD Well No. 1) was added to the short list of selected wells in Lower Moapa Valley.

A well near St. Thomas was drilled by the San Pedro, Los Angeles and Salt Lake Railroad to a total depth of 805 ft (Carpenter, 1915, p. 63). Two measurements were reported this well. During drilling, the first water was encountered at 30 ft-bgs. At this point, the hole was cased off and the well was drilled to 805 ft-bgs. At the time, the depth to water was 284 ft bgs. The mean depth-to-water was used to represent this well in the analysis.

The wells were ordered from north to south in the main direction of flow, and hydraulic gradients were calculated for each pair of wells starting from the northernmost well. The calculations are shown in Table D.3-2. An average hydraulic gradient was calculated using wells located in the lowlands of Lower Moapa Valley along the main direction of flow. The average water level for the St. Thomas well was used in the analysis. The resulting average hydraulic gradient in the valley-fill aquifer along the main axis of Lower Moapa Valley is about 0.00432.

The section of flow was identified on a hydrolgeologic map and projected on a line perpendicular to the direction of flow. The width of the projected section of flow was estimated to be 26,500 ft, and is approximately depicted on Figure D.3-2. The volume of subsurface outflow to the Colorado River was estimated using a transmissivity of 17,000 $ft^2$/day, a hydraulic gradient 0.00432, and a flow section width of about 26,500 ft. The estimated volume of outflow is about 16,000 afy.

**Table D.3-2**
**Hydraulic Gradient Calculations in Lower Moapa Valley and Black Mountains Area**

| Site ID | Well Name | Distance between Wells (ft) | Mean Depth to Water (ft) | Mean Head Elevation (ft-amsl) | Head Difference (ft) | Hydraulic Gradient (ft/ft) |
|---|---|---|---|---|---|---|
| 363832114323801 | 220 S15 E67 07CBD 1 | – – | 21.55 | 1,480.6 | – – | – – |
| 363715114292901 | 220 S15 E67 22BBCB1 Moapa Valley Water District | 17,266 | 22.00 | 1,390.1 | 90.473 | 0.00524 |
| 363531114284801 | 220 S15 E67 34AAB 1 | 11,039 | 7.18 | 1,349.9 | 40.190 | 0.00364 |
| 363419114271901 | 220 S16 E67 01CBBB1 | 10,284 | 7.95 | 1,304.2 | 45.778 | 0.00445 |
| 363315114260501 | 220 S16 E68 07CBC 1 | 8,853 | 9.91 | 1,272.2 | 31.956 | 0.00361 |
| 363102114254801 | 220 S16 E68 30BDAB1 | 13,525 | 21.44 | 1,230.7 | 41.539 | 0.00307 |
| St. Thomas Well - Average | St. Thomas Well - Average | 36,032 | 157.00 | 1,017.0 | 213.67 | 0.00593 |

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# Appendix E

# Description of Excel Analysis Files (CD-ROM Contents)

# E.1.0 Introduction

The purpose of this appendix is to describe in detail the calculations conducted in support of the data analyses related to the water resource assessment of the WRFS. The objectives of the calculations were to: (1) derive a spatial distribution of precipitation recharge for the WRFS using the water-balance method, (2) derive basin groundwater budgets, and (3) evaluate the solution through uncertainty analysis. The descriptions are organized based on the Excel files containing the calculations and provided with the report. These files consist of one file containing the solution and several files containing the uncertainty analyses. For hard copies of the report, the Excel files are included on a CD enclosed with the document. In the electronic version of the document, the files are in a companion zip file named “SNWA-WRFS-Excel-Analysis-Files.zip.”

The files are provided for the sole purpose of documentation of the analyses. In essence, the solution file contains a calibrated groundwater budget model for the WRFS. Any changes to the target value, the initial estimates of the parameters, or the constraints may immediately change the water budgets, and may yield a different solution or no solution at all if the solver is executed. Similarly, the uncertainty analysis files contain solutions to scenarios where a specific variable was selected and carefully altered to test its effect on the solution. Consequently, the reader should not alter the contents of the files unless they thoroughly understand their setup and have good knowledge about the WRFS. The uncertainty files constitute good examples of how the solution file may be altered and still yield a meaningful solution, yet perhaps unrealistic in some cases.

# E.2.0 Solution File

The Excel file containing the recharge solution and associated groundwater budget is named: “SNWA-WRFS-Groundwater-Budget-Solution.” A description of its contents and the solution process are provided in the following text.

## E.2.1 File Contents

The solution file includes four worksheets named as follows:

- Worksheet 1: “1-Explanation”
- Worksheet 2: “2-Groundwater-ET-Estimates”
- Worksheet 3: “3-Precipitation-Recharge-Details”
- Worksheet 4: “4-Solution”

Descriptions of each of the four worksheets follows.

#### *E.2.1.1 Worksheet 1 - "1-Explanation"*

The "explanation" worksheet contains a brief description of the file and its contents.

#### *E.2.1.2 Worksheet 2 - "2-Groundwater-ET-Estimates"*

This worksheet contains a table listing the groundwater ET volumes for each of the HAs of the WRFS, as estimated by this study. The sum of the groundwater ET volumes for all HAs in the flow system is used as the target in the solver window that can be activated from the solution worksheet (see solution process in Section E.2.2). The table contains the following fields:

- HA: Hydrographic Area Number used by Nevada State Engineer - HA is surrogate for groundwater basin in this report.
- SNWA GW ET: Groundwater ET estimate for HA in acre-feet per year derived as part of this study and forms the main basis for the solution. Details are provided in Section 4.0 of this report.
- SNWA/BARCASS GW ET: Groundwater ET estimate for HA in acre-feet per year. Consists of BARCASS (Welch and Bright, 2007) estimates for the northern basins (Long, Jakes, White River, and Cave valleys), and SNWA estimates (SNWA GW ET) for the southern basins derived as part of this study.
- Recon GW ET*: Groundwater ET estimate reported for HA in Reconnaissance reports. Star (*) refers to footnote which provides sources of estimates. Estimates are provided here for comparison purposes only.
- LVVWD (2001): Groundwater ET estimate reported for HA in report published by LVVWD in 2001 in support of SNWA's Water-Right Hearing for Spring Valley, Nevada. Estimates are provided here for comparison purposes only.

#### *E.2.1.3 Worksheet 3 - "3-Precipitation-Recharge-Details"*

This worksheet fulfills two roles: (1) it contains the precipitation data which serves as input data to the solution, and (2) contains the recharge calculations performed by the solver during the solution process. All calculations are performed by built-in formulas using the solution derived in worksheet 4. This worksheet should, therefore, not be altered by the user. A description of the table contents is provided, followed by an explanation of the process used to generate them.

##### *E.2.1.3.1 Table Contents*

Each row in the table contains information for the mid-interval precipitation value of 1-in. precipitation bands or zones, sorted by HA. The table contains the following information:

- HA Name: This is the name of the hydrographic area used by the Nevada State Engineer.

- HA Number: This is the number of the hydrographic area used by the Nevada State Engineer.
- Precipitation Rate: This is the middle precipitation value of 1-in. precipitation bands in inches. The generation process is described in Section E.2.1.3.2.
- Precipitation Band Area: This is the area (in acres) of a 1-in. precipitation band for a given basin. The generation process is described later in this section.
- Precipitation Volume: This field contains the volume of precipitation for a 1-in. band in afy within a given basin. It is obtained by multiplying the values in the previous two columns.
- Recharge Efficiency: The values in this field are extracted from the recharge efficiency table calculated during the solution process using the power function and the selected precipitation "values." The recharge efficiency table is located in the "solution worksheet" and is described later in the text.
- Recharge in afy: This field contains the recharge volume of a 1-in. precipitation band. It is the product of multiplying the "Precipitation Volume" by the "Recharge Efficiency."

#### *E.2.1.3.2 Generation of Precipitation Data*

The precipitation data serves as the basis for the solver calculations and the derivation of the spatial distribution of recharge. The precipitation values in the table were generated using ArcMap 9.2 as follows:

1. The process was initiated from the 800-m PRISM grid (Figure E.2-1A).
2. The 800-m PRISM grid was contoured to generate 1-in. contour lines (Figure E.2-1B). Two consecutive contour lines represent a 1-in. precipitation band.
3. The 1-in. precipitation bands were converted to polygons (Figure E.2-1C).
4. Additional contour lines were added midway between each two consecutive contour lines (Figure E.2-1D). These middle-of-the-band contour lines are used as "values" representing the bands.
5. "Areas of no recharge," which include the union of the valley floors, the less-than-8-inch-precipitation areas, and the groundwater ET areas, were then removed from the resulting precipitation map.
6. A table of precipitation "values" was generated starting from a minimum precipitation of 3 in. to the maximum precipitation occurring within the flow system.
7. The surface areas of each precipitation interval in each HA were calculated using the operation "Calculate Geometry" in ArcMap 9.2.

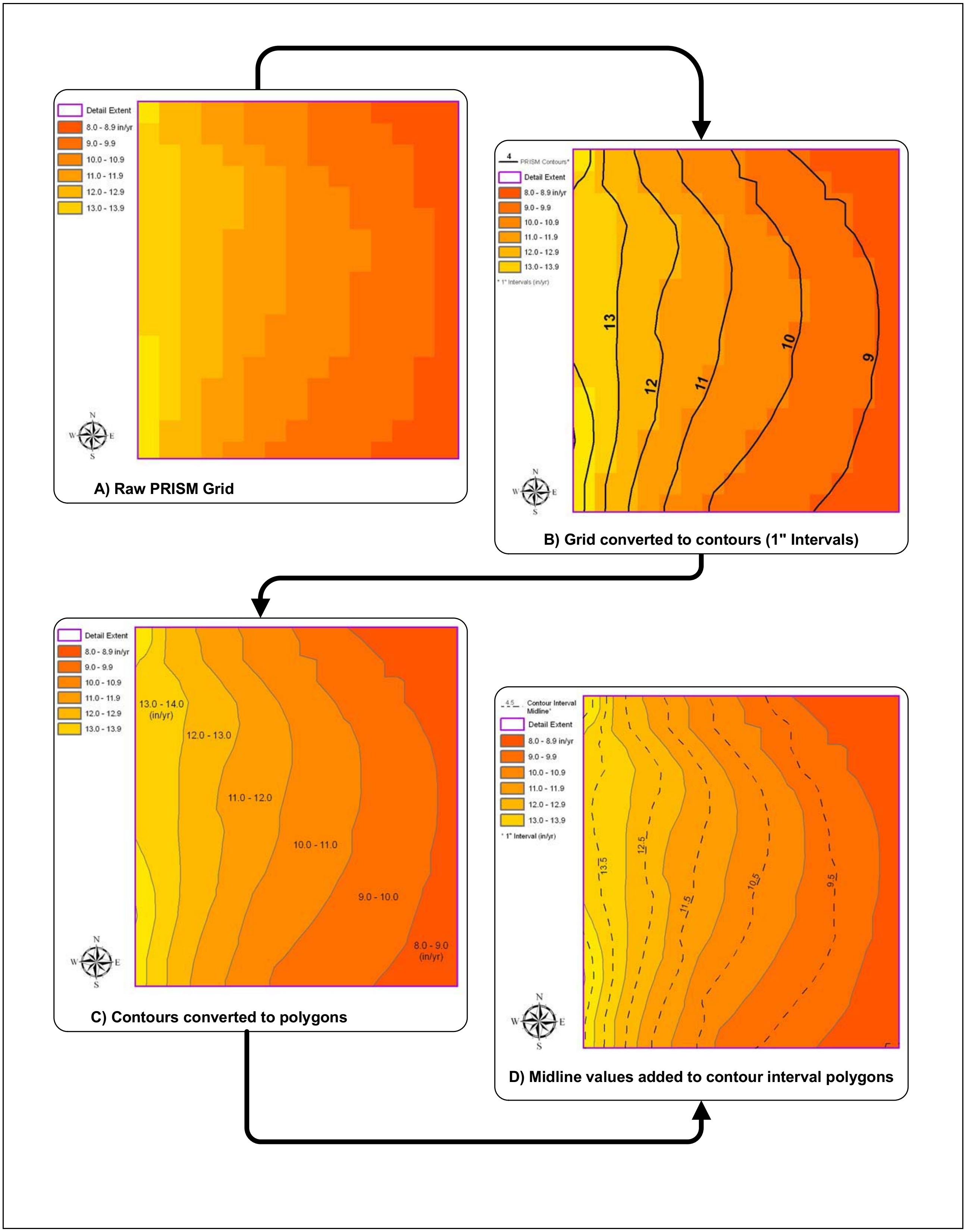


**Figure E.2-1**
**Generation Process of One-Inch Precipitation Bands**

8. The table was then exported to Excel and added to the solution file in Worksheet "3-Precipitation-Recharge-Details." The precipitation rate and the precipitation band area are in columns 3 and 4 of this table.

#### *E.2.1.4 Worksheet 4 - "4-Solution"*

Worksheet 4 is the core of the Solver. Worksheet 4 requires the table in Worksheet 3, described in Section E.2.1.3. Without the precipitation data and the recharge calculations in Worksheet 3, the Solver will not function. This worksheet is organized in three principal areas: (1) Area 1 - Main Solver Area, (2) Area 2 - Recharge Efficiency Calculations, (3) Area 3 - Basin Groundwater Budget Calculations. Each of these areas is described in the following text.

##### *E.2.1.4.1 Area 1 - Main Solver Area*

A description of the main solver area and the process followed to derive initial estimates for the coefficients of the power function are provided in the following text.

###### *E.2.1.4.1.1 Area 1 Description*

This area contains the target cell, parameter cell, and a list of the constraints used. Constraints were imposed on the parameters, but also on selected flow terms which are listed in this area as additional supporting information. The target, parameters and constraints are color-coded. The color codes are provided within this area. Cell R4 is the target cell and is color-coded as blue. Cells R6 to R9 contain the parameters and are color-coded as green. The appropriate initial estimates for the four parameters are provided in cells T6 to T9. These values are to be copied onto the parameter cells before executing the solver to ensure consistency of the solution. Cells R20, R21, V7, V16, and Q48 are the constraints and are color-coded as pink. Cell Q48 is located in the recharge efficiency calculation area described in the next section. Cells highlighted in yellow signify that the value in that cell or the cell next to it is constant.

The target is represented by the estimated value of total groundwater ET for the WRFS. The target cell contains a formula relating groundwater ET to the other components of the budgets; this formula is as follows:

$$ET_{gw} = R_T + Inflow - Outflow \quad \text{(Eq. E.2-1)}$$

where,

$ET_{gw}$ = total groundwater ET for the WRFS (afy)
$R_T$ = total natural recharge for the WRFS (afy)
Inflow = total groundwater inflow to the WRFS from the Meadow Valley Flow System (afy)
Outflow = total groundwater outflow from the WRFS to the Colorado River (afy)

The target value for "$ET_{gw}$" and the estimate of "Inflow" are 139,400 and 9,200 afy, respectively. Due to the large number of unknown parameters, no unique solution can be derived by the solver. The solution included here is the best based on initial estimates of parameters and defensible estimates of the constraints used. If the solver starts from different initial estimates or constraints, different solutions, and possibly no solution, may be produced. Thus, appropriate initial estimates for the parameters were estimated and are provided in cells T6 to T9. They are as follows:

- Power function constant: $a = 8.0 \times 10^{-5}$ (see Figure E.2-2)
- Power function exponent: $b = 3.62$ (see Figure E.2-2)
- Outflow from Coyote Spring Valley to Hidden Valley = 15,000 afy (Appendix D)
- Total outflow = 25,000 afy (Appendix D)

### *E.2.1.4.1.2 Initial Estimates for Coefficients of Power Function*

The initial estimates for the two coefficients of the power function, a and b, represent the constant and exponent of another power function derived from the step-function defined by the standard Maxey-Eakin coefficients. The precipitation ranges used in the Maxey-Eakin method were split into the two values defining the range (Table E.2-1). For the Maxey-Eakin range specified as "greater than 20 in.," the maximum value was set to match the mid-value of the maximum precipitation band identified for the WRFS in this analysis (25.5 in./yr). A mean precipitation value was then calculated for each precipitation range, and a mean recharge value was calculated by multiplying it by the corresponding Maxey-Eakin recharge efficiency (Table E.2-1). The resulting point data were fit with a power function shown in Figure E.2-2. The independent variable, X, represents precipitation in inches per year; and the dependent variable, Y, represents recharge in inches per year. The coefficients of this power function (Figure E.2-2) serve as the initial estimates for the recharge versus precipitation power function derived for this study.

**Table E.2-1**
**Data for Maxey-Eakin Power Function**

| Precipitation Zone Used in Maxey-Eakin Method (in./yr) | Minimum Precipitation Rate (in./yr) | Maximum Precipitation Rate (in./yr) | Mean Precipitation (in./yr) | Standard Maxey-Eakin Efficiency | Mean Recharge (in./yr) |
|---|---|---|---|---|---|
| 8 to 12 | 8.00 | 12.00 | 10.00 | 0.03 | 0.30 |
| 12 to 15 | 12.00 | 15.00 | 13.50 | 0.07 | 0.945 |
| 15 to 20 | 15.00 | 20.00 | 17.50 | 0.15 | 2.625 |
| Greater than 20 | 20.00 | 25.50 | 22.75 | 0.25 | 5.6875 |

### *E.2.1.4.2 Area 2 - Recharge Efficiency Calculations*

Area 2 of the solution sheet contains two tables and two graphs. The first table contains the 1-in. precipitation bands and the corresponding recharge efficiencies calculated using the power function

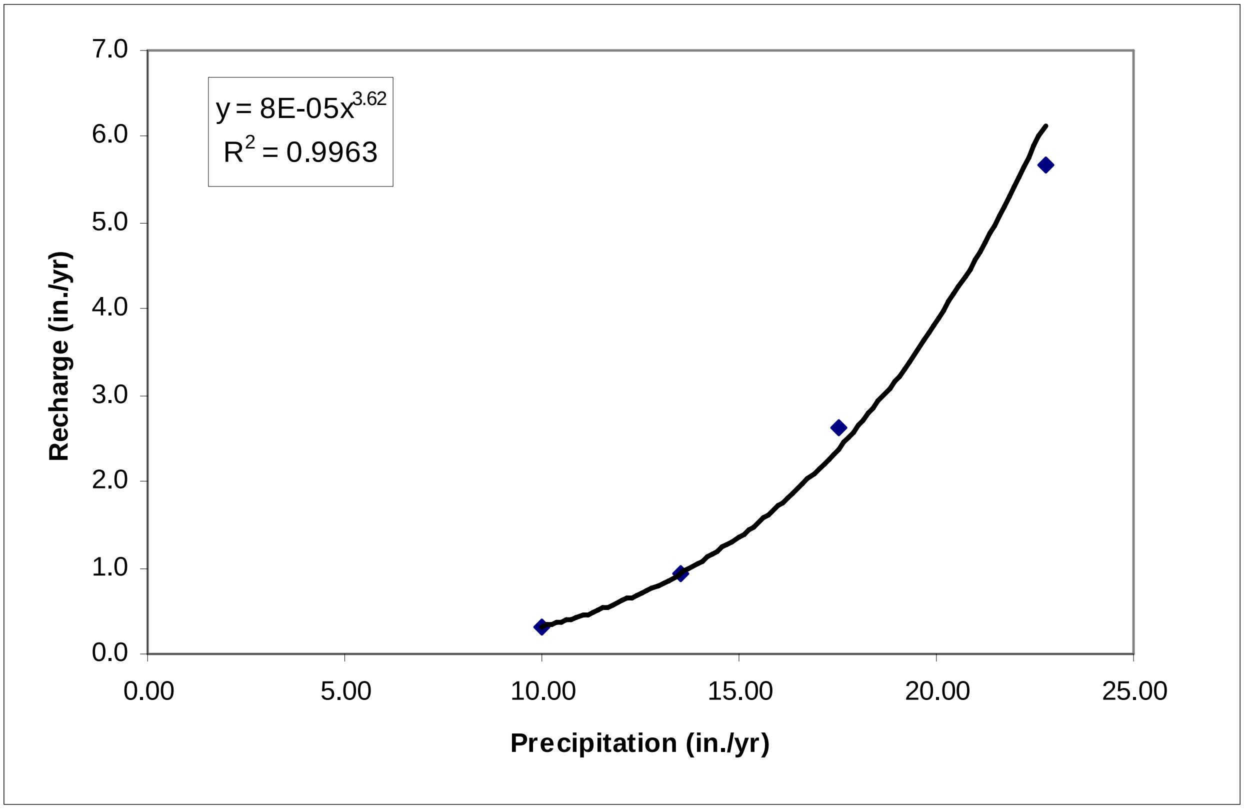


**Figure E.2-2**
**Power Function Fit to Maxey-Eakin Precipitation-Recharge Points (Table E.2-1)**

coefficients listed as parameters in the main Excel Solver area described above. For each precipitation band, the recharge efficiency is calculated as the recharge rate expressed as the power function divided by precipitation as follows:

$$Eff = \frac{[a(P-8)^b]}{P} \qquad \text{(Eq. E.2-2)}$$

where,

Eff = recharge efficiency or R/P as a fraction
a = power function constant
b = power function exponent
P = Precipitation (in./yr)
P – 8 = Effective precipitation (in./yr)

These efficiencies utilize whatever values of a and b are stored in the appropriate cells: initial estimates or the final values derived by the solver. A constraint is imposed on the maximum recharge efficiency (cell Q48). The maximum recharge efficiency cannot be greater than 1, but the exact efficiency for the WRFS is unknown and most likely much less than 1. Therefore, a literature review was conducted to identify the available reported values, which are listed in Table E.2-2 and discussed in the subsequent text.

**Table E.2-2**
**Maximum Recharge Efficiency Reported**

| Authors | Recharge Estimation Method and Location | Bedrock Aquifer | Maximum Recharge Efficiency (Fraction of Precipitation) |
|---|---|---|---|
| Maxey and Eakin (1949) | Water balance WRFS | Carbonate-rock aquifer | 0.25 |
| Lichty and McKinley (1995) | Precipitation runoff modeling, index-site extrapolation and chloride mass balance methods | Volcanic tuffs | 0.50 |
| Maurer and Berger (1997) | Application of Darcy's Law and chloride mass balance in Kings Canyon of Carson Basin, Nevada | Metamorphic rocks | 0.35 |
| Nichols (2000) | Water balance, eastern Nevada | Mainly limestone and dolomite, with some volcanic and metamorphic rocks | 0.63 |
| Davisson and Rose (2000) | Hydrologic mass balance calibrated groundwater age dates in Fenner Basin California | Granitic, metamorphic and volcanic rocks | 0.48 |
| Faybishenko (2007) | Potential evapotranspiration at meteorological stations in western U.S. | N/A | 0.41 |

Maxey and Eakin (1949) derived a maximum recharge efficiency of 0.25 for the precipitation zone greater than 20 in. based on the Hardman (1936) precipitation map. This value represents a maximum for a large interval, but not the maximum for the much smaller 1-in. bands used in this study. Lichty and McKinley (1995) reported a maximum recharge efficiency of 0.50 for two small basins located in central Nevada. They derived their recharge efficiencies based on the application of a precipitation-runoff model, the PET index-site extrapolation method, and the chloride mass balance to volcanic tuffs. Maurer and Berger (1997) estimated a maximum recharge efficiency of 0.35 for metamorphic rocks in Kings Canyon of Carson Basin by application of Darcy's Law and the chloride mass balance. Nichols (2000) reported a maximum recharge efficiency of 0.63 percent based on new ET estimates and a preliminary version of the 4-km 1971-to-2000 PRISM precipitation map for basins in Nevada dominated by carbonate rocks. Davisson and Rose (2000) calibrated the Maxey-Eakin recharge model to the local conditions of the Fenner Basin in California, using local recharge estimates estimated with field information. Faybishenko (2007) calculated a maximum infiltration efficiency of 0.412 based on data from several states including Nevada. The largest reported recharge maximum efficiency is 0.63 percent of precipitation. This value was used to constrain the upper limit of the recharge efficiency in the solver. It is deemed appropriate not only because it is the largest value, but also because it was derived for a nearby area with similar climatologic and geologic conditions.

The solution's recharge efficiencies are displayed on a scatter plot showing the calculated recharge efficiencies versus precipitation rates (first graph) in Area 2 of the solution worksheet. The other table and graph show the same results averaged over the wider precipitation zones defined by Maxey and Eakin (1949) for comparison.

#### *E.2.1.4.3 Area 3 - Groundwater Budget Calculations*

This area contains the groundwater budget calculations for each of the basins of the WRFS in the form of a chart. Two additional estimates of interbasin flow volumes were added to support the calculations and are provided at the top of the area. In the lower-left corner of this area, the budget for the entire flow system is shown for comparison with the overall groundwater budget resulting from the individual basin calculations for checking purposes. The cells in the chart are linked to the appropriate cells in the solver area, the ET worksheet, and the detailed precipitation-recharge worksheet. The chart and the WRFS budget are automatically updated when the solver is executed.

### *E.2.2 Solution Process*

The solution process includes two major steps: (1) execution of the Excel Solver to derive a recharge distribution, and (2) derivation of the basin budgets using the recharge distribution.

#### *E.2.2.1 Executing the Solver*

The solver is activated by clicking "Solver" under Excel menu item "Tools" from the solution sheet (Worksheet 4). At this point, the "Solver Parameters" window pops up (Figure E.2-3). In its upper part, the window displays information about the objective of the solver. This information includes the specification of the target cell (Cell R4) and an option for the objective function specifying whether the solver is to maximize, minimize, or equate the objective function to a target value. When the equality option ("Value of") is selected as it is in this case, a target value must be specified. In this case, a value of "139,424" is specified, representing the total GW ET in afy for the WRFS calculated in Worksheet 2.

Under the objective function information, the cells where the parameters are located in the worksheet are provided under "By Changing Cells." In this case the parameter cells range from R6 to R9. During the solution process, the solver iteratively changes the values in these cells until the objective is achieved, in this case, until the value in the target cell equals the specified target value of 139,424 afy.

Under the parameter information, a list of the constraints is provided to the solver to constrain the solution under the title "Subject to the Constraints." Each row in the list consists of a cell address in the solution worksheet, a logical operator, and a value. The logical operator may be set to "Equal," "Less than or equal", or "Greater than or equal." The constraints on the solution allow the solver to narrow the domain of feasible solutions for problems with many unknowns. The constraints used in this case are as follows:

- Power Function Constant, a is positive

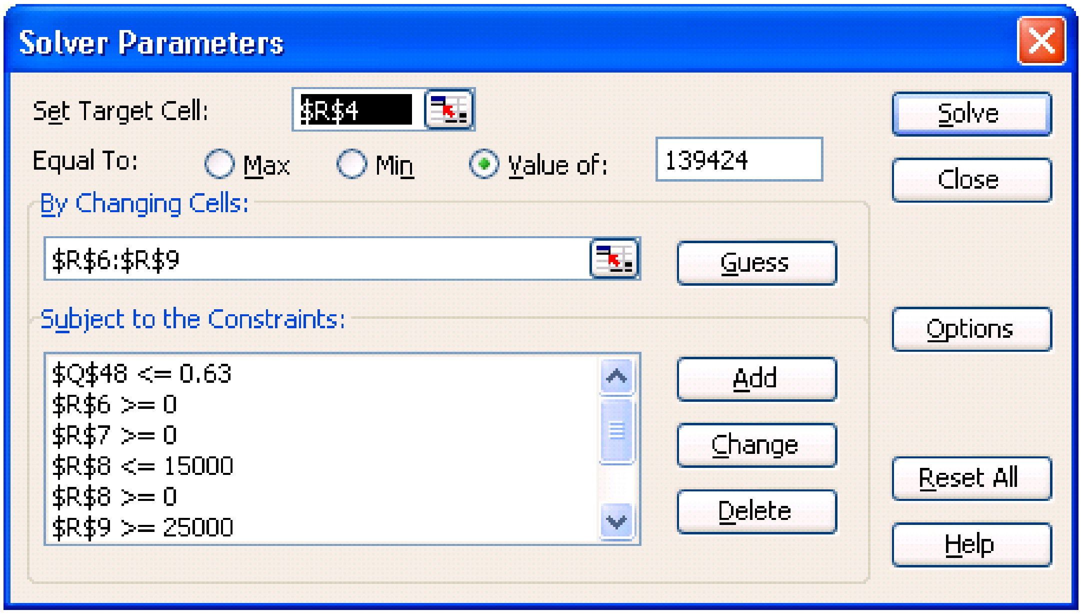


**Figure E.2-3**
**Excel Solver Window**

- Power Function Exponent, b is positive
- Outflow from White River Valley is between 6,300 and 40,000 afy (Maxey and Eakin, 1949 and LVVWD, 2001)
- Outflow from Coyote Spring Valley to Hidden Valley is less than or equal to 15,000 afy (Appendix D)
- Total inflow to Muddy River Springs Area is greater or equal to 40,000 afy (Section 4.0)
- Total outflow is greater or equal to 25,000 afy (Appendix D)
- Maximum recharge efficiency is less or equal to 63 percent (specified as 0.63) (Nichols, 2000)

In the right-hand side of the solver window are a "Solver" button to execute the solver, a "close" button to close the window, an "options" button to specify the solution method and convergence criteria, a "Reset" button, and a "Help" button. Once the "Solve" button is activated, the user is presented with various options for keeping or resetting the solution, saving scenarios, and reporting results. The novice user should use the default options.

### *E.2.2.2 Deriving Basin Groundwater Budgets*

The groundwater budgets in the appropriate area of the solution worksheet (Area 3) are updated automatically every time the solver is executed. Although these calculations are conducted in Excel, they are performed outside of the solver, but using the results of the solver (recharge and selected interbasin flow volumes). The solver provides a recharge distribution for all basin in the WRFS in Worksheet 3. Assuming that each basin is under predevelopment steady-state conditions, a groundwater budget is derived for each basin. The process starts from the most upgradient basin of the WRFS (Long Valley), and ends at the southernmost basins (Lower Moapa Valley and Black Mountains Area). For each basin, any inflow to the basin is added to the estimate of basin recharge, and the basin's groundwater ET value is then subtracted. The remainder is the outflow is routed to the next contiguous basin(s) located downgradient. For basins having more than one outflow boundary, independent estimates of selected outflow boundaries were made. Such is the case for two basins: Cave Valley and Pahroc Valley. Outflow from Cave Valley is to White River Valley and Pahroc Valley. Outflow from Pahroc Valley is to Pahranagat Valley and Dry Lake Valley. Portions of these outflows are specified in this area of the top of this worksheet (Area 3).

# E.3.0 UNCERTAINTY ANALYSIS EXCEL FILES

All Excel files containing the eleven uncertainty cases are organized exactly the same as the solution file. The only difference in the first ten cases (Table E.3-1) is that each file contains an alternate scenario where a single variable was assigned a different value to test the solution. Each of these ten scenarios corresponds to the low and high values of the four most uncertain variables. The corresponding filenames and related information are listed in Table E.3-1. The eleventh Excel file is named: "SNWA-BARCASS-WRFS-Groundwater-Budget-Solution," and contains the special scenario conducted to evaluate the BARCASS interpretation for the northern portion of the WRFS. The contents of this file are identical to the contents of the file containing the main solution, except for the following:

- The groundwater ET values under the heading "SNWA/BARCASS GW ET" in Worksheet 2 were used in the calculations, instead of those under the "SNWA GW ET" heading.
    - The target value in the solver window was changed from 139,424 to 147,791 afy.
    - The ET values for the four northern valleys were replaced with the BARCASS estimates in the basin groundwater budget chart located in the solution sheet (Worksheet 4 - Area 3).
- In the groundwater budget chart (Worksheet 4 - Area 3), all groundwater outflow from Cave Valley was routed to White River Valley, instead of White River and Pahroc valleys.

The solver in all eleven uncertainty files is executed in the same manner as in the solution file.

## Table E.3-1
## Range of Uncertainty for Selected Budget Components

| Excel Filename | Variable | Low Value | High Value | Sources |
|---|---|---|---|---|
| SNWA-WRFS-Groundwater-Budget-Unc-WRV-GWET-Low<br>SNWA-WRFS-Groundwater-Budget-Unc-WRV-GWET-High | White River Valley Groundwater ET (afy) | 37,000 | 79,560 | Eakin, 1966; LVVWD, 2001 |
| SNWA-WRFS-Groundwater-Budget-Unc-MRSA-GWET-Low<br>SNWA-WRFS-Groundwater-Budget-Unc-MRSA-GWET-High | Muddy River Springs Area ET (afy) | 2,300 | 5,989 | Eakin, 1966; this study in Section 4.0 |
| SNWA-WRFS-Groundwater-Budget-Unc-Inflow-Low<br>SNWA-WRFS-Groundwater-Budget-Unc-Inflow-High | Total Inflow to WRFS (afy) | 7,000 | 32,000 | Rush, 1968; LVVWD, 2001 |
| SNWA-WRFS-Groundwater-Budget-Unc-Outflow-Low<br>SNWA-WRFS-Groundwater-Budget-Unc-Outflow-High | Total Outflow from WRFS (afy) | 11,100 | 49,000 | Rush, 1968; LVVWD, 2001 |
| SNWA-WRFS-Groundwater-Budget-Unc-Max-Eff-Low<br>SNWA-WRFS-Groundwater-Budget-Unc-Max-Eff-High | Maximum Recharge Efficiency (percent of precipitation) | 0.25 | 1 | Maxey and Eakin, 1949 |

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SOUTHERN NEVADA WATER AUTHORITY

# Part B

# Hydrogeology of Cave, Dry Lake, and Delamar Valleys

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November 2007

SOUTHERN NEVADA WATER AUTHORITY
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## Acronyms

| | |
|---|---|
| AMT | audiomagnetotelluric |
| BLM | Bureau of Land Management |
| NDWR | Nevada Division of Water Resources |
| SNWA | Southern Nevada Water Authority |
| USAF | U.S. Air Force |
| USGS | U.S. Geologic Survey |
| UTM | Universal Transverse Mercator |
| WRFS | White River Flow System |

## Abbreviations

| | |
|---|---|
| afy | acre-feet per year |
| amsl | above mean sea level |
| bgs | below ground surface |
| ft | foot |
| km | kilometer |
| m | meter |
| mGal | milligalileo |
| mi | mi |

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# 1.0 INTRODUCTION

Part B of this report describes the geologic framework and the occurrence and movement of groundwater within Cave, Dry Lake, and Delamar Valleys. The purpose and scope of this description is presented in the following section.

## 1.1 Purpose and Scope

The purpose of describing the geologic framework of Cave, Dry Lake, and Delamar Valleys is to provide the basis from which an understanding of the hydrogeology of the basins can be developed, particularly the geologic features controlling local and regional groundwater flow. The hydrogeology is further defined through an evaluation of the hydraulic data that describes the occurrence and movement of groundwater.

The geologic framework is presented as a surface geologic map and a series of geologic cross sections (Plate 1), depth-to-basement maps, and profiles interpreting seismic and audiomagnetotelluric (AMT) data. Hydraulic data from wells and springs are used in conjunction with the geologic framework to describe the occurrence and movement of groundwater within the basins and vicinity. The hydrogeologic description is relied upon in Part C of this report, which evaluates the potential water-related effects of developing the Southern Nevada Water Authority (SNWA) applications in these basins.

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# 2.0 GEOLOGIC FRAMEWORK

The SNWA has described the stratigraphy, structural geology, and hydrogeology of the study area in a report titled "Geology of White Pine and Lincoln Counties and Adjacent Areas, Nevada and Utah: The Geologic Framework of Regional Groundwater Flow Systems" (Dixon et al., 2007). This section provides an overview of the geologic information for Cave, Dry Lake, and Delamar valleys presented in that report.

## 2.1 Cave Valley

### 2.1.1 Geology

Cave Valley is part of the White River Flow System (WRFS) and consists of two distinct but connected areas, separated by an oblique-slip fault at Shingle Pass (Plate 1). One of these areas, northern Cave Valley, is a narrow graben with mostly east-dipping Cambrian rocks at shallow depth and containing relatively thin basin-fill sediments. The southern area, south of Shingle Pass, generally contains less than 3,000 ft of basin-fill sediments and volcanic rocks but in a narrow, central, north-trending axial part, these Cenozoic rocks are 6,000 ft or more thick (Plate 1, Cross Sections U—U', R—R', and Q—Q').

Along the western side of Cave Valley, the Egan Range is a complexly faulted horst of east-dipping Cambrian to Permian rocks, overlain by Tertiary volcanic rocks (Plate 1). The Egan Range separates Cave Valley from White River Valley to the west. Halfway southward down Cave Valley a northeast-striking oblique-slip fault passes through the Egan Range at Shingle Pass. This fault has partitioned the valley into two sub-basins by displacing a section of the Egan Range and forming an east-dipping fault block that extends northeast across and beneath Cave Valley where it terminates against the range-front fault of the Schell Creek Range. Based on oil test well drilling and gravity surveys, this block contains the Mississippian Chainman Shale (Hess, 2004; Mankinen et al., 2007; Scheirer, 2005; Eastman, 2007a and b).

Farther south, the Egan Range remains an east-tilted horst of Cambrian through Tertiary rocks, then bends southeast to join the southern end of the Schell Creek Range. Here Cave Valley terminates where the Egan and Schell Creek ranges join each other in a complex of north-northeast- and north-northwest-striking normal and oblique-slip faults. To the east, the Schell Creek Range separates Cave Valley from Lake and northern Dry Lake (Muleshoe) Valleys. This section of the Schell Creek Range contains a narrow, heavily faulted sequence of Precambrian through Tertiary rocks that dips east. Here the dominant fault is on the western flank of the range. In the northeast part of the valley, the Schell Creek Range is cored by Precambrian to Cambrian quartzite. West of the Geyser Ranch, the rocks are mostly Late Proterozoic and Cambrian quartzite (Van Loenen, 1987), but farther south the rocks are dropped down along an east-trending fault at Patterson Pass and are mostly of middle to upper Paleozoic and Tertiary age. In the south, where Cave Valley terminates at the intersection of the Schell Creek Range and the Egan Range, a Tertiary pluton has mineralized adjacent carbonate rocks at the Silver King Mine.

### 2.1.2 Geophysics

#### 2.1.2.1 Gravity

The isostatic gravity anomaly of Cave Valley is characterized by 20 to 30 mGal lows centered on the valleys relative to the isostatic values in the surrounding ranges. There are significant gravity fluctuations within the ranges, reflecting the lithologic variation within them. Larger and more continuous maximum gradient picks are present in southern Cave Valley relative to northern Cave Valley (Scheirer, 2005). In the south, two main lines of maximum gradients are found paralleling the eastern and western margins of the valley.

The depth-to-basement separates the isostatic gravity anomaly into portions that arise from the Cenozoic deposits (basin-fill) from those of pre-Cenozoic rocks (basement), and the resulting basin gravity anomaly is illustrated in Figure 2-1. Basin depths estimated from gravity extend to approximately 6.0 km, or to almost 20,000 ft-bgs in Cave Valley. In northern Cave Valley, typical basement depths are hundreds of meters, and no site has an estimated depth greater than 2 km. In southern Cave Valley, the basin has depth-to-basement estimates greater than 1 km for more than half of its length; its deepest inferred depth is just east of the valley's axis.

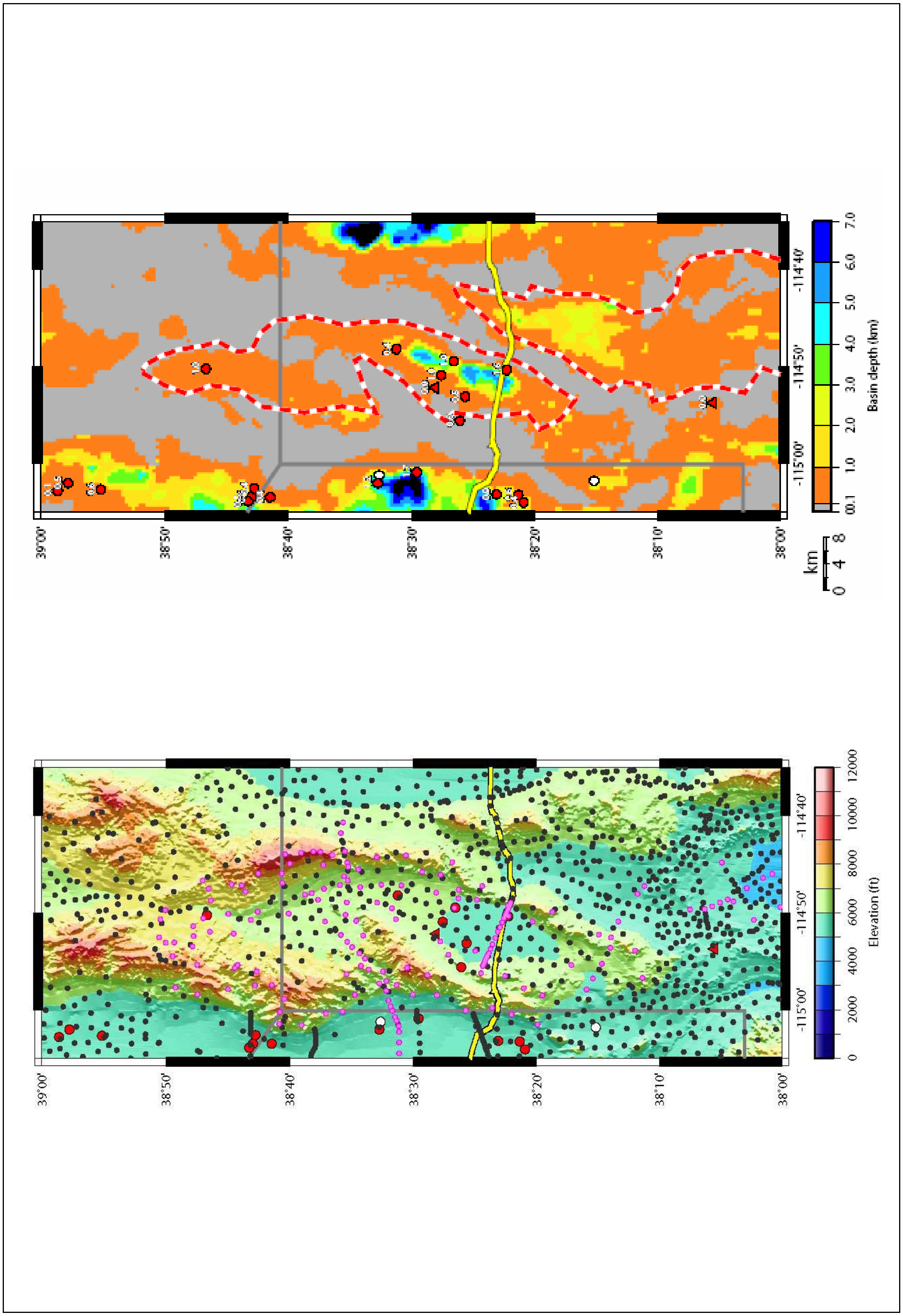
#### 2.1.2.2 Audiomagnetotellurics

In conjunction with gravity studies of Scheirer (2005) the AMT method was applied to Cave Valley in an effort to delineate structure and stratigraphy in the upper 1 km, in particular, faults and stratigraphy within the valleys, as well as estimates of depth to basement rocks.

An abrupt contact between the resistive limestone basement rock on the east side of Cave Valley in the Sidehill Pass area (Figure 2-2) and the more conductive valley fill agrees with the sharp gravity gradient observed by Scheirer (2005), who calculated a steep eastern basin margin which is bounded by a range-front fault (Figure 2-2). Drill hole 180W902M provided additional evidence of the reliability of the method.

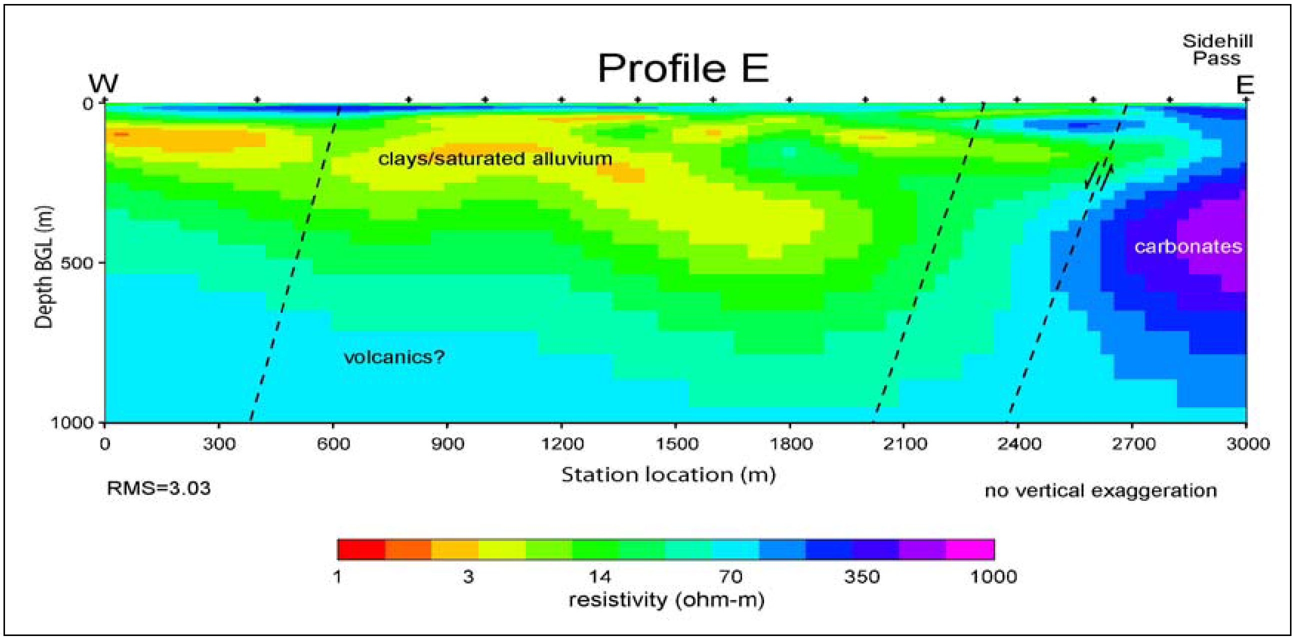
#### 2.1.2.3 Seismic Studies

Subsurface structure of Cave Valley and northern Dry Lake Valley (Muleshoe) is provided by a portion of the industry-shot ECN-01 seismic reflection line (Figure 2-3). The seismic reflection image illustrates the asymmetric character of Cave Valley, with steeper eastern side where the range-front fault of the Schell Creek Range lies and a less-steep, but still fault controlled, western side along the eastern side of the Egan Range.




