Case No. 84739

IN THE SUPREME COURT OF THE STATE OF NEVADA

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ADAM SULLIVAN, P.E., NEVADA STATE ENGINEER, et al.

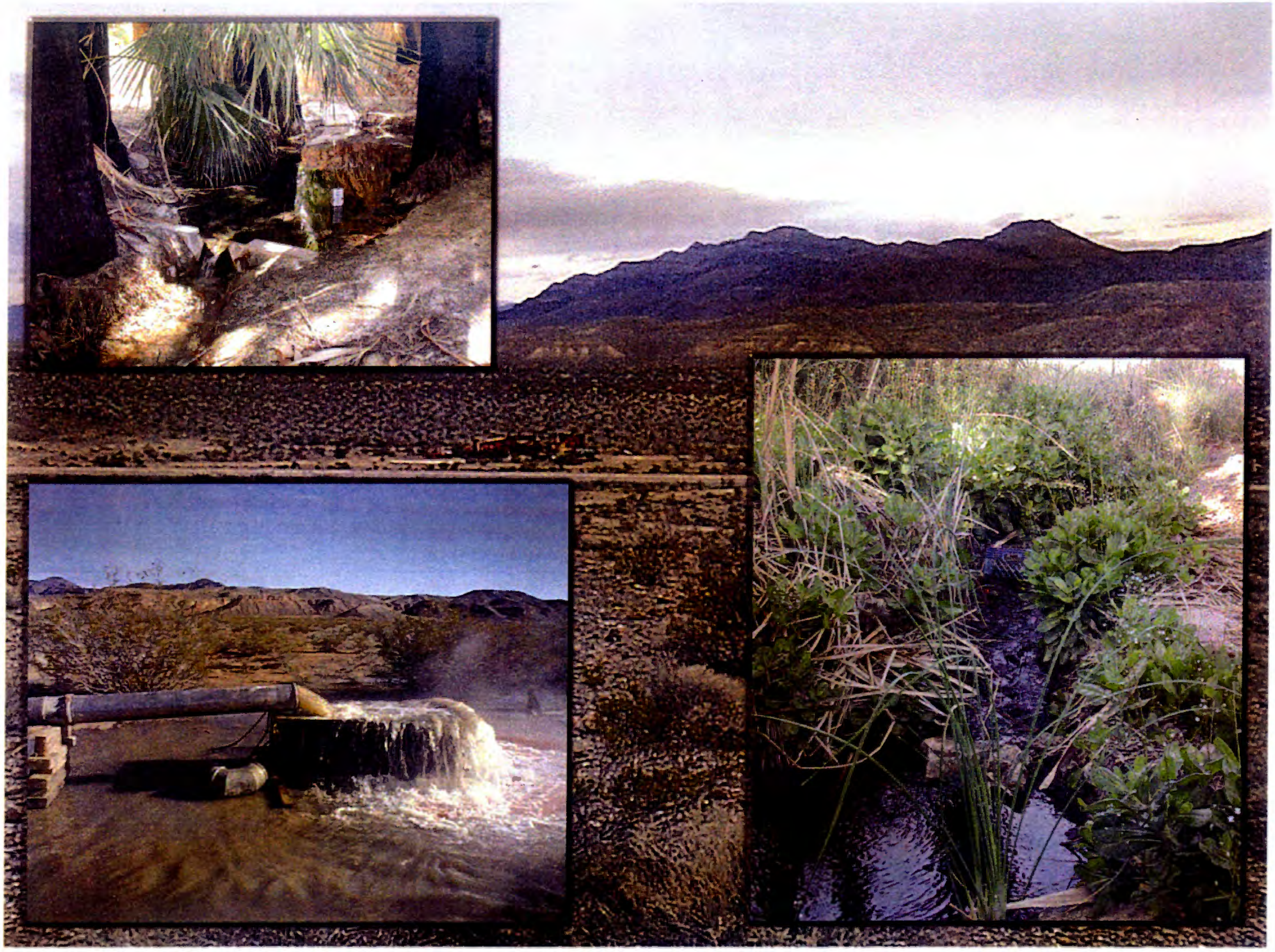
Appellants,

vs.

LINCOLN COUNTY WATER DISTRICT, et al.

<u>JOINT APPENDIX</u>

VOLUME 24 OF 49



WATER RESOURCES AND GROUND-WATER MODELING IN THE WHITE RIVER AND MEADOW VALLEY FLOW SYSTEMS
Clark, Lincoln, Nye and White Pine Counties, Nevada

by

Las Vegas Valley Water District

June 2001

LAS VEGAS VALLEY WATER DISTRICT

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Front cover picture insets from top left: Iverson Spring at Muddy Springs near Moapa (May 2001), discharge from MX-5 well after pump start-up (February 1998), spring flow below Pederson Spring at Muddy Springs near Moapa (May, 2001). Background picture of Coyote Spring Valley near MX-4 and MX-5 with pump rig in background.

List of Acronyms and Abbreviations

amsl	Average mean sea level
%	Percent
3-D	Three-dimensional
afy	Acre-feet per year
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
cfs	Cubic feet per second
CRBP	Colorado River Basin Province
CRBPN	Colorado River Basin Province of Nevada
CSI	Coyote Spring Investment LLC
DEM	Digital Elevation Model
DOI	U.S. Department of Interior
DRI	Desert Research Institute
DTW	Depth-to-water
ESA	Endangered Species Act
ESRI	Environmental Systems Research Institute
ET	Evapotranspiration
ft	Foot (feet)
ft/d	Foot (feet) per day
GIS	Geographic Information System
gal/min (gpm)	Gallon(s) per minute
gpd	Gallons per day
GWSI	Groundwater Site Inventory
in.	Inch(es)
K	Hydraulic conductivity
K_x, K_y	Horizontal hydraulic conductivity
K_z	Vertical hydraulic conductivity
LDS	Latter Day Saints
LVVWD	Las Vegas Valley Water District
ME	Maxey-Eakin
mi	Mile(s)
mi^2	Square mile(s)
MBPI	Moapa Band of Paiute Indians
MVWD	Moapa Valley Water District
MVIC	Moapa Valley Irrigation Company
NDOW	Nevada Department of Wildlife
NDWR	Nevada Department of Water Resources
NPC	Nevada Power Company
NPS	National Park Services
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
NV	Nevada
P	Precipitation

PRISM	Parameter-elevation Regressions on Independent Slopes Model
r_e	Natural recharge efficiency
SNWA	Southern Nevada Water Authority
S_s	Storage coefficient
S_y	Specific yield
T	Transmissivity
TNC	The Nature Conservancy
U.S.	United States
USAF	U.S. Air Force
USBR	U.S. Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WRCC	Western Regional Climate Center
yr	Year

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WATER RESOURCES AND GROUND-WATER MODELING IN THE WHITE RIVER AND MEADOW VALLEY FLOW SYSTEMS, Clark, Lincoln, Nye and White Pine Counties, Nevada

EXECUTIVE SUMMARY

This Executive Summary is a synopsis of the report entitled, *Water Resources and Ground-water Modeling in the White River and Meadow Valley Flow Systems, Clark, Lincoln, Nye and White Pine Counties, Nevada*, prepared by the Las Vegas Valley Water District (LVVWD). This report has been prepared in support of the Las Vegas Valley Water District's ground-water applications (54055 through 54059 inclusive) in Coyote Spring Valley; applications have a total combined duty of 27,512 acre-feet per year.

Introduction

Urban development in southern Nevada is continuing and is now expanding to include the regions adjacent to Las Vegas Valley along the Interstate-15 corridor, including communities like Moapa Valley. In addition, numerous power-generating companies have expressed interest in building facilities in the same area. In Coyote Spring Valley, just north of Las Vegas and the "I-15 Corridor," there are over 16,000 acre-feet of ground-water permits owned by the Southern Nevada Water Authority (SNWA), Nevada Power Company (NPC), and Coyote Spring Investment Inc (CSI). In addition to the existing ground-water permits there are 27,512 acre-feet of ground-water applications filed in 1989 by the Las Vegas Valley Water District (LVVWD).

This report was prepared to define the regional hydrology and geology of the White River and Lower Meadow Valley Flow Systems, estimate their ground-water and surface water budgets, and simulate potential impacts on the regional ground-water and surface water resources from development of the LVVWD applications. However, due to the lack of hydrologic data and minimal ground-water development, the large-scale response of the aquifer system is poorly understood and prediction of future ground-water development is difficult to assess. For this reason ground-water development from the regional carbonate rock aquifer should be accompanied by monitoring to protect existing water right holders and environmental resources.

Hydrogeologic Setting

A regional hydrogeological evaluation was made of the entire White River and Meadow Valley Flow Systems. The geologic framework was defined and numerous cross-sections were constructed to help understand the movement of ground water through these two flow systems. New precipitation-altitude relationships were defined based on data collected over the last thirty years. Because of these additional data and revised methods, these relationships led to an estimate of more ground-water recharge than estimated by previous investigators. Ground-water discharge by evapotranspiration was also estimated at greater volumes than estimates by previous investigators.

The water-resources budget for the entire area shows ground-water recharge estimated at 324,000 acre-feet/year. Of this amount about 275,000 acre-feet/year is utilized by vegetation leaving a remainder of nearly 50,000 acre-feet/year to discharge from the two flow systems in the carbonate aquifer. About 10,000 to 20,000 acre-feet/year of this discharge is surface water in the Muddy River that actually flows into Lake Mead. The water-resources budget for the ground-water model area, a subset of valleys, including Coyote Spring Valley, at the southern end of these two flow systems, shows inflow from the regional carbonate aquifer plus local ground-water recharge to equal 117,000 acre-feet/year. Evapotranspiration consumes about 67,000 acre-feet/year leaving about 50,000 acre-feet/year of discharge out of the area.

The geochemical data base for the area was re-evaluated by the Desert Research Institute (University of Nevada System) and a deuterium-mass-balance model was developed. This geochemistry model, which has some commonality with the estimation of the water budget, is consistent with the hydrogeological model. The data from these two models were used to develop a numerical ground-water model.

Simulated Impacts

A three-dimensional ground-water flow model was developed to assist in understanding the response of the ground-water system from developing LVVWD ground-water applications in Coyote Spring Valley. The results based on the regional evaluation and model simulations are described below:

The ground-water flow model is calibrated based on predevelopment conditions and reasonably replicates responses to the hydrologic system from existing pumping through the year 2000. However, the model predicts a two cubic feet/second decline in the flow of the Muddy Springs that is not observed. Thus, the model tends to over estimate somewhat the response of the ground-water system.

Baseline for ground-water development is the pumping of the existing permits, about 44,000 acre-feet per year in the valleys (Coyote Spring Valley, Garnet Valley, California Wash, Lower Meadow Valley Wash, Muddy River Springs, and Black Mountain) where pumpage occurs in the model area. The simulated net response between pumping the permitted water rights, 18,000 acre-feet/year and the applications, 27,500 acre-feet/year, is 2.5 cubic feet/second decrease in the Muddy Springs.

Rogers and Blue Point Springs are not affected by the baseline (permitted) pumping or the addition of the proposed pumping as a result of the applications. The model predicts that the impact to the Muddy Springs in 61 years of pumping the permitted water rights will be a decrease of about four cubic feet per second. However, as stated above the model predicted a decline in spring flow of about two cubic feet per second in the year 2000, which has not been observed.

A model is only a tool dependent upon accurate hydrogeologic data. The availability of data in the model area is extremely limited. Therefore, the results from the model are very limited. The impacts of future ground-water development in the carbonate aquifer will remain largely unknown and speculative until there are opportunities to evaluate transient responses to significant, long-term ground-water pumping from the carbonate-rock aquifer. As data is collected from ground-water development the model will be continually refined and used for analysis of potential impacts.

1 INTRODUCTION

Urban development in southern Nevada is continuing and is now expanding to include the regions adjacent to Las Vegas Valley along the Interstate-15 corridor, including communities like Moapa Valley. In addition, numerous power-generating companies have expressed interest in building facilities in the same area.

Increased land development includes the need for additional water. In Coyote Spring Valley, just north of Las Vegas and the "I-15 Corridor," there are over 16,000 acre-feet of ground-water permits owned by the Southern Nevada Water Authority (SNWA), Nevada Power Company (NPC), and Coyote Spring Investment Inc (CSI). In addition to the existing ground-water permits there are 27,512 acre-feet of ground-water applications filed in 1989 by the Las Vegas Valley Water District (LVVWD). Also, there are over 100,000 acre-feet of ground-water applications more recently filed by CSI in 1997 and 1998, for a potential residential and golf course development in Coyote Spring Valley.

It is uncertain how many of the ground water applications in Coyote Spring Valley can be developed without impacting the down-gradient Muddy Springs in Upper Moapa Valley. The Muddy Springs are managed by the U.S. Fish and Wildlife Service (USFWS) and are the home of the Moapa dace (U.S. Fish and Wildlife Service, 1995), a protected species of fish listed as endangered under the Endangered Species Preservation Act of 1966 on March 11, 1967 (32 Federal Register 4001). Other aquatic species of concern that occur in the Muddy River ecosystem are three fish, two snails, and two insects. There are also springs in hydrologic basins near Coyote Spring Valley on lands managed by the U.S. Park Service (USPS) and Bureau of Land Management that are of concern to those agencies and the public who uses them.

Because there is need for development in the I-15 Corridor and Coyote Spring Valley and because impacts on nearby springs are unknown, LVVWD has carried out a detailed analysis in an attempt to understand the origin, movement, volume, and fate of ground-water in the general area. This report summarizes those findings. It is also a supporting document for the hearing scheduled before the Nevada State Engineer in July 2001 for water rights applications 54055 through 54059 (inclusive) held by LVVWD.

1.1 PURPOSE AND SCOPE

The purpose of this study is to further define the ground-water flow systems that are contributory to the Muddy Springs in Upper Moapa Valley and to determine if there is ground-water flow that bypasses the springs. The scope of the study is to estimate a water-resource budget for the White River Flow System, including the Meadow Valley Flow System component. This was done using additional precipitation data, the results of recent geologic investigations, geochemistry, and interpretive techniques that were not available to earlier investigators. Finally, a ground-water model was constructed to evaluate the hydrogeologic processes and to assess the future spring flow impacts of permitted and potential additional groundwater pumpage using various pumping simulations.

1.2 DEFINITION OF STUDY AREA OF THIS REPORT

The Muddy Springs and Muddy River represent a major discharge point in the White River and Meadow Valley Flow System that drains to the Colorado River. There are 27 hydrographic basins in eastern and southern Nevada that are part of the Colorado River Basin drainage (**Figure 1-1**). These basins form the White River and Meadow Valley Flow Systems; in this report, these basins are referred to collectively as the Colorado River Basin Province of Nevada. Much of the area is accessible by mule and rail. There are several other valleys in Nevada that are also tributaries to the Colorado River drainage, but are not within the study area.

The Muddy Springs and Muddy River, in part the focus of this study, are located in the eastern edge of Upper Moapa Valley (Eakin, 1964, Plate 1) and are the source of the Muddy River. There are 20-30 separate spring orifices that make up the Muddy Springs and these are located over an area of about three square miles (3 mi^2). Additionally there are undoubtedly diffuse seeps to the Muddy River and to the alluvial ground-water system within the Upper Moapa Valley that are undefined. The collective spring flow represents part of the discharge from the White River Flow system.

The study area includes all of the valleys that make up the White River Flow system as first defined by Eakin (1964) and we have included Hidden, Garnet, California Wash, Black Mountain Basin and Lower Moapa Valley. Also part of the study are all of the valleys that are tributary to, and including, Meadow Valley Wash as described by Rush and Eakin (1963), and Rush (1964). All valleys in the study area are listed in **Table 1-1** along with their appropriate references. The area modeled is much smaller and is shown on **Figure 1-1**. The detailed geologic interpretations are mostly confined to the area modeled.

Not all 27 basins are represented in the ground-water model constructed for this study, but their collective hydrologic resources are used. The net ground-water flow across the model boundary in both the alluvial aquifer system and the underlying, interconnected, regional carbonate aquifer system represents a valuable resource.

The study area encompasses about 7,734,000 acres (12,080 square miles) and covers significant parts of White Pine, Lincoln, and Clark Counties and a small part of Nye County. The highest points in the study area are Currant Mountain (11,513 feet) in the White Pine Range and Troy Peak (11,298 feet) in the Grant Range.

Most of the valleys within the study area have no surface outflow, yet all are tributaries to the Colorado River drainage through ground-water discharge. All of these valleys are in the classic Basin and Range physiographic region, as described by Fenneman (1931). The Basin and Range is a series of parallel to sub-parallel, north trending mountain ranges separated by elongated valley lowlands and are further classified by Heath (1984), as being in the Alluvial Basins Ground-Water Region. These basins are also part of the carbonate rock province of eastern-southern Nevada and western Utah as described by Plume and Carlton (1988). The carbonate rock province represents a regional aquifer system that underlies the entire area. The hydraulic

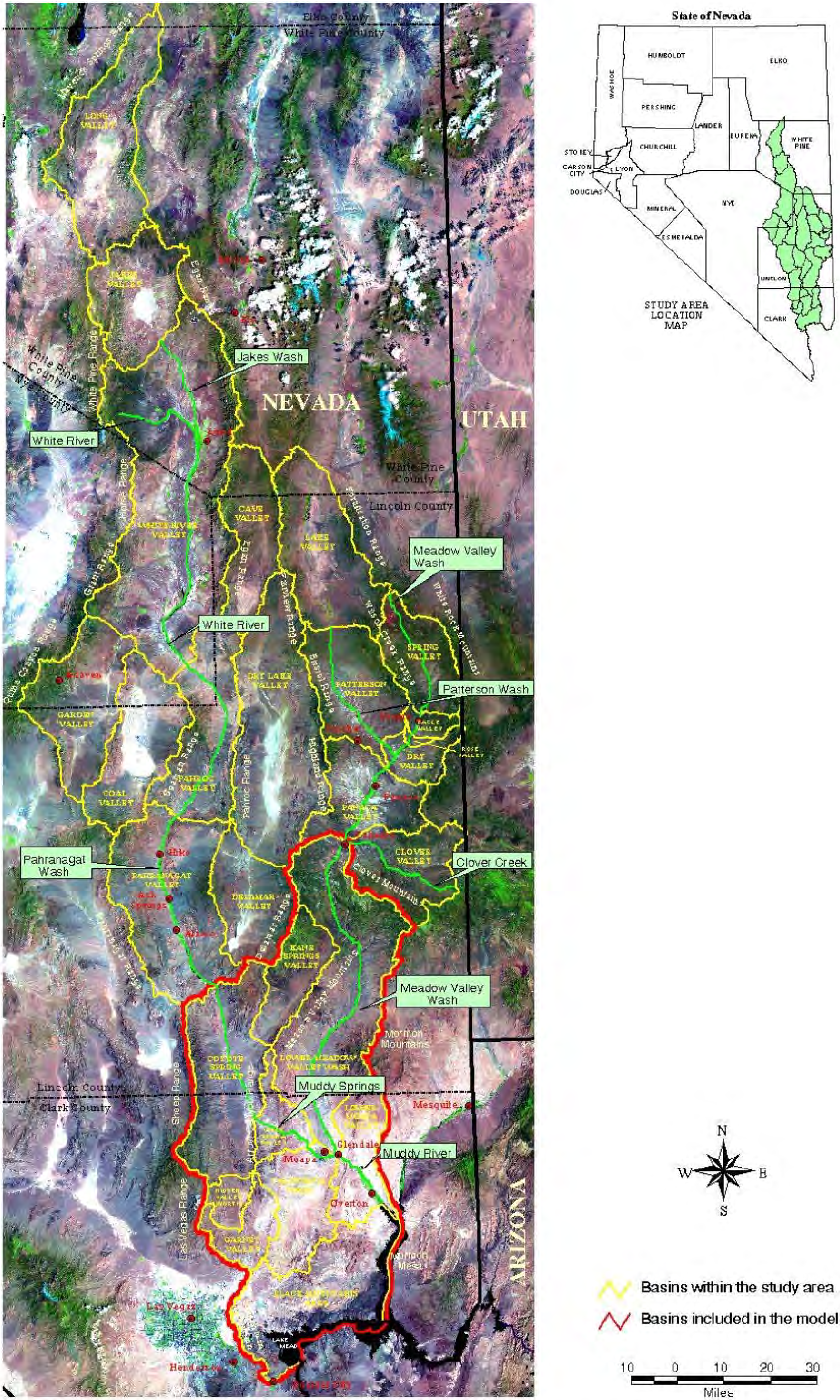

Figure 1-1. Location of Study area drainage basins and basins included within the model.

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connectivity of this aquifer system is believed to be large, but there may be structural blocks that compartmentalize different parts of the flow system. Most of these valleys are part of the White River ground-water flow system first described by Eakin (1966). These 27 basins are collectively referred to here as the Colorado River Basin Province of Nevada (CRBPN).

The northwestern part of the study area is bounded by a long continuous northeasterly trending mountain range which includes the White Pine, Grant and Quinn Canyon Range. The northwestern part of the study is also bounded by parts of the northerly Egan Range. The southwestern part is bounded by the northerly trending Sheep Range and the smaller northwesterly trending Pahranagat Range. The extreme southwestern part is bounded by the Las Vegas Range and Frenchman Mountain.

The eastern part of the study area is bounded by the northwesterly trending Fortification Range, parts of the northwesterly Wilson Creek Range and parts of the basically east-west Clover Mountains. The southeastern boundary transects the Mormon Mountains and Mormon Mesa and the Overton arm of Lake Mead. The southern boundary is Lake Mead in Nevada and Arizona. All of the northeasterly trending Delamar, Meadow Valley and virtually all of the Clover Mountains are within the study as are numerous small ranges like the Fairview, Bristol, Highland Peak, Seaman, and North and South Pahroc Ranges.

The largest hydrographic basin in the study area is the White River Valley at about 1,017,000 acres, and the smallest, Rose Valley is about 8,000 acres. Most of the western side of the study area is composed of large valleys bounded by high mountain ranges. The eastern side is composed of smaller valleys nestled in amongst generally rugged terrain.

1.3 PREVIOUS INVESTIGATIONS

The U. S. Geological Survey (USGS) has evaluated the hydrology of the entire study area **(Figure 1-1)** through a series of building block studies that began in the early 1960s. Most of these were at a reconnaissance level in a cooperative program with the state of Nevada with a few additional in-depth studies. Scott and others (1971) summarized hydrologic data for many of the hydrographic basins in the state. Winograd and Thordarson (1975) in their investigation of the regional hydrogeologic framework for the Nevada Test site provided insights into the recharge and direction of ground-water flow from the Sheep Range.

As part of the MX Missile investigations numerous wells were drilled in many of the valleys and Ertec Western (1981) conducted an extensive aquifer test in Coyote Spring Valley in well No. CE-DT-5, commonly known as MX No. 5. This well pumped at least 3,400 gallons per minute (gpm) for a 30-day test with virtually no drawdown at the wellhead. According to Buqo and others (1992, p. 28) the 3,400 gpm was the capacity of the pump used to test the well so the aquifer system was not significantly stressed.

The USGS Regional Aquifer Systems Analyses (RASA) started in the 1980s and continued on into the 1990s. The RASA project was funded in total by the USGS and resulted in the development of a three-dimensional finite difference ground-water flow model that includes all of the entire carbonate-rock province of Nevada, Utah, and California and covers all of the valleys of interest for this study. According to Prudic et al. (1995, p. D 38) the model results are only conceptual. The Department of the Interior Agencies (DOI) funded the USGS to take this conceptual steady state ground-water model and run transient scenarios. These scenarios were based on proposed ground-water withdrawals by the Las Vegas Valley Water District through out much of the carbonate-rock province.

According to the authors of the modeling effort, Schaefer and Harrill (1995, p. 2 and 7) the results of this 200 year simulation need to be viewed with caution. Also in the mid 1980s the USGS initiated the Carbonate Aquifer program in cooperation with the LVVWD, City of North Las Vegas, Desert Research Institute (DRI) and the U. S. Bureau of Reclamation (USBR).

Other studies by the USGS, DRI, the LVVWD, and SNWA focused on specific disciplines or a combination of disciplines such as geochemistry, geophysics, geology, evapotranspiration (ET) and hydrology. Kirk and Campana (1990), as part of a regional, multi-agency study of the carbonate rock aquifer, developed a ground-water flow model for the White River Flow System based on geochemistry.

LVVWD developed ground-water models for many of the valleys as part of their regional investigations of ground-water basins in eastern and southern Nevada. Prudic and others (1993) developed a conceptual evaluation of regional flow in the carbonate rocks of eastern and southern Nevada through the use of a ground-water flow model. Dettinger and others (1995) studied the distribution of the carbonate-rock aquifers and their potential for development and have indicated the best way to develop ground water from the carbonate aquifer is a staged approach with adequate monitoring of related effects. Thomas (1996) synthesized ground-water flow in southern Nevada through the use of geochemistry and Plume (1996) described the hydrogeologic framework of the carbonate rock province in Nevada, Utah, and California. Katzer (1996) developed a conceptual model for the ground-water flow system in Coyote Spring Valley. Bredehoeft and Hall, (1996) developed a ground-water model for the Upper Muddy River Valley. They observed that pumping from the Arrow Canyon Well will ultimately reduce the flow of the river and springs by an equal amount.

In another study within the California Wash, Johnson and others, (2001) concluded that long-range impacts from proposed pumping (7000 AFY) on the Muddy Springs discharge is minimal. There are also studies referenced that include Master of Science thesis, consultant's reports, and reports by the U. S. Air Force (USAF) for the MX Missile-siting project. **Table 1-1** lists the various studies that have contributed to the understanding of the complex hydrogeology of this vast area. The geologic references are many and are referenced in the geology section of this report and are not included in **Table 1-1.**

All of these publications are referenced in the text and are listed alphabetically by senior author and chronologically by year in the Reference Section.

Table 1-1. Previous hydrologic investigations in the study area of the Colorado River Basin Province of Nevada.

VALLEY and Hydrologic Site No.		TYPE OF STUDY Valley	Regional	REFERENCE[1]
WHITE RIVER FLOW SYSTEM				
Long	175	X	X	R-3, B-33, W-1409,1475 L, P-1628, O-96-469
Jakes	174	-	X	B-33, W-1409, 1475 L, P-1628, O-96-469
White River	207	X	X	B-8, 33, W-365, 1409, 1475 L, O-96-469
Garden	172	X	X	R-18, B-33, W-365, 1409, 1475 L, L-8, O-96-469
Coal	171	X	X	R-18, B-33, W-365, 1409, 1475 L, L-8, O-96-469
Cave	180	X	X	R-13, B-33, W-365, 1409, 1475 L, L-11, O-96-469
Pahroc	208	X	X	R-21, B-33, W- 365, 1409, 1475 L, L-10
Dry Lake	181	X	X	R-16, B-33, W- 365, 1409, L-16, O-96-469
Delamar	182	X	X	R-16, B-33, W- 365, 1409, L-16, O-96-469
Pahranagat	209	X	X	R-21, B-33, W- 365, 1409, 1475 L, WRI- 91-4146
Kane Springs	206	X	X	R-25, B-33, W-365, 1409, WRI- 91-4146
Coyote Spring	210	X	X	R-25, B-33, W-224, 365, 1409, L-3, OP, O-96-469, WRI- 91-4146
Upper Moapa	219	X	X	R-50, B-33, W-224, 365, 1409, O-96-469, WRI-91-4146
Lower Moapa	220	X	X	R-50, W-224, 365, 1409, WRI- 91-4146
Hidden	217	X	X	R-50, W-224, 365, 1409, WRI- 91-4146
Garnet	216	X	X	R-50, W-224, 365, 1409, WRI- 91-4146
California Wash	218	X	X	R-50, W-224, 365, 1409, WRI- 91-4146
Black Mountains	215	X	X	R-50, W224, 365, 1409, P-295, 298, WRI- 91-4146
MEADOW VALLEY FLOW SYSTEM				
Lake	183	X	X	R-24, W-365, W-1409, 1475 L
Patterson	202	X	X	R-27, B-7, W-1409, 1475 L, O-96-469
Spring	201	X	X	R-27, B-7, W-365,1409, 1475 L, WRI- 91-4146
Eagle	200	X	X	R-27, B-7, W-365,1409, 1475 L, WRI- 91-4146
Rose	199	X	X	R-27, B-7, W-365,1409, 1475 L, WRI- 91-4146
Dry	198	X	X	R-27, B-7, W-365,1409, 1475 L, WRI- 91-4146
Clover	204	X	X	R-27, B-7, W-365,1409, 1475 L, WRI- 91-4146
Panaca	203	X	X	R-27, B-7, W-365,1409, 1475 L, WRI- 91-4146
Meadow Valley Wash	205	X	X	R-27, W-224, 365, 1409, 1475 L, WRI- 91-4146

1. *USGS Publications: R - Reconnaissance Series Report; W- Water-Supply Paper; Professional Paper-P, Water-Resource Investigations Report-WRI, B - Nevada Water Resources Bulletin, and O - Open-File Report. DRI Publications- D. LVVWD Publications-L., and Other Publications-OP.*

1.4 AVAILABILITY OF DATA

A variety of data and information from numerous sources were compiled for the purposes of this study and the construction of a ground-water flow model. Since much of the study area is located in remote and undeveloped areas, few data are available. However, significant data and information were acquired in the form of published and unpublished documents and data sets for the various parameters required for the development of a conceptual model of the study area and the construction of a flow model. To assist in the development of records, information was garnered from site reconnaissance and field investigations and from numerous interviews with local, state, and federal agencies and various ground-water consultants working within the boundary of the study area.

Historical records of (climatic) precipitation were acquired from the DRI Western Regional Climatic Center website, www.wrcc.dri.edu/summary/climsmnv.html. Additional precipitation station data were obtained from NDWR unpublished records. For the period 1984 to 2000, high-elevation precipitation data was compiled from Water Resources Data reports published annually by the USGS.

Well and spring data were compiled from numerous sources including data collected by SNWA and data obtained from the USGS Ground-water Site Inventory database (GWSI), NDWR Well Log Database and Water Rights Database, and published and unpublished reports, hydrogeologic investigations, and maps. A significant portion of the water-level and ground-water production data were compiled from MVWD and NPC hydrologic monitoring reports submitted to NDWR. Interviews conducted with representatives of MVIC, MVWD, NDWR, and various consultants working within the study area were used to assist in the development of the various historical records.

Surface-water data, including stream flow and spring discharges, were compiled from the USGS National Water Information System database and published USGS Water Resources Data reports for water years 1913 to 2000. Continuous records of stream-flow were compiled for water years 1944 to 2000 for the Moapa gaging station, and 1950 to 2000 for the Glendale gauging station. Data for water-year 2000 have not yet been fully published and is considered preliminary.

Selected coverages depicting spatial (vector) data were acquired from the USGS Eros Data Center and developed through site reconnaissance and field investigations by SNWA. USGS 30-meter seamless digital-elevation-model data were acquired from the USGS National Elevation Dataset. Satellite imagery for the years 1981 and 1998 was acquired from the USGS Eros Data Center. Aerial photography for 1953 was acquired from the USGS Eros Data Center, and for 1997-2000 from the private sector. Geologic data (geologic outcrop and fault maps) were acquired from the Nevada Bureau of Mines and Geology and the USGS.

Additional data acquired for the purposes of this study and ground-water modeling effort that are not discussed in this section are discussed in subsequent sections of this report.

2 HYDROLOGIC SETTING

The valleys that make up the White River and the Meadow Valley Flow Systems are in the Colorado River Basin Province of Nevada **(Figure 2-1)**. These two parallel flow systems are probably in hydraulic continuity with each other at depth and both discharge ground water from the deep seated carbonate aquifer. These valleys are part of the Basin and Range Province and are characterized as bounded by north- to northeast trending sub-parallel mountain ranges. The mountain ranges, depending on location, are made up of a mixture of marine sedimentary rocks from the Paleozoic and Mesozoic Eras and volcanic rocks of Tertiary age. The valleys' unconsolidated sediments reflect the erosion process from the mountain blocks and are filled with sediments that range in size from clay to boulders. Carbonate rocks, mostly of Paleozoic age underlie virtually all the valley aquifer systems, thus providing continuity of ground-water flow throughout the entire area. Ground-water storage and flow in the carbonate rocks are enhanced by dissolution and an extensive fracture system. In some valleys volcanic rocks are on top of carbonate rocks and underneath the valley unconsolidated aquifer system.

The dominant hydrologic features of the area are the several large springs scattered throughout the area that represent flow from the carbonate aquifer system. The largest of these are the Muddy Springs located near the central part of Upper Moapa Valley that collectively discharge about 37,000 acre-feet/year (adjusted for evapotranspiration). This spring flow is virtually unchanged since it was first estimated by Eakin (1966). The Muddy Springs are the headwaters of the Muddy River, which historically was a tributary to the Virgin River, but now flows to Lake Mead because of the construction of Hoover Dam.

The White River flows several thousand afy from its headwaters in the White Pine Range and is a continuous drainage to its junction with Lake Mead. The channel, once it leaves White River Valley is ephemeral and is a remnant of the wetter climate dating back to the late Pleistocene time (Eakin, 1966). The drainage is known as Pahranagat Wash once it reaches Pahranagat Valley and turns into the Muddy River in Upper Moapa Valley.

There are other perennial streams mostly in the higher mountain blocks in the northern parts of the area such as in the White Pine and Eagan Ranges in the White River Valley drainage and Clover Mountains that drain to Clover Valley. Meadow Valley Wash is perennial to intermittent for most of its length starting in Spring Valley (east side of the Wilson Creek Range) and flowing generally to a point about 10 miles north of Moapa.

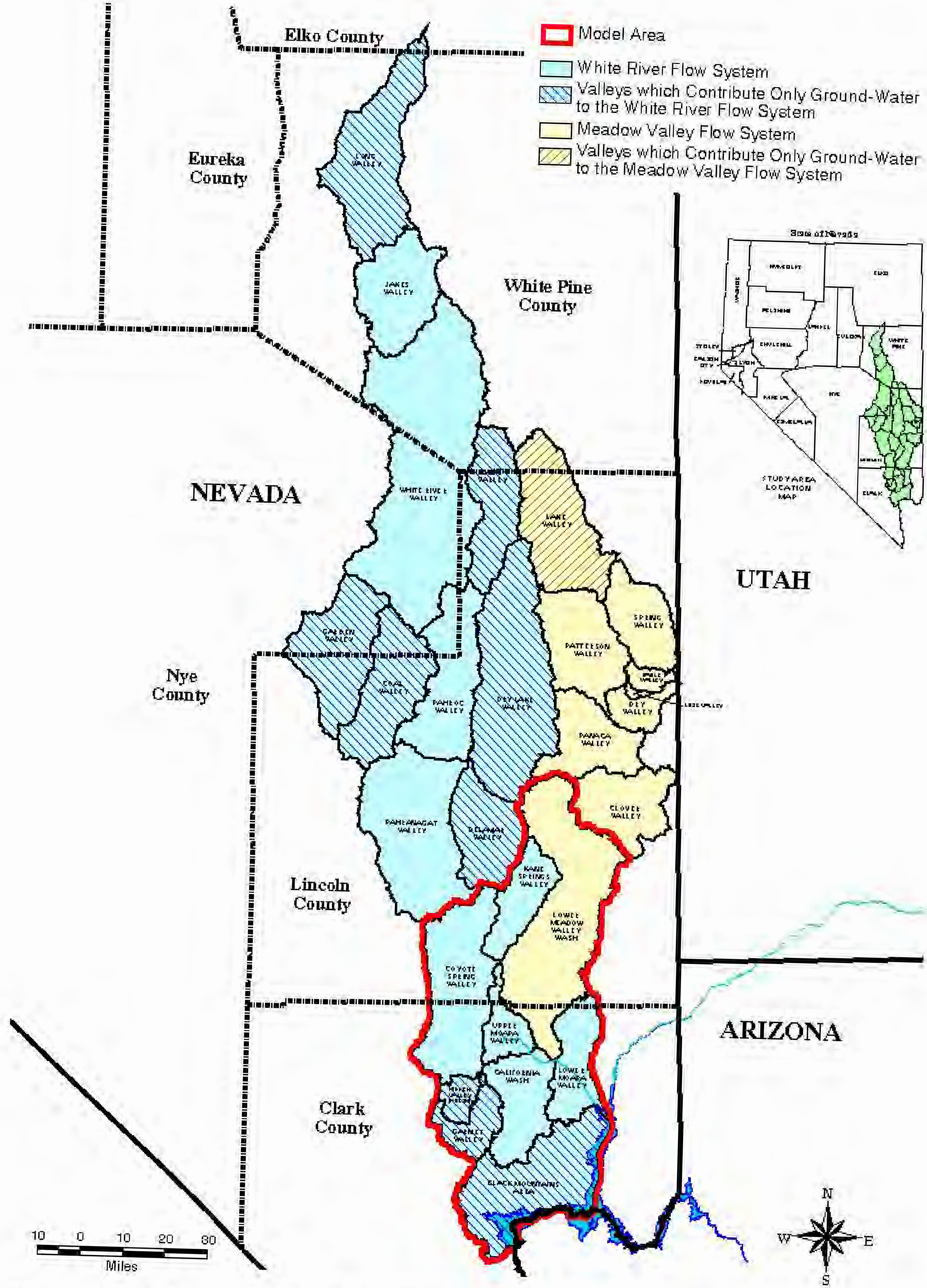

Figure 2-1. Location map for White River and Meadow Valley Flow Systems.

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3 GEOLOGY

3.1 GENERAL GEOLOGY

The exposed bedrock in the ranges in the northern part of the modeled area consists generally of fresh volcanic rocks, which continue to south of the Lincoln County-Clark County line. Most of these volcanic rocks are ash-flow tuffs, which form thin, widespread planar sheets of brittle rock. The area also contains two major eruptive centers, the Caliente caldera complex at and just south of Caliente, and further to the south, the Kane Springs Wash caldera complex. The volcanic centers are the source of most of the tuffs in the area. In the southern part of the study area, thick Paleozoic carbonate rocks are exposed and they form the carbonate-rock aquifer of eastern and southern Nevada. The valley-fill overlying these carbonate rocks are made up of poorly to moderately consolidated Quaternary to latest Tertiary clastic basin-fill deposits that are also aquifers. **Plate 1** and **Plate 2** show the regional geology and hydrogeology and the locations of the cross-sections. **Figure 3-1** describes the hydrogeologic units displayed in the cross-sections. Geologic cross-sections sections A-A' through K-K are **Figure 3-2, Figure 3-3**, and **Figure 3-4**, and are referred to throughout this section.

The modeled area is in the Basin and Range physiographic province, which is characterized by the most severe extension (pulling apart) of continental crust in the World (Rowley and Dixon, 2000, in press). Ground-water flow in the study area may be controlled in part by faults of two major Tertiary extensional episodes. They are equally important in terms of magnitude of structural deformation, but the younger episode is more important in terms of producing structures that may facilitate ground-water flow. The older of these episodes, the middle Cenozoic pre-basin-range episode, has formed many of the faults in the study area. However, these faults may be less conducive to ground-water flow because they are older and thus their accompanying fractures tend to have rehealed, since stress was transtensional rather than pure extensional. The faults that led to the older fracturing generally strike (that is, are oriented) northeast and northwest. Offset along these faults is known as oblique slip, that is, it combines normal-slip and strike-slip movement. The age of this episode is from about 25 to 14 million years, in the Miocene. Fault deformation was accompanied by volcanism that formed most of the tuffaceous volcanic rocks in the area, including their two eruptive centers. The faults in the Caliente area are the best examples of this fault type because this area, within the Caliente caldera complex, has been less affected by the younger of the two episodes of deformation.

The younger of the two episodes of deformation is the late Cenozoic basin-range episode. This episode blocked out the present topography into north-striking ranges and intervening basins. These basins and ranges were created by north-striking normal faults, which formed when the crust was pulled apart (extended) in an east-west direction. In parts of the study area, however, range front faults trend northeast, as along the northwestern side of the Meadow Valley Mountains and southern Delamar Range. The fault along the northwestern side of the southern Delamar Mountains continues southwest of the study area as the Pahranagat shear zone, which was mapped by Ekren and others (1977). The Pahranagat shear zone is a left-lateral strike-slip transfer fault zone, which connects at both ends with northeast-striking normal faults. These northeast-striking faults, then, "transfer" the strain of east-west pulling apart along a different

HYDROGEOLOGIC UNITS DISPLAYED IN CROSS-SECTIONS

Qs | **QTs** | **Ts**

QTs – Quaternary and Tertiary sediments. Composite unit in the ground-water model locally divided on cross-sections into Qs and Ts. The Qs unit is chiefly unconsolidated alluvium and colluvium of Quaternary age deposited in basins. Thickness ranges from 0 to 2,500 feet. Unit is highly permeable. The Ts unit is chiefly the Muddy Creek Formation that is predominately siltstones, sandstone, and conglomerates. The Muddy Creek Formation is of Tertiary age and variable in thickness (up to 3,000 feet). Unit is very permeable where sandy and coarse grained, poorly permeable where clays are present. In the southern part of the flow system, unit includes Lovell Wash-Bitter Ridge basin rocks, Thumb Formation, and rocks of the Rainbow Gardens.

Tv

Tv –Tertiary volcanic rocks. Includes non to densely welded ash-flow tuffs, rhyolites, basalt flows, volcanic breccias, andesites, quartz latites, and tuffaceous sediments. Volcanic rocks are much thicker in the northern part of area but present to the south near the southern border of flow system. Volcanic rocks are Tertiary in age and range in thickness from 0 to greater than 10,000 feet. Unit is moderately permeable, especially where fractured.

Ti

Ti – Tertiary intrusive volcanic and granitic rocks. Primarily associated with the Caliente Caldera complex, Kane Spring Caldera, and the Cleopatra/Black Mountain intrusive as ring fractures, stocks, dikes, and resurgent domes. Unit has very poor permeablilty.

KPs

KPs -- Cretaceous through Permian clastic (siliciclastic) rocks. Permian and Mesozoic rocks of the Colorado Plateau. Includes unnamed Permian red beds possibly equivalent to the Supai Formation. Also includes: Kaibab and Toroweap Formations (cherty limestones with abundant gypsum, sandstone, and shale, these two formations are lithologically similar but separated by an unconformity), (Kayenta Formation (silty shale and sandstone), Moenave Formation (sandstone, conglomerate, and mudstone), Chinle Formation (mudstone, shale, and conglomerate), and Moenkopi Formation (mudstone, sandstone, siltstone) with several members that are chiefly siltstones, shales, silty limestones, dolomites, sandstones, and conglomerates. Unit is thin to the north (less than 1,000 feet) to over 10,000 feet in the south central part of the area. Overall the unit has low permeability, however where limestones predominate, the unit is moderately permeable.

POc

POc – Permian through Ordovician carbonate rocks. Upper Paleozoic carbonate section (a.k.a. "upper carbonate aquifer"). Includes the Bird Spring Formation (limestone and minor dolomites), Monte Cristo Group that includes Yellowpine Limestone, Bullion Dolomite, Ancor Limestone, and the Dawn Limestone (limestone, minor dolomite, interbedded cherts in lower part of section), Guilmette Formation with upper and lower members of predominately limestones and dolomites, Simonson Dolomite and Laketown Dolomite of Silurian age, through the Ely Springs Dolomite to the Eureka Quartzite. With the exception of shales in the Mississippian and the Eureka Quartizite, the unit is very permeable. Accumulative thickness of approximately 15,000 feet.

Cc

Cc -- Cambrian carbonate rocks. Lower Paleozoic carbonate section (a.k.a. "lower carbonate aquifer"). Composed of all carbonate rocks below Eureka Quartzite and therefore includes units that are, in part, lower Ordovician, and upper pre-Cambrian. Includes Antelope Valley Limestone, Goodwin Limestone, and the carbonate part of the Nopah Formation. Unit is approximately 3,500 feet thick and generally very permeable and was therefore combined with overlying unit (POc) in the associated ground-water model of this study.

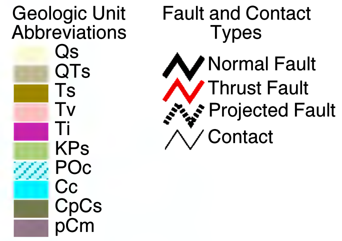
CpCs

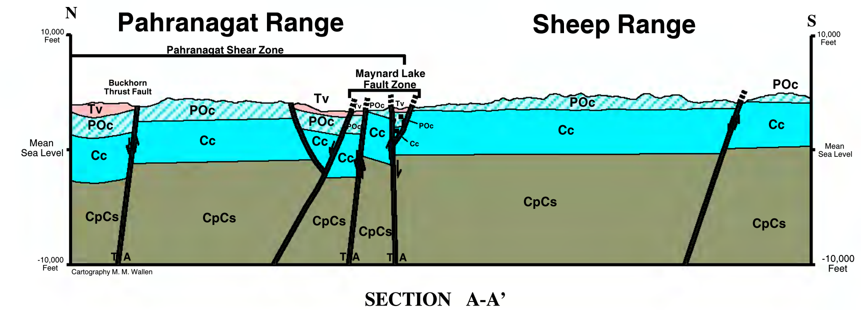
CpCs -- Cambrian and pre-Cambrian siliciclastic rocks. Lower clastic aquitard. Includes Cambrian Prospect Mountain Quartzite, Zabriskie Quartzite and Wood Canyon Formation which is composed of shales, quartzites, quartzose sandstones, and metasedimentary rocks. Unit is greater than 3,500 feet thick of poorly permeable to impermeable rock.

pCm

pCm – pre-Cambrian igneous and metamorphic rocks. Griess, schists, quartzites, granites, and metasedimentary rocks. Unit forms the core of Mormon Mountains, Virgin Mountains, and Gold Butte. Unit is very impermeable. Combined with the overlying unit (CpCs) and represented as a "no-flow" boundary at the base of the associated ground-water model in this study.

Figure 3-1. Hydrogeologic unit descriptions.





Hydrogeologic descriptions are on Figure 3-1.
Hydrogeologic units conform to Plate 2.

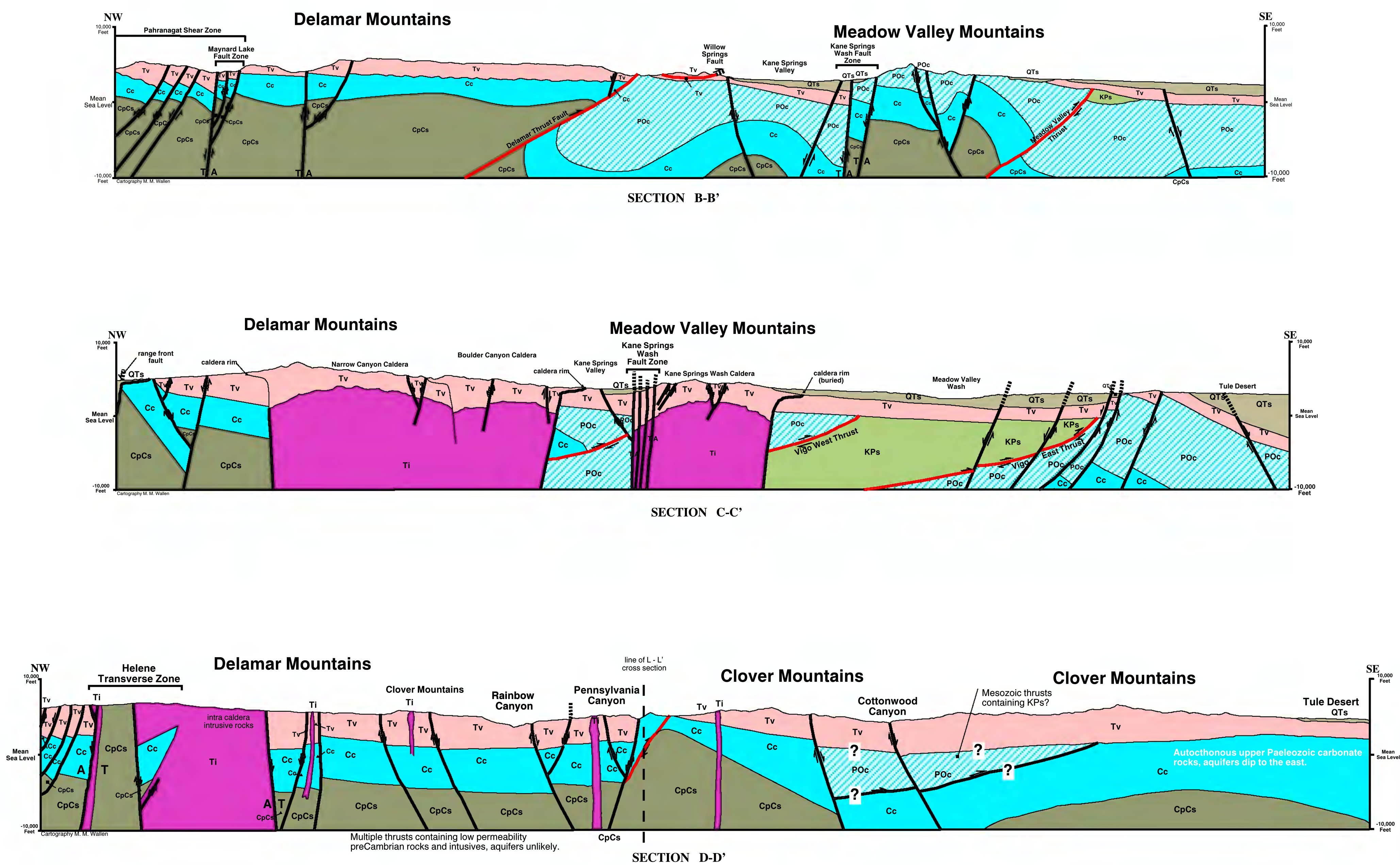


Figure 3-2. Hydrogeologic cross sections A-A', B-B', C-C', and D-D'.

Scale = 1:200,000

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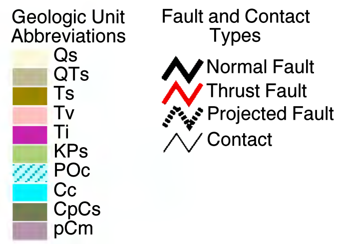
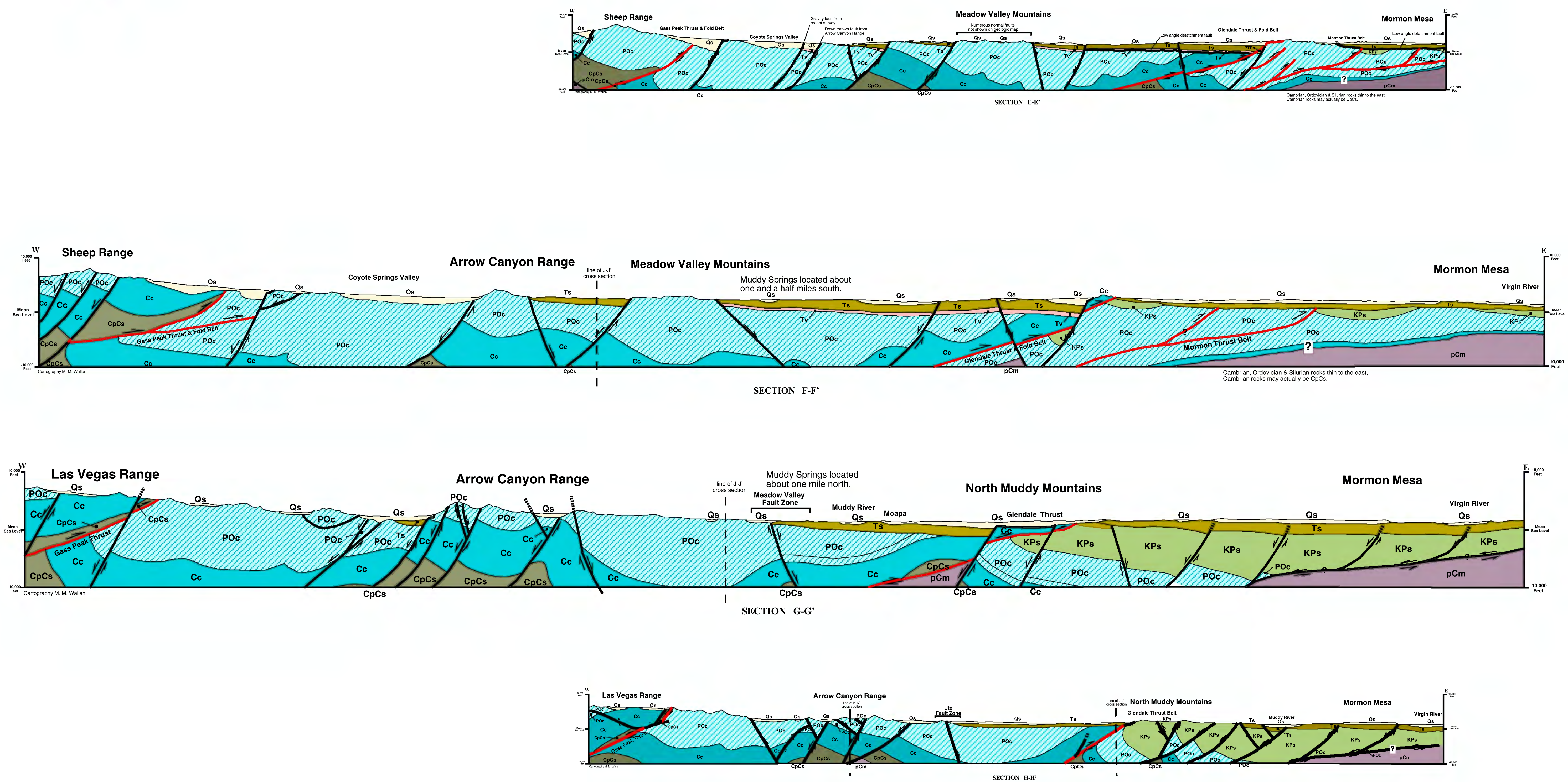


Hydrogeologic descriptions are on Figure 3-1.
Hydrogeologic units conform to Plate 2.



Scale = 1:200,000

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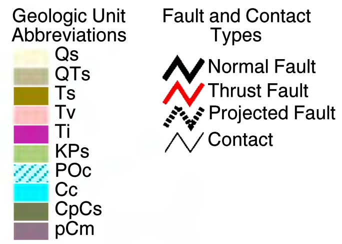
Figure 3-3. Hydrogeologic cross sections E-E', F-F', G-G' and H-H'.



Hydrogeologic descriptions are on Figure 3-1.
Hydrogeologic units conform to Plate 2.

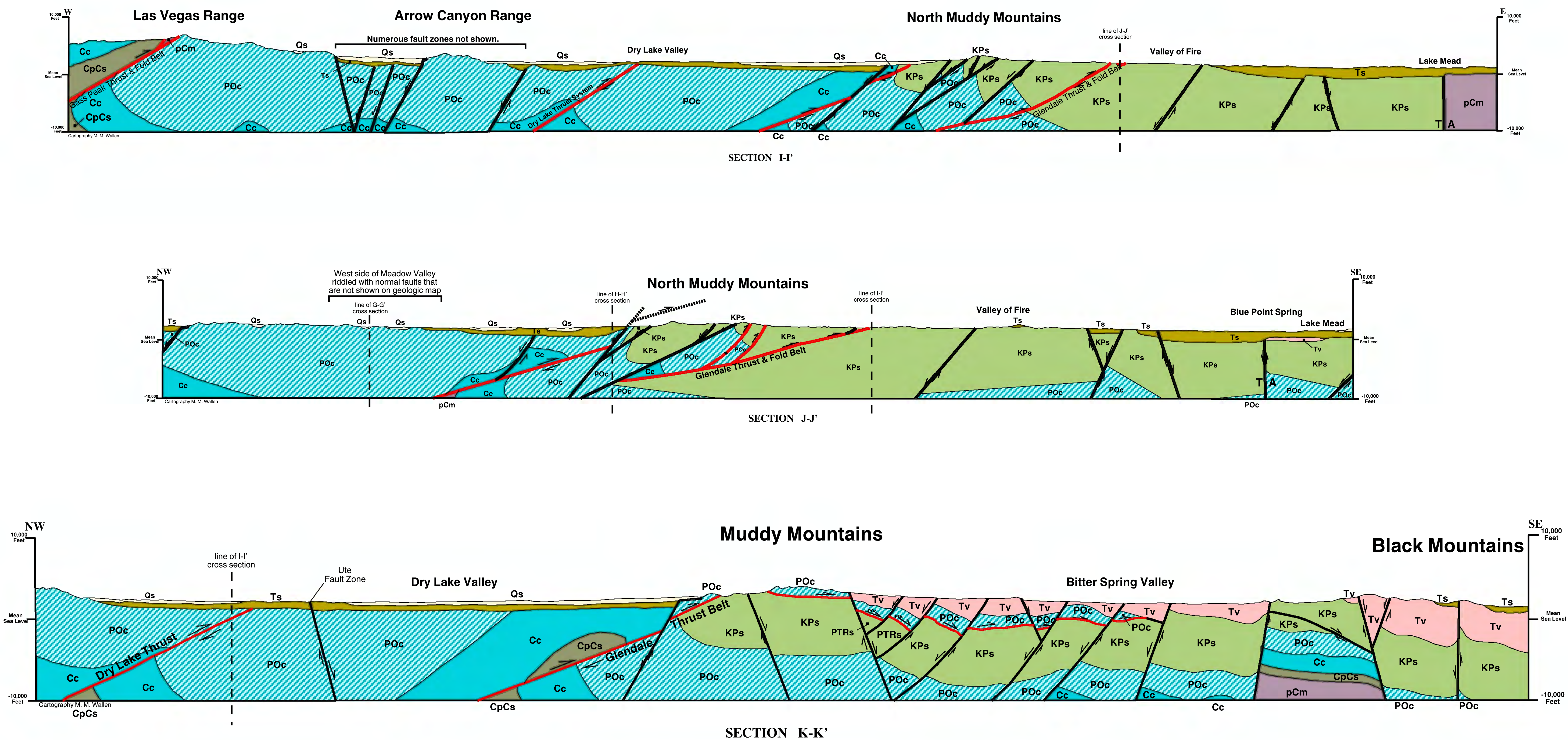


Figure 3-4. Hydrogeologic cross sections I-I', J-J, and K-K'.

Scale = 1:200,000

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(northeast) fracture. More than likely, this younger northeast-striking fracture followed older northeast-striking oblique faults of the middle Cenozoic episode. The normal and left-lateral faults of the basin-range episode in most places obscure the faults and fractures of the middle Cenozoic episode. The basin-range episode formed some time after about 12 million years ago and continues today, as evidenced by young north-striking faults that cut Quaternary basin-fill sediments in many parts of the study area. In places, basin-range faults were synchronous with sparse rhyolite tuffs and basalt lava flows in the study area. Because these basin-range faults, and the parallel fractures (joints) formed by them, are recent, they can remain open as conduits for ground water.

One other structural type, which is synchronous with the faulting and volcanism of both the middle and late Cenozoic episodes, consists of zones of major east-striking faults, fractures, dikes, folds, and eruptive centers known as transverse zones. Two of these zones cut through north of the model area and probably impact ground-water flow to unknown extent. These are the Timpahute and the Helene transverse zones, which respectively bound the northern side and southern side of the Caliente caldera complex (Ekren and others, 1976, 1977; Rowley, 1998; Rowley and others, 1998). In other words, the Timpahute zone passes through the north of Caliente, whereas the Helene passes through the ghost mining towns of Delamar and Helene.

3.2 STRUCTURAL SETTING

3.2.1 <u>Western Clover Mountains and Northern Delamar Range</u>

Rainbow Canyon separates the western Clover Mountains on the east from the western Delamar Range on the west (geologic cross section B-B’, C-C’, and D-D’).

The southern Panaca basin, and Caliente area have been geologically mapped, first at 1:250,000 scale (Ekren and others, 1977) and later at 1:24,000 scale (Rowley and Shroba, 1991; Rowley and others, 1992, 1994). Between Panaca Basin and the area of the railroad siding of Boyd, in central Rainbow Canyon, Meadow Valley Wash cuts through the Caliente caldera complex, one of the largest caldera complexes in the conterminous U.S. The caldera extends about 50 miles east-west and about 21 miles north-south and it underlies an area from Delamar Valley on the west, through the highest parts of the northern Delamar Range (7800 ft) and Clover Mountains (7500 ft), to the western Bull Valley Mountains of Utah on the east. The age of the Caldera Complex ranges from at least 23 to 13 million years (Nealey and others, 1995; Rowley and others, 1995; Unruh and others, 1995; Snee and Rowley, 2000; Rowley and others, in press). It consists of intracaldera rhyolite ash-flow tuff and local rhyolite volcanic domes that are several kilometers thick. The northern and southern sides of this east-elongated caldera complex are controlled by east-striking transverse zones: the Timpahute on the north and the Helene on the south (Ekren and others, 1976, 1977; Rowley and others, 1995, in press; Scott and others, 1996).

The faults bounding and within the Panaca basin are abundant and consist entirely of basin-range normal faults that strike northerly (Rowley and Shroba, 1991; Rowley and others, 1994). Many of these faults appear to pass across the east-striking faults of the Timpahute transverse zone. Within the caldera complex, northwest-striking oblique-slip faults of the middle Cenozoic tectonic episode are abundant and long (Ekren and others, 1977; Rowley and Shroba, 1991; Rowley and others, 1992, 1994; P.D. Rowley, unpub. mapping, 1995). Younger less common, north-striking basin-range faults, also continue southward. Although the Helene transverse zone may form a local barrier to southward flow of ground water through the caldera complex, the abundant north- to northwest-striking faults cutting through this transverse zone probably act as conduits for ground-water flow through the barrier.

South of the caldera complex and the stratovolcanoes and intrusions that mark the southern side of the complex (Helene transverse zone), the volcanic rocks consist of much thinner outflow ash-flow tuffs and intermediate-composition lava flows. These volcanic rocks unconformably overlie apparently east-dipping, thick Proterozoic to lower Cambrian quartzite (Sterling Quartzite, Wood Canyon Formation, Zabriskie Quartzite) and thick lower Cambrian carbonates (Highland Peak Formation). Although heavily faulted and fractured, the quartzite is likely an aquitard, whereas the Paleozoic carbonate rocks are aquifers. Here, at the latitude of the southern part of Rainbow Canyon (the southern end is just south of Elgin), the older northwest-striking oblique slip faults and presumably younger (basin-range) north-striking faults continue to dominate the structural pattern (Ekren and others, 1977). The same pattern is seen east of Rainbow Canyon, in the Clover Mountains, including the small Pennsylvania gold district. And at Delamar, a major gold mining district, controlled by east-striking faults, dikes, and eruptive centers of the Helene transverse zone, northwest-striking oblique-slip faults and north-striking normal faults likewise are common (Rowley, unpub. mapping, 1995). But increasingly, farther southward, north-northwest-striking faults pass into north-striking faults; strike-slip movement decreases southward and normal faults become dominant. This is especially apparent along the western margin of the Delamar Range, which trends northward and is formed by the Delamar Valley basin-range fault zone (Scott and others, 1995a) that uplifts the range with respect to Delamar Valley at and north of the latitude of Elgin. The Delamar Valley fault zone has significant Quaternary normal displacement on it.

3.2.2 Southern Delamar Range

South of the latitude of Elgin, the southern Delamar Range trends northeast and is cut by many north- and northeast-striking faults (geologic cross section C-C'). The western range front fault, however, trends northeast and is defined by one strand (Maynard Lake fault zone) of the northeast-striking Pahranagat shear zone (Ekren and others, 1977). To the northeast, this strand passes into the north-striking Delamar Valley fault zone. Elsewhere, all southwest and northeast ends of strands of the shear zone pass into major north-striking normal faults of the basin-range episode (Ekren and others, 1977; Scott and others, 1990a, b, 1993, 1995a; Swadley and Scott, 1990). The shear zone thus is a transfer fault zone that formed, like the basin-range faults, in an environment of east-west extension and transferred displacement to the northeast (Ekren and others, 1976, 1977; Scott and others, 1995a, 1996; Rowley, 1998).

Farther to the south in the Delamar Range, the 17-12-Ma Kane Springs Wash caldera complex (geologic cross section C-C') (Harding and others, 1995; Scott and others, 1995a, b, 1996) underlies an area about 18 miles by 15 miles in the southern Delamar Range, and extending eastward into part of the Meadow Valley Mountains. As with the Caliente caldera complex, intracaldera tuffs of at least several kilometers thickness were deposited in the calderas, and intracaldera intrusions have been emplaced into these tuffs, although they are exposed only locally. The caldera complex is likely a barrier to southward flow of ground water in the Delamar Range, but in Kane Springs Valley it is cut and offset left-laterally about 3 miles by the north-northeast-striking oblique-slip (left lateral and down-to-the-west normal) Kane Springs Valley fault zone. This major fault zone underlies the north-northeast-trending Kane Springs Valley and uplifts the Meadow Valley Mountains on the east with respect to the Valley. The Kane Springs Wash caldera complex and adjacent parts of the southern Delamar Range have been mapped in detail by Scott and others (1990a, b, c, 1991, 1993), Swadley and Scott (1990), and Swadley and others (1994). South of the caldera complex, north-striking faults characterize the southern end of the Delamar Range and probably provide ground-water pathways from southern Delamar Valley into Kane Springs Valley.

3.2.3 Kane Springs Valley and Meadow Valley Mountains

The northern Meadow Valley Mountains are separated from the southern Clover Mountains by a deep canyon cut by Meadow Valley Wash (geologic cross section C-C'). From there, the mostly low altitude Meadow Valley Mountains extend southwest to just past the Lincoln County line into Clark County. The northern part of the range consists, except for the faulted eastern lobe of the Kane Springs Wash caldera complex (Harding and others, 1995), of mostly outflow ash-flow tuffs that are as much as 2 km thick (Pampeyan, 1993). These volcanic rocks, as well as underlying Tertiary sedimentary rocks less than 300 ft thick, thin southward and pinches out north of the southern end of the range. Pre-Cenozoic sedimentary rocks, which unconformably underlie the Cenozoic rocks, are exposed in the central to southern part of the range (Pampeyan, 1993; Page and Pampeyan, 1996). Pampeyan (1993) showed these pre-Cenozoic rocks occupying several north-striking, east-verging Sevier thrust sheets. In one of these thrust sheets, exposed in the central part of the range, the youngest of the pre-Cenozoic rocks are the Triassic Moenkopi and Chinle Formations. These formations include a thick, Lower Permian redbed sequence and, where not removed by Triassic erosion, thin eroded parts of the Lower Permian Kaibab Limestone and Toroweap Formation. These fine-grained clastic rocks are about one mile thick and likely represent an aquitard. In the other thrust sheets, the rocks are about 2 miles thick ad dominated by carbonates of Ordovician to late Permian age. They are underlain by Cambrian rocks that are exposed to a thickness of about a half mile thick and also are dominated by carbonates. Both of these carbonate packages are important aquifers in Nevada and are, in turn, underlain by the thick Cambrian to Proterozoic quartzite (aquitard) section.

Northeast-trending Kane Springs Valley bounds the Meadow Valley Mountains on the west. The basin-fill sediments in the valley consist mostly of Quaternary deposits that overlie deposits at least as old as latest Miocene or early Pliocene (Scott and others, 1991; Pampeyan, 1993; Swadley and others, 1994). The Meadow Valley Mountains were uplifted relative to Kane Springs Valley by the major oblique Kane Springs Valley fault zone (Scott and others, 1991, 1995a; Pampeyan, 1993; Swadley and others, 1994). Despite its oblique motion, most if not all of the motion along the fault zone is considered part of the basin-range extensional episode. Some of that offset is Quaternary, and recent mapping by G.L. Dixon (unpublished) indicates that, like the major oblique-slip Pahranagat shear zone, at least the southern end of the Kane

Spring Valley fault zone passes southward into a north-striking basin-range fault. The western edge of the southern end of the Meadow Valley Mountains, changes trend southward from northeast to north, and the basin-range fault that causes this north-trending range front continues due south to define the western edge of the Arrow Canyon Range as well (Page and Pampeyan, 1996). The northeastern end of the Kane Springs Valley fault zone, which passes northeastward across Meadow Valley Wash into the southern Clover Mountains, is less apparent from the topography and has not yet been mapped completely. But mapping by Scott and Rowley (unpub. mapping, 1995) suggests that it also changes strike direction, from northeast to north and northwest. Thus the Kane Springs Valley fault zone is another transfer fault, like the Pahranagat shear zone.

Because the structure of the generally narrow Meadow Valley Mountains is dominated by the Kane Springs Valley fault zone, faults in the range likewise strike northeast (Scott and others, 1991, 1995a; Pampeyan, 1993; Swadley and others, 1994). Farther south, as the range widens and, at its southern end where it bends south, most faults strike north and normal slips dominate (Pampeyan, 1993; Page and Pampeyan, 1996). Large fractures filled with veins of coarsely crystalline calcite represent orifices of ancient spring discharge are well exposed in the Wildcat Wash area of the southern Meadow Valley Mountains, north of Nevada Highway 168 (Page and Pampeyan, 1996).

3.2.4 Lower Meadow Valley Wash

The basin referred to as the Glendale basin by Schmidt (1994), that is occupied by lower Meadow Valley Wash, is broad and contains a thick sequence of basin-fill clastic sediments (geologic cross sections E-E’ and F-F’). A small part of the basin has been geologically mapped in reconnaissance or detail. The youngest part of the basin-fill sequence is made up of unconsolidated Quaternary sediments. These are underlain by clastic sedimentary deposits that Pampeyan (1993) lumped together as the Pliocene (?) and Miocene Muddy Creek Formation. The northern most area where detailed investigation of the basin – fill sediments has been undertaken in the Farrier quadrangle (Schmidt, 1994), along the Lincoln-Clark County line. The oldest deposits of the basin-fill sequence here belong to the Horse Spring Formation, correlated with deposits of the same name studied in the Lake Mead area (Bohannon, 1984). In the Farrier area, it consists largely of conglomerate considered by Schmidt (1994) to range from 20 to 12 Ma and to represent syn-extensional deposition during opening and deepening of the basin during the basin-range episode. The Horse Spring is overlain by the Muddy Creek Formation, considered by Schmidt to range from 12 to 5 Ma. in age Schmidt (1994) proposed that the Muddy Creek here represents deposition of finer grained clastic and lacustrine sediments that largely postdate the main extensional development of the basin. In the Riverside area (lower Virgin Basin), about 12 miles to the east and outside the study area, Williams and others (1997) mapped the Muddy Creek likewise as Miocene, however, continuing eastward to the Mesquite area, it is coarsely clastic (well exposed along U.S. Highway I-15) and thus clearly is not post-extensional. Some of the faults mapped in basin-fill deposits in the Farrier quadrangle strike north-northeast and north-northwest; these cut deposits as old as the Horse Spring, suggesting that they represent deformation of the pre-basin-range tectonic episode. More abundant basin-range faults that strike north cut deposits as young as Quaternary. Schmidt (1994) concluded that the Muddy

Creek Formation is the youngest unit representing closed-basin deposition and that, at least in the Glendale basin (Lower Meadow Valley Wash), integration began at about the end of the Miocene or beginning of the Pliocene. Pliocene sediments that Schmidt mapped are primarily alternating cut and fill stream sediments that contain abundant carbonate spring deposits, evidence of a wetter climate in the Pliocene.

In the Moapa and Glendale area to the south, at the southern end of the basin (geologic cross section E-E'), the stratigraphy of the basin-fill deposits is generally the same as that in the Farrier quadrangle, although an underlying limestone member of the Horse Spring Formation is also exposed (Schmidt and others, 1996). North-striking basin-range faults, some associated with Pliocene carbonate spring deposits, are abundant throughout the area.

3.2.5 Western Mormon Mountains

The Mormon Mountains are a high (about 7500 feet altitude) domal mountain range whose crest is on the eastern side of the Glendale basin and the study area (geologic cross section F-F'). To the north of the Mormon Mountains, a low, south-pointing prong of the Clover Mountains, and to the south of the Mormon Mountains, another south-trending ridge at the same longitude also mark the eastern edge of the Glendale basin (Lower Meadow Valley Wash) and the eastern edge of the model area. The Mormon Mountains are underlain by about 2,000 m of Cambrian through Pennsylvanian carbonate rocks. Cambrian and younger rocks were thrust eastward over Mississippian and Pennsylvanian rocks in the area of the range during Sevier deformation (Wernicke and others, 1985). The present form of the range has been suggested by Wernicke and others (1985) and Axen and others (1990) to result from a gently west-dipping Tertiary detachment fault that partly followed the Sevier thrusts and passed westward in the subsurface beneath the Meadow Valley Mountains. In places on the western side of the range, the low-angle normal fault rests on Proterozoic crystalline metamorphic and igneous rocks, and elsewhere at shallow depth below the Cambrian rocks, these basement rocks are exposed. During and after the suggested detachment, the deroofed footwall block to the east apparently arched upward, as a core complex, to form the present dome shape of the Mormon Mountains (Axen and others, 1990). Flat-lying Muddy Creek Formation in the Glendale basin unconformably overlies the low-angle normal fault.

Anderson and Barnhard (1993a, b) and Anderson and Bohannon (1993) criticized the detachment model for the Mormon Mountains and adjacent areas. They concluded that extension in the area was accompanied by major vertical structural uplift of the Mormon Mountains and adjacent ranges that produced structural thinning (attenuation) of the rocks on the crest of the uplifts. As mapped by Wernicke and others (1985), most normal faults at the surface in the Mormon Mountains are low angle but, based on tilts of strata in the hanging walls of these faults, Anderson and Barnhard (1993a, b) interpreted that the faults become steeper with depth, as in basement-cored uplifts in Wyoming and other parts of the Rocky Mountains. Such an interpretation seems more reasonable. But, regardless of the geologic model for the evolution of the Mormon Mountains, the Proterozoic basement rocks beneath the Mormon Mountains form an aquitard that blocks ground-water flow through the range. We interpret this large regional domal uplift not only to impede ground-water flow through the range, but also acts as a barrier to ground-water moving from the Tule Desert into the lower Meadow Valley Wash. Glancy and Van Denburgh (1969) indicated Tule Desert is part of the Lower Virgin River Valley, as did subsequent investigators (Brothers et al. (1992); and Dixon and Katzer (in review, 2001)).

Wernicke and others (1985) noted that, in the Mormon Mountains area, "No evidence was found for a younger episode of widely spaced high-angle normal faults ("Basin and Range" faulting)." Yet the youthful age of the Mormon Mountains suggests to us that this is an example of the basin-range episode of faulting, which here was expressed as low-angle normal faults at the surface, rather than as high-angle normal faults. The south-trending ridge of the Clover Mountains just north of the Mormon Mountains is underlain by east-dipping Tertiary volcanic rocks (Ekren and others, 1977) bounded by a high-angle basin-range fault on its western side. Similarly, the south-trending ridge south of the Mormon Mountains is bounded by a high-angle basin-range fault along its western side. This latter fault, in fact, abruptly changes its northern strike at the northern end of the ridge, just south of the Mormon Mountains, and strikes east-northeast, where its motion is oblique left lateral (G.L. Dixon, unpub. data, 2000). Then, east of the study area, the fault abruptly turns northward and bounds the western side (Carp road fault and Sam's camp fault of Axen and others, 1990) of the East Mormon Mountains, a low north-trending range east of the Mormon Mountains that was mapped by Axen and others (1990), Anderson and Barnhard (1993a, b), and Anderson and Bohannon (1993). This left-lateral part of the fault, like the Pahranagat shear zone and the Kane Springs Valley fault zone, represents another example of a transfer fault that passes into north-striking normal faults at both of its ends (G.L. Dixon, unpub. mapping, 2000).

3.2.6 Sheep Range, Las Vegas Range, and Elbow Range

The Sheep Range is an abrupt (almost 10,000 ft high in the wider southern part of the range; 7500 ft high in the narrow northern part), north-trending range that bounds the southwestern side of the study area. Its rocks are mainly Cambrian through Devonian carbonate sedimentary rocks that dip generally eastward (Guth, 1980) (geologic cross sections G-G', H-H', and I-I'). The main basin-range fault that creates the range is on its western side, but the eastern side also is uplifted along a north-striking normal fault; thus the range is a large horst block. Within the range, minor north-striking faults dominate, but some cross-faults that strike east to east-northeast also have been mapped. The northern end of the main Sheep Range is terminated against the southern strand (Maynard Lake fault zone) of the east-northeast-striking left-lateral oblique-slip Pahranagat shear zone (Jayko, 1990) (geologic cross section A-A'). We interpret that the western part of this strand of the shear zone joins the main normal fault and defines the western side of the main Sheep Range. Under this interpretation, the Maynard Lake zone is a transfer fault that transfers east-west pulling apart into left lateral shear. In other words, where faults strike north, all east-west extension is taken up by normal movement down the dip of the fault plane; where faults strike northeast, east-west pulling apart is taken up partly by left slip and partly by normal slip, in other words oblique movement.

A small north-trending range, whose northern end also terminates against the Maynard Lake fault zone, lies just to the east of the northern end of the main Sheep Range. This lessor range is also called the Sheep Range, but it forms a separate basin-range tilt block that consists largely of east-dipping volcanic rocks (Jayko, 1990). These rocks rest unconformably on Pennsylvanian and Permian carbonate rocks making up what Jayko (1990) calls the Coyote Spring syncline. Numerous north-striking normal faults that uplifted this tilt block occur on its western side. Minor north-striking faults occur within the smaller range. All these faults, which terminate against the Maynard Lake fault zone, are interpreted to pass into the Maynard Lake transfer zone and likewise transfer the slip northward from normal slip to oblique slip. In addition to these north-striking normal faults, Jayko (1990) projects the buried north-striking trace of the Gass Peak thrust fault (Sevier age) beneath the normal faults. The valley between the northern end of the main Sheep Range and the tilt block to the east is the northern part of Coyote Spring Valley.

East of the eastern tilt block of the northern Sheep Range is a valley occupied by U.S. Highway 93 and by Pahranagat Wash, which drains southward from Maynard Lake (dry) and other parts of Pahranagat Valley into northern Coyote Spring Valley. Basalt lava flows that issued from vents along the Maynard Lake fault zone are exposed along and beneath the wash as it drains southward. This valley, referred to as Evergreen Flat, continues southward and joins Coyote Spring Valley about 4 miles to the south. This gap is the boundary between the bedrock ridges of the northeastern Sheep Range to the west and the southwestern Delamar Range to the east. On the eastern side of Evergreen Flat, however, a north-striking basin-range fault zone several miles east of the gap uplifts the southwestern end of the Delamar Range. Here, Cambrian through Devonian carbonates overlain by volcanic rocks are uplifted and tilted to the east.

The western side of the model area is the crest of the Sheep Range and at the southern end of the Sheep Range, the boundary runs eastward along a series of hills making up the broad southeastern part of the range. From there the boundary swings south, then east across the southern Las Vegas Range, a low north-trending basin-range east of the southern Sheep Range. The boundary of the model area continues east to just south of Apex in Garnet Valley. The Las Vegas Range northwest of Apex is defined by the Gass Peak thrust, which transports rocks as old as the Cambrian Wood Canyon Formation over Mississippian, Pennsylvanian, and Permian carbonates of the thick Bird Spring Formation (Maldonado and Schmidt, 1991) (geologic cross section F-F’). Most of the Las Vegas Range is made up of folded Bird Spring limestones and minor dolomites, with the Gass Peak thrust striking north along its western side and continuing beneath Quaternary deposits east of the main part of the Sheep Range (Maldonado and Schmidt, 1991; Page, 1998). The small Elbow Range, which bounds the Las Vegas Range on the northeast, is made up of thrusted and folded Bird Spring Formation (Page and Pampeyan, 1996). The folds and faults in the range strike north and may provide conduits for ground-water flow.

3.2.7 Coyote Spring Valley and the Arrow Canyon Range

The Arrow Canyon Range is a sharp, narrow north-trending basin range consisting of a syncline of Cambrian to Mississippian carbonates. It is uplifted along its western side by normal faults of the Arrow Canyon Range fault zone (Page and Pampeyan, 1996; Schmidt and Dixon, 1995; Page, 1998) (geologic cross section I-I’). The trace of the north-striking Dry Lake thrust, which carries Cambrian rocks over Silurian through Permian carbonates, is exposed and projected north just east of the Range (Schmidt and Dixon, 1995). East of the Dry Lake thrust, the Silurian through Permian rocks form a series of low unnamed, north-trending hills. These hills are controlled by north-striking normal faults, along some of which are Pleistocene carbonate spring-mound deposits that indicate that the faults formerly carried significant ground water (Schmidt and Dixon, 1995).

3.2.8 Northern Muddy Mountains, and Muddy Mountains, and Dry Lake Range

The southern end of the study area is defined by north-striking ridges of the North Muddy Mountains and, to the south, the northern and northwestern parts of the larger Muddy Mountains (Bohannon, 1983) (geologic cross sections H-H', I-I, and K-K'). The North Muddy Mountains separate the Glendale basin on the west from the Mesquite basin to the east. The Muddy Mountains occupy the northern side of Lake Mead. The southernmost part of the study area extends southwest to include the small Dry Lake Range east of Apex. This range is made up mostly of Bird Spring carbonates. A bedrock gap at Apex connects the Dry Lake Range with the southern Arrow Canyon Range/Las Vegas Range. This gap most probably was a pathway for Tertiary and Quaternary basin-fill sediments entering the Las Vegas Valley, just southwest of the study area. The gap also is along the trace of the Dry Lake Thrust (Page and Dixon, 1996) Basin-fill sediments to the northeast along the I-15 corridor (Glendale basin) thus are not connected with those in the Las Vegas Valley and, from limited mapping in the area, are not correlated with those in the Las Vegas Valley. In the Muddy Mountains and in the North Muddy Mountains, faults strike north-northeast (Bohannon, 1983), and the gap between the two ranges, now occupied by Tertiary and Quaternary basin-fill sediments, likely also is underlain by fractures of the same strike. The northern Muddy Mountains and North Muddy Mountains contain significant Jurassic sedimentary rocks (Bohannon, 1983), some of which (Aztec Formation) make up a prominent aquifer in southwestern Utah (where it is called the Navajo Sandstone), but here the sandstone has very low permeabilities and forms an aquitard, as do other Jurassic rocks in the area. The northwestern side of the North Muddy Mountains contains carbonates. Nonetheless, the Mesozoic sediments create a barrier to most southward flow that might pass through them into Lake Mead. An additional ground-water flow barrier is provided by east-striking faults of the northern Muddy Mountains, notably the northeast–verging Glendale thrust (Bohannon, 1983). Bohannon interpreted this structure as the northern continuation of the Keystone Thrust system which has been displaced approximately 40 miles right laterally by the Las Vegas Shear Zone. As with the Keystone/Glendale Thrust system, the Dry Lake Thrust (thrust fault system just west of the Keystone/Glendale thrust) has been displaced 40 miles by the same shear zone and its southern equivalent is the Deer Creek Thrust in the Spring Mountains.

The southeastern part of the study area, where the Muddy and Virgin Rivers enter the Overton Arm of Lake Mead, is probably an area of ground-water discharge. Basin-fill sediments, dominated at the surface by resistant Quaternary calcretes also underlie Mormon Mesa and its northward extension. This prominent calcrete is underlain by Pliocene to upper Miocene basin-fill deposits that underlie the southwestern end of the Mesquite basin The Black Mountains and Gold Butte areas form the eastern margin of the study area in a series of complex Proterozoic metamorphic rocks which extends from the southwestern Virgin Mountains south to the southern edge of Lake Mead. Numerous fault zones have been mapped in this area including faults that are discharge points of Rogers and Blue Point springs in the Lake Mead National Recreation

Area. These faults most likely are related to a series of faults that strike to the northeast, have oblique dip-slip motion, and are part of the Lake Mead Fault Zone (Anderson and Barnhard, 1993a).

4 GROUND-WATER FLOW SYSTEM

The ground-water flow system for the Colorado River basins **(Figure 1-1)** in the study area covers an extensive area of about 12,084 mi^2 and is roughly a north-south zone marked by major mountain blocks. From north to south the western boundary is: Maverick Springs Range, the White Pine Range, the Grant and Quinn Canyon Ranges, the Pahranagat Range, and the Sheep Range. The eastern boundary is the mountain blocks of: Butte Mountains, Egan Range, Wilson Creek Range, Clover Mountains, and the Mormon Mountains. This is a very large part of the carbonate rock province of eastern Nevada described by numerous investigators, most recently Dettinger et al. (1995), Prudic et al. (1995), Thomas et al. (1996), and Plume (1996). The hydrologic properties have a great deal of similarity throughout this area, however, the hydrologic connectivity is not known exactly. It is for certain though that ground-water flow begins at the higher altitudes in the northern edge of the province and moves to the south gaining in flow volume as recharge from the various mountain blocks enters the ground-water system in the carbonate rocks. Undoubtedly the carbonates discharge some water to the overlying alluvial aquifer systems.

Part of the ground water in the White River Flow System discharges into the Muddy River ground- and surface-water system (Muddy Springs) with the remainder discharging through the carbonate rocks underlying Hidden and Garnet Valleys, and California Wash. A minor amount of this flow in California Wash probably flows to the Black Mountain Area discharging at Roger and Blue Point Springs. The remainder of the ground-water flow discharges into the Muddy River system and from great depth in the carbonate rocks discharges either into the Virgin and Colorado Rivers or further to the south at undefined locations.

The Meadow Valley Flow System, both surface- and ground-water, is also tributary to the Muddy River and Lower Moapa Valley and like the White River system discharges from great depth through the carbonate rocks underlying Lake Mead and the Colorado River.

The individual valleys in the two flow systems are generally connected by surface drainage, such as White River and Meadow Valley Wash, and in some valleys, ground-water flow in the alluvial aquifer systems such as between Dry Lake and Delamar Valley and between several of the Valleys in the Meadow Valley Flow System. However, it is at varying depths in the underlying carbonate rocks that there is a complete hydrologic connection. It is also this part of the flow system that is the most difficult to define. There are water-level maps such as by Rush (1974) and Harrill and Prudic (1998), Thomas et. al. (1986), based on sparse data, that show the general direction of ground-water flow in the carbonate rocks, but the data points are generally in the valley lowlands and virtually nothing is known about the mountain blocks. There may be ground-water mounding in some blocks that act as barriers or partial barriers to flow from one block to another. There are also differences in permeability between the various carbonate rocks that create preferred directions of flow. High permeable zones within the carbonate rocks are probably caused by mineral dissolution in the rock and fractures caused by faults. Volcanic rocks are less permeable than carbonate rocks, but where fractured are able to readily transmit ground water. There are low-permeability rocks within the study area that act as a barrier to ground-water flow such as clastic sedimentary rocks and crystalline basement and granitic rocks.

4.1 GROUND-WATER SOURCE

All ground water, regardless of where it is starts out as surface water, is from precipitation in the form of rain and snow on the mountain blocks, which are the main recharge areas. Water that has evaporated from principally the Pacific Ocean moves inland as atmospheric water, condenses and falls as rain and snow upon the mountain blocks. Undoubtedly summer storms provide significant amounts of moisture, but it is winter storms that are the most important for water resources because the effect of summer storms at higher altitudes is minimal. Storm tracts are eastward and northeastward from the South Pacific Ocean and the Gulf of California, and in the more northern basins the tracks are more to the southeast from the northern Pacific Ocean.

Once water falls on the ground some of it evaporates immediately and returns to the atmosphere (sublimation takes its toll from snow packs), some of it runs off into stream channels where it may infiltrate to the water table as the streams transect alluvial fans. Most of the water infiltrates the shallow soil mantle overlying the bedrock and is used by the plant life and returns to the atmosphere by way of transpiration. That amount of water that is excess to the plant's needs and exceeds the moisture holding content of the soil infiltrates through the soil mantle into the underlying bedrock. Ultimately the water reaches the water table and becomes part of the ground-water system. Over large parts of many of the mountain blocks the soil cover is thin to non-existent and the water infiltrates directly into the bedrock. Ground-water recharge is generally greater and mountain front runoff is less in carbonate rocks compared to volcanic rocks.

4.2 PRECIPITATION

Precipitation in Nevada is strongly controlled by orographic effect because there is a definite increase of precipitation with altitude. Most researchers also assume the natural recharge efficiency (the percent of precipitation that becomes ground water recharge) increases with altitude and this increase is proportional to the precipitation. This results in an interpretation that the surrounding mountain ranges of any valley are the most important areas for analyzing climate and natural recharge.

The orographic effect in eastern Nevada although distinct is relatively minor compared to the Sierra Nevada or other major ranges of the Pacific Coast. Those ranges are transverse to the paths of storms and large rain shadows are located downwind of the ranges. West central Nevada is in the rain shadow of the central Sierra Nevada. Eastern Nevada commonly receives precipitation from Pacific Winter storms moving around the south end of the Sierra then north northeastward across eastern Nevada. The larger ranges in eastern Nevada are usually northeasterly (Grant, Quinn Canyon, Clover) subparallel with storm tracks and the windward (wetter) may be on the eastern rather than western side of these ranges.

Microclimates or local altitude-precipitation relationships are probably quite common but the details of most of them are unknown because of the low density of precipitation gages. The low density of gages in Nevada is partially related to the low density of population and the gages that exist with records of sufficient length are concentrated near population centers, in the valley lowlands. Like most natural systems, precipitation, is time dependent in addition to being a spatial phenomenon, and a distinction is usually made between weather (daily to yearly variations) and climate (10's to 1000's of years). Climate is of primary interest to ground-water hydrology, but both weather and climate are of interest to surface-water hydrologists. Long-term precipitation records become climatic data once sufficient data is collected to minimize the effects of yearly variations. Climatologists usually assume thirty years of record is required to minimize the yearly variation, however, some data is always better than none.

4.2.1 Existing Precipitation Estimates and Maps in the Study Area

Bixby and Hardman (1928, p. 8-9) documented the first estimate of orographic effects (local altitude-precipitation relationships) in Clark County. In the same report, they mentioned, but did not formally reference, two previous reports where the precipitation increase with altitude was estimated. L. H. Taylor in the Truckee River Basin, estimated an increase of 12.8 inches per 1,000 feet of altitude rise in the Sierra Nevada. The other report by W. O. Clark and C. W. Riddell estimated an increase of 4.5 inches per 1,000 feet of altitude rise in Steptoe Valley. Bixby and Hardman (1928) assumed this altitude precipitation relationship applied over most of central and eastern Nevada including Clark County and most of the orographic effect occurs between 6,000 and 9,000 feet of altitude. They also assumed that 8 inches of precipitation occurs approximately at 6,000 feet of altitude and there is minimal orographic effect below 6,000 feet and above 9,000 feet of altitude.

These same estimates and assumptions are well embedded in the literature. Hardman's first state-wide precipitation map was created in 1936 (Hardman, 1936) this map was published in 1949 (Hardman and Mason, 1949, p. 10), and was revised in, July 1965 (Hardman, 1965). The 1965 map was used to create the Nevada Division of Water Resources precipitation map (NDWR, 1971) published in the State Water Plan of 1972 (Bruce Scott, formerly with NDWR, personal communication, 2000). Both of the Hardman (1936, 1965) maps were not widely disseminated and are very difficult to obtain. Notes on both the 1965 map and in Hardman and Mason indicate this map, (Hardman and Mason, 1949, p. 10), is an exact reproduction of the 1936 Hardman map.

Both versions of Hardman's map have contour intervals of 5, 8, 12, 15, and 20. The 8-inch contour is usually close to 6,000 feet in eastern Nevada, at higher altitude in west-central Nevada, probably due the Sierra rainshadow effect, and at lower altitude in eastern and southern Clark County due to monsoonal storms. The NDWR 1971 precipitation map has slightly different intervals (uniform 4-inch intervals between 4 and 20).

Basin reports published by NDWR and USGS used the Hardman (1936, 1965) precipitation maps because no other source was available. Earlier reports reference either the 1936 map or Hardman and Mason, and later reports reference the 1965 map. The similarity between the Hardman maps (1936, 1965) and the Maxey-Eakin (Maxey and Eakin, 1949, p. 40) methodology extends to the choice of contour intervals (8, 12, 15, and 20) but as summarized by Eakin in 1966 (p. 260 - 262), and in several other reports, precipitation was generally estimated from altitude intervals of the 1:250,000 scale maps rather than directly from the Hardman maps. Avon and Durbin (1992, p.12) reported that USGS investigators deviated from the "standard" Maxey-Eakin technique about 37 percent of the time, for various reasons.

Precipitation maps, for Nevada and the rest of the United States, have been created since the early 1990s using a climatic model called the Parameter-elevation Regressions on Independent Slopes Model (PRISM) by Daly and others (1994) of the Oregon Climatic Service. As the name implies PRISM is a model or process and the maps of precipitation and other climatic variables are revised fairly often. These maps have been widely distributed through the Internet since the late 1990s. Their widespread use is related, in part, to availability, cost (free), and the format of the maps. The maps can be downloaded and directly imported into the "ARC" geographic information system (GIS) software of Environmental Systems Research Institute (ESRI), the most commonly used GIS software.

PRISM is specifically designed for use in mountainous terrain but uses the thirty year 1961-1990 climatic mean data. This means the data set in Nevada at high altitude was quite limited, because the USGS high altitude bulk precipitation gages were not installed until the mid 1980's. Long-term precipitation records in Nevada are generally uncommon and it appears never have been collected in some valleys. The May, 1997 version of the PRISM precipitation map was used in conjunction with an evapotranspiration and basin budget study by Nichols (2000, a, b, c) in east-central Nevada.

4.2.2 Differences between This and Other Estimates of Precipitation

Precipitation in this study was estimated using a modified Maxey-Eakin technique pioneered by Donovan and Katzer (2000) in Las Vegas Valley. The total estimate of precipitation for the study area (~ 6,636,000 acre-feet per year) by the modified Maxey-Eakin technique pioneered by Donovan and Katzer (2000) in Las Vegas Valley is significantly larger than the NDWR 1971 map (~ 5,516,000 acre-feet per year) but smaller than the May 1997 version of PRISM (~ 6,985,000 acre-feet per year). The maps vary in detail but the primary difference in interpretation between the older and more recent precipitation distributions is the amount of precipitation between 4,000 and 7,000 feet. This altitude interval contains 67 percent (2/3) of the total area and is composed of 12 percent between 4,000 and 5,000 feet, 30 percent between 5,000 and 6,000 feet and 25 percent between 6,000 and 7,000 feet.

On the NDWR 1971 and the Hardman (1936, 1965) precipitation maps significant parts of Long and Jakes Valleys, above 6,000 feet, are characterized as receiving less than 8 inches of precipitation but in general the 8-inch precipitation contour occurs close to 6,000 feet of altitude. Alternatively, on the PRISM precipitation map all of the study area above 4,000 feet is interpreted as receiving greater than 8 inches of precipitation.

Also large blocks (millions of acres) were assumed to have similar altitude-precipitation relationships. In the USGS and NDWR basin reports 19 out of the 27 valleys studied for this report were assumed to have the same ("standard" Maxey-Eakin) altitude-precipitation relationship summarized in Eakin (1966, p 260-262). Of the other eight, five have another relationship that is significantly "wetter" although the increase with altitude was the same, one is similar to the "standard" although slightly "dryer" and two are unreported.

4.2.3 Available Precipitation Data

The precipitation data used for this study are color coded by agency on **Figure 4-1**. The precipitation data for this analysis were selected for both quality of record and spatial distribution. The precipitation data in this analysis came from three sources, Desert Research Institute's Western Regional Climate Center (WRCC), Nevada Department of Conservation and Natural Resources, Division of Water Resources (NDWR), and the U.S. Geological Survey's (USGS) High Altitude Precipitation Network. The precipitation data used for this study are listed in **Table 4-1**.

The WRCC data were accessed through their website (http://www.wrcc.dri.edu) and includes historical (climatological) data for the National Oceanic and Atmospheric Admisistration's National Weather Service precipitation sites. These are daily low altitude gages with generally long periods of record. One issue associated with these sites are missed daily readings. These missed readings have a very high probability of occurring on days when precipitation actually occurred as the record commonly indicates either the station keeper could not access the gage (due to bad weather) or a mechanical failure became apparent to the station keeper because the gage did not record known precipitation. Because these missed readings have a high probability of occurring on a days when precipitation actually occurred, and precipitation is a rare event, this can be very serious problem in short duration records and may significantly underestimate the station's "average precipitation". Therefore only station with low percentages (< 7 %) of "missed" days were used for this analysis.

The NDWR data are from bulk precipitation gages measured annually and were installed in the mid 1950s and mid 1960s. At these gages, vandalism is the usual reason for "missing data". Because vandalism is a random event, not related to weather, these years of missing data may or may not bias the gage averages. The primary reason for under reporting of precipitation at these sites, if it occurs, would be related to insufficient gage size to contain very large snowfalls. This type of error would be difficult to detect or demonstrate.

The USGS High Altitude Precipitation Gage Network was established in the mid 1980's in support of the Carbonate Rock Study. The gages are measured semi-annually and are 12 feet in height, 1 foot in diameter and are designed to the Department of Agriculture, National Resources Conservation Service's (NRCS), Snowpack Telemetry (SnoTel) specifications. These gages are bulk precipitation gages, however, and not telemetered. Both the height of the gage and the periodicity of measurement are designed to minimize under reportage of precipitation. Vandalism and even forest fires have destroyed some of these gages and affected the records.

Over estimation of precipitation from gage data can also quite commonly occur, either because the data were collected in unrepresentative years or because of poor gage placement. The under estimates are "compensated" by the over estimates, however both can be serious problems and can significantly affect the representativeness of any particular gage record. The period of record

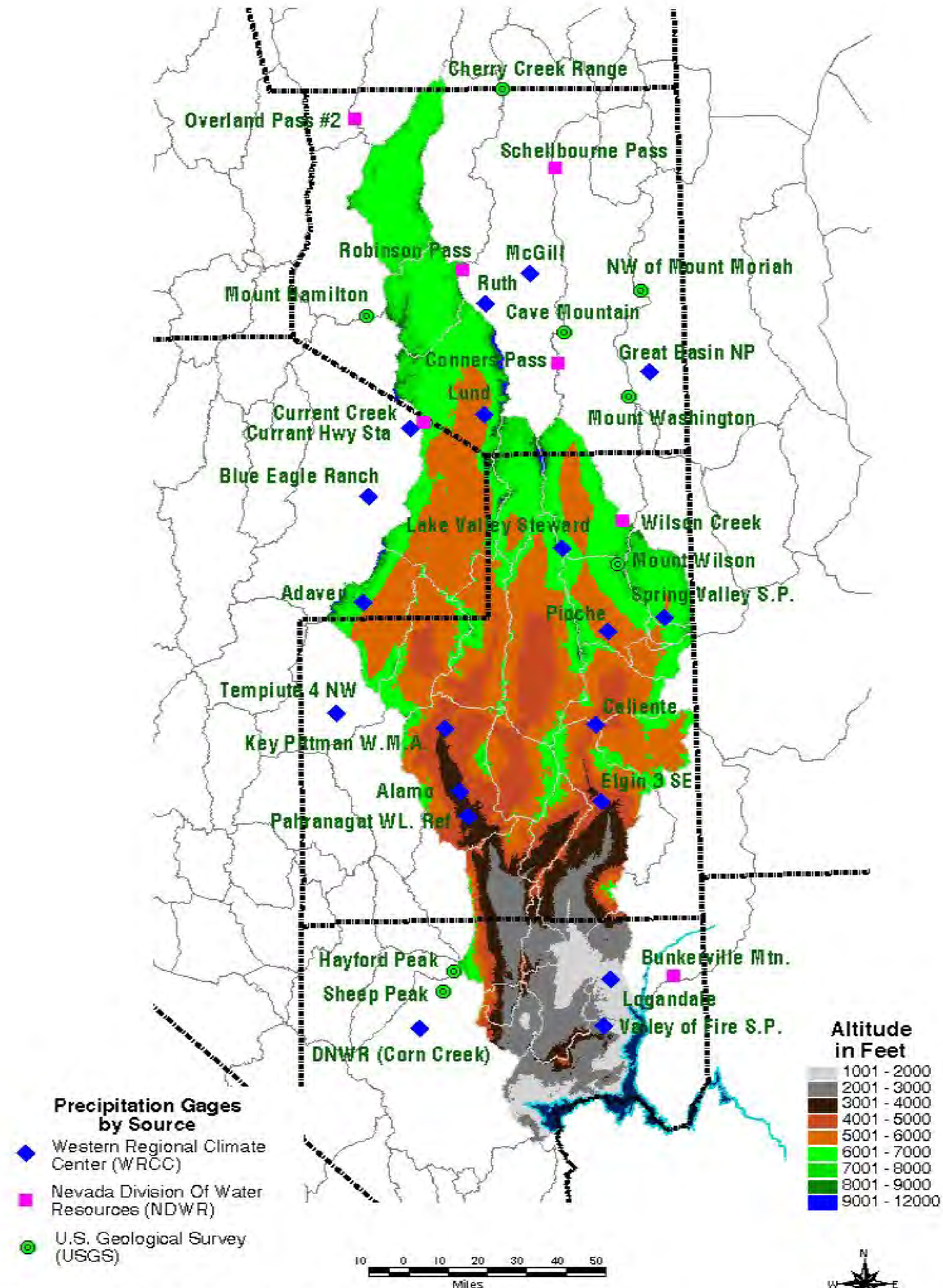

Figure 4-1. Altitude distribution in study area with precipitation gages.

Table 4-1. Precipitation data used in this analysis.

Site No.	Site Name	P[1]	Agency [2]	UTM[3]-X	UTM[3]-Y	Altitude	Years of Record		Average Annual Precipitation
				Meters	Meters	feet	start	last	Inches
Group 1 ("Western" or "Dry")									
1	DNWR (Corn Creek)	D	WRCC	647,271	4,033,702	2,920	1948	1998	4.41
2	Bunkerville Mountain	A	NDWR	751,159	4,055,820	3,250	1967	1998	6.18
3	Pahranagat WL. Ref.	D	WRCC	666,997	4,125,914	3,400	1964	2000	6.40
4	Alamo	D	WRCC	663,824	4,136,951	3,600	1948	1962	4.88
5	Key Pittman W.M.A.	D	WRCC	657,394	4,164,575	3,950	1964	1989	7.94
6	Blue Eagle Ranch Hk	D	WRCC	626,385	4,265,782	4,780	1978	2000	9.38
7	Tempiute 4 NW	D	WRCC	613,161	4,171,251	4,890	1972	1985	7.87
8	Lund	D	WRCC	673,561	4,301,824	5,570	1957	2000	10.37
9	Currant Hwy Station	D	WRCC	643,286	4,295,668	6,240	1963	1977	10.59
10	McGill	D	WRCC	692,309	4,363,337	6,300	1914	2000	8.84
11	Great Basin Natl. Pk.	D	WRCC	741,040	4,320,255	6,830	1948	2000	13.11
12	Ruth	D	WRCC	673,940	4,349,949	6,840	1958	2000	12.17
13	Schellbourne Pass	A	NDWR	702,954	44089648	7,100	1954	1998	13.28
14	Conners Pass	A	NDWR	703,749	4,323,830	7,732	1954	1998	13.98
15	Robinson Pass	A	NDWR	665,000	4,364,560	7,800	1954	1998	12.70
16	Sheep Peak	S	USGS	656,987	4,049,883	9,600	1985	1999	16.95
17	Cherry Creek Range	S	USGS	680,671	4,443,452	9,700	1985	1999	14.74
18	Hayford Peak	S	USGS	660,932	4,058,248	9,840	1985	1999	16.52
Group 2 ("Eastern or "Wet")									
19	Logandale	D	WRCC	725,069	4,055,097	1,410	1968	1992	5.14
20	Valley of Fire St. Pk.	D	WRCC	722,612	4,034,678	2,000	1972	2000	6.70
21	Elgin 3 SE	D	WRCC	721,539	4,132,729	3,300	1965	1985	14.07
22	Caliente	D	WRCC	719,183	4,165,980	4,440	1928	2000	9.06
23	Spring Valley St. Pk.	D	WRCC	747,214	4,213,053	5,950	1974	2000	12.31
24	Pioche	D	WRCC	723,958	4,206,828	6,180	1948	2000	13.38
25	Adaven	D	WRCC	624,188	4,219,501	6,250	1928	1982	12.73
26	Lake Valley Steward	D	WRCC	705,452	4,243,357	6,350	1971	1998	15.69
27	Overland Pass #2	A	NDWR	620,902	4,430,358	6,790	1966	1998	14.10
28	Wilson Creek	A	NDWR	730,287	4,254,672	7,200	1954	1998	16.45
29	Current Creek	A	NDWR	649,041	4,297,624	5,999	1954	1998	13.17
30	Mount Wilson	S	USGS	728,196	4,235,885	9,200	1985	1999	22.49
31	NW of Mount Moriah	S	USGS	737,769	4,355,738	9,300	1985	1999	18.28
32	Mount Washington	S	USGS	732,842	4,309,177	10,440	1985	1999	25.80
33	Mount Hamilton	S	USGS	625,636	4,344,581	10,600	1985	1999	21.81
34	Cave Mountain	S	USGS	706,185	4,337,345	10,650	1985	1999	21.40

[1] *P = Periodicity of measurement, D (Daily), A (Annual), S (Semi-Annual)*

[2] *Proper names of agencies, Western Regional Climate Center (WRCC), Nevada, Division of Water Resources (NDWR), U.S. Geological Survey (USGS)*

[3] *UTM = Universal Transverse Mercator, North American Datum 1927 (NAD27)*

annual averages reported in **Table 4-1** of the precipitation gages are assumed to be representative of the precipitation at the site of the gage and over a relatively large area (millions of acres). This assumption, however, may introduce errors into this or any other precipitation analysis.