Source: Scheirer, 2005

**Figure 2-1**
**Location of Gravity Stations and Depth-to-Basement Map for Cave Valley and Northern Dry Lake Valley**




Source: Dixon et al., 2007

**Figure 2-2**
**AMT Model along Profile E across Central Cave Valley, Nevada**

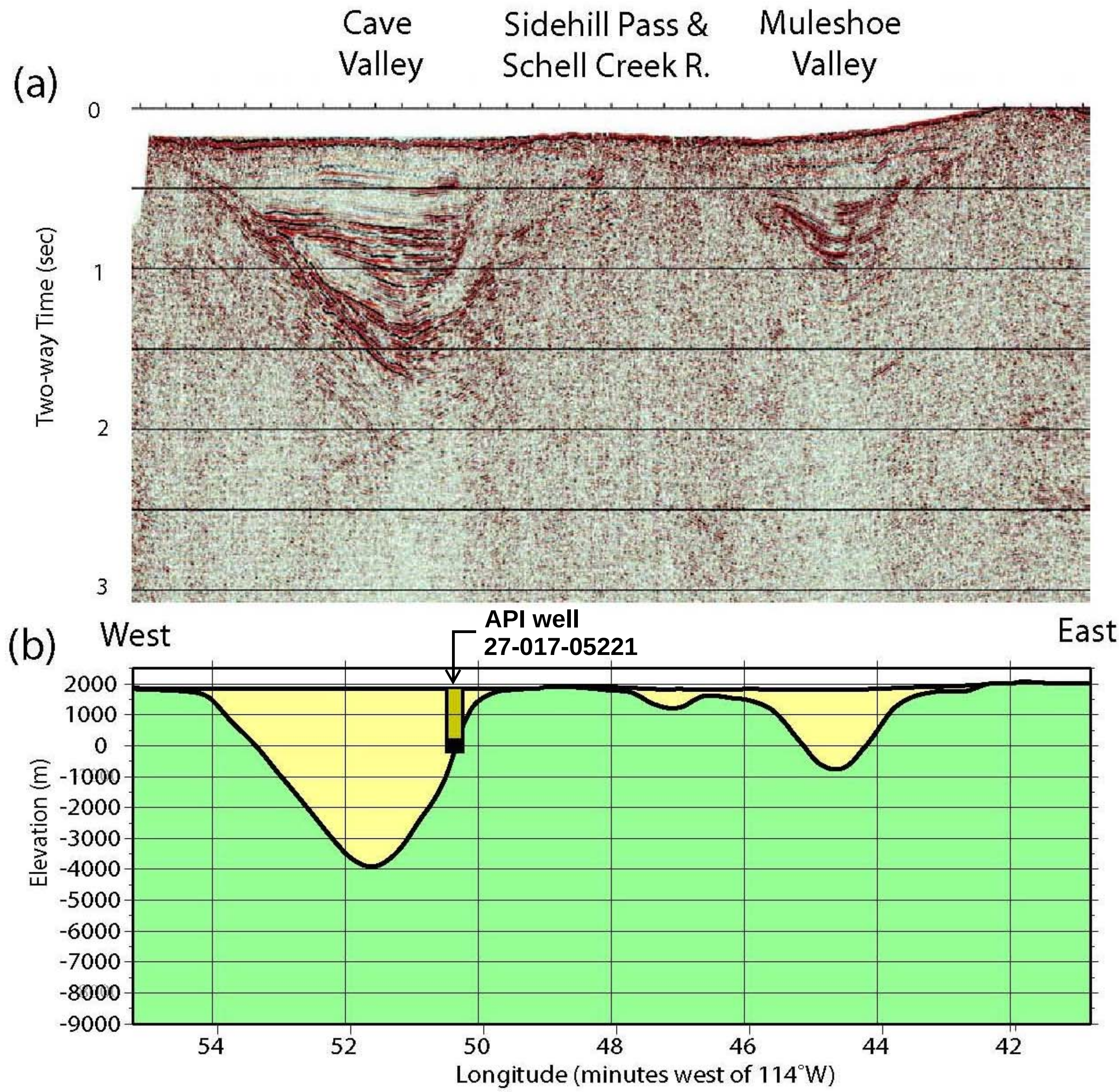
## 2.2 Dry Lake Valley

### 2.2.1 Geology

Dry Lake Valley is a deep graben that contains in most places 3,000 to 5,000 ft of basin-fill sediments (Mankinen et al., 2007) (Plate 1), but locally along the axis of the graben as much as 7,000 ft of sediments and underlying down faulted volcanic and carbonate rocks are present (Scheirer, 2005; modified by Mankinen, et al., 2007) (Plate 1, Cross Sections Q—Q', T—T', P—P', and S—S').

Along the western side of Dry Lake Valley at the junction with the southern Egan and Schell Creek ranges, the North Pahroc Range extends south for about 40 mi separating the valley from Pahroc Valley to the West (Plate 1). The North Pahroc Range consists of upper Paleozoic rocks overlain by Tertiary volcanic rocks (Plate 1, Cross Section T—T'). These rocks dip west off major faults along the eastern side of the range. The North Pahroc Range is separated from the smaller South Pahroc Range at the southern end of the valley by an east-trending belt of faulted rocks of low relief formed by the east-striking Timpahute transverse zone (Plate 1). The belt of faulted rocks are the oldest structural features in the valley, and help form the topographic divide between Dry Lake Valley and Delamar Valley to the south. This zone is of little consequence with respect to the hydraulic connectivity between the two basins. The Seaman and the North Pahroc ranges join together at their southern ends, and the Hiko Range continues south of this intersection.

On the east side and from north to south, the Fairview, Bristol, Highland, and Chief Ranges are a 60-mi-long group of north-trending, heavily-faulted ranges of mostly east-dipping rocks that separate Dry Lake Valley from Lake, Patterson and Panaca Valleys to the east. The northern portion of Dry




(a) Cross section of southern Cave and northern Muleshoe valleys ECN-01 seismic reflection section displayed in time. (b) Results of gravity depth-to-basement inversion with low-density basin fill in yellow. API well 27-017-05221 is displayed on the section, and its alluvial interval is shown in dark yellow. Vertical exaggeration = 1.5.

Source: after Scheirer, 2005

**Figure 2-3**
**(a) ECN-01 Seismic Reflection Section Displayed in Time**
**(b) Results of Gravity Depth-to-Basement**

Lake Valley (Muleshoe Valley) is bounded on the east by the Fairview Range (Plate 1). The Fairview Range is a horst made up of Devonian to Pennsylvanian rocks at both the northern and southern ends of the range (Plate 1, Cross Section Q—Q'). The central part of the range consists of the western lobe of the Indian Peak caldera complex. To the south, the valley is bounded on the east by the Bristol, Highland, and Chief ranges. A low pass between the Fairview Range and the Bristol Range is cut by numerous east-striking faults of the Blue Ribbon transverse zone, which crosses the entire Great Basin at about this latitude (Rowley, 1998; Rowley and Dixon, 2001). The small horsts due west of this area are named the West, Ely Springs, Black Canyon, and Burnt Spring Ranges.

The Bristol Range is a horst that consists mostly of an east-dipping sequence of Cambrian carbonate rocks. The range is cored by a Tertiary pluton on the northern end that is associated with silver deposits of the Jackrabbit and Bristol districts. A low angle, west-dipping detachment or gravity-slide fault that placed Devonian rocks on Cambrian rocks is exposed in the northwestern part of the range (Page and Ekren, 1995). The Highland Range, the southward continuation of the Bristol Range, consists of east-dipping Cambrian carbonate rocks, underlain by Precambrian and Cambrian quartzite. A west-dipping, west-verging, moderately dipping fault on the western side of the range, the breakaway part of the Highland detachment fault, placed the younger carbonate rocks on the older quartzite. The Chief Range, south of the Highland Range, is made up of east-dipping Precambrian and Cambrian quartzite that is unconformably overlain by Tertiary volcanic rocks and cut by a Tertiary pluton that controls the small Chief gold district. The faults that lift the range on the western side consist of an oblique-slip fault (right lateral and normal) and the west-dipping Highland detachment fault (Rowley et al., 1994).

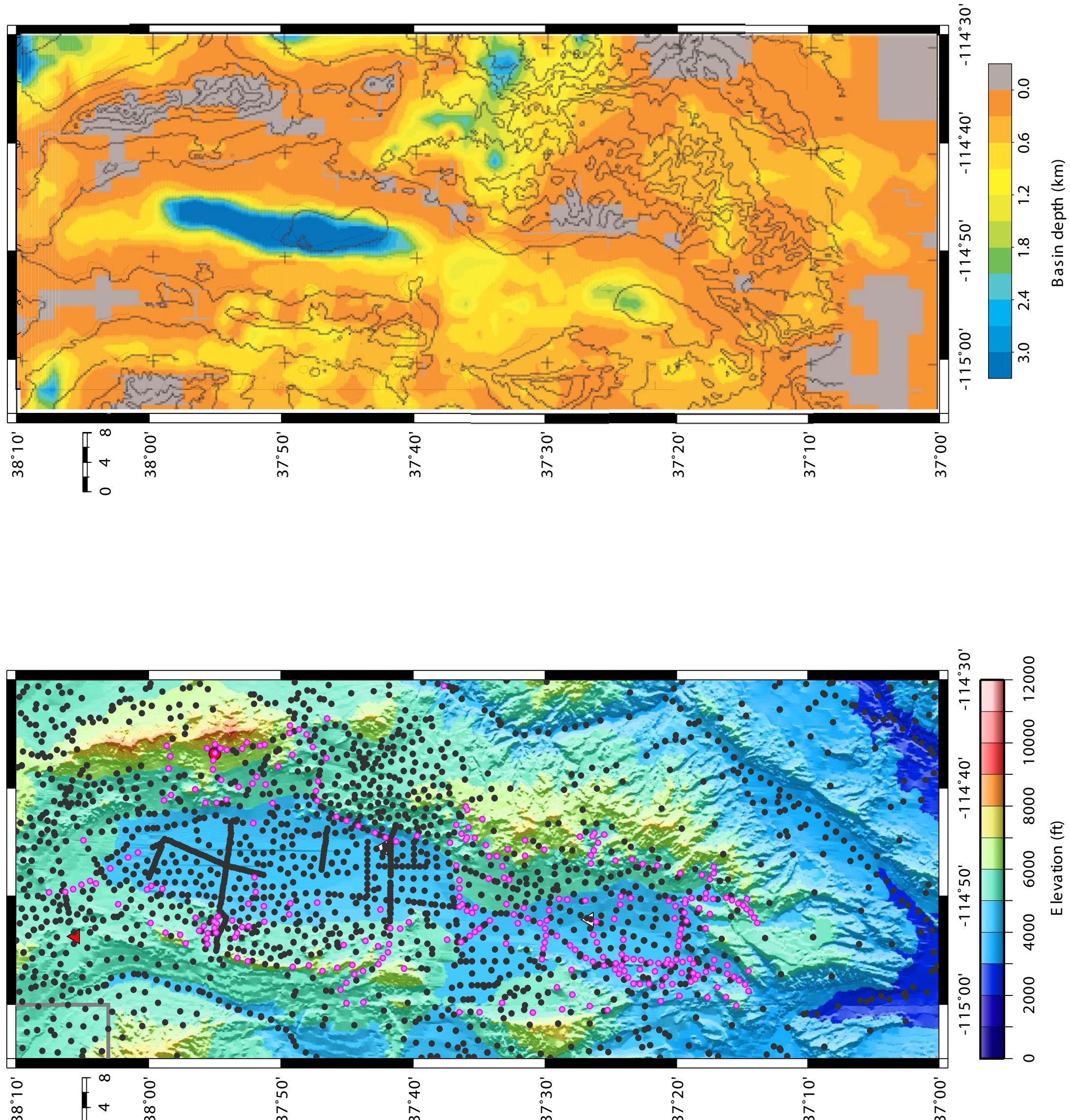
The small West Range consists of Devonian sedimentary rocks and Tertiary volcanic rocks on which are Devonian rocks emplaced by a low-angle fault that can be interpreted as either a detachment fault or a gravity-slide plane (Page and Ekren, 1995). The Ely Springs Range consists of Cambrian through Silurian rocks, overlain by Tertiary volcanic rocks. The Black Canyon Range consists of Cambrian sedimentary rocks and Tertiary volcanic rocks. The Burnt Springs Range consists of Cambrian sedimentary rocks unconformably overlain by Tertiary volcanic rocks.

### 2.2.2 Geophysics

#### 2.2.2.1 Gravity

Dry Lake Valley is bounded by the North Pahroc Range in the west and Highland and Bristol ranges in the east, and the valley is marked by low saddles to the north (adjoining Muleshoe Valley) and south (adjoining Delamar Valley). The isostatic gravity anomaly has a greater than 30 mGal negative value in the center of the valley (Figure 2-4).

The depth-to-basement solution for Dry Lake Valley exhibits a normal structural graben on the margins of the basin and also a central graben down the axis of the valley. The depth-to-basement in the margins of the valley are approximately 1 km, whereas in the central graben most depths are greater than 3 km. Because the ranges surrounding Dry Lake Valley are composed predominately of volcanic rocks, the sedimentary fill might have a lower density than most other basins, in which case the density contrasts with bedrock would be larger and inverted basins would be shallower.




Source: Scheirer, 2005; modified by Mankinen et al., 2007.

**Figure 2-4**
**Location of Gravity Stations and Depth-to-Basement Map for Dry Lake and Delamar Valleys**

#### 2.2.2.2 Seismic Reflection

A continuation of the industry-shot ECN-01 seismic line extends from Cave Valley to Northern Dry Lake Valley (a.k.a. Muleshoe Valley) (Figure 2-3). The seismic profile (reflectors) indicate that the shallow portions of Muleshoe Valley are weak to absent, but in its deeper section they exhibit characteristics similar to those of the Cave Valley reflectors and agree with the gravity surveys.

## 2.3 Delamar Valley

### 2.3.1 Geology

Delamar Valley, just south of Dry Lake Valley, is a graben that deepens to the south with a general maximum thickness of more than 5,000 ft of basin-fill sediments east of the South Pahroc Range (Plate 1) (Mankinen et al., 2007). Locally as much as 7,000 ft of sediments and underlying downfaulted volcanic and carbonate rocks are present (Plate 1, Cross Sections O—O', M—M', N—N') (Scheirer, 2005; modified by Mankinen et al., 2007).

Along the western side of the valley (Plate 1), the South Pahroc Range extends southward from the North Pahroc Range, separating the valley from Pahranagat Valley to the west. The South Pahroc Range is a series of west-titled blocks of volcanic rocks; the main faults are on the eastern side of the range. The South Pahroc Range terminates against the east-northeast-trending Pahranagat shear zone, which also terminates Pahranagat and Delamar Valleys at their southern extent.

The eastern side of the valley is bounded by the Delamar Mountains, which extend southward for 40 mi from the Burnt Springs Range in southern Dry Lake Valley (Plate 1). The boundary between the two ranges can be placed at the northern caldera wall of the Caliente caldera complex, here controlled by the east-trending Timpahute transverse zone (Ekren et al., 1976; Rowley, 1998; Swadley and Rowley, 1994). The Delamar Mountains consists of east-dipping Late Proterozoic to Cambrian rocks and Tertiary volcanic rocks. The range, however, is dominated by Tertiary caldera complexes. The western end of the Caliente caldera complex is in the northern part of the range, and the Kane Springs Wash caldera complex is in the central part of the range (Rowley et al., 1995; Scott et al., 1995 and 1996). The main bounding fault of the Delamar Mountains is the down-to-the-west normal fault on the western side, and this is joined from the southwest by several splays of the left-lateral Pahranagat shear zone (Ekren et al., 1977).

### 2.3.2 Geophysics

#### 2.3.2.1 Gravity

Delamar Valley is surrounded by volcanic ranges to west, south, and east that are highly faulted. The isostatic gravity anomaly is similar to those in the other valleys in the area, but the maximum horizontal gradients are only sporadically clustered along some sections of the South Pahroc and Delamar ranges. The basin gravity anomaly (Figure 2-4) has a minimum restricted to the southern half of Delamar Valley, which leads to the bowl-shaped basin inferred from the gravity inversion

(Figure 2-4). The maximum depth is almost 2.0 km, and it is located west of the center of the southern portion of Delamar Valley.

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# 3.0 GROUNDWATER OCCURRENCE AND MOVEMENT

Understanding the groundwater occurrence and movement within Cave, Dry Lake, and Delamar valleys is an important consideration when developing a conceptualization of the underlying groundwater systems. This section describes the occurrence and movement of groundwater within Cave, Dry Lake, and Delamar valleys based on an inventory of groundwater sites and an assessment of the current and recent water-level conditions.

## 3.1 Groundwater-Site Inventory

Groundwater sites within Cave, Dry Lake, and Delamar valleys include wells and springs which can provide an indication of groundwater conditions, including hydraulic gradients, potentiometric surfaces and flow directions within the basin-fill and carbonate-rock aquifers. Groundwater-site data were compiled from the Nevada Division of Water Resources (NDWR) Well Log database, U.S. Geological Survey (USGS) National Water Information System/Groundwater Site-Inventory database, published and unpublished reports, and internal SNWA databases. The compiled data include location data, reference elevations, site types, well-construction data, lithologic descriptions, and depth-to-water measurements. Table 3-1 lists a summary of these data for sites located within Cave, Dry Lake, and Delamar valleys.

## 3.2 Cave Valley

Twenty-five wells in Cave Valley were identified through the site inventory; 20 are completed in the basin fill and 5 are completed in carbonate rocks. Most of the basin-fill wells were drilled for stock watering where depths to water are shallow, and range from 2 to 327 ft-bgs. The remaining wells were drilled as part of groundwater exploration and monitoring programs involving the U.S. Air Force (USAF) MX-Missile Program or SNWA. NDWR driller's logs for wells in Cave Valley suggest that the basin fill is composed of mostly sand and gravel with significant cemented strata in the northern portion of the valley and interbedded sands and clay in the southern portion of the valley. Petroleum exploration drilling in Cave Valley provides additional geologic information to depths of several thousand feet. These data provide some insight as to the horizontal gradients of the basin-fill and carbonate aquifers comprising the groundwater system(s) of the basin, and are described in greater detail in the following sections.

### Basin-Fill Aquifer

Depths to water in Cave Valley range from near ground surface in parts of northern Cave Valley (i.e., near Cave Spring) to greater than 200 ft-bgs in the southern portion of the valley. Depths to water in the vicinity of the south playa are in excess of 150 ft-bgs, suggesting that the stand of phreatophytes in this area subsists mainly on a perched groundwater system and/or precipitation. Water-level elevations in Cave Valley range from approximately 7,000 ft-amsl in the far northern

# Table 3-1
## Water Level Data for Selected Wells and Springs in Cave, Dry Lake, and Delamar Valleys
(Page 1 of 2)

| Map-ID | Station Number | Station Name | Location | | Ref. Pt. Elev.[b] (ft-amsl) | Site Type | Well Depth (ft-bgs) | Open Interval (ft-bgs) | Last Water Level Measurement Date | Last Depth to Water[c] (ft-bgs) | Water Level Elevation[d] (ft-amsl) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | UTM Easting[a] (m) | UTM Northing[a] (m) | | | | | | | |
| 180-01 | 382223114502501 | 180 N06 E64 18CC 1 Sidehill Pass Well | 688,678 | 4,249,221 | 5,975 | Well-Basin Fill | -- | -- | 7/25/2005 | 158 | 5,817 |
| 180-02 | 180 N07 E63 13DB 1 | 180 N07 E63 13DB 1 | 687,817 | 4,259,662 | 6,014 | Well-Basin Fill | 250 | 200 to 240 | 12/15/1995 | 180 | 5,834 |
| 180-03 | 382822114515301 | 180 N07 E63 14AB 1 USGS-MX | 685,674 | 4,260,043 | 6,012 | Well-Basin Fill | 273 | 200 to 263 | 3/15/1994 | 223 | 5,789 |
| 180-04 | 382822114515302 | 180 N07 E63 14AB 2 USGS-MX | 685,674 | 4,260,043 | 6,012 | Well-Carbonate | 422 | 380 to 422 | 10/25/1980 | 231 | 5,781 |
| 180-05 | 382810114521501 | 180 N07 E63 14BADB1 USAF | 685,674 | 4,260,043 | 6,013 | Well-Basin Fill | 269 | 50 to 269 | 5/29/2007 | 219 | 5,794 |
| 180-06 | 382810114521502 | 180 N07 E63 14BADB2 USAF | 685,674 | 4,260,043 | 6,013 | Well-Carbonate | 418 | 50 to 418 | 7/15/2002 | 221 | 5,792 |
| 180-07 | 382807114521001 | 180 N07 E63 14BADD1 USGS-MX (Cave Valley) | 685,797 | 4,259,954 | 6,012 | Well-Carbonate | 460 | 210 to 250/ 375 to 435 | 5/29/2007 | 220 | 5,792 |
| 180-08 | 382747114525701 | 180 N07 E63 15DBAD1 USBLM | 684,672 | 4,259,311 | 6,026 | Well-Basin Fill | -- | -- | 8/4/2003 | 15 | 6,011 |
| 180-09 | 180 N07 E63 27CD 1 | 180 N07 E63 27CD 1 | 684,288 | 4,255,971 | 5,988 | Well-Basin Fill | 245 | 200 to 240 | 5/15/1998 | 157 | 5,831 |
| 180-10 | 180 N07 E63 27DD 1 | 180 N07 E63 27DD 1 | 685,088 | 4,255,990 | 5,988 | Well-Basin Fill | 290 | 240 to 280 | 5/15/1998 | 168 | 5,820 |
| 180-11 | 180 N07 E63 27DD 2 | 180 N07 E63 27DD 2 | 685,088 | 4,255,990 | 5,988 | Well-Basin Fill | 320 | 260 to 300 | 7/15/1998 | 183 | 5,805 |
| 180-12 | 180 N07 E63 33D 1 | 180 N07 E63 33D 1 | 683,325 | 4,254,561 | 5,982 | Well-Basin Fill | 300 | 198 to 300 | 1/15/2000 | 192 | 5,790 |
| 180-13 | 382640114492801 | 180 N07 E64 19 1 Gulf Oil Corp | 689,787 | 4,257,364 | 6,005 | Well-Basin Fill | 265 | 240 to 265 | 3/15/1980 | 215 | 5,790 |
| 180-14 | 383458114473601 | 180 N08 E64 04ABDD1 USBLM | 692,206 | 4,272,813 | 6,224 | Well-Basin Fill | 200 | 160 to 200 | 2/21/2007 | 131 | 6,093 |
| 180-15 | 383307114471001 | 180 N08 E64 15BCBC1 USBLM | 692,846 | 4,269,374 | 6,163 | Well-Basin Fill | -- | -- | 5/29/2007 | 262 | 5,901 |
| 180-16 | 383056114501501 | 180 N08 E64 30CDBC1 USBLM | 688,462 | 4,265,229 | 6,087 | Well-Basin Fill | 352 | 50 to 352 | 7/11/1999 | 327 | 5,760 |
| 180-17 | 383501114504801 | 180 N09 E63 01A 1 | 687,559 | 4,283,005 | 6,536 | Well-Basin Fill | -- | -- | 10/16/1962 | 2 | 6,534 |
| 180-18 | 383828114474501 | 180 N09 E64 16ACB 1 Cave Spring | 691,761 | 4,279,249 | 6,488[e] | Spring | -- | -- | -- | -- | 6,488 |
| 180-19 | 383632114465801 | 180 N09 E64 27BCDD1 USBLM | 692,983 | 4,275,700 | 6,414 | Well-Basin Fill | 315 | 277 to 315 | 5/29/2007 | 221 | 6,193 |
| 180-20 | 384207114505601 | 180 N10 E63 25A 1 | 686,984 | 4,285,891 | 6,604 | Well-Basin Fill | 20 | -- | 9/22/2006 | 14 | 6,590 |
| 180-21 | 384534114495301 | 180 N10 E64 06BDA 1 Robbers Roost Well | 688,337 | 4,292,295 | 6,848 | Well-Basin Fill | -- | -- | 7/26/2005 | 140 | 6,708 |
| 180-22 | 180 N11 E63 25DD 1 | 180 N11 E63 25DD 1 | 687,670 | 4,294,728 | 6,987 | Well-Basin Fill | 140 | 100 to 140 | 4/15/1998 | 91 | 6,896 |
| 180-23 | 382458114474301 | 180 S07 E64 33 1 Sidehill Spring | 692,408 | 4,254,280 | 6,531[e] | Spring | -- | -- | -- | -- | 6,531 |
| 180-24 | 180W501M | 180W501M | 688,048 | 4,273,716 | 6,457 | Well-Carbonate | 1,212 | 788 to 1,192 | 9/7/2007 | 1,051 | 5,406 |
| 180-25 | 180W902M | 180W902M | 689,805 | 4,248,363 | 5,987 | Well-Carbonate | 903 | 196 to 882 | 9/26/2007 | 138 | 5,849 |
| 180-26 | 382738114525601 | 180 N07 E63 15C 1 | 684,703 | 4,259,034 | 6,004 | Well-Basin Fill | -- | -- | 1/1/1900 | 300 | 5,704 |
| 180-27 | 381624114540302 | 180 N05 E63 34BBCC2 USBLM | 683,551 | 4,238,220 | 6,229 | Well-Basin Fill | -- | -- | 8/25/2003 | 8 | 6,221 |
| 181-01 | 375624114444501 | 181 N01 E62 24ABB 1 USBLM | 698,010 | 4,201,548 | 4,695 | Well-Basin Fill | 515 | 400 to 515 | 11/13/2006 | 48 | 4,648 |
| 181-02 | 181 N01 E65 02AA 1 | 181 N01 E65 02AA 1 | 706,529 | 4,206,411 | 5,663 | Well-Volcanic | -- | -- | 6/15/1960 | 10 | 5,653 |
| 181-03 | 181 N02 E63 13CA 1 | 181 N02 E63 13CA 1 Coyote Spring | 687,693 | 4,211,513 | 5,224[e] | Spring | -- | -- | -- | -- | 5,224 |
| 181-04 | 380336114473501 | 181 N02 E64 03B 1 USBLM | 693,124 | 4,215,351 | 4,972 | Well-Basin Fill | 742 | 702 to 742 | 5/9/2006 | 658 | 4,314 |
| 181-05 | 380531114534201 | 181 N03 E63 27CAA 1 USGS-MX (N. Dry Lake) | 684,519 | 4,218,103 | 5,391 | Well-Carbonate | 2,395 | No perforations | 7/25/2007 | 846 | 4,545 |

# Table 3-1
## Water Level Data for Selected Wells and Springs in Cave, Dry Lake, and Delamar Valleys
(Page 2 of 2)

| Map-ID | Station Number | Station Name | Location | | Ref. Pt. Elev.[b] (ft-amsl) | Site Type | Well Depth (ft-bgs) | Open Interval (ft-bgs) | Last Water Level Measurement Date | Last Depth to Water[c] (ft-bgs) | Water Level Elevation[d] (ft-amsl) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | UTM Easting[a] (m) | UTM Northing[a] (m) | | | | | | | |
| 181-06 | 380616114494101 | 181 N03 E64 20BD 1 USBLM - Coyote Well | 690,486 | 4,220,368 | 5,071 | Well-Basin Fill | 380 | 50 to 380 | 5/29/2007 | 269 | 4,801 |
| 181-07 | 380550114412301 | 181 N03 E65 21D 1 Bristol Well | 702,610 | 4,219,921 | 5,464 | Well-Basin Fill | 80 | 20 to 80 | 5/29/2007 | 20 | 5,444 |
| 181-08 | 181 N03 E65 22 1 | 181 N03 E65 22 1 | 703,867 | 4,220,163 | 5,593 | Well-Basin Fill | 240 | 60 to 240 | 1/15/1966 | 3 | 5,590 |
| 181-09 | 381256114500701 | 181 N04 E64 07DC 1 USGS-MX (Muleshoe Valley) | 689,481 | 4,232,096 | 5,534 | Well-Basin Fill | 1,190 | 1,050 to 1,190 | 5/29/2007 | 253 | 5,280 |
| 181-10 | 381256114500702 | 181 N04 E64 07DC 2 USGS-MX | 689,526 | 4,232,282 | 5,539 | Well-Basin Fill | 672 | 50 to 672 | 8/27/2003 | 269 | 5,270 |
| 181-11 | 381256114500703 | 181 N04 E64 07DC 3 USGS-MX | 689,526 | 4,232,282 | 5,539 | Well-Basin Fill | 1,134 | 50 to 1,134 | 3/10/1990 | 253 | 5,285 |
| 181-12 | 381358114412201 | 181 N04 E65 04DBD 1 Little Field Spring | 701,112 | 4,233,949 | 6,150[e] | Spring | -- | -- | -- | -- | 6,150 |
| 181-13 | 181 N04 E65 26DC 1 | 181 N04 E65 26DC 1 | 705,540 | 4,227,429 | 6,319 | Well-Volcanic | 81 | 60 to 80 | 10/15/1954 | 50 | 6,268 |
| 181-14 | 381029114430701 | 181 N04 E65 29CB 1 Spring | 699,080 | 4,227,795 | 6,090[e] | Spring | -- | -- | -- | -- | 6,090 |
| 181-15 | 381506114421801 | 181 N05 E65 32AD 1 Spring | 700,888 | 4,236,201 | 6,178[e] | Spring | -- | -- | -- | -- | 6,178 |
| 181-16 | 181 N05 E65 34DC 1 | 181 N05 E65 34DC 1 | 703,684 | 4,235,544 | 6,549 | Well-Volcanic | 28 | 10 to 28 | 5/1/1972 | 10 | 6,539 |
| 181-17 | 181 N05 E65 35BA 1 | 181 N05 E65 35BA 1 | 704,865 | 4,236,789 | 6,642 | Well-Volcanic | 22 | 12 to 22 | 7/15/1972 | 12 | 6,630 |
| 181-18 | 374536114443001 | 181 S02 E65 19CA 1 | 698,859 | 4,181,583 | 4,672 | Well-Basin Fill | 156 | 50 to 156 | 4/28/1994 | 49 | 4,623 |
| 181-19 | 374215114453101 | 181 S03 E64 12AC 1 USGS-MX (S. Dry Lake Well) | 697,515 | 4,175,351 | 4,643 | Well-Basin Fill | 1,000 | 600 to 970 | 7/30/2007 | 394 | 4,249 |
| 181-20 | 374215114453102 | 181 S03 E64 12AC 2 USGS-MX | 697,515 | 4,175,351 | 4,643 | Well-Basin Fill | 1,300 | 1,270 to 1,290 | 7/30/2007 | 382 | 4,262 |
| 181-21 | 374215114453103 | 181 S03 E64 12AC 3 USGS-MX | 697,515 | 4,175,351 | 4,643 | Well-Basin Fill | 798 | 768 to 788 | 3/10/1990 | 382 | 4,261 |
| 181-22 | 181M-1 | 181M-1 | 688,537 | 4,198,181 | 4,966 | Well-Carbonate | 1,472 | 765 to 1,471 | 9/4/2007 | 675 | 4,291 |
| 181-23 | 181W909M | 181W909M | 698,688 | 4,174,479 | 4,804 | Well-Basin Fill | 1,260 | 637 to 1,240 | 9/4/2007 | 497 | 4,307 |
| 181-24 | 181 S03 E63 22AB 1 | 181 S03 E63 22AB 1 | 684,620 | 4,172,308 | 5,313 | Well-Basin Fill | -- | -- | 3/15/1966 | 3 | 5,310 |
| 181-25 | 181 S04 E64 07AC 1 | 181 S04 E64 07AC 1 Jacob 7B | 689,759 | 4,165,424 | 4,810 | Well-Basin Fill | -- | 50 to 1,000 | 5/26/2003 | 515 | 4,295 |
| 182-01 | 182 S05 E64 02CB 1 | 182 S05 E64 02CB 1 Grassy Spring | 695,124 | 4,157,193 | 5,786[e] | Spring | -- | -- | -- | -- | 5,786 |
| 182-02 | 372639114520901 | 182 S06 E63 12AD 1 USGS-MX (Delamar Well) | 688,422 | 4,146,273 | 4,713 | Well-Basin Fill | 1,195 | 920 to 980/<br>1,040 to 1,180 | 7/30/2007 | 863 | 3,850 |
| 182-03 | 372639114520902 | 182 S06 E63 12ADBD2 USGS-MX | 688,422 | 4,146,273 | 4,713 | Well-Basin Fill | 981 | 540 to 630/<br>816 to 847/<br>877 to 940/<br>950 to 971 | 4/1/1981 | 867 | 3,846 |
| 182-04 | 182M-1 | 182M-1 | 680,874 | 4,135,306 | 4,582 | Well-Volcanic | 1,321 | 1,000 to 1,300 | 9/4/2007 | 827 | 3,755 |
| 182-05 | 182W906M | 182W906M | 690,078 | 4,133,299 | 4,802 | Well-Volcanic | 1,702 | 1,274 to 1,677 | 9/4/2007 | 1,316 | 3,486 |
| 209-04 | 209M-1 | 209M-1 | 677,377 | 4,168,166 | 5,123 | Well-Carbonate | 1,616 | 1,273 to 1,595 | 9/4/2007 | 1,200 | 3,923 |

[a]Coordinates are in Universal Transverse Mercator, Zone 11, North American Datum of 1983.
[b]Elevations are in North American Vertical Datum of 1988.
[c]Sources: Luzier, 2003; NDWR, 2004; SNWA Field Measurements; USGS, 2004; USGS, 2007
[d]Calculated using last depth-to-water measurement.
[e]USGS, 2001 DEM

portion of the valley to approximately 5,800 ft-amsl in the south (Figure 3-1). These water-level elevations indicate a north-to-south hydraulic gradient of approximately 0.009.

### Carbonate Aquifer

As described in Section 2.0, Cave Valley is effectively partitioned into two sub-basins by the northeast-striking oblique-slip Shingle Pass Fault that has displaced a part of the Egan Range, forming an east-dipping tilt block that extends northeast across and underneath Cave Valley where it terminates against the range-front fault of the Schell Creek Range. This partitioning is reflected in the limited carbonate water-level data.

In the northern sub-basin, a well constructed by SNWA and completed in carbonate rocks to a depth of 1,212 ft-bgs, has a depth-to-water of about 1,051 ft-bgs and water-level elevation of about 5,406 ft-amsl (Figure 3-1). Groundwater production from this well was very limited during air-lift development and subsequent pumping to purge the well before water-chemistry sampling, suggesting that the hydraulic connection between the well and the regional carbonate aquifer is also very limited. The water-level elevation most likely represents the hydraulic head of the nearby Shingle Pass Fault through which a small amount of inter-basin flow from Cave Valley to White River Valley is presumed to occur (Appendix D of Part A). This well is about 80 ft higher than the elevation of nearby local springs in adjacent White River Valley.

In the southern sub-basin, there are two groundwater sites indicative of hydraulic heads in the carbonate aquifer. The first is a well cluster located on the western margin of the basin drilled as part of the USAF MX-Missile Program (Figure 3-1). Depth-to-water at this location is about 220 ft-bgs with a water-level elevation of about 5,790 ft-amsl. The second location is a SNWA monitor well located at the western range-front fault of the Schell Creek Range, near Sidehill Pass. Depth-to-water at this location is about 140 ft-bgs, with a water-level elevation of about 5,850 ft-amsl. Water-level elevations ranging from about 5,850 to 5,790 ft-amsl in the southern sub-basin are almost 450 ft higher than the well site in the northern sub-basin.

### Water-Level Trends

The Cave Valley MX well (Map ID 180-07), located in the south-central portion of the valley, has shown a subtly rising water-level trend since the early 1980s with about a 10 ft increase in the overall water-level elevation for the well (Figure 3-2). This well was identified as penetrating the carbonate rocks. Inspection of the other hydrographs for Cave Valley found in Appendix A show a similar type of increasing trend. The other wells for which hydrographs were constructed were identified as penetrating basin-fill materials.

### Interbasin Flows

As described in Appendix D of Part A of this report, groundwater outflow from Cave Valley is thought to occur on the western side of Cave Valley through Shingle Pass to the southern third of White River Valley, and through the southern portion of the valley to northern Pahroc Valley. Outflow from Cave Valley to White River Valley occurs through fractured bedrock associated with the Shingle Pass Fault and was estimated to be less than 4,000 afy (Appendix D of Part A). The outflow from southern Cave Valley to the northeastern portion of Pahroc Valley occurs through fractured carbonate bedrock and along fault zones associated with the west range-front fault of the

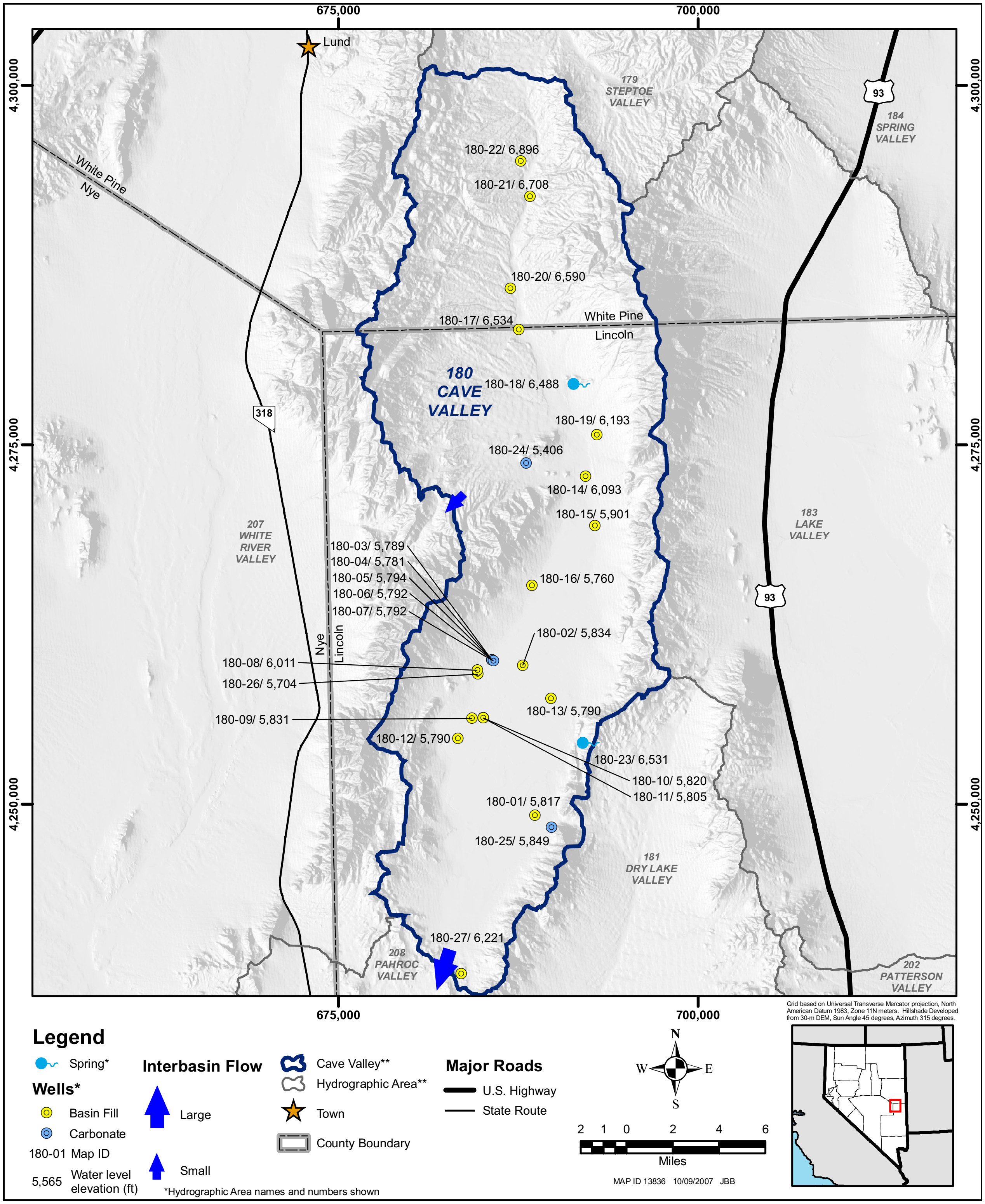


**Figure 3-1**
**Cave Valley Water-Level Elevation Map**

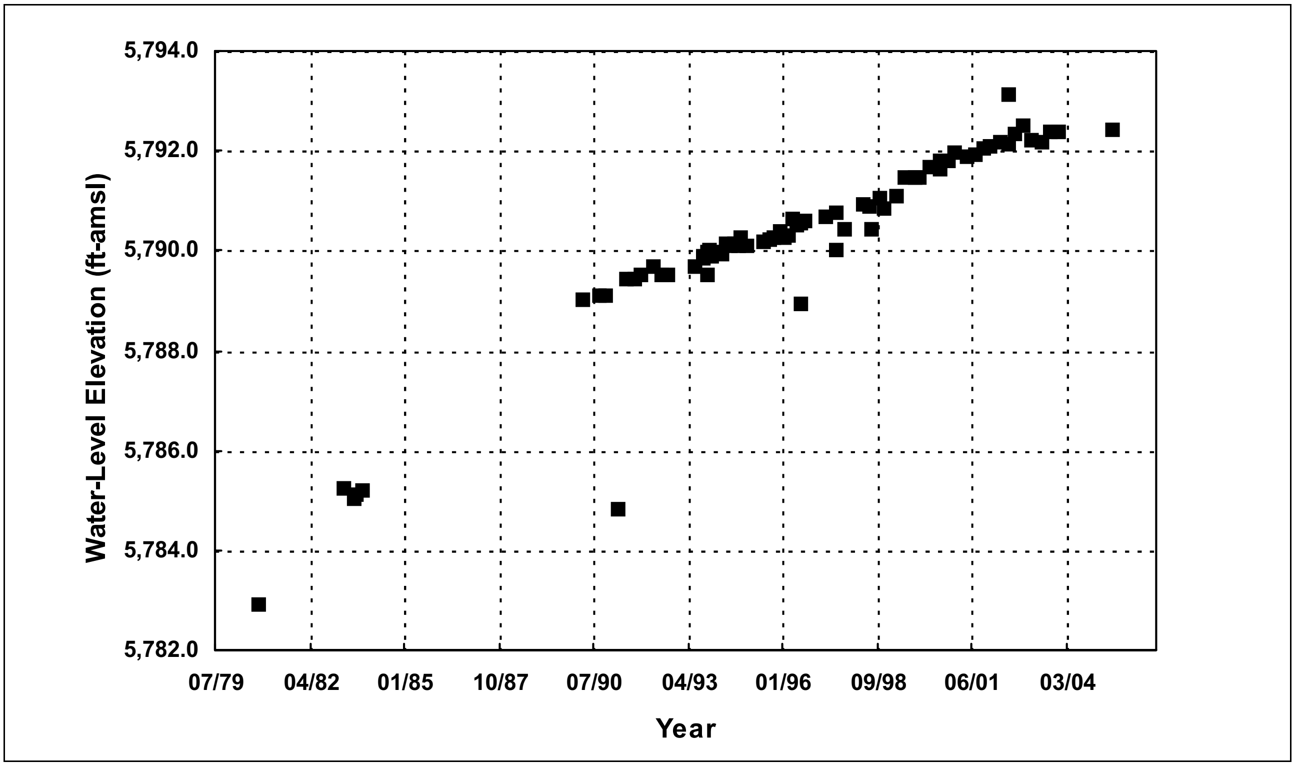


**Figure 3-2**
**Historical Water-Level Elevations at Cave Valley MX Well (Map ID 180-07)**

southern Schell Creek Range. Outflow at this location was estimated to be 9,400 afy (Appendix D of Part A, p. D-6).

### *3.3 Dry Lake Valley and Delamar Valley*

As described in the geology and geophysical discussion of Section 2.0, Dry Lake and Delamar Valleys are essentially one basin from a geologic framework perspective. This conclusion is supported by the available water-level data compiled and evaluated for the two basins.

Twenty-five groundwater sites were compiled for Dry Lake and Delamar Valleys; 17 are completed in the basin fill, 6 are completed in volcanic rocks, and 2 are completed in carbonate rocks. Like Cave Valley, most of the basin-fill wells were drilled for stock watering where depths to water are relatively shallow. As with Cave Valley, the remaining wells were drilled as part of groundwater exploration and monitoring programs involving the USAF MX-Missile Program or SNWA.

SNWA constructed two monitor wells in Dry Lake Valley and two monitor wells in Delamar Valley in 2005. In Dry Lake Valley, one well was drilled to 1,260 ft-bgs and completed in the basin-fill (181W909M), while the other well was drilled to 1,472 ft-bgs and completed in carbonate rocks (181M-1). SNWA monitor wells constructed in Delamar Valley (182M-1 and 182W906M) were drilled to 1,321 and 1,702 ft-bgs, respectively, both completed in volcanic rocks. SNWA constructed a fifth well (209-M1) in Pahranagat Valley at the northwest margin of Delamar Valley, which was drilled to 1,616 ft-bgs and completed in carbonate rocks.

### *Basin-Fill Aquifer*

The NDWR driller's logs indicate the basin fill of Dry Lake and Delamar Valleys consists primarily of sands and gravels, with increasing clay content and thicker sequences of volcanic tuff to the south. The water-level data indicate that the depth to water in northern Dry Lake Valley is relatively shallow, ranging from 10 to about 270 ft-bgs. The depth to water deepens to the south, where it ranges from 3 to about 658 ft-bgs in the central and southern portion of Dry Lake Valley, and exceeds 1,300 ft-bgs in southeastern Delamar Valley. Water-level elevations range from 6,540 to 5,270 ft-amsl in the northern portion of Dry Lake Valley, and from 5,653 to 4,249 ft-amsl in the central and southern portion of the valley. Water-level elevations in Delamar Valley range from 3,850 ft-amsl in the central portion of the valley to about 3,490 in the southeastern portion of the valley. The systematic decrease in water-level elevations from northern Dry Lake Valley to southern Delamar Valley are indicative of a north-south gradient and direction of groundwater flow. A hydraulic gradient from the central portion of Dry Lake Valley to the central portion of Delamar Valley was calculated to be 0.0025.

### *Carbonate Aquifer*

Two wells in the compiled data set were identified as penetrating the carbonate-rock aquifer. Both wells are located on the west side of Dry Lake Valley (Figure 3-3), with water-level elevations ranging from 4,545 to 4,291 ft-amsl. These water-level elevations are approximately 1,300 to 1,500 ft lower in elevation than carbonate-rock wells in Cave Valley to the north. An SNWA monitor well in Pahranagat Valley on the northwestern margin of Delamar Valley has an elevation of 3,923 ft-amsl, which is 370 to 620 ft lower than the water levels in the carbonate wells north of this location in Dry Lake Valley, and about 70 to 440 ft higher than the basin-fill wells in southern Delamar Valley.

### *Water-Level Trends*

Water-level fluctuations in Dry Lake and Delamar valleys appear to be minor with a slight upward trend over the past 25 years similar to the trend observed for Cave Valley. The water-level variations can likely be attributed to climatic variability, as there is little to no groundwater development in these two basins. Figure 3-4 shows that water-level elevations for the USGS-MX (N. Dry Lake Well) have increased approximately five feet from 1986 to the present. This well was identified as penetrating the carbonate-rock aquifer. The other wells for which hydrographs were constructed were identified as penetrating the basin-fill aquifer system. The other hydrographs are provided in Appendix A.