A significant issue in this analysis was the low density of precipitation data. Precipitation data are available from existing or recently existing sites in 11 of the 27 valleys in the study area. No records were found for gages in the other valleys. Because of the low density, precipitation data from adjacent valleys were used to augment the data set. This low density of data also effects any precipitation analysis.

4.2.4 Development of Altitude-Precipitation Relationships

The precipitation-altitude relationships used in this study were estimated slightly differently than was done in Las Vegas Valley (Donovan and Katzer, 2000). Las Vegas Valley is a much smaller area, has a higher density of data, and much more apparent variability. The historic precedents all assumed the altitude-precipitation relationships were different in the two major mountain ranges (Spring Mountains and Sheep / Las Vegas Ranges). Donovan and Katzer (2000) simply used the gage data to better define the differences between the two mountain ranges. The plot of the data (Donovan and Katzer, 2000; Figures 1 and 2) displays some very obvious geographic groupings consistent with historical analysis. In Las Vegas Valley the data were simply separated into four groups and regressed.

The historical precedents for this current study all assumed the altitude-precipitation relationship was similar throughout the entire area. The one general distinction was a difference between northern basins (dryer) and southern basins (wetter). This difference was presumably related to the influence of summer monsoonal precipitation. Therefore it was originally thought that one uniform altitude-precipitation relationship could serve to characterize the area.

The first step in developing an altitude-precipitation relationship is plotting the station period of record averages **(Figure 4-1** and **Figure 4-2)** to determine if a geographic relationships exist. The precipitation gages on **Figure 4-2** are shape-varied by the source of the data.

This general regression appears to generally explain the altitude-precipitation relationship but the coefficient of determination is not very high (Adjusted $r^2 = 0.78$) indicating 22 percent of the variation is not explained by the regression.

Rather than northern-southern, a general eastern-western relationship was observed. That is; stations on the eastern side, of the study area, tended to plot above the regression line ("wetter" than predicted) and stations on the western side tend to plot below the regression line ("dryer" than predicted). Therefore it was hypothesized that the western part of the study area (White River Flow System) is "dryer" than the eastern (Meadow Valley Flow System) part and use of a "general" altitude-precipitation relationship would tend to over estimate precipitation in the White River Flow System and under estimate precipitation in the Meadow Valley Flow System.

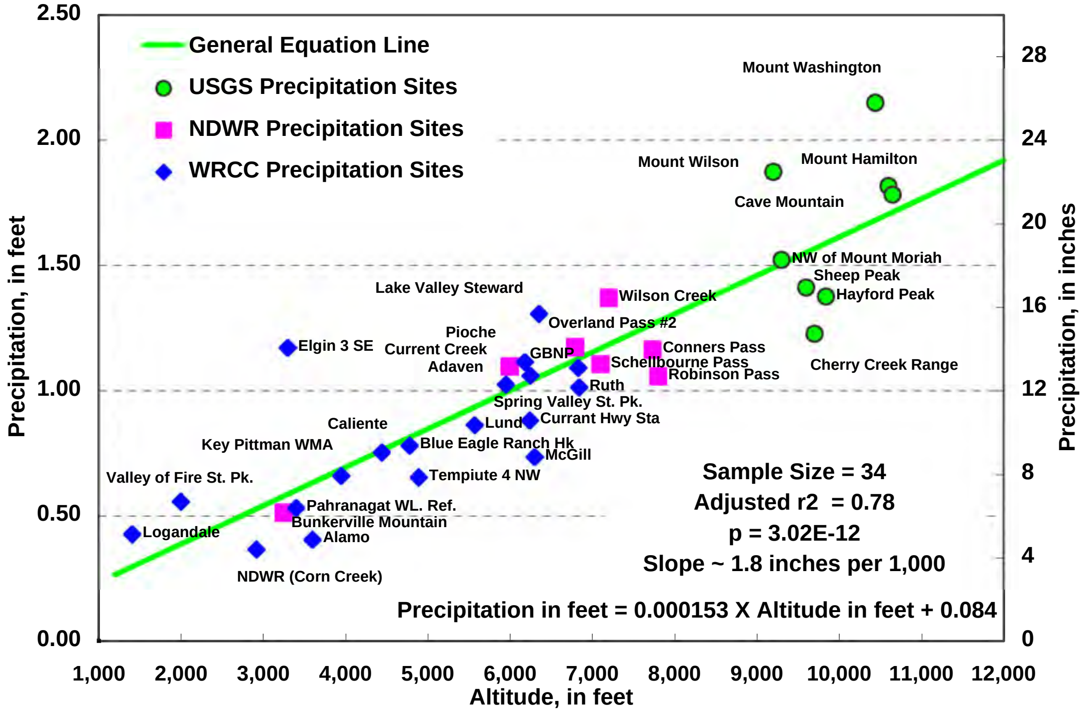

Figure 4-2. General regression of precipitation gage data in this study.

"Dryer" implies that a location at a specific altitude in one area receives less precipitation than in other areas at the same altitude. This "dryness" is also most obvious on the valley floors where most humans interact with the environment. Use of "dryer" and "wetter" is unsatisfying because these terms do not differentiate between reduction in the slope of the local altitude-precipitation relationship and "regional dryness" associated with large and perhaps overlapping rainshadows.

The period of record averages were separated into two groups simply based on whether the point plotted below (**Table 4-1**, Group 1) or above (**Table 4-1**, Group 2) the general regression line, with one exception. Caliente was included in the "wet" group (Group 2) to balance the influence of the Elgin precipitation station. These observed groupings were thought to be a combination of; overlapping rainshadows, general geometry of the valleys, including the height of the ranges above the valley floors, and orientation of the ranges with respect to storm tracks. The data and regressions are portrayed on **Figure 4-3** (Group 1) and **Figure 4-4** (Group 2).

The "dry" regression includes some of the same data used to create the "Sheep Range" altitude-precipitation relationship in Las Vegas Valley (Donovan and Katzer, 2000) which is "dryer" (both slightly shallower slope and smaller intercept). This appeared reasonable because the physical meaning of this regression suggests the valleys included within this particular analysis are relatively "dry" but not as "dry" as the nearby region within Las Vegas Valley.

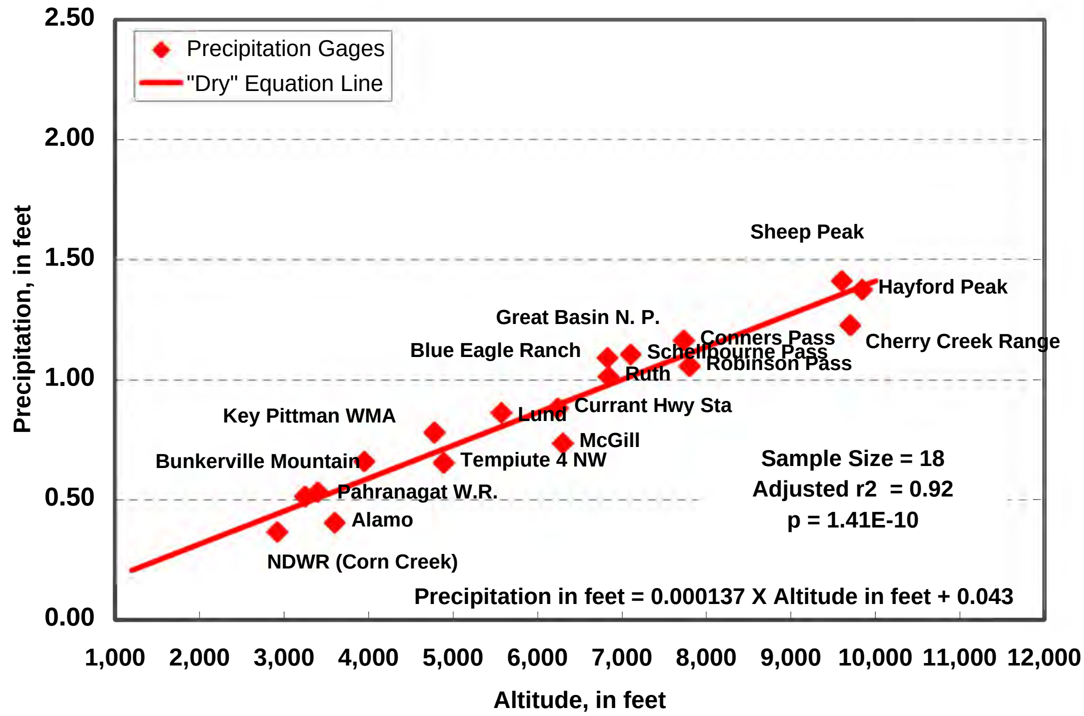

Figure 4-3. Data and regression of the "dry" group (Group 1).

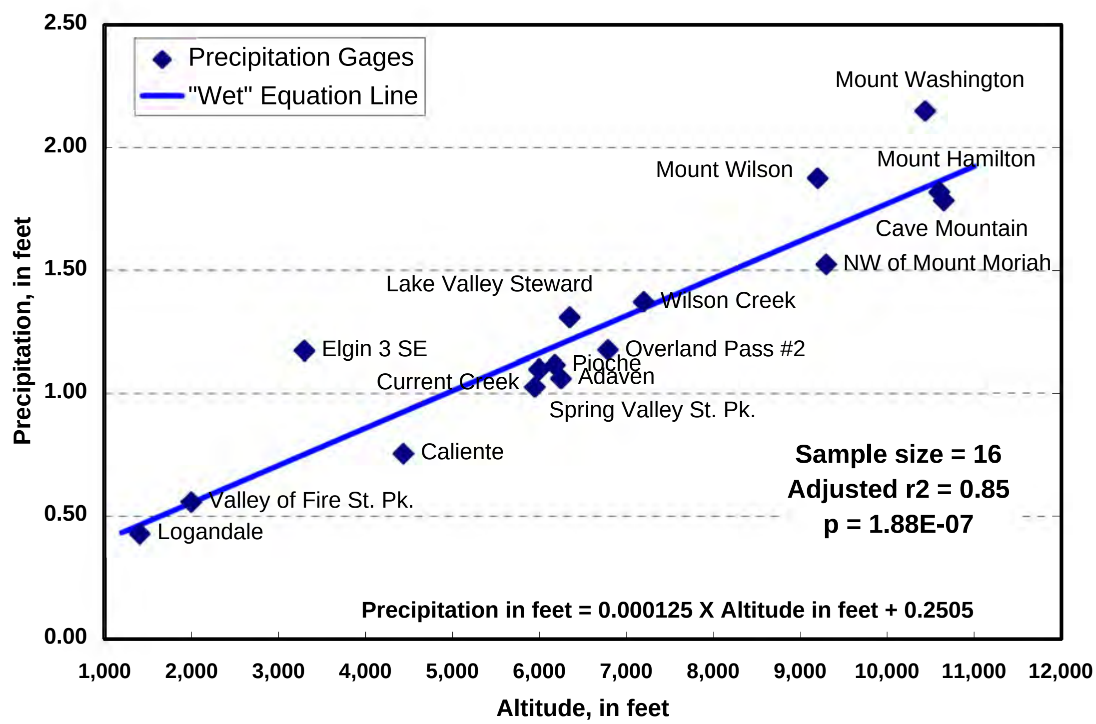

Figure 4-4. Data and regression of the "wet" group (Group2).

These regression analyses resulted in two roughly parallel equations with slopes that are slightly shallower (less steep) than the general altitude-precipitation relationship. The regression coefficient are somewhat improved (adjusted $r^2 = 0.92$ and 0.85) but generally not as good as observed in Las Vegas Valley (Donovan and Katzer, 2000).

It was also observed from plotting the data on **Figure 4-1** and **Figure 4-2** that stations in the northern White River Flow System were generally "dry" on the valley floors and "wet" in the mountain ranges. This implies the altitude-precipitation relationship is relatively steep in this area. It was also recognized that the highest ranges (from valley floor) in the study area are generally along the western margin of the study area and that the Quinn Canyon, Grant, and White Pine Ranges form a long continuous range.

The precipitation stations in and near the northern White River Flow System were then separated and regressed as a separate group. This part of the White River Flow System is dominated by White River Valley proper and therefore was called the "White River Valley" regression. This resulted in the fourth (altitude-precipitation) regression of this study, shown in **Figure 4-5**. Unlike the other regressions the intercept is negative. This was thought to be unimportant because the physical meaning of the intercept is the value of precipitation at 0 feet of altitude. No part of this study area is less than 1,200 feet of altitude and no part of the northern White River Flow System where this estimate was used is less than 5,000 feet of altitude.

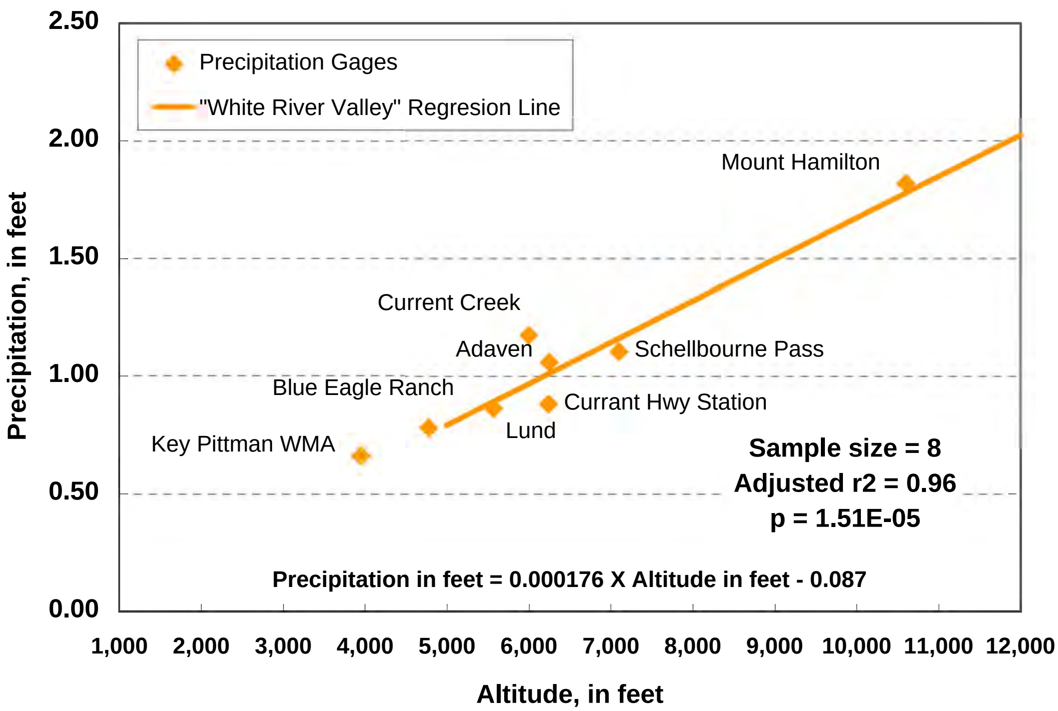

Figure 4-5. "White River Valley" precipitation data and regression.

Once the altitude-precipitation relationships were developed they were applied to various valleys within the study area. This was done to reduce the precipitation estimate of the entire study area and provide an appropriate altitude-precipitation relationship. The choice was determined by the locations of the various precipitation gages and physiography of the various valleys. This reduces the total estimate of precipitation in the study area by about 3 percent from 6,827,000 afy (general relationship, **Figure 4-2**.) to 6,636,000 afy, the sum of the precipitation based on all relationships.

The regression line as portrayed on **Figure 4-2** through **Figure 4-5** intentionally does not cover the entire altitude interval of the study area. The regression line portrays only the altitude intervals where the regression equation was applied. **Table 4-2** summarizes which of the various precipitation gages averages were used to create the various regression equations and then how the regression equations were applied. The predicted precipitation column is denoted to indicate which altitude-precipitation relationship was considered appropriate for the various sites ("general", "dry", "wet", "WRV"). **Figure 4-6** displays the spatial distribution of where the equations were applied. The hydrographic basin number (Valley Number) included in **Table 4-2** to minimize confusion caused by using valley names. There is precipitation data from two "Spring Valleys" in the precipitation analysis. One is the large valley (184) between the Schell Creek and Snake Ranges, the other (201) is located near Ursine.

Once the altitude-precipitation relationships were created through the four regressions, precipitation was estimated by multiplying the area of the 1,000-foot altitude intervals (in acres) in each valley by the predicted precipitation (in feet per year). This results in a estimated amount of precipitation in afy. The totals of the 1,000 foot altitude intervals are summed for in each valley and then for the total area. For any one 1,000-foot altitude interval, the rate of precipitation was calculated from one of the altitude-precipitation relationships. Only one altitude-precipitation relationship was used in each of the 27 valleys. **Table 4-3** summarizes the precipitation analysis for each valley. The full analysis is included in Appendix A

Although this precipitation analysis is characterized as a "modified Maxey-Eakin" the precipitation estimates cannot be directly compared to the precipitation estimates in the various basin reports. Commonly, precipitation was not estimated for areas that receive less than eight inches of precipitation and therefore the reported value reported may or may not be an estimate of the "total" precipitation in any one valley. Both total precipitation and the precipitation for the area that receives greater than eight inches of precipitation are listed in **Table 4-3**. All of the values reported in **Table 4-3** are rounded to the nearest 1,000 unless the estimated value is less than 1000.

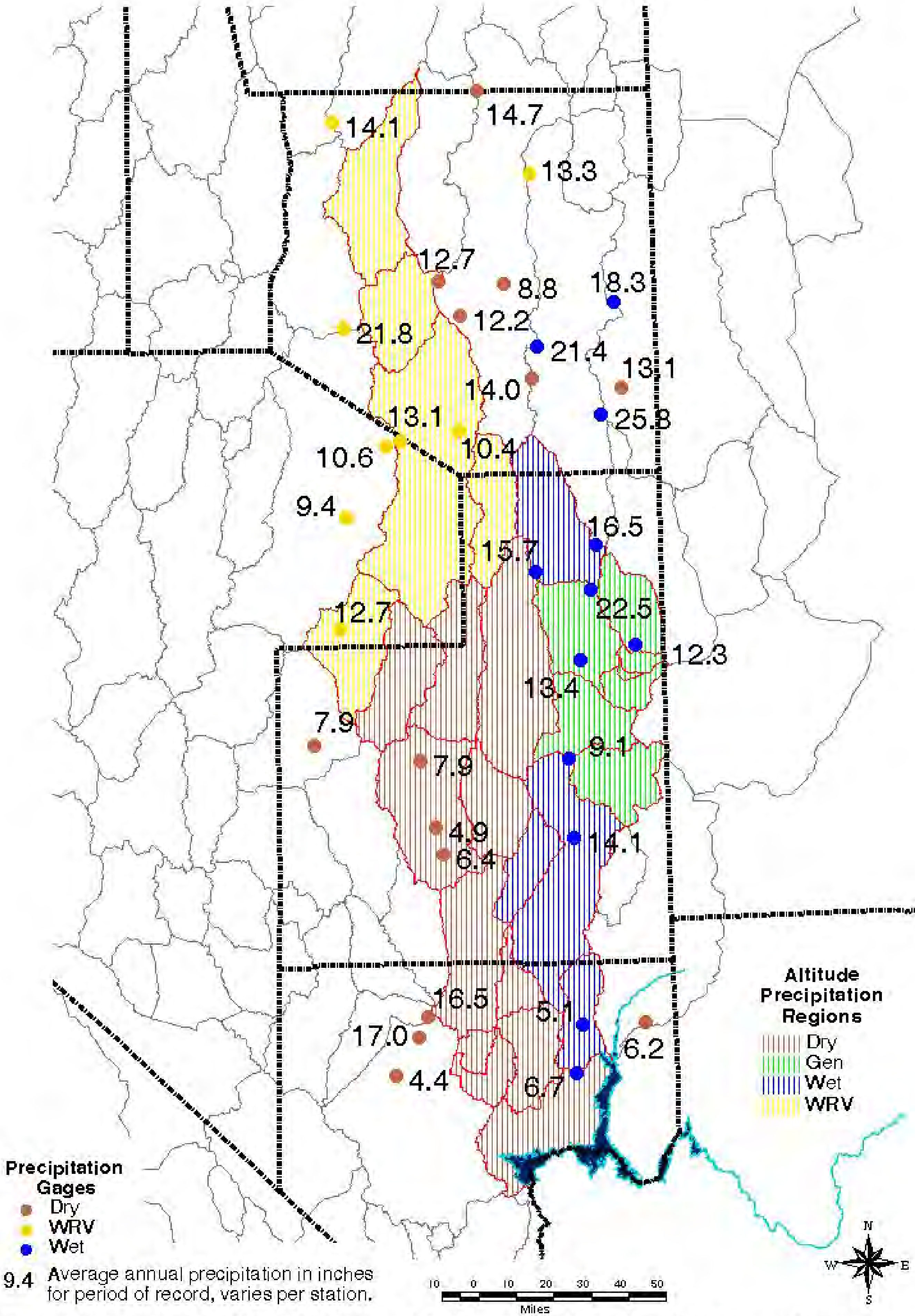

Figure 4-6. Distribution of local altitude - precipitation relationships and precipitation gage locations.

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Table 4-2. Use of data and application of regression equations at precipitation gage sites.

Site No.	Valley No.	Valley Name	Grp.[1]	Use of data for regression	Application of regression	Site contained within study area	Actual Average Precip. (ft)	Predicted Precip. (ft)
1	212	Las Vegas	1	Dry	N/A	OUT	**0.43**	0.44[b]
2	223	Gold Butte	1	Dry	N/A	OUT	**0.56**	0.49 [b]
3	209	Pahranagat	1	Dry	Dry	IN	**0.37**	0.51 [b]
4	209	Pahranagat	1	Dry	Dry	IN	**0.52**	0.54 [b]
5	209	Pahranagat	1	WRV	Dry	IN	**1.17**	0.58 [b]
6	173B	Railroad	1	WRV	N/A	OUT	**0.41**	0.75[d]
7	170	Penoyer	1	Dry	N/A	OUT	**0.66**	0.71 [b]
8	207	White R. V.	1	WRV	WRV	IN	**0.76**	0.89 [d]
9	173B	Railroad	1	WRV	N/A	OUT	**0.78**	1.01 [d]
10	179	Steptoe	1	Dry	N/A	OUT	**0.66**	0.91 [b]
11	195	Snake	1	Dry	N/A	OUT	**0.86**	0.98 [b]
12	179	Steptoe	1	Dry	N/A	OUT	**1.03**	0.98 [b]
13	179	Steptoe	1	WRV	N/A	OUT	**1.12**	1.16 [d]
14	179	Steptoe	1	Dry	N/A	OUT	**0.88**	1.10 [b]
15	179	Steptoe	1	Dry	N/A	OUT	**1.06**	1.11 [b]
16	212	Las Vegas	1	Dry	N/A	OUT	**0.74**	1.36 [b]
17	178B	S. Butte V.	1	Dry	N/A	OUT	**1.31**	1.37 [b]
18	210	Coyote	1	Dry	Dry	IN	**1.18**	1.39 [b]
19	220	L. Moapa	2	Wet	Wet	IN	**1.09**	0.46 [c]
20	215	Black Mtns.	2	Wet	Dry	IN	**1.01**	0.55 [c]
21	205	L. MVW	2	Wet	Wet	IN	**1.11**	0.75 [c]
22	203	Panaca	2	Wet	Gen	IN	**0.53**	0.76 [a]
23	201	Spring V. (L)	2	Wet	Gen	IN	**1.37**	0.99 [a]
24	202	Patterson	2	Wet	Gen	IN	**1.30**	1.03 [a]
25	172	Garden	2	WRV	WRV	IN	**1.17**	1.01 [d]
26	183	Lake	2	Wet	Wet	IN	**1.06**	1.22 [c]
27	176	Ruby V..	2	WRV	WRV	OUT	**1.87**	1.11 [d]
28	183	Lake.	2	Wet	Wet	IN	**1.52**	1.34 [c]
29	207	White R. V.	2	WRV	WRV	IN	**1.10**	1.00 [c]
30	183	Lake	2	Wet	Wet	IN	**1.23**	1.65 [c]
31	184	Spring V.	2	Wet	N/A	OUT	**1.38**	1.66 [c]
32	184	Spring V.	2	Wet	N/A	OUT	**2.15**	1.84 [c]
33	154	Newark	2	WRV	N/A	OUT	**1.82**	1.78 [d]
34	184	Spring V.	2	Wet	N/A	OUT	**1.78**	1.87 [c]

[1] Grp. = Indicates in which group (1 or 2, "dry" or "wet") the site was initially included. All stations were used in the "general" regression.
[a] Indicates precipitation was estimated using the "general" altitude-precipitation relationship.
[b] Indicates precipitation was estimated using the "dry" altitude-precipitation relationship.
[c] Indicates precipitation was estimated using the "wet" altitude-precipitation relationship.
[d] Indicates precipitation was estimated using the "WRV" altitude-precipitation relationship.

Table 4-3. Summary table of precipitation analysis.

Hydro-graphic No.	Valley Name	Area (ac.)	Total Precipitation (af.)	Precipitation greater than 8 inches (af.)
175	Long Valley	417,000	460,000 [d]	460,000 [d]
174	Jakes Valley	271,000	312,000 [d]	312,000 [d]
207	White River Valley	1,017,000	1,032,000 [d]	1,032,000 [d]
172	Garden Valley	318,000	320,000 [d]	320,000
171	Coal Valley	290,000	234,000 [b]	201,000 [b]
180	Cave Valley	230,000	258,000 [d]	258,000 [d]
208	Pahroc Valley	325,000	260,000 [b]	219,000 [b]
181	Dry Lake Valley	574,000	455,000 [b]	343,000 [b]
182	Delamar Valley	232,000	176,000 [b]	108,000 [b]
209	Pahranagat Valley	497,000	344,000 [b]	139,000 [b]
206	Kane Springs Valley	150,000	140,000 [c]	139,000 [c]
210	Coyote Springs Valley	392,000	224,000 [b]	72,000 [b]
219	Muddy River Springs Area	93,000	38,000 [b]	200 [b]
220	Lower Moapa Valley	176,000	101,000 [c]	12,000 [c]
217	Hidden Valley	52,000	28,000 [b]	5,000 [b]
216	Garnet Valley	102,000	45,000 [b]	5,000 [b]
218	California Wash	206,000	76,000 [b]	15 [b]
183	Lake Valley	354,000	437,000 [c]	437,000 [c]
202	Patterson Valley	267,000	275,000 [a]	275,000 [a]
201	Spring Valley	185,000	212,000 [a]	212,000 [a]
200	Eagle Valley	34,000	37,000 [a]	37,000 [a]
199	Rose Valley	8,000	7,000 [a]	7,000 [a]
198	Dry Valley	76,000	77,000 [a]	77,000 [a]
204	Panaca Valley	232,000	224,000 [a]	224,000 [a]
203	Clover Valley	220,000	205,000 [a]	205,000 [a]
205	Lower Meadow Valley Wash	606,000	523,000 [c]	437,000 [c]
215	Black Mountains Area	409,000	132,000 [b]	200 [b]
Total		**7,734,000**	**6,636,000**	**5,540,000**

[a] *Indicates precipitation was estimated using the "general" altitude-precipitation relationship.*
[b] *Indicates precipitation was estimated using the "dry" altitude-precipitation relationship.*
[c] *Indicates precipitation was estimated using the "wet" altitude-precipitation relationship.*
[d] *Indicates precipitation was estimated using the "WRV" altitude-precipitation relationship.*

4.2.5 Discussion of Precipitation Analysis Related to Previous Studies

The strong conservativeness of the earlier precipitation estimates can be demonstrated by plotting the gage averages **(Figure 4-7)** on the NDWR 1971 precipitation map. The precipitation gage data from Caliente (9.1 inches, altitude 4,400 feet) in Panaca Valley, Key Pittman Wildlife Refuge (7.9 inches, altitude 3950 feet) in Pahranagat Valley and Elgin (14.1 inches, altitude 3,300 feet) in Lower Meadow Valley Wash all suggest the altitude of eight inches of precipitation is about 4,000 rather than 6,000 feet of altitude and is probably lower in Lower Meadow Valley Wash. In addition, the altitude-precipitation relationship is not as steep as

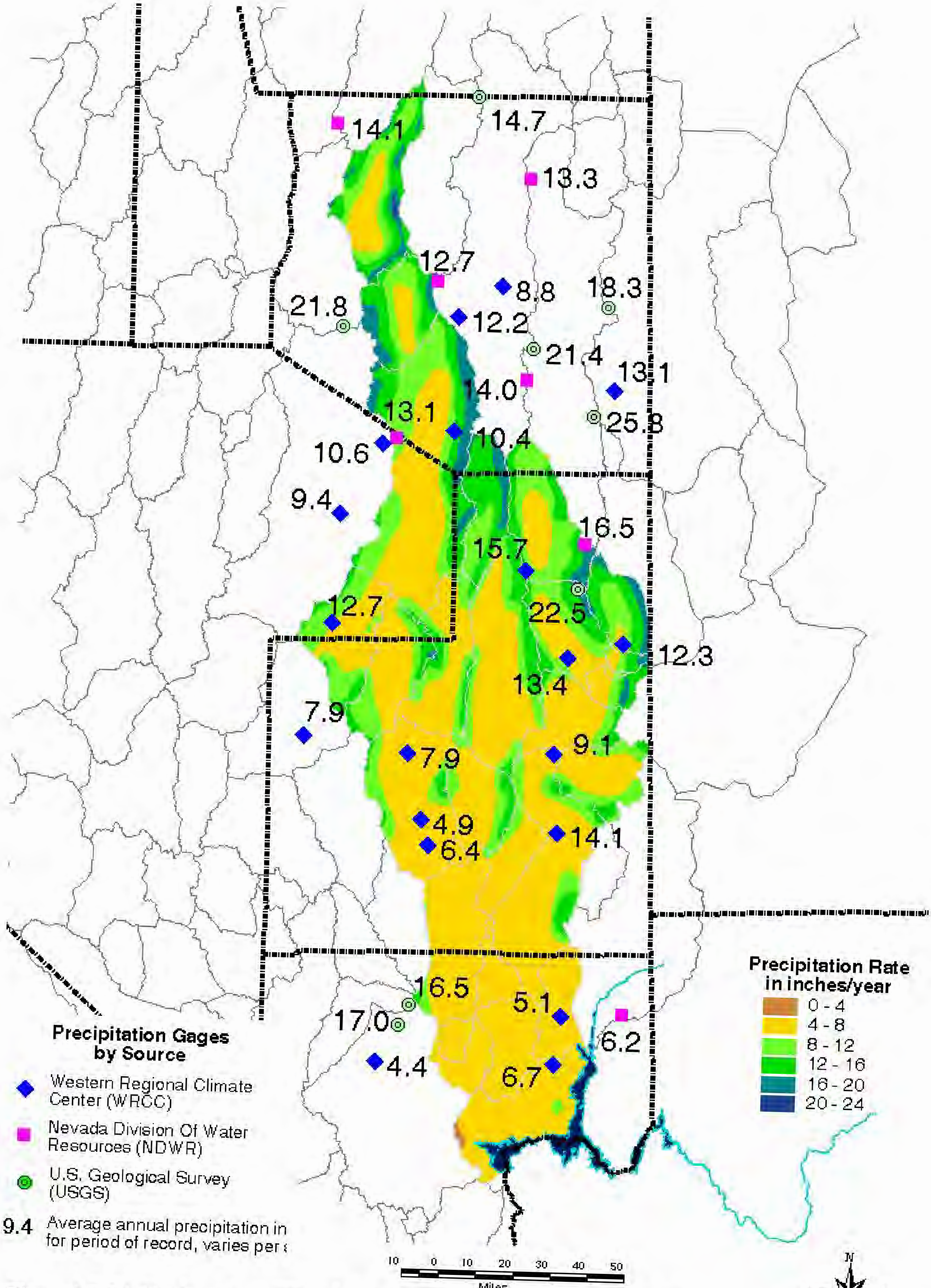

Figure 4-7 Digitized version of Nevada Division of Water Resources (NDWR) 1971 precipitation map with precipitation gages.

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reported by Bixby and Hardman (1928) (4.5 inches per 1,000 feet of altitude rise) but rather approximately 1.8 inches per 1,000 feet **(Figure 4-2)** of altitude rise. This altitude-precipitation relationship also appears to apply over the entire range of altitude.

This is a very different conclusion than would be expected from the Hardman (1936, 1965) or NDWR (1971) precipitation maps. This implies all of the acreage above 6,000 feet of altitude (36 percent) and 5,000 feet (66 percent) and potentially all of the acreage above 4,000 feet (78 percent) may receive "effective" precipitation that at least partially becomes natural recharge.

This can also be demonstrated by comparing the composite altitude-precipitation relationships in the various precipitation maps with the actual precipitation data **(Figure 4-8)**. This is fairly simple when comparing the precipitation data with a Maxey-Eakin analysis (including the modified form used here), because the altitude-precipitation relationship used in a particular valley or region is clearly stated. When using a precipitation map this relationship can only be determined either by visual inspection (visually comparing the altitude intervals and precipitation intervals) or GIS analysis (combining two digital geographic data sets, then determining the numerical relationship between them, typically by weighted averages). The curves determined by GIS analysis of the two precipitation maps (NDWR 1971) and PRISM are presented on **Figure 4-8** for comparative purposes and were created using standard GIS processing techniques. The GIS technique was preferred over visual inspection because it is reproducible.

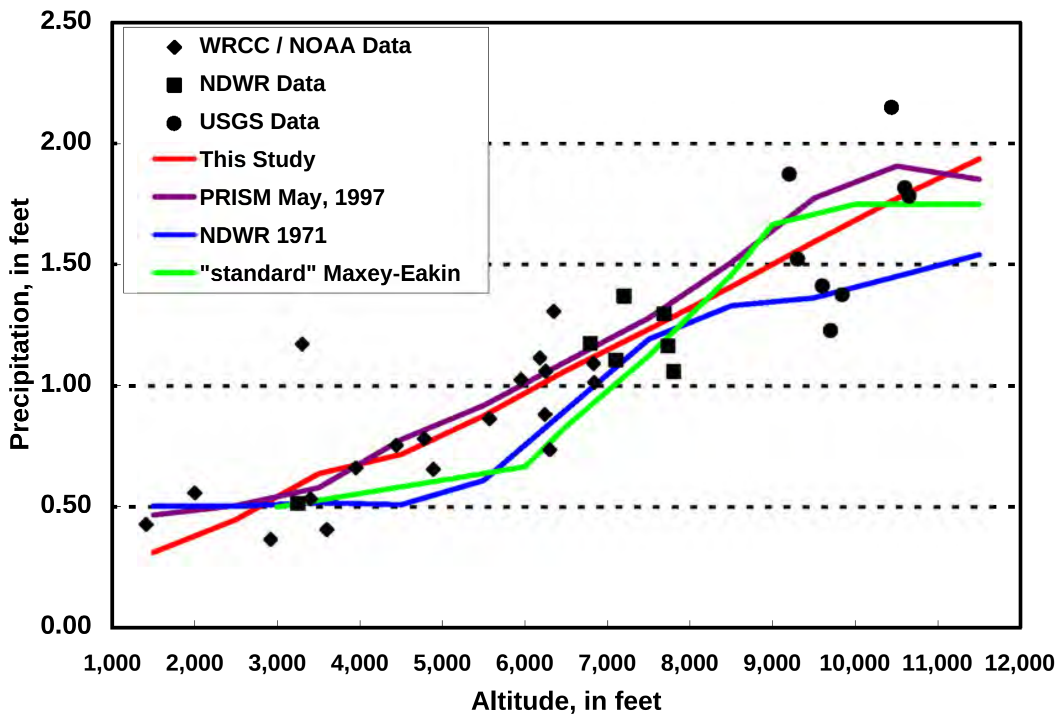

Figure 4-8. Composite altitude-precipitation relationships compared to gage data.

The line presented as "This study" is a weighted average line influenced by the relative size and altitude of the regions where the four altitude-precipitation relationships were used and was presented on this graphic for comparison with the other precipitation maps. This is a relatively straight line because the four altitude-precipitation relationships are similar. Four very different altitude-precipitation relationships would combine to create a very curved line. The four altitude-precipitation relationships were created simply to better characterize individual valleys within the study area; the four are local altitude-precipitation relationships that apply to specific valleys within the entire study area.

The distribution of precipitation presented in this study, although at variance with USGS and NDWR basin reports, is similar to the PRISM map. The PRISM precipitation distribution map, downloaded May 1997, has a similar but more generous distribution of precipitation. For the three precipitation maps, the total estimate of precipitation (~ 6,636,000 afy) in this study is significantly larger than the NDWR 1971 map (~ 5,516,000 afy) but smaller than the May 1997 version of PRISM (~ 6,985,000 afy).

Figure 4-9 is included for comparison with **Figure 4-7**. Precipitation was estimated by the modified Maxey-Eakin technique pioneered by Donovan and Katzer (2000) in Las Vegas Valley. In this technique, precipitation was estimated using 1,000-foot altitude interval tables and therefore a precipitation map was not required. The map is included here only for comparative purposes.

In Donovan and Katzer's (2000) precipitation estimation technique the altitude-precipitation relationship is determined by regression of the available precipitation data. This altitude-precipitation relationship is then applied to summary tables of 1,000-foot altitude intervals. Both the use of 1,000 foot intervals and the fact that the amount of precipitation is estimated from altitude intervals are features of the Maxey-Eakin technique as summarized by Eakin (1966, p. 260-262). Because of the similarities in the manner in which precipitation and natural recharge is estimated, Donovan and Katzer's (2000) method is characterized as a "modified Maxey-Eakin" rather than a new technique.

4.3 GROUND-WATER MOVEMENT

Ground-water in the study area flows from areas of high head in the upper altitudes of the basins to areas of lower head (lower altitude) in response to gravity. There is a change in altitude from the northern edge of the study area in Long Valley (Valley floor ~ 6,100 feet altitude) to the Colorado River (downstream from Hoover Dam ~ 600 feet altitude) of about 5,500 feet. Several of the mountain blocks have peaks that add an additional 4000-5,000 feet to this head change.

Ground water movement from areas of higher head, such as recharge areas, is toward the carbonate aquifer systems that underlie the entire Colorado River Basin Province of Nevada. Most of the valley fill aquifer systems are directly on top of the carbonate aquifer system and the movement of ground water is upwards from the carbonate aquifer to the alluvial aquifers. There are numerous valleys where these two aquifer systems are separated by a sequence of volcanic rocks, such as is in Dry Lake, Delamar, and Pahranagat Valleys. There is undoubtedly ground-water movement upward from the carbonate rocks through the overlying volcanic rocks to the

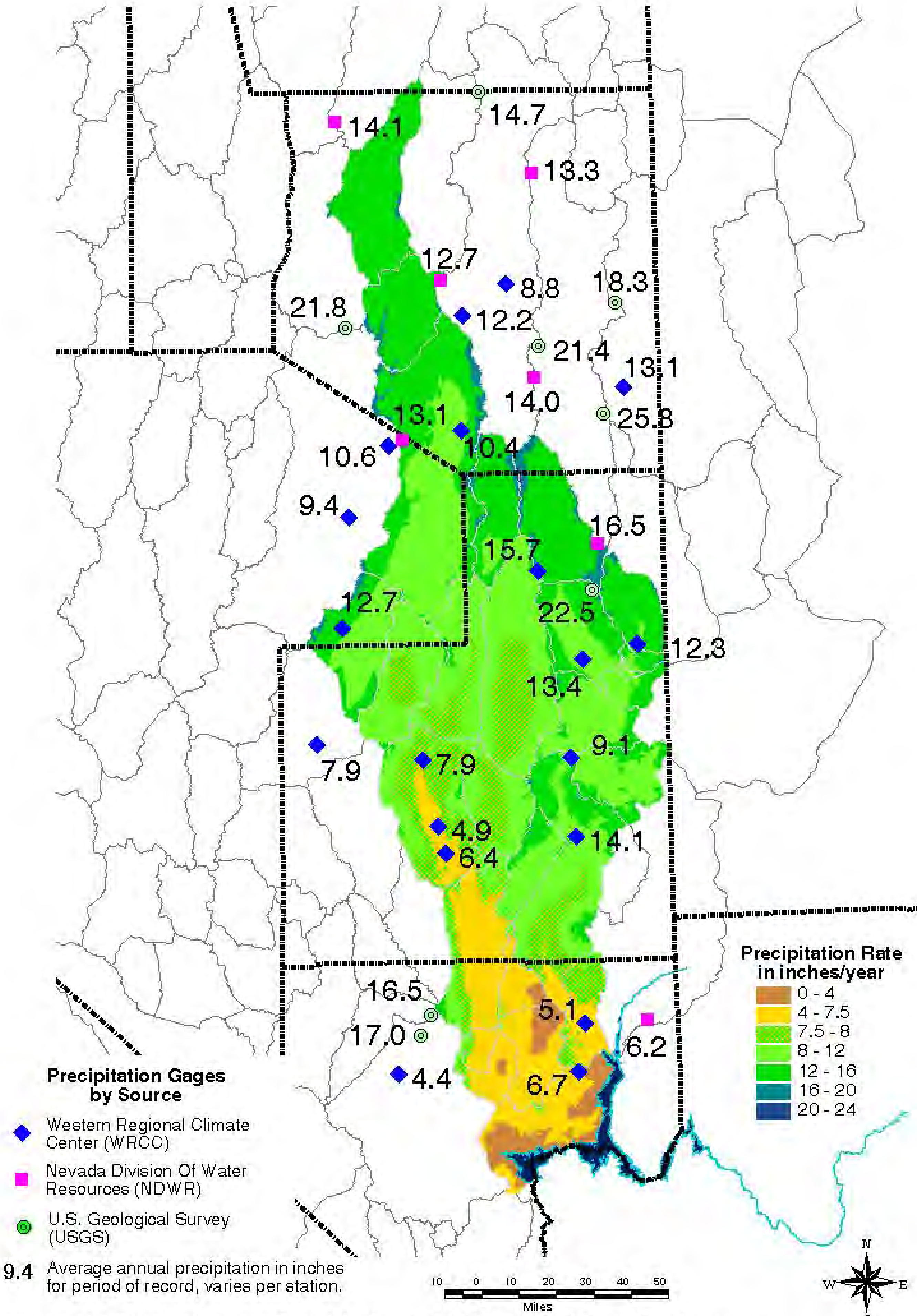

Figure 4-9. Distribution map of precipitation used in this study with precipitation gages

alluvial aquifer systems. Ground water also moves down through the volcanic rocks, in the recharge areas to the alluvial aquifer with lateral downgradient flow. There is ground-water movement from recharge areas at low altitude, such as in alluvial fans, directly down to the alluvial aquifer system and perhaps in some cases there may be flow from the alluvial aquifer through the volcanic rocks to the carbonate aquifer. There also may be flow from one basin to another through the connecting alluvial aquifer system such as in Dry Lake and Delamar Valleys. There is ground-water flow in the carbonate aquifer from the northern end of the system to the southern end, specifically from the carbonates underlying Long Valley to the carbonate rocks underlying Lake Mead and the Colorado River. The same holds true for the carbonates underlying Lake Valley at the north end of the Meadow Valley Flow System, for these carbonate rocks are also connected to the same carbonates underlying Lake Mead and the Colorado River. Even though this ground water system is extremely complex with ground-water mounding, degrees of permeability, varying lithologies, and structural complexities, there is most probably some degree of hydraulic connectivity throughout the study area.

4.3.1 White River Ground-Water Flow System

Ground water begins its circuitous path in the mountains and alluvial slopes of Long Valley exiting the valley in the underlying carbonate rocks to Jakes Valley. Local recharge in Jakes Valley from the Eagan and White Pine Ranges joins the outflow from Long Valley and moves south into White River Valley. Large springs in White River Valley discharge a significant amount of water from the underlying carbonate rocks. Recharge to the basin's alluvial ground-water system is from spring discharge from local recharge and from the underlying carbonate aquifer. There is also a component of local recharge in some of the springs, but most of the local recharge from the surrounding mountain blocks becomes part of the regional flow in the underlying carbonate aquifer.

Cave Valley, immediately east of White River Valley, contributes ground water to either the south end of White River Valley in the vicinity of the Shingle Pass fault zone or to the north end of Pahroc Valley. The width of the flow section in northern Pahroc Valley stretches from the Quinn Canyon Range on the west (including Garden and Coal Valleys) to the Bristol Range on the east (including Cave, Dry Lake, and Delamar Valleys). It is uncertain where the ground-water recharge from Garden and Coal Valleys actually joins the regional carbonate aquifer, but the ground water from both valleys may move east and south along a series of north trending faults until finally moving into the regional carbonate aquifer underlying Pahranagat Valley. East of Pahranagat Valley ground-water recharge from Dry Lake and Delamar Valleys is probably moving mostly to the south with some westerly component. The recharge from these two valleys originates mostly in the carbonates of the Bristol-Highland Range and the volcanic rocks of the Delamar Mountains.

Ground-water flow out of Delamar Mountains into Kane Springs Valley and Coyote Spring Valley must move through the Caliente caldera complex, an assemblage of tuffaceous and basaltic rocks. These rocks have undergone extensive structural deformation that allows ground water to flow through the caldera complex along numerous north trending fault structures. It is these same faults that breach the Pahranagat Valley shear zone, a northeast structure that cuts through the south end of Pahranagat Valley. The ground-water gradient across this shear zone was first defined by Eakin (1966, Figure 5) who attributed the steep gradient (based on sparse data) to a barrier effect caused by structure. We suggest the steep gradient is caused by an increase in permeabilities in the volcanic rock across this fault zone as the flow moves downward and southward into the underlying carbonate rocks in Coyote Spring Valley. Conversely there may not be a gradient and the water is simply perched above the regional carbonate flow system. Winograd and Friedman (1972) thought the barrier described by Eakin (1966) deflected about 6,000 acre-feet/year of regional ground water from the White River Flow System to the west toward the Amargosa Desert (not shown on **Figure 1-1**). According to Jim Thomas (DRI, oral commun.,2001) ground water in the carbonate rocks west of this theoretical barrier does not need the geochemical imprint from the White River Flow System to be explained, because local recharge, for instance from the Spring Mountains, has the same geochemical signature. Thus, the evidence is inconclusive and we have chosen to construct our ground-water model so ground water does not leave the White River ground-water system in this area.

The exact nature of the ground water flowing south in the carbonate rocks in Coyote Spring Valley is unknown, but in the northern part of the valley it probably moves differentially across a broad front. This front extends from the top of a ground-water mound in the Sheep Range bounding the valley on the west, through the Meadow Valley Mountains, to a similar ground-water mound under the Morman Mountains. White River ground water in the northern part of Coyote Spring Valley is moving mostly south and not mixing significantly with Meadow Valley Wash water, but it is connected hydraulically. The range front fault on the east side of the Sheep Range is highly permeable and is a major conduit for the southward moving ground water. Additional preferential flow is thought to occur along the range front fault on the west side of the Meadow Valley Mountains including the course of Pahranagat Wash. Groundwater from the valley moves as fracture flow to the east-southeast along the general course of Pahranagat Wash through Arrow Canyon to discharge at the Muddy Springs. According to Thomas et al. (2001) the temperature of the ground water in MX wells 4 and 5 is nearly the same, (30^{o} and 31^{o} C) and compares favorably with the Muddy Springs water temperature at 32.1^{o}C ; these elevated temperatures indicate vertical flow paths of several thousand feet. The remainder of the ground water exiting Coyote Spring Valley continues to the south and is somewhat split by the Arrow Canyon Range causing some flow into Hidden and Garnet Valleys with the remainder into California Wash. Some ground water in Coyote Spring Valley moves along the range front fault on the east side of the Sheep and Las Vegas Ranges and flows into Hidden Valley and on into Garnet Valley. The southern edge of Garnet Valley is bounded, in part, by a thick section of Muddy Creek Formation sediments that are thought to have low permeabilities. Additionally, the Dry Lake thrust, and further to the northeast the Glendale thrust, appear to act as partial barriers to, not only White River ground-water flow, but also Meadow Valley ground-water flow, because ground-water levels are fairly uniform on the north side of these thrust systems over a large area, about a 15-20 mile radius from the Muddy Springs. Thus the southern end of these two ground-water flow systems merge into one large system with a very flat gradient to the east-southeast. Even though these fault structures act as barriers to ground-water flow, permeabilities across the fault zones are sufficient to allow a flow of about 36,000 afy to leave the area.

A greater part of ground-water flows from Garnet and Coyote Spring Valleys flows to California Wash with a minor amount moving to the south through the Dry Lake thrust to Black Mountain

Basin. According to Thomas et al., (2001) the spring discharge and phreatophyte ET (~ 2,000 acre-feet/year) at Rogers and Blue Point Springs on the eastern edge of Black Mountain Basin is made up of about 1/3 local recharge with the remainder coming from the White River Flow System. It is also possible that the discharge at these springs is from the Meadow Valley Flow System. If there is additional flow from Black Mountain Basin greater than spring flow and ET, it undoubtedly discharges from the carbonate rocks underlying Lake Mead and the Colorado River. The remainder of the ground water in California Wash probably discharges to the Muddy River up gradient from the Glendale thrust complex with some amount moving through the complex to discharge from the carbonate rocks beneath Lake Mead and the Colorado River.

4.3.2 Meadow Valley Ground-Water Flow System

The Meadow Valley Flow System is very similar to the White River Flow System with numerous valleys linked together by the carbonate rock aquifer and a ground-water gradient to the south. This flow system also discharges in part to the Muddy River in Lower Moapa Valley with the remainder of the flow discharging from the lower carbonate aquifer beneath Lake Mead and the Colorado River.

Lake Valley is the most northern valley in this flow system and ground-water recharge from the Fairview, Fortification and the Wilson Creek Ranges provides most of the ground-water outflow from this valley. As this flow moves south to Patterson Valley it increases in volume from recharge in the southern part of the Fairview Range, the Bristol Range and the southwest part of the Wilson Creek Range. This ground-water flow is separated by topographic divides from valleys to the east, (Spring, Eagle, Rose, and Dry), but is undoubtedly connected hydraulically with them. Flow patterns in these eastern valleys are complicated by several thousand feet of volcanic rocks that overlie the carbonate rock aquifer. Nevertheless, some amount of ground-water recharge occurs in the volcanic rocks and ultimately reaches the underlying carbonate rocks. Because volcanic rocks have considerably less permeability than carbonate rocks some of the potential recharge does not reach the deeper ground-water system, but ends up as surface flow in Meadow Valley Wash

Panaca Valley receives a mixture of ground-water flow from up-gradient areas; carbonate water from Lake and Patterson Valleys and water from volcanic rocks in Spring, Rose, Eagle, and Dry Valleys. There is a significant amount of local recharge in Panaca Valley, mostly from the Highland Range (carbonate rock) to the west and the Clover Mountains (volcanic rock) to the east. All of this flow is tributary to Lower Meadow Valley Wash and the ground-water outflow from Clover Valley.

Ground-water flow in Lower Meadow Valley Wash moves to the south and is in hydraulic connection with ground water from the White River Flow System in the volcanic rocks of the Caliente caldera near Kane Springs Valley. Ground-water flow from Lower Meadow Valley Wash ultimately discharges at great depth from the volcanic rocks to the carbonate rocks and near the southern boundary of the valley is constrained by the northeast end of the Glendale thrust. This thrust, as discussed previously, is in part responsible for the pooling effect defined by wells in the carbonate rocks that have nearly the same water-level in a 15-20 mile radius centered on the Muddy Springs. This reduction in permeability at the fault zone is in part caused by the lower permeabilities of the Mesozoic clastic rocks. However, ground-water flow across and through this thrust does take place along zones of structural weakness and in the fractured carbonate rocks of Paleozoic age and probably to a lessor extent in some of the Mesozoic rocks.

Ground-water outflow from both flow systems is toward the southeast. Some of the outflow surfaces in the Muddy River in Lower Moapa Valley, but most of the flow discharges probably into several fault structures that define the present trace of the Colorado River or to undefined areas to the south.

4.4 GROUND-WATER RECHARGE

Ground-water recharge to the various aquifer systems within the CRBP in the study area starts as precipitation on the recharge areas. Precipitation in the form of snow is probably the most important source of recharge, but winter rain and summer convection storms also add appreciable volumes of water to the general area. Ground-water recharge processes have not been fully defined and there are significant differences in the amount of recharge in the various geologic terrain dependent on rock types and the degree of permeability. Rocks with greater permeability, such as carbonates, have greater amounts of recharge than other types of rocks within the study area. Although we recognize the actual recharge rate is strongly affected by rock type and other factors, the method used to estimate natural recharge in this study, Maxey-Eakin, has been used for over half a century, all over Nevada, in a wide variety of geologic terrains and climatic settings.