### *Interbasin Flows*

As described in Appendix D of Part A of this report, interbasin flow for Dry Lake Valley occurs as a minor amount of inflow from northern Pahroc Valley, and as outflow to Delamar Valley in the south. The location of inflow is coincident with a series of northwest-trending right-lateral faults that form the boundary between southern Cave Valley, northern Pahroc Valley, and northern Dry Lake Valley. The inflow at this location was estimated to be less than 2,000 afy (Appendix D of Part A). The outflow from Dry Lake Valley to northern Delamar Valley occurs through fractured carbonate rocks and the basin fill. These two hydrographic areas are topographically separated by a low alluvial divide, but are connected geologically and hydrologically making them one contiguous basin.

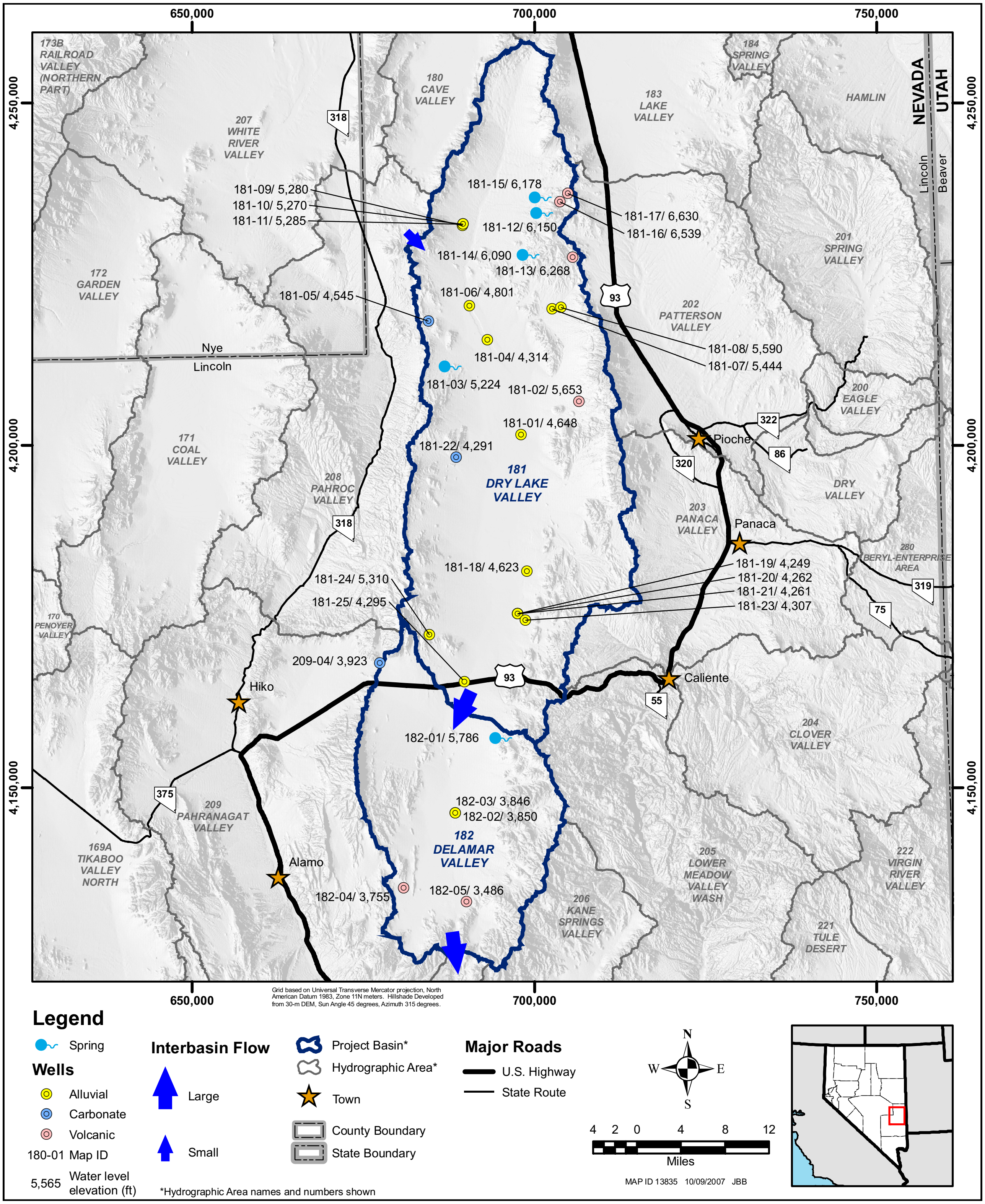


**Figure 3-3**
**Dry Lake and Delamar Valleys Water-Level Elevation Map**

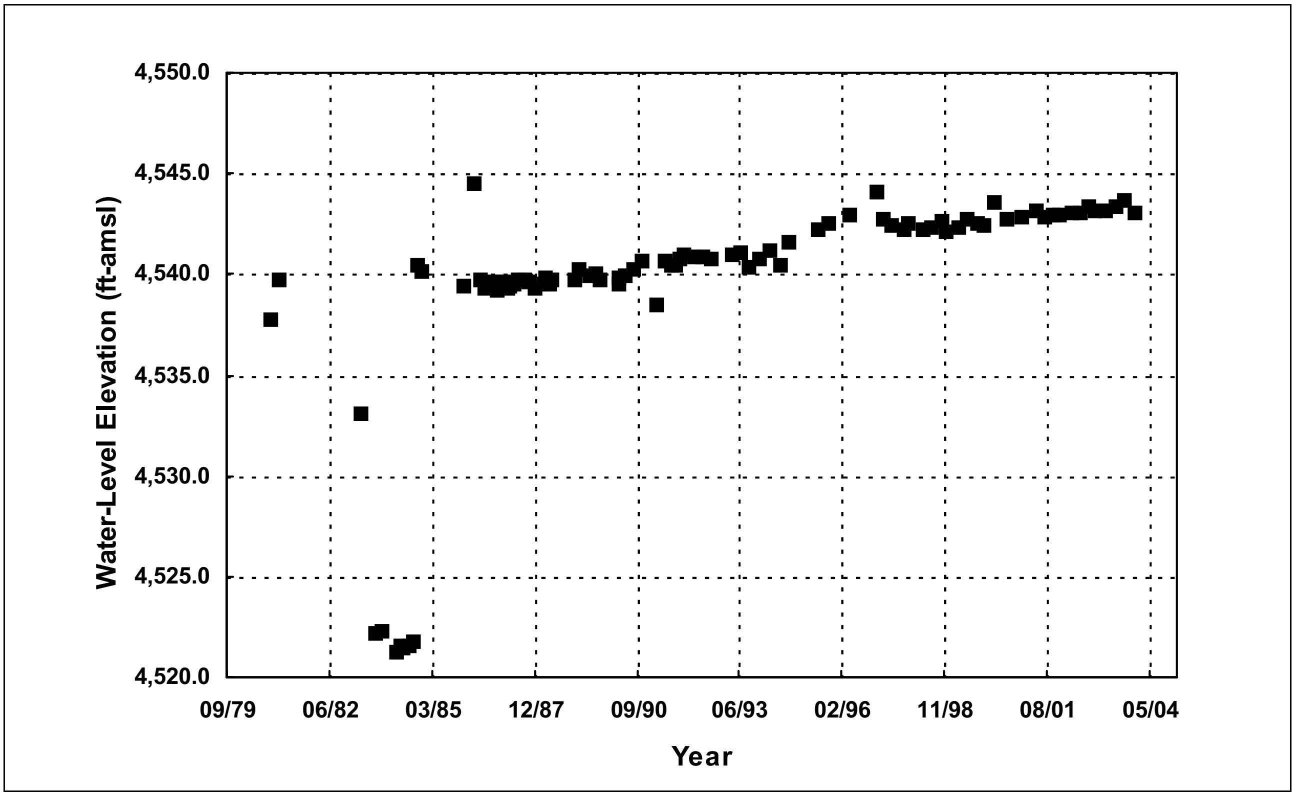


**Figure 3-4**
**Historical Water-Level Elevations at Dry Lake MX Well (Map ID 181-05)**

Groundwater outflow from Delamar Valley is controlled by the Kane Springs Wash caldera complex underlying the Delamar Mountains to the southeast, the South Pahroc Range and western Delamar Mountains and associated range-front faults to the west, and the northeast/southwest trending Pahranagat shear zone in the south. Regional flow through the caldera complex is unlikely, as the majority of flow occurs along the north-south trending range-front faults and the northeast extension of the Pahranagat Shear Zone to areas of lower potential in northern Coyote Spring Valley and possibly the very southern part of Pahranagat Valley. The range-front faults transition into right-lateral shear zones as they pass through southern Pahranagat Valley and become normal faults on the eastern side of the Sheep Range. Water-level elevation data from the few wells and springs in Delamar Valley and the adjacent areas of southern Pahranagat and northern Coyote Spring valleys indicate a hydraulic gradient to the southwest and south along the shear zone and into northern Coyote Spring Valley.

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# 4.0 SUMMARY AND CONCLUSIONS

Geologic and geophysical data and information was assembled and used to describe the geologic framework of Cave, Dry Lake, and Delamar valleys. The resultant framework is presented on Plate 1 of this report as a surficial geology map and a series of geologic cross sections. A groundwater-site inventory was completed to identify groundwater sites within the three basins, and included compiling relevant hydrologic data for the purpose of developing a conceptualization of groundwater flow within the basins. The results and conclusions of this effort is summarized for each basin in the following sections:

## 4.1 Cave Valley

### Geology

- In the east, Cave Valley is bounded by the southern extension of the Schell Creek Range which is comprised of an east-dipping and heavily faulted sequence of Precambrian to Tertiary rocks. The dominant fault is on the western flank of the range, and in the northeast portion of the valley, the range is cored by Precambrian to Cambrian quartzite.

- In the west, Cave Valley is bounded by the Egan Range, which is a complexly faulted, east-dipping horst comprised of Cambrian to Permian rocks overlain by Tertiary volcanic rocks.

- Cave Valley has been effectively partitioned into two sub-basins by the northeast-striking oblique-slip Shingle Pass Fault, which has displaced a part of the Egan Range, forming an east-dipping fault block that extends northeast across and underneath the valley where it terminates against the west range-front fault of the Schell Creek Range. This fault block contains the Mississippian Chainman Shale formation which, in this area, is considered a confining unit because of its thickness and hydraulic properties.

### Hydrogeology

- The northern sub-basin is relatively shallow as the depth to basement is typically no greater than 3,300 ft-bgs. The basin fill is comprised of mostly sands and gravels, and occasional cemented strata near the surface. Depth to water in the basin fill for this area ranges from 2 to 221 ft-bgs, with water-level elevations ranging from 6,896 to 6,119 ft-amsl. A single well drilled by SNWA to a depth of 1,212 ft-bgs has a depth to water of 1,051 ft-bgs and water-level elevation of 5,406 ft-amsl. This carbonate water-level is most likely reflective of the hydraulic head within the Shingle Pass Fault.

- The southern sub-basin is significantly deeper, with the depth to basement extending to almost 20,000 ft-bgs. The basin fill is comprised of mostly sands and gravels, but with greater clay content than the northern sub-basin. Depth to water in the basin fill ranges from 8 to 327 ft-bgs, with water-level elevations ranging from 6,221 to 5,704 ft-amsl. Two wells are completed in carbonate rocks on the east and west side of the sub-basin. Depth to water in these wells ranges from 140 to 220 ft-bgs, with water level elevations ranging from 5,850 to 5,790 ft-amsl.

- Within the basin fill, there is a north to south hydraulic gradient and direction of groundwater flow. The hydraulic heads in the carbonate rocks appear to be structurally controlled by the fault block associated with the Shingle Pass Fault, as reflected by the water-level elevations north and south of the block. Flow through this fault block is unlikely because of the presence of the Mississippian Chainman Shale formation.

- Water-level data indicate a slight increasing trend since the early 1980s of about 10 ft during the period of record. Because there is virtually no groundwater development within the basin, this trend is most likely reflective of the natural variability of the groundwater system.

### *Interbasin Flow*

- Inter-basin flow associated with Cave Valley is limited to a small amount of outflow through the Shingle Pass Fault zone to the southern third of White River Valley, and outflow from the southern portion of the valley to northern Pahroc Valley. These outflows are estimated to be about 4,000 afy and 9,400 afy, respectively.

- Inflow from southern Steptoe Valley is unlikely due to the lithology and structure of the geologic framework underlying northern Cave Valley. It is also likely that a groundwater divide between northern Cave Valley and southern Steptoe Valley exists because groundwater recharge occurs in this area. However, the available water-level data are insufficient to verify this conclusion.

## *4.2 Dry Lake and Delamar Valleys*

Dry Lake and Delamar valleys can be considered one basin from the geologic and hydrologic perspective. This is supported by the geologic and geophysical data compiled to develop the geologic framework, and hydraulic data used to conceptualize groundwater flow within the basins.

### *Geology*

- To the west, Dry Lake and Delamar valleys are bounded by the North Pahroc Range and the South Pahroc Range, respectively. The North Pahroc Range is a west-dipping horst consisting of upper Paleozoic rocks overlain by Tertiary volcanic rocks. The South Pahroc Range consists of a series of west-dipping volcanic rocks, which extend southward to southern Delamar Valley where they are terminated by the east-northeast trending Pahranagat Shear Zone.

- To the east, Dry Lake and Delamar valleys are bounded from north to south by the Fairview, Bristol, Highland, and Chief Ranges, and the Delamar Mountains to the south. To the north, the Fairview Range consists of Devonian to Pennsylvanian carbonate rocks, which are interrupted by the Indian Peak Caldera Complex. To the south, the Bristol, Highland and Chief Ranges consist of Cambrian carbonate rocks underlain by Precambrian to Cambrian quartzites. Further south, the Delamar Mountains consist of east-dipping Late Proterozoic to Cambrian rocks and Tertiary volcanic rocks associated with the Caliente and Kane Springs Wash caldera complexes.

- The geometry of Dry Lake and Delamar valleys was defined, in part, by gravity surveys and depth to basement estimates which indicate the presence of low saddles to the north adjoining northern Dry Lake Valley (a.k.a. Muleshoe Valley) and to the south adjoining Delamar Valley. Two grabens are present in Dry Lake Valley, one along the margins of the valley and another along the central axis of the valley. The depth to basement in these areas are estimated to range from about 3,300 to almost 10,000 ft-bgs. In southwest Delamar Valley, a bowl-shaped basin is inferred, and the maximum depth to basement is estimated to be almost 7,000 ft-bgs, with much of the area only about 5,000 ft-bgs.

### *Hydrogeology*

- The basin fill of Dry Lake and Delamar Valleys consists primarily of sands and gravels, with increasing clay content and thicker sequences of volcanic tuffs to the south.

- Depth to water in Dry Lake and Delamar Valleys ranges from 3 to 1,316 ft-bgs, and deepens to the south. Water-level elevations range from 6,630 to 3,486 ft-amsl and indicate a north to south gradient and direction of groundwater flow in both the basin fill and carbonate aquifer. This conceptualization of flow is supported by the data and is consistent with previous investigations by Eakin (1966), Scott et al. (1971) and Harrill et al. (1988).

### *Interbasin Flow*

- Interbasin flow is limited by the geologic framework and occurs as a minor amount of inflow from northern Pahroc Valley to Dry Lake Valley, and as outflow from Delamar Valley to Coyote Spring Valley.

- The location of inflow is coincident with a series of northwest-trending right-lateral faults that form the boundary between southern Cave Valley, northern Pahroc Valley, and northern Dry Lake Valley. The inflow is estimated to be about 2,000 afy (Appendix D of Part A).

- Groundwater flows from Dry Lake Valley to Delamar Valley where flow is controlled by the Caliente and Kane Springs Wash caldera complexes to the east, and the South Pahroc Range and associated range-front faults to the west. The geologic framework in this area precludes flow to Pahranagat Valley to the west and Lake and Patterson Valleys to the east.

- Interbasin outflow from Delamar occurs along and across the Pahranagat Shear Zone and into northern Coyote Spring Valley and possibly the very southern part of Pahranagat Valley. This outflow is estimated to be about 24,000 afy and is comprised of the inflow from northern Pahroc Valley and locally-derived recharge generated from within hydrographic area boundaries.

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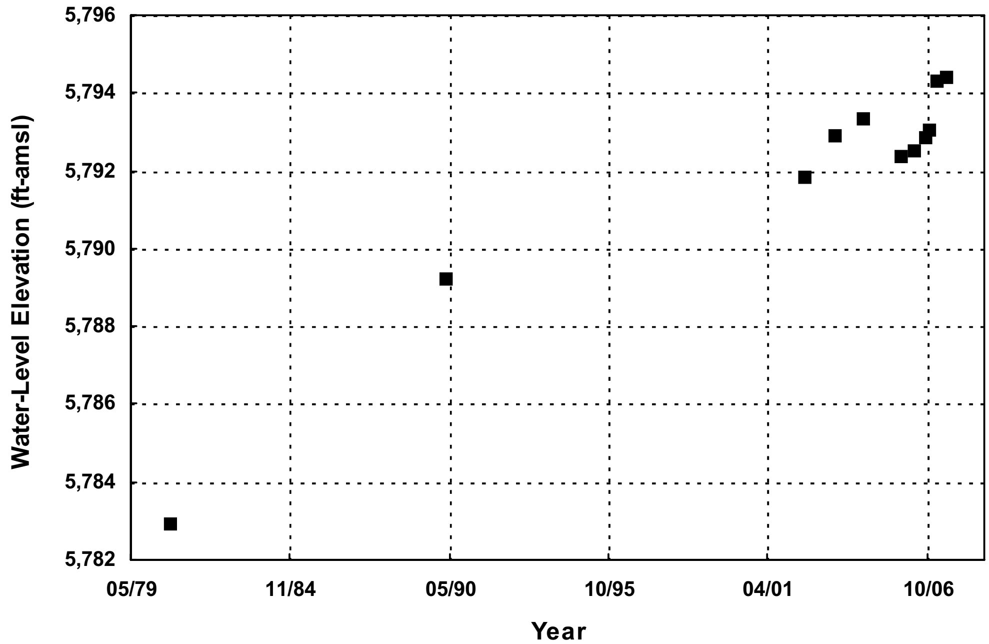
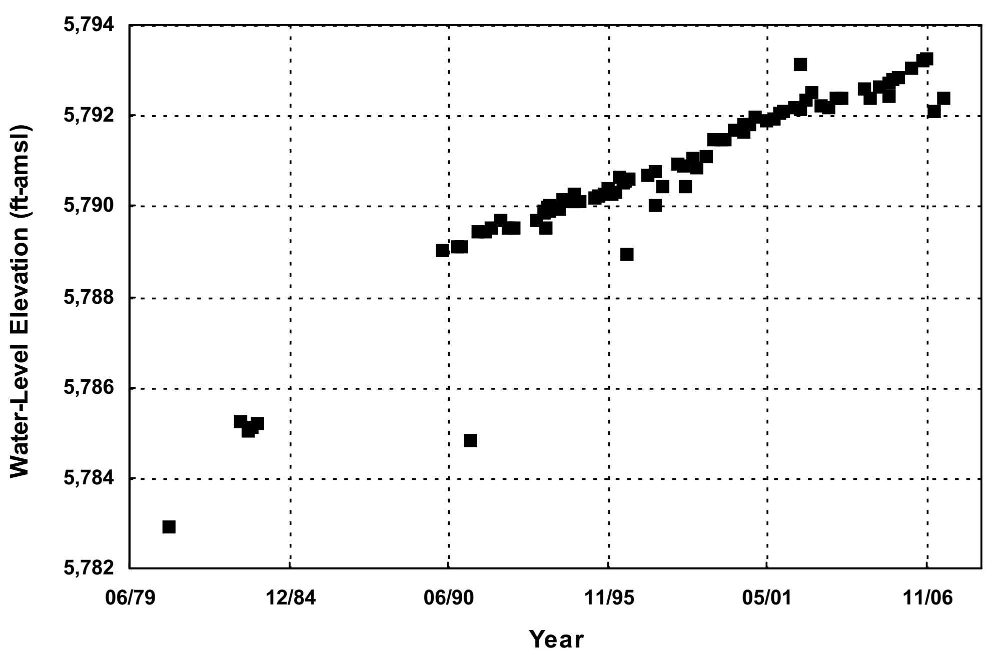
# Appendix A

# Hydrographs for Wells in Cave, Dry Lake, and Delamar Valleys



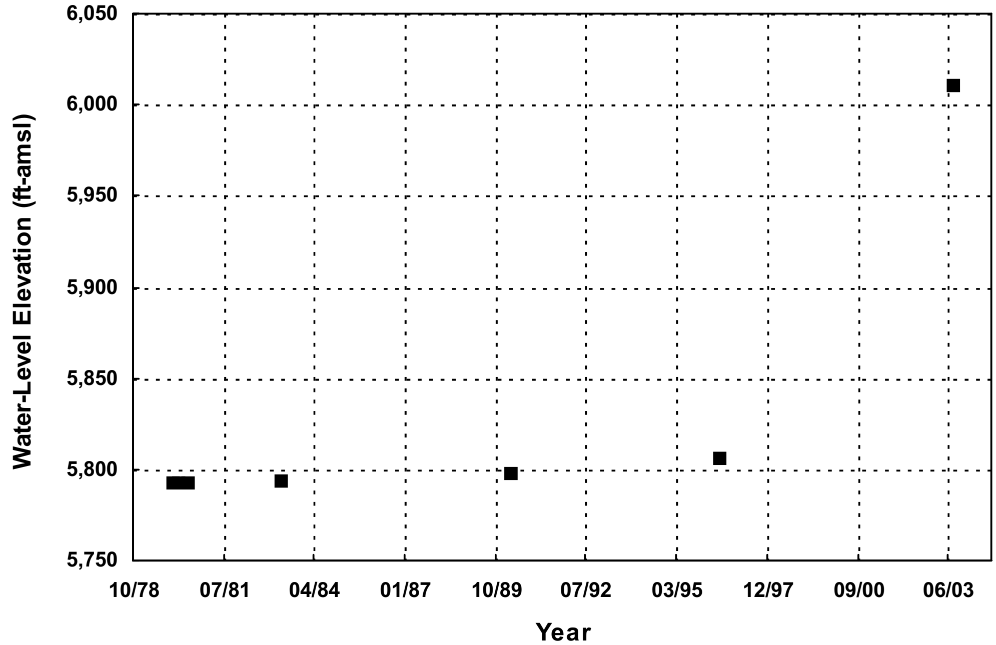

| | | | |
|---|---|---|---|
| **Basin Name:** | **Cave Valley** | **Land Surface (ft-amsl):** | **6,013** |
| **Aquifer Type:** | **Basin Fill** | **Well Depth (ft-bgs):** | **269** |

**Figure A.1-1**
**Historical Water-Level Elevations at 180 N07 E63 14BADB1 USAF (Map ID 180-05)**



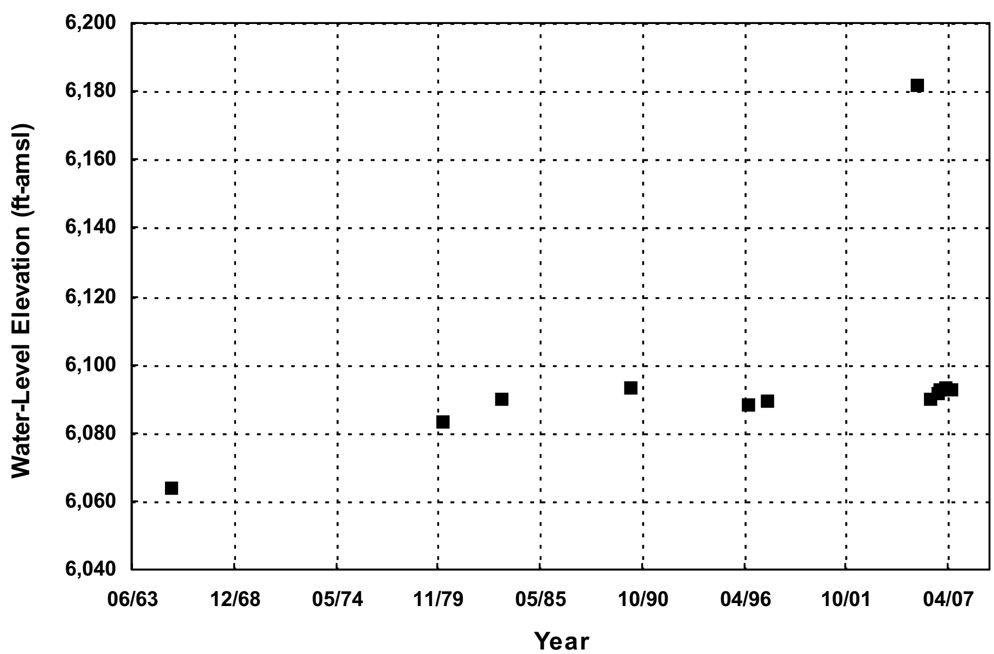

| | | | |
|---|---|---|---|
| **Basin Name:** | **Cave Valley** | **Land Surface (ft-amsl):** | **6,012** |
| **Aquifer Type:** | **Carbonate Well** | **Well Depth (ft-bgs):** | **460** |

**Figure A.1-2**
**Historical Water-Level Elevations at 180 N07 E63 14BADD1 USGS-MX (Cave Valley) (Map ID 180-07)**




| | | | |
|---|---|---|---|
| **Basin Name:** | **Cave Valley** | **Land Surface (ft-amsl):** | **6,026** |
| **Aquifer Type:** | **Basin Fill** | **Well Depth (ft-bgs):** | |

**Figure A.1-3**
**Historical Water-Level Elevations at 180 N07 E63 15DBAD1 USBLM (Map ID 180-08)**




| | | | |
|---|---|---|---|
| **Basin Name:** | **Cave Valley** | **Land Surface (ft-amsl):** | **6,224** |
| **Aquifer Type:** | **Basin Fill** | **Well Depth (ft-bgs):** | **200** |

**Figure A.1-4**
**Historical Water-Level Elevations at 180 N08 E64 04ABDD1 USBLM (Map ID 180-14)**

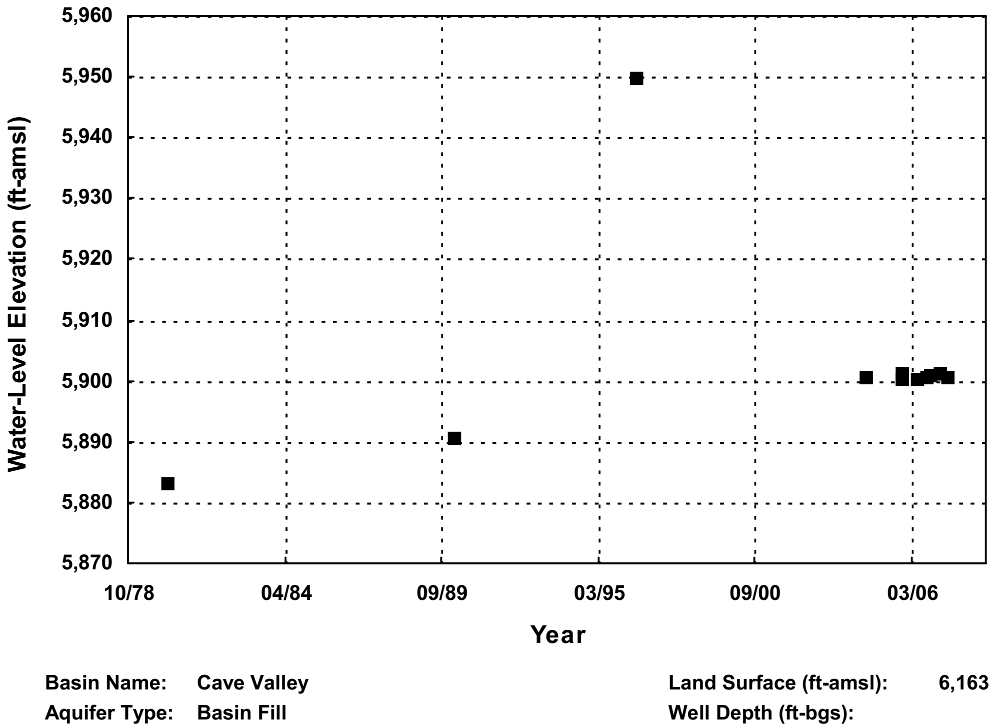



**Figure A.1-5**
**Historical Water-Level Elevations at 180 N08 E64 15BCBC1 USBLM (Map ID 180-15)**

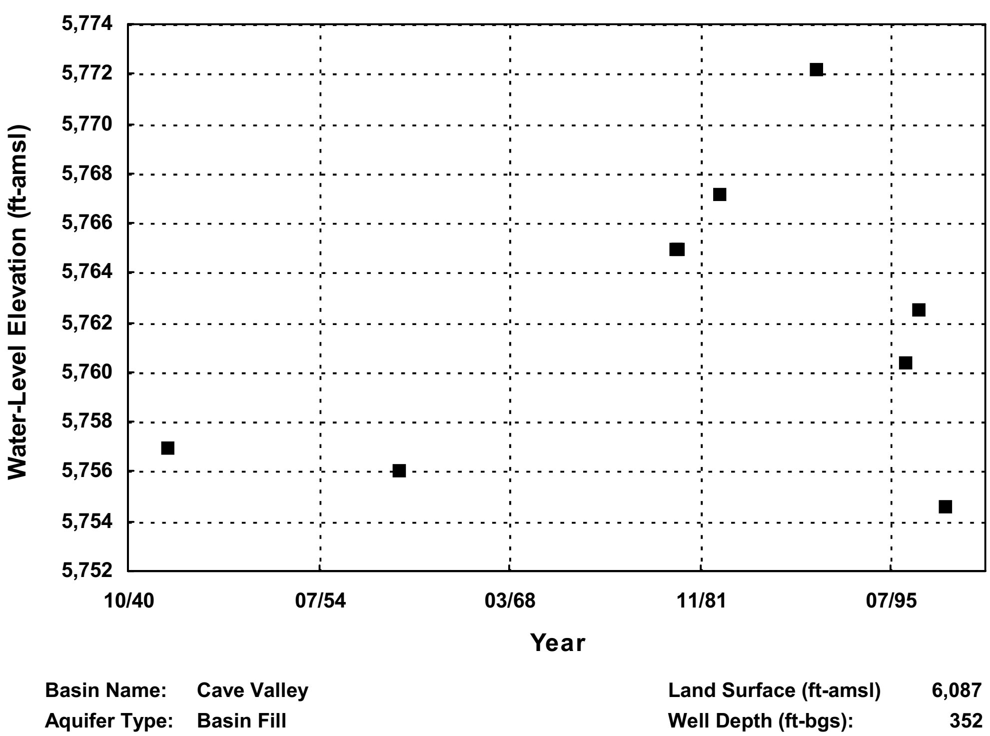
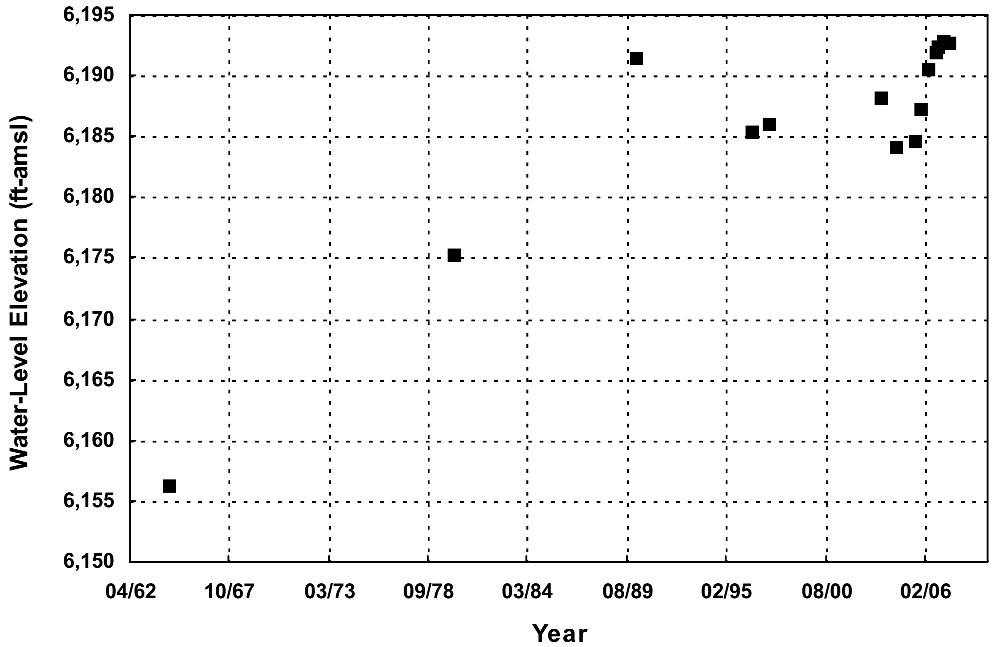
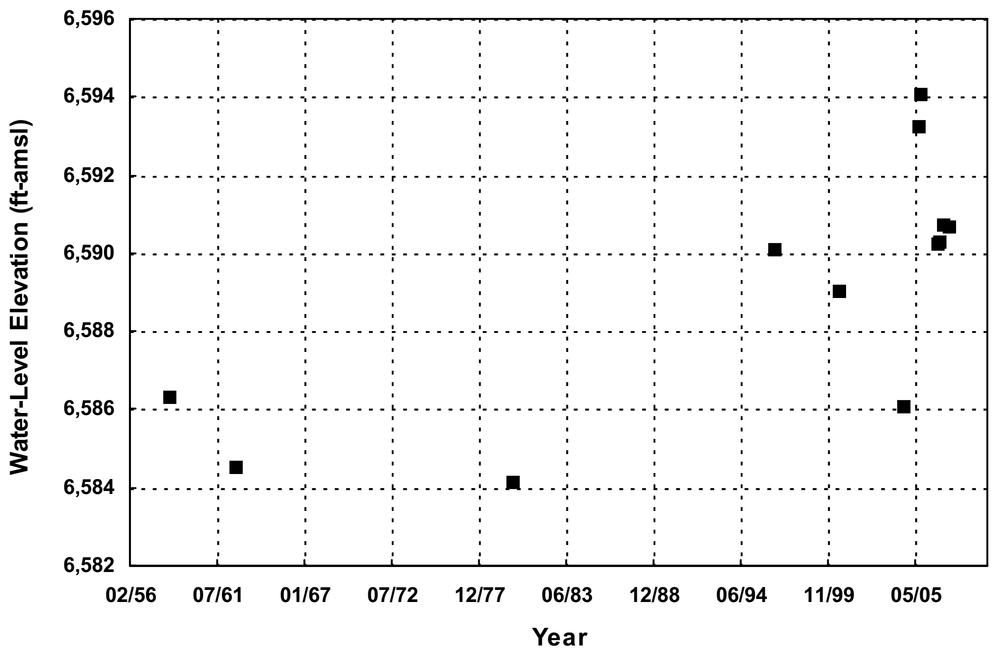



**Figure A.1-6**
**Historical Water-Level Elevations at 180 N08 E64 30CDBC1 USBLM (Map ID 180-16)**



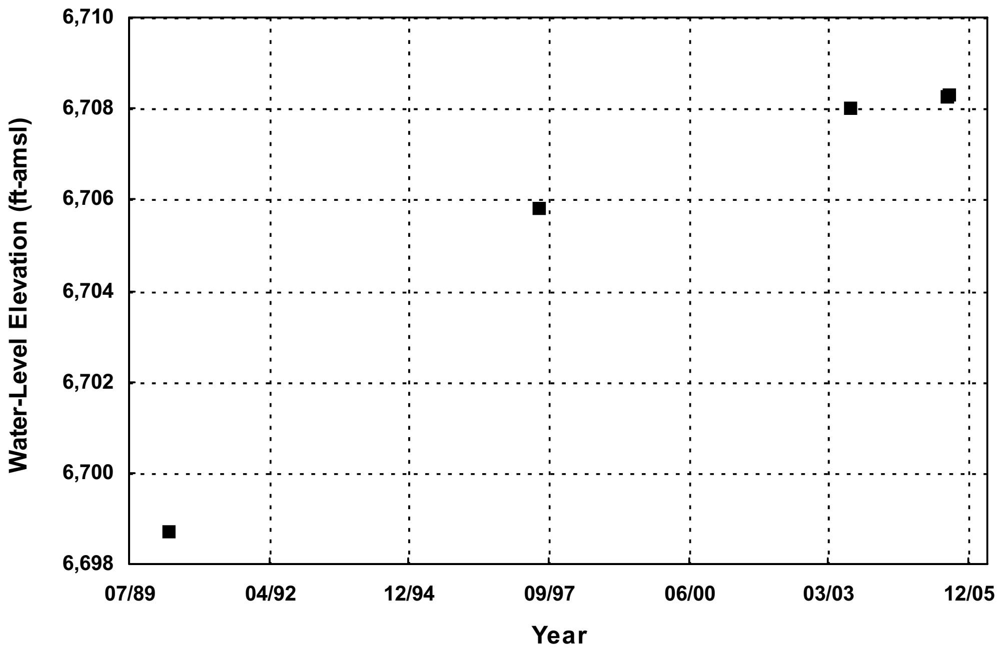

| | | | |
|---|---|---|---|
| **Basin Name:** | **Cave Valley** | **Land Surface (ft-amsl):** | **6,414** |
| **Aquifer Type:** | **Basin Fill** | **Well Depth (ft-bgs):** | **315** |

**Figure A.1-7**
**Historical Water-Level Elevations at 180 N09 E64 27BCDD1 USBLM (Map ID 180-19)**



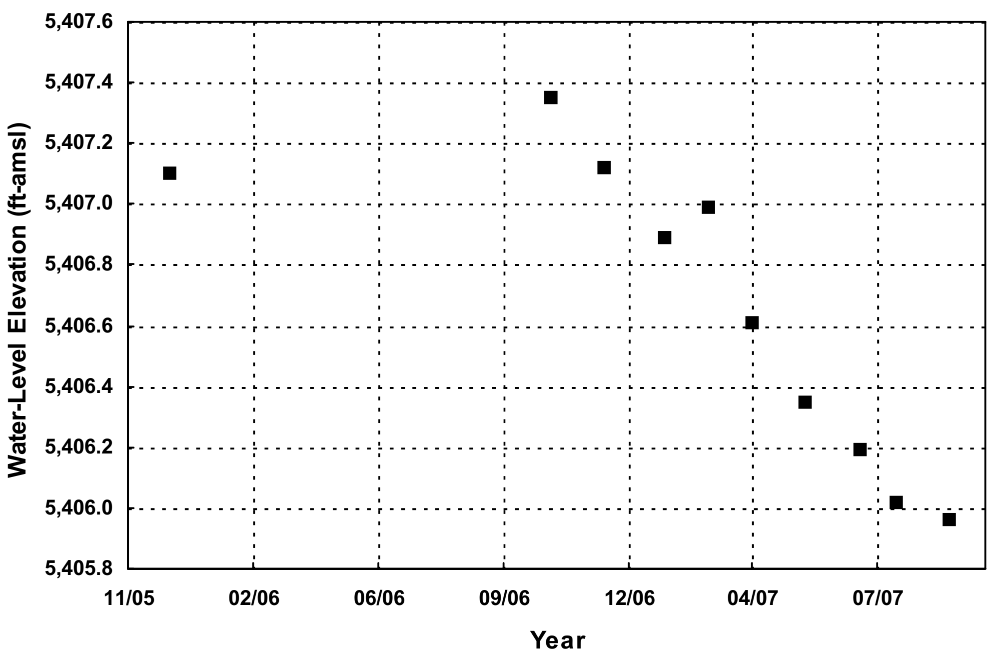

| | | | |
|---|---|---|---|
| **Basin Name:** | **Cave Valley** | **Land Surface (ft-amsl):** | **6,604** |
| **Aquifer Type:** | **Basin Fill** | **Well Depth (ft-bgs):** | **20** |

**Figure A.1-8**
**Historical Water-Level Elevations at 180 N10 E63 25A 1 (Map ID 180-20)**



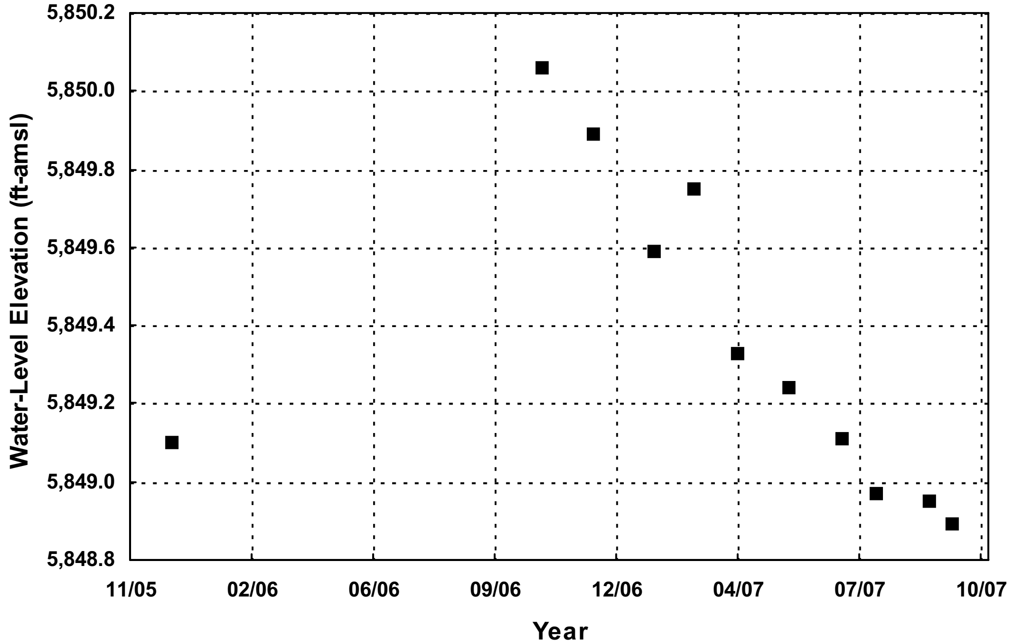

| | | | |
|---|---|---|---|
| **Basin Name:** | **Cave Valley** | **Land Surface (ft-amsl):** | **6,848** |
| **Aquifer Type:** | **Basin Fill** | **Well Depth (ft-bgs):** | |

**Figure A.1-9**
**Historical Water-Level Elevations at 180 N10 E64 06BDA 1 Robbers Roost Well (Map ID 180-21)**



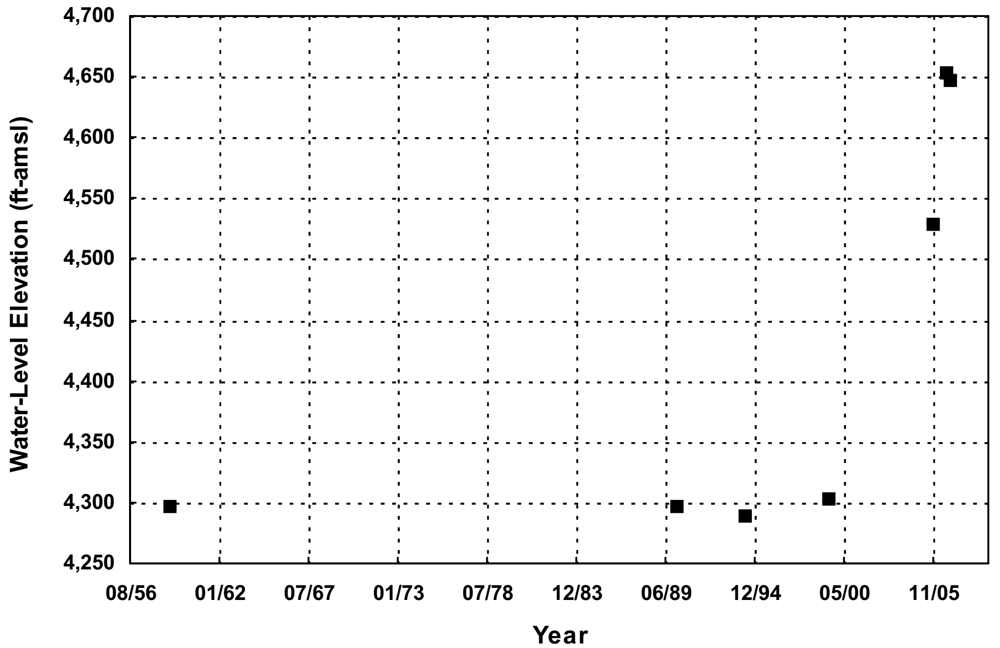

| | | | |
|---|---|---|---|
| **Basin Name:** | **Cave Valley** | **Land Surface (ft-amsl):** | **6,457** |
| **Aquifer Type:** | **Carbonate Well** | **Well Depth (ft-bgs):** | **1,212** |

**Figure A.1-10**
**Historical Water-Level Elevations at 180W501M (Map ID 180-24)**



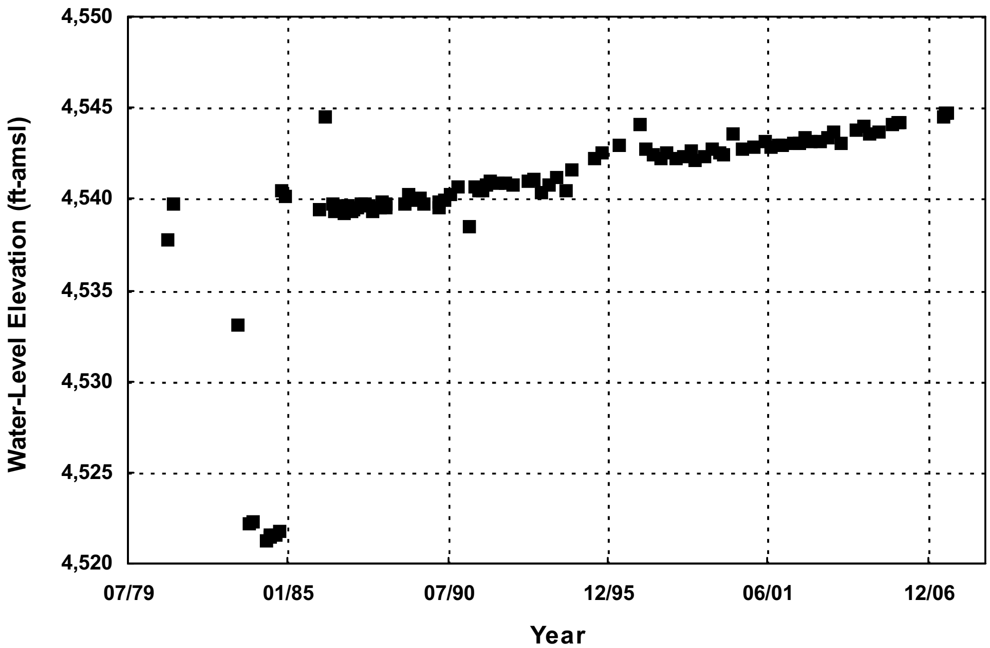

| | | | |
|---|---|---|---|
| Basin Name: | Cave Valley | Land Surface (ft-amsl): | 5,987 |
| Aquifer Type: | Carbonate Well | Well Depth (ft-bgs): | 903 |