4.4.1 Development of Natural Recharge Estimates from Altitude-Precipitation Relationships

Natural recharge for the basins in this study were estimated from precipitation by a technique pioneered in Las Vegas Valley (Donovan and Katzer, 2000). It is conceptually similar to, and borrows heavily from, the Maxey-Eakin technique (Maxey and Eakin, 1949) and is characterized in the report as a "modified Maxey-Eakin". The primary variation between the two techniques is the relationship between altitude and precipitation. Nichols (2000) has also pioneered a new technique for estimating natural recharge but his technique varies significantly from the Maxey-Eakin technique in both the manner in which precipitation and the assumed recharge efficiency (recharge coefficients) are estimated. Nichols' (2000) technique is specifically for use with a modified version of the May 1997 Parameter-elevation Regressions on Independent Slopes Model (PRISM) map by Daly and others (1994) of the Oregon Climatic Service.

The "standard" Maxey-Eakin technique as summarized by Eakin (1966, p. 260-262) has been in use for over a half century and has probably been applied to every valley in Nevada although the estimate may not have been published. When the U.S. Geological Survey (USGS) and the Nevada Division of Water Resources (NDWR) estimated most of the basin budgets, either the standard or variants of the Maxey-Eakin technique were used. Avon and Durbin (1994, p.102) reported investigators deviated from the standard form of the method about 37 percent of the time.

In the "standard" Maxey-Eakin technique the acreage of an individual valley was divided into five altitude intervals listed below in **Table 4-4** (Eakin, 1966, Table 2):

Table 4-4. "Standard" Maxey-Eakin assumptions.

Precipitation Zone (in.)	Altitude Zone (ft.)	Average Annual Precipitation (ft.)	Recharge Efficiency (%)
< 8	< 6,000	Variable	Negligible
8 to 12	6,000 to 7,000	0.83	3
12 to 15	7,000 to 8,000	1.12	7
15 to 20	8,000 to 9,000	1.46	15
> 20	> 9,000	1.75	25

The acreage of the altitude intervals was multiplied by the average precipitation in feet, then multiplied by the recharge efficiency (the percentage of precipitation that becomes natural recharge), then summed to estimate the natural recharge as shown in **Table 4-5**. Typical variation of the technique was modification of the altitude intervals. Implicit in the technique, is that the recharge efficiency is a function of precipitation rather than altitude and at least two precipitation maps Hardman (1936 and 1965) were used in the USGS and NDWR basin reports.

The acreage of the valleys as reported in this study are within 3 percent of the acreage as reported in the various basin reports with exception of Coyote Spring and Muddy Springs Valleys. These small differences are mostly related to round-off, digitizing errors, and map scales. The major increase (~ 25 percent) in Muddy Springs Valley is due to the inclusion of Wildcat Wash which was historically included in Coyote Spring Valley on USGS hydrographic basin maps.

In the modified Maxey-Eakin technique (Donovan and Katzer, 2000), the available precipitation data is selected based on quality (length of record, percentage of record completeness). The data are separated into geographic regions, and processed through regression analysis to determine the local altitude-precipitation relationships. The development of the four local altitude-precipitation relationships, ("general", "dry", "wet", and "WRV") used in this study was described and presented in the Precipitation (4.2) section.

Donovan and Katzer (2000) introduced a slight variation in calculating the Maxey-Eakin natural recharge efficiency coefficients. The coefficients are calculated directly from the precipitation rate using the equation $r_e = 0.05 (P)^{2.75}$ where r_e is the natural recharge efficiency coefficient and P is equal to precipitation rate in feet per year. The only purpose of this equation was to minimize calculation errors and the time required to calculate the estimate of natural recharge. The assumptions of mathematical approximation used by Donovan and Katzer (2000) were the same as Maxey-Eakin; Precipitation falling on areas that receive less than 8 inches is considered ineffective for producing ground-water recharge, the maximum recharge efficiency (25 percent) occurs at 20 inches and the recharge efficiency of the intervening intervals are the same. Donovan and Katzer (2000, p. 1142) reported that the mathematical approximation of the Maxey-Eakin efficiency coefficients reduced the natural recharge estimate by 3 percent when compared to the traditional methodology.

Table 4-5. Comparison of this study to previous Maxey-Eakin (1949) natural recharge estimates.

<table>
<tr><th rowspan="2">Valley</th><th rowspan="2">Acres</th><th colspan="2">Volume of Precipitation (afy)</th><th colspan="2">Ground-water Recharge (afy)</th></tr>
<tr><th>Maxey-Eakin[1]</th><th>This Study</th><th>Maxey-Eakin</th><th>This Study</th></tr>
<tr><td>Long Valley</td><td>416,966</td><td>296,940</td><td>459,937</td><td>10,300</td><td>31,112</td></tr>
<tr><td>Jakes Valley</td><td>271,493</td><td>NR</td><td>312,462</td><td>13,000</td><td>24,194</td></tr>
<tr><td>White River Valley</td><td>1,016,871</td><td>NR</td><td>1,032,143</td><td>40,000</td><td>62,133</td></tr>
<tr><td>Garden Valley</td><td>318,055</td><td>137,080</td><td>320,039</td><td>10,000</td><td>19,153</td></tr>
<tr><td>Coal Valley</td><td>289,998</td><td>62,038</td><td>234,361</td><td>2,000</td><td>7,002</td></tr>
<tr><td>Cave Valley</td><td>229,755</td><td>206,495</td><td>258,445</td><td>14,000</td><td>19,595</td></tr>
<tr><td>Pahroc Valley</td><td>325,289</td><td>56,764</td><td>260,197</td><td>2,200</td><td>7,545</td></tr>
<tr><td>Dry Lake Valley</td><td>574,417</td><td>117,562</td><td>454,998</td><td>5,000</td><td>13,254</td></tr>
<tr><td>Delamar Valley</td><td>231,582</td><td>33,530</td><td>176,189</td><td>1,000</td><td>4,597</td></tr>
<tr><td>Pahranagat Valley</td><td>497,312</td><td>42,640</td><td>344,195</td><td>1,800</td><td>7,407</td></tr>
<tr><td>Kane Springs Valley</td><td>150,429</td><td rowspan="2">48,878</td><td>140,218</td><td rowspan="2">2,600</td><td>6,757</td></tr>
<tr><td>Coyote Spring Valley</td><td>391,621</td><td>224,278</td><td>4,000</td></tr>
<tr><td>Muddy River Springs Area</td><td>92,541</td><td>NR</td><td>38,380</td><td>Minor</td><td>237</td></tr>
<tr><td>Lower Moapa Valley</td><td>175,656</td><td>1,160</td><td>101,358</td><td>50</td><td>1,354</td></tr>
<tr><td>Hidden Valley</td><td>52,435</td><td>11,400</td><td>27,512</td><td>400</td><td>339</td></tr>
<tr><td>Garnet Valley</td><td>101,981</td><td>10,600</td><td>45,268</td><td>400</td><td>393</td></tr>
<tr><td>California Wash</td><td>205,550</td><td>2,000</td><td>75,608</td><td>100</td><td>311</td></tr>
<tr><td>Lake Valley</td><td>354,246</td><td>228,930</td><td>437,170</td><td>13,000</td><td>41,320</td></tr>
<tr><td>Patterson Valley</td><td>267,430</td><td>136,860</td><td>275,015</td><td>6,000</td><td>15,761</td></tr>
<tr><td>Spring Valley</td><td>184,945</td><td>176,600</td><td>212,364</td><td>10,000</td><td>16,151</td></tr>
<tr><td>Eagle Valley</td><td>34,458</td><td rowspan="6">197,810</td><td>36,927</td><td rowspan="6">8,000</td><td>2,349</td></tr>
<tr><td>Rose Valley</td><td>7,647</td><td>7,349</td><td>352</td></tr>
<tr><td>Dry Valley</td><td>76,339</td><td>77,388</td><td>4,237</td></tr>
<tr><td>Panaca Valley</td><td>220,435</td><td>204,587</td><td>9,041</td></tr>
<tr><td>Clover Valley</td><td>231,964</td><td>223,852</td><td>10,557</td></tr>
<tr><td>Lower Meadow Valley Wash</td><td>605,723</td><td>523,247</td><td>22,823</td></tr>
<tr><td>Black Mountains Area</td><td>408,919</td><td>132,254</td><td>132,254</td><td>100</td><td>438</td></tr>
<tr><td>Total</td><td>7,734,059</td><td>1,899,541</td><td>6,635,742</td><td>147,950</td><td>332,413</td></tr>
</table>

[1] *Only represents precipitation greater than 8 inches.*

In estimating the precipitation for this study, the standard assumption that precipitation less than 8 inches is "ineffective" had no impact on the estimation of natural recharge in valleys where the "general" and "WRV" local altitude-precipitation relationship was used. These are generally high northern valleys with minimal or no acreage below 5,000 feet. All of the local altitude-precipitation relationships predict, and the available gage suggests, that all of the acreage above 5,000 feet of altitude in the study area receive greater than 8 inches of precipitation. This assumption also had no effect on the only northern valley (Lake) where precipitation was estimated using the "wet" local altitude-precipitation relationship.

It was observed, however, (**Figure 4-9**) that, in valleys where the "wet" local altitude-precipitation equation was used to estimate precipitation the interval between 3,000 and 4,000 feet of elevation is about 7.6 inches. It was also noted that, in valleys where the "dry" local altitude-precipitation equation was used to estimate precipitation the interval between 4,000 and 5,000 feet of elevation is about 7.9 inches.

These transitional altitude intervals are a significant amount of acreage in the valleys in the central and southern parts of the study area. If the standard Maxey-Eakin assumptions are used, the precipitation in these intervals could either be considered "ineffective" (none of the precipitation in these areas becomes natural recharge), or partially effective (part of the precipitation could have been included in the recharge estimate). Another possibility exists however.

When Pohlmann and others (1998) analyzed the springs in the Lake Mead area, using stable and radio isotopes they concluded that the recharge sources of one-third of springs are "local" and low altitude. The area described in Pohlmann and others (1998) is the southernmost valley (Black Mountains Area) of this current study area **(Figure 4-1)**. Most of the area is at low altitude (< 3,000 feet) and the highest peak, Muddy Peak, is at an altitude of 5,363 feet. The use of the term "local" introduces the idea that precipitation below 8 inches may be "effective" although the recharge efficiency is very low (less than a percent). Eakin's (1966, p. 260-262) summary of the Maxey-Eakin method characterizes recharge in areas that receive less than 8 inches of precipitation as "negligible" rather than "none".

The Maxey-Eakin technique, as originally developed, is a step function designed for use with paper maps, planimeters, and adding machines. As long as the precipitation is reported by the same irregular intervals (8, 12, 15 and 20 inches of precipitation) of the traditional method no confusion exists as to the appropriate recharge efficiency coefficients. If an alternative precipitation map with either regular intervals (NDWR, 1971), other irregular intervals (some variations of the PRISM map), or in units other than feet and inches (meters, centimeters, millimeters) questions arise about the appropriate recharge efficiency coefficients to use near the break points. Because the Donovan and Katzer's (2000) mathematical approximation of the Maxey-Eakin efficiencies is a continuous function it can easily be used in conjunction with non-traditional precipitation maps and estimates.

Donovan and Katzer (2000) examined the potential use of the equation to estimate the natural recharge efficiency directly from the precipitation estimate of a given altitude interval ($r_e = 0.05 (P)^{2.75}$) for estimating the recharge efficiency coefficients for areas that receive less than 8 inches of precipitation. The increase in the Las Vegas Valley natural recharge estimate would have been about 5 percent.

Because of the large size of the transitional altitude areas in this current study, the same logic was applied. The increase in the natural recharge estimate in the whole area is about 3.5 percent from about 321,000 afy to 332,000 afy. As mentioned previously, modification of the assumption that precipitation of less than 8 inches is "ineffective" has no effect on the recharge estimate of the high altitude northern valleys and a minor increase (5 percent) in the Lower Meadow Valley natural recharge estimate. The largest percentage increases are in the 5 small valleys (including the Black Mountains Area) where recharge is estimated to be less than 500 afy and the one valley

(Lower Moapa) where the recharge is estimated to be about 1,400 afy. In the center of the study area where there are large areas of the transitional altitude zones, the natural recharge estimate for the valleys increased by about 20 percent. The 20 percent increase in the natural recharge estimate was assumed to be similar to the increase that would have occurred if the altitude intervals were adjusted, as was done on many Maxey-Eakin analysis, to include part of the acreage (the part of the area that receives greater than 8 inches) of the transitional altitude intervals.

Table 4-6 summarizes the natural recharge estimates used in this study. The complete analysis is included in Appendix A. Note: The recharge within the modeled area is reported as 37,000 afy because it is rounded off to the nearest 1,000 afy. The actual estimated natural recharge within the modeled area is 36,652 afy, which was rounded to 37,000 afy in the ground water model.

Although this approach is a partial modification of the Maxey-Eakin assumptions, there are several advantages. One advantage is that the distribution of the Maxey-Eakin natural recharge efficiency coefficients for precipitation greater than 8 inches is preserved within Donovan and Katzer (2000) mathematical approximation. The Maxey-Eakin technique and the USGS and NDWR basin reports have well served the citizens of Nevada, for over half a century by consistent use of a simple, easy to understand, natural recharge estimation technique with a reasonable distribution of the relationship between precipitation and natural recharge coefficients. Another advantage of the approach used in this study is consistency, because a uniform methodology is applied to all of the precipitation that is estimated to fall on any valley. Two natural recharge analyses using two radically different precipitation maps can be compared directly on the influence of the precipitation estimate alone rather than on a combination of the precipitation distribution and the technique used to estimate natural recharge. The Hardman precipitation maps (1936, 1965) are no longer the only estimates of precipitation distributions available. Since the early 1990s, PRISM through it's widespread availability on the Internet, support by, and linked to, websites of important sources of climatic information like Desert Research Institute's Western Regional Climate Center (WRCC) (http://www.wrcc.dri.edu/precip.html), and The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service, SCS) (http://www.ftw.nrcs.usda.gov/prism/prism.htmldistribution), is the most commonly used precipitation distribution map.

There are also disadvantages to the approach used to estimate natural recharge in this study. The approached used is a modified Maxey-Eakin therefore the advantages of the method are the advantages of the Maxey-Eakin (consistency, ease of use) and the disadvantages are the same as those of the Maxey-Eakin. Although the relationship between precipitation and natural recharge is reasonable, it is an assumption (non-unique), since the natural recharge estimate is strongly dependent on the precipitation estimate. The relationship between natural recharge and mountain front runoff is not intuitive. No factor that actually determines what portion of precipitation becomes natural recharge is actually included in the estimation technique. A short list of these factors includes: rock type, vegetation, average temperature, soil type, form (snow or rain) of the precipitation, typical storm size and duration, and the time of year when the precipitation occurs.

Table 4-6. Summary of annual natural recharge estimated for this study.

Valley No.	Valley Name	Area (ac.)	Total Estimated Precipitation (af.)	Natural Recharge Estimate (af)		Within Model Area
				A	B	
175	Long Valley	417,000	460,000[4]	31,000	31,000[a]	Tributary
174	Jakes Valley	271,000	312,000[4]	24,000	24,000	Tributary
207	White River Valley	1,017,000	1,032,000[4]	62,000	62,000	Tributary
172	Garden Valley	318,000	320,000[4]	19,000	19,000	Tributary
171	Coal Valley	290,000	234,000[2]	6,000	7,000	Tributary
180	Cave Valley	230,000	258,000[4]	20,000	20,000	Tributary
208	Pahroc Valley	325,000	260,000[2]	7,000	8,000	Tributary
181	Dry Lake Valley	574,000	455,000[2]	11,000	13,000	Tributary
182	Delamar Valley	232,000	176,000[2]	4,000	5,000	Tributary
209	Pahranagat Valley	497,000	344,000[2]	5,000	7,000	Tributary
206	Kane Springs Valley	150,000	140,000[3]	7,000	7,000	Modeled
210	Coyote Spring Valley	392,000	224,000[2]	3,000	4,000	Modeled
219	Muddy River Springs Area	93,000	38,000[2]	5	200	Modeled
220	Lower Moapa Valley	176,000	101,000[3]	400	1,400	Modeled
217	Hidden Valley	52,000	28,000[2]	150	300	Modeled
216	Garnet Valley	102,000	45,000[2]	150	400	Modeled
218	California Wash	206,000	76,000[2]	0	300	Modeled
183	Lake Valley	354,000	437,000[3]	41,000	41,000	Tributary
202	Patterson Valley	267,000	275,000[1]	16,000	16,000	Tributary
201	Spring Valley	185,000	212,000[1]	16,000	16,000	Tributary
200	Eagle Valley	34,000	37,000[1]	2,000	2,000	Tributary
199	Rose Valley	8,000	7,000[1]	400	400	Tributary
198	Dry Valley	76,000	77,000[1]	4,000	4,000	Tributary
203	Clover Valley	220,000	205,000[1]	11,000	11,000	Tributary
204	Panaca Valley	232,000	224,000[1]	9,000	9,000	Tributary
205	L. Meadow Valley Wash	606,000	523,000[3]	22,000	23,000	Modeled
215	Black Mountains Area	409,000	132,000[2]	5	400	Modeled
	Totals	**7,734,000**	**6,636,000**	**321,000**	**332,000**	**37,000[5]**

Recharge estimate "B" is the estimate used in this study, Estimate "A" is provided only for comparison.
[1] Precipitation was estimated using the "general" local altitude-precipitation relationship (Section 4.2)
[2] Precipitation was estimated using the "dry" local altitude-precipitation relationship (Section 4.2)
[3] Precipitation was estimated using the "wet" local altitude-precipitation relationship (Section 4.2)
[4] Precipitation was estimated using the "WRV" local altitude-precipitation relationship (Section 4.2)
[5] Total natural recharge of modeled area, Actual estimate = 36,652 acre-feet per year, Area = 2,186,000 acres, Total estimated precipitation = 1,307,000 acre-feet per year
[a] Only 23,000 afy is used in total because of ground-water outflow to non-White River Flow System Valleys based on proportionality of outflow defined by Nichols (2000).

Maxey-Eakin is one of numerous natural recharge estimation techniques, although it is the oldest and most commonly used in Nevada. In addition to numerous geochemical techniques, which include: conservative ion (usually Chloride), stable isotopes (Hydrogen and Oxygen), radiogenic isotopes (Chloride, Carbon, Uranium, etc..), tracers (chemical and isotopic) and combinations of the various technique appropriate at the "local" or regional scale. There are other empirical precipitation "budget" types techniques conceptually similar and dissimilar to Maxey-Eakin. There are also manual and computerized (models) techniques related to the Darcy equation. There are other runoff estimation techniques that may or may not include an estimate of the natural recharge. At least one natural recharge technique is strongly tied to soil types. All of these grow out of standard assumptions from Civil Engineering, Chemistry, Hydrology, Climatology and Soil Physics, and Biological Sciences.

An example of an empirical precipitation "budget" type of technique that are dissimilar to the Maxey-Eakin was discussed in Harrill and Prudic (1998, p A25). This technique is defined by the equation: $\log Q_r = -1.74 + 1.10 \log P_{p>8}$. Where Q_r is equal to the total natural recharge estimate in afy and $P_{p>8}$ is equal to the total volume of precipitation, where average annual precipitation is greater than 8 inches. This was developed following the example of Anderson (1985, p. 102-103) for the Southwest Alluvial Basins study area. Anderson's equation for southern Arizona is: $\log Q_r = -1.40 + 0.98 \log P_{p>8}$. Use of these equations implies that the total natural recharge estimate can be estimated directly from the total "effective" precipitation and all of the "effective" precipitation is equally "effective". This is very different conceptually from the Maxey-Eakin because the various recharge efficiency zones are distributed over the range of precipitation. The primary assumption in the Maxey-Eakin method is that higher precipitation rates yield a higher percentage of natural recharge, they further specify that the distribution of the percentages increase in a specific non-liner relationship with respect to increases in precipitation.

4.4.2 Mountain-Front Runoff

Mountain front runoff has its origin in precipitation that falls on mountain blocks. It is one component of precipitation that exits the mountain block in three ways. The other two are ground water recharge and evapotranspiration. Even though these are separate processes they are greatly interrelated. Mountain front runoff is defined as the volume of surface water that crosses the contact between the consolidated rocks of the mountain block and the unconsolidated sediments of the alluvial basin. How does it occur? It is caused when water from melting snow or rain literally runs off of the mountain block. This occurs when the infiltration capacity of the soil and rock and the evapotranspiration rate is exceeded by the volume of available water. Precipitation that infiltrates through the soil mantel and escapes evapotranspiration and moves down-gradient is often intersected by a drainage channel or is brought to the surface by springflow. Also fractures in the mountain block intercept ground water flow and provide a conduit to the surface where the water emerges from spring orifices. Thus ground water, which started as surface water, reappears through specific springflow orifices or as diffuse springflow and is considered once again to be surface water. This surface water is subject to evapotranspiration during its transient time to the valley and also, depending on other hydrogeologic parameters, may reinfiltrate to the ground water system. Springflow that does not reach a channel in sufficient volume to create runoff either evapotranspires or reinfiltrates to the ground water system once more becoming ground water recharge. Depending on the individual drainage, surface water runoff in perennial streams probably always has a component of ground water in it when it reaches the mountain front contact.

There is a significant amount of runoff into many of the valleys from ephemeral drainages, which do not have a ground-water component. The flow in these channels is generally sudden and last for perhaps just a few short days one or more times a year. In an effort to account for some of this runoff that potentially can become ground-water recharge we have extended the recharge efficiencies down to the lowest altitude in those basin that receive precipitation less than 8 inches as defined by the altitude precipitation relationships discussed previously. In an effort to collaborate this low-altitude recharge process we evaluated the ephemeral flow in Kane Springs and Coyote Spring Valleys using a technique described by Hedmen and Osterkamp (1982). This technique is based on certain channel characteristics that are formed by the discharge of water and sediment in a natural channel. The magnitude, duration, and frequency of flows dictate stream channel geometry, with additional control imposed by the distribution and size of sediment on the channel bed and banks. The channel characteristic measured in the ephemeral tributaries was the active channel width and the equations governing its use are found in Hedman and Osterkamp (1982, Table 2, p. 13, equations 12 -15). The standard error for these equations has not been determined, but is believed to be large, perhaps as much as 50 percent. The results of these measurements are listed in **Table 4-7** and the sites are shown on **Figure 4-10**. Measurements could not be made at some sites for a variety of reasons and the notation of ND (not determined) is indicated.

The results of this limited investigation show there may be a minimum of ~3,000 afy of runoff in Kane Springs Valley and nearly the same amount in Coyote Spring Valley that is lost from the respective channels. In reality there is probably much more, but because of tributary inflow and lack of reliable data, sites measurements could not be made. Some amount of this water that saturates the channel beds is lost to the atmosphere through ET and the remainder, probably a large percentage because of the coarse-grained nature of the channel sediments, infiltrates through the channel bed and moves down the soil column to the water table as ground-water recharge.

In this study all of Kane Springs Valley is in the precipitation zone that produces ground-water recharge, yet there is a significant amount of runoff from the mountain block that may be unaccounted for in the Maxey-Eakin method. If this is true then the amount of ground-water recharge estimated for this valley is conservative. Conversely this runoff may simply be rejected recharge from the mountain block because of the low permeabilities of the volcanic rock. In Coyote Spring Valley parts of the basin are below the effective precipitation threshold of 8 inches and by extending the Maxey-Eakin method to include this area results in an additional 1,000 afy (**Table 4-6**) of ground-water recharge. This value is within the estimated ground-water recharge that takes place as a result of mountain front runoff. This process of ground-water recharge from ephemeral channels has been discussed by other investigators such as Glancy and Van Denburgh (1969), Osterkamp et al (1994), Berger (2000a and b), and Savard (1998).

4.5 GROUND-WATER DISCHARGE

Discharge from the basins in pre-development times was by spring flow, evapotranspiration, and ground- and surface-water outflow. In some of the basins there has been no significant development and hydrologic conditions remain unchanged. In other basins there has been a high degree of water-resource development and pumpage for agriculture has replaced or is additive to spring flow use by phreatophytes. In some basins evapotranspiration increases yearly as

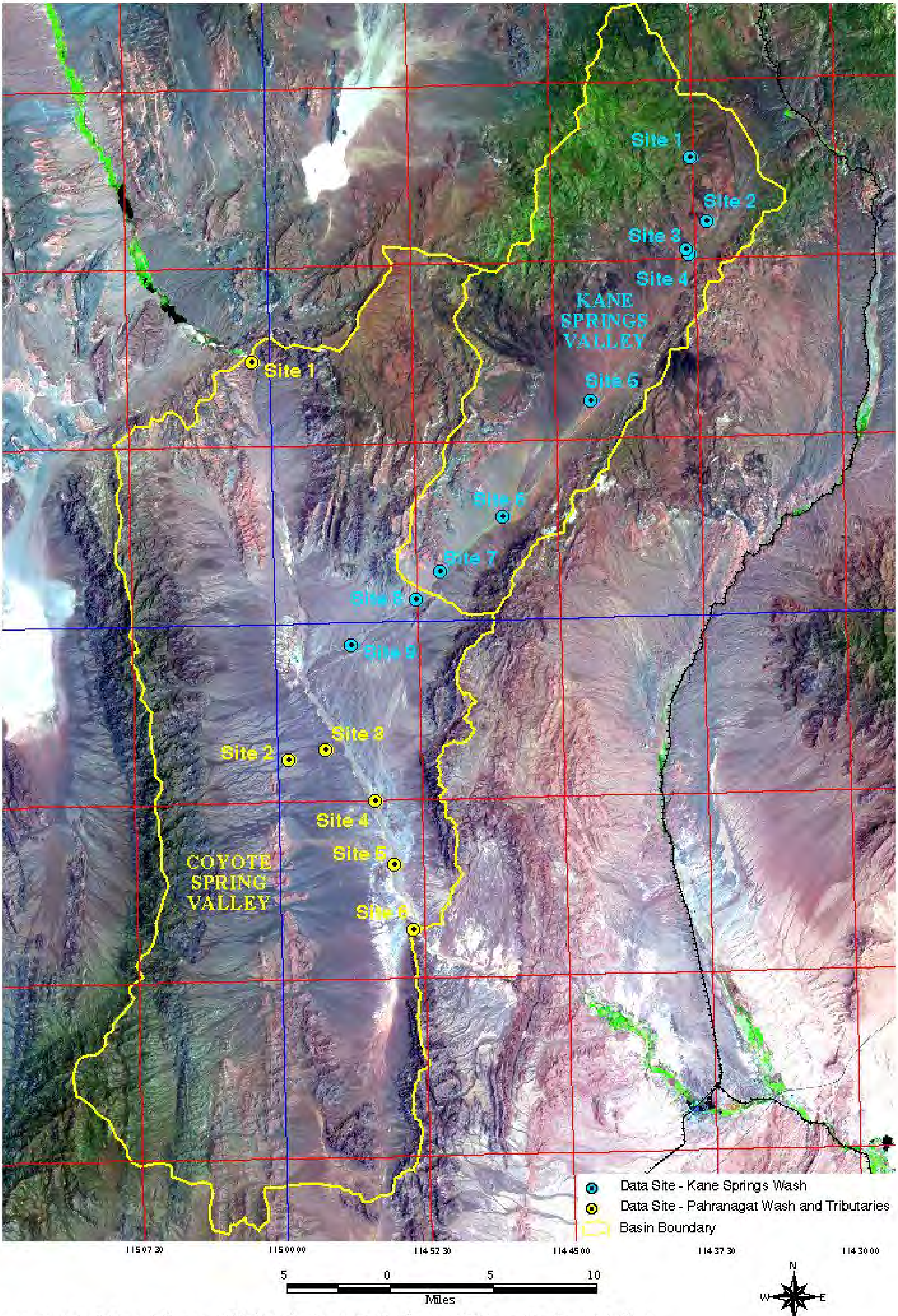

Figure 4-10. Mountain runoff sites in Coyote Spring and Kane Springs Valleys.

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urbanization continues. Regardless of the amount of ground-water pumpage ground-water outflow remains about the same in many of the basins simply because of the vast amount of ground water in storage in the various aquifer systems.

Discharge from the Colorado River Basins is by ground-water outflow and ET. Many of the basins have significant discharge by both processes, but it is the discharge through the ET that dominants the hydrologic system. Little of this discharge can be actually measured and inter-basin flow can only be inferred with large potential errors. The value that represents this flow is usually the difference between the estimated recharge and the estimated ET. There are several large springs that discharge from carbonate rocks and are assumed to represent part of the inter-basin flow. The most critical of these springs with regard to the purpose of this study are the Muddy River Springs. The measured discharge from these springs represents a significant amount of ground-water flow from the White River flow system. A lessor amount of flow has also been gaged from Rogers and Blue Point Springs. These are the only points in the lower part of the flow systems where actual measurements with time have been made.

Ground-water outflow from the model area occurs over a broad front as described in the Ground-Water Movement and Model Section. The fate of this outflow is unknown, but believed to be the fault structure that contains the lower Virgin/Muddy River or even the Colorado River. How is it possible that 36,000 afy could be tributary to a river system yet unknown by geologists mapping the Colorado River prior to the construction of Hoover Dam? The only model we have to answer such a question is the Littlefield Springs in the Lower Virgin River in Arizona. These springs have been described by Glancy and Van Denburgh (1969), Trudeau (1979), and Cole and Katzer (2000). The average discharge of these springs is about 50 - 60 cfs, not dissimilar to the outflow from the study area, and provides the base flow of the Lower Virgin River. Well over a hundred spring orifices and seeps discharge directly to the river from the channel bed and banks over about eight miles, which equals an acreation rate of about 7 cfs per linear mile of channel. Most of these orifices are within the low-water channel and can not be seen unless the river is at very low flow and there is virtually no sediment being transported. This is a condition never seen in the Colorado River, which by contrast is wide, deep and carries a large sediment load that would preclude the observation of springs emanating from its bed and lower banks. This is one explanation of several for ground-water outflow from the White River and Meadow Valley Flow Systems.

Table 4-7. Mountain Front Runoff at Selected Sites in Coyote Spring and Kane Springs Valley.

Site No. on Figure	Active Channel Width (ft.)	Annual Runoff (af.)	Estimated Channel Loss (afy)	Channel Sediment Characteristics
COYOTE SPRING VALLEY				
1	7	200		Some cobbles, gravel and sand
2	18	880	700	Cobbles, gravel and sand
3	7	200		Gravel
4	26	1,600		Course sand
5	43	3,400	2200	Minor gravel, coarse sand
6	22	1,200		Gravel, coarse sand, some silt
KANE SPRINGS VALLEY				
1	25	1,460	700 }200	Boulders ~ 4 ft., cobbles, gravel
2	17	800		Boulders, cobbles, gravel, coarse sand
3	14	600		Boulder, cobbles, gravel
4	29	1,840		Gravel, sand; cobbles/boulders
5	30	1,940	700	Gravel and coarse sand
6	22	1,200		Gravel and coarse sand, some cobbles, and silt
7	36	2,600	}400 }400	Gravel and coarse sand
8	33	2,250		Gravel and coarse sand
9	29	1,850		Gravel and coarse sand
Total			**5,300**	

4.5.1 Evapotranspiration

Evapotranspiration (ET) is the process whereby water is returned to the atmosphere through evaporation from soil, wet plant surfaces, open water bodies and transpiration from plants. The type of plants we are most concerned with are termed phreatophytes as first defined by Meinzer (1927) as "plants that habitually grow where they can send their roots down to the water table or the capillary fringe immediately overlying the water table and are then able to obtain a perennial and secure supply of water". The plant assemblage of interest is composed primarily of greasewood (*Sarcobatus vermiculatus*), saltgrass (*Distichlis spicata*), rabbitbrush (*Chrysothamnus nauseosus*), saltbush (*Atriplex canescens*), spiny hopsage (*Grayia spinosa*), shadscale (*Atriplex confertifolia*), and big sagebrush (Artemisia tridentata). There is also a riparian plant assemblage that is of interest and this includes cottonwood (*Populus fremontii*), willow (*Chilopsis linearis*), saltcedar (*Tamarix ramosissima*), mesquite (*Prosopis glandulosa*), and tules (*Typha sp.*).

Water-use rates for phreatophytes in the study area were first estimated starting nearly a half century ago. More recently, in the last ten years, research has shown that the early estimates of water use were low. This recent research in Nevada was conducted mainly by the University of Nevada, Department of Biological Sciences, and the USGS. Of particular importance is the work of Devitt et al., (1998) who conducted a three year study of ET from a stand of salt cedar on the floodplain of the lower Virgin River about 3 miles upstream from Lake Mead. The ET rate varied from a low of 2.8 af to a high of 4.8 af and these values may not represent the actual minimum and maximum caused by climatic differences. This particular ET rate is controlled by the availability of relatively shallow ground water provided by recharge from stream flow, canopy development, atmospheric demand, and the degree of advection (Devitt et al., 1998). Smith et al. (1998) have indicated that the leaf-level transpiration rates along the Virgin River are similar to native species, but in general have a higher transpiration rate than do other native plants. These interpretations probably apply in general to ET throughout the study area and in particular to Lower Meadow Valley Wash and the Muddy River area. In Las Vegas Valley Devitt et al. (in review, 2000) reevaluated ET first estimated by Malmberg (1965) for pre-development conditions in 1905. This reevaluation shows an increase in ET over the original USGS estimate by about 60 percent.

USGS research conducted by Nichols (2000) in 16 valleys in central and eastern Nevada also dramatically increases the ET compared to the original estimates made by earlier USGS investigators. Nichols (2000) increased the ET by an average factor of about 2.7. To match this discharge requires an increase in ground-water recharge of about 2.8 times the original estimates. Nichols (2000) showed that ET rates vary widely, and are similar to the variability defined by Devitt et al. (1998) along the Virgin River. This variability of ET with time and changing climatic conditions casts some uncertainty into ground-water budgets that rely on annual averages.

The two valleys that are common to this study and the study by Nichols (2000) are Long and Jakes Valleys. The ground-water recharge and discharge for these two valleys used in this study are based entirely on the techniques and data described in this study. We did use Nichols' (2000) estimate of ET for both valleys and his distribution of outflow by percent from Long Valley. In other valleys of this study (White River, Garden, Cave, Pahranagat, Lake, Patterson, Spring, Eagle, Rose, Panaca, and Clover) the ET rate for phreatophytes was estimated based on plant density, usually estimated between 10 and 20 percent and an average leaf area index of 2. These factors were substituted into Nichols equation No. 3 (2000, Chapter A, p. A6) to estimate the annual ET rate based on plant cover. The ET rate is very sensitive to densities under 35 percent and, for instance, a 5 percent increase from 15 to 20 percent nearly doubles the rate.

ET rates for Valleys in the model area are based on the work of Devitt et al. (1998, and in review 2001). The same ET rate of 5 af/acre/year is used throughout this area for agriculture and phreatophytes. This rate was used by the USGS and is in the range reported by the HRCS.

The land use and acreage were determined from LANDSAT scenes (July 1998) and virtually all areas were field checked. In the southern end of the flow systems aerial photographs for 1953 and 2000 were used in addition to LANDSAT scenes. Water-use rates used in this study are listed in **Table 4-8** and are compared to rates used by previous USGS investigators for phreatophytes and the Natural Resource Conservation Service (NRCS, formally the Soil Conservation Service) for agriculture. Additionally, and not referenced in **Table 4-8**, are the evaporation rates from open water; these values were taken from Shevenell (1996). The specifics of the valleys in the study area are discussed as follows:

Table 4-8. Water-use rates for valleys with significant ground-water discharge.

Valley	Land use[1] and area (ac.)	Water-Use Rates				
		Acre-feet/acre/year[2]			Volume (afy)	Total Volume (afy/valley)
		This study	USGS[3]	NRCS[4]	This study	This study
Long[5]	P/21,882	--	Variable	--	--	11,000
Jakes[5]	P/416	--	Variable	--	--	600
White River[6]	P/147,211	0.3	6/	--	44,736	
	A/14,736	2.0	--	2 - 4.5	29,472	
	W/1,975	3.0	--	--	5,925	79,560
Garden[7]	P/6,144	0.75	--	--	4,608	4,608
Cave[8]	P/9,272	0.3	--	--	2,781	
	A/1,021	2.0	--	2 – 4.5	2,042	4,823
Pahranagat[6]	P/1,431	0.45	6/	--	644	
	A/6,256	5.0	--	3.5 - 6	31,280	
	W/1,289	5.0	--	--	6,445	38,369
Upper Muddy	P/1,016	5.0	5.0	--	5,080	5,080
California Wash	P/1152	5.0		--	5,760	5,760
Lake	P/6,654	0.45	0.1 – 1.5	--	2,994	
	A/6,883	3.0	--	2.5 -5	20,649	23,643
Patterson	A/1,607	3.0	--	2.5 - 5	4,821	4,821
Spring	P/1,548	0.45	0.1 – 1.5	--	697	
	W/45	3.0	--	--	135	832
Eagle	A/549	2.0	3.0	2.5 - 5	1,098	1,098
Rose	A/350	2.0	3.0	2.5 - 5	700	700
Dry	P/153	0.45	0.1-0.2	--	69	
	A/2,039	2.0	3.0	2.5 - 5	4,078	
	W/58	4.0	--	--	232	4,379
Panaca	P/145	0.45	0.1-0.2	--	65	
	A/8,649	3.0	3.0	2.5 - 5	25,947	26,012
Clover	P/101	0.45	0.2-0.5	--	45	
	A/1,066	2.0	3.0	2 - 4	2,132	2,177
L. Meadow Valley Wash	P/3,854	5.0	0.1-3	--	19,270	
	A/1,576	5.0	5.0	3 - 7	7,880	27,294
Lower Moapa	P/5,301	5.0	--	5 - 7	26,505	26,505

1 *Abbreviations: P, Phreatophytes; A, Agriculture; and W, open water.*
2 *If no value is listed then no estimate was made or the estimate was not available.*
3 *Values referenced are from appropriate USGS Reconnaissance and Bulletin Series.*
4 *Consumptive use values according to the Natural Resource Conservation Service (NRCS, formally the Soil Conservation Service,1981), taken from sites closest to indicated valley (rounded to nearest half foot) and represent the range for alfalfa and pasture.*
5 *Nichols (2000, p. C42-43).*
6 *Eakin (1966, Table 1) indicates that evapotranspiration is equal to regional spring discharge.*
7 *Land use acreage includes several hundred acres of undifferentiated agriculture*

4.5.1.1 White River Valley

There are three types of ET that represent current conditions; ET from phreatophytes, agriculture, and open water. Clearly this was not the case in predevelopment times, because there was no agriculture. However, phreatophytes and open water under natural conditions most likely covered the land that is currently being irrigated. There are some irrigated lands on higher parts of the alluvial fans that undoubtedly did not support phreatophytes, but it was beyond the scope of this project to make this determination. Eakin (1966) did not map the phreatophytes, but simply indicated that ET probably took up the spring discharge of 37,000 acre-feet/year. We believe the valley, under natural conditions, had a very high water table near land surface over large areas with extensive marsh land and that the ET rate was much greater than estimated by Eakin. Ground-water levels remain high today along the central axis of the valley, in spite of the numerous wells used for irrigation. Thus ground-water discharge and associated land areas under natural conditions are replaced by pumping for agriculture. We assume the higher rate of ET for agriculture verses the ET rate for phreatophytes is justified to represent natural conditions. The total ET for this valley is estimated at 80,000 acre-feet/year and it falls within the range and magnitude for other large valleys where ET was estimated by Nichols (2000), such as Railroad Valley to the west and Steptoe and Spring Valleys to the east.

4.5.1.2 Garden Valley

There are agriculture lands that are adjacent to perennial drainages such as Cherry and Pine Creeks. These are prime areas for phreatophytes and we believe under natural conditions the lower reaches of these drainages and their relatively small flood plains were covered with phreatophytic vegetation. Many of the canyons draining the east slope of the Quinn Canyon Range and the southern end of the Grant Range have numerous springs of varying discharge. Most of this water is captured by local ET, but some undoubtedly infiltrates to the valley ground-water system. Eakin (1966, Table 1) estimated 2,000 acre-feet/year for ET and we have increased this estimate to 5,000 acre-feet/year.

4.5.1.3 Cave Valley

The single estimate of ET is reported by Eakin (1966, Table 1) to be a few hundred acre-feet/year, however there is a large playa with a healthy stand of greasewood in the south end of the valley. A monitoring well constructed on the southwest side of the playa within the greasewood assemblage showed the water table to be about 30 feet below land surface. The water is obviously perched because most of the other wells (Brothers et al., 1993, Table 1, p. 6) have reported depths over 100 feet to water. Even though part of the ground-water system is perched it is still part of the total water resource for the valley. If the water were not perched it would have infiltrated to the main valley aquifer. The playa altitude is about 6,000 feet, nearly 1,000 feet lower than the north end of the valley so ground water could have reached the playa from the north. However, because the valley floor is well within altitudes commonly accepted as recharge areas we believe there is a component of ground-water recharge that takes place directly from the valley floor and is the principal source of the perched water table. There are other numerous springs in the mountain blocks and there is some agriculture of mostly meadow grass. We estimate the ET for this valley at 5,000 acre-feet/year.

4.5.1.4 Pahranagat Valley

This long and narrow valley floor has been converted from phreatophytes to agriculture. Under natural conditions the floor was probably covered by a dense growth of phreatophytes that, according to Eakin (1966, Table 1) consumed only the estimated regional spring discharge of 25,000 acre-feet/year. Our rationale for increasing this amount to 38,000 acre-feet/year is the same as discussed previously for White River Valley. Water levels were probably shallow and resulted in large marshy areas in the southern and northern parts of the valley. The now breached and dry Maynard Lake at the extreme south end of the valley probably indicates the abundance of water during natural conditions and a redistribution of ET under current conditions.

4.5.1.5 Upper Muddy Springs

The hydrographic area for the Muddy Springs has about 5,000 afy of natural ET. The distribution of ET upstream and downstream of the USGS gage (Muddy River near Moapa) is about 3,000 and 2,000 acre-feet/year respectively. The estimated ET (this study) upstream from the river gage agrees closely with Eakin's (1966, Table 1) original estimate of 2,300 acre-feet/year. Unlike ET estimates in other valleys current conditions for ET were not estimated. The reason for this is natural ET conditions were needed to determine if there were any impacts to total spring discharge. Within error of all hydrologic measurements by many investigators, the volume of spring discharge today appears to be equal to predevelopment conditions.

4.5.1.6 California Wash

Phreatophytic vegetation along the Muddy River corridor during predevelopment conditions was probably dominated by Mesquite and salt grass. The relatively flat flood plain where these phreatophytes grew has been converted to agriculture. We estimate the predevelopment ET was about 6,000 afy.

4.5.1.7 Lake Valley

Spring discharge along the west side of the valley undoubtedly accounted for much of the predevelopment ET. The larger springs are in the northwest part of the valley and under natural conditions there would have been an even larger marshy area than there is today. There is a large amount of agriculture land currently under production that is irrigated by ground-water pumpage and water levels are within a few 10s of feet of land surface throughout much of the valley. We believe that most, if not all, of this land was type converted from natural areas of phreatophytes, mostly the greasewood assemblage, to agriculture. ET for this valley is estimated at 24, 000 afy and is assumed to represent predevelopment conditions.

4.5.1.8 Patterson Valley

There are no remnants of natural ET left in this valley. The estimated ET today of about 5,000 afy is based on agriculture usage. Under natural conditions there was probably a much higher water table than currently exists and Patterson Wash would have had a significant amount of phreatophytes, mostly greasewood, particularly along its lower reach.

4.5.1.9 Panaca Valley

The predevelopment water table in this valley was undoubtedly very near land surface, and despite large scale agricultural development, large areas of standing water are common. Meadow Valley Wash is perennial today and even though there are significant still flows several thousand afy. So under natural conditions the flow was probably much larger. Additionally permeable carbonate rocks are at land surface and are in contact with less permeable volcanic rocks which tends to bring water closer to land surface. Phreatophytes and marsh land probably occupied much of the lands now under agriculture, and the predevelopment ET is estimated to be about 26,000 afy.

4.5.1.10 Remaining Valleys in the White River Flow System

Coal, Pahroc, Dry Lake, Delamar, Kane Springs, Coyote Spring, Hidden, and Garnet Valleys have only small amount of ET. The ET from Hidden and Garnet Valleys is virtually zero. The ET was estimated at a token 1,000 acre-feet/year for each of the other valleys to account for local spring discharge that is consumed including evaporation from bare soil. Most of the springs in these valleys are in the mountain blocks, some have been developed for stock watering. The hydrology of Black Mountain is dominated by surface flow in Las Vegas Wash and also the ET along the wash. These components are not part of this study

Estimates of ET and ground-water outflow are listed in **Table 4-9** and are compared to previous USGS estimates. In general the ET has been increased significantly in this study compared to previous estimates, although only minimally in some valleys. Ground-water outflow is also increased because the ground-water recharge is much higher than previously estimated.

4.5.2 Spring Flow in Model Area

Surface-water discharge in the model area occurs in Kane Springs Wash, Coyote Spring Valley, Lower Meadow Valley, California Wash, the Muddy Springs Area, and Black Mountains Area. The major springs in the model area are shown in **Figure 4-11**.

Several small springs discharge in Kane Springs Wash, Coyote Spring Valley, and California Wash at rates generally less than a few hundred acre-feet per year. The discharge from these springs is consumed locally through ET. In Kane Springs Valley the numerous small "local" springs are not part of the large regional carbonate aquifer system. These local springs are generally in volcanic rock and reflect local recharge and discharge. A single discharge point at the location of Kane Springs was used in the ground-water model to represent the diffuse local

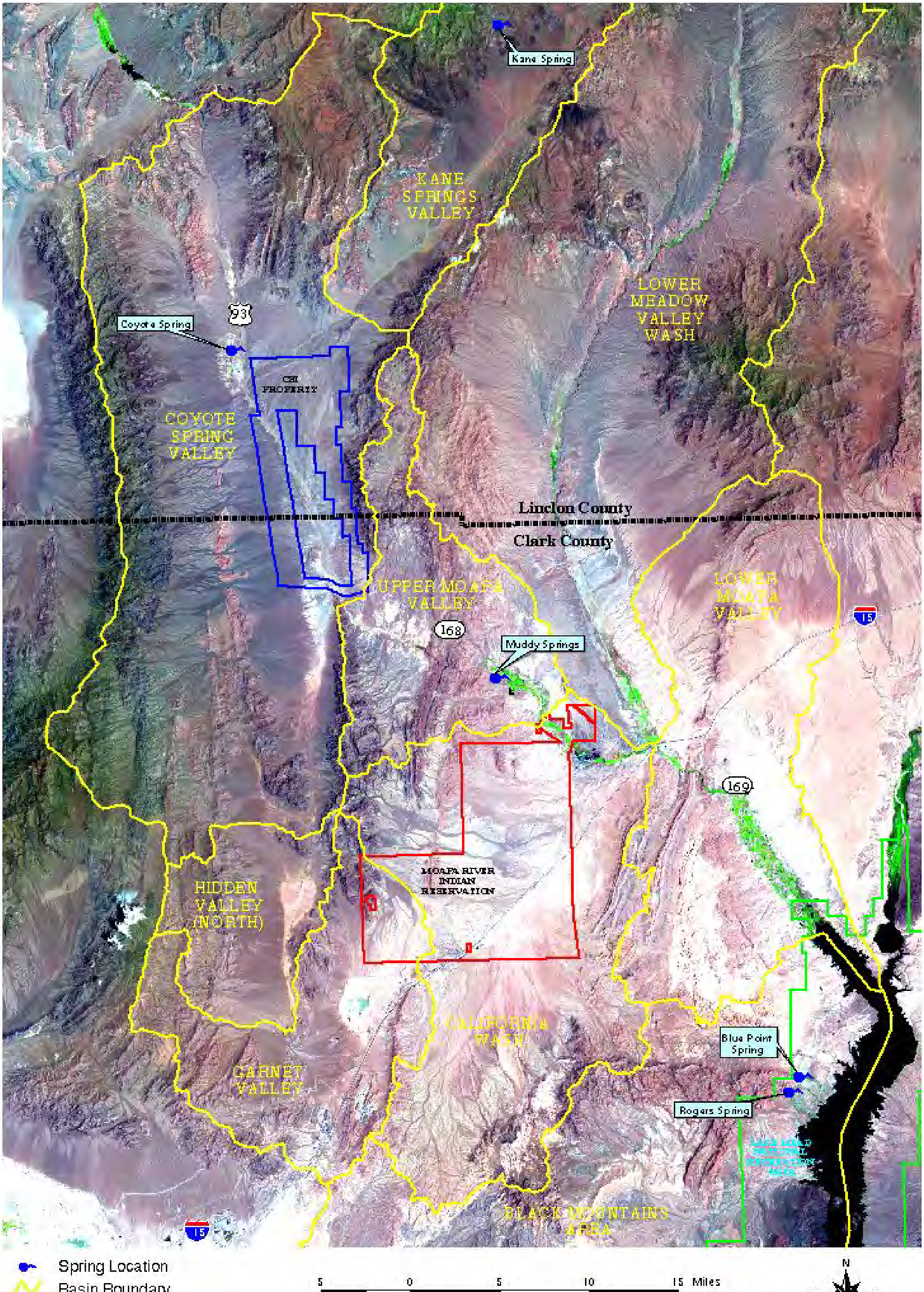

Figure 4-11. Locations of spring flow in the model area.

springs and associated ET in Kane Springs Valley. In Coyote Spring Valley several small springs exist in the mountain block, but a single discharge point at Coyote Spring, located on the valley floor in the northern end of the valley was utilized as the location of ET for the water budget and ground-water model in this study. California Wash has a couple of small local seeps south of the Muddy River that discharge very small volumes of water. These seeps were not considered significant in the overall water budget.

Table 4-9. Comparison of discharge estimated by previous USGS investigators and this study, in acre-feet/year. Numbers in *italics* are this study.

Valley	Discharge			Total Discharge	
	ET	Ground-water Outflow			
WHITE RIVER FLOW SYSTEM					
Long	2,200[a]/*11,000*	8,000[a]/*12,000*		10,200/*23,000*	
Jakes	Minor/*600*	17,000/*35,000*		17,000/*36,000*	
Cave	<1,000/*5,000*	14,000/*15,000*		14,000/*20,000*	
White River	37,000/*80,000*	40,000/*32,000*		77,000/*112,000*	
Garden	2,000/*5,000*	8,000/*14,000*		10,000/*19,000*	
Coal	Minor/*1,000*	10,000/*20,000*		10,000/*21,000*	
Pahroc	Minor/*1,000*	42,000/*59,000*		42,000/*60,000*	
Pahranagat	25,000/*38,000*	35,000/*28,000*		60,000/*66,000*	
Dry Lake	Minor/*1,000*	5,000/*12,000*		5,000/*13,000*	
Delamar	Minor/*1,000*	6,000/*16,000*		6,000/*17,000*	
Kane Spring	Minor/*1,000*	NR/*6,000*		NR/*7,000*	
Coyote Spring	<1,000/*1,000*	36,000/*53,000*		36,000/*54,000*	
Hidden	0/*0*	300/	*17,000*	600/*17,000*	
Garnet	0/*0*	600/			
California Wash	/*6,000*	1/*41,000*		/*47,000*	
Black Mountains	1,200/*2,000*	400/*0.3*		1,600/*2,000*	
Upper Moapa	2,300/*5,000*	36,000/*32,000*[b]		38,000/*37,000*	
MEADOW VALLEY FLOW SYSTEM					
Lake	8,500/*24,000*	3,000/*17,000*		11,500/*41,000*	
Patterson	80/*5,000*	*7,000*[c]	*28,000*	27,000[c]	*33,000*
Spring	1030/*1,000*		*15,000*		*16,000*
Eagle	290/*1,000*		*16,000*		*17,000*
Rose	10/*700*		*16,000*		*17,000*
Dry	10/*4,000*		*16,000*		*20,000*
Panaca	530/*26,000*		*27,000*		*53,000*
Clover	210/*2,000*		*9,000*		*11,000*
Meadow Valley Wash	20,000/*27,000*		*32,000*		*59,000*
Lower Moapa	25,000/*26,000*	11,000[b]/*48,000*[b]		36,000/*74,000*	

a. Eakin (1961), Not Nichlos (2000).
b. Combination of ground and surface water.
c. Rush (1964) lumped all ET, added ET to estimated outflow and subtracted from ground-water recharge.