**Figure A.1-11**
**Historical Water-Level Elevations at 180W902M (Map ID 180-25)**



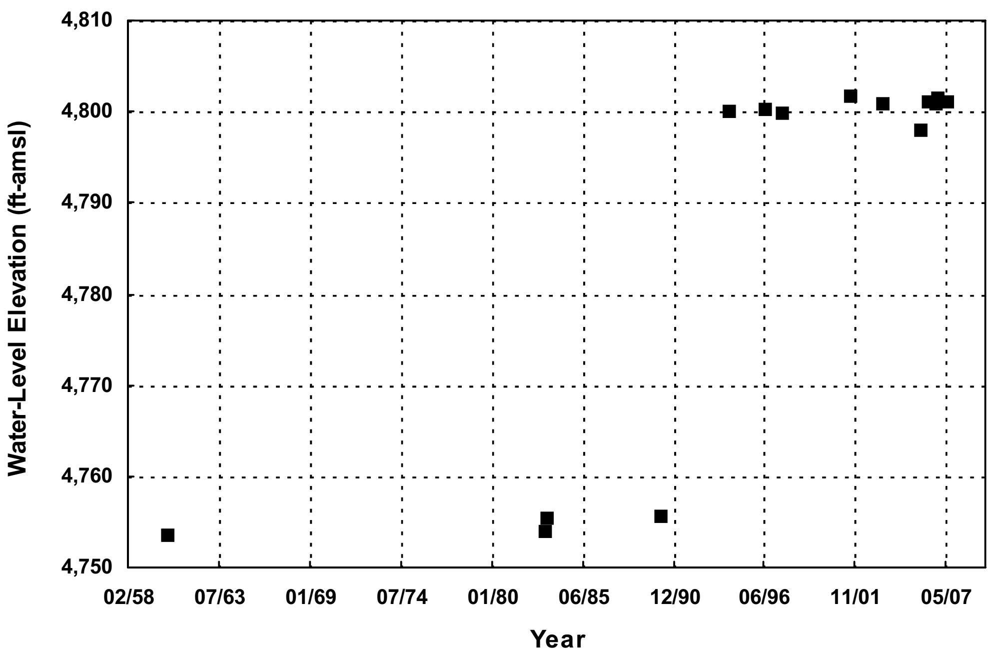

| | | | |
|---|---|---|---|
| Basin Name: | Dry Lake Valley | Land Surface (ft-amsl): | 4,695 |
| Aquifer Type: | Basin Fill | Well Depth (ft-bgs): | 515 |

**Figure A.1-12**
**Historical Water-Level Elevations at 181 N01 E62 24ABB 1 USBLM (Map ID 181-01)**



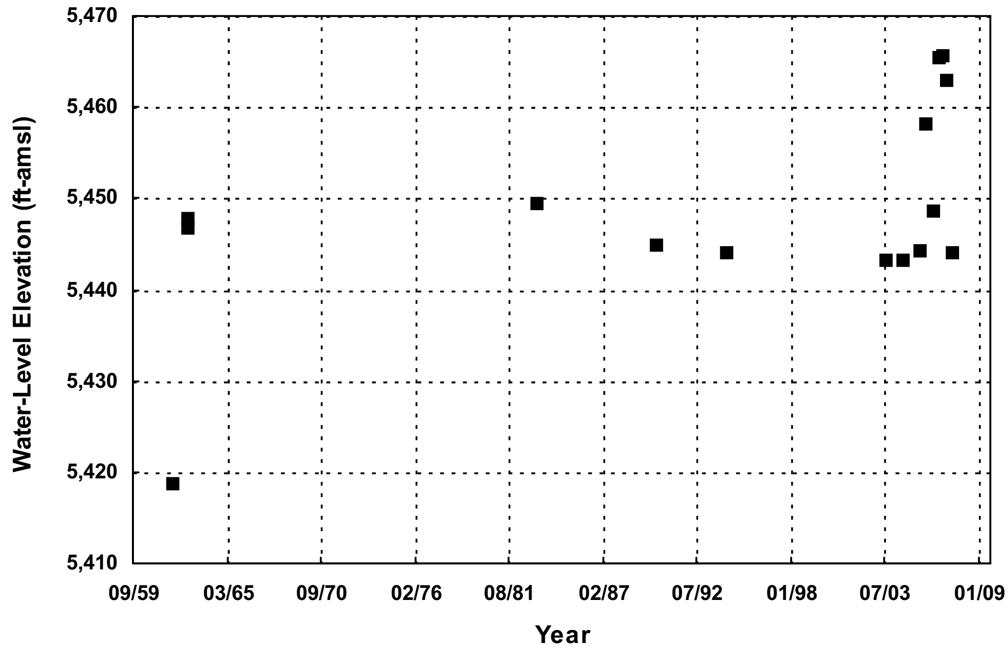

| | | | |
|---|---|---|---|
| **Basin Name:** | **Dry Lake Valley** | **Land Surface (ft-amsl):** | **5,391** |
| **Aquifer Type:** | **Carbonate Well** | **Well Depth (ft-bgs)** | **2,395** |

**Figure A.1-13**
**Historical Water-Level Elevations at 181 N03 E63 27CAA 1 USGS-MX (N. Dry Lake) (Map ID 181-05)**



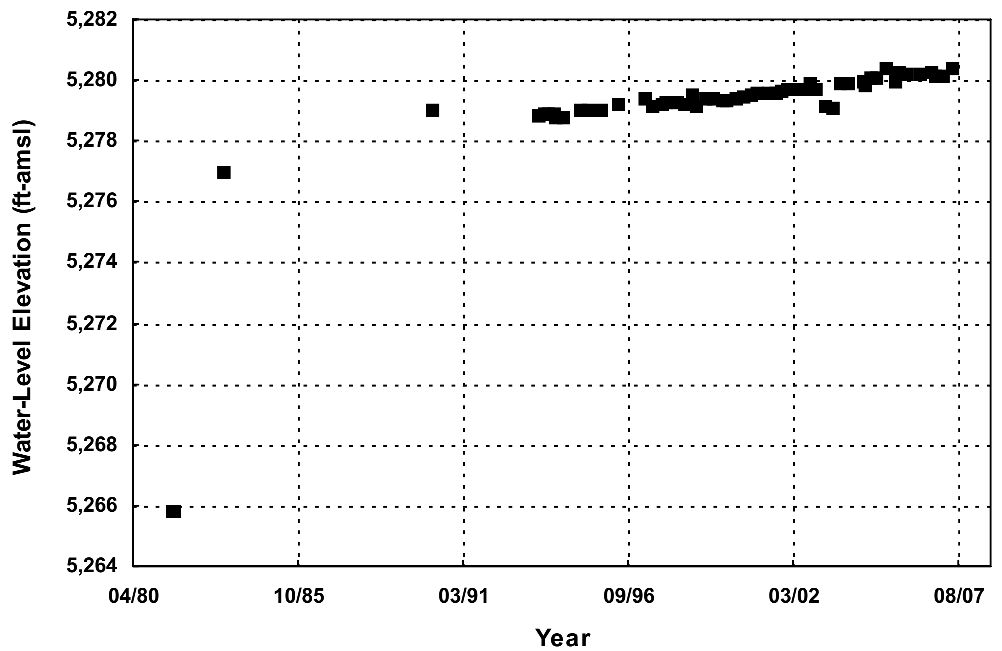

| | | | |
|---|---|---|---|
| **Basin Name:** | **Dry Lake Valley** | **Land Surface (ft-amsl):** | **5,071** |
| **Aquifer Type:** | **Basin Fill** | **Well Depth (ft-bgs):** | **380** |

**Figure A.1-14**
**Historical Water-Level Elevations at 181 N03 E64 20BD 1 USBLM - Coyote Well (Map ID 181-06)**



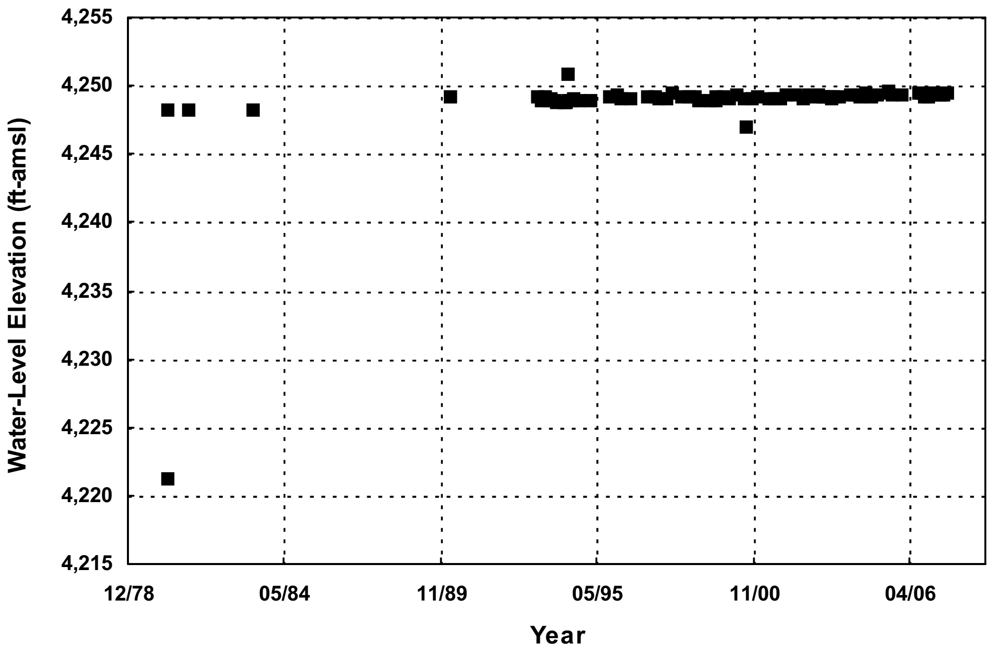

| | | | |
|---|---|---|---|
| **Basin Name:** | **Dry Lake Valley** | **Land Surface (ft-amsl):** | **5,464** |
| **Aquifer Type:** | **Basin Fill** | **Well Depth (ft-bgs):** | **80** |

**Figure A.1-15**
**Historical Water-Level Elevations at 181 N03 E65 21D 1 Bristol Well (Map ID 181-07)**



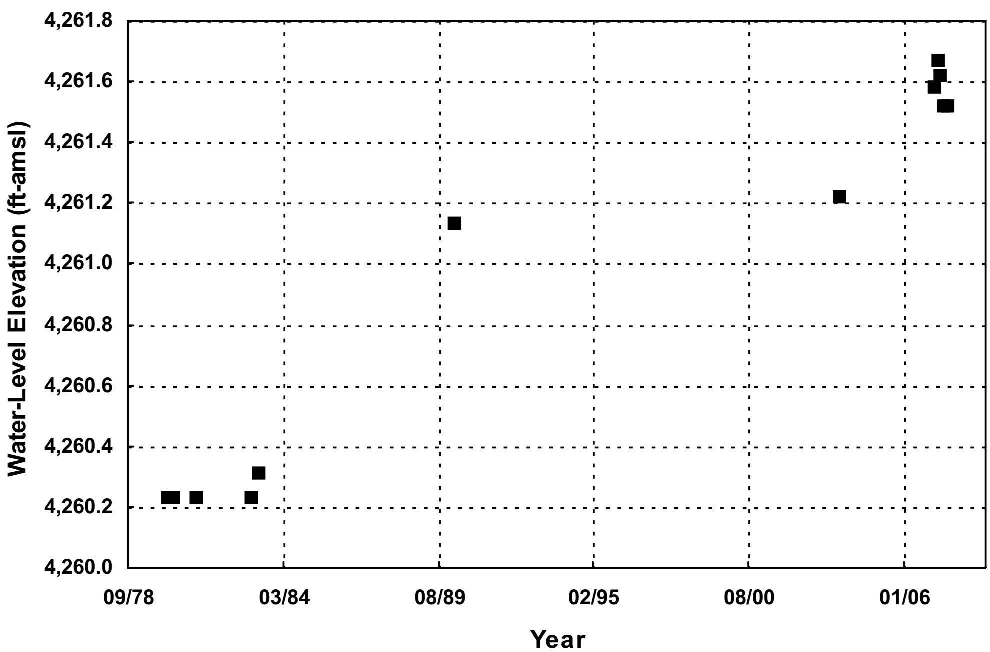

| | | | |
|---|---|---|---|
| **Basin Name:** | **Dry Lake Valley** | **Land Surface (ft-amsl):** | **5,534** |
| **Aquifer Type:** | **Basin Fill** | **Well Depth (ft-bgs):** | **1,190** |

**Figure A.1-16**
**Historical Water-Level Elevations at 181 N04 E64 07DC 1 USGS-MX (Muleshoe Valley) (Map ID 181-09)**



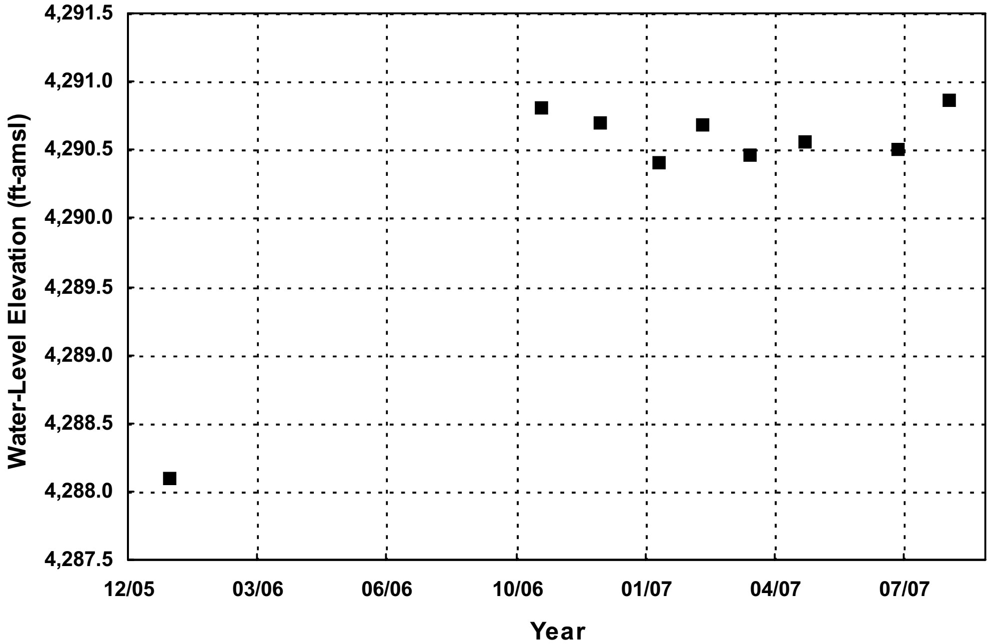

**Basin Name:** Dry Lake Valley
**Aquifer Type:** Basin Fill
**Land Surface (ft-amsl):** 4,643
**Well Depth (ft-bgs):** 1,000

**Figure A.1-17**
**Historical Water-Level Elevations at 181 S03 E64 12AC 1 USGS-MX (S. Dry Lake Well) (Map ID 181-19)**



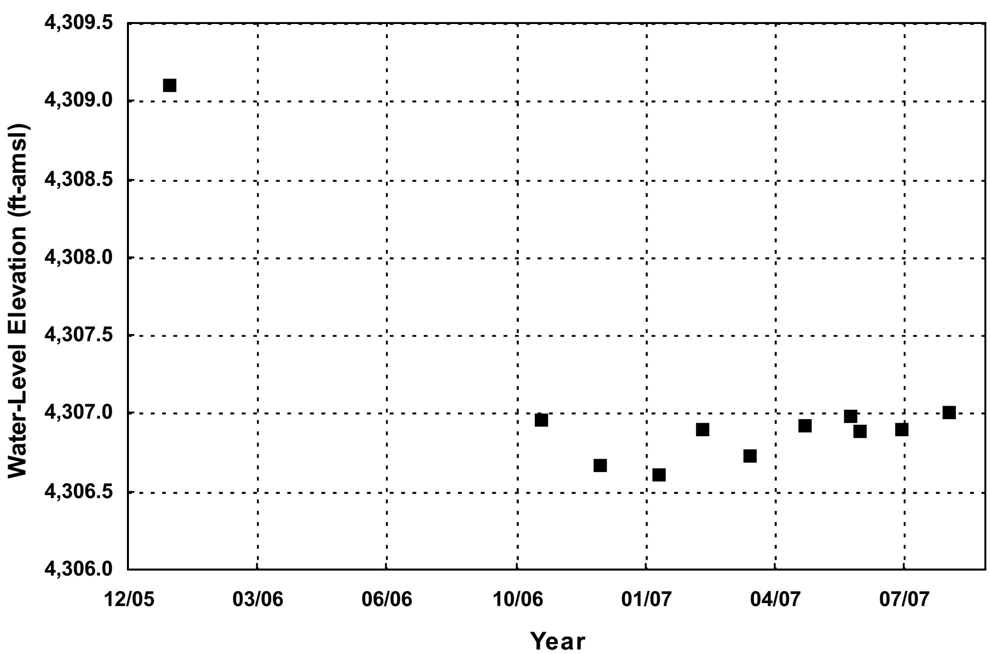

**Basin Name:** Dry Lake Valley
**Aquifer Type:** Basin Fill
**Land Surface (ft-amsl):** 4,643
**Well Depth (ft-bgs):** 1,300

**Figure A.1-18**
**Historical Water-Level Elevations at 181 S03 E64 12AC 2 USGS-MX (Map ID 181-20)**




| | | | |
|---|---|---|---|
| **Basin Name:** | **Dry Lake Valley** | **Land Surface (ft-amsl):** | **4,966** |
| **Aquifer Type:** | **Carbonate Well** | **Well Depth (ft-bgs):** | **1,472** |

**Figure A.1-19**
**Historical Water-Level Elevations at 181M-1 (Map ID 181-22)**

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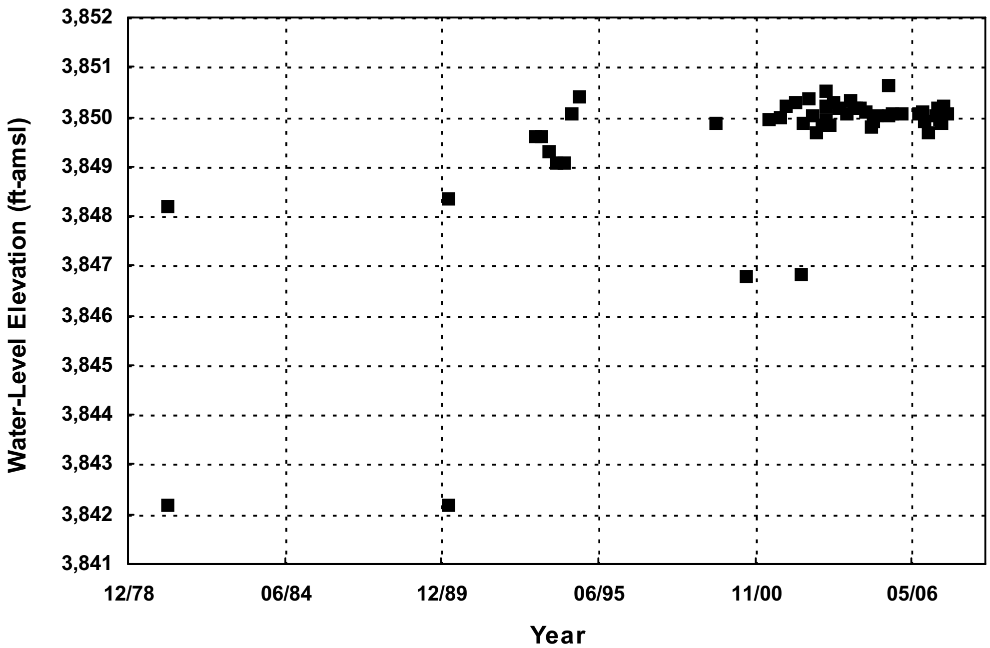
|---|---|---|---|
| **Basin Name:** | **Dry Lake Valley** | **Land Surface (ft-amsl)** | **4,804** |
| **Aquifer Type:** | **Basin Fill** | **Well Depth (ft-bgs):** | **1,260** |

**Figure A.1-20**
**Historical Water-Level Elevations at 181W909M (Map ID 181-23)**

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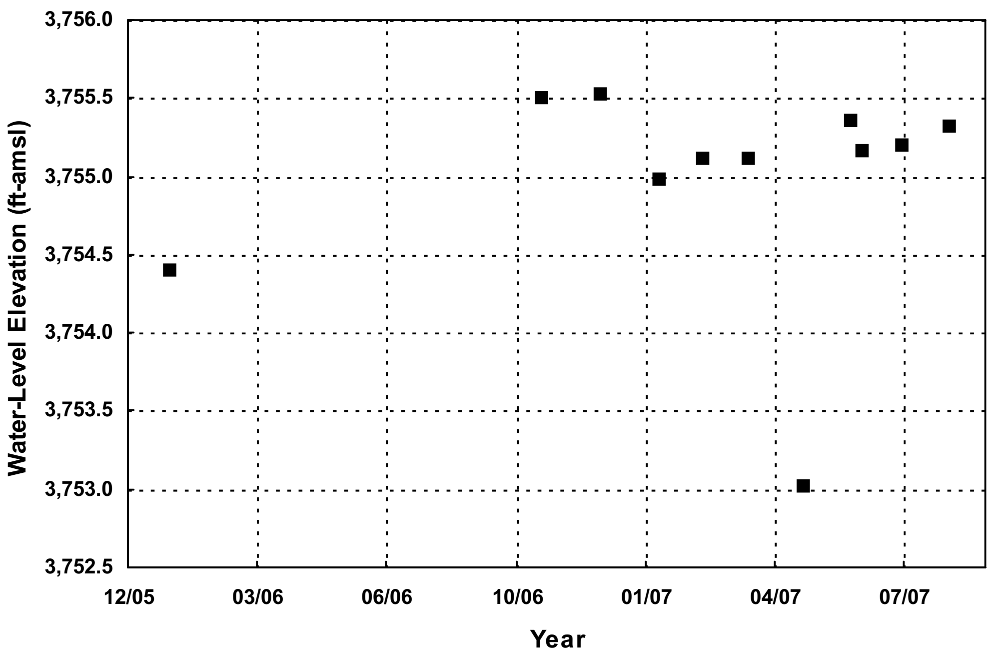
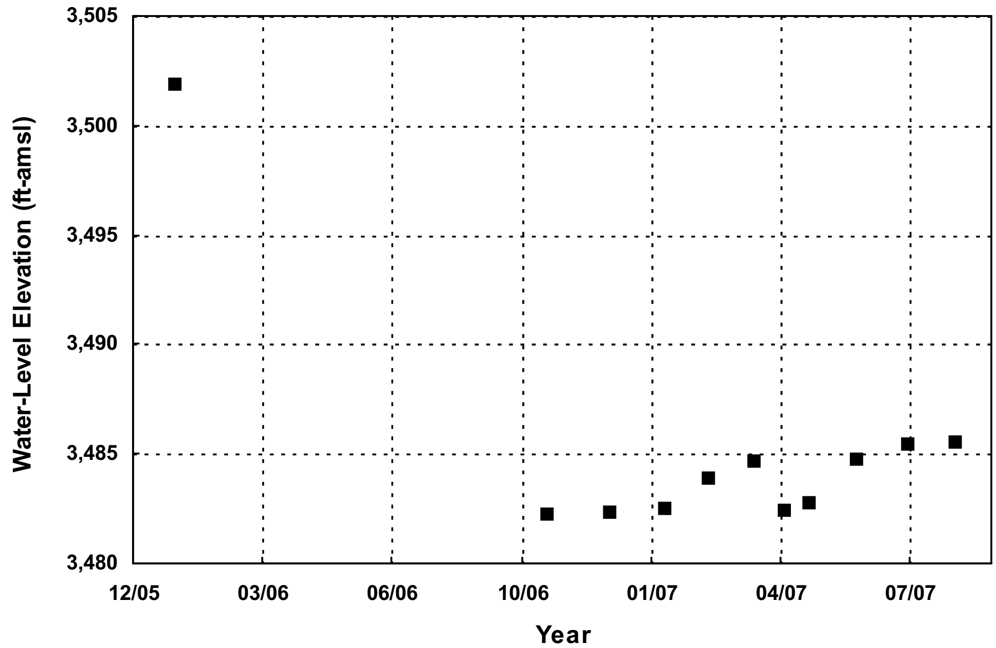
|---|---|---|---|
| **Basin Name:** | **Delamar Valley** | **Land Surface (ft-amsl):** | **4,713** |
| **Aquifer Type:** | **Basin Fill** | **Well Depth (ft-bgs):** | **1,195** |

**Figure A.1-21**
**Historical Water-Level Elevations at 182 S06 E63 12AD 1 USGS-MX (Delamar Well) (Map ID 182-02)**




| | | | |
|---|---|---|---|
| **Basin Name:** | **Delamar Valley** | **Land Surface (ft-amsl):** | **4,582** |
| **Aquifer Type:** | **Volcanic** | **Well Depth (ft-bgs):** | **1,321** |

**Figure A.1-22**
**Historical Water-Level Elevations at 182M-1 (Map ID 182-04)**

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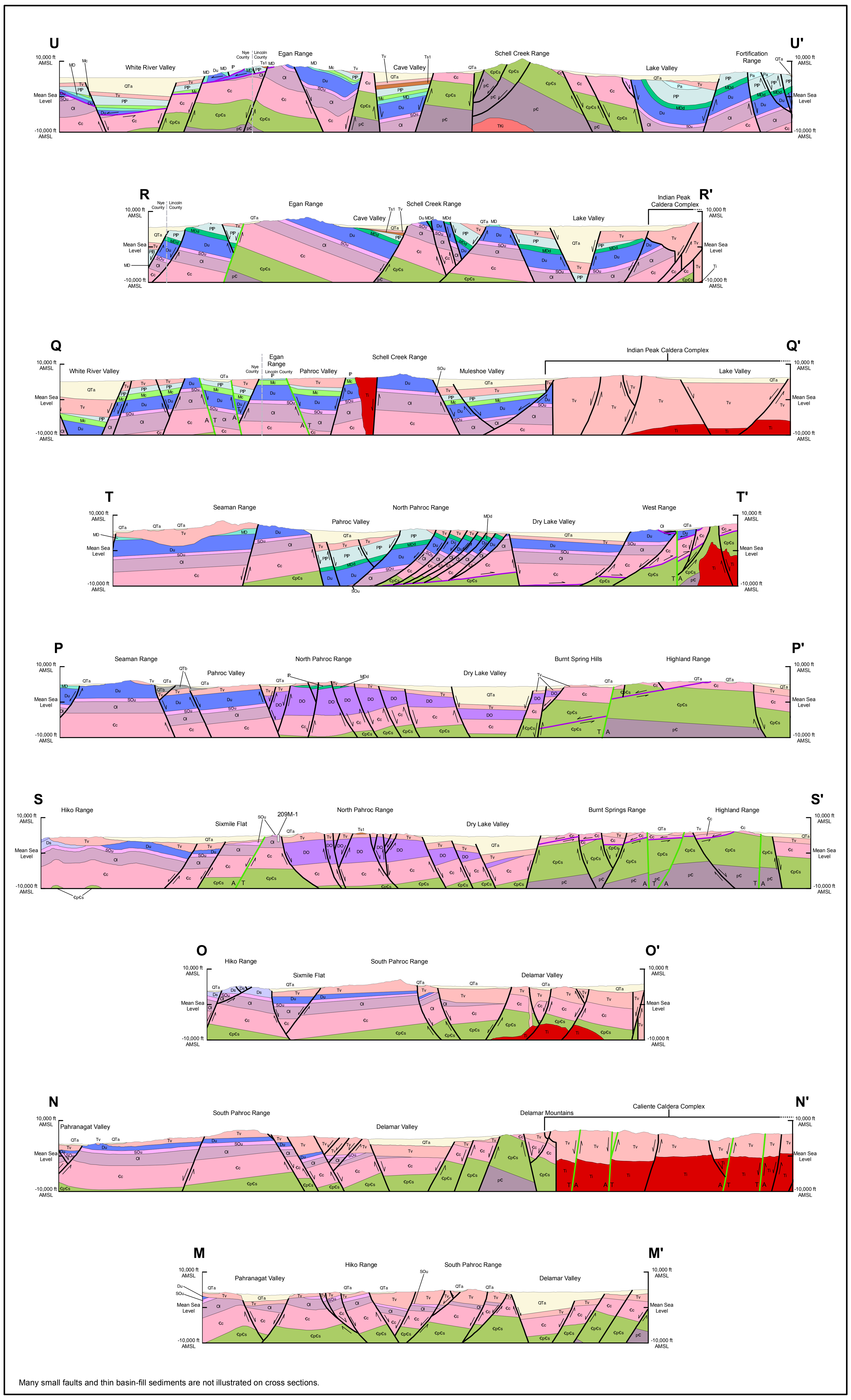
|---|---|---|---|
| **Basin Name:** | **Delamar Valley** | **Land Surface (ft-amsl)** | **4,802** |
| **Aquifer Type:** | **Volcanic** | **Well Depth (ft-bgs):** | **1,702** |

**Figure A.1-23**
**Historical Water-Level Elevations at 182W906M (Map ID 182-05)**

# Plates

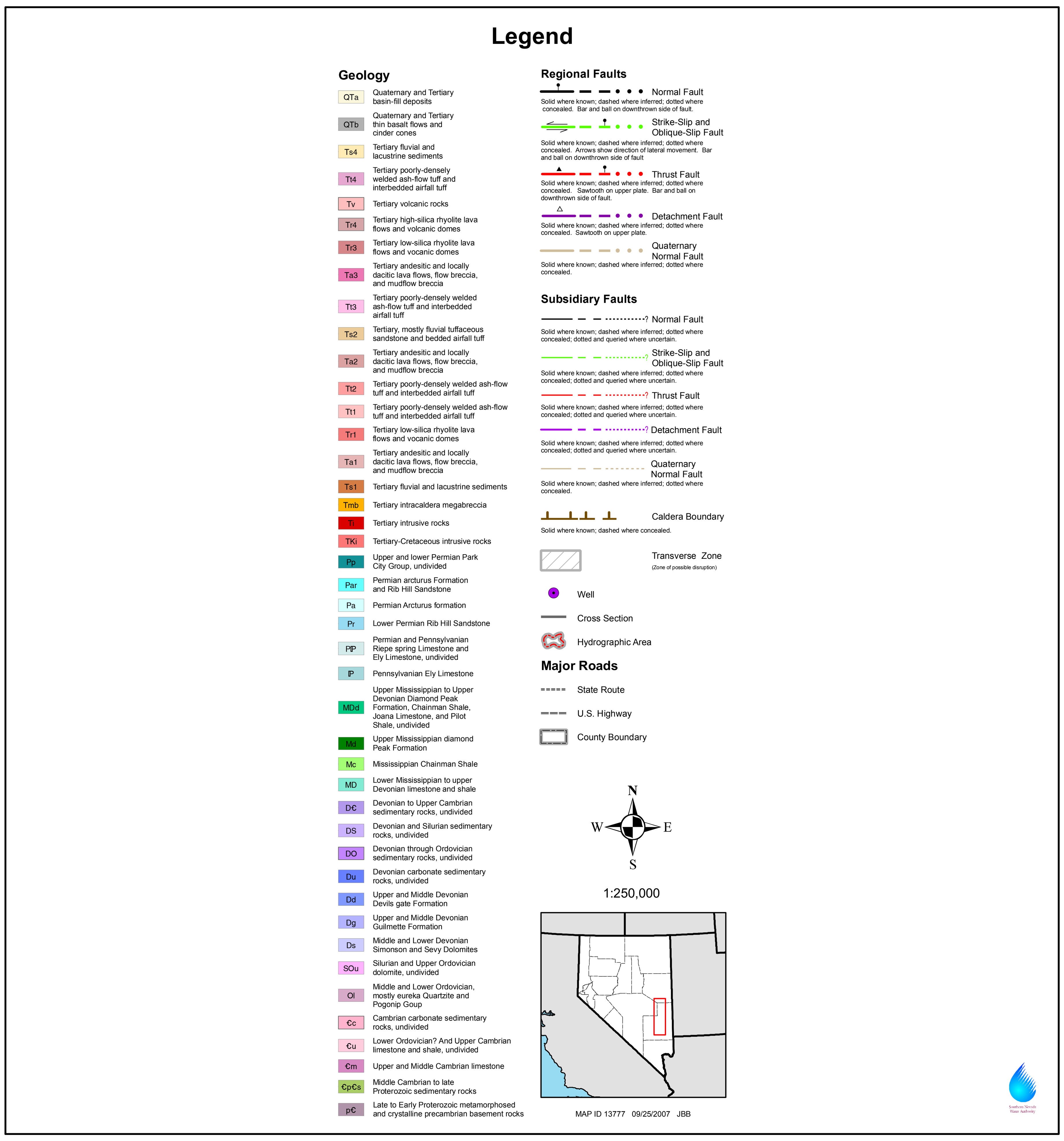




PLATE 1. GEOLOGY AND GEOLOGIC CROSS SECTIONS OF CAVE, DRY LAKE, AND DELAMAR VALLEYS

SOUTHERN NEVADA
WATER AUTHORITY

# Part C

# Water-Related Effects Analysis Related to Southern Nevada Water Authority Groundwater Applications in Cave, Dry Lake, and Delamar Valleys

Prepared by: Andrew G. Burns, James M. Watrus, and Gary L. Dixon

---

November 2007

SOUTHERN NEVADA WATER AUTHORITY
Groundwater Resources Department
Water Resources Division
snwa.com

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# TABLES

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## ACRONYMS

| | |
|---|---|
| BLM | Bureau of Land Management |
| NAD83 | North American Datum of 1983 |
| NDWR | Nevada Division of Water Resources |
| SNWA | Southern Nevada Water Authority |
| 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 |
| gpm | gallons per minute |
| m | meter |
| mi | mile |

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# 1.0 INTRODUCTION

Part C of this report provides a description of the existing water rights in Cave, Dry Lake, and Delamar valleys, an analysis of the potential effects related to the Southern Nevada Water Authority's (SNWA) applications 53987 through 53992, inclusive, and a monitoring and management plan developed to monitor and manage any effects. The purpose and scope of this part of the report is described in the following section.

## 1.1 Purpose and Scope

The purpose of the work described in this document is to present an analysis of the potential water-related effects associated with the SNWA applications in Cave, Dry Lake, and Delamar valleys, including a description of existing water rights, an analysis of the potential effects, and a description of a program that would be implemented to monitor and manage effects as they occur. The focus of these analyses is primarily limited to Cave, Dry Lake, and Delamar valleys, although some of the data that were used in the analyses are from locations in adjacent valleys.

The scope of the work involves (1) the compilation and presentation of existing water rights within Cave, Dry Lake, and Delamar valleys, with an emphasis on the underground water rights that will be analyzed as part of the effects analysis; (2) a description of the simplified effects analysis that addresses the proposed pumping associated with the SNWA applications; (3) a discussion of the monitoring and management program associated with development of the groundwater resources in Cave, Dry Lake, and Delamar valleys.

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# 2.0 SUMMARY OF WATER RIGHTS

This section provides information on the water rights within Cave, Dry Lake, and Delamar valleys, with emphasis on currently committed underground water rights. The following discussion is based on hydrographic abstracts (i.e., formalized descriptions of water-right applications) obtained from the Nevada Division of Water Resources (NDWR) on August 13, 2007 (NDWR, 2007a) and included in Appendix A.

## 2.1 Cave Valley Permitted Rights

Table A.1-1 contains the hydrographic abstracts for Cave Valley. The NDWR Hydrographic Basin Summary (NDWR, 2007b) indicates 46.58 afy of committed duties for underground rights in Cave Valley.

The majority of the permitted water rights in Cave Valley are associated with springs located primarily in the mountain blocks on the eastern and western sides of the valley; however, there are rights associated with Haggerty and Silver creeks, emanating from the Egan Range, and with North and Sheep creeks, flowing from the western slope of the Schell Creek Range. These creeks flow toward the valley floor on the north end of the valley, enter Cave Valley Wash, and proceed to a terminal depression located at the southern end of the valley.

A majority of the permitted rights in Cave Valley are for stock water, with ten rights for irrigation and one right for domestic use. There are eight underground rights, with each having a manner of use of stock water. There are three reserved rights on springs in the southwest portion of the valley. The reserved rights are held by the Bureau of Land Management (BLM) for stock water.

Figure 2-1 depicts (1) the locations of the points of diversion for permitted water rights in Cave Valley, with each point symbolized by source and labeled with application number and manner of use; and (2) the location of the two SNWA application points of diversion.

## 2.2 Dry Lake Valley Permitted Rights

Table A.1-2 contains the hydrographic abstracts for Dry Lake Valley. The NDWR Hydrographic Basin Summary (NDWR, 2007b) indicates 56.56 afy of committed duties for underground rights in Dry Lake Valley.

The majority of the permitted rights in Dry Lake Valley are associated with springs located primarily in the mountain block on the eastern and western sides of the valley; however, there are rights associated with Black Canyon, Fairview, and Porphry washes that flow intermittently from the ranges on the eastern edge of the basin. These creeks flow toward the valley floor on the north end of the

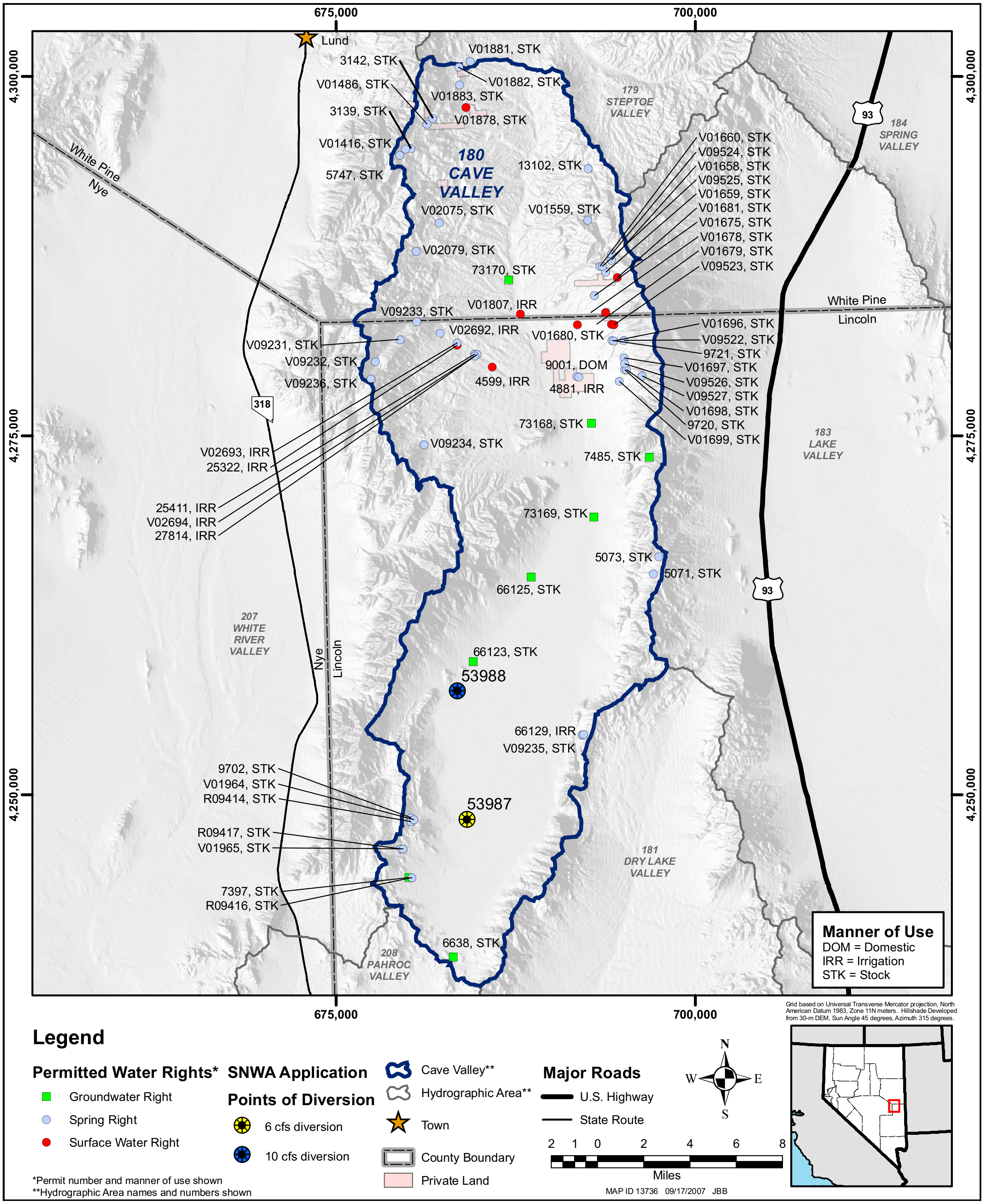


**Figure 2-1**
**Points of Diversion for Permitted Water Rights in Cave Valley**

valley and enter Coyote Wash, and proceed to a terminal depression located at the southern end of the valley.

A majority of all the permitted rights in Dry Lake Valley are for stock water, with four rights for irrigation and one right for mining and milling. There are six underground rights; five of which have a manner of use of stock water, and the sixth is for mining and milling. There are four reserved rights on springs. The reserved rights are held by BLM for stock water and other uses.

Figure 2-2 depicts (1) the locations of the points of diversion for permitted water rights in Dry Lake Valley, with each point symbolized by source and labeled with application number and manner of use; and (2) the location of the two SNWA application points of diversion.

### 2.3 Delamar Valley Permitted Rights

Table A.1-3 contains the hydrographic abstracts for Delamar Valley. The NDWR Hydrographic Basin Summary (NDWR, 2007b) indicates only one committed duty for underground water rights of 7.24 afy in Delamar Valley.

The majority of the permitted rights in Delamar Valley are from springs located primarily in the mountain block on the eastern and western sides of the valley; however, there are rights associated with several reservoirs within the valley. A majority of the rights are for stock water, with one right each for domestic, irrigation, and mining and milling. There is one underground water right with a manner of use of stock water. There is one reserved right on a spring. The reserved right is held by BLM for stock water.

Figure 2-3 depicts (1) the locations of the points of diversion for permitted water rights in Delamar Valley, with each point symbolized by source and labeled with application number and manner of use; and (2) the location of the two SNWA application points of diversion.

### 2.4 Domestic Water Rights

A domestic well is defined as one well that serves one home (NDWR, 2007c). These wells are exempt from the water-right permitting process when the pumpage does not exceed a daily maximum of 1,800 gallons and the water cannot be furnished by an entity such as a water district or municipality (NDWR, 2007c). This means that domestic wells may not be identified in the hydrographic abstracts of a particular valley. To assess whether domestic wells were located within 2,500 ft of a SNWA application point of diversion, figures were created showing a 2,500-ft buffer around those points of diversion overlain on National Agriculture Imagery Program images (Appendix B). No private lands or homes were visible within the 2,500-ft buffered region.

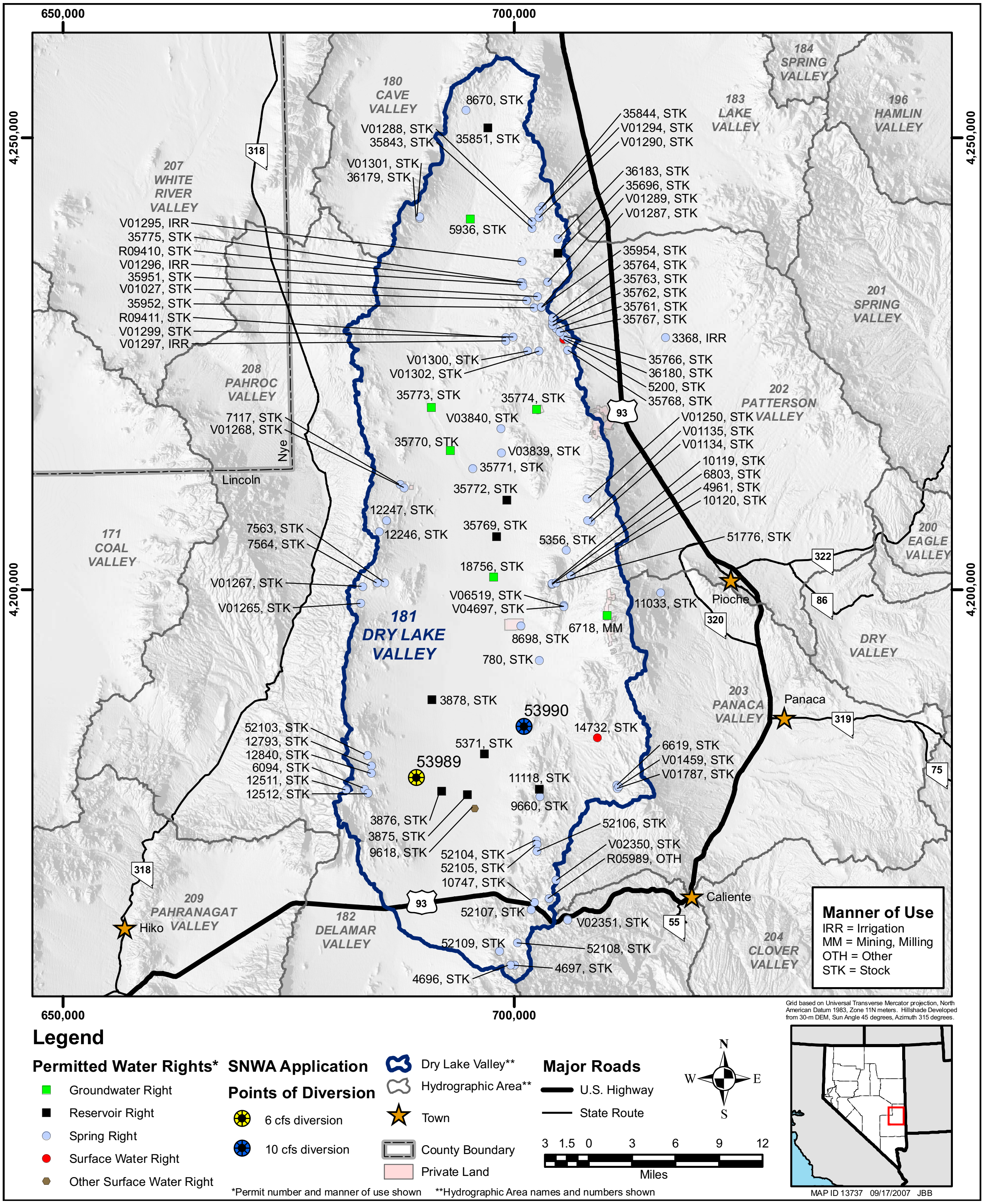


**Figure 2-2**
**Points of Diversion for Permitted Water Rights in Dry Lake Valley**

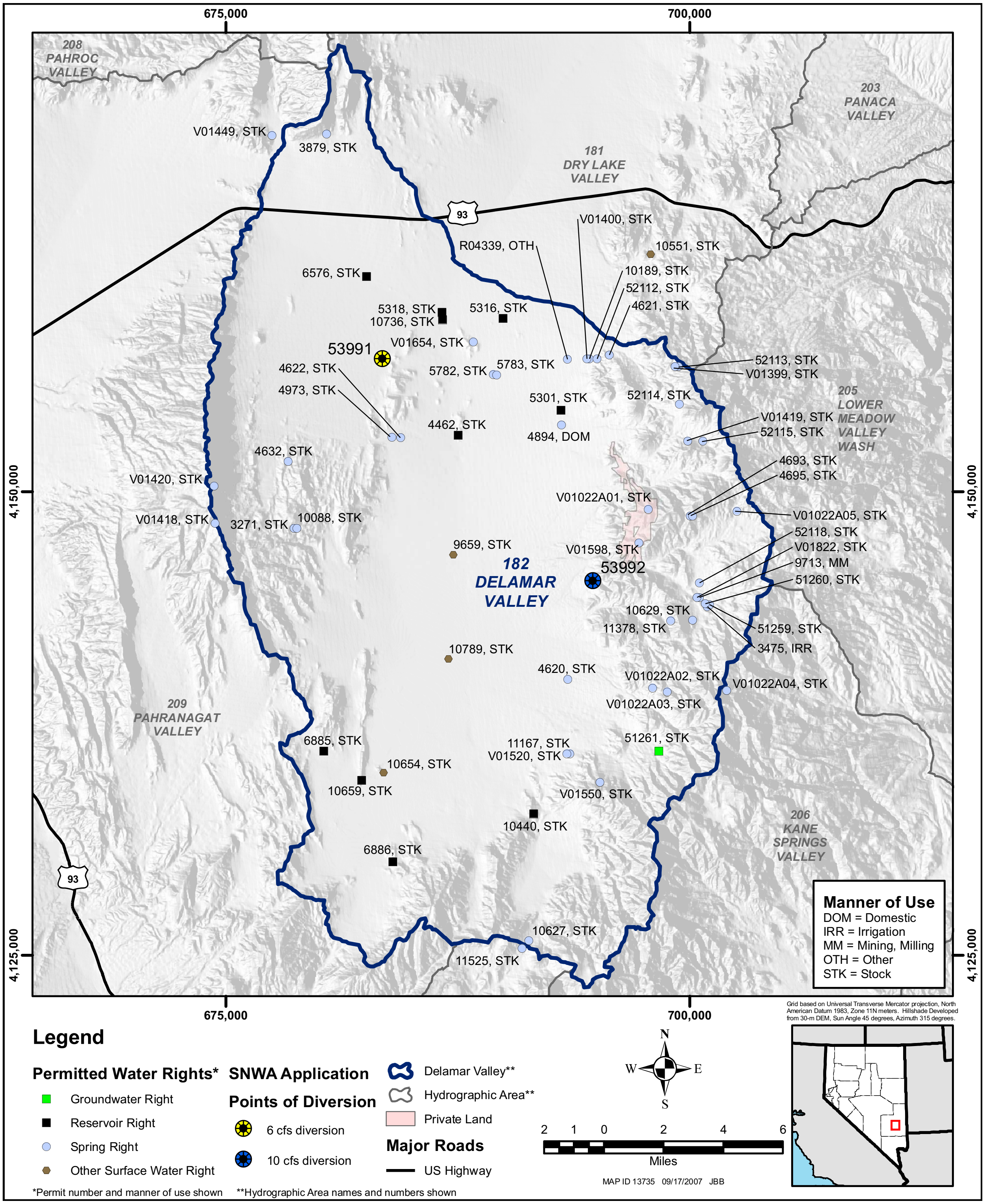


**Figure 2-3**
**Points of Diversion for Permitted Water Rights in Delamar Valley**

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# 3.0 Effects Analysis

The objective of this effects analysis is to quantitatively estimate the water-level drawdowns at points of diversion associated with currently permitted underground and spring water rights (Section 2.0) and at environmental areas of concern that may result from continuously pumping the wells associated with SNWA's water-right applications in Cave, Dry Lake, and Delamar valleys. The quantitative analysis was performed using a simplified analytical model and a pumping scenario that was developed to evaluate the potential effects associated with pumping SNWA's requested application volume from the application points of diversion. The locations of interest, analytical model, model inputs, and model results are described in the following sections.