The major spring flow in the model area occurs in the Muddy Springs Area, Lower Meadow Valley Wash, and the Black Mountains Area. The Muddy Springs Area has several discrete springs orifices (possibly 30) with varying discharge as described by Eakin (1964). Numerous channels funneling the spring discharge into the Muddy River. These springs are the major surface-water outflow for the White River Flow System. The Muddy Springs are characterized in this study using 3 large springs and the discharge is calibrated to the measured flow as described in Section 5 and Section 8.

Lower Meadow Valley Wash has two carbonate springs at Rox and Ferrier. These springs were not explicitly defined in the model but were treated as part of the ET discharge within the valley.

In the Black Mountains Area along the shore of Overton Arm of Lake Mead, there are several springs referred to as the North Shore Complex (Pohlmann et al., 1998). These springs are located along a series of faults that are part of the Lake Mead Fault Zone (Anderson and Barnhard, 1993a). These springs are idealized as two springs, Rogers and Blue Point Springs and the discharge was calibrated to the measured flow as described in Section 5.0 Surface Water in Model Area.

5 SURFACE WATER IN MODEL AREA

Surface-water flow in the model area occurs in the Muddy Springs area of Upper Moapa Valley, the Black Mountains Area, and Lower Meadow Valley Wash. The dominate surface-water flow is at the Muddy Springs area which flows as the Muddy River through Upper Moapa Valley, California Wash, and Lower Moapa Valley terminating in Lake Mead. The USGS has maintained gaging stations at various locations in some of the Valleys in the modeled area since 1913 **(Figure 5-1)**. The long-term records from these gages are used in the water budget calculations in conjunction with the development and calibration of the ground-water flow model in this study.

5.1 MEASURED FLOWS

5.1.1 <u>Moapa Gage</u>

The largest volume of water discharged in the model area is to the Muddy Springs and is the principal source of ground-water discharge in the White River Regional Flow System (Eakin, 1964). USGS gaging station *09416000 Muddy River near Moapa*, *NV* (Moapa gage) is located downstream of the springs and measures the baseflow of the springs (i.e. the Muddy River) less surface-water diversions and ET between the gage and the springs (**Figure 5-2**). Records of flow were collected intermittently from 1913 to the present (U.S. Geological Survey Water-Data Reports, Water Years 1913 through 1999).

Runoff from local precipitation events contributes additional stream flow measured at the Moapa gage, which is referred to as flood flows in this study. These flood flows need to be removed from the daily mean flows to determine the actual baseflow at the gage. To remove the flood flows from the daily mean flows, all days with flood flows were identified and the median monthly flow used in its place. This method is described in Johnson (1999, Appendix 2.1 to the *Las Vegas Wash Comprehensive Adaptive Management Plan*).

The annual average flow at the Moapa gage from 1913 to 1947, based on available data without flood flows, is approximately 33,900 afy (47 cfs) **(Figure 5-3)**. This period, for the purposes of this study, represents pre-development conditions, because the first well in Upper Moapa Valley was drilled in 1947 according to the NDWR Well Log Database. Eakin (1964) calculated the average flow of the Muddy Springs to be 46.5 cfs (33,700 afy) based on 25 water years from 1914 to 1962. Eakin further estimated that approximately 2,000 to 3,000 afy of spring flow was being consumed by phreatophytes between the springs and the Moapa gage, which means the spring discharge must be approximately 36,000 to 37,000 afy (50 to 51 cfs).

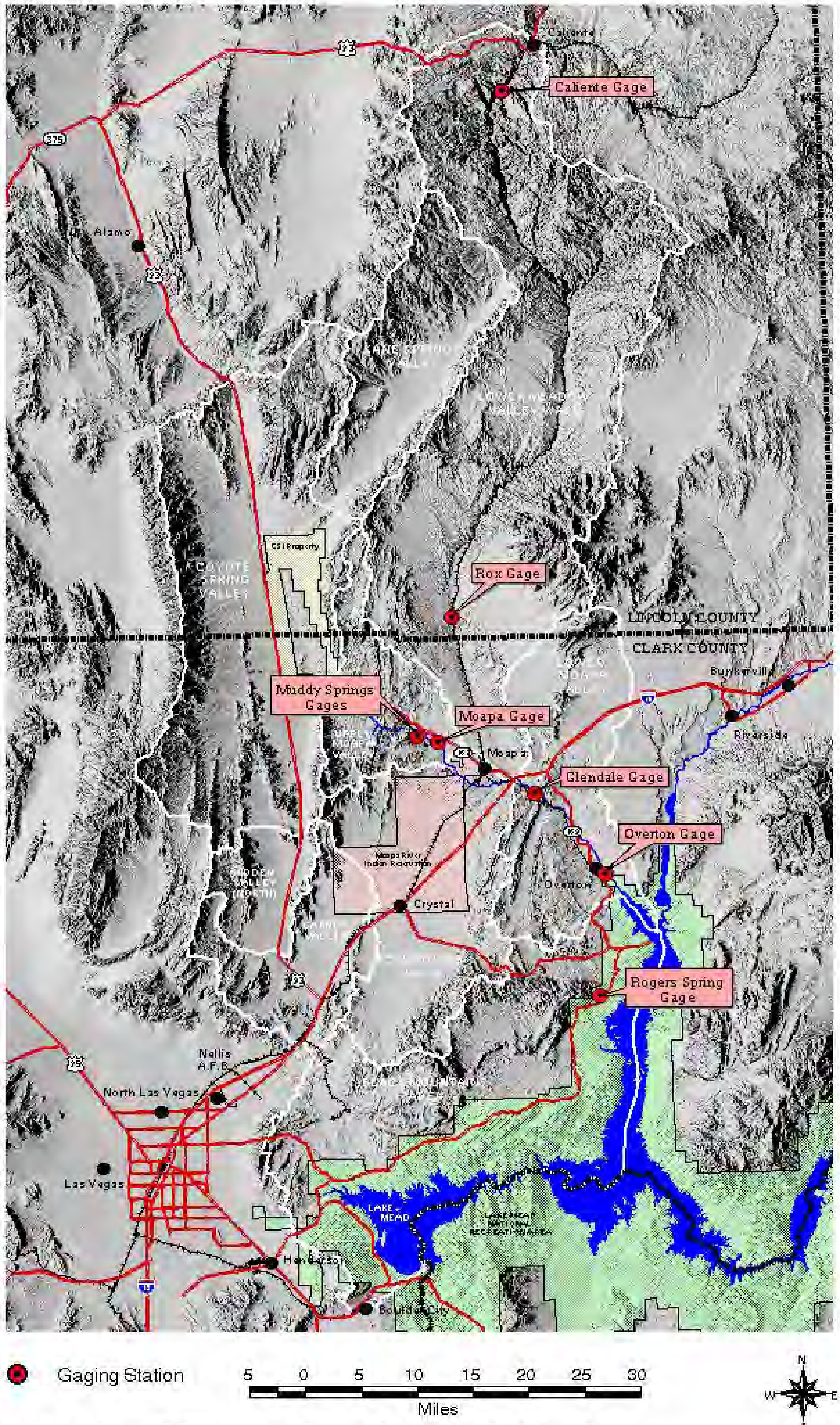

Figure 5-1. Locations of USGS streamflow gaging stations in the model area.

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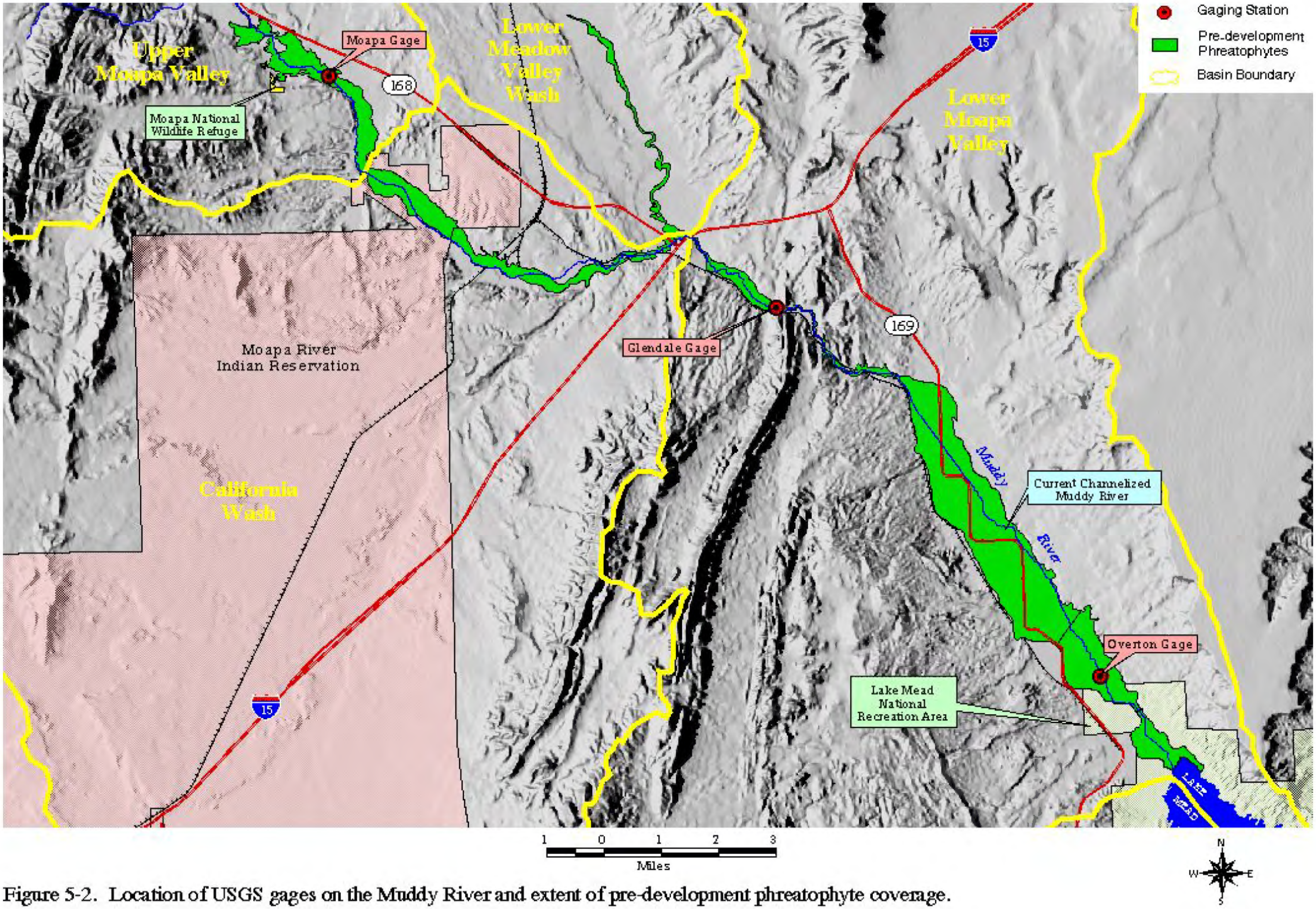

Figure 5-2. Location of USGS gages on the Muddy River and extent of pre-development phreatophyte coverage.

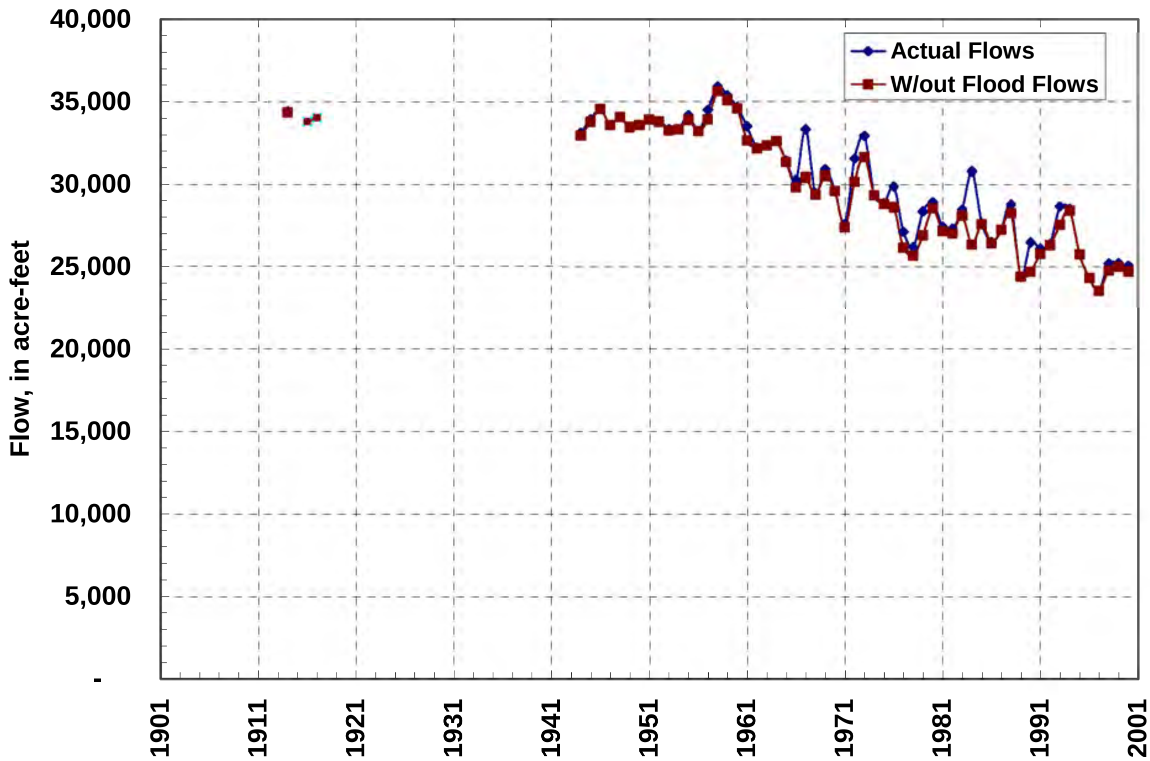

Figure 5-3. Annual flow with and without flood flows at USGS gaging station *09416000 Muddy River near Moapa, NV*

Analysis of October 1953 aerial photography of the Muddy Springs area, which shows phreatophytes and established agriculture, and September 2000 aerial photography, which shows limited active farming, demonstrated that approximately 600 acres of native phreatophytes existed prior to ground-water development **(Figure 5-4)**. Applying a consumptive use factor of 5 ft per acre per year (Eakin, 1964) results in 3,000 afy of ET above the Moapa gage, which places the annual average spring discharge at 37,000 afy. This flow record is used to develop the water budget and for the calibration of the ground-water flow model.

The annual flow at the Moapa gage was approximately 25,000 af for water year 2000. This reduction in flow is due to nearby ground-water production and surface-water diversions above the gage and is discussed in detail in Section 5.2.

5.1.2 Glendale Gage

USGS gaging station *09419000 Muddy River near Glendale, NV* (Glendale gage) is located in Lower Moapa Valley and measures a depeleted baseflow of the Muddy River along with periodic flood flows from the Muddy River, California Wash, and Lower Meadow Valley Wash. This is discussed in greater detail in Section 5.2. **Figure 5-5** depicts the annual flows at the Glendale gage with and without flood flows (U.S. Geological Survey Water-Data Reports, Water Years

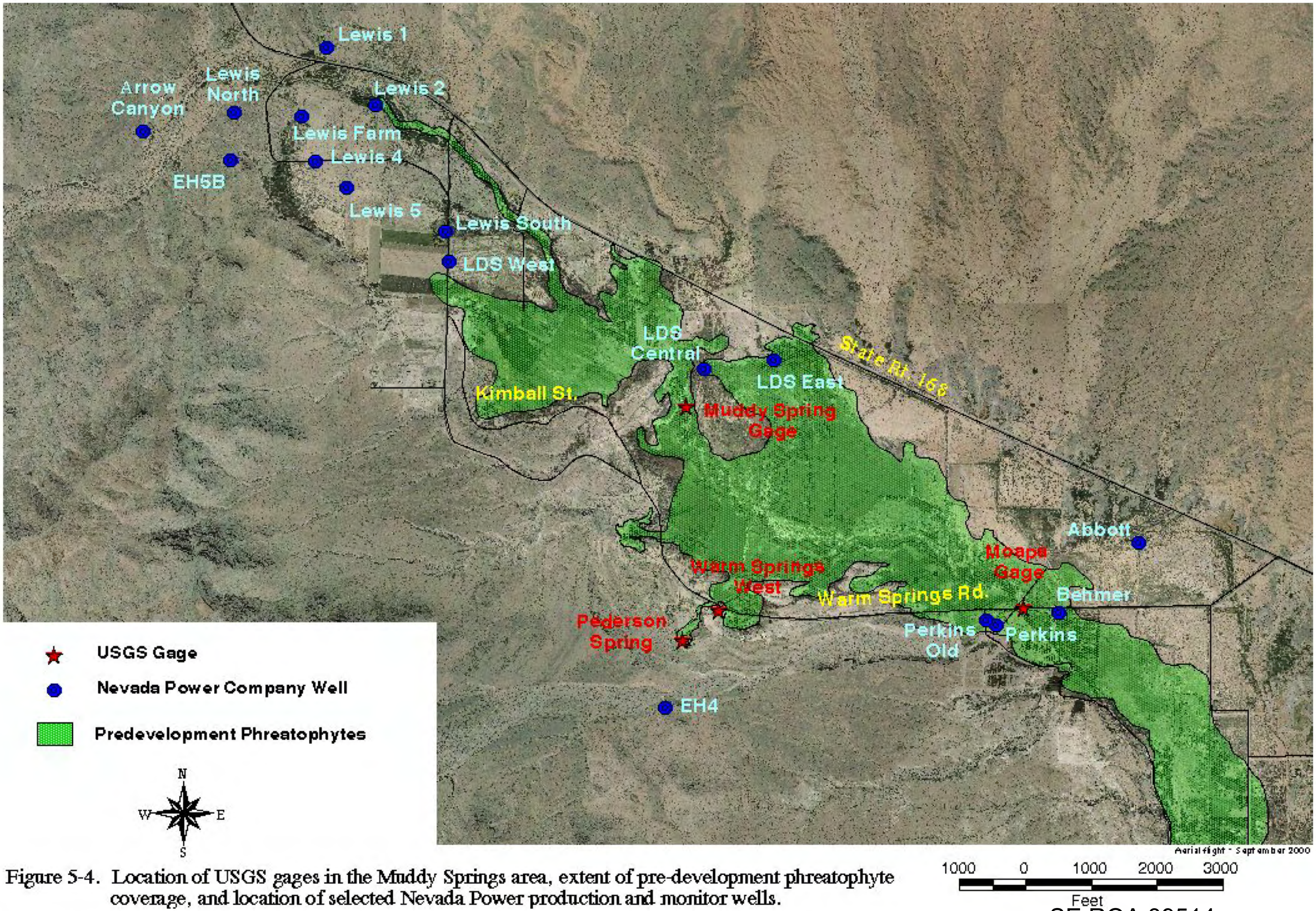

Figure 5-4. Location of USGS gages in the Muddy Springs area, extent of pre-development phreatophyte coverage, and location of selected Nevada Power production and monitor wells.

1951 through 1999). The annual average flow at the Glendale gage from 1951 to 1960 after removing flood flows is 33,600 afy. This gaged flow record is used to develop the water budget and for the calibration of the ground-water flow model.

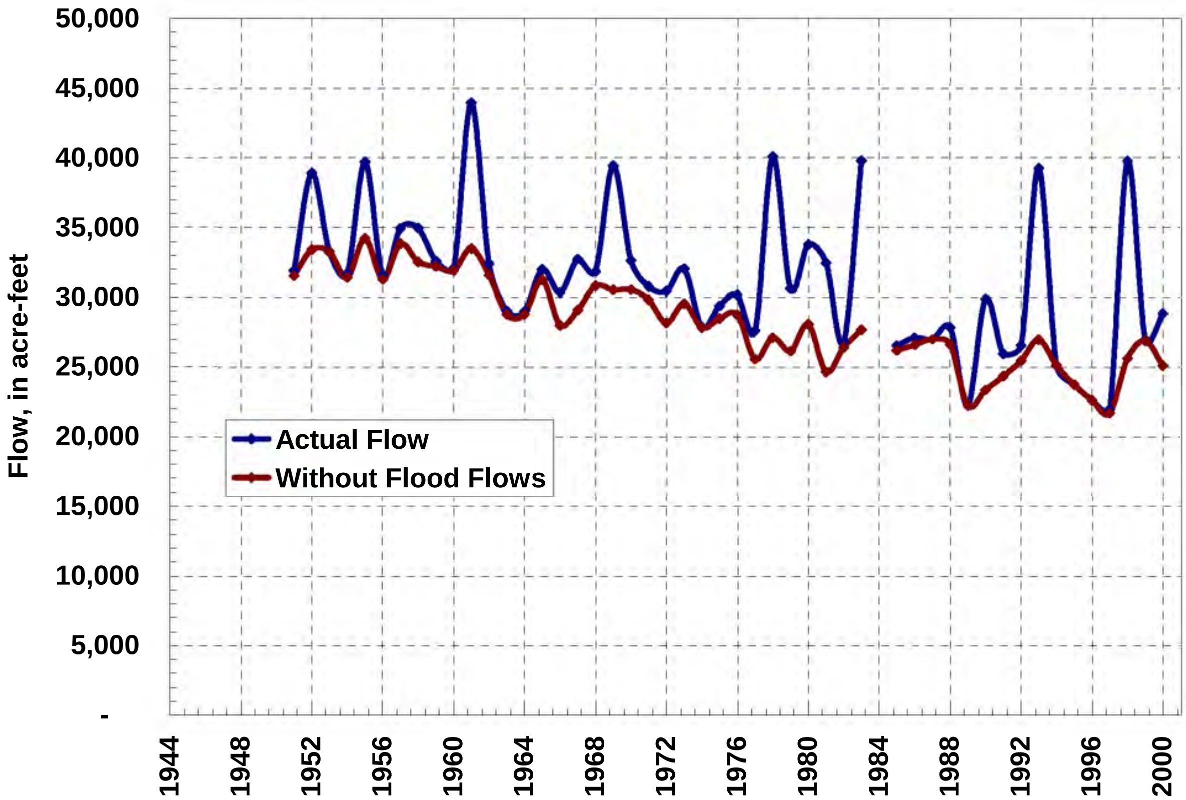

Figure 5-5. Annual flow with and without flood flows at USGS gaging station *09419000 Muddy River near Glendale, NV*

5.1.3 Overton Gage

USGS gaging station *09419507 Muddy River at Lewis Avenue at Overton, NV* (Overton gage) is located in Lower Moapa Valley approximately 1.5 miles above Lake Mead. Flows at the gage are predominantly irrigation returns, because the entire flow of the Muddy River is diverted for agricultural use by the Muddy Valley Irrigation Company at Wells Siting approximately 7 miles upstream; although, there may be ground-water inflows reflected in the flow record of the gage. This gage was installed in August 1997, and the annual flows for water years 1998 and 1999 are 12,960 af and 10,430 af respectively including flood flows. The flow record of the gage is used in the development of the water budget and during the calibration of the ground-water flow model to approximate the magnitude of surface-water flows into Lake Mead. Obtaining the current measured flows at the Overton gage was not an objective of the modeling effort, because the majority of flow is irrigation returns and a detailed analysis of the current acreage of agricultural in Lower Moapa Valley was not conducted in this study.

5.1.4 Lower Meadow Valley Wash

The USGS gaging station *09418500 Lower Meadow Valley Wash near Caliente, NV* (Caliente gage) has been operational since water year 1951. The annual average flow during water years 1951-1999 is 8,160 afy (U.S. Geological Survey Water-Data Reports, Water Year 1999) (**Figure 5-6**). Flow at the gage is influenced by snow melt, which causes the seasonal variability in the flow at the gage. Surface-water flow from the upper portion of Lower Meadow Valley Wash generally does not extend into Clark County except during flood flows. An annual average surface-water inflow of 10,000 afy from Panaca Valley is utilized in the water budget of this study, which accounts for streamflow losses due to ET above the Caliente gage within Lower Meadow Valley Wash.

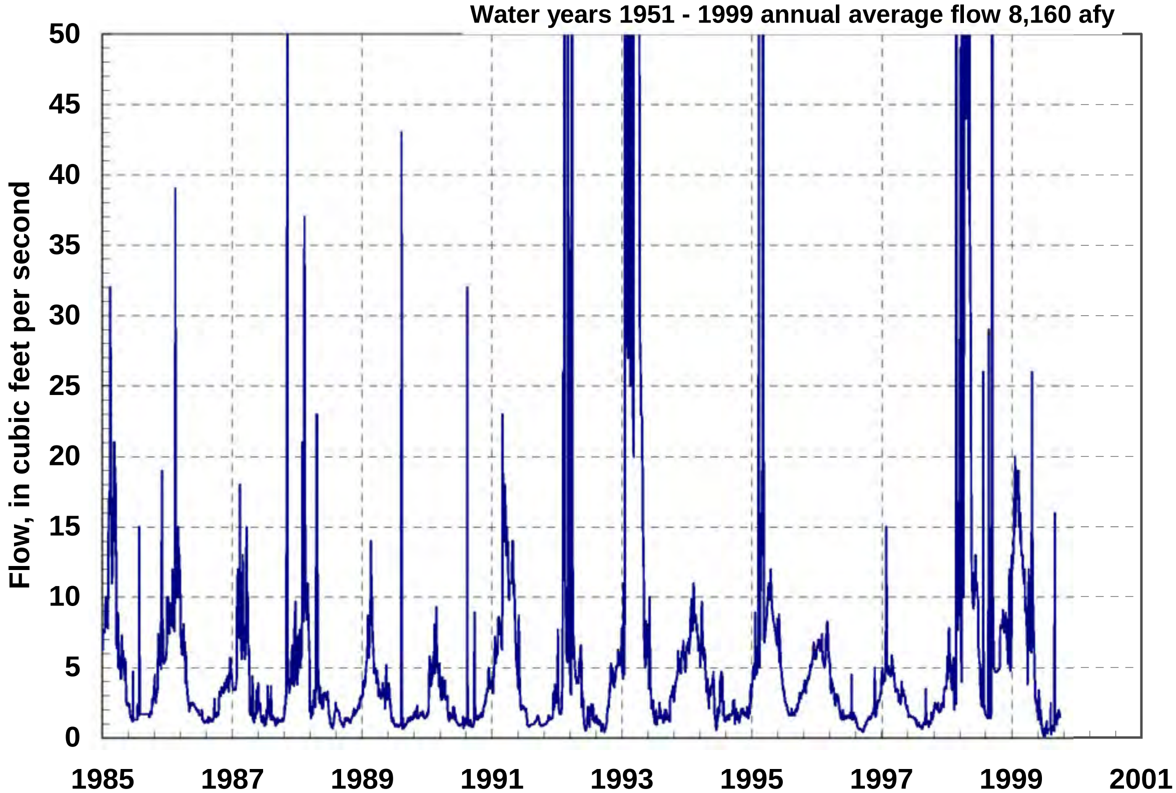

Figure 5-6. Daily mean flow at USGS gaging station *09418500 Lower Meadow Valley Wash near Caliente, NV.*

Spring flow in Lower Meadow Valley Wash also exists near Rox and Ferrier based on field investigations and historic USGS gaging stations *09418700 Meadow Valley Wash near Rox, NV* **(Figure 5-7)** and station *09418750 Meadow Valley Wash below Ferrier near Rox, NV.* Relatively small volumes of water are discharged at these sources and the water is entirely consumed through ET. These locations are utilized as ET areas in the ground-water flow model.

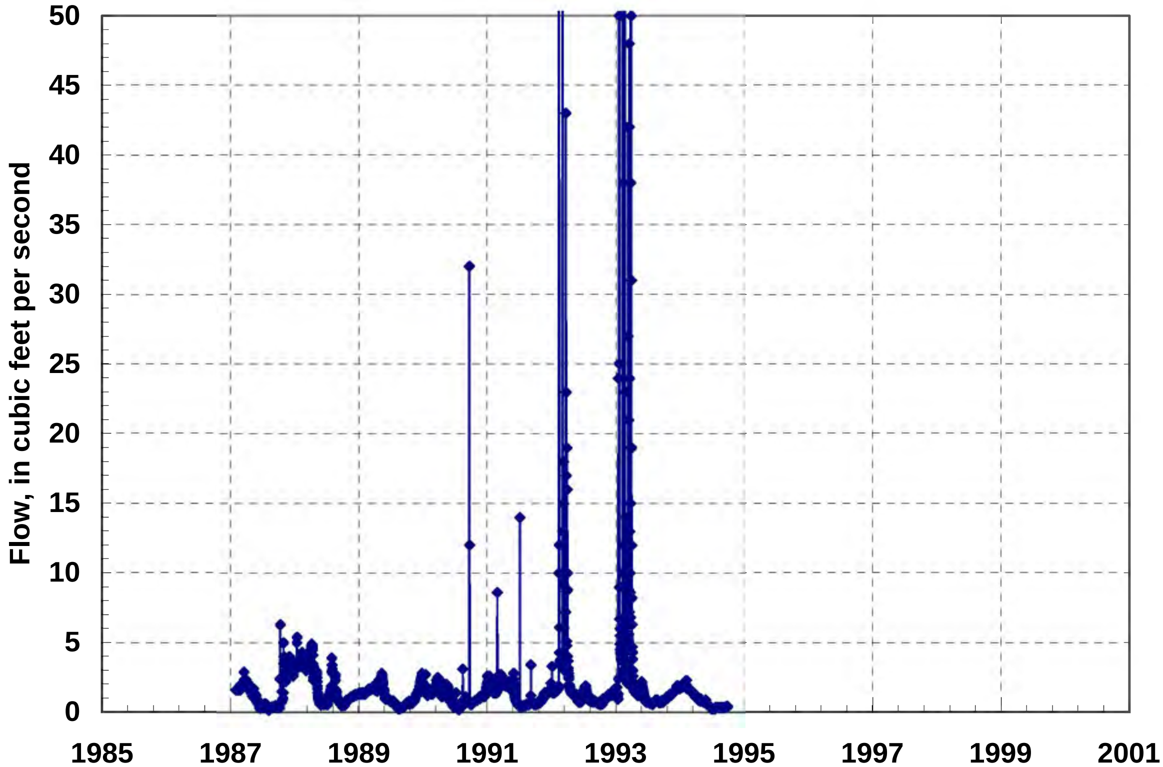

Figure 5-7. Daily mean flow at USGS gaging station *09418700 Lower Meadow Valley Wash near Rox, NV*

5.1.5 Blue Point and Roger Springs (North Shore Complex)

Springs located on the west side of the Overton Arm of Lake Mead, as a group, have been termed the North Shore Complex (Pohlmann et al., 1998). Two of the most notable springs in this complex are Rogers and Blue Point Springs. The USGS has measured Rogers Spring since October 1985, and the average flow has been relatively constant at 1.6 cfs **(Figure 5-8)** (USGS Water-Data Reports, Water Years 1984 through 1999). The average flow of Blue Point spring is 0.6 cfs. Combining these measured flows with additional flow from smaller springs in the complex, an annual average discharge of approximately 2,000 afy is utilized in the water budget and during calibration of the ground-water flow model.

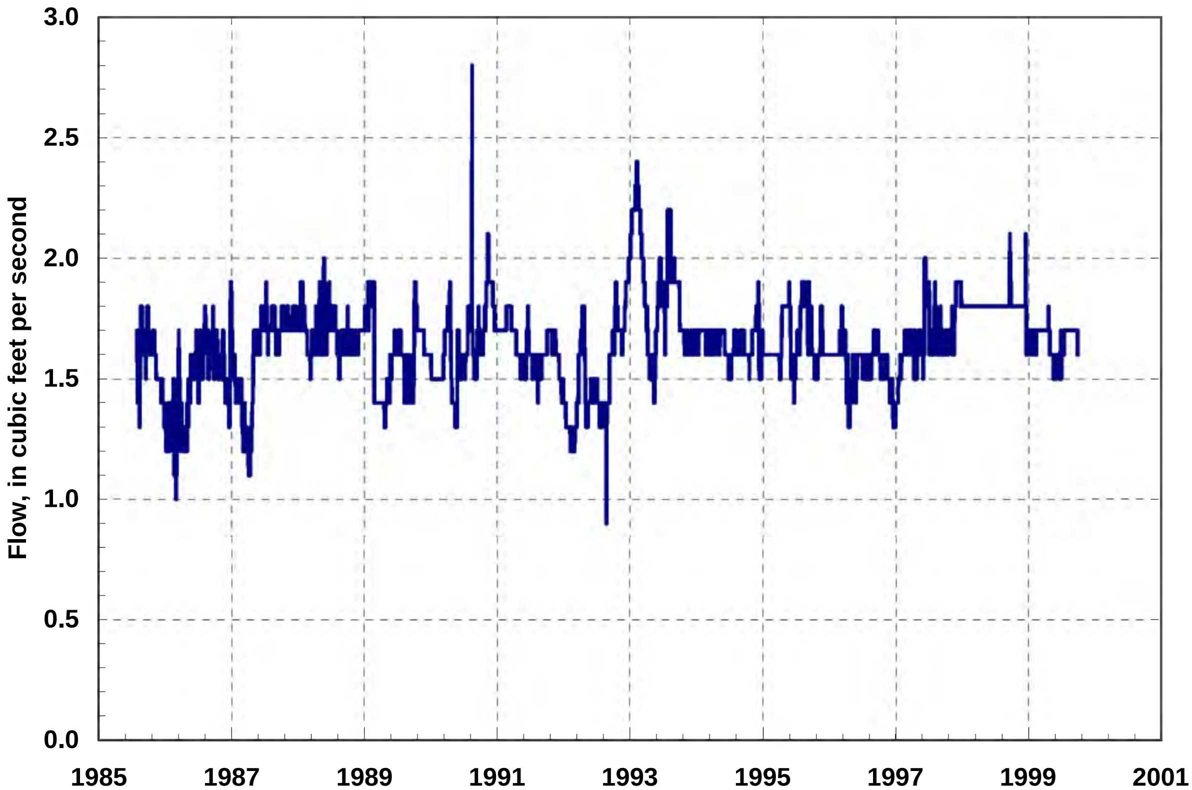

Figure 5-8. Daily mean flow at USGS gaging station *09419550 Rogers Spring near Overton Beach, NV*.

5.2 GROUND WATER AND SURFACE WATER INTERACTION

5.2.1 Muddy Springs Area

Development of water resources in the Muddy Springs area began around 1947 when the first well was drilled as described in Section 8 and Appendix B. Diversions of surface water upstream of the Moapa gage began in 1968 when the Nevada Power Company leased 1920 decreed Muddy River water rights from the Muddy Valley Irrigation Company.

A correlation exists between the ground-water pumpage in the Muddy Springs area of Upper Moapa Valley and the decline in stream flow at the Moapa gage. The measured flow at the Moapa gage without flood flows and the corresponding volume of ground-water pumpage and surface-water diversion, which are described in Section 8 and Appendix B, are shown on **Figure 5-9**. Subtracting ground-water pumpage and surface-water diversions from the pre-development stream flow of water year 1946 for each water year from 1947 to 2000 equals a theoretical flow that closely approximates the actual measured flow **(Figure 5-10)**. This suggests the decline in gage flow at the Moapa gage is directly related to ground-water pumpage and surface-water diversions. The exception to this is water years 1998 to 2000. To correct for this, only the valley-fill ground-water pumpage and surface-water diversions are subtracted from the pre-development stream flow of water year 1946 (carbonate ground-water pumpage is excluded), and a better comparison is achieved for water years 1998 to 2000 **(Figure 5-11)**. Inclusion of the carbonate pumpage yields a difference from the gage flow, while the exclusion of the carbonate pumpage yields a closer comparison to the gage record. This suggests that ground-water pumpage from the carbonate aquifer may not be having an effect on the flows at the Moapa gage. Future observations of stream flow and ground-water pumpage will need to be collected to further corroborate this hypothesis. The comparison of gage flow and pumpage/surface-water diversion records does not directly answer the question if spring flow is decreasing. Therefore the gage records at spring orifices were also examined.

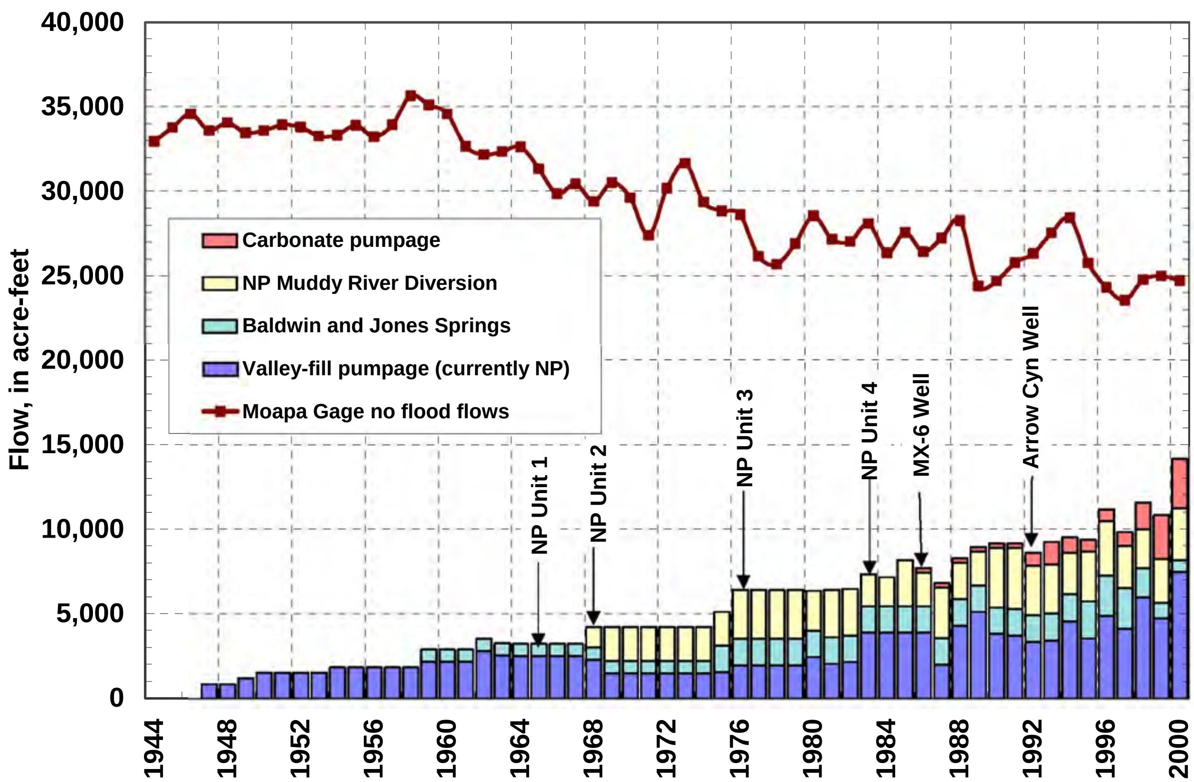

Figure 5-9. Annual flow without flood flows at USGS gaging station *09416000 Muddy River near Moapa, NV*, compared to ground-water pumpage and surface-water diversions. The year key production wells became operational as well as each generating unit at Nevada Power Company's Reid Gardner power generation station is also indicated.

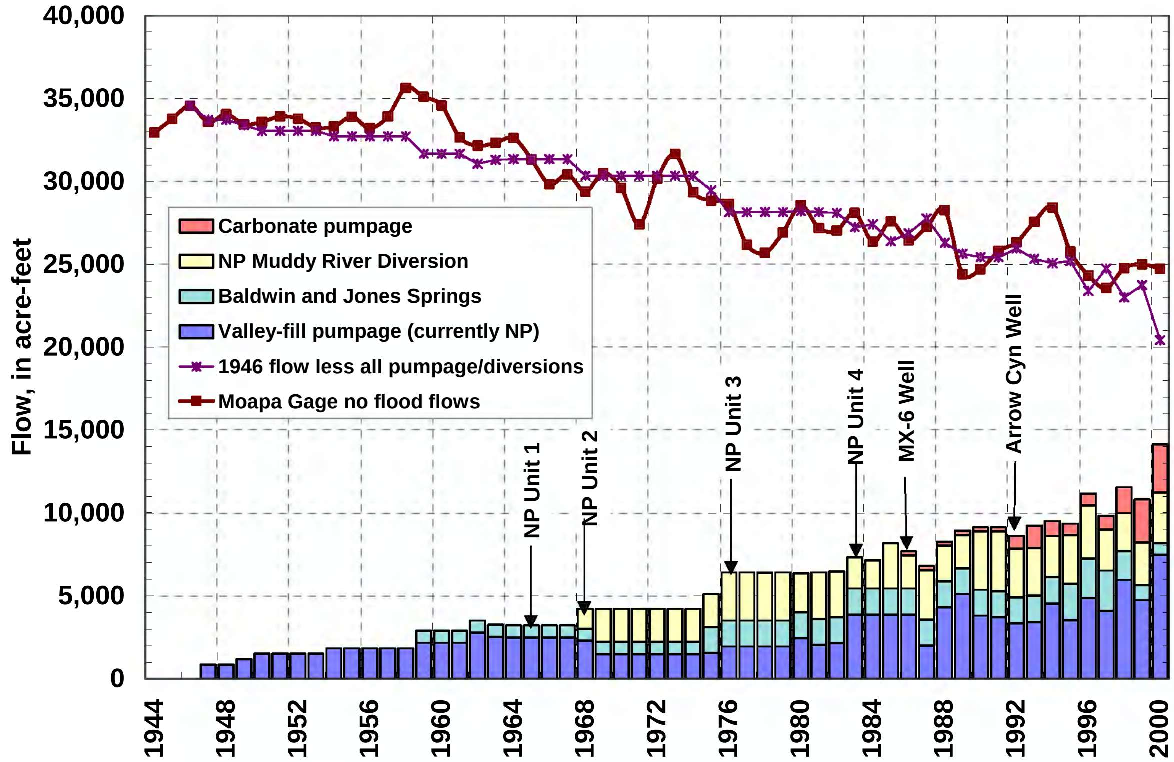

Figure 5-10. Comparison between decline in flow at the Moapa gage and nearby ground-water pumpage and surface-water diversions.

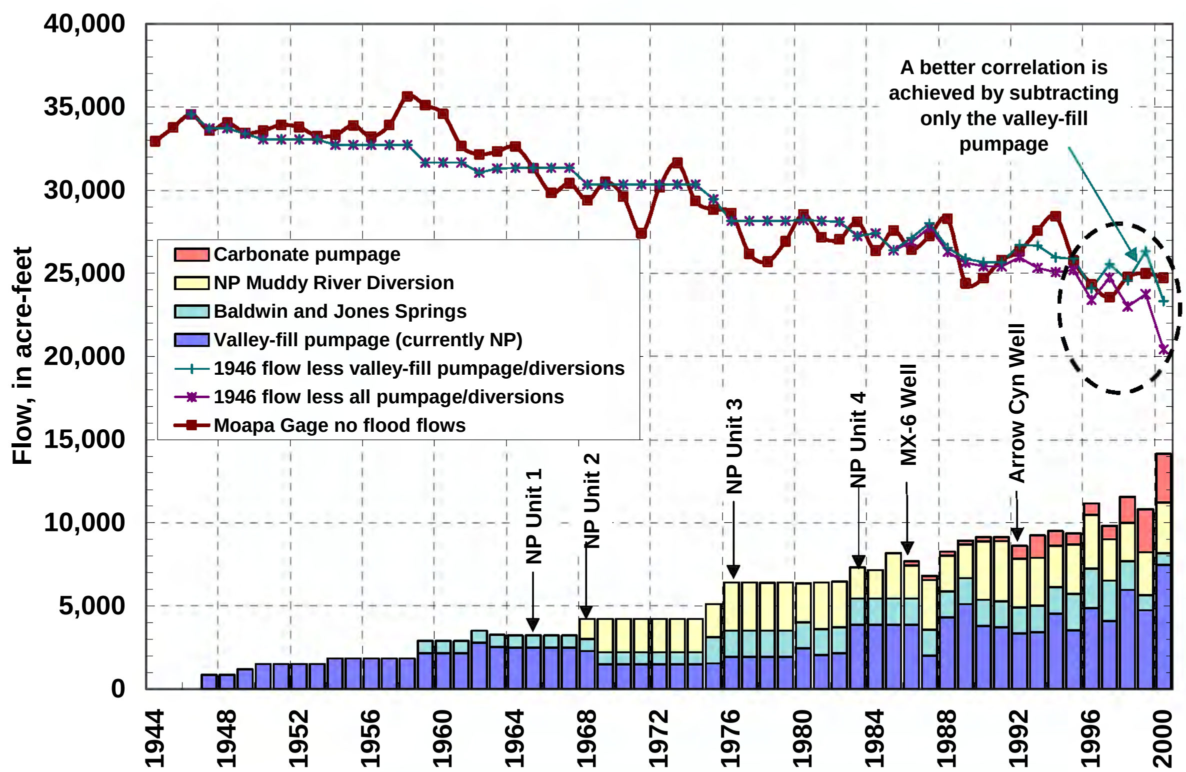

Figure 5-11. Comparison between decline in flow at the Moapa gage and valley-fill vs. carbonate ground-water pumpage and surface-water diversions

Spring discharge at USGS gaging stations: Muddy Springs at LDS Farm near Moapa, NV; Pederson Spring near Moapa, NV; and Warm Springs West near Moapa, NV show a relatively constant flow during the period of record for the gages **(Figure 5-12** and **Figure 5-4)**. This spring discharge remains constant when ground-water pumpage and surface-water diversion are at an all time high. This constant flow combined with the observations at the Moapa gage that the valley-fill pumpage has caused the decline in the streamflow at the gage supports Eakin's (1964) conclusion "…ground water in the valley fill, which is a natural reservoir, is recharged largely from the springs." and "In effect, the natural regimen of the springs is one of relatively constant flow year round."

Eakin's (1964) conclusions are also supported by the fact that seasonal valley-fill ground-water pumpage occurring in the Muddy Springs area above the Moapa gage has not caused long-term, declining water levels even though they have been pumped for up to 50 years (See **Appendix C** for hydrographs on Lewis north and Lewis south wells).

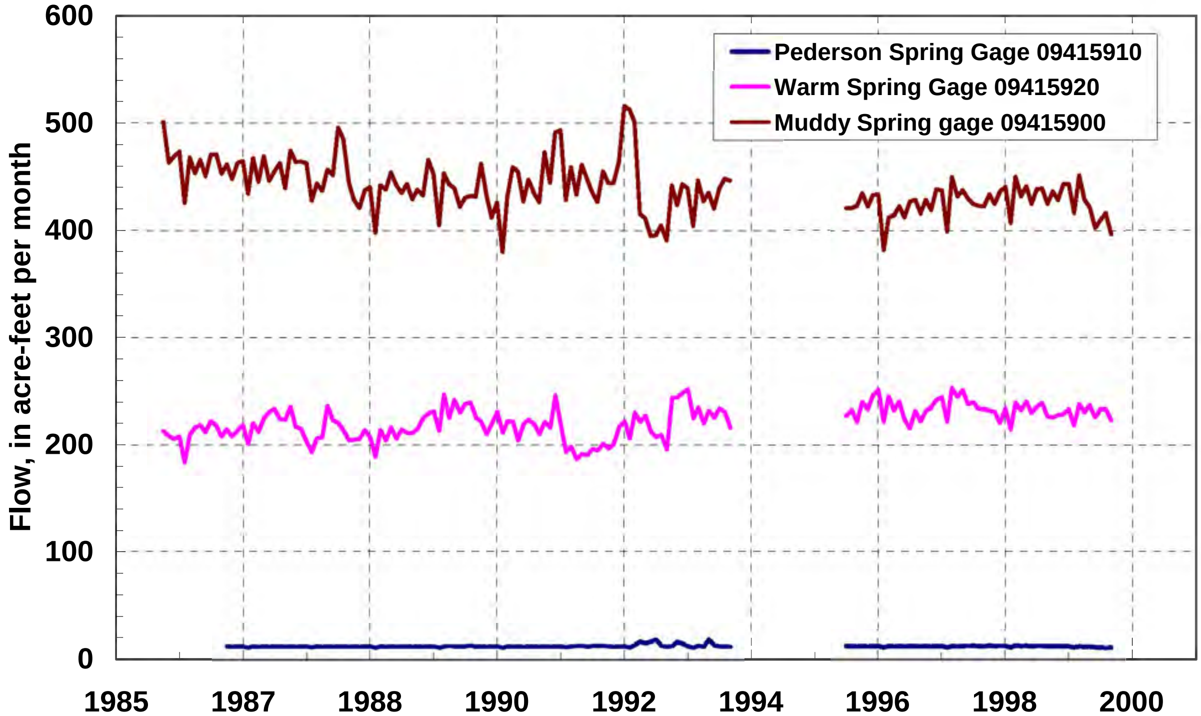

Figure 5-12. Monthly mean spring flow at three USGS gaging stations in the Muddy Springs area.

5.2.2 Moapa Gage to Glendale Gage

Approximately 1,830 acres of phreatophytes existed between the Moapa and Glendale gages under pre-development conditions. Using a consumptive use rate of 5 ft/acre the phreatophytes consume approximately 9,000 afy. Under current conditions the phreatophytes have been replaced with agricultural fields on the Moapa River Indian Reservation and the Hidden Valley

Ranch. Utilizing September 2000 aerial photography, the current estimated consumptive use continues to be approximately 9,000 afy, which is also supported by the Moapa/Glendale gage correlation discussed below.

Flows at the Glendale gage correspond to flows at the Moapa gage and do not show the 9,000 afy loss due to ET **(Figure 5-13)**. Based on the close comparison between the two gages and the calculated losses between the gages, additional inflow from California Wash and/or Lower Meadow Valley Wash is suggested. In this study approximately 9,000 afy of ground-water inflow is estimated to occur between the Moapa and Glendale gages (6,000 afy from California Wash and Upper Moapa Valley below the Moapa gage and 3,000 afy from Lower Meadow Valley Wash), thus matching the historical gage records.

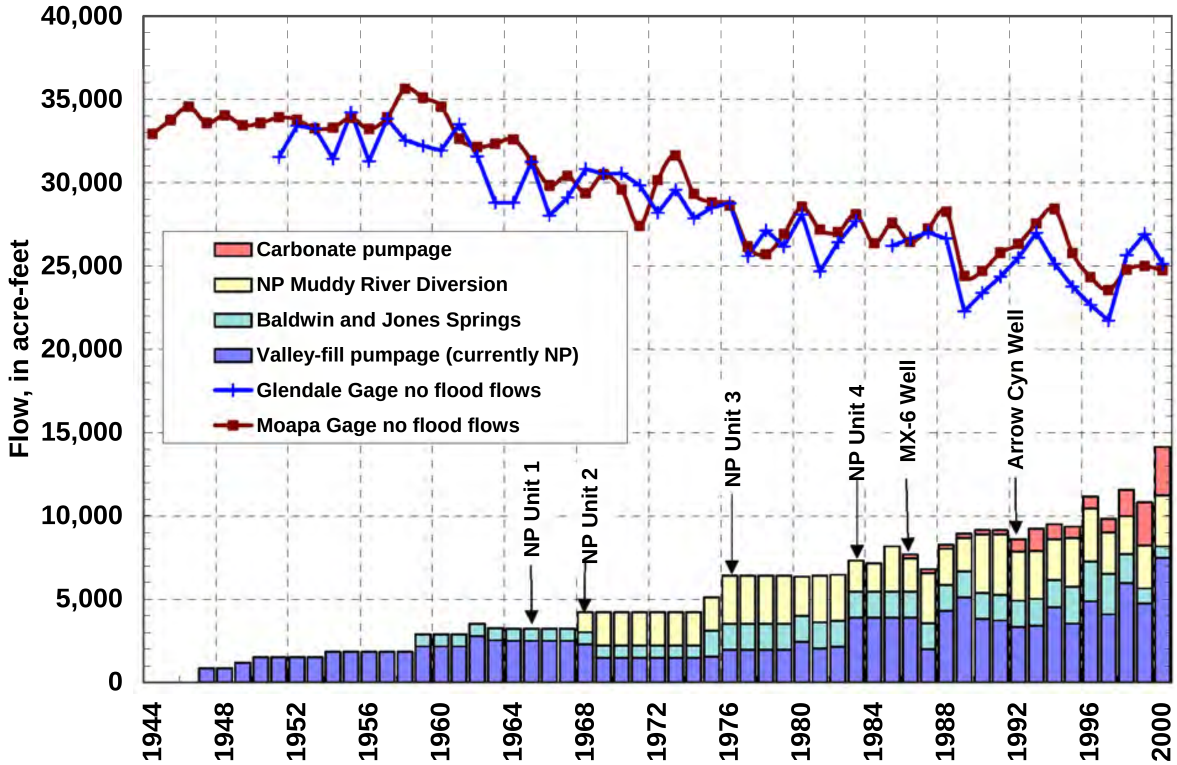

Figure 5-13. Comparison between the measured flow at the Moapa and Glendale gages without flood flows.

5.2.3 Glendale Gage to Overton Gage

The surface-water flow of the Muddy River was decreed under Nevada State Statute in 1920. Virtually all of the decreed surface-water rights in the early 1900's were utilized in Lower Moapa Valley, and based on 1944 and 1974 water right maps (Plan of Muddy River showing decreed water rights, U.S. Dept. of Interior, Office of Indian Affairs and map accompanying proof of beneficial use under permits 21847 and 21873 to 21877 respectively), the entire flood plain of the lower Muddy River was under cultivation. Due to limited availability of information about cropping patterns in Lower Moapa Valley, a detailed analysis of diversions, consumptive uses, and irrigation returns in the flood plain of Lower Moapa Valley was not performed. As stated in Section 5.1.3 the Overton gage is utilized in the development of the water budget and during model calibration only to approximate the magnitude of surface-water flows into Lake Mead since the majority of flow is irrigation returns and a detailed analysis of the current acreage of agricultural in Lower Moapa Valley was not conducted in this study.

6 WATER RESOURCE BUDGET

6.1 WATER RESOURCE BUDGET IN THE STUDY AREA

The water-resources budget for each valley in the study area is an accounting of ground-water inflow and outflow based on the local ground-water recharge, ground-water inflow if it occurs, and the local evapotranspiration. The ground-water outflow is the residual between inflow and evapotranspiration. These values are listed in **Table 6-1** and shown in **Figure 6-1**. Most of the valleys have ground-water inflow and all have ground-water outflow. The ground-water outflow from a valley becomes the inflow to the adjacent down gradient valley. There are some unknowns in this routing of ground water between valleys. We do not know, for instance, if Cave Valley is tributary to White River Valley or to Pahroc. Large structural features in the west-central part of the South Eagan Range may be an avenue for ground-water flow from Cave Valley to White River Valley. Sparse water-level data indicate the flow may be to Pahroc Valley out of the south end of Cave Valley. It makes little difference in the overall project goal, however, it does cause discontinuity between the interpretation in this routing and the geochemistry model by Thomas et al. (2001). The same is true for the ground-water flow from Coal Valley either into Pahroc Valley or Pahranagat Valley. In terms of the ground-water model this is not a problem because the model boundary has a ground-water flux across it that represents the residual ground-water outflow from all the up-gradient valleys.

In the model area for this section there is a lumping of ground- and surface-water flows together as inter-basin flow. As an example, ground-water discharge forms the surface water of the Muddy Springs and the springs become the Muddy River which is considered inter-basin flow from Upper Moapa Valley to California Wash and on into Lower Moapa Valley. Ground-water flow into the model area from Panaca Valley has a surface-water component that is not separated out. In the ground-water model the distinction is made between ground and surface water regardless of where it occurs. **Table 6-2** lists the sum of the budget components for the entire study area. The water-resources budget for the model area is listed in **Table 6-3**. These three budget variations are considered a water-resources budget which is dominated by ground water, based on the values listed in **Table 6-1**.

6.2 GROUND-WATER YIELD

Historically, in the ground-water basins of Nevada, the perennial yield for a ground-water system was based on the amount of discharge by ET that could be reasonably captured and the value varies per basin. The concept of perennial yield can also extend to the capture of ground-water outflow from major flow systems such as the White River and Meadow Valley through deep seated carbonate rocks underneath Lake Mead and the Colorado River. However, the complexity of the relationship between surface and ground-water, recharge and discharge, and geology and hydrology is such that generally the total discharge can never be captured, no matter if the discharge is from ET or ground-water outflow. This is further complicated by the vast amounts of water in storage in the carbonate aquifer and the overlying alluvial aquifers and the long transient time, measured in hundreds to thousands of years (Thomas et al., 1991), for ground water to move from recharge areas to discharge areas.

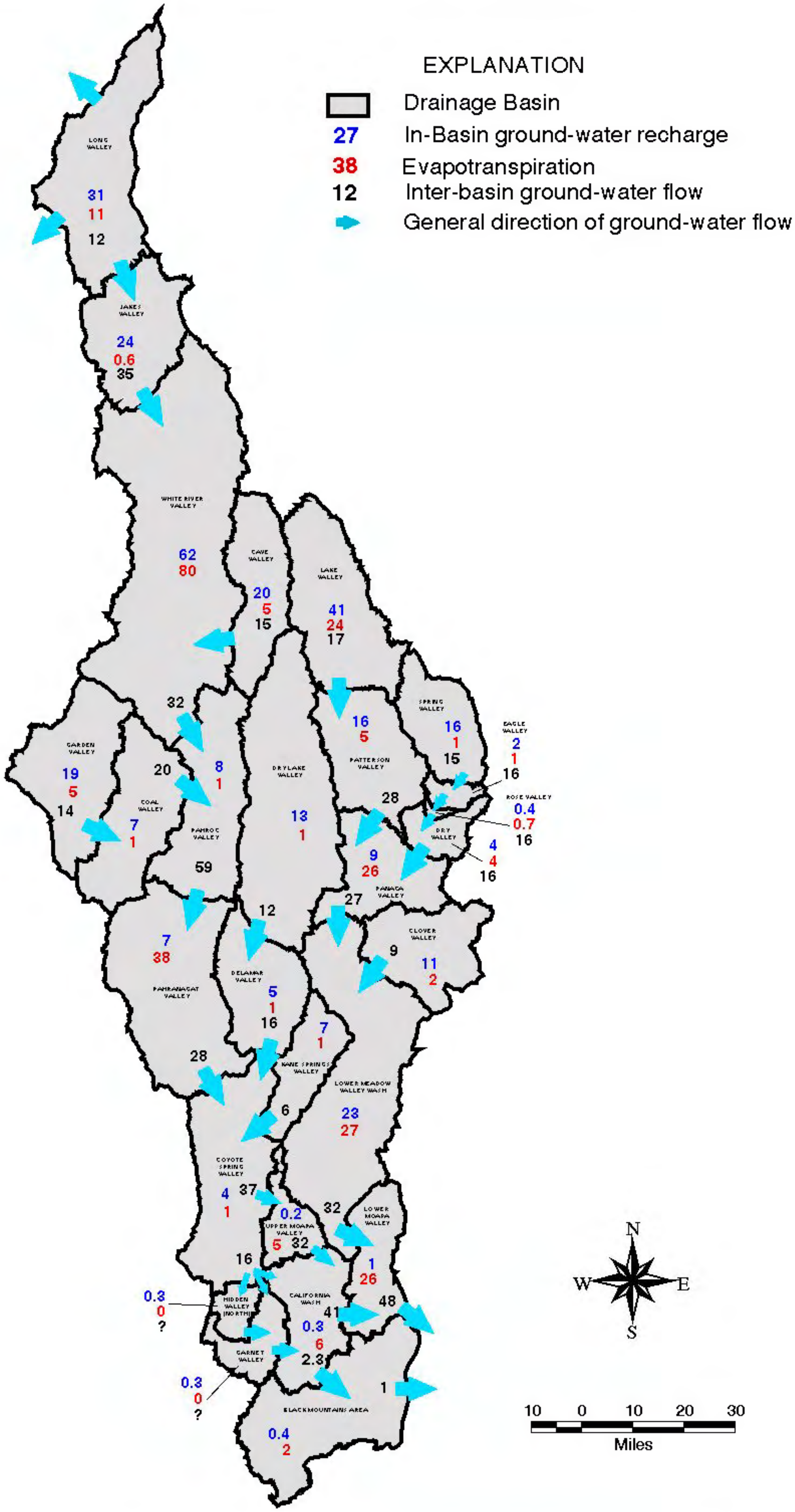

Figure 6-1. Generalized ground-water recharge, evapotranspiration, and inter-basin flow of the White River and Meadow Valley Flow Systems, units in thousands of acre-feet per year.

Table 6-1. Ground-water recharge, discharge, and inter-basin flow for selected Colorado River Basins in Nevada, in thousands of acre-feet/year (rounded).

Valley	Recharge from precipitation	Ground-water inflow	ET	Ground-water outflow	
				To	Volume
WHITE RIVER GROUND-WATER FLOW SYSTEM					
Long	31[a]	0	11	Jakes	12
Jakes	24	12	.6	WRV	35
Cave	20	0	5	WRV	15
WRV	62	50	80	Pahroc	32
Garden	19	0	5	Coal	14
Coal	7	14	1	Pahroc	20
Pahroc	8	52	1	Pahranagat	59
Pahranagat	7	59	38	Coyote	28
Dry Lake	13	0	1	Delamar	12
Delamar	5	12	1	Coyote	16
Kane	7	0	1	Coyote	6
Coyote	4	50	1	U. Muddy	37
				Hidden	16
				Garnet	
Hidden	0.3	16	0	California Wash	17
Garnet	0.3		0		
U. Moapa	0.2	37	5	California Wash	32
California Wash	0.3	49	6	L. Moapa	41
				Black Mtn.	2.3
Black Mountain	0.4	2.3	2	Carbonate outflow	1
Subtotals	200.5		158.6		
MEADOW VALLEY WASH GROUND-WATER FLOW SYSTEM					
Lake	41	0	24	Patterson	17
Patterson	16	17	5	Panaca	28
Spring	16	0	1	Eagle	15
Eagle	2	15	1	Rose	16
Rose	0.4	16	0.7	Dry	16
Dry	4	16	4	Panaca	16
Panaca	9	44	26	LMVW	27
Clover	11	0	2	LMVW	9
LMVW	23	36	27	L. Moapa	32
L. Moapa	1	73	26	Carbonate outflow	48
Subtotals	123		116.7		
Totals	**324**		**275**		

a. Only 23,000 acre-feet included in totals, remainder to non-White River flow system valleys (Nichols, 2000).

Table 6-2. Water-resources budget for the White River and Meadow Valley flow systems.

INFLOW	Volume (afy)
Precipitation (6,635,741)	
Ground-water recharge	324,000
Total	**324,000**
OUTFLOW	**Volume (afy)**
Evapotranspiration	275,000
Ground water	36,000
Surface water	13,000
Total	**324,000**

Table 6-3. Water-resources budget for the model area.

INFLOW	Volume (afy)
Ground water	80,000
Local Recharge	37,000
Total	**117,000**
OUTFLOW	**Volume (afy)**
Ground water	36,000
Surface water	13,000
Evapotranspiration	68,000
Total	**117,000**

To salvage or capture ground-water that is being discharged through ET requires lowering the water table through ground-water pumping. Once the water table is lowered beyond the depth phreatophytes can reach with their roots then the ground water is considered salvaged. This simple concept is difficult to put into practice. For example in Las Vegas Valley where ground-water pumping has been ongoing for over a hundred years and the water table, at one time and in one area, was drawn down about 300 feet and in other parts of the valley there are still living remnants of phreatophytes, the mesquite forest, that once blanketed much of the valley (Pete Duncombe, horticulturist, LVVWD, oral commun., 2001).

In the Carbonate Rock Province of Nevada the alluvial system, which contains the phreatophytes, is on top of the carbonate rocks. Thus, recharge to the alluvial aquifers is mostly dependent on the recharge in the carbonate rock aquifers, and attempts to capture the perennial yield by developing wells in the carbonate aquifer are difficult. This is particularly true because of the vast distances between areas of large ET volumes, such as Pahranagat and White River Valleys and areas of potential high development of ground water, such as the southern end of the White River Flow System. Thus the concept of the perennial yield regarding phreatophytes has certainly limited application in this instance. This same assumption also applies to the Meadow Valley Flow System. Virtually all of the ET located in the northern valleys such as Lake, Patterson, and Panaca is associated with agriculture. In Lower Meadow Valley Wash, much of the ET is associated with the perennial flow in the wash; for both phreatophytes and agriculture (see **Table 4-8** for a breakdown of ET by phreatophytes and agriculture). This surface flow is the result of ground-water discharge to the wash from the thin narrow strip of alluvium that occupies the canyon bottom.

It may seem simpler to capture ground-water outflow from the numerous basins, but it is not. Ground-water flow in carbonate rocks is probably along preferred pathways caused by fractures, which are related to earth movements and to some extent dissolution of the rock-aquifer. While we generally believe fault systems have a higher probability of being conduits for ground-water flow rather than retarding flow as a barrier it is difficult to define the ground-water flow along these pathways which in turn makes predicting impacts very uncertain. The net discharge from the two ground-water flow systems, White River and Meadow Valley, occurs at great depth through the carbonate rocks underneath Lake Mead and possibly into or underneath the Colorado River and is estimated to be 49,000 acre-feet/year. This outflow includes about 10,000-20,000 afy of surface water from the Muddy River to Lake Mead.

In summary the perennial yield for the entire Colorado River Basin Province in Nevada can not be defined as it has been in the past for individual basins without regard for interbasin flow. Furthermore, capturing or salvaging this outflow is nearly impossible to do simply because of the complexity of the fracture-flow system, the vast amounts of water in transient storage, and the long transient time of ground-water movement.

The "Safe Yield" is also equally difficult to apply and has some commonality with perennial yield. The two yields differ because "Safe Yield" does not depend on estimating "Perennial Yield". This term as indicated by Lohman (1972, p. 61) "….has about as many definitions as the number of people who have defined it." Meinzer (1920, p.330) first defined the term as "….The rate at which the ground water can be withdrawn year after year, for generations to come, without depleting the supply." Todd (1959, p. 200) states "The safe yield of a ground-water basin is the amount of water that can be withdrawn from it annually without producing an undesired result." Lohman (1972, p. 62) offers his own definition as " The amount of ground water one can withdraw without getting into trouble". There are many other definitions for this term that are directed to specific cases, but the one by Lohman (1972, p.62) has the most appeal. "Getting into trouble" is to cause undesirable impacts, which can mean a wide variety of resultant actions and in particular a decrease in discharge of Muddy, Rogers or Blue Point Springs. This is an impact that can be avoided with monitoring and mitigation.

Therefore, we believe an alternative definition for ground-water yield from the Colorado River Basin Province is the *Available Yield*. We define this as the amount of water that potentially is available over hundreds of years from the ground-water system. This term does not recognize economic constraints, but relies entirely on the volume of water in storage, the long transient times, and the annual recharge to the ground-water system. The amount of ground water in transient storage is enormous. If, for example, we consider just that part of the carbonate aquifer in the modeled area **(Table 6-4)** the estimated specific yield as reported by Dettinger et al. (1995, Table 13, p. 72) is 0.01 (dimensionless) so there may be as much as two million acre-feet of water in storage in every 100 feet of saturated carbonate rock. The combined alluvial aquifers of the above valleys are smaller in area and contain over four times as much water as the carbonate rocks, assuming a specific yield of 15 percent (~ 9 million acre-feet). So the amount of available yield as storage in just the top 100 feet of saturated carbonate rock and alluvial aquifer dwarfs the estimated annual recharge of about 117,000 acre-feet to these valleys. We are not advocating allocating the vast amount of water in storage, but we do believe there are sufficient uncertainties in the components of the water budget that cannot be resolved in the short term and there is probably more water available than we have defined. Thus a portion of the transient storage can be used safely, particularly with a monitoring plan in place, to further the economic interests of the state and at the same time provide much needed hydrogeological data.

Table 6-4. Estimated transitional ground-water storage in modeled area.

Valley	Estimate ground-water storage in upper 100 feet of saturated zone, in acre-feet.		Total (afy)
	Alluvial Basin	Carbonate Rock	
Kane Springs	529,000	150,000	679,000
Coyote Spring	2,546,000	392,000	2,938,000
Hidden	150,000	52,000	202,000
Garnet	500,000	102,000	602,000
California Wash	1,000,000	206,000	1,206,000
Black Mountain Area	1,113,000	409,000	1,522,000
Lower Meadow Valley Wash	2,800,000	606,000	3,406,000
Upper Moapa	30,000	93,000	123,000
Lower Moapa	800,000	176,000	976,000
TOTAL	**9,468,000**	**2,186,000**	**11,654,000**

7 ISOTOPE GEOCHEMISTRY

For this study, Thomas et al. (2001) conducted a reevaluation of the geochemistry of the White River and Meadow Valley ground-water flow systems. The executive summary for this report is provided below:

Deuterium data were used to evaluate new ground-water recharge and discharge (evapotranspiration) rate estimates developed by the Las Vegas Valley Water District (LVVWD, 2001) for the regional ground-water flow systems in southeastern Nevada. A deuterium-calibrated mass-balance model was constructed for the White River, Meadow Valley Wash, and Lake Mead (introduced here) ground-water flow systems. This model was used to evaluate if proposed ground-water recharge rates, evapotranspiration rates, sources, and mixing are possible or not. If model-calculated deuterium values for ground-water in the regional aquifers match measured values (within 2 permil), then proposed recharge rates, evapotranspiration rates, sources, and mixing for these flow systems are possible. However, the deuterium mass-balance model developed for the water budget of these flow systems produces a non-unique solution, because a proportionate decrease or increase in both recharge and ET rates, or a different combination of ground-water sources and mixing, can produce the same results.

Results of the deuterium mass-balance model show that:

New estimates of ground-water recharge and evapotranspiration rates (Section 4.2), and proposed groundwater sources and mixing for the White River, Meadow Valley Wash, and Lake Mead flow systems are consistent with the results of a deuterium-calibrated mass-balance model.

The White River Flow System acts as one continuous carbonate-rock aquifer from Long Valley in the north to Upper Moapa Valley (Muddy River Springs area) in the south.

The results of the deuterium mass-balance model of the White River Flow System are consistent with 53,000 acre-feet per year (afy) of groundwater flowing out of Coyote Springs Valley to the Muddy River Springs area in Upper Moapa Valley (37,000 afy) and to the south-southeast in the carbonate-rock aquifers (16,000 afy).

The Meadow Valley Flow System acts as a two-layer flow system with a carbonate-rock aquifer flow system to the north and west and a volcanic-rock alluvial-fill aquifer system to the east and south that overlies the carbonate-rock aquifer flow system.

The results of the deuterium mass-balance model of the Meadow Valley Flow System are consistent with measured deuterium values in Panaca Valley for a two-layer regional flow system, but deuterium data are lacking for the underlying carbonate-rock aquifer in Lower Meadow Valley Wash, so the estimated 32,000 afy of groundwater flowing out of Lower Meadow Valley Wash to Upper Moapa Valley cannot be evaluated.

The Lake Mead Flow System is primarily a carbonate-rock aquifer flow system that transports groundwater from the White River and Meadow Valley flow systems to Lake Mead.

The results of the deuterium mass-balance model of the Lake Mead Flow System are consistent with 16,000 afy of groundwater flowing from the Coyote Springs Valley-Upper Moapa Valley area to the Hidden Valley-Garnet Valley-California Wash Valley area.

The deuterium mass-balance model of the Lake Mead Flow System cannot evaluate the inflow of 32,000 afy from Lower Meadow Valley Wash and 8,000 afy from California Wash Valley to Upper Moapa Valley because of the lack of deuterium data for groundwater in the carbonate-rock aquifer in Upper Moapa Valley.

The deuterium mass-balance model of the Lake Mead Flow System indicates that ground-water discharging in the Rogers and Blue Point springs area is mostly regional ground-water flow in the carbonate-rock aquifers with some local recharge. However, on the basis of deuterium data, another water source for the spring area from Upper Moapa Valley cannot be ruled out.

Preliminary analyses of oxygen-18 and geochemical data show that these data are consistent with the deuterium mass-balance model of the regional flow systems.

More work needs to be done to better define deuterium compositions of recharge-area ground-waters (many recharge areas have little or no data) and the variability of deuterium values of springs in recharge areas over time.

8 GROUND-WATER FLOW MODEL

A ground-water model was developed for the southern part of the study area **(Figure 8-1)**. The geographic extent of the model includes Coyote Spring Valley, Kane Springs Valley, Garnet Valley, Hidden Valley, California Wash, Lower Meadow Valley Wash, Upper Moapa Valley, Lower Moapa Valley, and Black Mountains area. This region, which is referred to as the model area, has an area of approximately 3,400 mi^2, and an elevation range of 1,200 to 10,000 ft above sea level.

The model was developed for three purposes: First, to test the hydrogeologic and hydrologic conceptualization of the modeled area; second, to examine the impacts of current and past water use on spring flows and ground-water levels; and third, to identify the effects of future water use on spring flows and ground-water levels. To accomplish these purposes, the model was constructed to represent the 56-year historical period 1945-2000 and the 61-year future period 2001-2061. The model simulates these periods using one-year time steps.

8.1 DESCRIPTION OF CONCEPTUAL MODEL

8.1.1 Hydrogeologic Conceptualization

The hydrogeologic conceptualization of the modeled area includes six hydrogeologic units (described in the Geology section). These include basement rocks of Cambrian and older age, carbonate rocks of Cambrian to upper Paleozoic age, clastic rocks of predominately Mesozoic age, volcanic and intrusive rocks of Tertiary age, and alluvial deposits of upper Tertiary to Quaternary age. The stratigraphic relationships among units are shown on **Figure 8-2**, which diagrammatically shows the presence or absence of each hydrogeologic unit in the modeled area, based on the geographic delineations shown on **Figure 8-3a** through **Figure 8-3d**. The subareas referenced on **Figure 8-2** relate to the structure blocks shown on **Figure 8-4**.

The basement rocks include the Lower Cambrian Prospect Mountain Quartzite, Wood Canyon Formation, and the Proterozoic Vishnu Schist, and Gold Butte Metamorphic Complex. These rocks consist of clastics (quartzite) and metamorphics, and they are non-water-bearing relative to the overlying carbonate rocks. Correspondingly, the top of the basement rocks form the base of the ground-water system.

The carbonate rocks **(Figure 8-3a)** include the Ordovician to Pre-Cambrian Antelope Valley Limestone and Goodwin and Nopah Formations. These rocks are overlain by the Ordovician Eureka Quartzite. The overlying Ordovician to Permian consists of Simonson and Laketown Dolomite, Guilmette Formation, Monte Cristo Group and the Bird Spring Formation. Within the modeled area, these rocks are as much as 27,000 ft in thickness. The carbonate rocks underlie essentially all of the modeled area except in the north where intrusive volcanic rocks penetrate the carbonate rocks, and in the southeast where clastic rocks directly overlie the basement rocks. The carbonate rocks are broadly folded, highly faulted, and fractured. Faulting occurs on both regional and local scales. On the regional scale, large-scale faults **(Figure 8-4)** that are nearly perpendicular to ground-water flow tend to restrict ground-water flow. On the local scale, small-

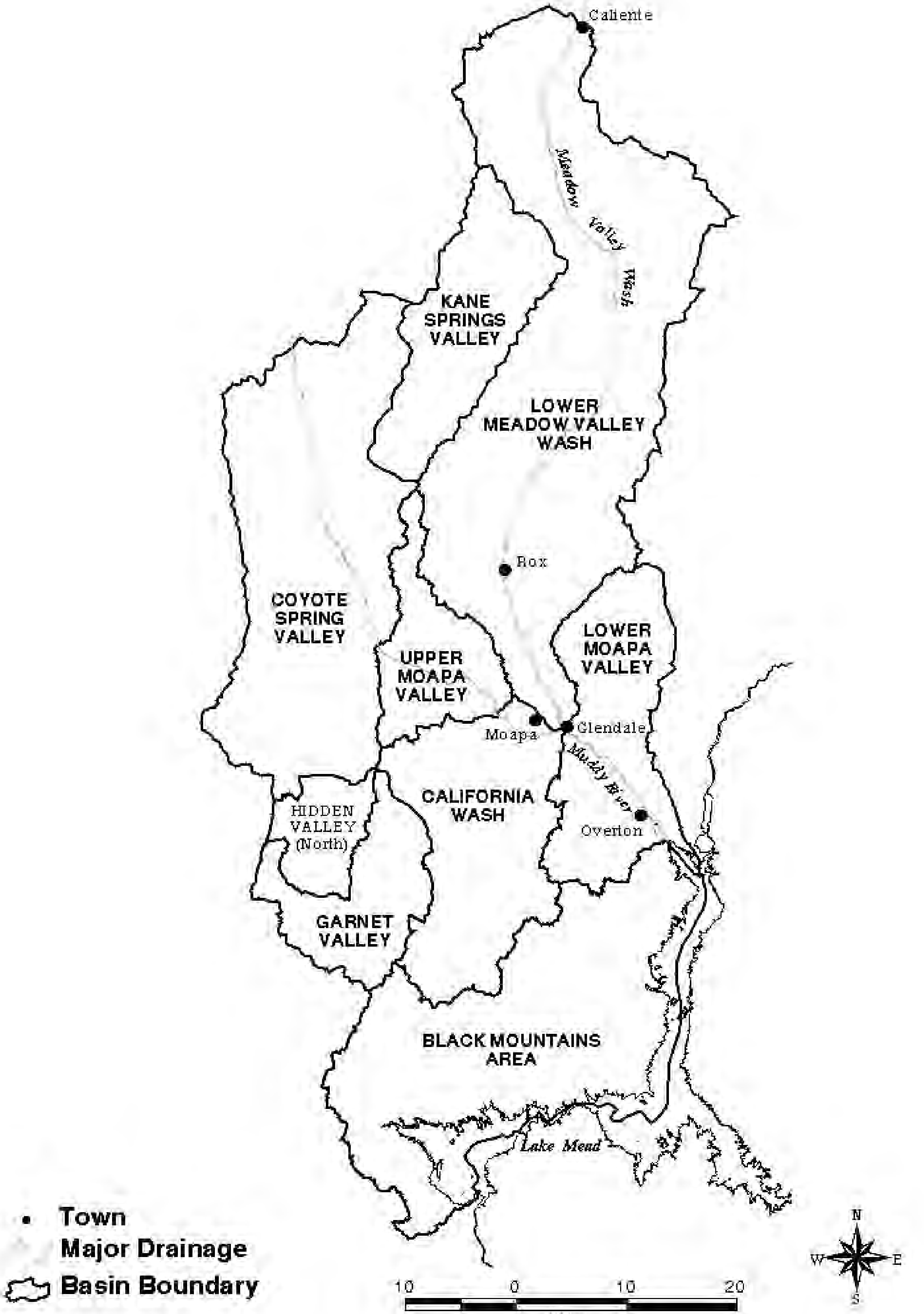

Figure 8-1. Model Area

SE ROA 39533

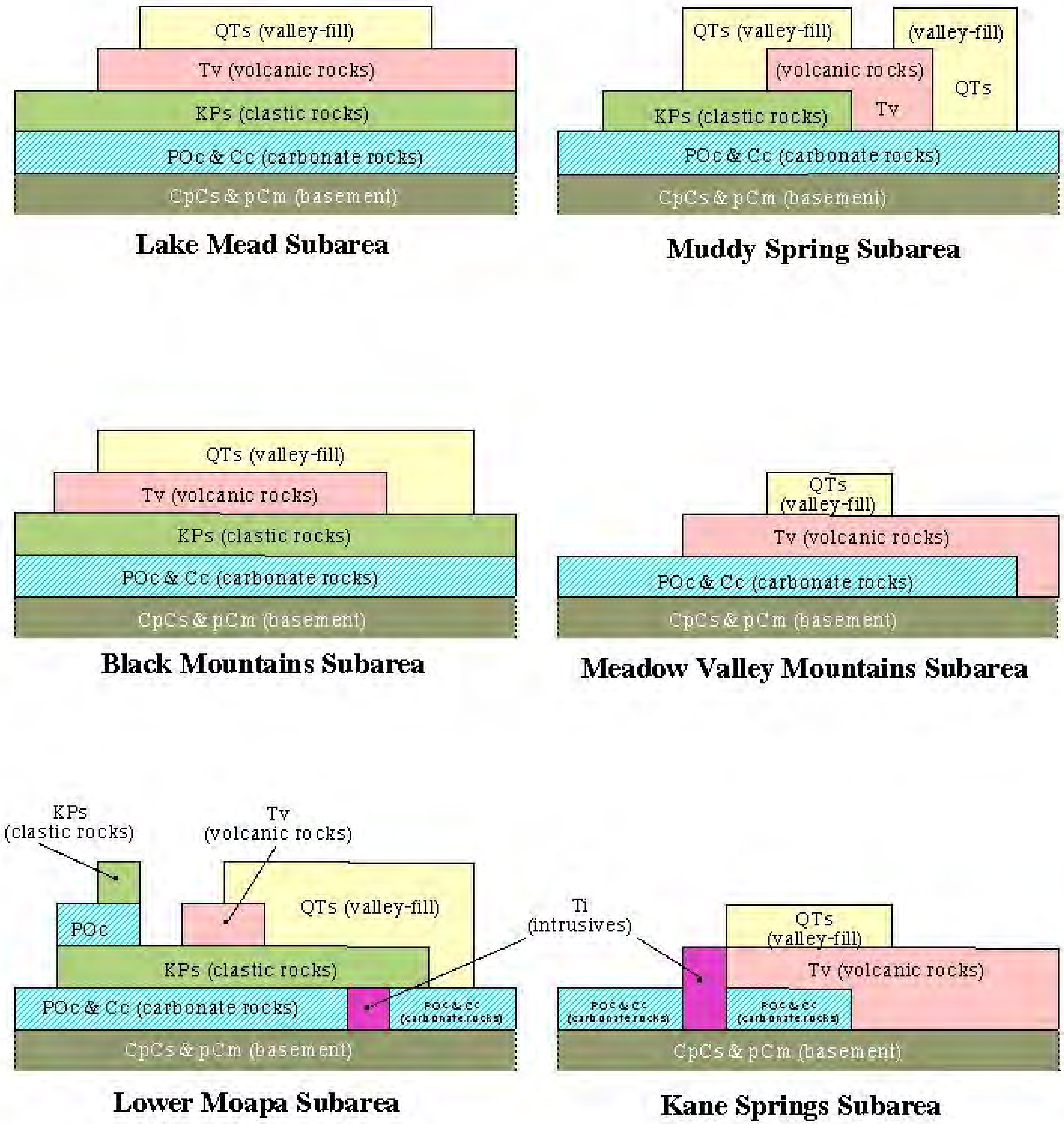

Figure 8-2. Stratigraphic relations within structural blocks.

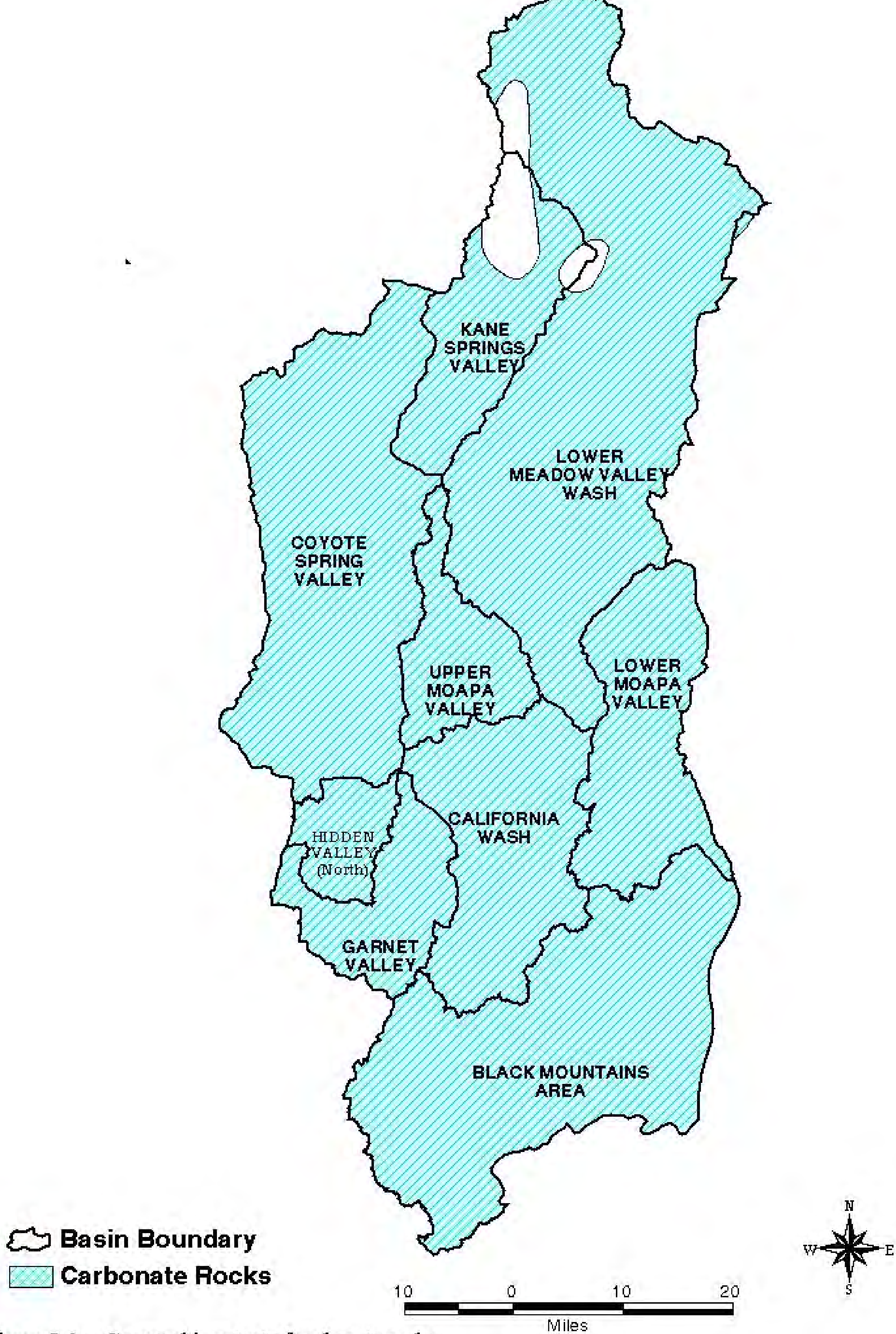

Figure 8-3a. Geographic extent of carbonate rocks.

SE ROA 39535

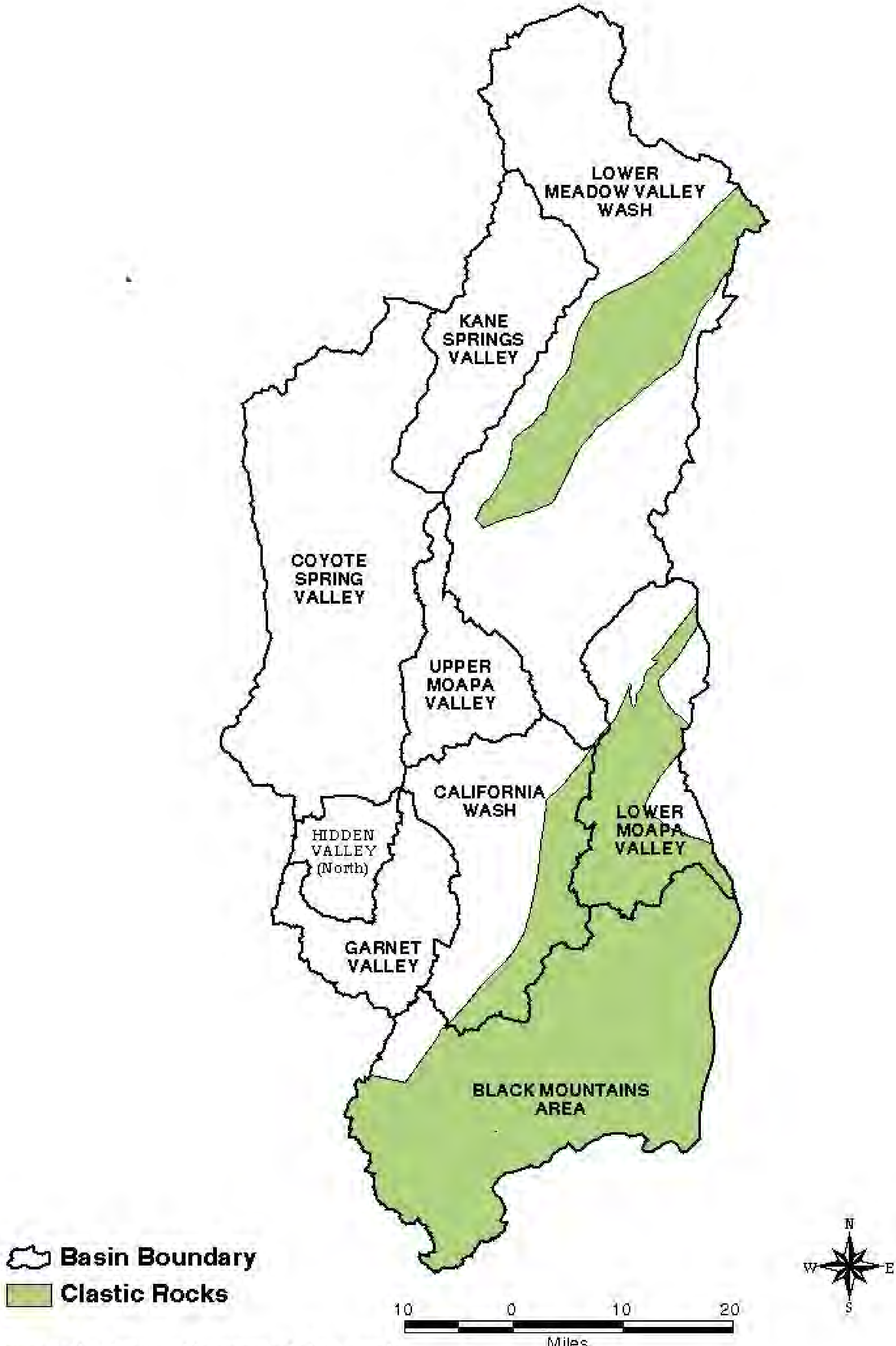

Figure 8-3b. Geographic extent of clastic rocks.

SE ROA 39536

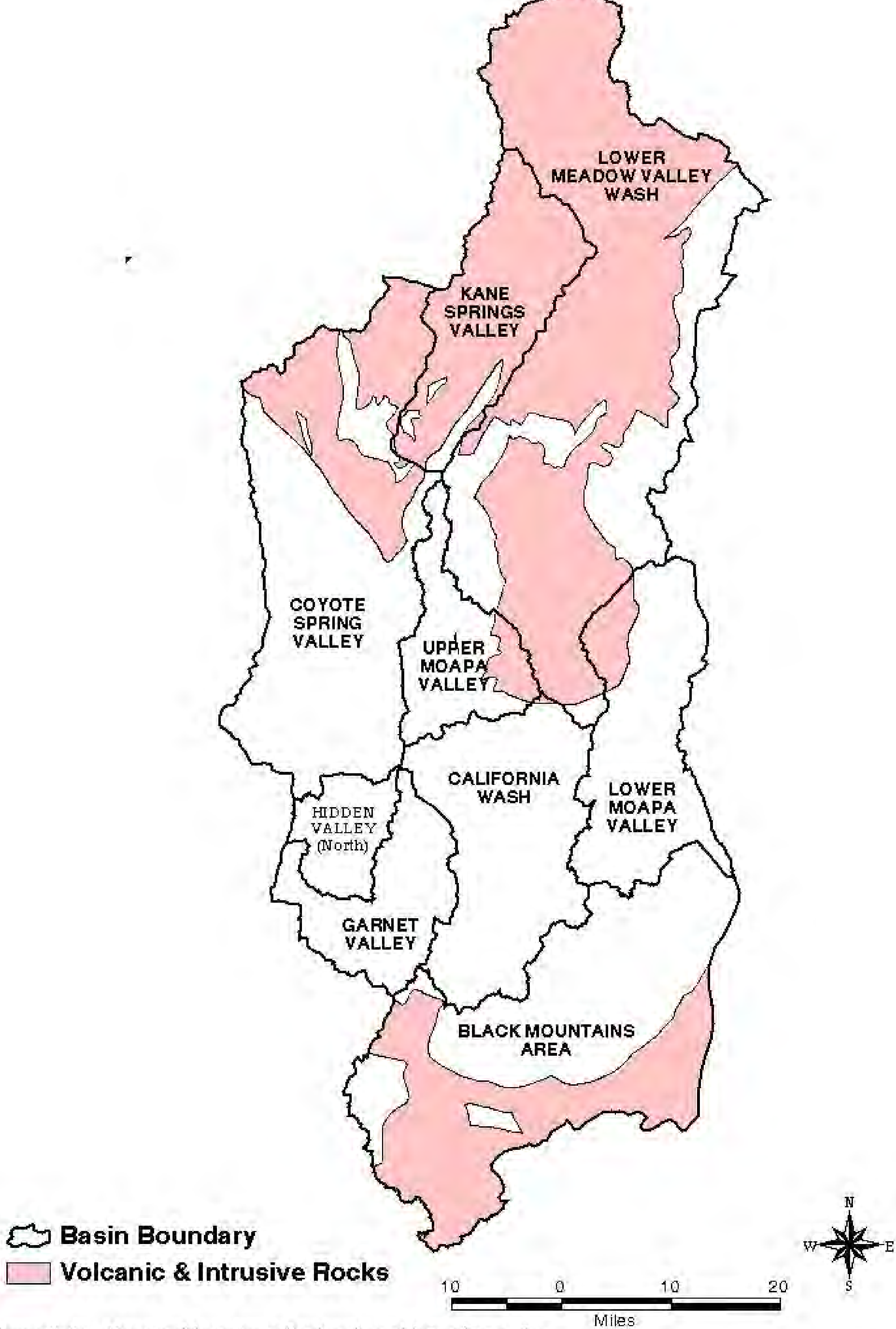

Figure 8-3c. Geographic extent of volcanic and intrusive rocks.

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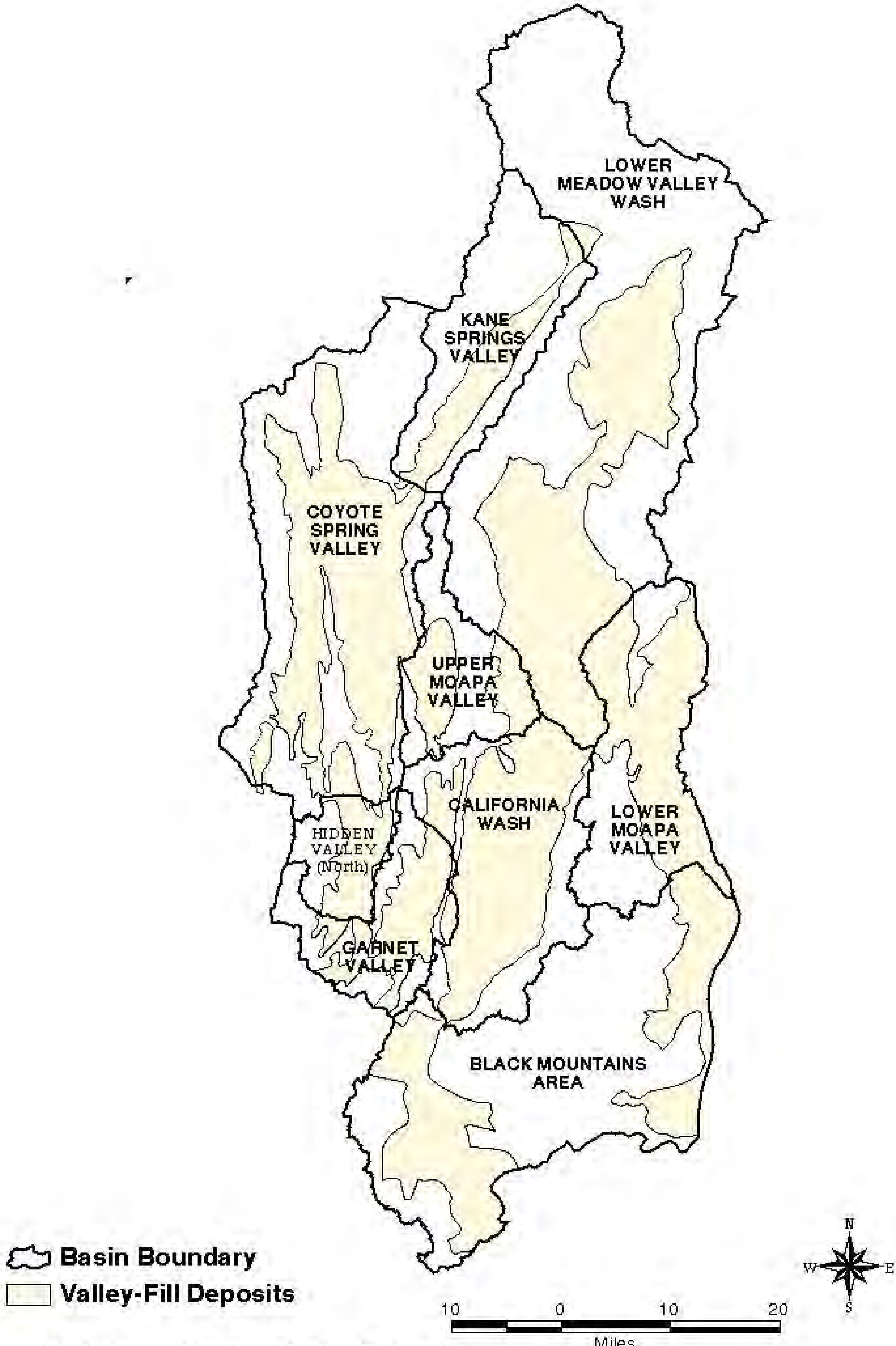

Figure 8-3d. Geographic extent of valley-fill deposits.

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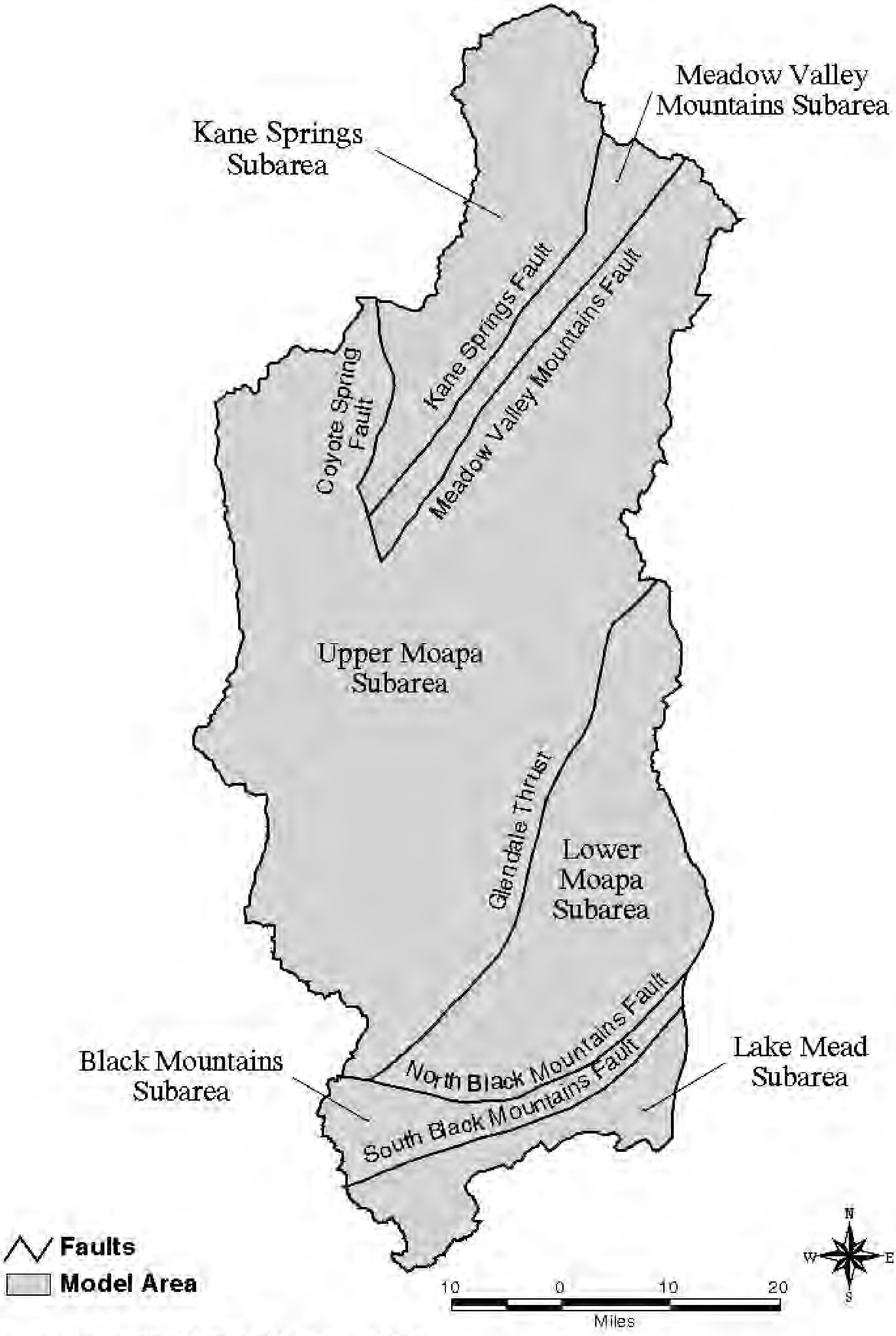

Figure 8-4. Structural blocks within the model area.

scale faults likely produce conduits for ground-water movement. Similarly, fractures likely produce conduits for ground-water flow. Most regional and local ground-water flow within the carbonate rocks occurs within the secondary permeability produced by faults and fracturing, and associated solution channels.

The clastic rocks **(Figure 8-3b)** include the Jurassic Aztec Formation, the Triassic Moenkopi and Chinle Formations and the Lower Permian red bed sequence, Kaibab Limestone and Toroweap Formation. Within the modeled area these rocks are as much as 10,000 ft in thickness. The clastic rocks underlie only a portion of the modeled area in the central and southern area. The clastic rocks have low permeability and form an aquitard overlying the carbonate rocks. While the clastic rocks are fractured, the fracturing has not produced significant secondary permeability vertically through these rocks.

The volcanic rocks **(Figure 8-3c)** include both intrusive and volcanic-flow units. Intrusive rocks occur principally in the northern part of the modeled area. The volcanic rocks occur principally in the northern and to a lesser extent, in the southern part of the modeled area. Within the modeled area, volcanic rocks are as much as 10,000 ft in thickness. The volcanic rocks have low permeability and tend to form an aquitard where they overlay the carbonate rock. Additionally, the volcanic rocks retard vertical ground-water flow where they overlay the clastic rocks, which also have low permeability.

The valley-fill deposits **(Figure 8-3d)** include Quaternary alluvial deposits, the Muddy Creek Formation, and the Horse Spring Formation. The alluvial deposits consist of unconsolidated sediments, the Muddy Creek Formation consists of fine-grained clastic and lacustrine sediments, and the Horse Springs Formation consists primarily of conglomerate. The valley-fill deposits overall are moderately permeable; however, the alluvial deposits tend to be more permeable than the Muddy Creek Formation. The valley-fill deposits tend to be thin relative to underlying units, but locally they are as much as 4,000 ft in thickness.

Regional faults partition the modeled area into hydrogeologic subareas **(Figure 8-4)**. The faults retard ground-water movement between the subareas. While local faulting has enhanced the secondary permeability of the carbonate rocks and perhaps other rocks, extensive lateral and vertical displacements on regional faults have had an opposite effect. This occurs because faulting has juxtaposed low-permeability beds opposite higher-permeability beds so as to block ground-water flow within higher-permeability beds. Additionally, the extensive displacements tend to be correlated with the formation of fault gouge or secondary mineralization along the fault plane. Both of these occurrences tend to restrict ground-water flow within the fault plane and transverse to the fault plane.

The regional faults partition the modeled area into six subareas **(Figure 8-4)**. The north Black Mountains Fault and south Black Mountains Fault divide the southern part of the modeled area into three subareas. South of the southern fault is the Lake Mead subarea, between the faults is the Black Mountains subarea, and north of the northern fault is the Lower Moapa subarea, where the Black Mountain subarea is displaced upward relative to the Lake Mead and Lower Moapa subareas. The vertical displacements are up to 2,000 to 3,000 ft on both faults. The Glendale Thrust separates the Lower Moapa subarea from the Upper Moapa Valley subarea (Muddy Springs). The horizontal displacement along the thrust is about 30,000 ft. The Kane Springs Fault and Meadow Valley Mountains Fault divide the modeled area into two additional subareas.

The vertical displacements are 500 to 1,000 ft on the Kane Springs Fault and 2,000 to 3,000 ft on the Meadow Valley Mountains Fault. The Meadow Valley Mountains Fault separates the Upper Moapa Valley subarea from the Meadow Valley Mountains subarea, and the Kane Springs Fault separates the Meadow Valley Mountains subarea from the Kane Springs subarea. Additionally, the Coyote Spring Fault separates the Upper Moapa subarea from the Kane Springs subarea. The Meadow Valley Mountains subarea is displaced upward relative to the Upper Moapa and Kane Springs subareas.