## 3.1 Locations of Interest

Locations of interest to SNWA's groundwater development project in Cave, Dry Lake, and Delamar valleys are the points of diversion associated with currently permitted underground and spring water rights in those valleys as well as environmental areas of concern as identified in SNWA (2007).

Many of the permitted water right locations were excluded from the analysis as a result of their location in relation to the SNWA application points of diversion or priority date. Nearly all of the spring rights in these valleys occur high in the mountain block and their waters are derived from local precipitation. It is therefore assumed, that because these springs are likely not in hydraulic continuity with either the alluvial or carbonate-rock aquifer systems, it is highly unlikely that they would be impacted from pumping on the valley floor and are therefore excluded from the effects analysis. Table 3-1 lists the location information for the selected underground and spring water rights that exist on the valley floors as well as the location information for the SNWA application points of diversion.

Table 3-2 lists the location information for the environmental areas of concern as identified in SNWA (2007). Except for Grassy Spring in Delamar Valley, all of the environmental areas of concern are either located in the mountain block, or are separated from the proposed pumping locations by potential physical barriers (as in the case of unnamed spring at Parker Station). The local nature of these springs is supported by the variable discharge and cold temperatures of the springs (Appendix C). Therefore, these locations are highly unlikely to be effected by SNWA's proposed pumping on the valley floor. Grassy Spring while located at the edge of the mountain block and approximately 7.26 miles from the nearest application, is located along the same fault structure as SNWA application 53992, and therefore this location will be analyzed as part of this work.

The locations of these points of diversion and environmental areas of concern are depicted in Figures 3-1, 3-2, and 3-3.

## Table 3-1
## SNWA Application Points of Diversion and Selected Permitted Underground and Spring Water Rights, Listed by Valley
(Page 1 of 2)

| Application Number | Priority Date | Source | Location | | Elevation (ft-amsl) | Manner of Use | Application Number for Nearest Proposed Pumping Well | Distance from Point of Diversion to Nearest Proposed Pumping Well (ft) | Distance from Point of Diversion to Nearest Proposed Pumping Well (mi) | Drillers Log Number |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | UTM Easting[a] (m) | UTM Northing[a] (m) | | | | | | |
| **Cave Valley SNWA Proposed Production Wells** | | | | | | | | | | |
| 53987 | 10/17/1989 | Underground | 684,117 | 4,248,279 | 5,978 | Municipal | – – | – – | – – | – – |
| 53988 | 10/17/1989 | Underground | 683,439 | 4,257,220 | 6,047 | Municipal | – – | – – | – – | – – |
| **Cave Valley Permitted Underground and Spring Water Rights** | | | | | | | | | | |
| 6638 | 2/27/1922 | Underground | 683,156 | 4,238,721 | 6,202 | Stock | 53987 | 31,516 | 5.97 | – – |
| 7397 | 6/14/1925 | Underground | 680,091 | 4,244,266 | 6,253 | Stock | 53987 | 18,650 | 3.53 | – – |
| **Dry Lake Valley SNWA Proposed Production Wells** | | | | | | | | | | |
| 53989 | 10/17/1989 | Underground | 672,793 | 4,179,072 | 4,791 | Municipal | – – | – – | – – | – – |
| 53990 | 10/17/1989 | Underground | 701,088 | 4,184,836 | 4,811 | Municipal | – – | – – | – – | – – |
| **Dry Lake Valley Underground and Spring Water Rights** | | | | | | | | | | |
| 5936 | 1/5/1920 | Underground | 695,162 | 4,241,005 | 5,667 | Stock | 53990 | 185,304 | 35.10 | – – |
| 8698 | 9/17/1928 | Spring | 700,487 | 4,195,177 | 4,767 | Stock | 53990 | 33,984 | 6.44 | – – |
| 18756 | 4/26/1960 | Underground | 697,709 | 4,201,362 | 4,706 | Stock | 53990 | 55,341 | 10.48 | 5511 |
| 35770 | 8/18/1978 | Underground | 692,956 | 4,215,376 | 4,975 | Stock | 53990 | 103,688 | 19.64 | – – |
| 35771 | 8/18/1978 | Spring | 695,348 | 4,212,756 | 4,906 | Stock | 53990 | 93,517 | 17.71 | – – |
| 35773 | 8/18/1978 | Underground | 690,834 | 4,220,143 | 5,072 | Stock | 53990 | 120,623 | 22.85 | 39357 |
| 35774 | 8/18/1978 | Underground | 702,490 | 4,219,938 | 5,442 | Stock | 53990 | 115,256 | 21.83 | – – |
| V03839 | 1/1/1890 | Spring | 698,577 | 4,214,407 | 5,006 | Stock | 53990 | 97,367 | 18.44 | – – |

**Table 3-1**
**SNWA Application Points of Diversion and Selected Permitted Underground and Spring Water Rights, Listed by Valley**
(Page 2 of 2)

| Application Number | Priority Date | Source | Location | | Elevation (ft-amsl) | Manner of Use | Application Number for Nearest Proposed Pumping Well | Distance from Point of Diversion to Nearest Proposed Pumping Well (ft) | Distance from Point of Diversion to Nearest Proposed Pumping Well (mi) | Drillers Log Number |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | UTM Easting[a] (m) | UTM Northing[a] (m) | | | | | | |
| V03840 | 1/1/1890 | Spring | 698,549 | 4,217,584 | 5,173 | Stock | 53990 | 107,763 | 20.41 | – – |
| **Delamar Valley SNWA Proposed Production Wells** | | | | | | | | | | |
| 53991 | 10/17/1989 | Underground | 683,444 | 4,157,168 | 4,913 | Municipal | – – | – – | – – | – – |
| 53992 | 10/17/1989 | Underground | 694,792 | 4,145,180 | 5,329 | Municipal | – – | – – | – – | – – |
| **Delamar Valley Underground and Spring Water Rights** | | | | | | | | | | |
| 4620 | 10/8/1917 | Spring | 693,455 | 4,139,886 | 5,024 | Stock | 53992 | 17,914 | 3.39 | – – |
| 4622 | 10/8/1917 | Spring | 683,947 | 4,153,060 | 4,914 | Stock | 53991 | 13,578 | 2.57 | – – |
| 4894 | 2/7/1918 | Spring | 693,098 | 4,153,581 | 5,268 | Domestic | 53992 | 28,117 | 5.33 | – – |
| 4973 | 3/21/1918 | Spring | 683,947 | 4,153,060 | 4,914 | Stock | 53991 | 13,578 | 2.57 | – – |
| 5782 | 9/29/1919 | Spring | 689,434 | 4,156,310 | 4,961 | Stock | 53991 | 19,853 | 3.76 | – – |
| 5783 | 9/29/1919 | Spring | 689,434 | 4,156,310 | 4,961 | Stock | 53991 | 19,853 | 3.76 | – – |
| 10189 | 12/3/1937 | Spring | 694,609 | 4,157,153 | 5,666 | Stock | 53991 | 36,631 | 6.94 | – – |
| 11167 | 9/14/1944 | Spring | 693,546 | 4,135,873 | 5,249 | Stock | 53992 | 30,807 | 5.83 | – – |
| 52112 | 1/1/1880 | Spring | 695,009 | 4,157,163 | 5,766 | Stock | 53991 | 37,943 | 7.19 | – – |
| V01400 | 1/1/1900 | Spring | 694,609 | 4,157,153 | 5,666 | Stock | 53991 | 36,631 | 6.94 | – – |
| V01520 | 4/1/1900 | Spring | 693,546 | 4,135,873 | 5,249 | Stock | 53992 | 30,807 | 5.83 | – – |
| V01654 | 1/1/1900 | Spring | 688,343 | 4,158,084 | 4,949 | Stock | 53991 | 16,351 | 3.10 | – – |

[a]North American Datum of 1983, Zone 11N

**Table 3-2**
**Environmental Areas of Concern, Listed by Valley**

| Name | Location | | Elevation (ft-amsl) | Application Number of Nearest Proposed Pumping Well | Distance from Spring to Nearest Proposed Pumping Well (ft) | Distance from Spring to Nearest Proposed Pumping Well (mi) |
|---|---|---|---|---|---|---|
| | UTM Easting[a] (m) | UTM Northing[a] (m) | | | | |
| **Cave Valley** | | | | | | |
| Unnamed Spring at Parker Station | 687,827 | 4,282,583 | 6,514 | 53988 | 84,448 | 15.99 |
| Cave Spring | 691,761 | 4,279,249 | 6,488 | 53988 | 77,259 | 14.63 |
| **Dry Lake Valley** | | | | | | |
| Meloy Spring | 700,888 | 4,236,201 | 6,178 | 53990 | 168,522 | 31.92 |
| Fence Spring | 700,139 | 4,228,221 | 6,277 | 53990 | 142,373 | 26.96 |
| Bailey Spring | 699,080 | 4,227,795 | 6,090 | 53990 | 141,096 | 26.72 |
| Coyote Spring | 687,693 | 4,211,513 | 5,224 | 53990 | 97,937 | 18.55 |
| **Delamar Valley** | | | | | | |
| Grassy Spring | 695,124 | 4,157,193 | 5,783 | 53991 | 38,317 | 7.26 |

Source: Environmental Areas of Concern Identified in SNWA, 2007
[a]North American Datum of 1983, Zone 11N

## *3.2 Selected Analytical Model*

The local effects of SNWA's proposed production wells were evaluated using the Theis equation as implemented in RockWorks (RockWare, 2004). Descriptions of the Theis equation, data requirements, the implementation software, and the presentation of results are provided in the following subsections.

### *3.2.1 Theis Analysis*

The local effects of pumping were evaluated with the Theis equation (Theis, 1935) along with the principle of superposition. Drawdowns caused by each pumping well at a given point were calculated separately then summed (superposed) to estimate the total drawdown at that location.

The following solution to the Theis equation was used in the drawdown calculations:

$$h - h_0 = Q / 4\pi \bullet T \bullet [W(u)]$$

$$W(u) = -0.5772 - \ln(u) + u - u^2/(2 \times 2!) + u^3/(3 \times 3!) + ... + u^{20}/(20 \times 20!) \quad (3\text{-}1)$$

$$u = r^2 S / 4Tt$$

where,

h = Hydraulic head at time t (ft)

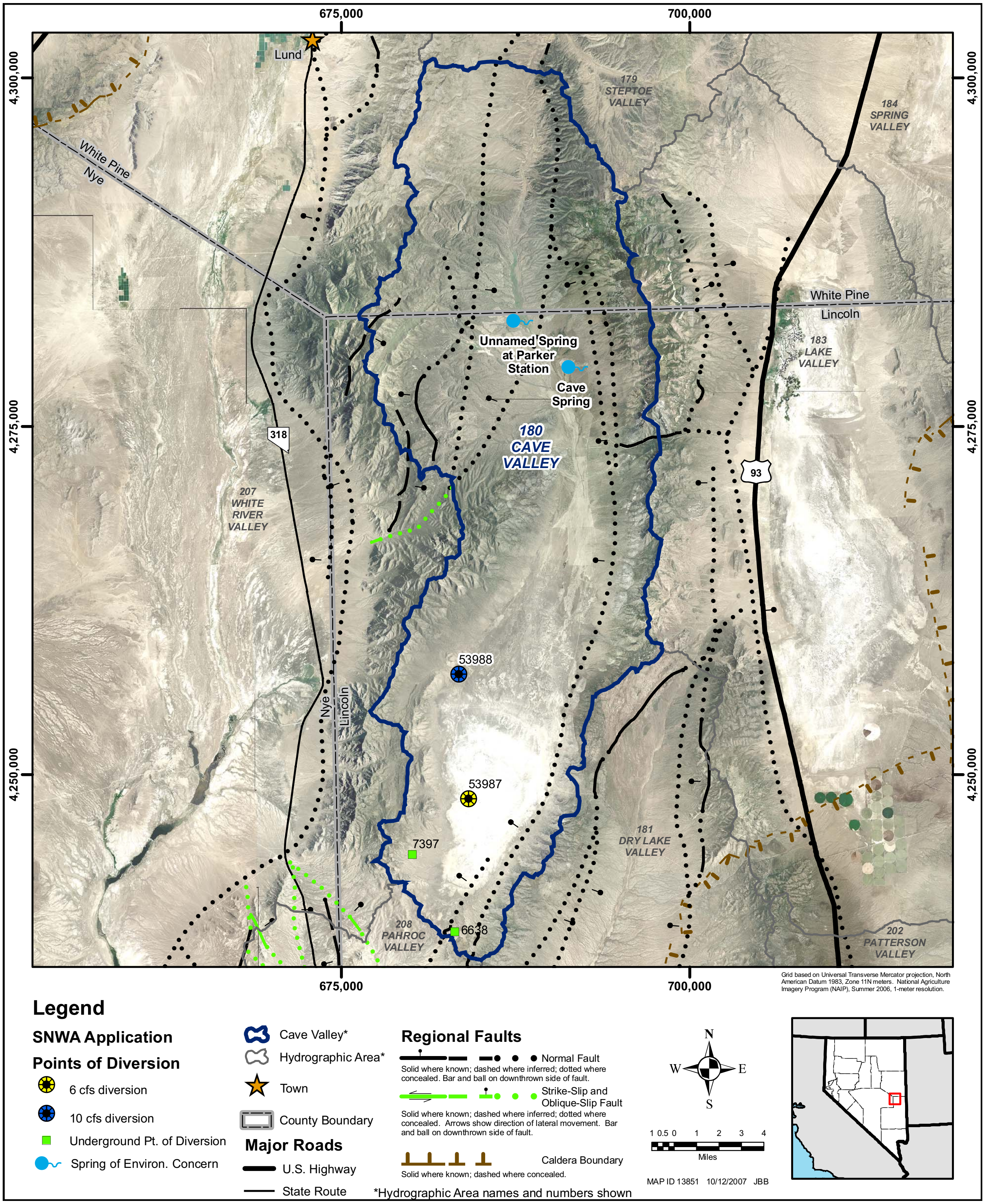


**Figure 3-1**
**Locations of Selected Water Rights and Environmental Areas of Concern for Cave Valley**

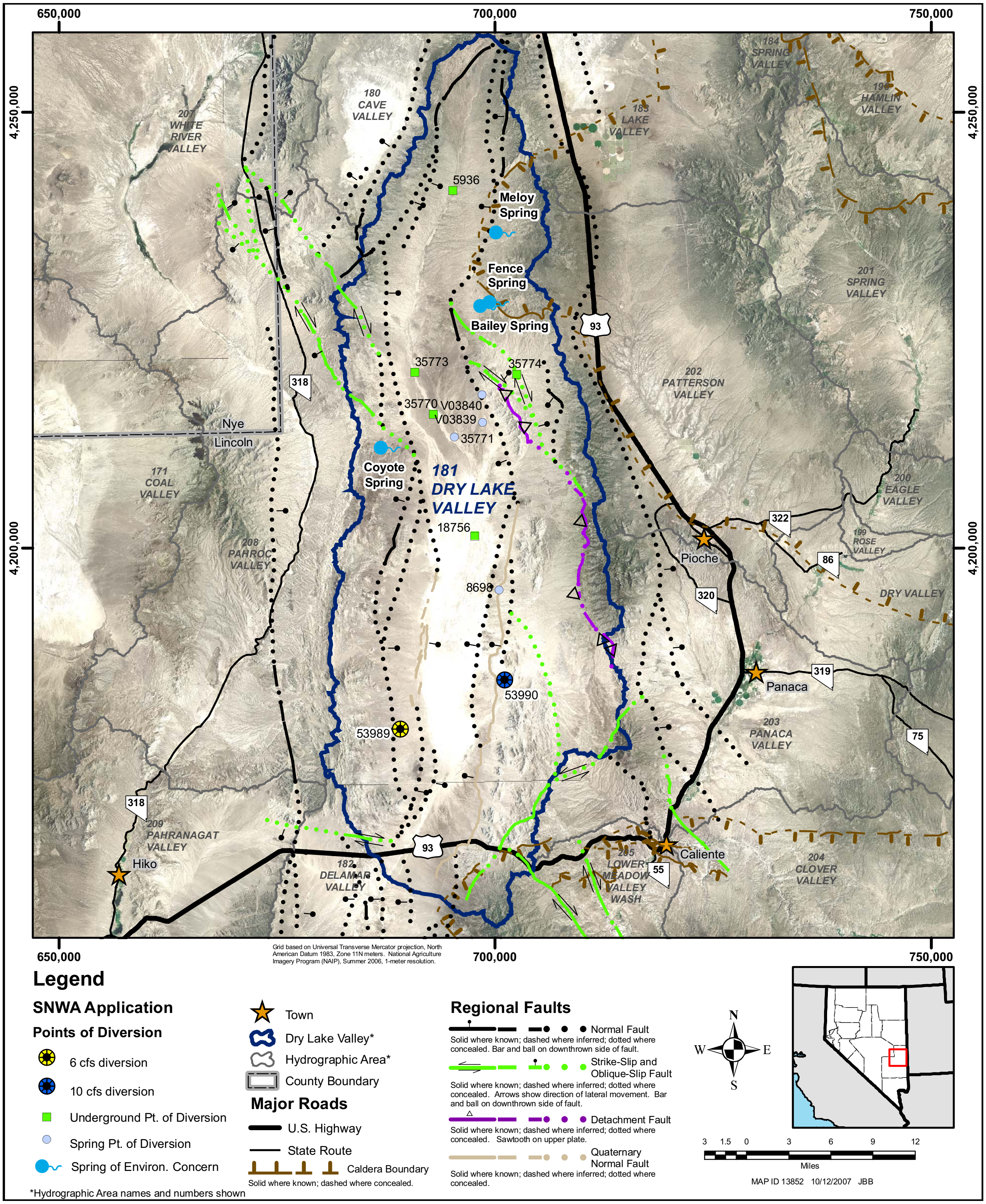


**Figure 3-2**
**Locations of Selected Water Rights and Environmental Areas of Concern for Dry Lake Valley**

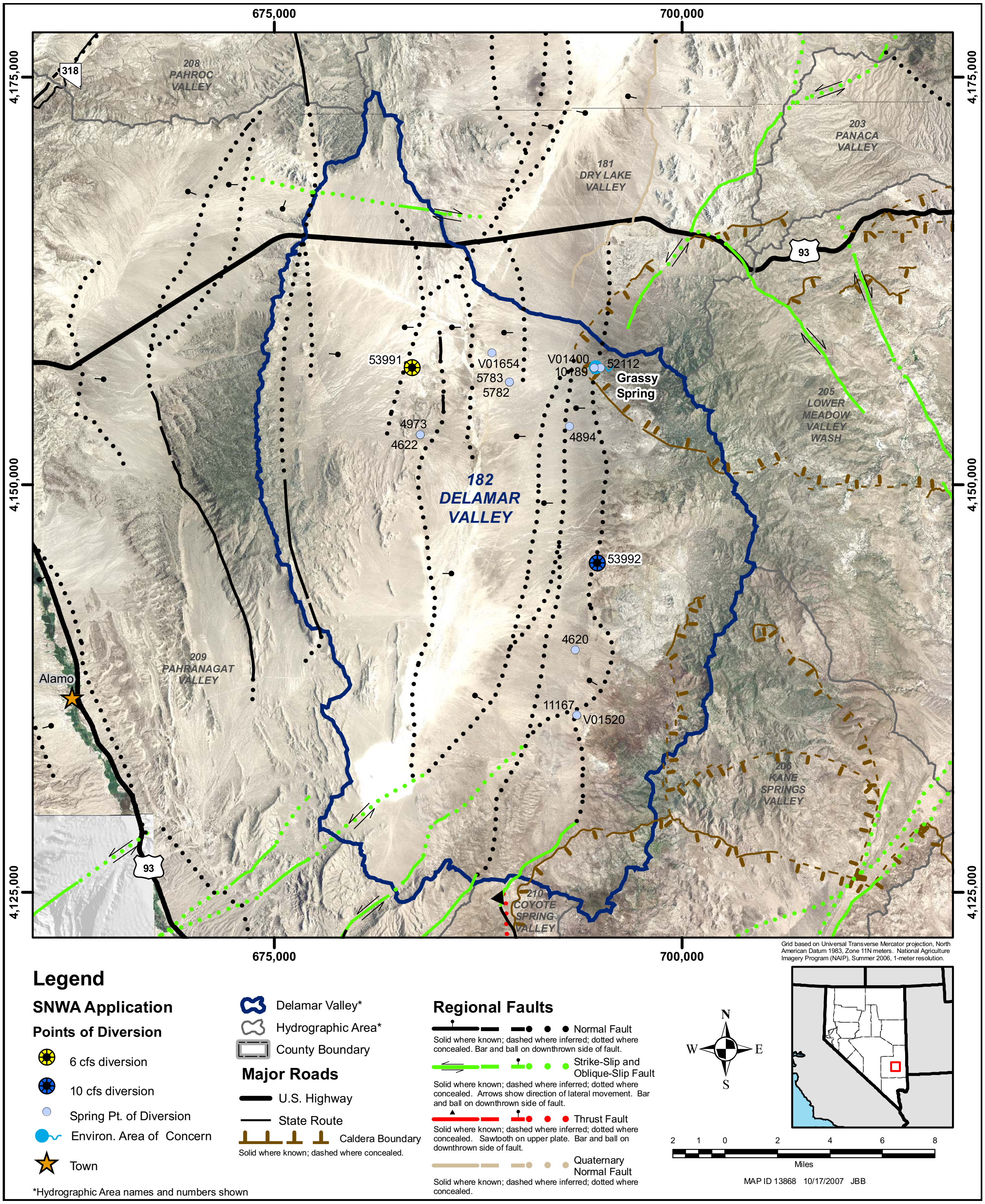


**Figure 3-3**
**Locations of Selected Water Rights and Environmental Areas of Concern for Delamar Valley**

$h_0$ = Hydraulic head at time zero (ft)
Q = Pumping rate ($ft^3$/day)
T = Transmissivity ($ft^2$/day)
W(u) = Well function
r = Well radius or interwell distance (ft)
S = Coefficient of Storage
t = Time since pumping started (days)

Assumptions associated with the Theis equation are as follows:

1. The aquifer has infinite areal extent.
2. The aquifer is homogeneous, isotropic, and of uniform thickness.
3. The pumping well is fully or partially penetrating.
4. Flow to the pumping well is horizontal when the pumping well is fully penetrating.
5. The aquifer is confined.
6. The flow is unsteady.
7. Water is released instantaneously from storage with decline of hydraulic head.
8. The diameter of the pumping well is very small so that storage in the well can be neglected.

Other assumptions that are inherent in the Theis equation include: (1) no regional drawdown, (2) no regional gradient, (3) no explicit barriers to flow other than those subsequently specified, (4) no recharge from precipitation, (5) no subsurface inflow or outflow, and (6) no induced recharge. Induced recharge includes stream depletions, reduction in spring flow, and reduction in evapotranspiration. Drawdown at a given location that is caused by several pumping wells is calculated by superposing drawdowns caused by each pumping well. The effect of a flow barrier may be simulated using image wells.

Uncertainties in these calculations may result from the violation of one or more of the Theis equation assumptions. For instance, homogeneity and isotropic characteristics are seldom found in nature, recharge does occur, the full thickness of the aquifer is not known and the well does not fully penetrate the aquifer, a water-level gradient exists, and delayed-yield responses occur. Another common use of the Theis equation is to simulate the response of an unconfined aquifer, which violates one of the main assumptions of the equation. The Theis equation, however, provides good estimates of drawdown in an unconfined aquifer provided that the simulated drawdown is less than 20 percent of the thickness of the aquifer.

Due to the limitations discussed above and further in Section 3.3.5, the use of Theis equation is an approach that can only provide estimates of the potential drawdowns. Geologic features not accounted for in the Theis equation could result in conservative results for certain areas and nonconservative for others. For example, in the case of a single production well, the presence of a barrier would yield larger drawdowns on the production well's side of the barrier, and lesser or no drawdown on the other side. As described in Section 4.0, drawdown will be monitored at several monitor well sites to manage the resource and minimize the effects of the proposed production wells.

### *3.2.2 Implementation*

RockWorks is a software application for subsurface data analysis that includes several tools that can be used to develop maps, logs, cross sections, fence diagrams, solid models, and volumetrics. RockWorks can utilize various geologic and hydrologic data. The hydrology module allows for the construction of water table or drawdown maps. RockWorks uses the Theis equation and the principle of superposition to calculate drawdowns due to pumping from multiple wells at specified grid points.

### *3.2.3 Data Requirements*

The relevant information needed in the Theis calculations as implemented by RockWorks for each well location is as follows:

#### *General Information*

- Production well radius in feet
- Production well open interval length in feet
- Pumping period in days

#### *Aquifer Properties*

- Transmissivity in gpd/ft
- Storage coefficient or specific yield

#### *Production Well Information*

- Well ID
- Well location coordinates in feet
- Pre-pumping water-level elevation in feet (set to 0 for drawdown calculations)

#### *Pumping Schedule Information*

- Pumping rate in gpm
- Duration in days

The production well information and the pumping schedule are known by design. However, the aquifer properties used in this analysis are estimates based on the best available test data. This information is input to RockWorks in table form. In addition, the computational grid must be specified with minimum and maximum coordinates and spacing in feet. This information allows RockWorks to calculate a drawdown value at each grid node for each pumping well. All grids are then superposed, and the drawdowns at each grid point are summed to derive a total drawdown resulting from all pumping wells.

## *3.3 Groundwater Development Scenario*

This section describes the data and information necessary to evaluate the effects of the proposed SNWA groundwater development in Cave, Dry Lake, and Delamar valleys using the Theis equation.

### 3.3.1 Conceptual Model

The conceptual model applied to the Theis analysis involved two separate analyses one for Cave Valley and a combined analysis for Dry Lake and Delamar valleys. This is consistent with the interpretation for Dry Lake and Delamar valleys that these two hydrographic areas are connected geologically and hydrologically, making them one contiguous basin.

Simulated flow barriers were placed along the eastern and western margins of each of southern Cave, Dry Lake, and Delamar valleys to simulate the lack of interbasin flows in those directions. This interpretation is consistent with the flow interpretations presented in Section 2.0 and 3.0 of Part B of this report. The flow barriers have been simulated in the analysis with the use of image wells. Image wells are imaginary discharging wells, used in the analysis, that are placed across the flow boundaries at the same distance from, and perpendicular to, the boundaries as the application points of diversion. The resulting drawdown at any point within the boundaries is the algebraic sum of the drawdowns produced at that point by the application point of diversion and its image. In this case, the use of image wells results in greater drawdowns within the valley than would be observed without the simulated flow barriers.

While the alluvial and carbonate-rock aquifers were evaluated separately in this analysis, the drawdowns simulated in each were summed for each location of interest. This is a conservative assumption because it is unlikely that pumping an alluvial point of diversion would have much effect on a location of interest sourced in the carbonate-rock aquifer, and visa versa.

### 3.3.2 General Design Information

The pumping scenario developed for the analysis describes the water-right applications for Cave, Dry Lake, and Delamar valleys. The objective of the scenario is to pump the application volume from the points of diversion and analyze the effects on water levels over a 75-year period. The total pumping period was designed to match the expected life of the equipment and infrastructure. This scenario represents the application points of diversion and therefore, the locations of the points of diversion are fixed at the locations requested in the applications (Table 3-1). The volumes of water to be withdrawn are also fixed under this scenario as the individual application volumes. In this scenario, all of the wells are screened with an open interval of 1,000 ft. It is also assumed for the Theis analysis that the well radii will be 0.83 ft.

### 3.3.3 Aquifer Properties

Aquifer properties were derived from the available site-specific data as well as published data for the regional system.

#### 3.3.3.1 Site Specific Information

Site-specific data for the valley-fill and carbonate-rock aquifers were derived from aquifer tests conducted in support of the MX missile-siting investigation. In particular, two aquifer tests conducted in Dry Lake Valley provide useful information regarding the aquifer properties of both the alluvial and carbonate-rock aquifers. The results for these two tests have been presented in Ertec (1981a, Table 4-5, p. 45-46), Bunch and Harrill (1984, p. 115-119), Dettinger et al. (1995, Table 1, p. 13-16), and Belcher et al. (2001, hydraulic properties database).

#### *3.3.3.1.1 Site Specific Information for the Carbonate-Rock Aquifer*

A carbonate MX well, DL-DT-3, was drilled and tested in northwestern Dry Lake Valley during October through December, 1980 (Figure 3-4). Drill cuttings indicated the well was completed in the Guilmette Formation and/or Simonson Dolomite with an effective open interval from the depth-to-water at 853 ft-bgs to the total depth of the well at 2,395 ft-bgs (Ertec, 1981a, Table 4-9, p. 56). Results of the aquifer test conducted at that location indicated a transmissivity of 13,400 $ft^2$/day (Ertec, 1981a, Table 4-9, p. 56). This was a single well test and no specific yield or storativity numbers were reported.

#### *3.3.3.1.2 Site Specific Information for the Alluvial Aquifer*

An alluvial MX well cluster, DL-TW-2 and DL-OW-2, was drilled and tested in southern Dry Lake Valley during January through April, 1980 (Figure 3-4). Drill cuttings and geophysical logging indicated the lithology of the boreholes was poorly sorted to well sorted gravels with less than 30 percent sand and just traces of silt and clay. No confining layers were identified within either borehole (Ertec, 1981b, p. 4-5). The data collected from the observation well were preferred by the authors of the Ertec report and those from the shallow piezometer were preferred over the deep because it was assumed that the shallow piezometer was better developed during air lifting (Ertec, 1981b, p. 30). The shallow peizometer has a perforated interval from 765 to 785 ft-bgs. The cited transmissivity was 3,400 $ft^2$/day and the storativity value cited was the lower bound of the specific yield which was 0.013 (Ertec, 1981b, p. 30). These values may be effected by the limited tested interval.

#### *3.3.3.1.3 Regional Information*

Site specific aquifer-property information is very limited within the basins of east central Nevada. To augment that information, additional aquifer-property data were compiled from a much larger region that encompasses areas such as the Death Valley Regional Flow System where many more studies have been conducted. As most of the aquifer tests are not of long enough duration to derive storage parameters that are suitable for the analysis of pumping effects that may last over long durations, the available data were supplemented with literature data, particularly values derived from other studies within the region.

The range of specific yield used for the carbonate-rock aquifer is 0.01 to 0.05, with a 0.03 mid-range value. The minimum value of 0.01 is based on estimates made by Dettinger et al. (1995, p. 32) and used in several studies including the one conducted for Three-Lakes Valley South by SNWA (2005). The maximum value of 0.05 is the same as that used by Schaefer and Harrill (1995, p. 8) in their simulations of the effects of pumping potential production wells associated with the LVVWD water-right applications.

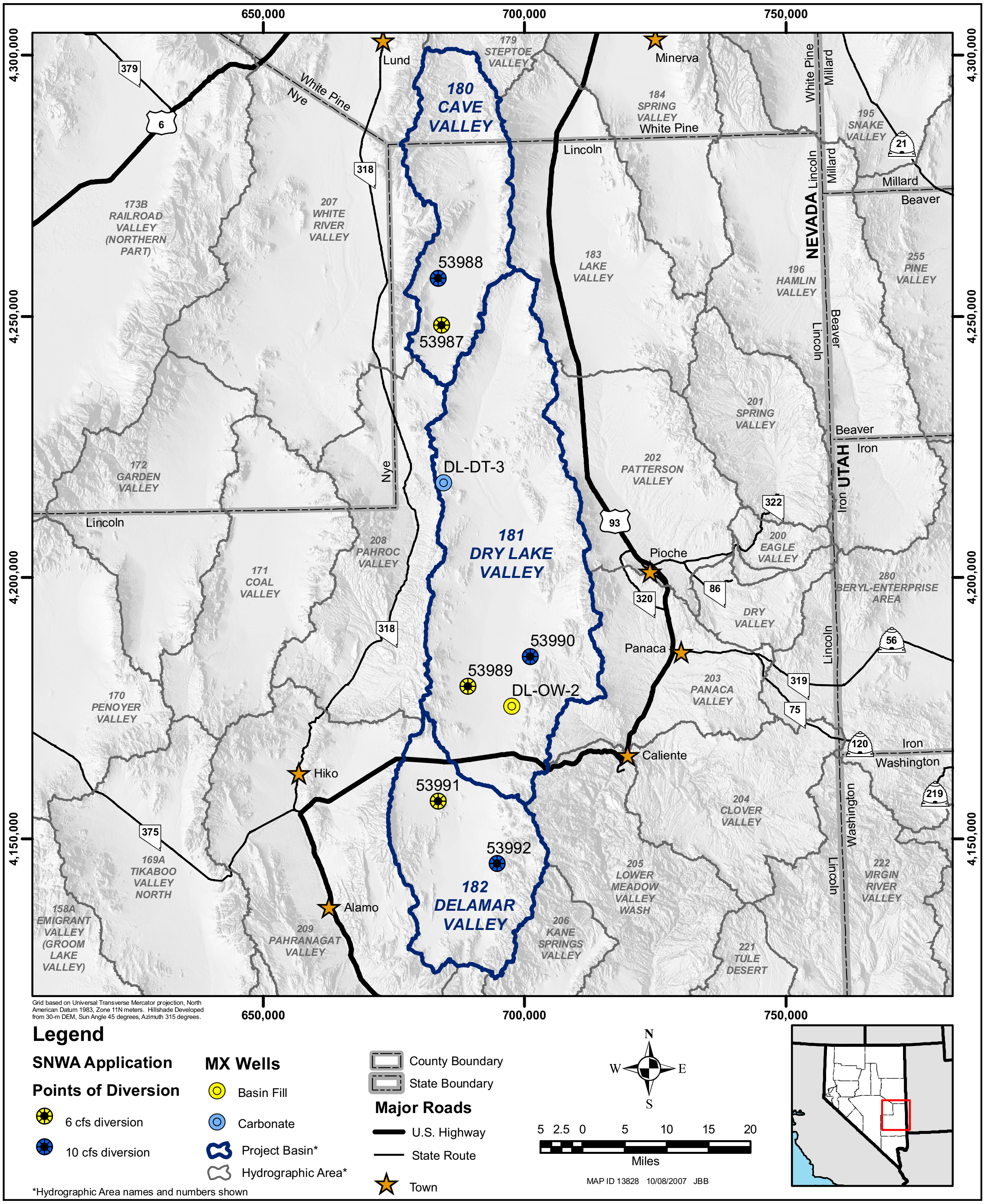


**Figure 3-4**
**Site-Specific Aquifer Test Locations**

#### *3.3.3.1.4 Aquifer Property Values Applied to Theis*

The site specific aquifer property information described in the previous sections was used in the simplified Theis analysis. The transmissivities reported for the carbonate and alluvial aquifers were first converted into hydraulic conductivities by dividing them by the effective open intervals for each well. The hydraulic conductivity values were then multiplied by the 1,000 ft open interval that was assumed for each of the proposed wells. The storativity/specific yield number used for the alluvial aquifer was the same as what was reported in Ertec (1981b, p. 30). There is no site specific information available for the storativity/specific yield of the carbonate-rock aquifer. Therefore, as described previously, an average of values for the regional carbonate-rock aquifer was used for this analysis (Table 3-3).

**Table 3-3**
**Aquifer Properties used in Theis Analysis**

| Aquifer | Calculated Transmissivity $ft^2$/day | Source for Original Transmissivity Used | Storativity/ Specific Yield | Source for Storativity/ Specific Yield Used |
|---|---|---|---|---|
| Alluvial Aquifer | 170,000 | Site Specific Information from DL-OW-2 | 0.013[a] | Site Specific Information from DL-OW-2 |
| Carbonate-Rock Aquifer | 8,690 | Site Specific Information from DL-DT-3 | 0.03 | Average of regional values |

[a]This value was reported as a lower bound (Ertec, 1981b)

### *3.3.4 Effects Analysis Results*

The effects of the production wells associated with SNWA's water right applications in Cave, Dry Lake, and Delamar valleys calculated by the Theis equation are presented in this section. The results are expressed in terms of drawdowns. The drawdowns simulated after 75 years of continuous pumping under the production scenario and described aquifer properties are presented in Table 3-4. As can be seen from the simulation results, the effects of pumping are most significant near the carbonate production wells, after 75 years of continuous pumping. The following sections describe the simulated drawdowns in Cave, Dry Lake, and Delamar valleys.

#### *3.3.4.1 Cave Valley*

As indicated in Table 3-4, simulated drawdowns at the end of 75 years of continuous pumping range from 41 ft at water-right number 6638 to 50 ft at water-right number 7397. Water-right numbers 6638 and 7397 are both underground rights located in the southern portion of Cave Valley (Figure 3-1). To further evaluate the effects of the proposed SNWA pumping on underground water rights, the well construction and water-levels must be considered. However, well construction information is not available for these two wells. The simulated drawdowns at these locations are believed to be at the upper bounds of what is expected due to the conservative assumptions in this analysis (i.e., drawdowns in the carbonate rock aquifer and the alluvial aquifer were combined and the storativity in the alluvial aquifer is a lower bound).

## Table 3-4
## Simulated Drawdowns at Selected Permitted Underground and Spring Water Rights and Environmental Areas of Concern

| Application Number or Environmental Area of Concern | Source | Location | | Distance from Observation Point to Nearest Proposed Pumping Well (mi) | Simulated Drawdowns at the end of 75 years of Continuous Pumping (ft-bgs) |
|---|---|---|---|---|---|
| | | UTM Easting[a] (m) | UTM Northing[a] (m) | | |
| **Cave Valley** | | | | | |
| 6638 | Underground | 683,156 | 4,238,721 | 5.97 | 41 |
| 7397 | Underground | 680,091 | 4,244,266 | 3.53 | 50 |
| **Dry Lake Valley** | | | | | |
| 5936 | Underground | 695,162 | 4,241,005 | 35.10 | 8 |
| 8698 | Spring | 700,487 | 4,195,177 | 6.44 | 48 |
| 18756 | Underground | 697,709 | 4,201,362 | 10.48 | 37 |
| 35770 | Underground | 692,956 | 4,215,376 | 19.64 | 21 |
| 35771 | Spring | 695,348 | 4,212,756 | 17.71 | 23 |
| 35773 | Underground | 690,834 | 4,220,143 | 22.85 | 17 |
| 35774 | Underground | 702,490 | 4,219,938 | 21.83 | 18 |
| V03839 | Spring | 698,577 | 4,214,407 | 18.44 | 21 |
| V03840 | Spring | 698,549 | 4,217,584 | 20.41 | 19 |
| **Delamar Valley** | | | | | |
| 4620 | Spring | 693,455 | 4,139,886 | 3.39 | 65 |
| 4622 | Spring | 683,947 | 4,153,060 | 2.57 | 55 |
| 4894 | Spring | 693,098 | 4,153,581 | 5.33 | 64 |
| 4973 | Spring | 683,947 | 4,153,060 | 2.57 | 55 |
| 5782 | Spring | 689,434 | 4,156,310 | 3.76 | 58 |
| 5783 | Spring | 689,434 | 4,156,310 | 3.76 | 58 |
| 10189[b] | Spring | 694,609 | 4,157,153 | 6.94 | 61 |
| 11167 | Spring | 693,546 | 4,135,873 | 5.83 | 53 |
| 52112[b] | Spring | 695,009 | 4,157,163 | 7.19 | 61 |
| V01400[b] | Spring | 694,609 | 4,157,153 | 6.94 | 61 |
| V01520 | Spring | 693,546 | 4,135,873 | 5.83 | 53 |
| V01654 | Spring | 688,343 | 4,158,084 | 3.10 | 56 |
| Grassy Spring | Spring | 695,124 | 4,157,193 | 7.26 | 61 |

[a]North American Datum of 1983, Zone 11N
[b]Water-rights 10189, 52112, and V01400 are all on Grassy Spring

### *3.3.4.2 Dry Lake Valley*

As indicated in Table 3-4, simulated drawdowns at the end of 75 years of continuous pumping range from 8 ft at water-right number 5936 located in the northern portion of Dry Lake Valley to 48 ft at water-right number 8698 which is located approximately 6.44 mi from the nearest SNWA application point of diversion.

To further evaluate the effects of the proposed SNWA pumping on underground water rights, the well construction and water-levels must be considered. Drillers logs could only be found for water-right numbers 18756 and 35773. Water-right number 18756 corresponds to drillers log number 5511 (NDWR, 2007d). According to this drillers log, the well was completed to a depth of 515 ft-bgs with a static depth to water of approximately 398 ft-bgs. Water-right number 35773 corresponds to drillers log number 39357 (NDWR, 2007d). According to this drillers log, the well was completed to a depth of 480 ft-bgs with a static depth to water of 310 ft-bgs. Water-right number 35774 is the Bristol Well (Table D.2-2 of Part A). The Bristol Well was completed to a depth of 80 ft-bgs and has a depth to water of 20 ft-bgs. Therefore, the simulated drawdowns for these locations, 37 ft at 18756, 17 ft at 35773, and 18 ft at 35774, resulting from pumping the proposed production wells, would be unlikely to cause the wells to go dry or even impair their usefulness as stock water wells.

Water-right numbers 8698 and 35771 both have sources identified as springs. Inspection of these points on topographic sheets and aerial imagery suggests that they may be reservoirs fed by springs located within the mountain block to the east (USGS, 1970; 1971). If they are reservoirs, then pumping the proposed production wells would not effect these locations.

### *3.3.4.3 Delamar Valley*

As indicated in Table 3-4, the simulated drawdowns at the end of 75 years of continuous pumping range from 53 ft at water-right numbers 11167 and V01520 to 65 ft at water-right number 4620.

The one environmental area of concern in Delamar Valley is Grassy Spring, which also has water rights associated with it. Water-right numbers 10189, 52112, and V01400 are all on Grassy Spring. Grassy Spring is located in northern Delamar Valley approximately 6.94 mi from the nearest proposed SNWA production well. The simulated drawdown at Grassy Spring is 61 ft. This spring is located over 450 ft higher in elevation than the nearest proposed pumping well and is located within the walls of a caldera complex (Figure 3-3). The discharge measurements and temperatures for Grassy Spring indicate it is derived from local precipitation (Appendix B). These factors suggest a different water source than the source underlying the application point of diversion. Furthermore, the depth to water at the application point of diversion is likely to be on the order of 1,000 ft based on the depth to water of other wells in the valley. Therefore, it is highly unlikely that any effects will occur as a result of pumping the proposed SNWA applications.

The remaining water rights in Delamar Valley are associated with springs. The limited water-level data in Delamar Valley, as described in Section 2.0 of Part B, indicates a deep water table. This would suggest that the springs shown in Figure 3-3 are likely derived from a perched system that would be unaffected by pumping the proposed SNWA applications.

### 3.3.5 Limitations

Drawdowns simulated using the Theis equation are only approximations of the potential drawdowns. In reality, the magnitude of the drawdowns caused by pumping at a given observation point depends on several factors:

- The distance between the pumping well and the observation point
- The presence of major heterogeneities including barriers to groundwater flow
- The actual aquifer properties in the region of pumping
- The magnitude, length, and continuity of pumping

The assumption of continuous pumping is a conservative one. Wells are not designed to produce without any interruptions. Downtime can be accidental or intentional. Accidental interruptions may be due to power outages or equipment malfunction. Intentional interruptions may be imposed for maintenance or management purposes. For example, the aquifer could be pumped on an intermittent basis to lessen the effects of pumping on the aquifer system. Periods of halted pumping would allow the aquifer system to partially or completely recover, depending on their duration, and decrease the cumulative drawdowns in the area.

The Theis solution cannot accurately simulate drawdowns in a complex flow system such as the one comprising the project area and vicinity. It can, however provide conservative approximations of the range of drawdowns that may actually occur.

# 4.0 MONITORING AND MANAGEMENT

SNWA will coordinate the development of a program to monitor long-term fluctuations in water levels and spring discharge at selected monitoring sites in Cave, Dry Lake, and Delamar valleys and vicinity as per the permit conditions set forth by the Nevada State Engineer. The monitoring program will be developed in cooperation with NDWR and other stakeholders with water-related interests in Cave, Dry Lake, and Delamar valleys and vicinity.

## 4.1 Monitoring Objectives

The objectives of the monitoring program will be to provide long-term monitoring of Cave, Dry Lake, and Delamar valleys and vicinity through evaluation of the monitoring sites of the Joint Funding Agreement between SNWA, USGS, and NDWR and augmentation as necessary.

## 4.2 Existing Monitoring Sites

SNWA installed two monitor wells in each of Cave, Dry Lake, and Delamar valleys in 2005 as well as a monitor well in northern Pahranagat Valley (Eastman, 2007a through g). Additionally, SNWA cooperatively funds USGS monitoring of wells and springs in Cave, Dry Lake, and Delamar valleys as well as in nearby areas. These monitoring sites are described in Table 4-1 and depicted in Figure 4-1. The monitoring sites are regularly evaluated by SNWA, USGS, and NDWR to ensure data adequacy and appropriate spatial coverage. The monitoring of these sites may be included in the permit conditions prescribed by the Nevada State Engineer.

## 4.3 Monitoring Frequency and Data Reporting

The proposed monitoring program is envisioned to include depth-to-water measurements collected on a continuous and quarterly basis. Continuous recorders will be installed in the SNWA application production wells and in selected monitor wells to monitor water-level fluctuations, temperature, and barometric pressure. Discrete depth-to-water measurements will be obtained on a regular basis. Spring discharge will be monitored at the springs listed in Table 4-1.

The requirements for submitting monitoring reports will be specified in the Nevada State Engineer approved monitoring plan. SNWA will cooperate in data collection efforts and will compile the data into organized annual reports to be submitted to NDWR and made available to other stakeholders with water-related interests in Cave, Dry Lake, and Delamar valleys and vicinity.

## Table 4-1
## Monitoring Sites in Cave, Dry Lake, and Delamar Valleys and Vicinity
(Page 1 of 2)

| Map-ID | USGS Number | Additional Site Identifier | Type | Location | | Current Monitoring Frequency | Period of Record |
|---|---|---|---|---|---|---|---|
| | | | | UTM Easting[a] (m) | UTM Northing[a] (m) | | |
| **Cave Valley** | | | | | | | |
| 180-24 | – – | 180W501M | Well | 688,048 | 4,273,716 | Continuous | 2005 to 2007 |
| 180-25 | – – | 180W902M | Well | 689,805 | 4,248,363 | Continuous | 2005 to 2007 |
| 180-05 | 382810114521501 | 180 N07 E63 14BADB1 USAF | Well | 685,674 | 4,260,043 | Quarterly | 1980 to 2007 |
| 180-14 | 383458114473601 | 180 N08 E64 04ABDD1 USBLM | Well | 692,206 | 4,272,813 | Quarterly | 1965 to 2007 |
| 180-15 | 383307114471001 | 180 N08 E64 15BCBC1 USBLM Cave Valley 4 | Well | 692,845 | 4,269,374 | Quarterly | 1990 to 2007 |
| 180-19 | 383632114465801 | 180 N09 E64 27BCDD1 USBLM | Well | 692,983 | 4,275,700 | Quarterly | 1964 to 2007 |
| 180-20 | 384207114505601 | 180 N10 E63 25A 1 Cave Valley 1 | Well | 686,984 | 4,285,891 | Quarterly | 1958 to 2007 |
| **Dry Lake Valley** | | | | | | | |
| 181-22 | – – | 181M-1 | Well | 688,537 | 4,198,181 | Continuous | 2005 to 2007 |
| 181-23 | – – | 181W909M | Well | 698,688 | 4,174,479 | Continuous | 2005 to 2007 |
| 181-01 | 375624114444501 | 181 N01 E62 24ABB 1 USBLM | Well | 698,010 | 4,201,548 | Quarterly | 1990 to 2007 |
| 181-04 | 380336114473501 | 181 N02 E64 03B 1 USBLM | Well | 693,124 | 4,215,351 | Quarterly | 2005 to 2007 |
| 181-05 | 380531114534201 | 181 N03 E63 27CAA 1 USGS-MX (N. Dry Lake) | Well | 684,519 | 4,218,103 | Continuous | 1980 to 2007 |
| 181-06 | 380616114494101 | 181 N03 E64 20BD 1 USBLM - Coyote Well | Well | 690,486 | 4,220,368 | Quarterly | 1983 to 2007 |
| 181-07 | 380550114412301 | 181 N03 E65 21D 1 Bristol Well | Well | 702,610 | 4,219,921 | Quarterly | 1962 to 2007 |
| 181-09 | 381256114500701 | 181 N04 E64 07DC 1 USGS-MX (Muleshoe Valley) | Well | 689,481 | 4,232,096 | Quarterly | 1981 to 2007 |
| 181-19 | 374215114453101 | 181 S03 E64 12AC 1 USGS-MX (S. Dry Lake Well) | Well | 697,515 | 4,175,351 | Continuous | 1980 to 2007 |
| **Delamar Valley** | | | | | | | |
| 182-04 | – – | 182M-1 | Well | 680,874 | 4,135,306 | Continuous | 2005 to 2007 |
| 182-05 | – – | 182W906M | Well | 690,078 | 4,133,299 | Continuous | 2005 to 2007 |
| 182-02 | 372639114520901 | 182 S06 E63 12AD 1 USGS-MX (Delamar Well) | Well | 688,422 | 4,146,273 | Continuous | 1980 to 2007 |
| **White River Valley** | | | | | | | |
| 207-11 | 382259115090801 | 207 N06 E61 18AADA1 NDW-Hot Creek Spring | Spring | 661,290 | 4,249,926 | Continuous | 1935 to 2007 |
| 207-21 | 382111115055901 | 207 N06 E61 27AADC1 USGS-MX | Well | 666,042 | 4,246,692 | Quarterly | 1980 to 2007 |
| 207-27 | 09415510 | Preston Big Spring near Preston NV | Spring/ Stream | 666,191 | 4,310,441 | Continuous | 1947 to 2007 |
| 207-28 | 383540115081801 | 207 N09 E61 32DABC1 Moorman Spring | Spring | 662,053 | 4,273,440 | Biannual | 1935 to 2006 |
| 207-29 | 385158115000401 | 207 N11 E62 04AABA1 Lund Spring | Spring | 673,266 | 4,302,019 | Biannual | 1910 to 2006 |

**Table 4-1**
**Monitoring Sites in Cave, Dry Lake, and Delamar Valleys and Vicinity**
(Page 2 of 2)

| Map-ID | USGS Number | Additional Site Identifier | Type | Location | | Current Monitoring Frequency | Period of Record |
|---|---|---|---|---|---|---|---|
| | | | | UTM Easting[a] (m) | UTM Northing[a] (m) | | |
| 207-30 | 385507114574801 | 207 N12 E61 12BDAD1 Cold Springs | Spring | 667,609 | 4,309,454 | Biannual | 1910 to 2006 |
| 207-31 | 385530115044601 | 207 N12 E61 12DBDD1 Nicholas Springs | Spring | 668,104 | 4,308,847 | Biannual | 1910 to 2006 |
| 207-32 | 382526115011401 | 207 N07 E62 33BCAB1 Flag Spring 1 | Spring | 672,719 | 4,254,696 | Biannual | 1982 to 2006 |
| 207-33 | 382522115012001 | 207 N07 E62 33BCCB1 Flag Spring 2 | Spring | 672,576 | 4,254,570 | Biannual | 1982 to 2006 |
| 207-34 | 382517115012001 | 207 N07 E62 33BCCC1 Flag Spring 3 | Spring | 672,579 | 4,254,416 | Biannual | 1949 to 2006 |
| 207-35 | 382624115004001 | 207 N07 E62 28ABDC1 Butterfield Spring | Spring | 673,530 | 4,256,472 | Biannual | 1949 to 2006 |
| 207-36 | 381613115110101 | 207 N05 E60 24CDDA1 Murphy Meadows | Well | 658,843 | 4,237,388 | Quarterly | 1985 to 2007 |
| 207-37 | 382211115133801 | 207 N06 E60 22BBBC1 USBLM | Well | 654,962 | 4,248,321 | Quarterly | 1985 to 2007 |
| 207-38 | 383154115101501 | 207 N08 E60 24DD 1 USBLM | Well | 659,362 | 4,266,385 | Quarterly | 1965 to 2007 |
| 207-39 | 383113115061201 | 207 N08 E61 27DDBA1 USGS-MX | Well | 665,638 | 4,265,125 | Quarterly | 1979 to 2007 |
| 207-40 | 383113115061202 | 207 N08 E61 27DDBA2 USGS-MX | Well | 665,638 | 4,265,125 | Quarterly | 1979 to 2007 |
| 207-41 | 382432115095801 | 207 N09 E61 07BCCC1 Sorenson Well | Well | 659,186 | 4,280,043 | Quarterly | 1948 to 2007 |
| 207-42 | 384713115034801 | 207 N11 E61 25BC 1 USBLM Wilson Meadows West | Well | 668,134 | 4,294,907 | Quarterly | 1990 to 2007 |
| 207-43 | 383122115083701 | 207 N11 E61 32B 1 Point | Well | 660,910 | 4,293,336 | Quarterly | 1947 to 2007 |
| 207-44 | 384640115045001 | 207 N11 E61 35ACCD1 Public Domain Well 25 | Well | 666,483 | 4,293,084 | Quarterly | 1953 to 2007 |
| 207-45 | 385226115124201 | 207 N12 E60 27ACBD1 USBLM | Well | 655,061 | 4,304,294 | Quarterly | 1957 to 2007 |
| 207-46 | 385400115024001 | 207 N12 E62 18DDAA1 USGS Well 24 | Well | 670,117 | 4,307,132 | Quarterly | 1947 to 2006 |
| **Pahroc Valley** | | | | | | | |
| 208-06 | 380505114593501 | 208 N03 E62 35BBB 1 USBLM White River MX | Well | 675,936 | 4,217,111 | Quarterly | 1963 to 2006 |
| 208-10 | 374525115061801 | 208 S02 E61 23D 2 | Well | 666,856 | 4,180,533 | Quarterly | 1985 to 2007 |
| **Pahranagat Valley** | | | | | | | |
| 209-04 | – – | 209M-1 | Well | 677,377 | 4,168,166 | Continuous | 2005 to 2007 |
| 209-07 | 09415590 | 209 S05 E60 10 1 Crystal Spring near Hiko, NV | Spring/ Stream | 656,168 | 4,155,349 | Continuous | 1912 to 2007 |
| 209-09 | 09415640 | Ash Springs Creek below Hwy 93 at Ash Springs, NV | Spring/ Stream | 659,683 | 4,147,461 | Continuous | 1912 to 2007 |

[a]North American Datum of 1983, Zone 11N

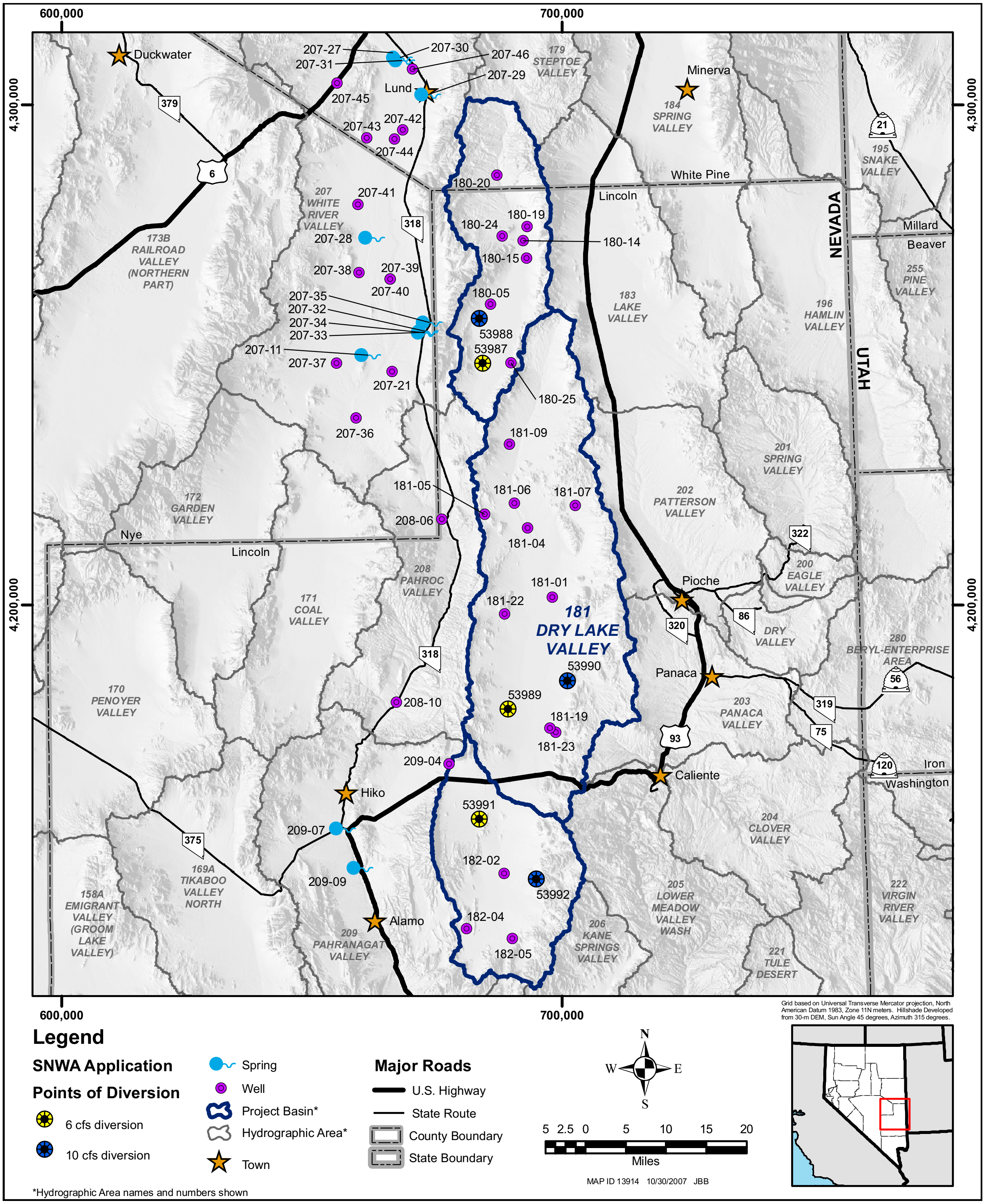


**Figure 4-1**
**Existing Monitoring Network**

### 4.4 Resource Management

SNWA will abide by all permit conditions attached to the water-right permits and work within the water-right administrative process set forth by the State Engineer to (1) manage its use of the water resources and (2) avoid unreasonable lowering of the water table such that adverse impacts to senior water-right holders do not occur. Additionally, SNWA will seek to manage its use of the water resources permitted to it by the State Engineer in a manner that does not adversely affect environmental resources.

Water-resource management scenarios could include the following:

- Spatial redistribution of pumping from production wells that are understood to be causing site-specific effects, to other production wells located farther away from the affected location

- Temporal re-distribution of pumping from continuous to seasonal operations, or other operational scenarios that would reduce effects

- Mitigation of unreasonable effects, as determined by the State Engineer

- Reduction of production rates to allow for recovery in the aquifer being effected

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# 5.0 SUMMARY

Based on abstracts obtained from NDWR, the majority of water rights in Cave, Dry Lake, and Delamar valleys are on springs and are used for the purposes of stock watering. Committed duties for underground rights in these valleys include 46.58 afy in Cave Valley, 56.56 afy in Dry Lake Valley, and 7.24 afy in Delamar Valley.

A simplified analysis using Theis (1935) was conducted to evaluate the potential effects of SNWA's proposed groundwater development project in Cave, Dry Lake, and Delamar valleys. The purpose of the simplified analysis was to evaluate the effects of continuously pumping the application volume from two wells in each of the three basins for a period of 75 years. Although the drawdowns were quantitatively simulated using the Theis equation, the estimates are still considered qualitative because of the many assumptions that are inherent to this equation.

The findings of the quantitative effects analyses are summarized as follows:

- Simulated drawdowns at the end of 75 years of continuous pumping in Cave Valley range from 41 to 50 ft at the two underground water rights located in the southern portion of the valley. No drillers log information was available for these wells.

- Simulated drawdowns at the end of 75 years of continuous pumping in Dry Lake Valley range from 8 to 48 ft. Drillers logs and additional well information was available for three of the five underground water right locations. Based on this information it is unlikely that the three wells would be adversely impacted by the proposed pumping. Two of the valley floor spring water-right locations appear to be reservoirs and therefore no effects are anticipated at those locations. Additional springs in Dry Lake Valley were unlikely to experience effects due to their nature, geographic location, and the geologic complexity between the proposed pumping locations and the springs.

- Simulated drawdowns at the end of 75 years of continuous pumping in Delamar Valley range from 53 to 65 ft. However, the water rights in this valley are associated with springs that are likely from a perched system and are therefore unlikely to be effected by pumping from the proposed SNWA application points of diversion. Grassy Spring was evaluated as part of the Theis analysis and based on its location, nature and the fact that the proposed pumping well location for SNWA likely has a depth to water of 1,000 ft or more, it is highly unlikely that Grassy Spring will be effected by the proposed pumping.

- The estimates of drawdowns presented in this report are conservative. Actual drawdowns are likely to be much lower. This conservative nature is the result of the assumptions that are made in the analysis as well as in using the Theis equation. Examples of these assumptions include: (1) combining the effects of pumping in both the alluvial and carbonate-rock aquifers; (2) the aquifer is homogeneous, isotropic, and of uniform thickness; and (3) there is no regional gradient, just to name a few. Based on the list of assumptions involved with the Theis analysis, these results are considered conservative.

SNWA will abide by all permit conditions attached to the water-right permits and work within the water-right administrative process set forth by the State Engineer to (1) manage its use of the water resources, and (2) avoid unreasonable lowering of the water table such that adverse impacts to senior water-right holders do not occur. In support of its resource management program, the SNWA will develop a monitoring program in cooperation with NDWR and other stakeholders with water-related interests in Cave, Dry Lake, and Delamar valleys. The purpose of this program will be to monitor long-term fluctuations in water levels and spring discharge at selected monitoring sites in the vicinity of pumping.

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# Appendix A

# NDWR Hydrographic Abstracts for Cave, Dry Lake, and Delamar Valleys

# A.1.0 WATER RIGHTS

This appendix contains hydrographic abstracts for Cave, Dry Lake, and Delamar valleys downloaded from the NDWR website on August 13, 2007. The fields and codes in these tables are described as follows:

- App. - Application Number.
- Change of App. - Change of Application Number.
- Cert. - Certificate Number.
- File Date - Date of filing.
- Status - Status of the Application.
    - ABR - Abrogated
    - APP - Application
    - CAN - Cancelled
    - CER - Certificate
    - DEN - Denied
    - PER - Permit
    - RES - Reserved
    - RFA - Ready for Action
    - RFP - Ready for Action (Protested)
    - VST - Vested Right
    - WDR - Withdrawn
- Source - Source of the water.
    - LAK - Lake
    - OSW - Other Surface Water
    - RES - Reservoir
    - SPR - Spring
    - STR - Stream
    - UG - Underground
- POD QQ - Point of Diversion Quarter Quarter.
- POD Qtr - Point of Diversion Quarter.

- POD Sec - Point of Diversion Section.
- POD Twn - Point of Diversion Township.
- POD Rng - Point of Diversion Range.
- Div. Rate (cfs) - Diversion Rate in cubic feet per second.
- Type of Use - The use identified for the water.
    - DOM - Domestic
    - IND - Industrial
    - IRD - Irrigation-DLE
    - IRR - Irrigation
    - MM - Mining and Milling
    - MUN - Municipal
    - OTH - Other
    - PWR - Power
    - QM - Quasi-Municipal
    - STK - Stock
- Sup - Supplemental, Yes or No.
- Annual Duty - Annual duty of water right.
- Duty Units - Units associated with the annual duty either AFY for acre-feet per year or AFS for acre-feet per season.
- Owner of Record - Owner of the right.

## Table A.1-1
## NDWR Hydrographic Abstract for Cave Valley
(Page 1 of 5)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Duty Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 742 | – – | – – | 12/3/1907 | CAN | SPR | NE | NW | 16 | 09N | 64E | 14 | PWR | – – | 0 | – – | Robertson, Edward L. |
| 1137 | – – | – – | 10/2/1908 | CAN | SPR | NE | SE | 30 | 11N | 63E | 0 | MM | – – | 0 | – – | Hendrix, E.A. |
| 1379 | – – | – – | 6/9/1909 | CAN | OSW | – – | SW | 31 | 10N | 64E | 0 | IRR | – – | 0 | – – | Barnes, Benn |
| 3139 | – – | 1661 | 10/21/1914 | CER | SPR | NW | SW | 29 | 11N | 63E | 0.003 | STK | – – | 1.288938 | AFS | Carter, Alice |
| 3142 | – – | 2334 | 10/23/1914 | CER | SPR | SW | NW | 21 | 11N | 63E | 0.004 | STK | – – | 1.657206 | AFS | Reid, Robert |
| 4470 | – – | – – | 6/15/1917 | DEN | SPR | SE | NW | 16 | 09N | 64E | 1.6 | IRR | – – | 0 | – – | Olsen, Casten |
| 4599 | – – | 643 | 9/24/1917 | CER | STR | SE | SE | 11 | 09N | 63E | 0.12 | IRR | – – | 36 | AFS | Adams, Myron |
| 4881 | – – | 1060 | 1/31/1918 | CER | SPR | SW | NE | 16 | 09N | 64E | 0.751 | IRR | – – | 225.57 | AFS | Mull Revocable Trust 1/13/1999 |
| 5071 | – – | 540 | 5/13/1918 | CER | SPR | SW | SE | 25 | 08N | 64E | 0.015 | STK | – – | 7.518805 | AFS | Mull Revocable Trust, 1/13/1999 |
| 5073 | – – | 542 | 5/13/1918 | CER | SPR | NE | NE | 25 | 08N | 64E | 0.015 | STK | – – | 7.303982 | AFS | Mull Revocable Trust, 1/13/1999 |
| 5747 | – – | 707 | 9/19/1919 | CER | SPR | SW | SE | 30 | 11N | 63E | 0.004 | STK | – – | 1.503761 | AFS | Reed, G.M. |
| 5755 | – – | – – | 9/22/1919 | CAN | SPR | SE | SE | 12 | 09N | 62E | 0.012 | STK | – – | 2.946144 | AFS | Gregorio Urrutia Company |
| 5756 | – – | – – | 9/22/1919 | CAN | SPR | SE | NE | 32 | 10N | 63E | 0.012 | STK | – – | 0 | – – | Gregorio Urrutia Company |
| 5757 | – – | – – | 9/22/1919 | DEN | SPR | SW | NW | 23 | 10N | 64E | 0.025 | STK | – – | 0 | – – | Gregorio Urrutia Company |
| 5787 | – – | – – | 10/2/1919 | DEN | SPR | NW | SE | 22 | 10N | 64E | 0.5 | STK | – – | 3.007522 | AFS | Gregorio Urrutia Company |
| 5788 | – – | – – | 10/2/1919 | CAN | SPR | SW | NW | 11 | 09N | 64E | 0.012 | STK | – – | 2.946144 | AFS | Gregorio Urrutia Company |
| 5873 | – – | – – | 11/26/1919 | DEN | SPR | SW | SE | 25 | 08N | 64E | 0.006 | STK | – – | 0 | – – | Gregorio Urrulia Company |
| 5874 | – – | – – | 11/26/1919 | CAN | SPR | NE | NW | 13 | 09N | 64E | 0.006 | STK | – – | 0.736536 | AFS | Gregorio Urrutia Company |
| 6598 | – – | – – | 12/5/1921 | CAN | UG | – – | – – | – – | 06N | 63E | 0 | STK | – – | 0 | – – | Whipple, J.I. |
| 6616 | – – | – – | 1/20/1922 | WDR | SPR | SE | NW | 16 | 09N | 64E | 0.8 | IRR | – – | – – | – – | Stephens, Carl W. |
| 6638 | – – | 2105 | 2/27/1922 | CER | UG | NE | SE | 21 | 05N | 63E | 0.003 | STK | – – | 2.14823 | AFA | Jensen, Bruce A. |
| 7397 | – – | 1175 | 6/14/1925 | CER | UG | SW | SE | 31 | 06N | 63E | 0.015 | STK | – – | 1.872029 | AFS | Jensen, Bruce A. |
| 7485 | – – | 1876 | 8/20/1925 | CER | UG | SW | SE | 36 | 09N | 64E | 0.012 | STK | – – | 8.961188 | AFA | Kirkeby, Gordon A. |
| 9001 | – – | 4209 | 7/26/1929 | CER | SPR | SW | NE | 16 | 09N | 64E | 0.044 | DOM | – – | 0 | – – | Great Western Mining & Development Company |

## Table A.1-1
## NDWR Hydrographic Abstract for Cave Valley
(Page 2 of 5)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Duty Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9002 | – – | – – | 7/26/1929 | DEN | SPR | NE | SE | 4 | 09N | 63E | 0 | PWR | – – | 0 | – – | Great Western Mining & Development |
| 9003 | – – | – – | 7/26/1929 | DEN | SPR | NE | SE | 4 | 09N | 63E | 0 | MM | – – | 0 | – – | Great Western Mining & Development |
| 9702 | – – | 2135 | 10/9/1933 | CER | SPR | SE | NE | 19 | 06N | 63E | 0.01 | STK | – – | 7.242604 | AFA | Jensen, Bruce A. |
| 9720 | – – | 2269 | 2/8/1934 | CER | SPR | NW | NE | 14 | 09N | 64E | 0.025 | STK | – – | 17.922376 | AFA | Cave Valley Ranches |
| 9721 | – – | 2270 | 2/8/1934 | CER | SPR | SW | SW | 2 | 09N | 64E | 0.025 | STK | – – | 17.922376 | AFA | Cave Valley Ranches |
| 13102 | – – | 4059 | 10/13/1949 | CER | SPR | NE | SE | 33 | 11N | 64E | 0.019 | STK | – – | 5.585398 | AFS | Cave Valley Ranches |
| 19299 | – – | – – | 10/26/1960 | CAN | OSW | SW | NE | 9 | 08N | 64E | 0 | IRR | – – | 0 | – – | BLM |
| 22692 | – – | – – | 7/15/1965 | CAN | SPR | SE | NW | 6 | 09N | 64E | 0 | IRR | – – | 0 | – – | Cave Valley Ranches Inc. |
| 22693 | – – | – – | 7/15/1965 | CAN | SPR | NW | SW | 4 | 09N | 64E | 0 | IRR | – – | 0 | – – | Cave Valley Ranches Inc. |
| 22694 | – – | – – | 7/15/1965 | CAN | SPR | SW | NE | 16 | 09N | 64E | 0 | IRR | – – | 0 | – – | Cave Valley Ranches Inc. |
| 22695 | – – | – – | 7/15/1965 | CAN | SPR | NW | NW | 9 | 09N | 64E | 0 | IRR | – – | 0 | – – | Cave Valley Ranches Inc. |
| 23093 | – – | – – | 4/11/1966 | CAN | UG | SE | SE | 19 | 07N | 64E | 0 | IND | – – | 0 | – – | Gulf Oil Corporation |
| 25322 | – – | 8358 | 10/15/1969 | CER | STR | SE | SW | 3 | 09N | 63E | 0.89 | IRR | – – | 240 | AFA | Lewis, Lou Jeanne |
| 25411 | – – | 8359 | 1/5/1970 | CER | SPR | SW | NW | 11 | 09N | 63E | 0.56399999 | IRR | – – | 79.2 | AFA | Lewis, Lou Jeanne |
| 25412 | – – | – – | 1/5/1970 | CAN | SPR | SW | NE | 4 | 09N | 63E | 1 | IRR | – – | 320 | AFA | Murry Whipple Ranch |
| 27814 | – – | 9654 | 10/5/1973 | CER | SPR | SW | NW | 11 | 09N | 63E | 0.67 | IRR | – – | 126 | AFA | Lewis, Jeanne Lou |
| 41696 | – – | – – | 7/14/1980 | WDR | UG | NW | SE | 33 | 07N | 63E | 0 | QM | – – | 0 | – – | MX |
| 41697 | – – | – – | 7/14/1980 | WDR | UG | SW | NW | 8 | 06N | 64E | 0 | QM | – – | 0 | – – | MX |
| 41698 | – – | – – | 7/14/1980 | WDR | UG | SW | SW | 21 | 06N | 63E | 0 | QM | – – | 0 | – – | MX |
| 41699 | – – | – – | 7/14/1980 | WDR | UG | NE | NW | 9 | 08N | 64E | 1 | QM | – – | 0 | – – | MX |
| 41700 | – – | – – | 7/14/1980 | WDR | UG | SW | NW | 3 | 07N | 64E | 0 | QM | – – | 0 | – – | MX |
| 41701 | – – | – – | 7/14/1980 | WDR | UG | NE | NW | 14 | 07N | 63E | 0 | QM | – – | 0 | – – | MX |
| 53987 | – – | – – | 10/17/1989 | RFP | UG | SW | NW | 22 | 06N | 63E | 6 | MUN | – – | 4343.82 | AFA | Southern Nevada Water Authority |
| 53988 | – – | – – | 10/17/1989 | RFP | UG | SE | SE | 21 | 07N | 63E | 10 | MUN | – – | 7239.7 | AFA | Southern Nevada Water Authority |

**Table A.1-1**
**NDWR Hydrographic Abstract for Cave Valley**
(Page 3 of 5)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Duty Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 64670 | – – | – – | 12/11/1998 | RFP | UG | SE | NE | 8 | 05N | 63E | 10 | IRR | – – | 5210 | AFA | Lincoln County Water District |
| 64671 | – – | – – | 12/11/1998 | RFP | UG | NE | SE | 9 | 08N | 64E | 10 | IRR | – – | 5210 | AFA | Lincoln County Water District |
| 66123 | – – | 16617 | 3/8/2000 | CER | UG | NW | SE | 15 | 07N | 63E | 0.0156 | STK | – – | 11.201485 | AFA | Jensen, Bruce A. and Pamela G. |
| 66125 | – – | 16619 | 3/8/2000 | CER | UG | SE | SW | 30 | 08N | 64E | 0.0156 | STK | – – | 11.201485 | AFA | Jensen, Bruce A. and Pamela G. |
| 66129 | – – | – – | 3/8/2000 | PER | SPR | SE | SW | 33 | 07N | 64E | 0.15 | IRR | – – | 80 | AFA | Jensen, Bruce A. and Pamela G. |
| 68487 | – – | – – | 2/11/2002 | RFP | UG | NE | NE | 14 | 07N | 63E | 3.5 | IRR | – – | 1280 | AFA | Jensen, Pamela G. |
| 68488 | – – | – – | 2/11/2002 | RFP | UG | NE | NE | 14 | 07N | 63E | 3.5 | IRR | – – | 1280 | AFA | Jensen, Bruce A. |
| 73168 | – – | – – | 8/19/2005 | PER | UG | SW | NW | 27 | 09N | 64E | 0.05 | STK | Y | 11.2 | AFA | Mull Revocable Trust 1/15/1999 |
| 73169 | – – | – – | 8/19/2005 | PER | UG | SW | NW | 15 | 08N | 64E | 0.05 | STK | Y | 11.2 | AFA | Mull Revocable Trust 1/15/1999 |
| 73170 | – – | – – | 8/19/2005 | PER | UG | NW | NE | 25 | 10N | 63E | 0.05 | STK | Y | 11.2 | AFA | Mull Revocable Trust 1/15/1999 |
| 73815 | – – | – – | 2/9/2006 | RFA | UG | NE | SE | 4 | 09N | 63E | 4 | IRR | – – | 0 | AFA | Lewis, Paul |
| 73816 | – – | – – | 2/9/2006 | RFA | UG | SE | SW | 3 | 09N | 63E | 4 | IRR | – – | 0 | AFA | Lewis, Paul |
| 73817 | – – | – – | 2/9/2006 | RFA | UG | SE | NE | 10 | 09N | 63E | 4 | IRR | – – | 0 | AFA | Lewis, Paul |
| 75231 | – – | – – | 1/3/2007 | RFA | UG | NW | NE | 4 | 08N | 64E | 0.0156 | STK | – – | 0 | AFA | Whipple, Kevin |
| 75779 | – – | – – | 5/24/2007 | RFA | UG | SE | SE | 5 | 09N | 64E | 0 | QM | – – | 8.071 | AFA | Cave Valley Ranch, LLC |
| 76124 | – – | – – | 8/3/2007 | APP | STR | SE | SE | 5 | 09N | 64E | 0.16 | OTH | – – | 0 | AFA | Cave Valley Ranch, LLC |
| 76125 | – – | – – | 8/3/2007 | APP | STR | SE | SE | 5 | 09N | 64E | 0.07 | OTH | – – | 0 | AFA | Cave Valley Ranch, LLC |
| 76126 | – – | – – | 8/3/2007 | APP | UG | SE | SE | 5 | 09N | 64E | 0.07 | STK | – – | 0 | AFA | Cave Valley Ranch, LLC |
| 76127 | – – | – – | 8/3/2007 | APP | UG | SE | SE | 5 | 09N | 64E | 0.07 | OTH | – – | 0 | AFA | Cave Valley Ranch, LLC |
| 76128 | – – | – – | 8/3/2007 | APP | UG | SE | SE | 5 | 09N | 64E | 0.16 | OTH | – – | 0 | AFA | Cave Valley Ranch, LLC |
| 76129 | V01680 | – – | 8/3/2007 | APP | STR | SE | SE | 5 | 09N | 64E | 0.06 | STK | – – | 0 | AFA | Cave Valley Ranch, LLC |

# Table A.1-1
## NDWR Hydrographic Abstract for Cave Valley
(Page 4 of 5)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Duty Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R09414 | – – | – – | 4/6/2004 | RES | SPR | SE | NE | 19 | 06N | 63E | 0.0015 | STK | – – | 0 | AFA | BLM |
| R09416 | – – | – – | 4/6/2004 | RES | SPR | SW | SE | 31 | 06N | 63E | 0.0015 | STK | – – | 0 | AFA | BLM |
| R09417 | – – | – – | 4/6/2004 | RES | SPR | NE | SW | 30 | 06N | 63E | 0.0015 | STK | – – | 0 | AFA | BLM |
| V01416 | – – | – – | 8/30/1915 | VST | SPR | NE | SE | 30 | 11N | 63E | 0.1 | STK | – – | 0 | – – | Adams Mcgill Company |
| V01486 | – – | – – | 12/8/1916 | VST | SPR | NE | SE | 20 | 11N | 63E | 0.25 | STK | – – | 0 | – – | Adams Mcgill Company |
| V01559 | – – | – – | 4/8/1918 | VST | SPR | NW | SW | 10 | 10N | 64E | 0.5 | STK | – – | 0 | – – | Cave Valley Ranches |
| V01658 | – – | – – | 12/6/1919 | VST | SPR | SW | NW | 23 | 10N | 64E | 0.3 | STK | – – | 7.457427 | AFS | Cave Valley Ranches |
| V01659 | – – | – – | 12/6/1919 | VST | SPR | SE | SE | 22 | 10N | 64E | 0.3 | STK | – – | 7.457427 | AFS | Mull Revocable Trust, 1/13/1999 |
| V01660 | – – | – – | 12/6/1919 | VST | SPR | NW | SE | 22 | 10N | 64E | 0.3 | STK | – – | 7.457427 | AFS | Cave Valley Ranches |
| V01675 | – – | – – | 12/26/1919 | VST | SPR | SE | SW | 27 | 10N | 64E | 0.025 | STK | – – | 7.457427 | AFS | Mull Revocable Trust, 1/13/1999 |
| V01678 | – – | – – | 12/29/1919 | VST | STR | NE | SE | 34 | 10N | 64E | 1 | STK | – – | 0 | – – | Mull Revocable Trust, 1/13/1999 |
| V01679 | – – | – – | 12/29/1919 | VST | STR | NW | NW | 2 | 09N | 64E | 1 | STK | – – | 0 | – – | Cave Valley Ranches Inc. |
| V01680 | – – | – – | 1/8/1920 | VST | STR | NW | NE | 4 | 09N | 64E | 1 | STK | – – | 0 | AFA | Mull Revocable Trust, 1/13/1999 |
| V01680 | Changed By: | 76129 | – – | APP | STR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| V01681 | – – | – – | 1/8/1920 | VST | STR | NE | NW | 26 | 10N | 64E | 1 | STK | – – | 0 | – – | Mull Revocable Trust, 1/13/1999 |
| V01696 | – – | – – | 5/3/1920 | VST | SPR | SW | SW | 2 | 09N | 64E | 0.025 | STK | – – | 0 | – – | Geyser Land & Cattle Co. |
| V01697 | – – | – – | 5/3/1920 | VST | SPR | NW | SE | 11 | 09N | 64E | 0.025 | STK | – – | 0 | – – | Mull Revocable Trust, 1/13/1999 |
| V01698 | – – | – – | 5/3/1920 | VST | SPR | NW | NE | 14 | 09N | 64E | 0.025 | STK | – – | 0 | – – | Geyser Land & Cattle Co. |
| V01699 | – – | – – | 5/3/1920 | VST | SPR | NE | SW | 14 | 09N | 64E | 0.025 | STK | – – | 0 | – – | Cave Valley Ranches Inc. |
| V01807 | – – | – – | 8/18/1921 | VST | STR | NW | SW | 31 | 10N | 64E | 0.004 | IRR | – – | 0 | AFA | Mull Revocable Trust, 1/13/1999 |
| V01878 | – – | – – | 4/18/1925 | VST | STR | SW | SE | 15 | 11N | 63E | 0.25 | STK | – – | 0 | – – | Adams Mcgill Company |
| V01881 | – – | – – | 4/18/1925 | VST | SPR | SE | SE | 3 | 11N | 63E | 0.25 | STK | – – | 0 | – – | Adams Mcgill Company |

## Table A.1-1
## NDWR Hydrographic Abstract for Cave Valley
(Page 5 of 5)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Duty Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| V01882 | – – | – – | 4/18/1925 | VST | SPR | NE | NW | 10 | 11N | 63E | 0.25 | STK | – – | 0 | – – | Adams Mcgill Company |
| V01883 | – – | – – | 4/18/1925 | VST | SPR | SE | SW | 10 | 11N | 63E | 0.05 | STK | – – | 0 | – – | Adams Mcgill Company |
| V01964 | – – | – – | 1/11/1926 | VST | SPR | SE | NE | 19 | 06N | 63E | 0.004 | STK | – – | 0 | – – | Jensen, Bruce A. |
| V01965 | – – | – – | 1/11/1926 | VST | SPR | NE | SW | 30 | 06N | 63E | 0.002 | STK | – – | 0 | – – | Jensen, Bruce A. |
| V02075 | – – | – – | 3/21/1927 | VST | SPR | NW | SE | 9 | 10N | 63E | 0.25 | STK | – – | 6.720891 | AFS | Jensen, Bruce A. |
| V02079 | – – | – – | 4/8/1927 | VST | SPR | SW | SE | 17 | 10N | 63E | 0.25 | STK | – – | 6.720891 | AFS | Jensen, Bruce A. |
| V02692 | – – | – – | 11/25/1970 | VST | SPR | SW | NE | 4 | 09N | 63E | 0.414 | IRR | – – | 0 | AFA | Lewis, Lou Jeanne |
| V02693 | – – | – – | 11/25/1970 | VST | SPR | SE | SW | 3 | 09N | 63E | 0.414 | IRR | – – | 0 | – – | Lewis, Lou Jeanne |
| V02694 | – – | – – | 11/25/1970 | VST | SPR | SW | NW | 11 | 09N | 63E | 0.12 | IRR | – – | 0 | – – | Lewis, Lou Jeanne |
| V09231 | – – | – – | 3/8/2000 | VST | SPR | NE | SE | 6 | 09N | 63E | 0.013 | STK | – – | – – | – – | Jensen, Bruce A. |
| V09232 | – – | – – | 3/8/2000 | VST | SPR | NW | SE | 12 | 09N | 62E | 0.013 | STK | – – | – – | – – | Jensen, Bruce A. |
| V09233 | – – | – – | 3/8/2000 | VST | SPR | SW | SE | 32 | 10N | 63E | 0.013 | STK | – – | 3.37579 | AFS | Jensen, Bruce A. |
| V09234 | – – | – – | 3/8/2000 | VST | SPR | NE | NE | 32 | 09N | 63E | 0.1 | STK | – – | – – | – – | Jensen, Bruce A. |
| V09235 | – – | – – | 3/8/2000 | VST | SPR | SE | SW | 33 | 07N | 64E | 0.05 | STK | – – | – – | – – | Jensen, Bruce A. |
| V09236 | – – | – – | 3/8/2000 | VST | SPR | SE | NW | 13 | 09N | 62E | 0.025 | STK | – – | – – | – – | Jensen, Bruce A. |
| V09522 | – – | – – | 8/19/2005 | VST | SPR | SW | SE | 2 | 09N | 64E | 0.025 | STK | – – | 0 | AFA | Mull Revocable Trust Dated 1/15/1999 |
| V09523 | – – | – – | 8/19/2005 | VST | STR | NW | NW | 2 | 09N | 64E | 1 | STK | – – | 0 | AFA | Mull Revocable Trust Dated 1/15/1999 |
| V09524 | – – | – – | 8/19/2005 | VST | SPR | NW | NW | 23 | 10N | 64E | 0.333 | STK | – – | 0 | AFA | Mull Revocable Trust Dated 1/15/1999 |
| V09525 | – – | – – | 8/19/2005 | VST | SPR | NW | SE | 22 | 10N | 64E | 0.333 | STK | – – | 0 | AFA | Mull Revocable Trust Dated 1/15/1999 |
| V09526 | – – | – – | 8/19/2005 | VST | SPR | SW | SE | 11 | 09N | 64E | 0.025 | STK | – – | 0 | AFA | Mull Revocable Trust Dated 1/15/1999 |
| V09527 | – – | – – | 8/19/2005 | VST | SPR | SE | NW | 13 | 09N | 64E | 0.025 | STK | – – | 0 | AFA | Mull Revocable Trust Dated 1/15/1999 |

Source: Data downloaded from Nevada Division of Water Resources on August 13, 2007.