8.1.2 Hydrologic Conceptualization

The hydrologic system within the model area includes ground water and surface water as shown on **Figure 8-5**. This system is conceptualized into the regional ground-water system and local streams and riparian ground water. The sources of ground-water include underflow from adjacent areas and precipitation within the modeled area. The discharges of ground-water include spring discharges, consumption of diverted streamflow and riparian ground water, seepage to stream channels, pumping, and underflow to the Colorado River. The sources of surface water include spring discharges and seepage to stream channels. The discharges include consumption of diverted streamflow and riparian ground water and surface water outflow to the Colorado River.

Ground-water enters the modeled area as underflow within the carbonate rocks from valleys upgradient **(Table 8-1)**. Underflow enters Coyote Spring Valley **(Figure 8-5a)** from Pahranagat and Delamar Valleys. These underflows are 28,000 afy from Pahranagat and 16,000 afy from Delamar Valley. Underflow enters the Lower Meadow Valley Wash basin from Panaca and Clover Valleys. These underflows are 17,000 afy from Panaca Valley and 9,000 afy from Clover Valley. Additionally, streamflow from the Meadow Valley Wash enters the model area from Panaca Valley and is estimated at 10,000 afy. The cumulative estimated underflow and streamflow into to the modeled area is 80,000 afy **(Table 8-1)**.

Ground-water recharge occurs within the modeled area from precipitation **(Table 8-1)**. Most of that recharge occurs in the mountain areas, but some recharge occurs from ephemeral streamflow on alluvial fans and valley floors. Snowmelt and rainfall in mountain areas infiltrates rocks or seeps into fractures. Much of that water is consumed by native vegetation. However, part of the snowmelt and rainfall percolates downward past the root zone and eventually becomes ground-water recharge within the mountain area. When the snowmelt rate or precipitation rate exceeds the infiltration capacity of soils or fractured rocks, streamflow occurs. Within alluvial-fan or valley-fill areas, streamflow infiltrates into channel beds. Part of the infiltrated water percolates downward to become ground-water recharge. These processes act such that the ground-water recharge from precipitation on the modeled area is about 37,000 afy.

Ground-water discharges from the modeled area as spring discharges, ground-water seepage to channels, and pumping **(Table 8-1)**. The principal spring discharge occurs at the Muddy Springs. The discharge from the springs is about 37,000 afy, including ground-water seepage to the

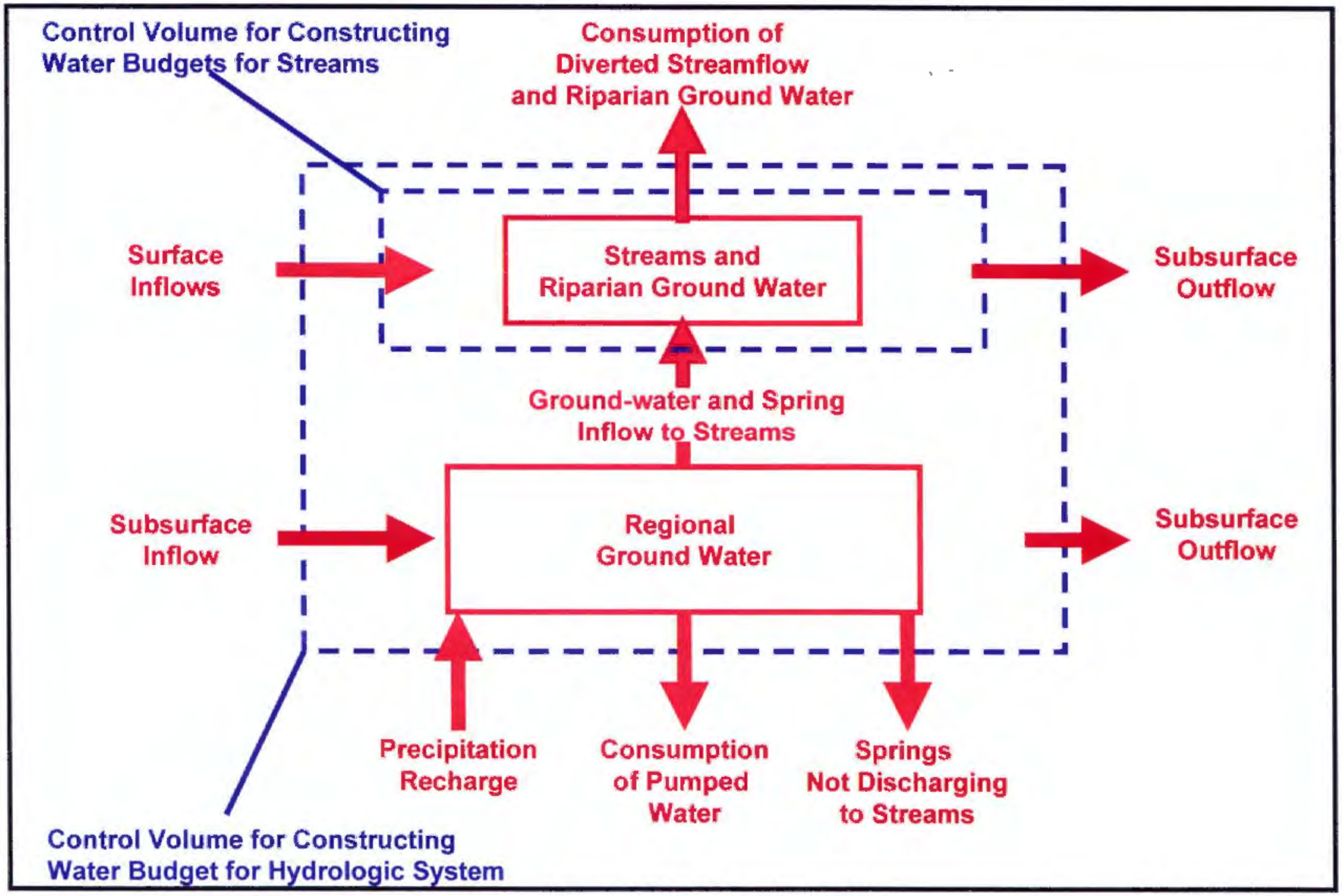

Figure 8-5 Conceptualization of hydrologic system.

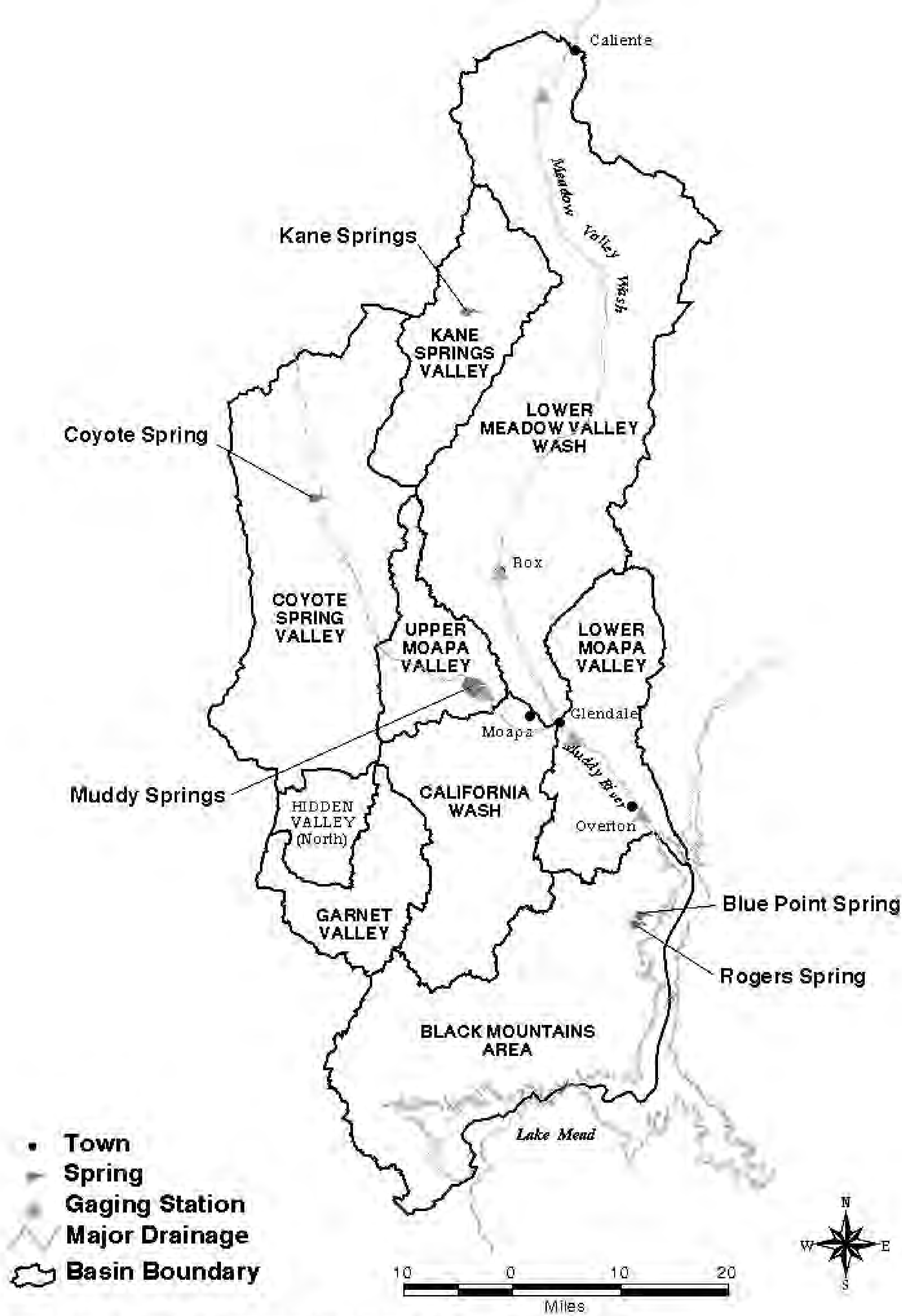

Figure 8-5a. Hydrologic features within the model area.

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Table 8-1. Water budgets for streams and hydrologic systems; historical pumping and diversions in 1945 and 2000[1].

Budget Component	Historical Pumping / Diversions 1945	Historical Pumping / Diversions 2000
WATER BUDGETS FOR MEADOW VALLEY WASH AND MUDDY RIVER		
Inflows – Meadow Valley Wash		
• Streamflow at model boundary	10,000	10,000
• Ground-water inflows above Rox	11,000	9,000
• Ground-water inflows Rox to mouth	4,000	3,000
Total	**25,000**	**22,000**
Outflows – Meadow Valley Wash		
• ET above Rox[2]	21,000	20,000
• ET from Rox to mouth[2]	2,000	0
• Streamflow at mouth	2,000	2,000
Total	**25,000**	**22,000**
Inflows – Muddy River		
• Meadow Valley Wash streamflow at mouth	2,000	2,000
• Ground-water inflows above Moapa	38,000	31,000[3]
• Ground-water inflows Moapa to Glendale	6,000	6,000
• Ground-water inflows Glendale to Overton	7,000	7,000
Total	**53,000**	**46,000**
Outflows – Muddy River		
• ET above Moapa[2]	3,000	5,000
• ET Moapa to Glendale[2]	9,000	9,000
• ET Glendale to Overton[2]	25,000	25,000
• Streamflow at Overton	16,000	8,000
Total	**53,000**	**47,000**
HYDROLOGIC SYSTEM		
Inflows		
Ground-water underflow - Pahranagat Valley	28,000	28,000
Ground-water underflow - Delemar Valley	16,000	16,000
Ground-water underflow - Panaca Valley	17,000	17,000
Ground-water underflow - Clover Valley	9,000	9,000
Meadow Valley Wash streamflow at boundary	10,000	10,000
Boundary underflows	0	0
Precipitation recharge	37,000	37,000
Total	**117,000**	**117,000**
Outflows		
Ground-water pumpage	0	18,000
Surface-water outflow - Muddy River	16,000	8,000
Ground-water discharge to Colorado River	37,000	37,000
ET – Coyote Springs	1,000	1,000
ET – Kane Springs	1,000	1,000
ET – Rogers Springs	1,000	1,000
ET – Blue Point Springs	1,000	1,000
ET – Meadow Valley Wash above Rox	21,000	20,000
ET – Meadow Valley Wash below Rox	2,000	0
ET – Muddy River above Moapa	3,000	5,000
ET – Muddy River – Moapa to Glendale	9,000	9,000
ET – Muddy River – Glendale to Overton	25,000	25,000
Total	**117,000**	**126,000**
STORAGE CHANGE	**0**	**-9,000**

[1] *See Figure 8-5 for definition of control volumes.*
[2] *ET includes consumption of diverted streamflow and riparian ground water.*
[3] *After-effects of diversions and ground-water pumping above Muddy River streamgaging station near Moapa.*

Muddy River along the reach from the springs to the Moapa gage **(Figure 8-5)**. The cumulative discharge from other springs within the modeled area is about 4,000 afy. The individual discharges are 1,000 afy for Blue Point Spring, 1,000 afy for Rogers Spring (representing 2,000 afy for the North Shore Spring Complex), 1,400 afy from Coyote Spring, and 600 afy from Kane Springs. The discharge at the Muddy Springs, Blue Point Spring, and Rogers Spring is from deep carbonate rocks where fault intersections facilitate the discharge. The discharge at Kane Springs is from volcanic rocks, and the discharge from Coyote Spring is from valley-fill deposits. Ground-water discharges to the Muddy River channel from below the Muddy Springs to Lake Mead. Ground-water discharges toward the lower Virgin River channel in the vicinity of Fisherman's Cove and may actually not surface until it is constrained by the fault structure that defines the Colorado River. Finally, ground-water discharges to the Meadow Valley Wash along discontinuous reaches from Caliente to near Rox **(Figure 8-5)**. Additional discharge occurs near the confluence of Meadow Valley Wash with the Muddy River. The cumulative discharge to the Muddy River between Muddy Springs and the Overton gage is about 13,000 afy, which is in addition to the Muddy Springs discharge above the Moapa gage. The cumulative discharge to the Meadow Valley Wash between the Caliente gage to near the Rox gage is about 9,000 afy. The additional discharge to Meadow Valley Wash near its confluence with the Muddy River is 3,000 afy.

Ground-water is pumped within the modeled area for agricultural, industrial, and municipal uses **(Table 8-1)**. Additionally, minor ground-water is pumped at various locations for residential and commercial purposes. The agricultural and industrial pumping is located along the Muddy River from near the Muddy Springs to Overton. About 35 active wells occur along this reach, and the current consumptive pumpage is about 11,000 afy. Ground-water pumping along the Muddy River started in 1947 for irrigation. During 1947-2000 pumping tended to increase from year to year, but during the middle of this period, most agricultural pumping was replaced with industrial pumping. The industrial pumping is mostly for cooling at Nevada Power's Reid Gardner Station. The current consumptive industrial pumping is about 7,500 afy. Additional pumping for export to Lower Moapa Valley municipal and industrial uses began in the early 1990s, and has increased steadily to a current export of approximately 3,000 afy.

Spring discharges and ground-water seepage to streams are used consumptively within the modeled area **(Table 8-1)**. Consumption results from irrigation diversions or direct ground-water use by phreatophytes. Along Meadow Valley Wash, streamflow resulting from ground-water discharges is consumed. Streamflow enters the modeled area at Caliente, and is diverted for irrigation and consumed within the modeled area. The water use along the Meadow Valley Wash in year 2000 is such that streamflow almost ceases near Rox, except for occasional flood flows. The consumption along the wash is about 20,000 afy. Along the Muddy River, streamflow resulting from ground-water discharges is diverted for irrigation or industrial uses and consumed. The water use along the Muddy River is such that a substantial amount of the streamflow is consumed above the Overton gage. Nevertheless, some streamflow reaches Lake Mead. The consumption along the river is about 39,000 afy.

Ground-water discharges to Lake Mead and the Virgin River as upward ground-water flow to the lake or stream channel **(Table 8-1)**. The carbonate rocks within the modeled area terminate in the vicinity of Lake Mead where they transition into rocks of the Colorado Plateau series. The carbonate rocks are juxtaposed against low permeability rocks at that boundary, and ground-water flow in the carbonate rocks is forced upward. Prior to the construction of Hoover Dam in

1935, the current ground-water discharge to the Colorado River. With the dam and Lake Mead constructed, the current ground-water discharge to Lake Mead on the lower Virgin River is about 37,000 afy.

8.2 DEVELOPMENT OF NUMERICAL MODEL

A three-dimensional model was developed based on the hydrogeologic and hydrologic conceptualizations described above. The model was constructed using the U.S. Geological Survey computer program FEMFLOW3D (Durbin and Bond 1998). This program solves the governing equations of ground-water flow using the finite-element method, which is one of several mathematical techniques used in ground-water models. The program consists of modules for simulating inflows and outflows for a ground-water system. Those utilized within the current model include the specified-flux module, specified-head module, stream-aquifer module, and variable-flux module (Durbin and Bond, 1998). Additionally, the model utilizes the flexible-grid module (Durbin and Berenbrock, 1985).

The model utilizes a three-dimensional mesh that is specified as an assemblage of nodes and elements, and the modules for simulating ground-water inflows and outflows relate those quantities to nodes within the model mesh. The specified-flux module assigns recharge and discharge rates to specified mesh nodes. The specified-head module specifies a relation for a mesh node between discharge and the simulated ground-water level for the node. The stream-aquifer module specifies a relation for a mesh node between ground-water discharge to a stream and the simulated ground-water level at the stream. The variable-flux module specifies a relation for a mesh-boundary node between the boundary discharge and ground-water conditions outside the model area.

The flexible-grid module adjusts the grid geometry to account for the position of the ground-water table. As the water-table elevation changes during a simulation, the module adjusts mesh nodes upward or downward such that the node elevation equals the water-table elevation (Durbin and Berenbrock, 1985).

8.2.1 <u>Representation of Hydrogeology</u>

The ground-water model represents five hydrogeologic units **(Figure 8-6)**. These include the carbonate rocks, clastic rocks, intrusive rocks, volcanic rocks, and valley-fill deposits. The geographic extents and thickness of these units were derived from the geologic cross sections **(Figure 3-2** through **Figure 3-4** in Section 3**)**. **Figure 8-3a** through **Figure 8-3d** show the geographic extent of each unit.

The hydrogeologic units and structural features within the model area are represented in the ground-water model using a three-dimensional mesh. The mesh is an assemblage of vertically oriented prismatic elements. A typical element is shown on **Figure 8-7**. The elements project a triangle on a horizontal cross-section, which is represented by the top and bottom faces shown on the figure. The elements project a trapezoid on a vertical plane, which is represented by the

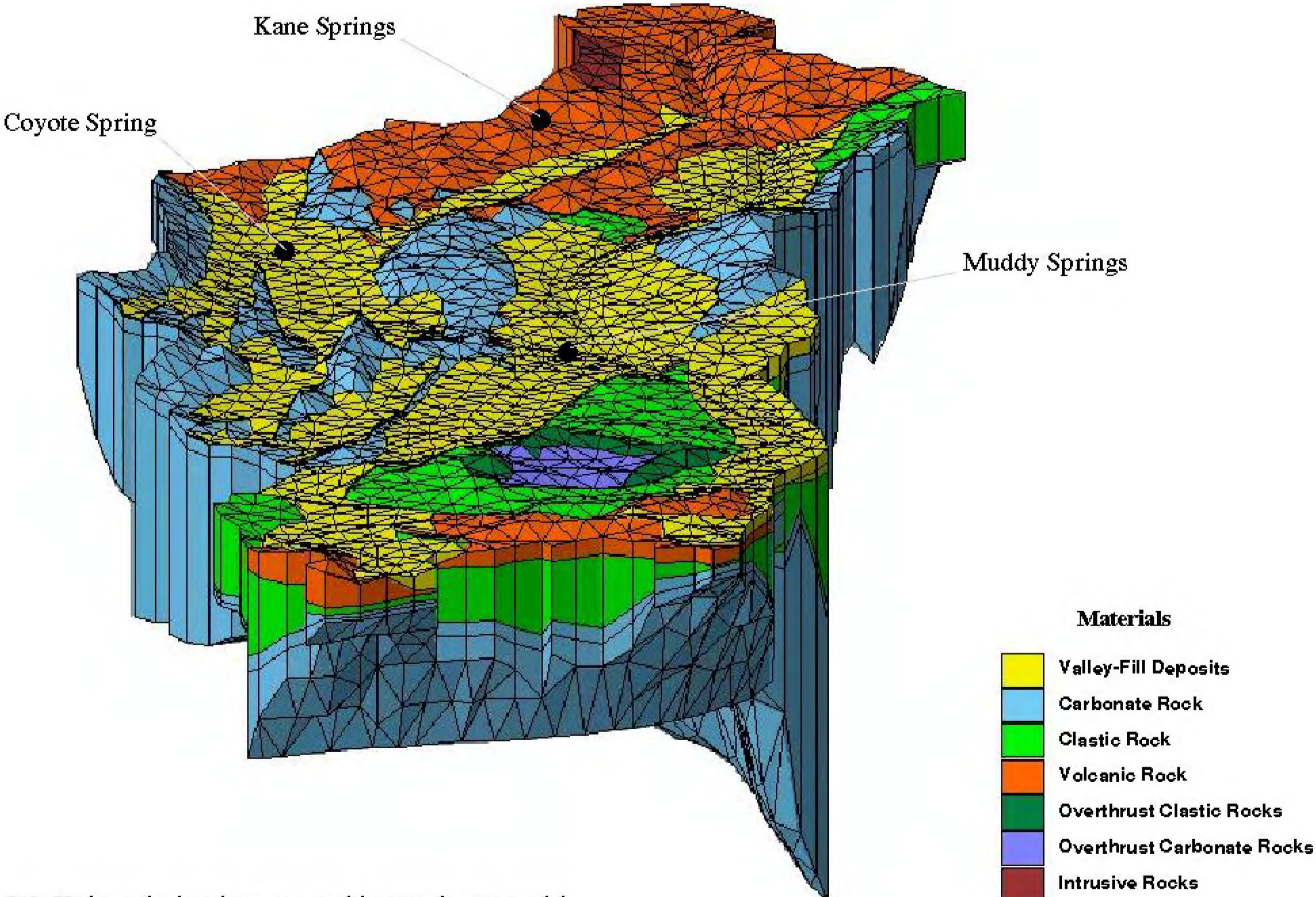

Figure 8-6. Hydrogeologic units represented in ground-water model.

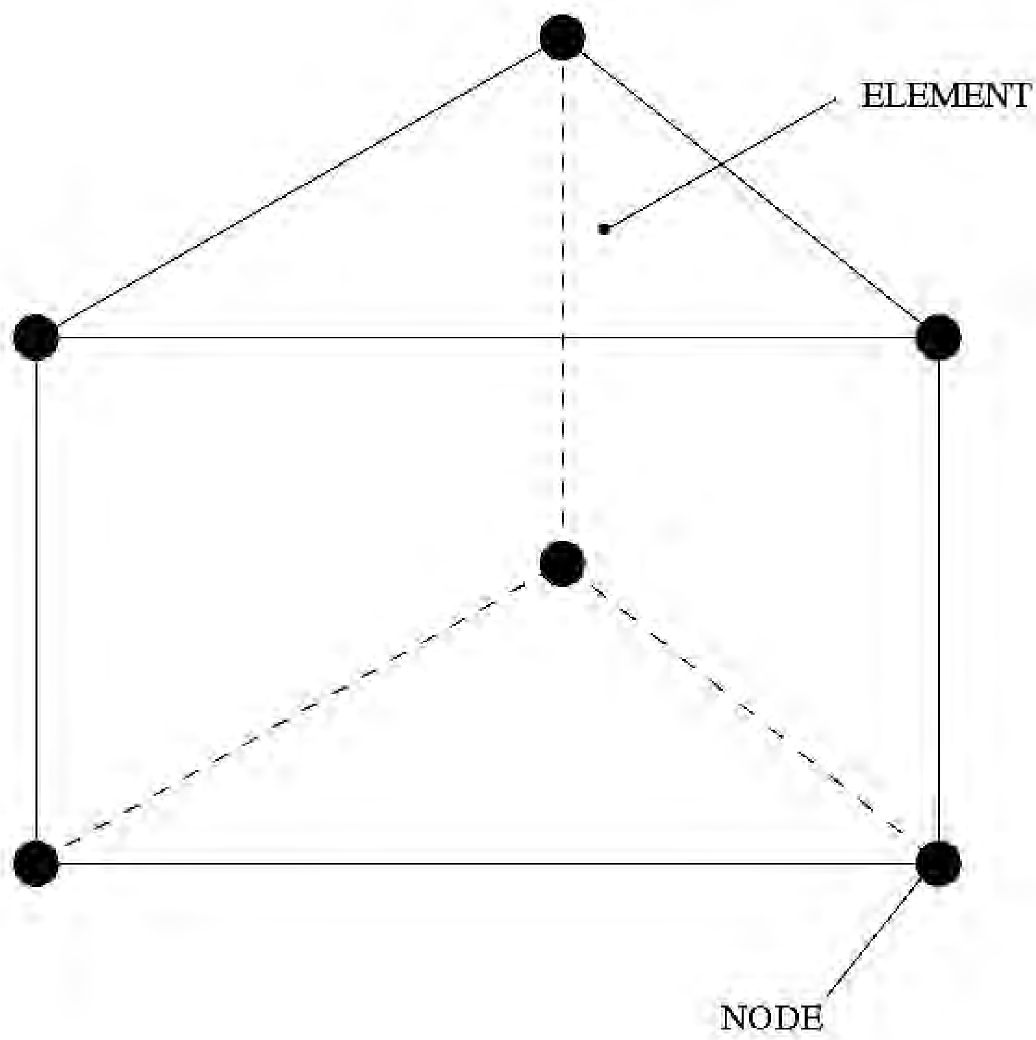

Figure 8-7. Typical element within finite-element mesh.

vertical faces shown on the figure. The particular size and spatial position of an element is specified by the three-dimensional coordinates representing the vertices of the prism, which are referred to as nodes. Laterally and vertically adjacent elements share nodes, which establish the continuity of the ground-water system within the modeled area.

The finite element mesh is shown on **Figure 8-8,** and **Figure 8-9a** through **Figure 8-9e**. **Figure 8-8** shows the geographic layout of the mesh. The mesh is constructed geographically to define the extents to the hydrogeologic units. As shown on **Figure 8-8**, element top or bottom faces define surface contacts between units. The mesh is constructed vertically to define the thickness and elevations of the hydrogeologic units. The layering of elements within the three-dimensional mesh represents the layering of the hydrogeologic units. Additionally, the mesh is constructed to represent location of regional faults. As shown on **Figure 8-8**, faults are represented in the mesh as linear assemblage of narrow elements.

Using the flexing-grid module of FEMFLOW3D, the mesh adjusts so that the top of the surface represents the ground-water table. The top surface of the mesh initially is the land surface, and nodes in the top surface are assigned an elevation equal to the land-surface elevation. If the ground-water table fluctuates during a transient-state simulation, the top surface of the finite-element mesh correspondingly fluctuates. This is accomplished by appropriately expanding or contracting the mesh. If the ground-water table rises or falls during a simulation, the top surface of the mesh rises or falls so that the local elevation of the top surface always equals the local computed elevation for the ground-water table.

While the mesh itself defines spatial relationships within the ground-water system, the assignment of material properties to elements defines the hydraulic characteristics of the ground-water system. Each element is assigned values for horizontal permeability, vertical permeability, and specific storage. Elements forming the top surface of the mesh also are assigned a value for specific yield. The collection of elements representing a particular hydrologic unit or fault is assigned material properties characterizing the unit or fault. In the model inputs, each element is assigned a material type taken from a list of materials. Each material is assigned a horizontal permeability, vertical permeability, specific storage, and specific yield, and material-type assignment correspondingly assigns values to elements. Elements are assigned hydraulic properties from a list of thirty-nine materials **(Table 8-X)**. The list contains material properties for each hydrogeologic unit and each subarea. Additionally, the list contains material properties for each fault. The specification of values for material properties was derived from a model calibration, which is a process for selecting material properties so that the ground-water model best fits historical conditions. That process is described later.

8.2.2 Representation of Natural Recharge

Using the specified-flux module of FEMFLOW3D, the model replicates natural recharge to the ground-water system, where the total recharge to the model area is about 107,000 afy groundwater and 10,000 afy surface-water **(Table 8-1)**. Natural ground-water recharge to the ground-water system includes precipitation recharge and subsurface inflows. Recharge from precipitation within the modeled area is based on a modified Maxey-Eakin method as described

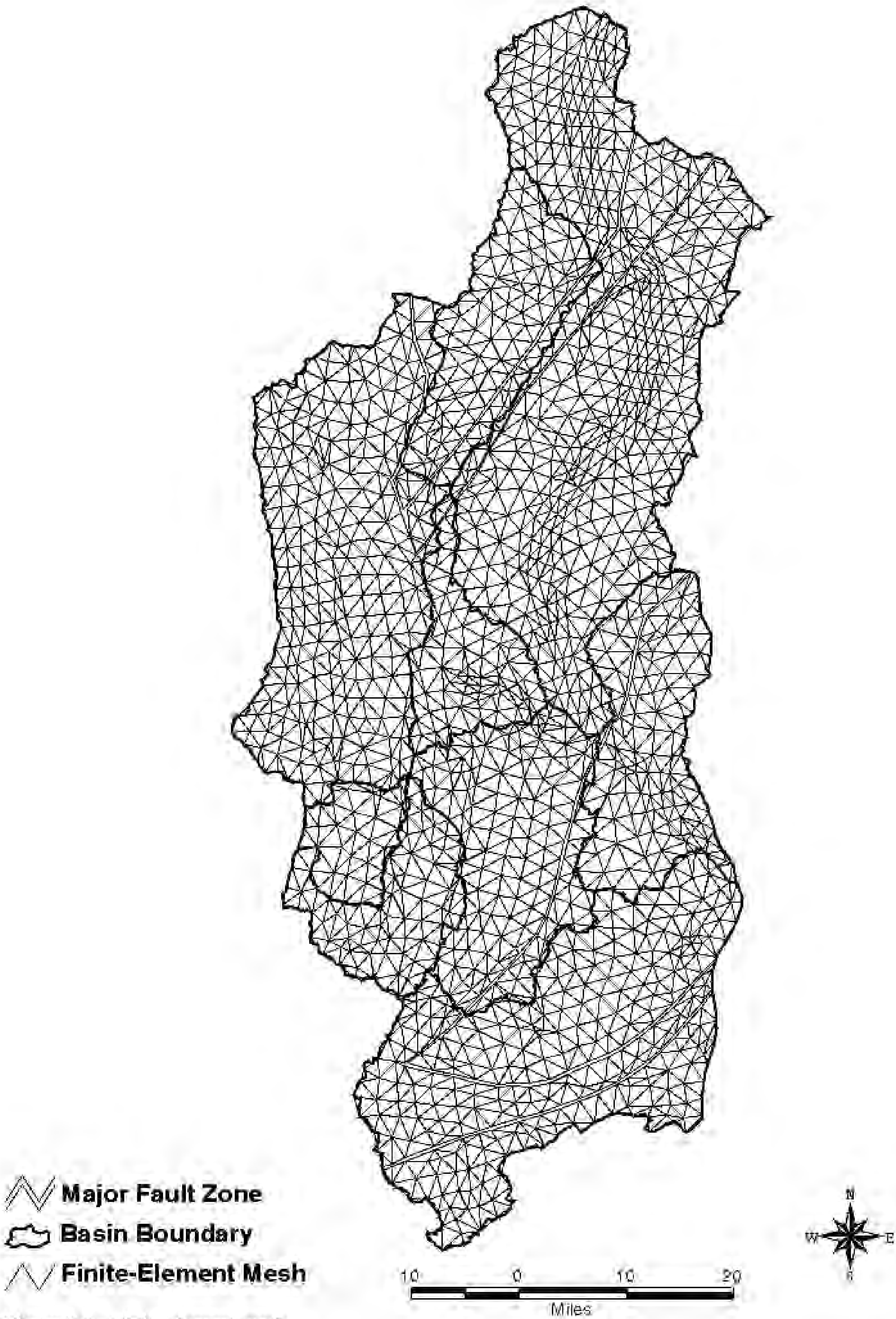

Figure 8-8. Finite-element mesh.

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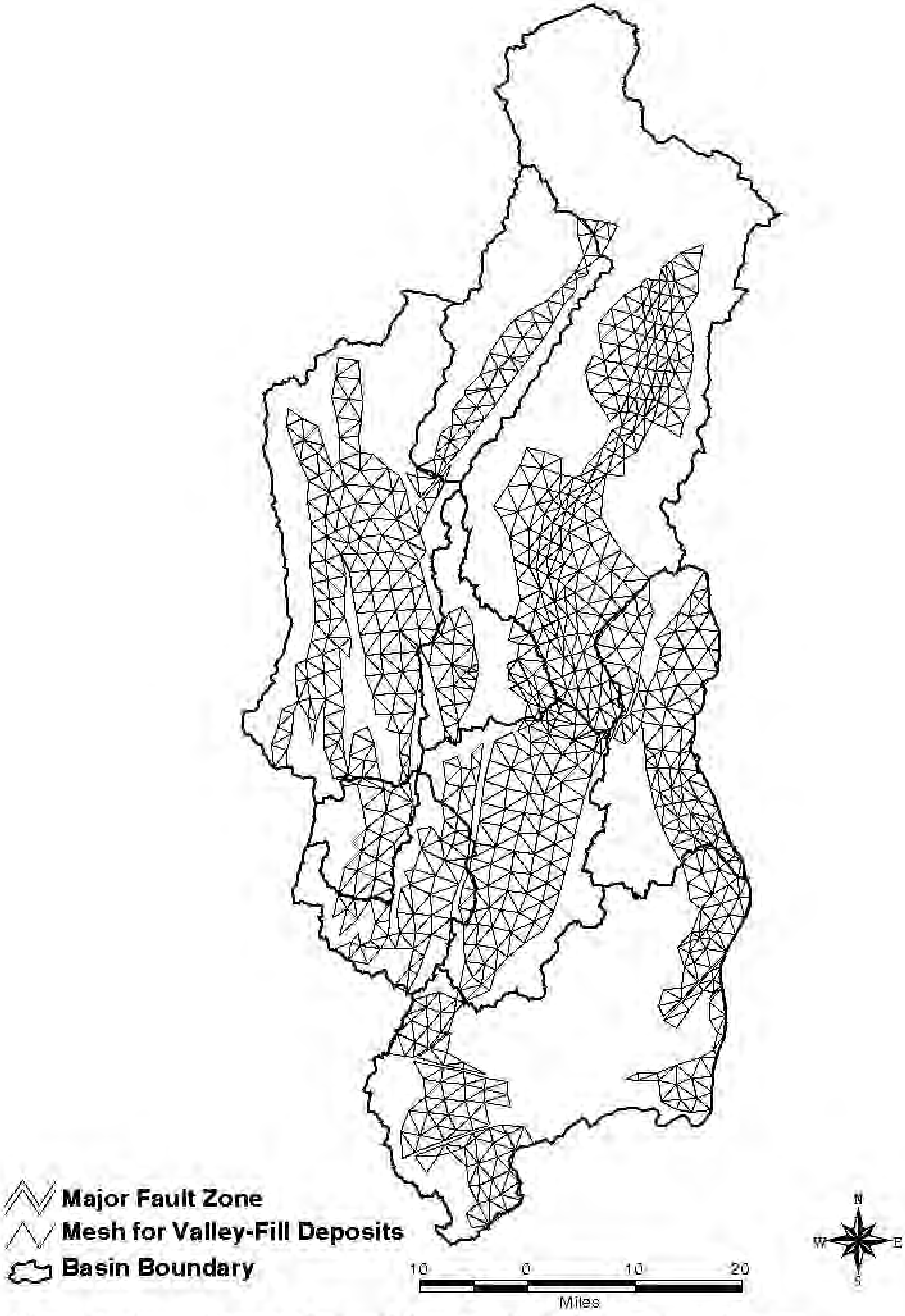

Figure 8-9a. Geographic extent of valley-fill deposits within finite-element mesh layer one.

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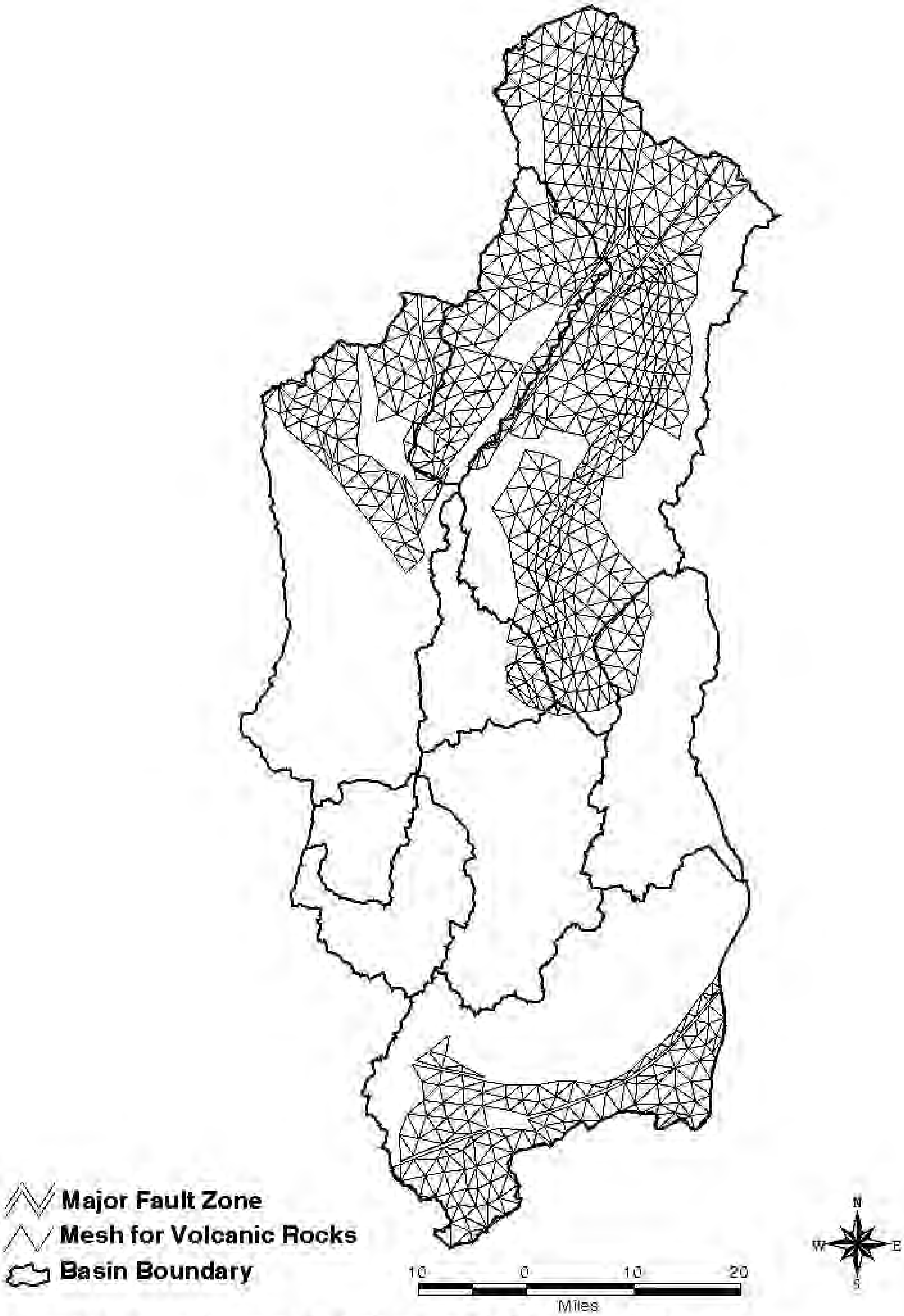

Figure 8-9b. Geographic extent of volcanic rocks within finite-element mesh, layer two.

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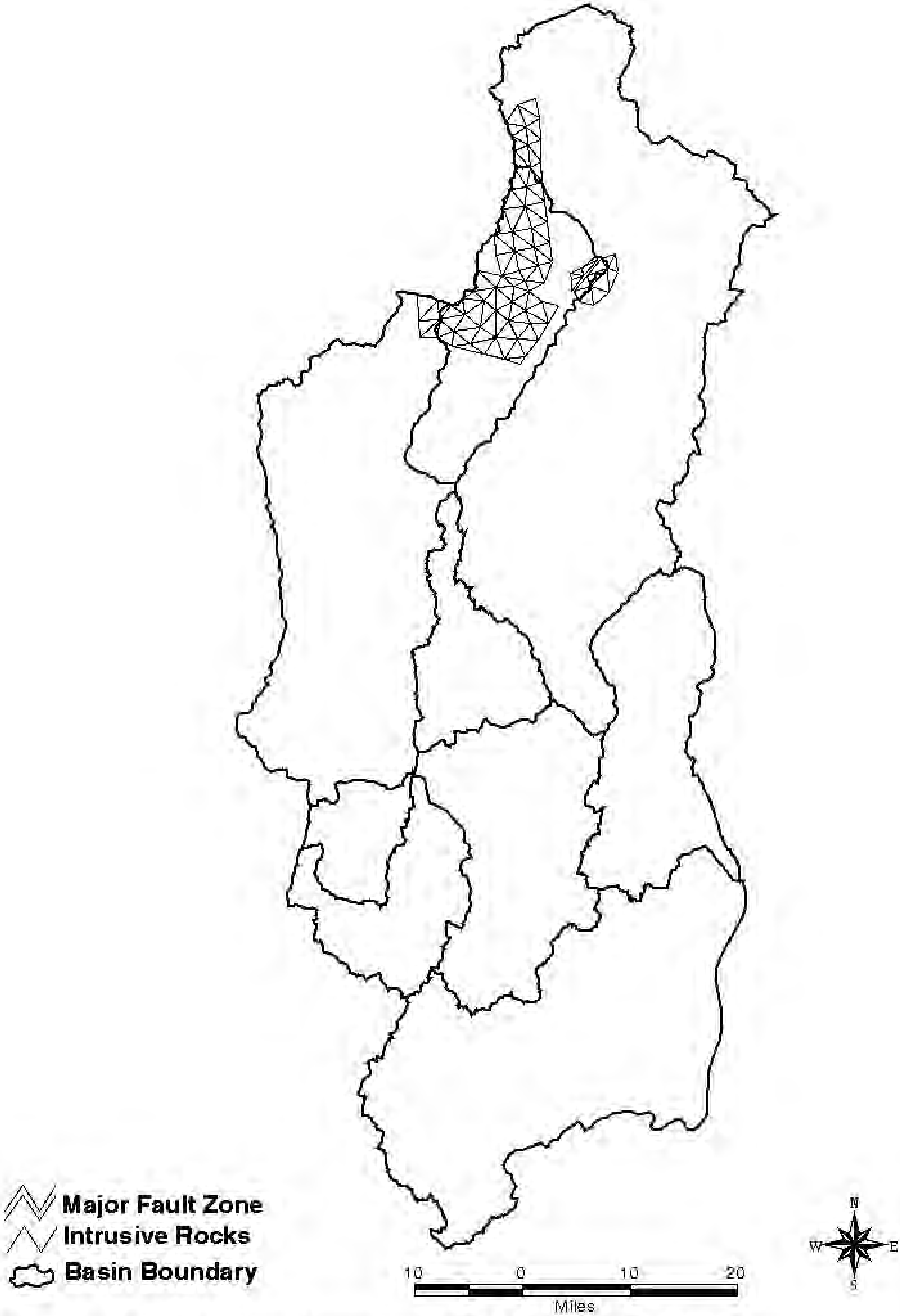

Figure 8-9c. Geographic extent of intrusive rocks within finite-element mesh, layer three.

SE ROA 39553

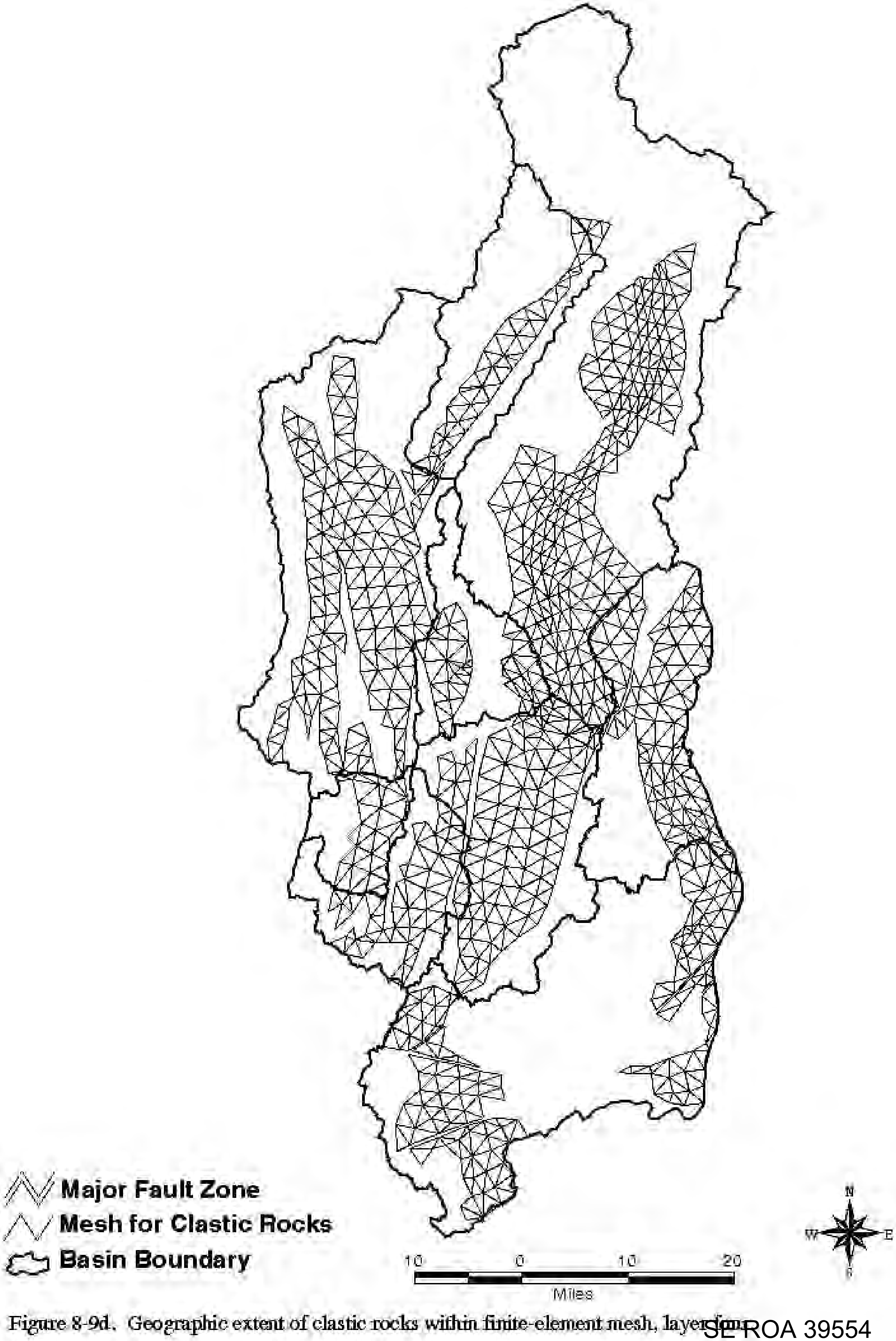

Figure 8-9d. Geographic extent of clastic rocks within finite-element mesh, layer four.

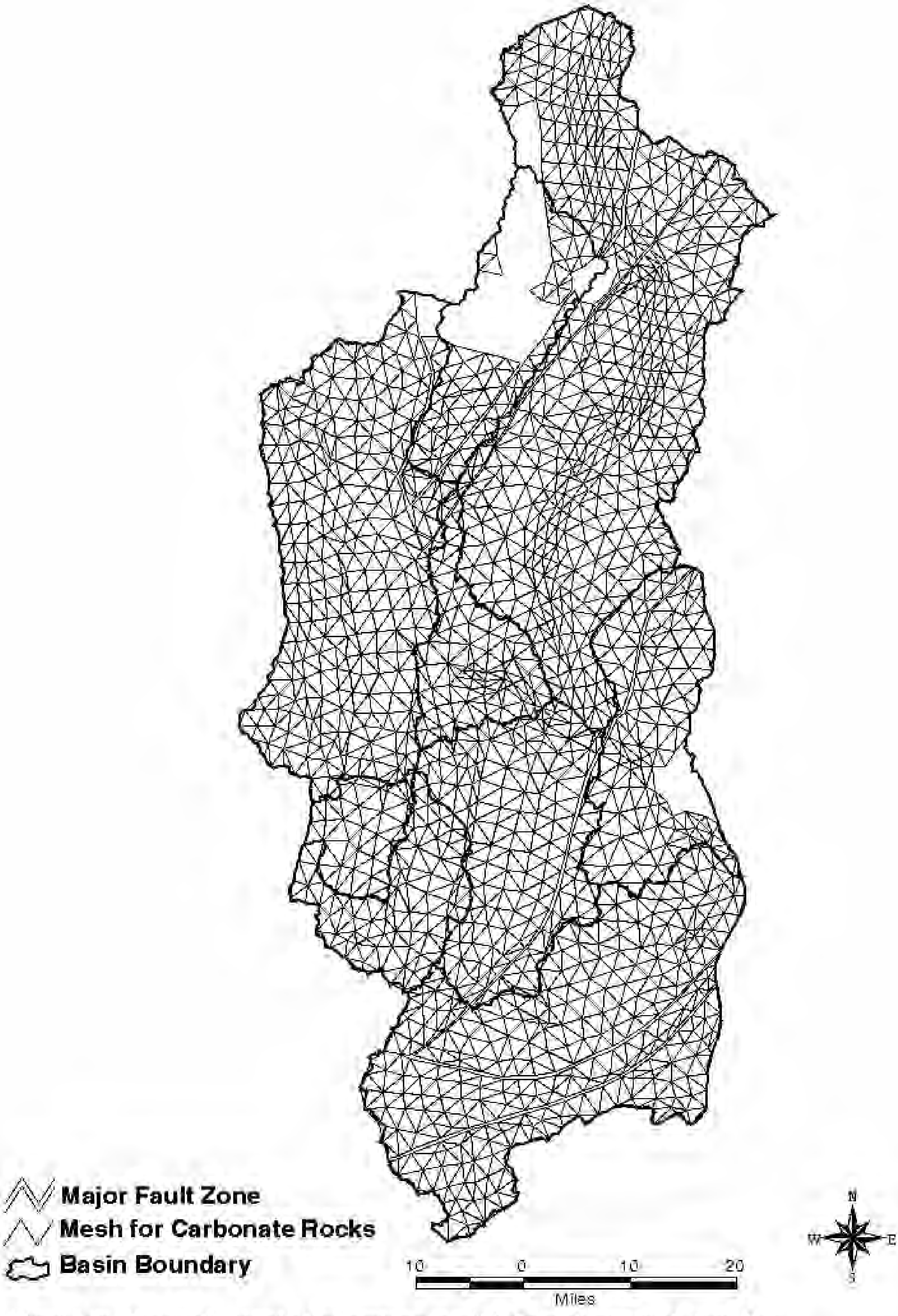

Figure 8-9e. Geographic extent of carbonate rocks within finite-element mesh, layer five.

in Section 4.4. Likewise, the subsurface inflows to the modeled area are based in part on the application of this modified Maxey-Eakin method to the source area, which is the study area upgradient from the modeled area. The resulting subsurface inflows represent the precipitation recharge within the source area less the consumption within that area.

Natural recharge is incorporated in the model by assigning recharge values to nodes within the model mesh that correspond to areas where recharge occurs. Precipitation recharge within the model area is assigned to nodes in the top surface of the model mesh. The recharge value assigned to a particular node represents the integration of the local recharge per unit area over the local area associated with the node. The integration translates local recharge expressed as depth per unit time to a nodal recharge expressed as a volume per unit time. The sum of the volumetric values for all nodes equals the total precipitation recharge for the model area. The subsurface inflows to the modeled area are assigned to nodes in the vertical surface of the model mesh at the boundary of the modeled area. Where mesh nodes occur on that vertical surface, a set of nodes occur as a column. The bottom three nodes in the column represent the carbonate rocks, and the subsurface inflows are assigned to the carbonate rocks at the bottom two nodes. **Figure 8-10** shows the locations where subsurface inflows are assigned to the model mesh.

8.2.3 Representation of Natural Discharge

Using the specified-head, stream-aquifer, and specified-flux modules of FEMFLOW3D, the model represents natural discharge from the ground-water system, where the total natural discharge from the model area is about 117,000 afy **(Table 8-1)**. Natural ground-water discharge includes spring discharges, ground-water seepage to streams, and subsurface outflows. Spring discharges and ground-water seepage are calculated internally within the model based on the simulated ground-water levels, except that valley-fill springs are simulated in the model as a specified discharge. Subsurface outflows are represented either as a head-dependent condition or a specified discharge.