## Table A.1-2
## NDWR Hydrographic Abstract for Dry Lake Valley
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| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 387 | – – | – – | 3/9/1907 | CAN | SPR | – – | – – | – – | 04N | 65E | 0 | IRR | – – | 0 | – – | Ellis, A.C. |
| 388 | – – | – – | 3/9/1907 | CAN | SPR | – – | – – | – – | – – | – – | 0 | IRR | – – | 0 | – – | E.& F. Mining |
| 524 | – – | – – | 6/13/1907 | CAN | SPR | – – | – – | 10 | 05N | 65E | 0 | MM | – – | 0 | – – | Newman, Geo. W. |
| 780 | – – | 566 | 1/10/1908 | CER | SPR | – – | – – | – – | 01S | 65E | 0.91599999 | STK | – – | 663.49618 | AFA | Carter, Dean |
| 780 | Changed By: | 36334 | – – | CAN | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 780 | Changed By: | 52105 | – – | CER | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 780 | Changed By: | 52108 | – – | CER | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 780 | Changed By: | 52109 | – – | CER | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 3368 | – – | 1980 | 4/26/1915 | CER | SPR | SW | SE | 25 | 04N | 66E | 0.03 | IRR | – – | 11 | AFS | Cyphers, Robert M. |
| 3592 | – – | – – | 9/27/1915 | CAN | SPR | NE | NW | 20 | 04S | 65E | 0.1 | DOM | – – | – – | – – | Butler, N.N. |
| 3593 | – – | – – | 9/27/1915 | CAN | SPR | NE | SE | 20 | 04S | 65E | 0.1 | DOM | – – | – – | – – | Butler, N.N. |
| 3875 | – – | 724 | 4/10/1916 | CER | RES | NE | NE | 3 | 03S | 64E | 0.01 | STK | – – | 7.5 | AFA | Corp Presiding Bishop Church JC LDS |
| 3876 | – – | 725 | 4/10/1916 | CER | RES | SW | SW | 33 | 02S | 64E | 0.01 | STK | – – | 7.5 | AFA | Corp Presiding Bishop Church JC LDS |
| 3877 | – – | – – | 4/10/1916 | CAN | SPR | NE | SW | 21 | 03S | 64E | 0.025 | STK | – – | – – | – – | Mackie, A.J. |
| 3878 | – – | 726 | 4/10/1916 | CER | RES | NW | SE | 32 | 01S | 64E | 0 | STK | – – | 7.5 | AFA | Corp Presiding Bishop Church JC LDS |
| 4550 | – – | – – | 8/23/1917 | CAN | SPR | – – | – – | – – | 01S | 64E | 0 | STK | – – | – – | – – | Imlay, James W. |
| 4551 | – – | – – | 8/23/1917 | CAN | SPR | – – | – – | – – | 01S | 64E | 0 | STK | – – | – – | – – | Imlay, James W. |
| 4612 | – – | – – | 10/1/1917 | DEN | SPR | – – | – – | – – | 04S | 65E | 0 | STK | – – | – – | – – | Robinson, J.R. Jr. |
| 4616 | – – | – – | 10/5/1917 | CAN | SPR | NE | NW | 20 | 04S | 65E | 0 | STK | – – | 0 | – – | Culverwell, Wm. |
| 4617 | – – | – – | 10/5/1917 | CAN | SPR | – – | – – | – – | 04S | 65E | 0 | STK | – – | – – | – – | Culverwell, Wm. |
| 4618 | – – | – – | 10/5/1917 | DEN | SPR | – – | – – | – – | 04S | 65E | 0.4 | STK | – – | – – | – – | Culverwell, Wm. |
| 4619 | – – | – – | 10/5/1917 | CAN | SPR | NE | SE | 20 | 04S | 65E | 0.4 | STK | – – | – – | – – | Culverwell, Wm. |
| 4694 | – – | – – | 11/12/1917 | CAN | UG | – – | – – | – – | 04S | 65E | 0 | STK | – – | – – | – – | Conoway, John H. |
| 4696 | – – | 732 | 11/12/1917 | CER | SPR | SE | SE | 31 | 04S | 65E | 0.003 | STK | – – | 2.178919 | AFA | Corp Presiding Bishop Church JC LDS |

## Table A.1-2
## NDWR Hydrographic Abstract for Dry Lake Valley
(Page 2 of 11)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4696 | Changed By: | 52111 | – – | WDR | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 4697 | – – | 733 | 11/12/1917 | CER | SPR | SW | SE | 31 | 04S | 65E | 0.001 | STK | – – | 1.074115 | AFA | Culverwell, William |
| 4697 | Changed By: | 52110 | – – | WDR | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 4699 | – – | – – | 11/12/1917 | CAN | SPR | NW | NW | 36 | 04S | 64E | 0.05 | STK | – – | – – | – – | Gardner Ranch Co. |
| 4855 | – – | – – | 1/21/1918 | CAN | SPR | SW | NW | 36 | 04N | 64E | 1 | IRR | – – | 0 | – – | Jeffcott, Vernon |
| 4906 | – – | – – | 2/13/1917 | CAN | STR | NW | SW | 20 | 03S | 64E | 1 | STK | – – | – – | – – | Thorley, Robert A. |
| 4934 | – – | – – | 2/23/1918 | DEN | SPR | SW | NW | 23 | 01N | 63E | 0.1 | STK | – – | – – | – – | Thorley, Robert A. |
| 4961 | – – | 525 | 3/14/1918 | CER | SPR | NW | NE | 23 | 01N | 65E | 0.003 | STK | – – | 2.178919 | AFA | Highbee, Florence S. |
| 4962 | – – | – – | 3/14/1918 | CAN | SPR | NE | NE | 14 | 01N | 65E | 0.4 | STK | – – | – – | – – | Mathews, Charles Jr. |
| 4972 | – – | 734 | 3/21/1918 | ABR | SPR | NE | NE | 26 | 03S | 65E | 0 | STK | – – | 0 | AFA | H.H. Land and Cattle Company |
| 4972 | Changed By: | 52106 | – – | CER | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 5057 | – – | – – | 5/7/1918 | CAN | STR | SW | NE | 26 | 04N | 65E | 0 | IRR | – – | 0 | – – | West Side Cattle Company |
| 5200 | – – | 1924 | 8/12/1918 | CER | STR | SW | SE | 26 | 04N | 65E | 0.063 | STK | – – | 44.80594 | AFA | West Side Cattle Company |
| 5356 | – – | 526 | 1/16/1919 | CER | SPR | SE | NW | 11 | 01N | 65E | 0.002 | STK | – – | 0.153445 | AFS | Goodman, R.F. |
| 5371 | – – | 1119 | 1/25/1919 | CER | RES | SW | NW | 24 | 02S | 64E | 0 | STK | – – | 10 | AFS | Whipple, Deeann |
| 5372 | – – | – – | 1/25/1919 | CAN | OSW | SW | SE | 35 | 01S | 64E | 0 | STK | – – | – – | – – | Thorley, Frank A. |
| 5935 | – – | – – | 1/5/1920 | WDR | UG | SE | NW | 14 | 05N | 64E | 0.5 | IRR | – – | – – | – – | Adams McGill Company |
| 5936 | – – | 854 | 1/5/1920 | CER | UG | SE | NW | 14 | 05N | 64E | 0.025 | STK | – – | 18.075821 | AFA | Adams McGill Company |
| 6076 | – – | – – | 4/30/1920 | DEN | OSW | SW | NW | 24 | 02S | 64E | 0.031 | STK | – – | – – | – – | Ellsworth, Roy and Mathews, Dan |
| 6094 | – – | 1053 | 5/6/1920 | CER | SPR | NE | SE | 33 | 02S | 63E | 0.00899999 | STK | – – | 6.506068 | AFA | Corp Presiding Bishop Church JC LDS |
| 6095 | – – | 1054 | 5/6/1920 | ABR | SPR | SW | NW | 22 | 02S | 63E | 0 | STK | – – | 0 | AFA | H.H. Land and Cattle Company |
| 6095 | Changed By: | 52103 | – – | CER | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |

## Table A.1-2
## NDWR Hydrographic Abstract for Dry Lake Valley
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| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6337 | – – | – – | 11/27/1920 | DEN | SPR | NE | NW | 21 | 03S | 64E | 0.5 | STK | – – | – – | – – | Jeffcott, Vernon |
| 6338 | – – | – – | 11/29/1920 | DEN | SPR | NE | NW | 21 | 03S | 64E | 0 | STK | – – | 0 | – – | Jeffcoat, Vernon |
| 6376 | – – | – – | 1/15/1921 | DEN | SPR | NW | SE | 33 | 02S | 66E | 0.167 | STK | – – | – – | – – | Thorley, Robert A. |
| 6432 | – – | – – | 4/6/1921 | WDR | SPR | NW | SW | 34 | 04N | 65E | 0.5 | MM | – – | – – | – – | Nevada Silver Horn Mining Co. |
| 6454 | – – | – – | 5/5/1921 | CAN | SPR | SE | SE | 35 | 04N | 65E | 0.1 | STK | – – | – – | – – | Brodie, W.E. |
| 6619 | – – | 835 | 1/27/1922 | CER | SPR | NE | SW | 33 | 02S | 66E | 0.015 | STK | – – | 10.74115 | AFA | Williams, Alex B. |
| 6718 | – – | 1629 | 7/17/1922 | CER | UG | SW | SW | 32 | 01N | 66E | 0.025 | MM | – – | 18.075821 | AFA | Comet Mines Co. |
| 6803 | – – | 971 | 10/23/1922 | CER | SPR | NE | SW | 22 | 01N | 65E | 0.002 | STK | – – | 1.595828 | AFA | Federal Land Bank of Berkeley |
| 7064 | – – | – – | 3/19/1924 | CAN | OSW | SW | NW | 36 | 04N | 65E | 0.25 | MM | – – | – – | – – | Nevada Lead Company |
| 7111 | – – | – – | 5/9/1924 | CAN | SPR | – – | SE | 26 | 01N | 66E | 0.33 | MM | – – | – – | – – | Pioche Union Mines Company |
| 7117 | – – | 1466 | 5/16/1924 | CER | SPR | NW | SW | 13 | 02N | 63E | 0.002 | STK | – – | 1.565139 | AFA | Robison Brothers |
| 7563 | – – | 2209 | 11/4/1925 | CER | SPR | SE | NE | 22 | 01N | 63E | 0.006 | STK | – – | 2.608565 | AFA | Clark, Douglas |
| 7564 | – – | 2210 | 11/4/1925 | CER | SPR | SE | NW | 22 | 01N | 63E | 0.012 | STK | – – | 4.848862 | AFA | Clark, Douglas |
| 7565 | – – | – – | 11/4/1925 | DEN | SPR | NE | NE | 34 | 02N | 63E | 0.003 | STK | – – | – – | – – | Hamilton, R.H. |
| 8405 | – – | – – | 12/8/1927 | DEN | SPR | SE | NW | 15 | 06N | 64E | 0.5 | STK | – – | – – | – – | Imperial Farms Land & Cattle Co., Inc. |
| 8406 | – – | – – | 12/8/1927 | WDR | SPR | – – | – – | – – | 06N | 65E | 0.5 | STK | – – | – – | – – | Skinner, Lucille A. |
| 8669 | – – | – – | 8/28/1928 | WDR | SPR | NW | NE | 15 | 06N | 64E | 0.5 | STK | – – | 40.325346 | AFA | Swallow, R.T. |
| 8670 | – – | 8146 | 8/19/1928 | CER | SPR | NE | SE | 3 | 06N | 64E | 0.01 | STK | – – | 7.242604 | AFA | Imperial Farms Land and Cattle Co. |
| 8698 | – – | 5705 | 9/17/1928 | CER | SPR | NE | SE | 5 | 01S | 65E | 0.017 | STK | – – | 12.060777 | AFA | Whipple, Deeann |
| 9335 | – – | – – | 9/15/1930 | DEN | UG | NE | NE | 2 | 01N | 65E | 0.03 | STK | – – | – – | – – | Thorley, Frank A. |
| 9618 | – – | 2107 | 8/11/1932 | CER | OSW | NE | NW | 11 | 03S | 64E | 0.00899999 | STK | – – | 6.782269 | AFA | Corp Presiding Bishop Church JC LDS |
| 9660 | – – | 2293 | 5/6/1933 | CER | SPR | SE | NE | 4 | 03S | 65E | 0.001 | STK | – – | 0.675158 | AFS | Whipple, Deeann |

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**NDWR Hydrographic Abstract for Dry Lake Valley**
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| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9965 | – – | – – | 3/6/1936 | WDR | UG | NW | NW | 6 | 02N | 65E | 0.5 | STK | – – | 361.5 | AFA | BLM |
| 10070 | – – | – – | 1/7/1937 | DEN | OSW | SW | NE | 7 | 04S | 64E | 0 | STK | – – | 3 | AFA | Jones, Erastus L. |
| 10119 | – – | 2355 | 5/17/1937 | CER | SPR | NE | SW | 22 | 01N | 65E | 0.015 | STK | – – | 5.21713 | AFS | Whipple, Deeann |
| 10120 | – – | 2356 | 5/17/1937 | CER | SPR | NW | NE | 23 | 01N | 65E | 0.015 | STK | – – | 5.21713 | AFS | Whipple, Deeann |
| 10747 | – – | 2805 | 10/17/1941 | CER | SPR | NE | SW | 9 | 04S | 65E | 0.01 | STK | – – | 7.181226 | AFA | Corp Presiding Bishop Church JC LDS |
| 11033 | – – | 3063 | 12/3/1943 | CER | SPR | SE | NE | 26 | 01N | 66E | 0.003 | STK | – – | 2.240297 | AFA | Bleak, Juanita W. and Wheller, Casey L. |
| 11118 | – – | 2826 | 5/10/1944 | CER | RES | SE | SE | 33 | 02S | 65E | 0.013 | STK | – – | 6.720891 | AFS | Whipple, Deeann |
| 11490 | – – | – – | 1/19/1946 | WDR | UG | NW | NW | 2 | 04S | 64E | 0.1 | STK | – – | 4.480594 | AFA | Conaway, John H. |
| 11780 | – – | – – | 2/15/1947 | WDR | UG | SW | SW | 9 | 01S | 66E | 2 | MM | – – | 0 | – – | Comet Coalition Mines Co. |
| 12246 | – – | 3583 | 2/6/1948 | CER | SPR | SW | SE | 34 | 02N | 63E | 0.013 | STK | – – | 5.21713 | AFS | Thorley, Frank |
| 12247 | – – | 3584 | 2/6/1948 | CER | SPR | NW | NW | 35 | 02N | 63E | 0.013 | STK | – – | 4.480594 | AFA | Thorley, Frank |
| 12509 | – – | – – | 6/18/1948 | CAN | SPR | NE | SW | 10 | 03S | 63E | 0.003 | STK | – – | – – | – – | Byron, A. |
| 12511 | – – | 4390 | 6/18/1948 | CER | SPR | NW | SE | 32 | 02S | 63E | 0.003 | STK | – – | 1.872029 | AFA | Higbee, E. Edwin, Kristine H. |
| 12512 | – – | 4391 | 6/18/1948 | CER | SPR | SW | SW | 34 | 02S | 63E | 0.003 | STK | – – | 1.503761 | AFA | Higbee, E. Edwin and Kristine H. |
| 12514 | – – | – – | 6/18/1948 | DEN | OSW | SE | SE | 29 | 02S | 64E | 0.025 | STK | – – | – – | – – | Ercanbrack, Byron A. |
| 12793 | 6497 | 4501 | 1/8/1949 | CER | SPR | NE | NW | 27 | 02S | 63E | 0.00899999 | STK | – – | 2.792699 | AFA | Higbee, E. Edwin and Kristine H. |
| 12840 | 11308 | 4502 | 3/7/1949 | CER | SPR | NE | SW | 27 | 02S | 63E | 0.002 | STK | – – | 1.626517 | AFA | Higbee, E. Edwin and Kristine H. |
| 12879 | – – | – – | 4/11/1949 | CAN | OSW | SE | SE | 8 | 01S | 66E | 0.1 | STK | – – | 13.441782 | AFA | Thorley, Robert A. |
| 12920 | 6497 | – – | 5/19/1949 | CAN | SPR | NE | NW | 27 | 02S | 63E | 0.015 | STK | – – | 0 | AFA | Ercanbrack, Bryon A. |
| 14732 | – – | 4712 | 12/24/1952 | CER | STR | SW | NW | 17 | 02S | 66E | 0 | STK | – – | 3.98957 | AFS | Jones, H. Wendell |
| 18756 | – – | 5059 | 4/26/1960 | CER | UG | NE | NW | 24 | 01N | 64E | 0.015 | STK | – – | 10.833217 | AFA | Delmue, Albert |
| 21868 | – – | – – | 3/11/1964 | WDR | UG | NW | NW | 21 | 03S | 64E | 0 | IRD | – – | – – | – – | Barnett, Cora A. |

## Table A.1-2
## NDWR Hydrographic Abstract for Dry Lake Valley
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| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21869 | – – | – – | 3/11/1964 | WDR | UG | SW | NW | 28 | 03S | 64E | 0 | IRD | – – | – – | – – | Steiner, Waunita |
| 21870 | – – | – – | 3/11/1964 | WDR | UG | NW | NW | 16 | 03S | 64E | 0 | IRD | – – | – – | – – | Burgess, Carolyn |
| 22345 | – – | – – | 12/1/1964 | DEN | UG | SE | SE | 27 | 03S | 64E | 5.4 | IRD | – – | – – | – – | Harris, Joyce C. |
| 27924 | – – | – – | 11/29/1973 | CAN | SPR | – – | NW | 31 | 07S | 65E | 0.02 | STK | – – | 14.331763 | AFA | Summa Corporation |
| 34573 | – – | – – | 11/7/1977 | CAN | UG | NE | NE | 4 | 03N | 65E | 0 | MM | – – | 0 | AFA | Folta, William D. |
| 35077 | – – | – – | 3/9/1978 | CAN | SPR | – – | NE | 3 | 03N | 65E | 0 | STK | – – | 0 | – – | Imperial Farms Land and Cattle Co. |
| 35081 | – – | – – | 3/9/1978 | CAN | SPR | – – | S2 | 16 | 04N | 65E | 0.25 | STK | – – | 10.096681 | AFA | Imperial Farms Land and Cattle Co. |
| 35082 | – – | – – | 3/9/1978 | CAN | SPR | SW | SW | 16 | 04N | 65E | 0 | STK | – – | 0 | – – | Imperial Farms Land and Cattle Co. |
| 35083 | – – | – – | 3/9/1978 | CAN | SPR | – – | NE | 22 | 04N | 65E | 0 | STK | – – | 0 | – – | Imperial Farms Land and Cattle Co. |
| 35084 | – – | – – | 3/9/1978 | CAN | SPR | – – | NW | 22 | 04N | 65E | 0 | STK | – – | 0 | – – | Imperial Farms Land and Cattle Co. |
| 35085 | – – | – – | 3/9/1978 | CAN | SPR | – – | SW | 22 | 04N | 65E | 0 | STK | – – | 0 | – – | Imperial Farms Land and Cattle Co. |
| 35086 | – – | – – | 3/9/1978 | CAN | SPR | – – | SE | 22 | 04N | 65E | 0 | STK | – – | 0 | – – | Imperial Farms Land and Cattle Co. |
| 35089 | – – | – – | 3/9/1978 | CAN | SPR | – – | N2 | 26 | 04N | 65E | 0 | STK | – – | 0 | – – | Imperial Farms Land and Cattle Co. |
| 35090 | – – | – – | 3/9/1978 | CAN | SPR | – – | N2 | 26 | 04N | 65E | 0 | STK | – – | 0 | – – | Imperial Farms Land and Cattle Co. |
| 35091 | – – | – – | 3/9/1978 | CAN | SPR | NE | SE | 35 | 04N | 65E | 0 | STK | – – | 0 | – – | Imperial Farms Land and Cattle Co. |
| 35095 | – – | – – | 3/9/1978 | CAN | RES | – – | NE | 1 | 01N | 64E | 0 | STK | – – | 0 | – – | Delmue, Frank |
| 35096 | – – | – – | 3/9/1978 | CAN | UG | – – |  | 4 | 02N | 64E | 0 | STK | – – | 0 | – – | Delmue, Frank |
| 35097 | – – | – – | 3/9/1978 | CAN | RES | – – | SW | 11 | 02N | 64E | 0 | STK | – – | 0 | – – | Delmue, Frank |
| 35098 | – – | – – | 3/9/1978 | CAN | RES | – – | NW | 30 | 02N | 65E | 0 | STK | – – | 0 | – – | Delmue, Frank |
| 35099 | – – | – – | 3/9/1978 | CAN | UG | – – | – – | 20 | 03N | 64E | 0 | STK | – – | 0 | – – | Delmue, Frank |

## Table A.1-2
## NDWR Hydrographic Abstract for Dry Lake Valley
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| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35100 | – – | – – | 3/9/1978 | CAN | UG | – – | – – | 21 | 03N | 65E | 0 | STK | – – | 0 | – – | Delmue, Frank |
| 35101 | – – | – – | 3/9/1978 | CAN | SPR | – – | – – | 5 | 04N | 65E | 0 | STK | – – | 0 | – – | Delmue, Frank |
| 35102 | – – | – – | 3/9/1978 | CAN | SPR | NE | SE | 35 | 04N | 65E | 0 | STK | – – | 0 | – – | Delmue, Frank |
| 35120 | – – | – – | 3/15/1978 | CAN | SPR | SE | SE | 10 | 05N | 65E | 0 | STK | – – | 0 | – – | Steward, Robert |
| 35127 | – – | – – | 3/15/1978 | CAN | SPR | – – | SW | 14 | 05N | 65E | 0.25 | STK | – – | 1.350316 | AFA | Steward, Robert |
| 35128 | – – | – – | 3/15/1978 | CAN | SPR | – – | SW | 15 | 05N | 65E | 0.25 | STK | – – | 1.350316 | AFA | Steward, Robert |
| 35129 | – – | – – | 3/15/1978 | CAN | SPR | – – | SE | 16 | 05N | 65E | 0.25 | STK | – – | 1.350316 | AFA | Steward, Robert |
| 35130 | – – | – – | 3/15/1978 | CAN | OSW | – – | N2 | 21 | 05N | 65E | 0.25 | STK | – – | 1.350316 | AFA | Steward, Robert |
| 35131 | – – | – – | 3/15/1978 | CAN | SPR | – – | SE | 22 | 05N | 65E | 0.25 | STK | – – | 1.350316 | AFA | Steward, Robert |
| 35328 | – – | – – | 4/24/1978 | CAN | SPR | – – | – – | 21 | 06N | 65E | 0.25 | STK | – – | – – | – – | Steward, Robert |
| 35334 | – – | – – | 4/26/1978 | CAN | RES | – – | – – | 35 | 06N | 64E | 0 | STK | – – | 11.416308 | AFA | Imperial Farms Land and Cattle Co. |
| 35336 | – – | – – | 4/26/1978 | CAN | RES | – – | – – | 12 | 06N | 64E | 0 | STK | – – | 15.835524 | AFA | Imperial Farms Land and Cattle Co. |
| 35696 | – – | 10175 | 8/7/1978 | CER | RES | SE | SW | 26 | 05N | 65E | 0.007 | STK | – – | 4.91024 | AFA | Geyser Ranch Limited Partnership |
| 35761 | – – | 10204 | 8/18/1978 | CER | SPR | NW | NW | 26 | 04N | 65E | 0.005 | STK | – – | 3.253034 | AFA | Geyser Ranch Limited Partnership |
| 35762 | – – | 10205 | 8/18/1978 | CER | SPR | SE | SE | 22 | 04N | 65E | 0.005 | STK | – – | 3.253034 | AFA | Geyser Ranch Limited Partnership |
| 35763 | – – | 10206 | 8/18/1978 | CER | SPR | NE | SE | 22 | 04N | 65E | 0.005 | STK | – – | 3.253034 | AFA | Geyser Ranch Limited Partnership |
| 35764 | – – | 10207 | 8/18/1978 | CER | SPR | SE | NE | 22 | 04N | 65E | 0.005 | STK | – – | 3.253034 | AFA | Geyser Ranch Limited Partnership |
| 35766 | – – | 10208 | 8/18/1978 | CER | SPR | NW | SE | 26 | 04N | 65E | 0.014 | STK | – – | 10.096681 | AFA | Geyser Ranch Limited Partnership |
| 35767 | – – | 10209 | 8/18/1978 | CER | SPR | SE | NW | 26 | 04N | 65E | 0.007 | STK | – – | 4.848862 | AFA | Geyser Ranch Limited Partnership |
| 35768 | – – | 10210 | 8/18/1978 | CER | SPR | NE | SE | 35 | 04N | 65E | 0.005 | STK | – – | 3.253034 | AFA | Geyser Ranch Limited Partnership |

# Table A.1-2
## NDWR Hydrographic Abstract for Dry Lake Valley
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| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35769 | – – | 10186 | 8/18/1978 | CER | RES | SW | NE | 1 | 01N | 64E | 0.005 | STK | – – | 3.253034 | AFA | Geyser Ranch Limited Partnership |
| 35770 | – – | 10869 | 8/18/1978 | CER | UG | SW | NE | 4 | 02N | 64E | 0.004 | STK | – – | 3.191656 | AFA | Geyser Ranch Limited Partnership |
| 35771 | – – | 10211 | 8/18/1978 | CER | SPR | NW | SW | 11 | 02N | 64E | 0.005 | STK | – – | 3.253034 | AFA | Geyser Ranch Limited Partnership |
| 35772 | – – | 10187 | 8/18/1978 | CER | RES | SE | SW | 19 | 02N | 65E | 0.005 | STK | – – | 3.253034 | AFA | Geyser Ranch Limited Partnership |
| 35773 | – – | 10870 | 8/18/1978 | CER | UG | SE | NW | 20 | 03N | 64E | 0.004 | STK | – – | 3.191656 | AFA | Geyser Ranch Limited Partnership |
| 35774 | – – | 10871 | 8/18/1978 | CER | UG | NW | SE | 21 | 03N | 65E | 0.004 | STK | – – | 3.191656 | AFA | Geyser Ranch Limited Partnership |
| 35775 | – – | 10212 | 8/18/1978 | CER | SPR | SE | SE | 5 | 04N | 65E | 0.014 | STK | – – | 10.096681 | AFA | Geyser Ranch Limited Partnership |
| 35843 | – – | 10288 | 9/6/1978 | CER | SPR | NW | NE | 21 | 05N | 65E | 0.002 | STK | – – | 1.166182 | AFA | Steward, Robert |
| 35844 | – – | 10289 | 9/6/1978 | CER | SPR | NE | SW | 10 | 05N | 65E | 0.002 | STK | – – | 1.350316 | AFA | Steward, Robert |
| 35849 | – – | – – | 9/6/1978 | WDR | RES | NE | SW | 35 | 06N | 64E | 0.25 | STK | – – | 11.416308 | AFA | Geyser Ranch Limited Partnership |
| 35851 | – – | 10215 | 9/6/1978 | CER | RES | SE | SW | 12 | 06N | 64E | 0.006 | STK | – – | 4.050948 | AFA | Geyser Ranch Limited Partnership |
| 35951 | – – | 10217 | 10/3/1978 | CER | SPR | SE | SE | 9 | 04N | 65E | 0.004 | STK | – – | 3.222345 | AFA | Geyser Ranch Limited Partnership |
| 35952 | – – | 10218 | 10/3/1978 | CER | SPR | NW | SE | 16 | 04N | 65E | 0.004 | STK | – – | 3.222345 | AFA | Geyser Ranch Limited Partnership |
| 35954 | – – | 10220 | 10/3/1978 | CER | SPR | NW | SW | 15 | 04N | 65E | 0.004 | STK | – – | 3.222345 | AFA | Geyser Ranch Limited Partnership |
| 36178 | – – | – – | 11/20/1978 | CAN | SPR | – – | NW | 12 | 04N | 65E | 0.25 | STK | – – | 4.848862 | AFA | Geyser Ranch Limited Partnership |
| 36179 | – – | 10222 | 11/20/1978 | CER | SPR | NE | NE | 18 | 05N | 64E | 0.008 | STK | – – | 5.800221 | AFA | Geyser Ranch Limited Partnership |
| 36180 | – – | 10223 | 11/20/1978 | CER | SPR | SE | SE | 26 | 04N | 65E | 0.007 | STK | – – | 4.848862 | AFA | Geyser Ranch Limited Partnership |

## Table A.1-2
## NDWR Hydrographic Abstract for Dry Lake Valley
(Page 8 of 11)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36183 | – – | 10295 | 11/20/1978 | CER | SPR | SE | SW | 23 | 05N | 65E | 0.002 | STK | – – | 1.350316 | AFA | Steward, Robert |
| 36334 | 780 | – – | 12/22/1978 | CAN | SPR | NW | NW | 33 | 01S | 63E | 0.004 | STK | – – | 3.222345 | AFA | Carter, Dean |
| 40433 | – – | – – | 1/30/1980 | WDR | UG | SW | NE | 12 | 03S | 64E | 5.5 | QM | – – | 3808.934546 | AFA | MX |
| 41732 | – – | – – | 7/14/1980 | WDR | UG | SW | NW | 6 | 06N | 64E | 1 | QM | – – | – – | – – | U.S. Government |
| 41733 | – – | – – | 7/14/1980 | WDR | UG | NE | SW | 6 | 05N | 65E | 1 | QM | – – | – – | – – | MX |
| 41734 | – – | – – | 7/14/1980 | WDR | UG | SW | SE | 7 | 04N | 64E | 1 | QM | – – | 577 | AFA | U.S. Government |
| 45588 | – – | – – | 4/26/1982 | DEN | UG | SW | NE | 12 | 03S | 64E | 5 | IRD | – – | 1280 | AFA | Meadow Valley Land & Cattle Co. |
| 51776 | – – | 13590 | 1/20/1988 | CER | SPR | NW | SE | 22 | 01N | 65E | 0.006 | STK | – – | 0.92067 | AFS | Hatch, Roger |
| 52103 | 6095 | 13775 | 5/18/1988 | CER | SPR | SW | NW | 22 | 02S | 63E | 0.00899999 | STK | – – | 6.506068 | AFA | Corp Presiding Bishop Church JC LDS |
| 52104 | V01549 | 13776 | 5/18/1988 | CER | SPR | SW | NE | 21 | 03S | 65E | 0.001 | STK | – – | 0.460335 | AFA | Corp Presiding Bishop Church JC LDS |
| 52105 | 780 | 13777 | 5/18/1988 | CER | SPR | NW | SE | 21 | 03S | 65E | 0.003 | STK | – – | 2.178919 | AFA | Corp Presiding Bishop Church JC LDS |
| 52106 | 4972 | 13778 | 5/18/1988 | CER | SPR | NW | NE | 28 | 03S | 65E | 0.002 | STK | – – | 1.442383 | AFA | Corp Presiding Bishop Church JC LDS |
| 52107 | V01027 | 13779 | 5/18/1988 | CER | SPR | NW | NW | 16 | 04S | 65E | 0.002 | STK | – – | 1.442383 | AFA | Corp Presiding Bishop Church JC LDS |
| 52108 | 780 | 13780 | 5/18/1988 | CER | SPR | SW | NW | 29 | 04S | 65E | 0.013 | STK | – – | 9.421523 | AFA | Corp Presiding Bishop Church JC LDS |
| 52109 | 780 | 13781 | 5/18/1988 | CER | SPR | SE | SE | 25 | 04S | 64E | 0.00899999 | STK | – – | 6.506068 | AFA | Corp Presiding Bishop Church JC LDS |
| 52110 | 4697 | – – | 5/18/1988 | WDR | SPR | SW | SE | 31 | 04S | 65E | 0.001 | STK | – – | 1.074115 | AFA | H.H. Land and Cattle Company |
| 52111 | 4696 | – – | 5/18/1988 | WDR | SPR | SE | SE | 31 | 04S | 65E | 0.003 | STK | – – | 2.178919 | AFA | H.H. Land and Cattle Company |
| 53989 | – – | – – | 10/17/1989 | RFP | UG | SE | SW | 30 | 02S | 64E | 6 | MUN | – – | 4343.905194 | AFA | Southern Nevada Water Authority |
| 53990 | – – | – – | 10/17/1989 | RFP | UG | NE | SE | 8 | 02S | 65E | 10 | MUN | – – | 7239.84199 | AFA | Southern Nevada Water Authority |

# Table A.1-2
## NDWR Hydrographic Abstract for Dry Lake Valley
(Page 9 of 11)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60179 | – – | – – | 7/1/1994 | DEN | UG | NW | SW | 5 | 04S | 64E | 27627 | MUN | – – | – – | – – | Spencer, Robert Wallace |
| 60180 | – – | – – | 7/1/1994 | DEN | UG | SE | SE | 6 | 04S | 64E | 27627 | MUN | – – | – – | – – | Spencer, Robert Wallace |
| 60181 | – – | – – | 7/1/1994 | DEN | UG | SE | NW | 7 | 04S | 64E | 27627 | MUN | – – | – – | – – | Spencer, Robert Wallace |
| 60182 | – – | – – | 7/1/1994 | DEN | UG | NW | NW | 8 | 04S | 64E | 27627 | MUN | – – | – – | – – | Spencer, Robert Wallace |
| 60189 | – – | – – | 7/1/1994 | DEN | UG | NW | SW | 5 | 04S | 64E | 27627 | PWR | – – | – – | – – | Spencer, Robert Wallace |
| 60190 | – – | – – | 7/1/1994 | DEN | UG | SE | SE | 6 | 04S | 64E | 0 | PWR | – – | – – | – – | Spencer, Robert Wallace |
| 60191 | – – | – – | 7/1/1994 | DEN | UG | NW | NW | 25 | 04S | 63E | 27627 | PWR | – – | – – | – – | Spencer, Robert Wallace |
| 60192 | – – | – – | 7/1/1994 | DEN | UG | SE | NW | 7 | 04S | 64E | 27627 | PWR | – – | – – | – – | Spencer, Robert Wallace |
| 60193 | – – | – – | 7/1/1994 | DEN | UG | NW | NW | 8 | 04S | 64E | 27627 | PWR | – – | – – | – – | Spencer, Robert Wallace |
| 64668 | – – | – – | 12/11/1998 | RFP | UG | SW | NE | 20 | 01S | 65E | 10 | IRR | – – | 5120 | AFA | Lincoln County Water District |
| 64669 | – – | – – | 12/11/1998 | RFP | UG | SW | NE | 33 | 05N | 64E | 10 | IRR | – – | 5120 | AFA | Lincoln County Water District |
| 69878 | – – | – – | 4/18/2003 | RFP | UG | SE | SE | 6 | 04S | 64E | 27627 | PWR | – – | 0 | AFA | Jacob, Beverly Joan |
| 69879 | – – | – – | 4/18/2003 | RFP | UG | SW | SE | 13 | 04S | 63E | 27627 | PWR | – – | 0 | AFA | Jacob, Beverly Joan |
| 69880 | – – | – – | 4/18/2003 | RFP | UG | NW | NW | 18 | 04S | 64E | 27627 | PWR | – – | 0 | AFA | Jacob, Beverly Joan |
| 69883 | – – | – – | 4/18/2003 | RFP | UG | NW | SW | 5 | 04S | 64E | 27627 | PWR | – – | 0 | AFA | Jacob, Beverly Joan |
| 69884 | – – | – – | 4/18/2003 | RFP | UG | NW | NW | 8 | 04S | 64E | 27627 | PWR | – – | 0 | AFA | Jacob, Beverly Joan |
| 69885 | – – | – – | 4/18/2003 | RFP | UG | SE | NW | 7 | 04S | 64E | 27627 | MUN | – – | 0 | AFA | Jacob, Beverly Joan |
| 69886 | – – | – – | 4/18/2003 | RFP | UG | SE | SE | 6 | 04S | 64E | 27627 | MUN | – – | 0 | AFA | Jacob, Beverly Joan |
| 69887 | – – | – – | 4/18/2003 | RFP | UG | NW | SW | 5 | 04S | 64E | 27627 | MUN | – – | 0 | AFA | Jacob, Beverly Joan |
| 69888 | – – | – – | 4/18/2003 | RFP | UG | SE | NW | 7 | 04S | 64E | 27627 | PWR | – – | 0 | AFA | Jacob, Beverly Joan |

**Table A.1-2**
**NDWR Hydrographic Abstract for Dry Lake Valley**
(Page 10 of 11)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 69889 | – – | – – | 4/18/2003 | RFP | UG | NW | NW | 8 | 04S | 64E | 27627 | MUN | – – | 0 | AFA | Jacob, Beverly Joan |
| 69890 | – – | – – | 4/18/2003 | RFP | UG | SW | SE | 13 | 04S | 63E | 27627 | MUN | – – | 0 | AFA | Jacob, Beverly Joan |
| 69891 | – – | – – | 4/18/2003 | RFP | UG | NW | NW | 18 | 04S | 64E | 27627 | MUN | – – | 0 | AFA | Jacob, Beverly Joan |
| R04778 | – – | – – | 2/8/1989 | RES | SPR | SE | NE | 8 | 06S | 65E | 0.002 | OTH | – – | 1.288938 | AFA | BLM |
| R05989 | – – | – – | 6/21/1993 | RES | SPR | SE | NW | 10 | 04S | 65E | 0 | OTH | – – | 0.214823 | AFA | BLM |
| R09410 | – – | – – | 3/23/2004 | RES | SPR | SE | SE | 5 | 04N | 65E | 0.0015 | STK | – – | 0 | AFA | BLM |
| R09411 | – – | – – | 3/23/2004 | RES | SPR | NW | SE | 30 | 04N | 65E | 0.0015 | STK | – – | 0 | AFA | BLM |
| V01027 | – – | – – | 3/10/1911 | VST | SPR | NW | NW | 16 | 04N | 65E | 0.011 | STK | – – | 7.948451 | AFA | Corp Presiding Bishop Church JC LDS |
| V01027 | Changed By: | 52107 | – – | CER | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| V01027 | Changed By: | 52112 | – – | CER | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| V01134 | – – | – – | 9/30/1912 | VST | SPR | SW | NW | 31 | 02N | 66E | 0.025 | STK | – – | 3.928192 | AFS | Lyttle, Edwin |
| V01135 | – – | – – | 9/30/1912 | VST | SPR | SE | NE | 36 | 02N | 65E | 0.033 | STK | – – | 2.792699 | AFS | Lyttle, Edwin |
| V01250 | – – | – – | 6/8/1913 | VST | SPR | SE | SE | 24 | 02N | 65E | 0.013 | STK | – – | 1.381005 | AFA | Delmue, Joseph |
| V01265 | – – | – – | 11/17/1913 | VST | SPR | | SW | 28 | 01N | 63E | 0.05 | STK | – – | 2.240297 | AFA | Adams McGill Company |
| V01267 | – – | – – | 11/17/1913 | VST | SPR | NE | SW | 21 | 01N | 63E | 0.1 | STK | – – | 6.720891 | AFA | Adams McGill Company |
| V01268 | – – | – – | 11/20/1913 | VST | SPR | SE | SW | 13 | 02N | 63E | 0.013 | STK | – – | 9.2067 | AFA | Adams McGill Company |
| V01287 | – – | – – | 11/6/1913 | VST | SPR | NW | SW | 15 | 04N | 65E | 0.013 | STK | – – | 5.616087 | AFA | Geyser Ranch Limited Partnership |
| V01288 | – – | – – | 2/24/1914 | VST | SPR | NW | SE | 16 | 05N | 65E | 0.013 | STK | – – | – – | – – | Adams McGill Company |
| V01289 | – – | – – | 2/24/1914 | VST | SPR | SW | SE | 3 | 04N | 65E | 0.013 | STK | – – | 5.616087 | AFA | Geyser Ranch Limited Partnership |
| V01290 | – – | – – | 2/21/1914 | VST | SPR | SW | NW | 15 | 05N | 65E | 0.1 | STK | – – | 4.480594 | AFA | Adams McGill Company |
| V01294 | – – | – – | 2/21/1914 | VST | SPR | SW | SW | 10 | 05N | 65E | 0.075 | STK | – – | 4.480594 | AFA | Adams McGill Company |

## Table A.1-2
## NDWR Hydrographic Abstract for Dry Lake Valley
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| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| V01295 | – – | – – | 2/21/1914 | VST | SPR | SE | NE | 32 | 05N | 65E | 0.25 | IRR | – – | 60 | AFS | Lloyd, Arthur M. |
| V01296 | – – | – – | 2/24/1914 | VST | SPR | NE | NE | 8 | 04N | 65E | 0 | IRR | – – | 12 | AFS | Geyser Ranch Limited Partnership |
| V01297 | – – | – – | 2/21/1914 | VST | SPR | SW | SE | 30 | 04N | 65E | 0 | IRR | – – | 1.6 | AFS | Geyser Ranch Limited Partnership |
| V01299 | – – | – – | 3/10/1914 | VST | SPR | NW | SW | 29 | 04N | 65E | 0.013 | STK | – – | 4.480594 | AFA | Geyser Ranch Limited Partnership |
| V01300 | – – | – – | 3/10/1914 | VST | SPR | NW | SW | 33 | 04N | 65E | 0.013 | STK | – – | – – | – – | Adams McGill Company |
| V01301 | – – | – – | 2/21/1914 | VST | SPR | NE | NE | 18 | 05N | 64E | 0.038 | STK | – – | 3.37579 | AFA | Adams McGill Company |
| V01302 | – – | – – | 2/21/1914 | VST | SPR | NE | SE | 33 | 04N | 65E | 0.125 | STK | – – | 4.480594 | AFA | Adams McGill Company |
| V01459 | – – | – – | 4/12/1916 | VST | SPR | SE | SW | 33 | 02S | 66E | 0.125 | STK | – – | 3.37579 | AFS | Thorley, William B. |
| V01549 | – – | – – | 3/21/1918 | ABR | SPR | NE | NW | 24 | 03S | 65E | 0 | STK | – – | 0 | AFS | H.H. Land and Cattle Company |
| V01549 | Changed By: | 52104 | – – | CER | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| V01787 | – – | – – | 1/27/1922 | VST | SPR | NE | SW | 33 | 02S | 66E | 0.025 | STK | – – | 6.720891 | AFA | Mackie, Alex J. |
| V02350 | – – | – – | 9/8/1947 | VST | SPR | NE | NE | 3 | 04S | 65E | 0.017 | STK | – – | 1.135493 | AFA | Corp Presiding Bishop Church JC LDS |
| V02351 | – – | – – | 9/8/1947 | VST | SPR | SW | SE | 14 | 04S | 65E | 0.017 | STK | – – | 1.350316 | AFA | Culverwell, Chas. |
| V03839 | – – | – – | 2/1/1982 | VST | SPR | NW | SW | 6 | 02N | 65E | 0.004 | STK | – – | 2.025474 | AFS | Imperial Farms Land and Cattle Co. |
| V03840 | – – | – – | 2/1/1982 | VST | SPR | SW | SW | 30 | 03N | 65E | 0.004 | STK | – – | 2.025474 | AFS | Imperial Farms Land and Cattle Co. |
| V04697 | – – | – – | 9/16/1988 | VST | SPR | NW | NW | 35 | 01N | 65E | 0.05 | STK | – – | 12.306289 | AFA | Hatch, Roger |
| V06519 | – – | – – | 5/19/1994 | VST | SPR | NW | NW | 35 | 01N | 65E | 0.05 | STK | – – | – – | – – | Whipple, Laird |

Source: Data downloaded from Nevada Division of Water Resources on August 13, 2007.

## Table A.1-3
## NDWR Hydrographic Abstract for Delamar Valley
(Page 1 of 7)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1532 | – – | – – | 11/26/1909 | CAN | SPR | – – | – – | – – | 04S | 64E | 0 | IRR | – – | 0 | – – | Edwards, JNO. L. |
| 3270 | – – | 269 | 2/15/1915 | ABR | SPR | SE | SE | 6 | 05S | 65E | 0 | STK | – – | 0 | AFA | H.H. Land and Cattle Company |
| 3270 | Changed By: | 52113 | – – | CER | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 3271 | – – | 1923 | 2/15/1915 | CER | SPR | NE | NE | 1 | 06S | 62E | 0.012 | STK | – – | 8.961188 | AFA | Pace, Sid |
| 3475 | – – | 427 | 6/30/1915 | CER | SPR | SW | SE | 17 | 06S | 65E | 0.037 | IRR | – – | 25.15 | AFS | LDS |
| 3475 | Changed By: | 9713 | – – | CER | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 3475 | Changed By: | 11705 | – – | CAN | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 3475 | Changed By: | 12388 | – – | ABR | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 3476 | – – | – – | 6/30/1915 | CAN | SPR | NE | NE | 16 | 05S | 63E | 0.025 | STK | – – | 0 | – – | Mathews, William Jr. |
| 3879 | – – | 1090 | 4/10/1916 | CER | SPR | SE | SE | 30 | 03S | 63E | 0.00899999 | STK | – – | 0 | – – | Corp Presiding Bishop Church JC LDS |
| 4462 | – – | 3186 | 6/8/1917 | CER | RES | NE | NW | 24 | 05S | 63E | 0.025 | STK | – – | 18.014443 | AFA | Corp Presiding Bishop Church JC LDS |
| 4620 | – – | 727 | 10/8/1917 | CER | SPR | SE | NE | 33 | 06S | 64E | 0.001 | STK | – – | 0.705847 | AFS | Gardner Ranch Co. |
| 4621 | – – | 728 | 10/8/1917 | CER | SPR | – – | – – | 2 | 05S | 64E | 0.003 | STK | – – | 2.178919 | AFA | Duffin Jr., Press W. |
| 4622 | – – | 729 | 10/8/1917 | CER | SPR | – – | – – | – – | 05S | 63E | 0.002 | STK | – – | 0.552402 | AFA | Gardner Ranch Company |
| 4628 | – – | – – | 10/10/1917 | CAN | SPR | SE | SE | 29 | 03S | 63E | 0.025 | STK | – – | 0 | – – | Conway, J.H. |
| 4632 | – – | 704 | 10/13/1917 | CER | SPR | SW | SE | 24 | 05S | 62E | 0.003 | STK | – – | 2.117540969 | AFA | Nevada Rock and Sand Corporation |
| 4644 | – – | – – | 10/17/1917 | CAN | SPR | SW | SW | 31 | 05S | 65E | 1 | STK | – – | 0 | – – | Jeffcott, Vernon |
| 4680 | – – | – – | 11/8/1917 | DEN | SPR | SE | SE | 15 | 07S | 64E | 0.1 | STK | – – | – – | – – | Jones, J. |
| 4683 | – – | – – | 11/8/1917 | DEN | SPR | SE | SE | 15 | 07S | 64E | 0.1 | STK | – – | – – | – – | Jones, J. |
| 4693 | – – | 730 | 11/12/1917 | CER | SPR | SW | SW | 32 | 05S | 65E | 0.011 | STK | – – | 7.97914 | AFA | Duffin, Maine R. |
| 4695 | – – | 731 | 11/12/1917 | CER | SPR | SW | SW | 32 | 05S | 65E | 0.011 | STK | – – | 0 | – – | Gardner Ranch Company |

## Table A.1-3
## NDWR Hydrographic Abstract for Delamar Valley
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| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4753 | – – | – – | 12/3/1917 | DEN | SPR | – – | – – | 34 | 04S | 63E | 0.5 | STK | – – | 0 | – – | Henrie and Thiriot |
| 4894 | – – | – – | 2/7/1918 | PER | SPR | SE | SE | 16 | 05S | 64E | 0.025 | DOM | – – | 0 | – – | Sawyer, Tillie B. |
| 4898 | – – | – – | 2/11/1918 | CAN | SPR | SW | NW | 2 | 05S | 63E | 1.6 | IRR | – – | 0 | – – | Duffin, Mamie Ryan |
| 4902 | – – | – – | 2/13/1918 | CAN | SPR | – – | – – | – – | 05S | 64E | 0.025 | STK | – – | 0 | – – | Burt, L.L. |
| 4903 | – – | – – | 2/13/1917 | CAN | SPR | – – | – – | – – | – – | – – | 0.025 | STK | – – | 0 | – – | Burt, L.L. |
| 4904 | – – | – – | 2/13/1917 | CAN | SPR | – – | – – | – – | 05S | 64E | 0.025 | STK | – – | 0 | – – | Burt, L.L. |
| 4950 | – – | – – | 3/6/1918 | CAN | SPR | SE | SE | 15 | 07S | 64E | 0.2 | IRR | – – | 80 | AFS | Horn, Cyrus |
| 4973 | – – | 735 | 3/21/1918 | CER | SPR | – – | – – | – – | 05S | 63E | 0.002 | STK | – – | 1.135493 | AFA | Gardner Ranch Co. |
| 5013 | – – | – – | 4/22/1918 | CAN | RES | SW | SW | 2 | 08S | 62E | 0 | STK | – – | 9.973925 | AFA | Richard, J.W. |
| 5092 | – – | – – | 6/5/1918 | CAN | OSW | – – | – – | – – | 07S | 63E | 0 | STK | – – | 10 | AFA | Adams, John A. |
| 5301 | – – | 736 | 10/25/1918 | CER | RES | SE | NE | 16 | 05S | 64E | 0.014 | STK | – – | 10.004614 | AFA | Duffin, Mame R. |
| 5316 | – – | 581 | 11/20/1918 | CER | RES | NW | NE | 31 | 04S | 64E | 0 | STK | – – | 15.682079 | AFS | Carter, Dona |
| 5317 | – – | – – | 11/20/1918 | WDR | RES | SE | SE | 36 | 04S | 63E | 0.025 | STK | – – | 0 | – – | Henrie, James |
| 5318 | – – | 582 | 11/20/1918 | CER | RES | SW | SE | 26 | 04S | 63E | 0.01 | STK | – – | 3.98957 | AFS | Corp Presiding Bishop Church JC LDS |
| 5344 | – – | – – | 12/26/1918 | CAN | RES | – – | – – | 16 | 05S | 64E | 0 | STK | – – | 9.973925 | AFA | Adams, John A. |
| 5782 | – – | 1005 | 9/29/1919 | CER | SPR | NW | NE | 7 | 05S | 64E | 0.012 | STK | – – | 9.053255 | AFA | Duffins, Mamie R. |
| 5783 | – – | 1006 | 9/29/1919 | CER | SPR | NW | NE | 7 | 05S | 64E | 0.015 | STK | – – | 10.863906 | AFA | Duffins, Mamie R. |
| 6113 | – – | – – | 5/12/1920 | DEN | SPR | SE | NE | 7 | 05S | 64E | 1 | STK | – – | 0 | – – | Norris, A.H. |
| 6201 | – – | – – | 7/12/1920 | WDR | UG | SE | NE | 33 | 05S | 64E | 0 | STK | – – | 0 | – – | Cutler, Warren |
| 6202 | – – | – – | 7/12/1920 | DEN | UG | – – | – – | – – | 05S | 63E | 0 | STK | – – | 0 | – – | Cutler, Warren |
| 6576 | – – | 1500 | 10/13/1921 | CER | RES | NW | SW | 21 | 04S | 63E | 0.014 | STK | – – | 4.971618 | AFS | Nevada Rock and Sand Corporation |
| 6885 | – – | 1225 | 4/28/1923 | CER | RES | NW | SE | 7 | 07S | 63E | 0 | STK | – – | 9.973925 | AFA | LDS |
| 6886 | – – | 1226 | 4/28/1923 | CER | RES | SE | NE | 33 | 07S | 63E | 0 | STK | – – | 9.973925 | AFA | LDS |

## Table A.1-3
## NDWR Hydrographic Abstract for Delamar Valley
(Page 3 of 7)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6887 | – – | – – | 4/28/1923 | WDR | RES | SW | SE | 22 | 07S | 64E | 0 | STK | – – | 9.973925 | AFA | Conaway, John H. |
| 6888 | – – | – – | 4/28/1923 | WDR | RES | NE | SE | 28 | 07S | 63E | 0 | STK | – – | 0 | – – | Conaway, John H. |
| 7287 | – – | – – | 1/14/1925 | CAN | SPR | – – | – – | – – | 05S | 65E | 0 | DOM | – – | – – | – – | Farling, John W. |
| 8800 | – – | – – | 12/28/1928 | CAN | RES | SE | SE | 8 | 06S | 63E | 0.001 | STK | – – | 0.982048 | AFA | Conway, John |
| 8801 | – – | – – | 12/28/1928 | CAN | RES | SE | SW | 33 | 06S | 63E | 0.001 | STK | – – | 0 | – – | Conway, John |
| 8921 | – – | 1700 | 5/24/1929 | ABR | SPR | SW | SW | 20 | 05S | 64E | 0 | STK | – – | 0 | AFA | H.H. Land and Cattle Company |
| 8921 | Changed By: | 52115 | – – | CER | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 9285 | – – | – – | 6/28/1930 | DEN | SPR | SW | SW | 32 | 05S | 65E | 11 | MM | – – | 0 | – – | Jones, C.R. |
| 9286 | – – | – – | 6/28/1930 | DEN | SPR | NE | SE | 13 | 06S | 65E | 0.1 | MM | – – | 0 | – – | Jones, C.R. |
| 9287 | – – | – – | 6/28/1930 | DEN | SPR | NW | SE | 13 | 06S | 64E | 0.2 | MM | – – | 0 | – – | Jones, C.R. |
| 9288 | – – | – – | 6/28/1930 | DEN | SPR | SW | SE | 24 | 06S | 64E | 0.1 | MM | – – | – – | – – | Jones, C.R. |
| 9289 | – – | – – | 6/28/1930 | DEN | OSW | SW | SW | 31 | 05S | 65E | 0.55 | MM | – – | 0 | – – | Jones, C.R. |
| 9659 | – – | 2109 | 5/12/1933 | CER | OSW | NW | NW | 12 | 06S | 63E | 0.00899999 | STK | – – | 5.984355 | AFA | LDS |
| 9713 | 3475 | 2423 | 11/25/1933 | CER | SPR | NE | SW | 17 | 06S | 65E | 0.05 | MM | – – | 25 | AFS | LDS |
| 9793 | – – | – – | 8/27/1934 | DEN | OSW | NW | SW | 10 | 06S | 63E | 0 | STK | – – | 9.973925 | AFS | Adams, W.B. |
| 9794 | – – | – – | 8/27/1934 | DEN | RES | NE | NE | 7 | 07S | 63E | 0 | STK | – – | 9.973925 | AFS | Adams, W.B. |
| 9834 | – – | – – | 1/28/1935 | WDR | UG | SW | SE | 5 | 06S | 65E | 0 | MM | – – | 0 | – – | Caliente Cyaniding Company |
| 10069 | – – | – – | 1/7/1937 | DEN | OSW | NW | SE | 13 | 04S | 63E | 0.027 | STK | – – | – – | – – | Jones, E.I. |
| 10088 | – – | 2622 | 2/10/1937 | CER | SPR | NE | NE | 1 | 06S | 62E | 0.003 | STK | – – | 2.240297 | AFA | Nevada Rock and Sand Corporation |
| 10189 | – – | 2403 | 12/3/1937 | CER | SPR | NE | SE | 3 | 05S | 64E | 0.025 | STK | – – | 18.10651 | AFA | Corp Presiding Bishop Church JC LDS |
| 10189 | Changed By: | 52366 | – – | DEN | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 10440 | – – | 2720 | 11/15/1939 | CER | RES | SW | SE | 20 | 07S | 64E | 0.003 | STK | – – | 2.792699 | AFA | LDS |

## Table A.1-3
## NDWR Hydrographic Abstract for Delamar Valley
(Page 4 of 7)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10551 | – – | 2595 | 8/21/1940 | CER | OSW | NW | NE | 24 | 04S | 64E | 0.003 | STK | – – | 2.240297 | AFA | Corp Presiding Bishop Church JC LDS |
| 10627 | – – | 2615 | 2/21/1941 | CER | SPR | NE | NW | 17 | 08S | 64E | 0.01 | STK | – – | 7.41 | AFA | Church JC LDS |
| 10629 | – – | 2596 | 2/24/1941 | CER | SPR | SW | NW | 20 | 06S | 65E | 0.006 | STK | – – | 4.327149 | AFA | Corp Presiding Bishop Church JC LDS |
| 10637 | – – | – – | 3/24/1941 | DEN | LAK | SE | NE | 24 | 07S | 62E | 0 | STK | – – | 39.987767 | AFS | Adams, W.B. |
| 10638 | – – | – – | 3/24/1941 | DEN | OSW | SE | SE | 9 | 06S | 63E | 0.055 | STK | – – | 39.987767 | AFS | Adams, W.B. |
| 10654 | 5878 | 2633 | 4/28/1941 | CER | OSW | SW | NE | 16 | 07S | 63E | 0.007 | STK | – – | 5.002307 | AFA | LDS |
| 10659 | – – | 2637 | 5/10/1941 | CER | RES | NE | SE | 17 | 07S | 63E | 0 | STK | – – | 9.973925 | AFA | LDS |
| 10736 | – – | 2668 | 10/2/1941 | CER | RES | NW | NE | 35 | 04S | 63E | 0.005 | STK | – – | 3.98957 | AFA | LDS |
| 10789 | – – | 2722 | 3/4/1942 | CER | OSW | NE | SE | 26 | 06S | 63E | 0.012 | STK | – – | 8.961188 | AFA | LDS |
| 10887 | – – | – – | 1/26/1942 | CAN | SPR | NE | SE | 13 | 06S | 64E | 0.025 | STK | – – | 0 | – – | Stewart, C.D. |
| 10888 | – – | – – | 10/26/1942 | CAN | SPR | SW | SE | 13 | 06S | 64E | 0.025 | STK | – – | 0 | – – | Stewart, C.D. |
| 10889 | – – | – – | 10/26/1942 | CAN | SPR | NW | SE | 13 | 06S | 64E | 0.025 | STK | – – | 0 | – – | Horn, Agnes |
| 10896 | – – | – – | 12/3/1942 | CAN | SPR | SE | SE | 9 | 07S | 64E | 0.025 | STK | – – | – – | – – | Conaway, John H. |
| 11167 | – – | 3073 | 9/14/1944 | CER | SPR | SE | SE | 9 | 07S | 64E | 0.003 | STK | – – | 2.178919 | AFA | LDS |
| 11377 | – – | – – | 10/1/1945 | DEN | SPR | NW | SE | 17 | 06S | 65E | 0.011 | STK | – – | 2.178919 | AFA | Conaway, John H. |
| 11378 | – – | 4047 | 10/1/1945 | CER | SPR | SE | NW | 19 | 06S | 65E | 0.002 | STK | – – | 1.442383 | AFA | Corp Presiding Bishop Church JC LDS |
| 11378 | Changed By: | 52116 | – – | WDR | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 11387 | – – | – – | 10/13/1945 | WDR | SPR | SW | NW | 20 | 06S | 65E | 0.034 | STK | – – | 24.612578 | AFA | Conaway, John H. |
| 11525 | – – | 3356 | 3/26/1946 | CER | SPR | SW | NW | 17 | 08S | 64E | 0.003 | STK | – – | 2.240297 | AFA | Church JC LDS |
| 11705 | 3475 | – – | 10/5/1946 | CAN | UG | SW | SE | 13 | 06S | 64E | 0.04 | STK | – – | – – | – – | Stewart, C.D. |
| 12388 | 3475 | 4085 | 3/29/1948 | ABR | SPR | SW | SE | 17 | 06S | 65E | 0 | STK | – – | 0 | AFS | H.H. Land and Cattle Company |
| 12388 | Changed By: | 51260 | – – | CER | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |

# Table A.1-3
## NDWR Hydrographic Abstract for Delamar Valley
(Page 5 of 7)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22073 | – – | 6683 | 6/23/1964 | ABR | UG | SE | SE | 12 | 07S | 64E | 0 | STK | – – | 0 | AFA | LDS |
| 22073 | Changed By: | 51261 | – – | CER | UG | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| 22847 | – – | – – | 11/8/1965 | CAN | UG | SE | SW | 25 | 04S | 63E | 5.4 | IRD | – – | 1600 | AFA | Clemmer, Lottie L. |
| 22848 | – – | – – | 11/8/1965 | CAN | UG | SE | SE | 25 | 04S | 63E | 5.4 | IRD | – – | 1600 | AFA | Clemmer, James R. |
| 22858 | – – | – – | 11/22/1965 | CAN | UG | SE | SW | 24 | 04S | 63E | 5.4 | IRD | – – | 5 | AFA | Harrison, Bertha E. |
| 22859 | – – | – – | 11/22/1965 | CAN | UG | SE | SE | 23 | 04S | 63E | 5.4 | IRD | – – | 5 | AFA | Harrison, Edna M. |
| 22872 | – – | – – | 11/26/1965 | CAN | UG | SW | NW | 14 | 05S | 69E | 3.4 | IRR | – – | – – | – – | Hafen, Hershel |
| 40434 | – – | – – | 1/30/1980 | WDR | UG | SE | NE | 12 | 06S | 63E | 0 | QM | – – | 0 | – – | MX |
| 45589 | – – | – – | 4/26/1982 | DEN | UG | SE | NE | 12 | 06S | 63E | 5 | IRD | – – | 0 | – – | Meadow Valley Land and Cattle Co. |
| 50905 | – – | – – | 5/6/1987 | CAN | UG | SE | NE | 12 | 06S | 63E | 0 | MM | – – | 0 | AFA | Mt. Heagan Development, Inc. |
| 51259 | – – | 12369 | 9/2/1987 | CER | SPR | SW | SE | 17 | 06S | 65E | 0.017 | STK | – – | 7.150537 | AFS | LDS |
| 51260 | 12388 | 12370 | 9/2/1987 | CER | SPR | SW | SE | 17 | 06S | 65E | 0.017 | STK | – – | 7.518805 | AFS | LDS |
| 51261 | 22073 | 12371 | 9/2/1987 | CER | UG | SE | SE | 12 | 07S | 64E | 0.01 | STK | – – | 7.242604 | AFA | LDS |
| 52112 | V01027 | 13782 | 5/18/1988 | CER | SPR | NW | SW | 2 | 05S | 64E | 0.008 | STK | – – | 5.800221 | AFA | Corp Presiding Bishop Church JC LDS |
| 52113 | 3270 | 14737 | 5/18/1988 | CER | SPR | SE | SE | 6 | 05S | 65E | 0.008 | STK | – – | 5.646776 | AFA | H.H. Land and Cattle Company |
| 52114 | V01398 | 14738 | 5/18/1988 | CER | SPR | NE | NE | 18 | 05S | 65E | 0.003 | STK | – – | 2.393742 | AFA | H.H. Land and Cattle Company |
| 52115 | 8921 | 14739 | 5/18/1988 | CER | SPR | SW | NE | 20 | 05S | 65E | 0.002 | STK | – – | 1.135493 | AFA | Corp Presiding Bishop Church JC LDS |
| 52116 | 11378 | – – | 5/18/1988 | WDR | SPR | NW | SE | 17 | 06S | 65E | 0.002 | STK | – – | 1.442383 | AFA | H.H. Land and Cattle Company |
| 52117 | – – | – – | 5/18/1988 | CAN | SPR | NW | SE | 17 | 06S | 65E | 0.027 | STK | – – | 19.548893 | AFA | Corp Presiding Bishop Church JC LDS |

# Table A.1-3
## NDWR Hydrographic Abstract for Delamar Valley
(Page 6 of 7)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 52118 | – – | 14740 | 5/18/1988 | CER | SPR | NE | NW | 17 | 06S | 65E | 0.001 | STK | – – | 0.337579 | AFA | Corp Presiding Bishop Church JC LDS |
| 52366 | 10189 | – – | 8/3/1988 | DEN | SPR | NW | SW | 2 | 05S | 64E | 0.025 | STK | – – | 18.10651 | AFA | H.H. Land and Cattle Company |
| 53991 | – – | – – | 10/17/1989 | RFP | UG | SE | NE | 4 | 05S | 63E | 6 | MUN | – – | 4343.82 | AFA | Southern Nevada Water Authority |
| 53992 | – – | – – | 10/17/1989 | RFP | UG | NE | NE | 15 | 06S | 64E | 10 | MUN | – – | 7239.7 | AFA | Southern Nevada Water Authority |
| 54144 | – – | – – | 11/6/1989 | DEN | UG | SE | NE | 12 | 06S | 63E | 0.2 | MM | – – | – – | – – | Delamar Minerals Company |
| 60183 | – – | – – | 7/1/1994 | DEN | UG | SW | SE | 13 | 04S | 63E | 27627 | MUN | – – | – – | – – | Spencer, Robert Wallace |
| 60184 | – – | – – | 7/1/1994 | DEN | UG | NW | NW | 18 | 04S | 63E | 27627 | MUN | – – | – – | – – | Spencer, Robert Wallace |
| 60185 | – – | – – | 7/1/1994 | DEN | UG | SE | SW | 24 | 04S | 63E | 27627 | MUN | – – | – – | – – | Spencer, Robert Wallace |
| 60186 | – – | – – | 7/1/1994 | DEN | UG | NW | NW | 25 | 04S | 63E | 27627 | MUN | – – | – – | – – | Spencer, Robert Wallace |
| 60187 | – – | – – | 7/1/1994 | DEN | UG | NW | NW | 18 | 04S | 64E | 27627 | PWR | – – | – – | – – | Spencer, Robert Wallace |
| 60188 | – – | – – | 7/1/1994 | DEN | UG | SE | SW | 24 | 04S | 63E | 27627 | PWR | – – | – – | – – | Spencer, Robert Wallace |
| 60194 | – – | – – | 7/1/1994 | DEN | UG | SW | SE | 13 | 04S | 63E | 27627 | PWR | – – | – – | – – | Spencer, Robert Wallace |
| 64678 | – – | – – | 12/11/1998 | RFP | UG | SE | SE | 30 | 05S | 64E | 10 | IRR | – – | 5120 | AFA | Lincoln County Water District |
| 64679 | – – | – – | 12/11/1998 | RFP | UG | SW | NW | 24 | 07S | 63E | 10 | IRR | – – | 5120 | AFA | Lincoln County Water District |
| 69881 | – – | – – | 4/18/2003 | RFP | UG | SE | SW | 24 | 04S | 63E | 27627 | PWR | – – | 0 | AFA | Jacob, Beverly Joan |
| 69882 | – – | – – | 4/18/2003 | RFP | UG | NW | NW | 25 | 04S | 63E | 27627 | PWR | – – | 0 | AFA | Jacob, Beverly Joan |

## Table A.1-3
## NDWR Hydrographic Abstract for Delamar Valley
(Page 7 of 7)

| App. | Change of App. | Cert. | File Date | Status | Source | POD QQ | POD Qtr | POD Sec | POD Twn | POD Rng | Div Rate (cfs) | Type of Use | Sup | Annual Duty | Units | Owner of Record |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 69892 | – – | – – | 4/18/2003 | RFP | UG | SE | SW | 24 | 04S | 63E | 27627 | MUN | – – | 0 | AFA | Jacob, Beverly Joan |
| 69893 | – – | – – | 4/18/2003 | RFP | UG | NW | NW | 25 | 04S | 63E | 27627 | MUN | – – | 0 | AFA | Jacob, Beverly Joan |
| R04339 | – – | – – | 5/3/1985 | RES | SPR | NW | SW | 3 | 05S | 64E | 0 | OTH | – – | 0 | – – | BLM |
| V01022A01 | – – | – – | 2/6/1911 | VST | SPR | – – | SE | 36 | 05S | 64E | 0 | STK | – – | 0 | AFA | LDS, Presiding Bishop |
| v01022a02 | – – | – – | 2/6/1911 | VST | SPR | – – | SE | 36 | 06S | 64E | 0 | STK | – – | 0 | AFA | Lincoln Lnd and Lvstk |
| V01022A03 | – – | – – | 2/6/1911 | VST | SPR | – – | SW | 31 | 06S | 65E | 0.0625 | STK | – – | 0 | AFA | Duffin, Press W Et All |
| V01022A04 | – – | – – | 2/6/1911 | VST | SPR | – – | SW | 33 | 06S | 65E | 0.0125 | STK | – – | 0 | AFA | Ballow, Carl |
| V01022A05 | – – | – – | 2/6/1911 | VST | SPR | – – | SE | 33 | 05S | 65E | 0.025 | STK | – – | 0 | AFA | LDS, Presiding Bishop |
| V01022A06 | – – | – – | 2/6/1911 | VST | SPR | – – | – – | – – | – – | – – | 0 | STK | – – | 0 | AFA | LDS, Presiding Bishop |
| V01398 | – – | – – | 7/3/1915 | ABR | SPR | SE | NW | 11 | 05S | 64E | 0 | STK | – – | 0 | AFA | H.H. Land and Cattle Company |
| V01398 | Changed By: | 52114 | – – | CER | SPR | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – | – – |
| V01399 | – – | – – | 7/3/1915 | VST | SPR | SE | SE | 6 | 05S | 65E | 0.025 | STK | – – | 0 | – – | Henrie, James Jr. |
| V01400 | – – | – – | 7/12/1915 | VST | SPR | NE | SE | 3 | 05S | 64E | 0.025 | STK | – – | 0 | – – | Duffin, Mamie Ryan |
| V01418 | – – | – – | 9/14/1915 | VST | SPR | SW | SW | 34 | 05S | 62E | 0.025 | STK | – – | 0 | – – | Henrie, James |
| V01419 | – – | – – | 9/2/1915 | VST | SPR | SW | NW | 20 | 05S | 65E | 0.025 | STK | – – | – – | – – | Mackie, A.J. |
| V01420 | – – | – – | 9/14/1915 | VST | SPR | NW | SW | 27 | 05S | 62E | 0.025 | STK | – – | 0 | – – | Henrie, James |
| V01449 | – – | – – | 3/13/1916 | VST | SPR | SW | SW | 25 | 03S | 62E | 0.1 | STK | – – | 0 | – – | Nevada Rock and Sand Corporation |
| V01520 | – – | – – | 10/8/1917 | VST | SPR | SE | SE | 9 | 07S | 64E | 0 | STK | – – | – – | – – | Gardner Ranch Co |
| V01550 | – – | – – | 3/21/1918 | VST | SPR | SE | SE | 15 | 07S | 64E | 0.025 | STK | – – | 0.122756 | AFA | Duffin, Mamie Ryan |
| V01598 | – – | – – | 10/25/1918 | VST | SPR | SE | SW | 1 | 06S | 64E | 0.025 | STK | – – | – – | – – | Lincoln Land and Livestock Co. |
| V01654 | – – | – – | 11/29/1919 | VST | SPR | SW | SE | 36 | 04S | 63E | 0.025 | STK | – – | 0.675158 | AFA | Duffin, Mame R. |
| V01822 | – – | – – | 7/10/1923 | VST | SPR | NE | SW | 17 | 06S | 65E | 0.05 | STK | – – | 1.687895 | AFA | Horn, C.A. |

Source: Data downloaded from Nevada Division of Water Resources on August 13, 2007.

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# Appendix B

# Application Points of Diversion Figures

# B.1.0 INTRODUCTION

This appendix contains figures showing a 2,500 ft buffer around SNWA's application points of diversion with imagery provided from the National Agriculture Imagery Program.

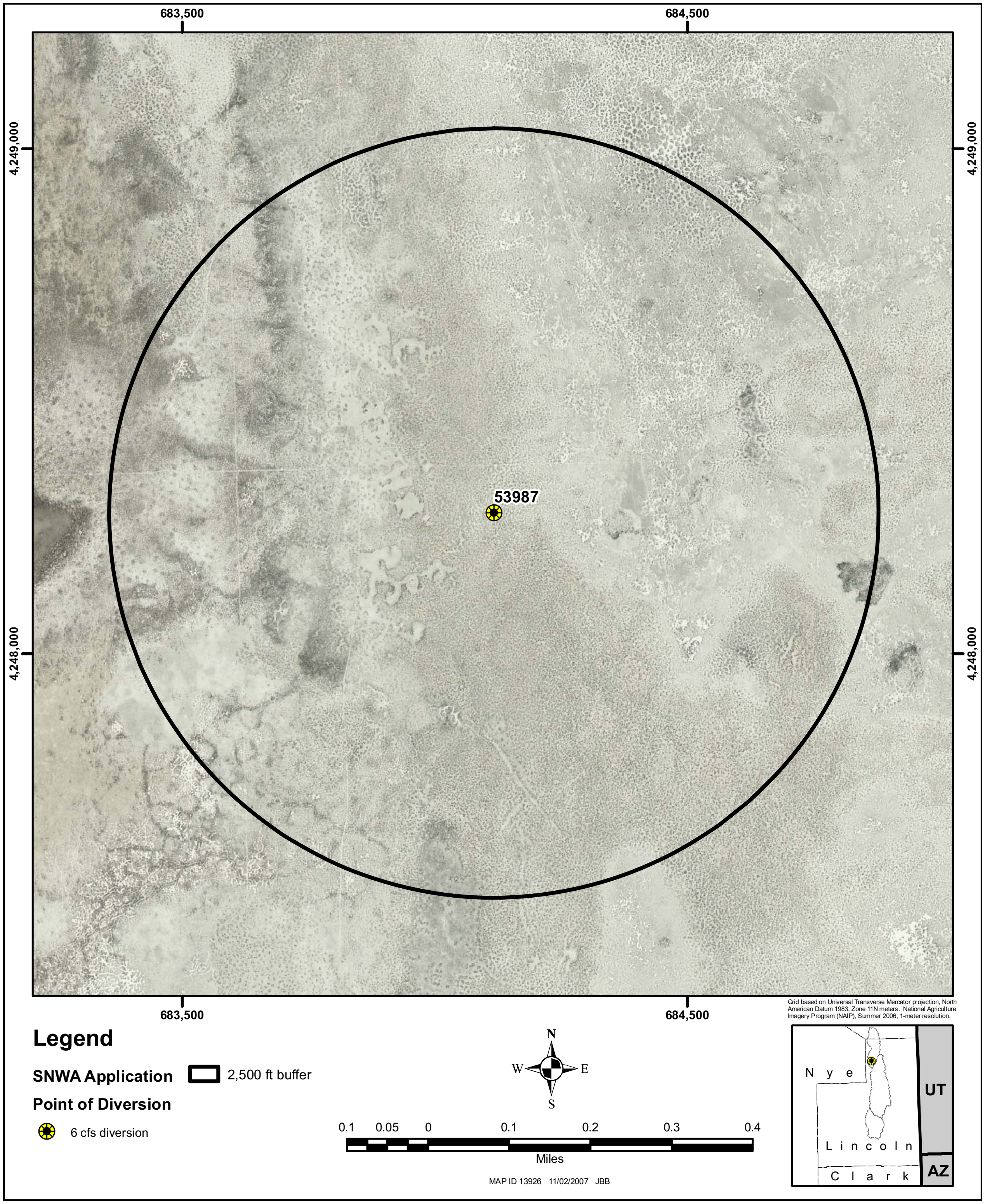


**Figure B.1-1**
**Area Surrounding Application Point of Diversion 53987 in Cave Valley**

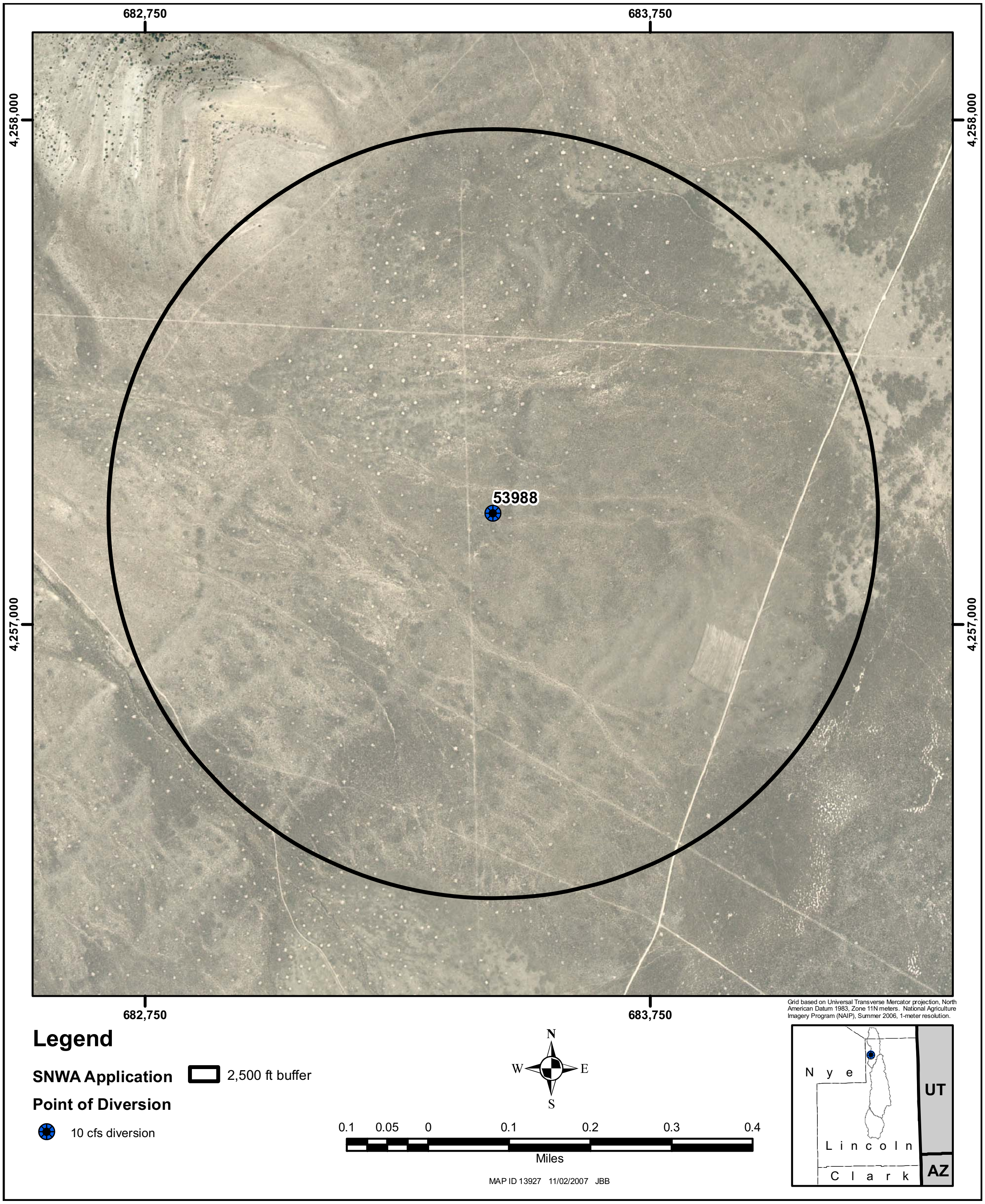


**Figure B.1-2**
**Area Surrounding Application Point of Diversion 53988 in Cave Valley**

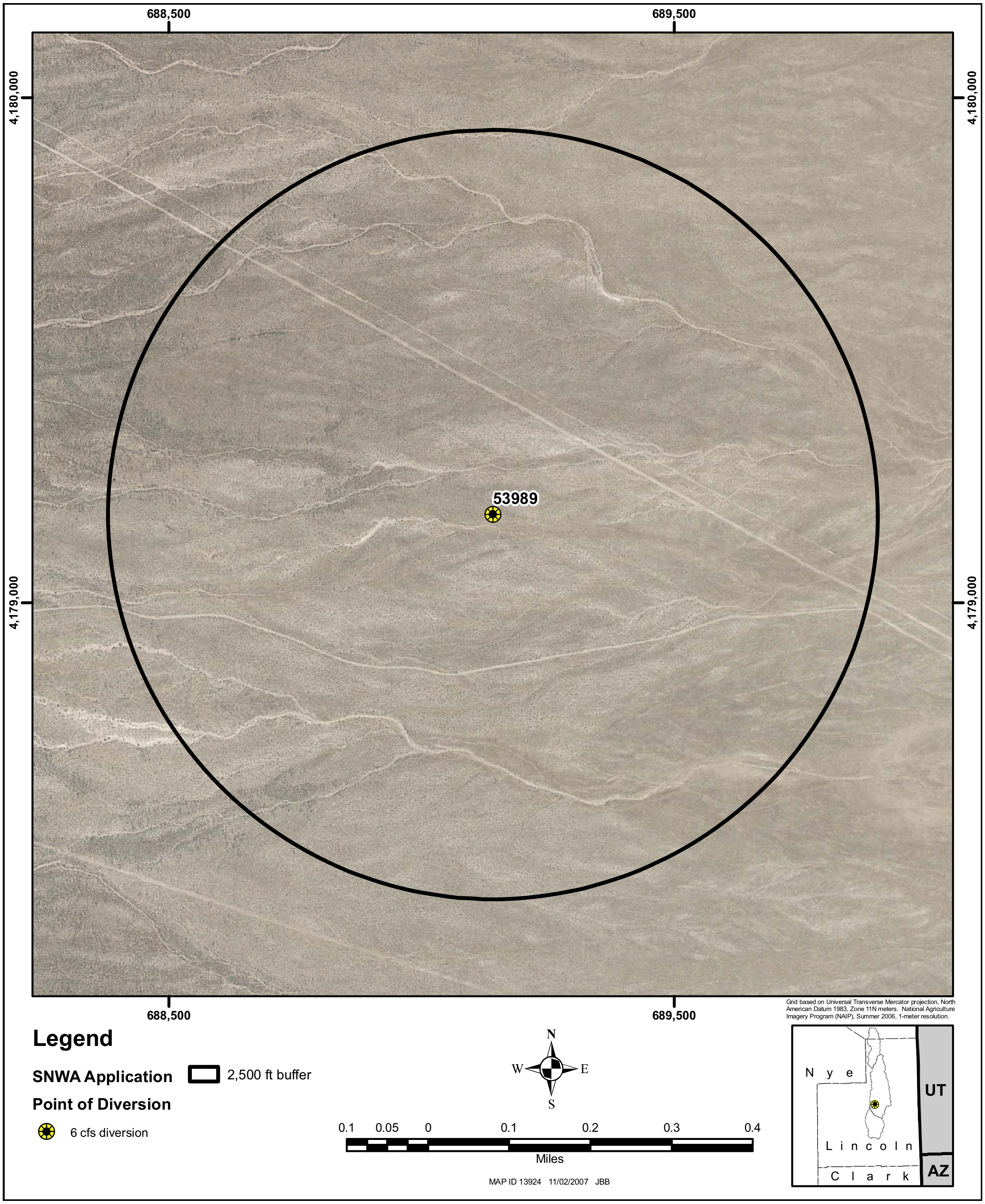


**Figure B.1-3**
**Area Surrounding Application Point of Diversion 53989 in Dry Lake Valley**

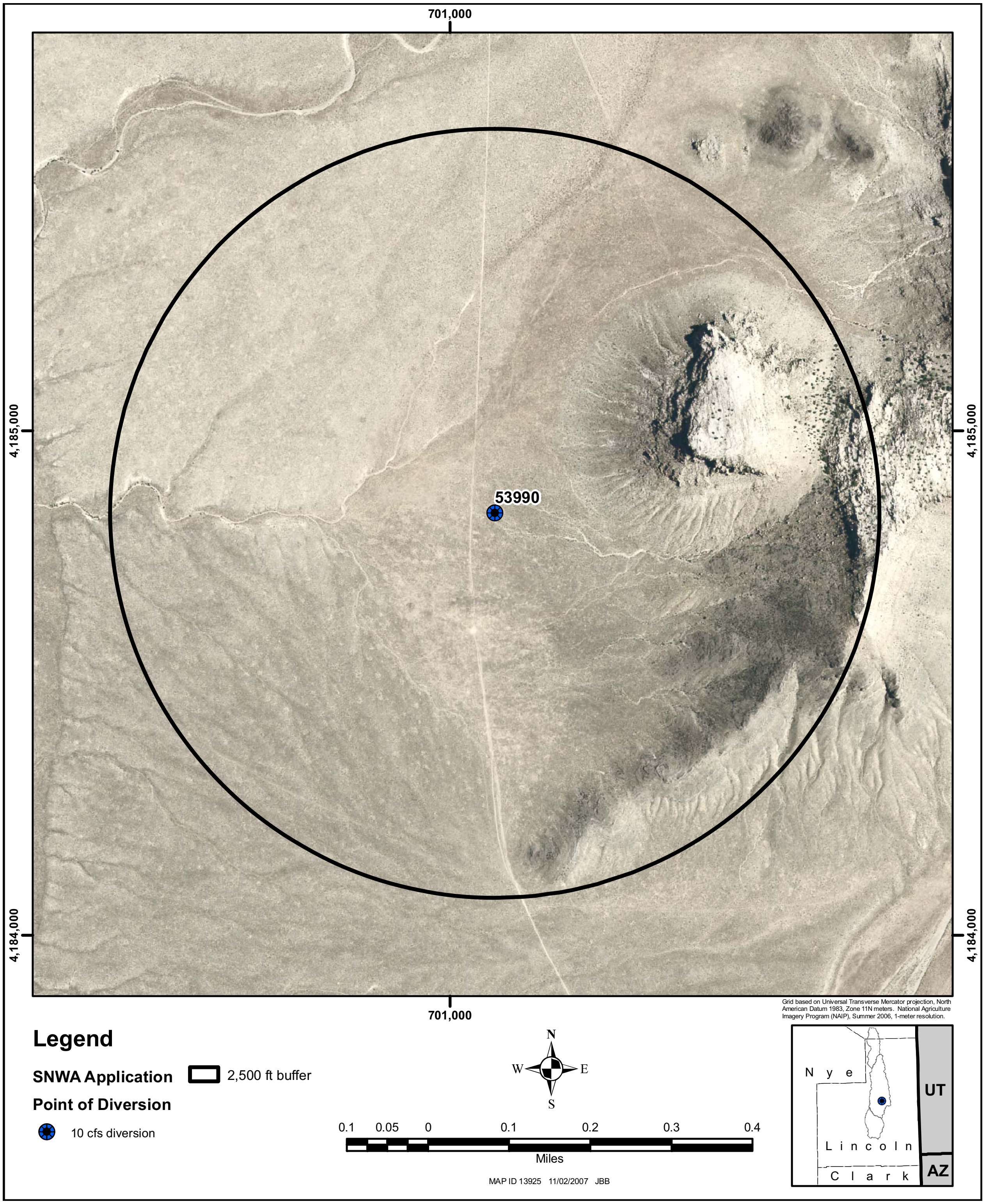


**Figure B.1-4**
**Area Surrounding Application Point of Diversion 53990 in Dry Lake Valley**

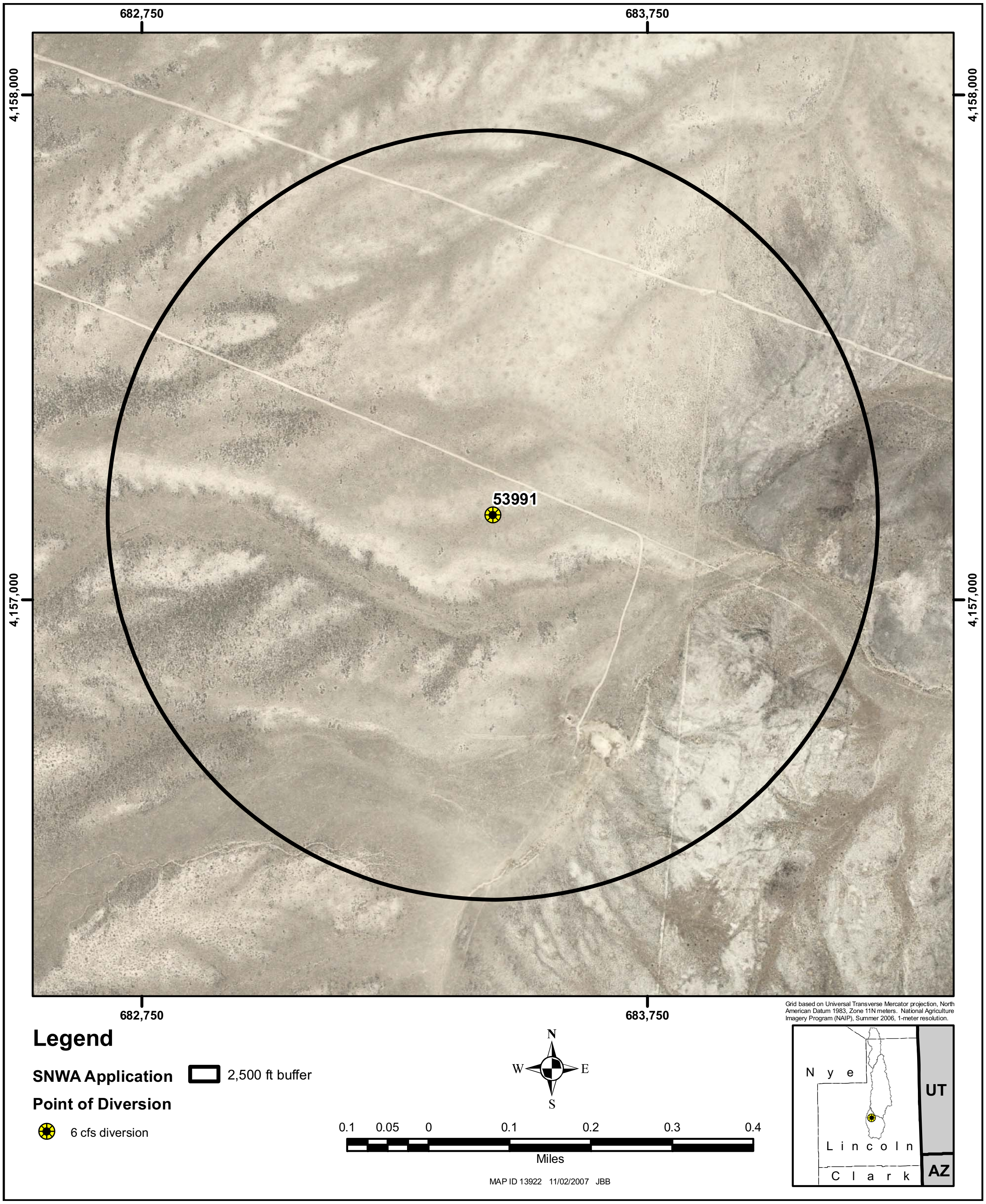


**Figure B.1-5**
**Area Surrounding Application Point of Diversion 53991 in Delamar Valley**

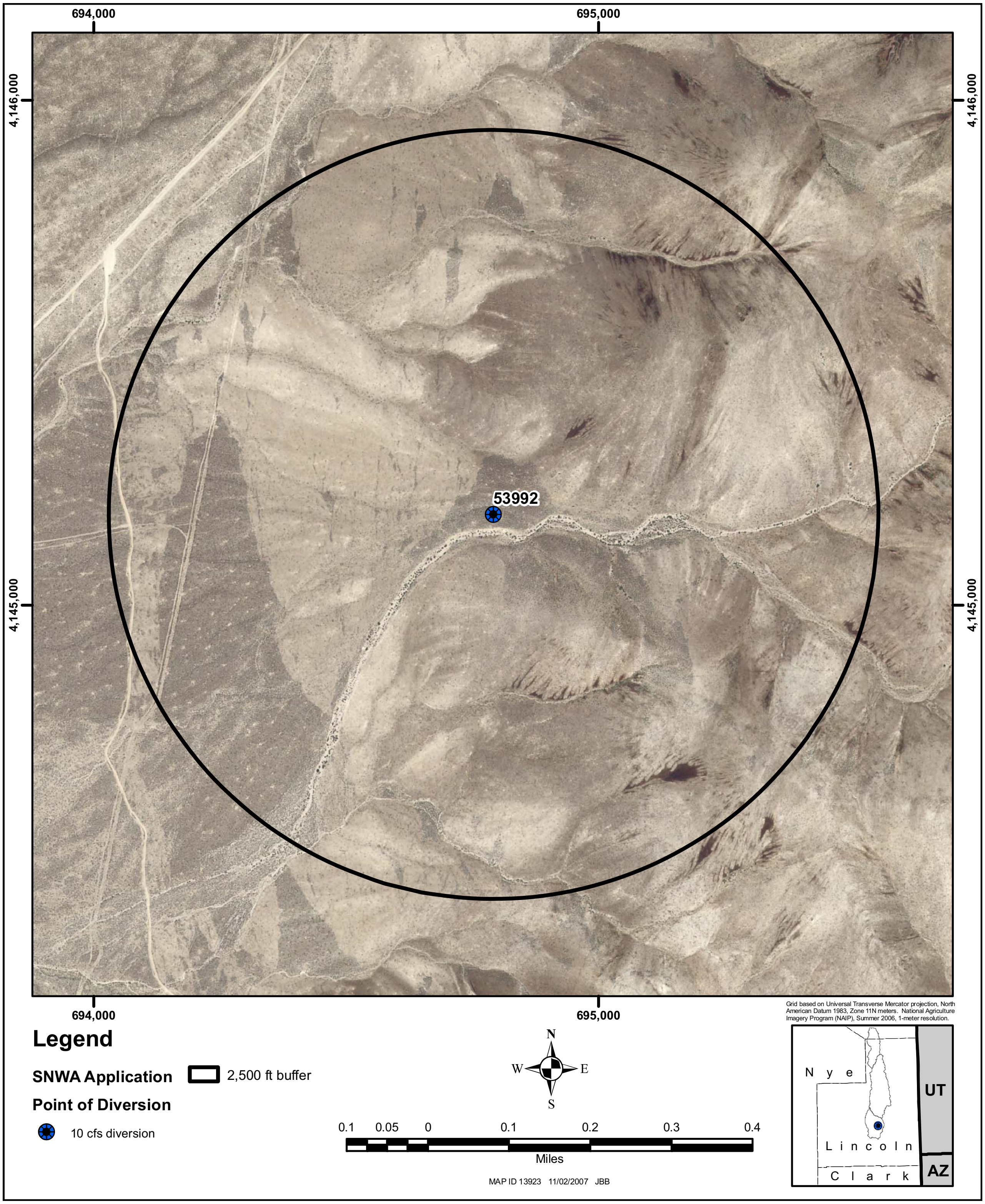


**Figure B.1-6**
**Area Surrounding Application Point of Diversion 53992 in Delamar Valley**

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# Appendix C

# Spring Discharge and Temperature Measurements

# C.1.0 INTRODUCTION

This appendix describes spring discharge and temperature measurements at selected springs within Cave, Dry Lake, and Delamar valleys.

# Table C.1-1
## Discharge and Temperature Measurements of Selected Springs in Cave, Dry Lake, and Delamar Valleys

| Report Spring ID | Date | Discharge (gpm) | Discharge (cfs) | Discharge Rating[a] | Discharge Method[b] | Water Temp. (°C) | Data Source | Remarks |
|---|---|---|---|---|---|---|---|---|
| Cave Spring | 5/24/1966 | 400 | 0.890 | – – | R | – – | Hess and Mifflin, 1978 | – – |
| Cave Spring | 6/7/76 | – – | – – | – – | – – | 8.8 | Pavelko, 2007 | – – |
| Cave Spring | 3/1/1980 | 1,000 | 2.23 | – – | E | 12 | Bunch and Harrill, 1984 | – – |
| Cave Spring | 4/20/80 | – – | – – | – – | – – | 13 | Pavelko, 2007 | – – |
| Cave Spring | 8/2/85 | – – | – – | – – | – – | 12 | Pavelko, 2007 | – – |
| Cave Spring | 6/27/92 | – – | – – | – – | – – | 12.1 | Pavelko, 2007 | – – |
| Cave Spring | 6/23/2004 | 105 | 0.230 | G | C | 12.3 | SNWA | – – |
| Cave Spring | 7/16/2004 | 36.4 | 0.080 | E | F | 13 | SNWA | – – |
| Cave Spring | 7/29/2004 | 9.87 | 0.020 | F | C | – – | SNWA | – – |
| Cave Spring | 9/14/2004 | 0 | 0 | E | – – | – – | SNWA | Dry |
| Cave Spring | 7/26/2005 | 359 | 0.800 | F | C | 12 | SNWA | – – |
| Cave Spring | 10/12/2006 | 14.8 | 0.033 | P | F | – – | SNWA | – – |
| Unnamed Spring at Parker Station | 6/27/92 | – – | – – | – – | – – | 14 | Pavelko, 2007 | – – |
| Meloy Spring | 5/1/1980 | 82.0 | 0.180 | – – | C | – – | USGS | – – |
| Meloy Spring | 7/13/1997 | 44.9 | 0.100 | P | E | 19.3 | SNWA | – – |
| Bailey Spring | 10/18/1912 | 3.00 | 0.010 | – – | E | – – | Carpenter, 1915 | – – |
| Bailey Spring | 5/1/1980 | 2.00 | 0.004 | – – | R | – – | Bunch and Harrill, 1984 | Reported as 2-3 gpm by Bunch and Harrill, 1984 |
| Bailey Spring | 6/3/2004 | 0.28 | 0.001 | E | F | 13 | SNWA | – – |
| Coyote Spring | 10/18/1912 | 5.00 | 0.010 | – – | E | – – | Carpenter, 1915 | – – |
| Coyote Spring | 8/1/1979 | 1.00 | 0.002 | – – | R | – – | Bunch and Harrill, 1984 | – – |
| Coyote Spring | 6/3/2004 | 0.11 | – – | G | V | 18 | SNWA | – – |
| Coyote Spring | 6/21/2004 | 0.02 | – – | G | V | – – | SNWA | – – |
| Coyote Spring | 7/14/2005 | 0.52 | 0.001 | G | V | 18 | SNWA | – – |
| Grassy Spring | 5/1/1980 | 7.00 | 0.020 | – – | R | 11 | Bunch and Harrill, 1984 | – – |
| Grassy Spring | 6/2/2004 | 0.06 | 0 | F | V | 20.5 | SNWA | Temperature taken at outfall from pipe. |
| Grassy Spring | 7/14/2005 | 6.01 | 0.010 | G | V | 21.2 | SNWA | Temperature taken at outfall from pipe. |
| Grassy Spring | 7/25/2005 | 5.40 | 0.010 | F | V | – – | SNWA | Temperature taken at outfall from pipe. |

[a]Discharge Rating: P = poor; F = fair; G = good; E = excellent
[b]Discharge Method: C = current meter; E = estimated; F= flume; R = reported; V = volumetric; W = weir

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