For a carbonate spring, when the hydraulic head within the source aquifer for the spring is above the spring-orifice elevation, the spring discharge in the model is proportional to the difference between the spring-orifice elevation and the source-aquifer head. Otherwise, the spring discharge equals zero. The coefficient of proportionality is the spring leakance. For a stream, when the ground-water level in the underlying aquifer for the stream is above the stream-surface elevation **(Figure 8-11a** and **Figure 8-11b)**, the ground-water seepage to the stream in the model is proportional to the difference between the stream-surface elevation and the underlying ground-water level. Otherwise, streamflow is lost from the channel. The constant of proportionality is the stream leakance, which is related in the model to streamflow depth **(Figure 8-12)**, streamflow width **(Figure 8-13)**, streambed permeability, streambed thickness, and reach length.

Ground-water discharge to carbonate springs and streams is incorporated in the model by identifying the spring and stream nodes. For the spring nodes **(Figure 8-14)**, the spring-orifice elevation and spring leakance are assigned. For the stream nodes **(Figure 8-15)**, the streambed elevation, thickness, and permeability are assigned. Additionally, a channel network is specified in order to link the nodes **(Figure 8-15)**, and channel-geometry relations are specified. Those

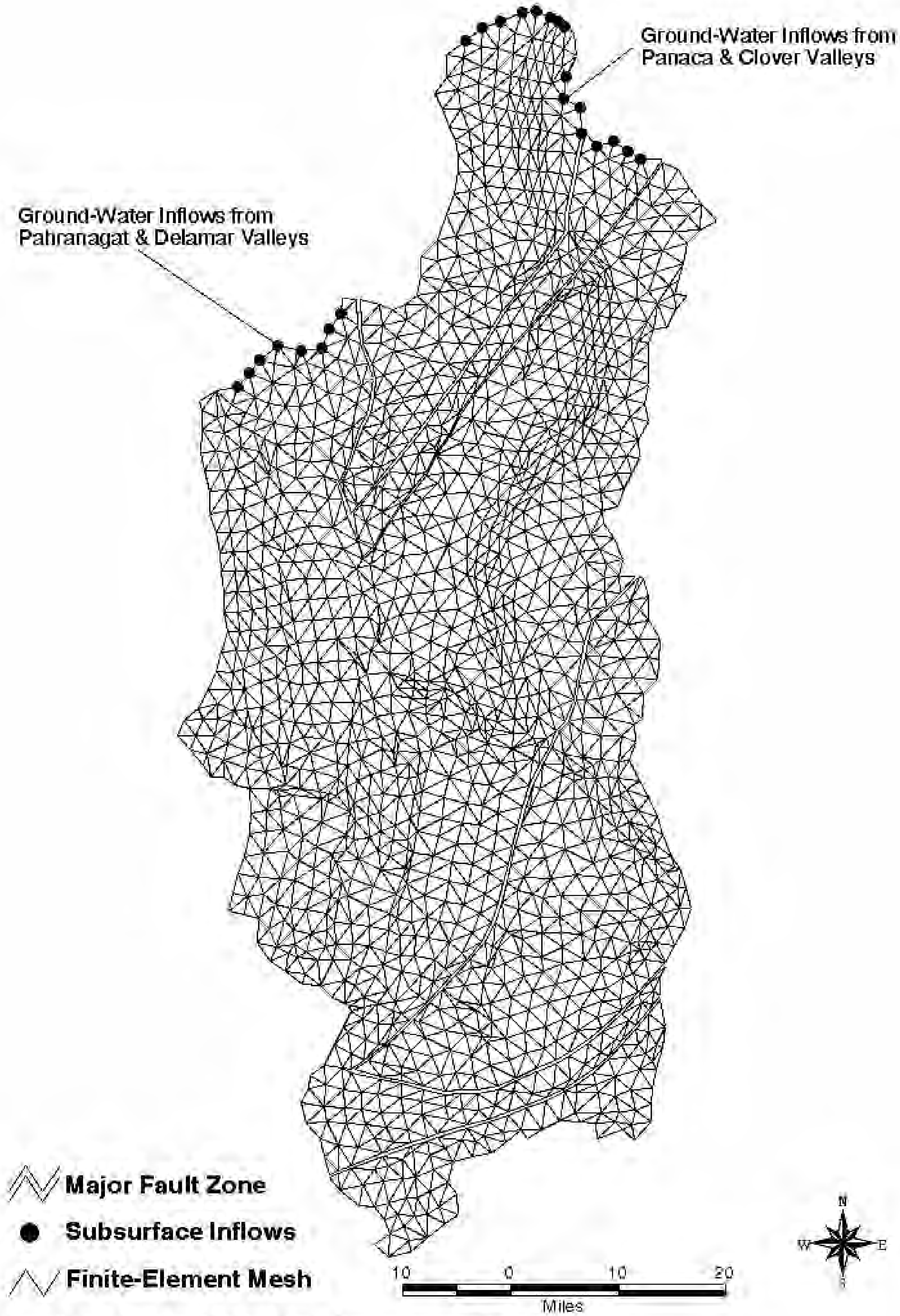

Figure 8-10. Location of subsurface inflows represented in model.

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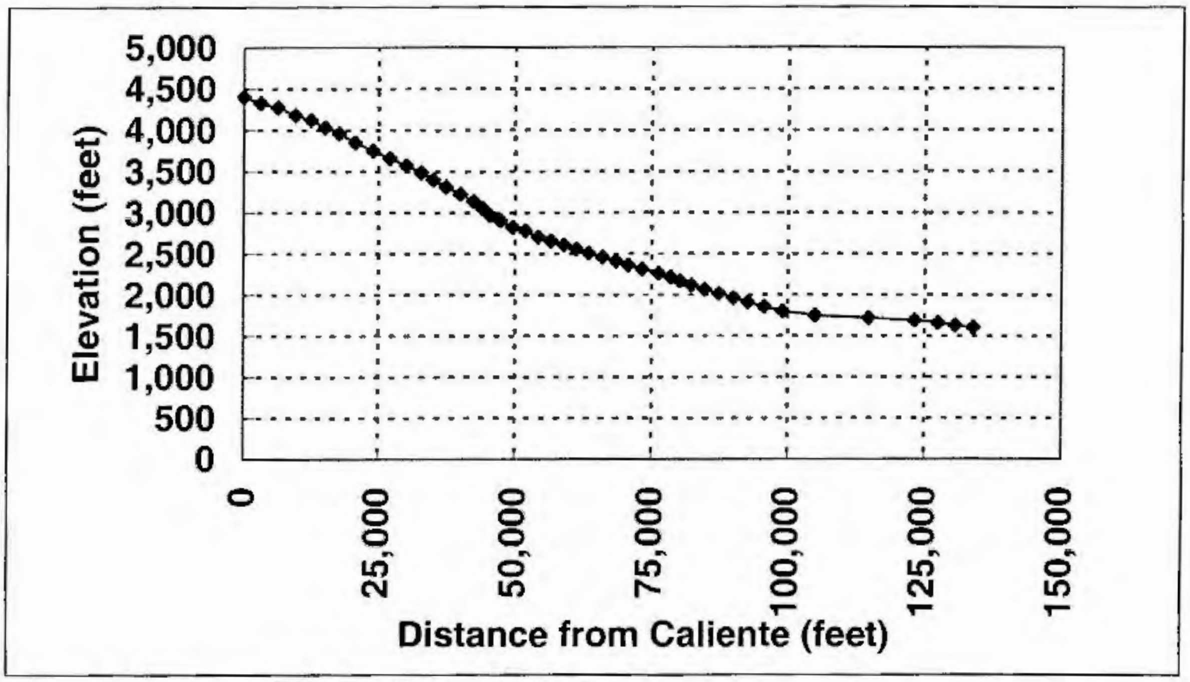

Figure 8-11a Lower Meadow Valley Wash Elevation.

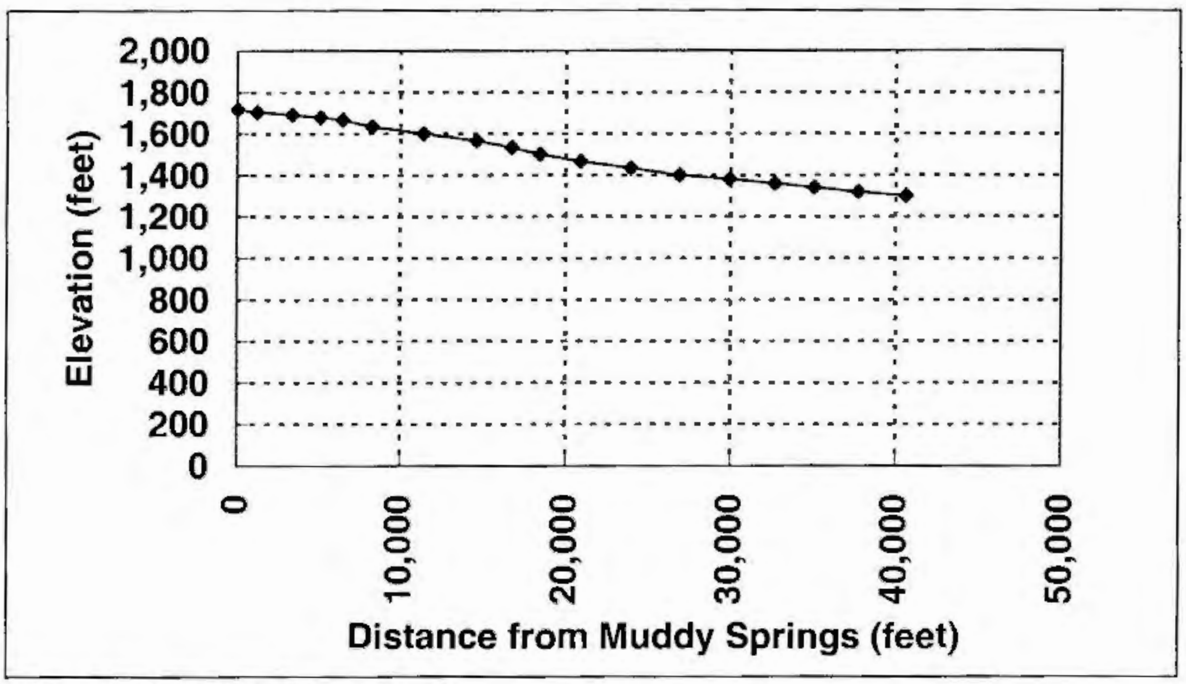

Figure 8-11b Muddy River Elevation.

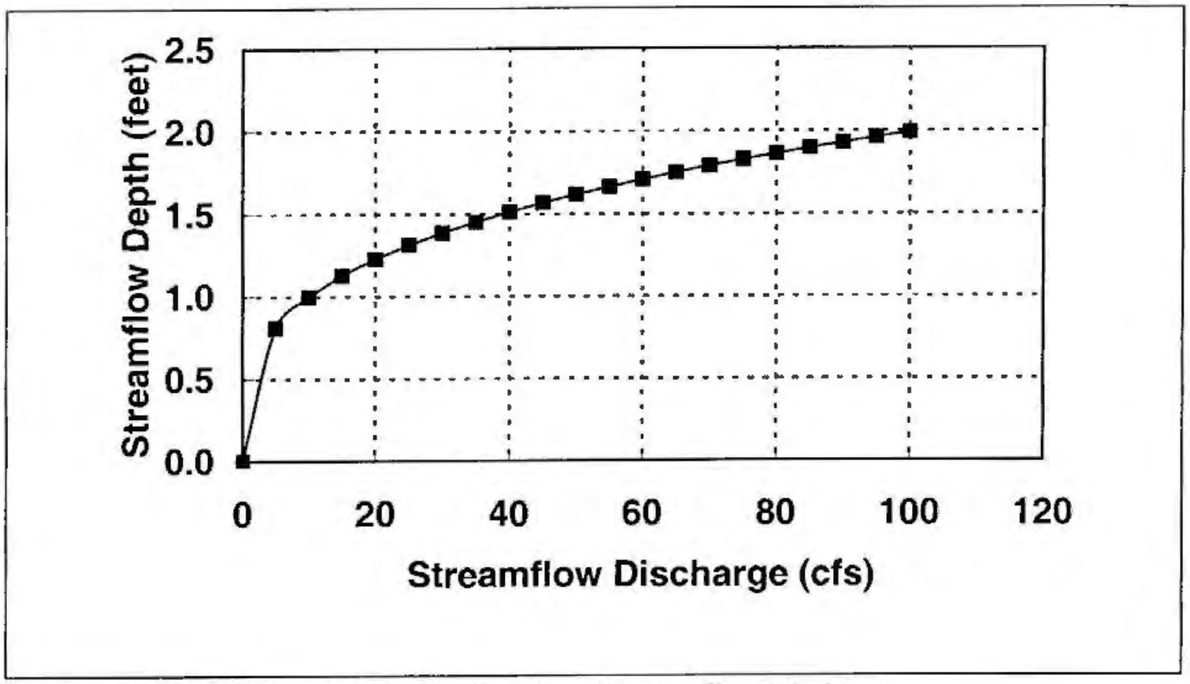

Figure 8-12 Streamflow Depth as a Function of Streamflow Discharge.

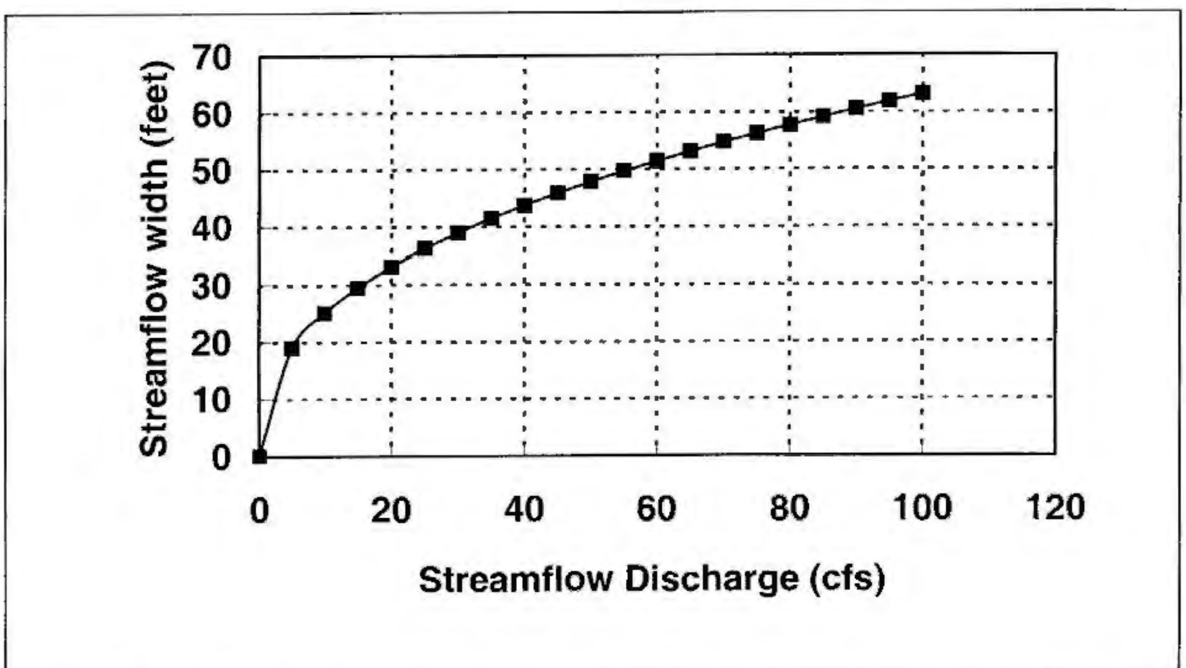

Figure 8-13 Streamflow Width as a Function of Streamflow Discharge.

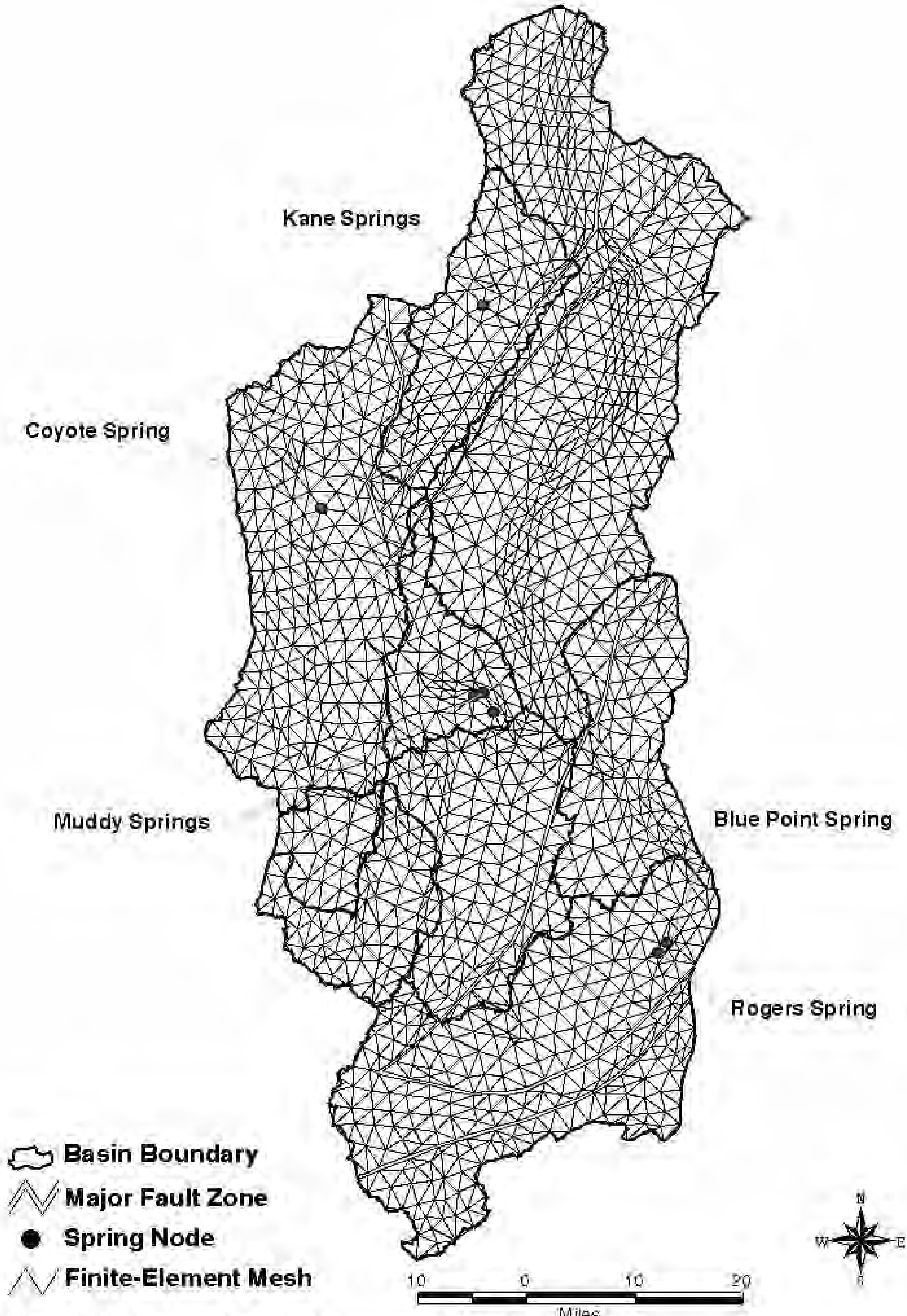

Figure 8-14. Location of spring nodes represented in model.

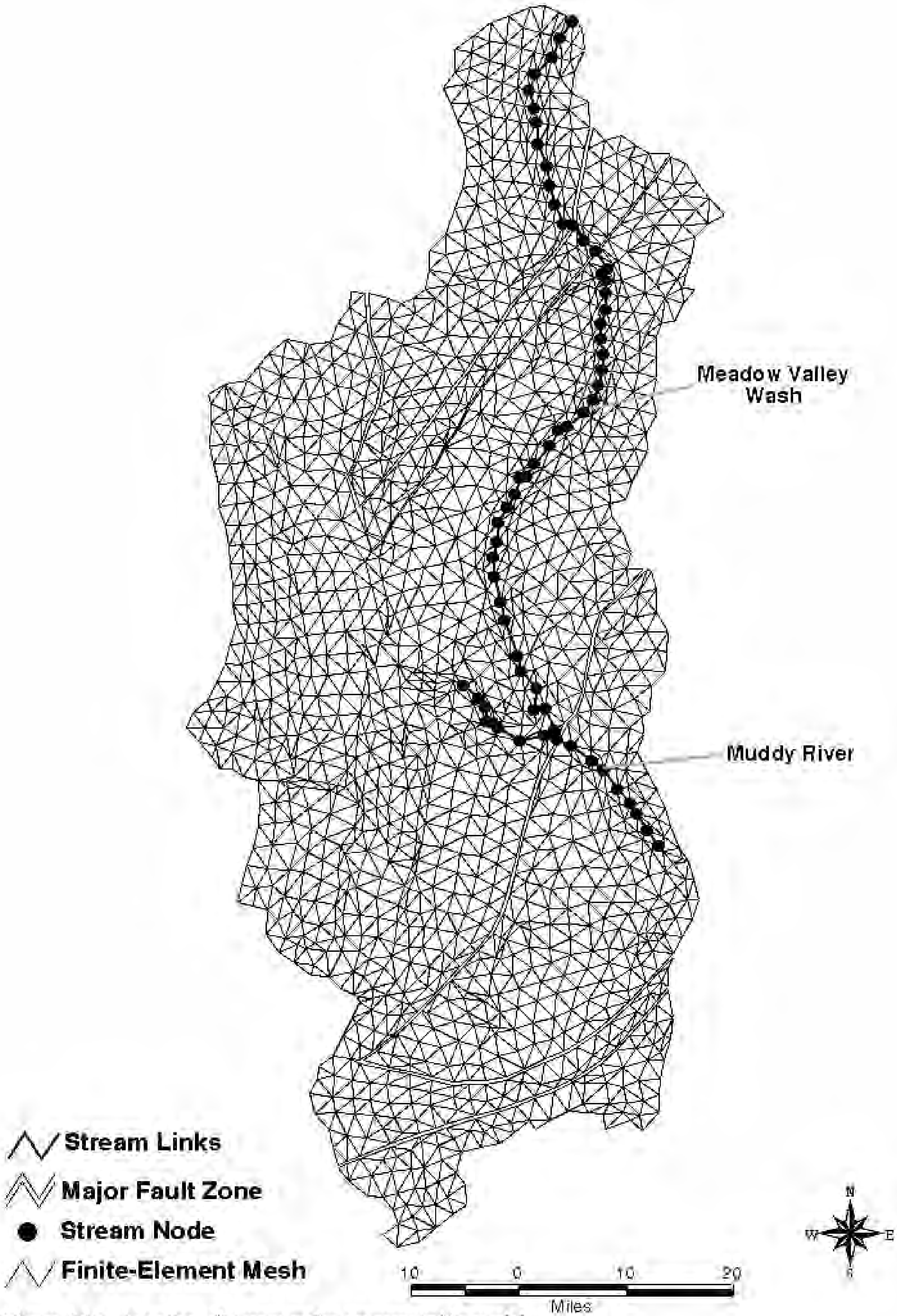

Figure 8-15. Location of stream nodes represented in model.

relations define the streamflow depth and width as functions of streamflow discharge **(Figure 8-12** and **Figure 8-13)**.

Ground-water discharge to Lake Mead is represented as a specified-head boundary condition, and subsurface outflow from the modeled area toward the Virgin River is represented as a specified discharge. Ground-water discharge to Lake Mead is represented by specified-head nodes on the top surface of the model mesh at the locations shown on **Figure 8-16**. Subsurface discharge toward the Virgin River is represented in the model as specified-discharge nodes within the carbonate aquifer at the locations shown on **Figure 8-17.** The discharge at a particular geographic location is assigned to the carbonate rocks at the bottom two nodes within the local model mesh.

8.2.4 Representation of Pumpage

The model represents pumping from the ground-water system, where the total pumping from the model area is about 18,000 afy in year 2000 **(Table 8-1)**. Ground-water pumping includes agricultural, industrial, and municipal pumping. Minor residential and commercial pumping within the model area is not represented in the model.

Pumping from a well is represented in the model by assigning a discharge to a node within the model mesh. The location of a well is represented by assigning the well to the geographically nearest node column. The depth of a well is represented by assigning the well to an appropriate node within a node column. Valley-fill wells are assigned to the top node within the node column, and carbonate wells are assigned to the second node from the bottom of the node column.

Pumping from 60 valley-fill wells and 11 carbonate wells is represented in the model in year 2000. The location of pumping-wells is shown on **Figure 8-18**. The total annual pumping from valley-fill wells is shown on **Figure 8-19** for 1945-2000, and the total annual pumping from carbonate wells is shown on **Figure 8-20**. The annual pumping for individual wells is listed in Appendix B.

Historically, ground-water development within the model boundary has been limited to areas located within the flood plains of the Muddy River and Meadow Valley Wash in Lower Moapa Valley, Lower Meadow Valley Wash, and the Upper Moapa Valley near the southeast portion of the modeled area. Ground water has principally been developed to supply water for agriculture in these areas, but has also been developed in the Upper Moapa Valley to supply water to the Reid Gardner facility located in California Wash and owned and operated by NPC. Until recently, there has been little to no ground-water development in the other basins comprising the remainder of the modeled area (Black Mountains, California Wash, Garnet Valley, Hidden Valley). However, since 1990, various commercial enterprises have been granted ground-water withdrawal permits within the Black Mountains Area and Garnet Valley, of which, only a few have been certified.

Records of ground-water production for each basin within the model boundary were developed for the period 1945 to 2000 based on data and information acquired from DRI, MVWD, NDWR,

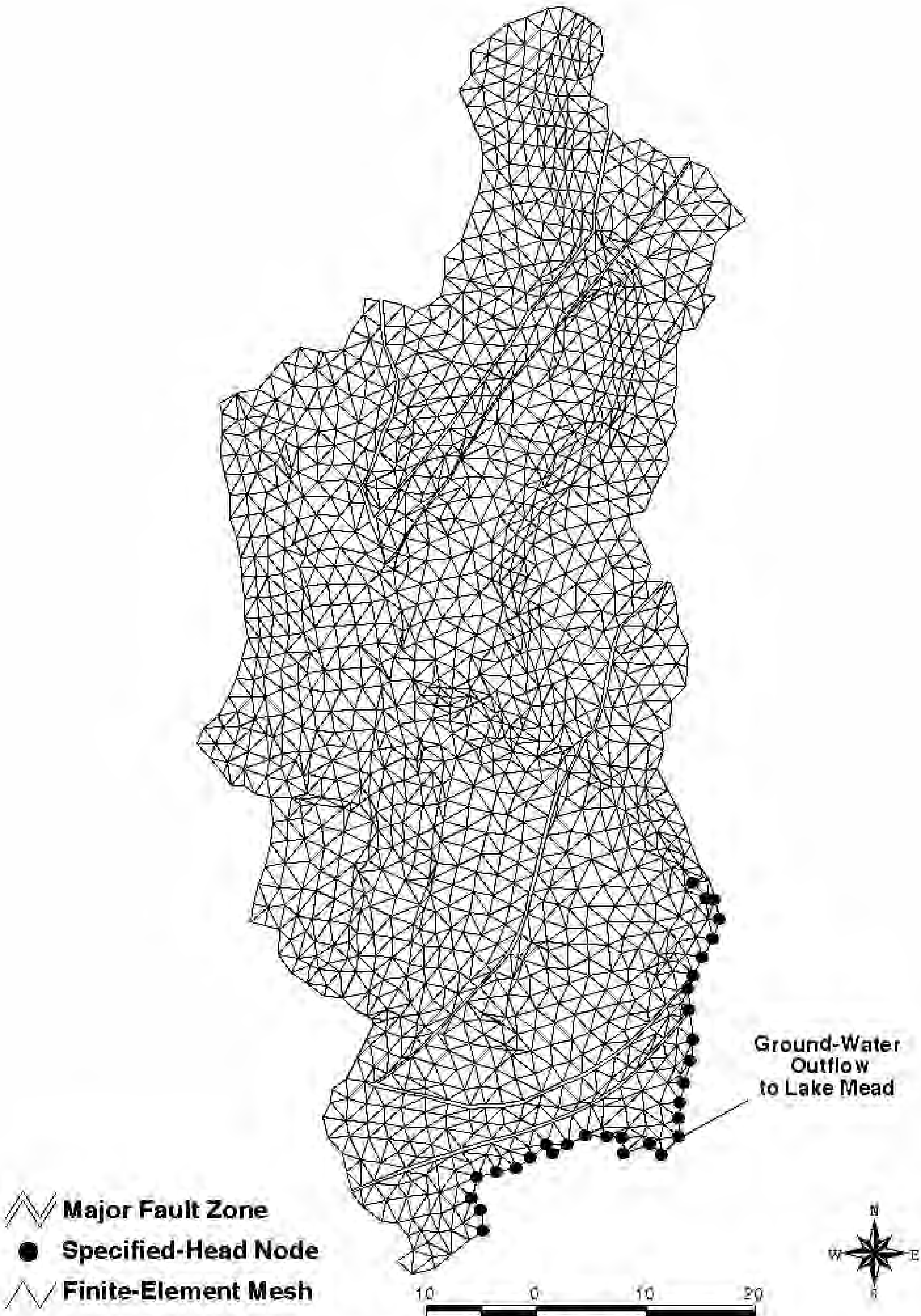

Figure 8-16. Location of specified-head nodes represented in model.

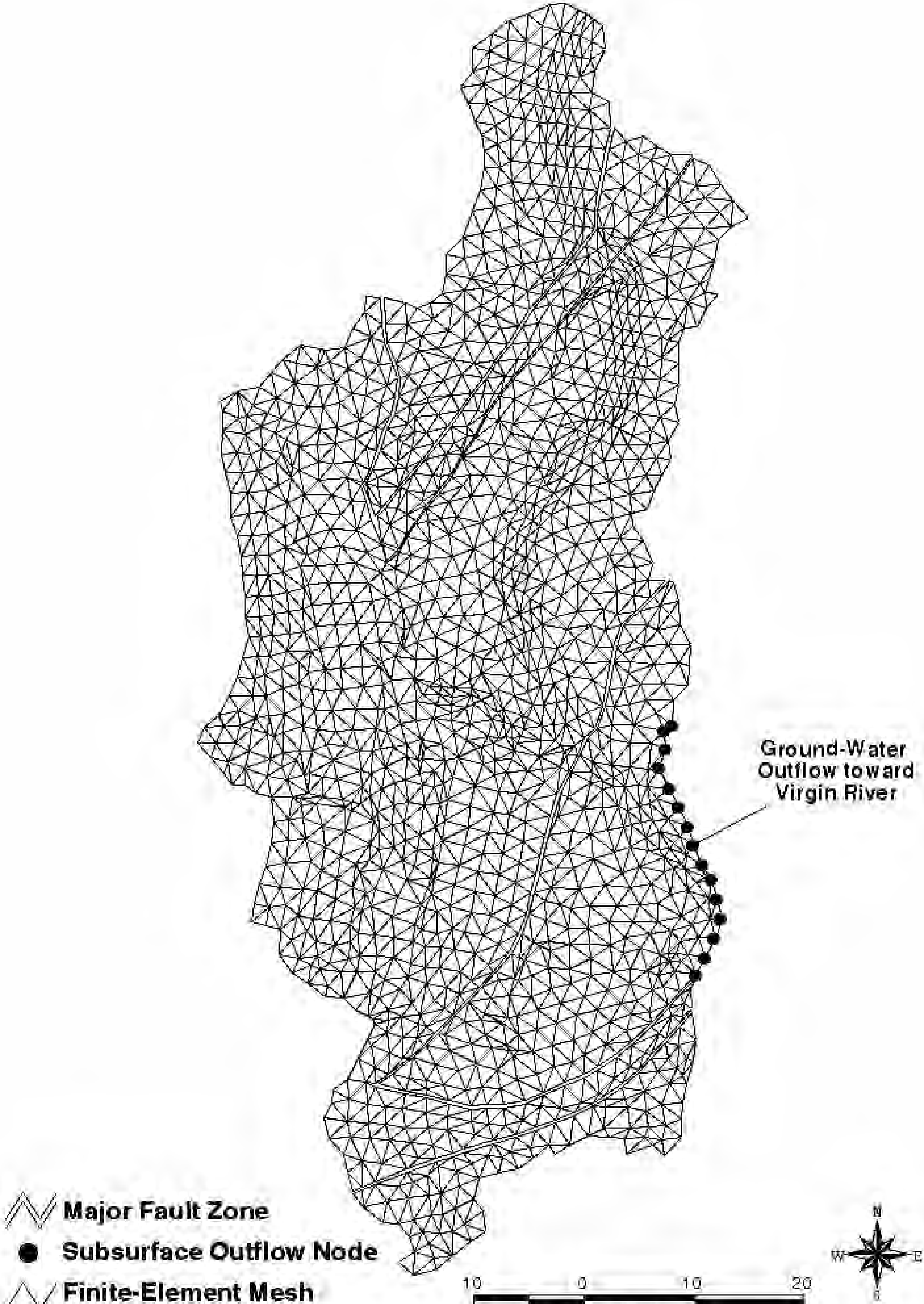

Figure 8-17. Location of subsurface outflow nodes represented in model.

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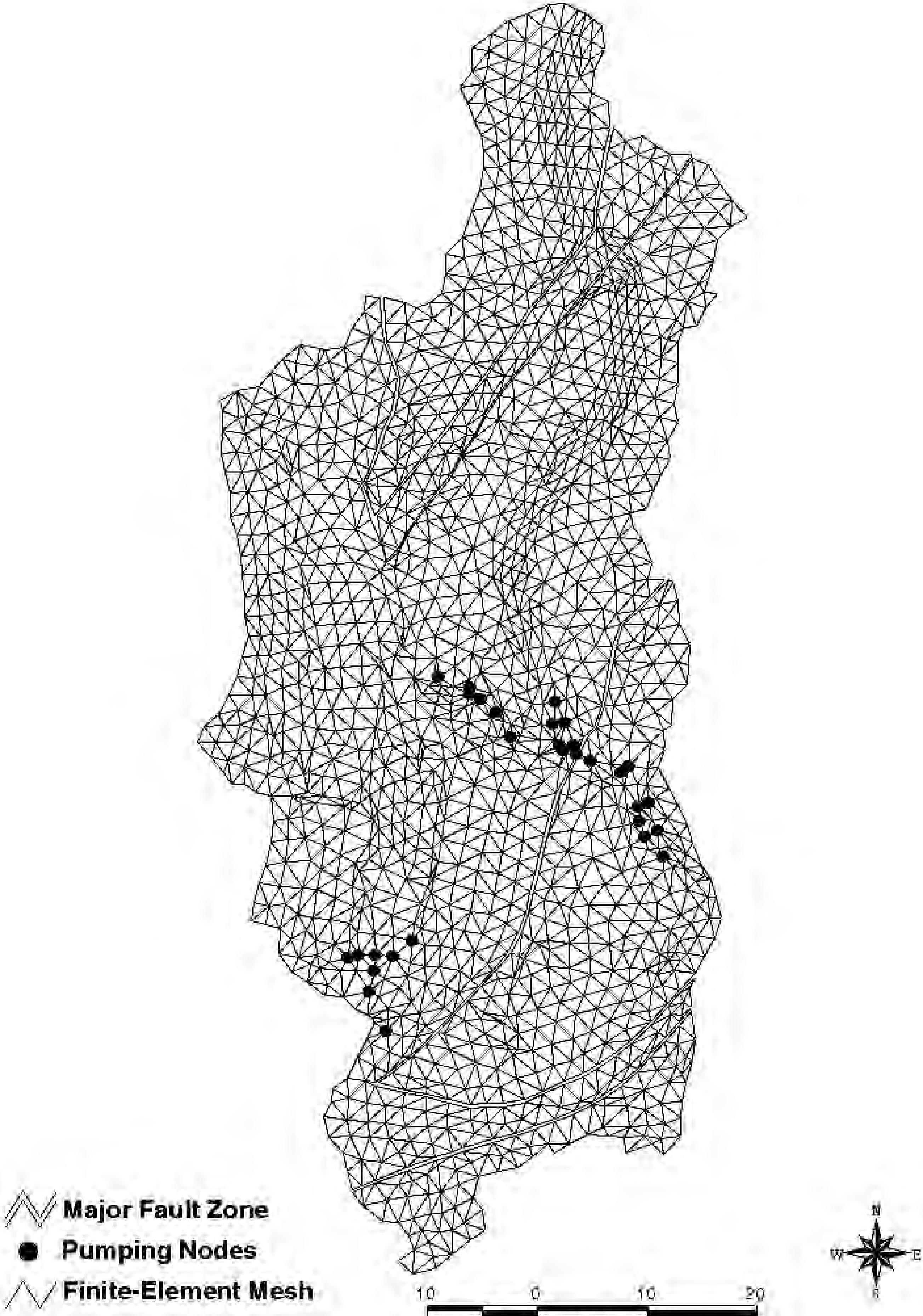

Figure 8-18. Location of pumping nodes represented in model.

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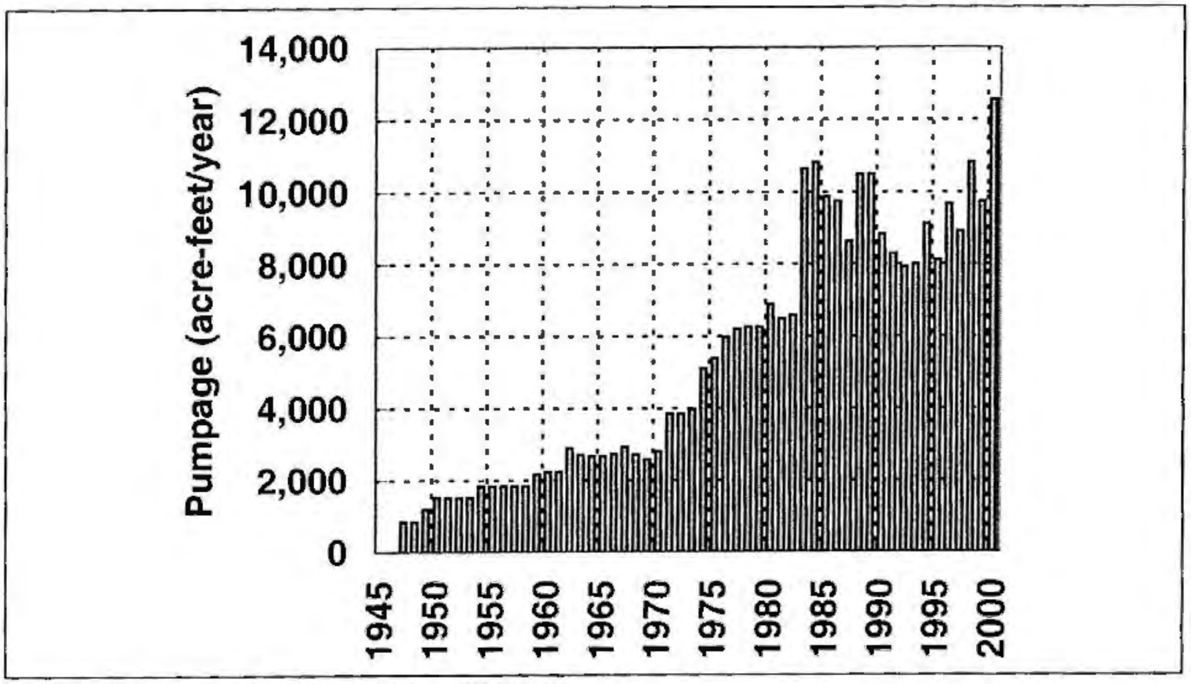

Figure 8-19 Pumping from Valley-fill Wells.

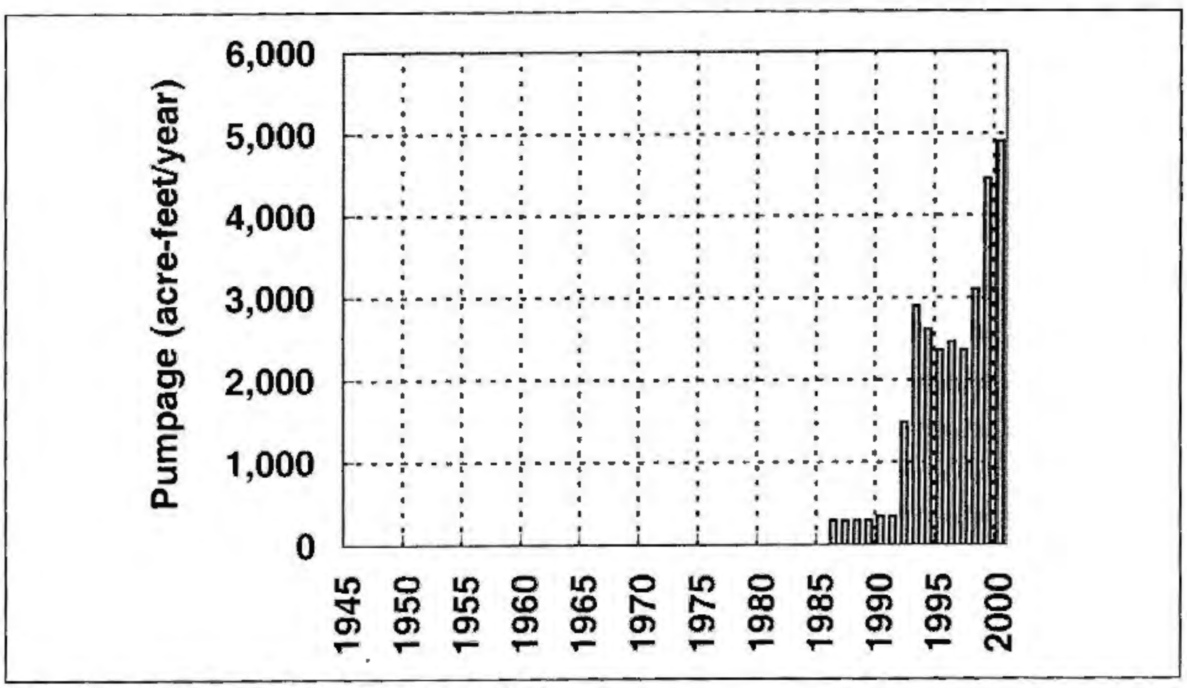

Figure 8-20 Pumping from Carbonate Wells.

NPC, and the USGS. **Figure 8-21** depicts the location of pumping wells used to simulate transient conditions during calibration of the ground-water flow model. Data and information for these wells were acquired in the form of published and unpublished documents and data sets. In addition, numerous interviews were conducted with representatives of MVIC, MVWD, NDWR, and various consultants working within the boundary of the modeled area to assist in the development of the records.

Few recorded data are available for years prior to 1987; therefore, information garnered from literature review and the interview process, water-right abstracts, land-use maps, aerial photography, and satellite imagery was relied upon to construct estimates of ground-water development for each basin for the period 1945 to 1986. Although all available data and information were used to develop the estimates, the fact that records do not exist or are unavailable for this period lend uncertainty to these estimates. Conversely, relatively complete records of ground-water production for the Black Mountains Area, Garnet Valley, and Upper Moapa Valley exist for the period 1987 to 2000. The Upper Moapa Valley has the most complete record due to monitoring programs established by DRI, MVWD, and NPC, and hydrologic investigations conducted by DRI and the USGS. Estimated totals of annual ground-water production for selected basins within the model boundary are listed in **Table 8-2.** A summary of ground-water development by MVWD and NPC in the Muddy River Springs Area for the period 1987 to 2000 is provided in **Table 8-3.**

Table 8-2. Estimates of ground-water production for selected sub-basins within the model boundary, in acre-feet.

	Estimated annual ground-water production					
Sub-basin	1950	1960	1970	1980	1990	2000
Black Mountains Area	0	0	0	0	0	1,693
Garnet Valley	0	0	50	150	496	952
Lower Moapa Valley	0	63	378	1,197	881	462
Meadow Valley Wash	0	0	880	3,080	3,740	3,960
Muddy River Springs Area	1,513	2,171	1,495	2,455	4,056	10,393

Table 8-3. Ground-water development in the Upper Moapa Valley since 1987 by MVWD and NPC, in acre-feet.

Year	MVWD	NPC
1987	245	2,304
1988	245	4,309
1989	245	7,126
1990	245	7,337
1991	245	7,342
1992	758	6,293
1993	1,345	6,287
1994	894	6,890
1995	678	6,414
1996	705	7,972
1997	808	6,589
1998	1,557	8,262
1999	2,579	7,333
2000	2,908	10,548

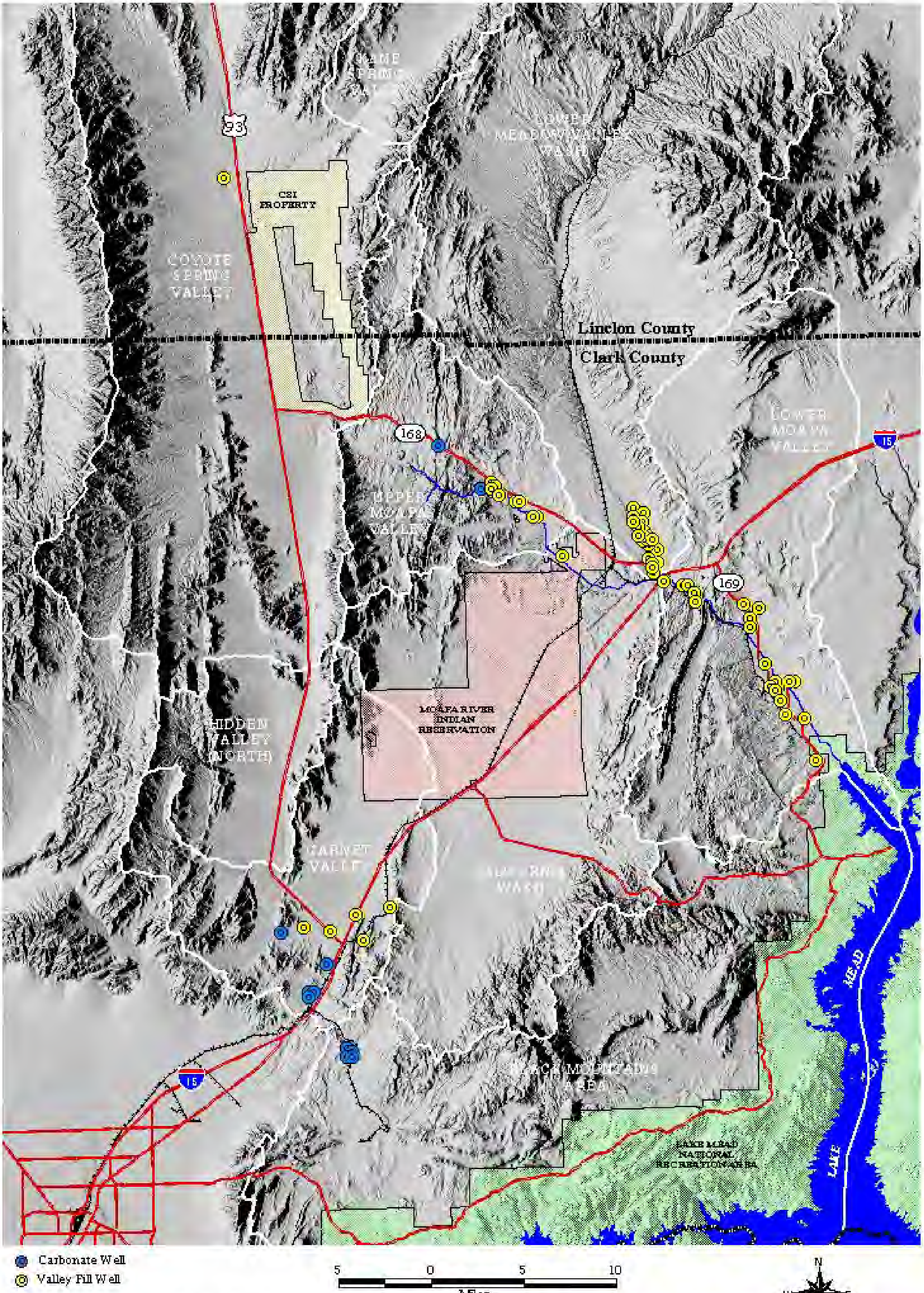

Figure 8-21. Location of pumping wells within the model area, historical 1945-2000.

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Appendix B provides a detailed discussion of the methods used to estimate and distribute ground-water pumping in each basin within the model boundary for the period 1945 to 2000. Included, are annual ground-water production totals for MVWD and NPC as reported by MVWD, DRI, and NPC, as well as, recent data submitted to NDWR by various water users in the Black Mountains Area and Garnet Valley.

8.2.5 Representation of Consumptive Use

The model represents the consumption of surface water and ground water, which results from vegetation and municipal and industrial use.

Vegetative consumption occurs where soils are moist owing to irrigation or shallow ground-water. About 5,000 acres produce consumption along Meadow Valley Wash from Caliente to its confluence with the Muddy River. About 4,000 acres occurs above the Rox gage, and about 1,000 acres occurs near the confluence with the Muddy River. About 7,400 acres produce consumption along the Muddy River from Muddy Springs to Lake Mead. Along the Muddy River, about 600 acres occurs along the river above the Moapa gage, about 1,800 acres occurs along the river from the Moapa gage to the Glendale gage, and about 5,000 acres occurs along the river from the Glendale gage to Lake Mead.

The annual consumption within the model area is about 5 ft per acre. Correspondingly, the consumption along Meadow Valley Wash is about 23,000 afy, and the consumption along the Muddy River from Muddy Springs to Lake Mead is about 37,000 afy. Along Meadow Valley Wash, the consumption is 20,000 afy above the Rox gage and 4,000 afy near the confluence with the Muddy River. Along the Muddy River, the consumption is 3,000 afy along the river above the Moapa gage, about 9,000 afy along the river from the Moapa gage to the Glendale gage, and about 25,000 afy along the river from the Glendale gage to Lake Mead.

This consumption most likely has remained essentially constant over a long period. This is the case even though water-use patterns have changed. Prior to the introduction of agriculture, the consumption resulted from water use by native phreatophytes. With the introduction of agriculture, the phreatophytes were replaced with forage and other crops, which have been irrigated from shallow ground water, streamflow diversions, and pumping. The acreage has remained essentially unchanged, the consumption per unit area has remained unchanged, and the total consumption has remained unchanged. This is the case except for lands along Meadow Valley Wash near its confluence with the Muddy River, which presently are irrigated with ground-water. Prior to the agricultural development of those lands, about 400 acres were covered with phreatophytes. Currently, about 1,000 acres are irrigated or covered with phreatophytes.

These conditions are represented in the model using the stream-aquifer module of FEMFLOW3D. The module simulates stream-aquifer interactions and the accretion or depletion of streamflow along a channel owing to the stream-aquifer interactions and upstream inflows. Consumption is represented by diversions from streamflow. Where irrigation occurs from actual diversions, the specified local diversion is the net diversions, which is the diversion less ground-water returns and surface-water returns. Where irrigation occurs from shallow ground-water, the specified local diversion is the net consumption, which is the vegetation ET. By this representation, the streamflow diversion is a surrogate in the model for the consumption of ground water **(Figure 8-5)**. **Figure 8-22** shows the location where consumptive diversions are represented in the model.

Ground water is pumped for supplemental irrigation along the Muddy River and Meadow Valley Wash. That pumping is represented in the model as the net pumping, which is the consumption of the pumped water. Where supplemental ground-water is used, the local streamflow diversion expressed in the model is reduced by the local net pumping. Correspondingly, supplemental pumping replaces diversions such that the total consumption is unchanged. The supplemental pumping and reduced diversions are shown on **Figure 8-23a** through **Figure 8-23c**, which are the values represented in the model. **Figure 8-23a** shows in particular the pumping and reduced diversions for the Meadow Valley Wash below the Rox stream gaging station. As shown on the figure, the supplemental pumping exceeds the initial local diversion after 1970. This represents a case where the total vegetative consumption is not unchanged, but it increases owing to supplemental pumping that exceeds the consumption prior to any pumping.

8.2.6 Representation of Boundary Shifts

While the boundaries of the modeled area follow drainage divides, pumping causes the boundary location to shift. Under the 1945 steady-state conditions, the model boundaries correspond to the boundaries of the modeled area, which follow drainage divides. Topographic divides correspond with ground-water boundaries owing to the higher recharge beneath mountain areas. Post-1945 pumping has induced ground-water flow across the prior steady-state boundaries such that the boundaries moved outward. However, because post-1945 carbonate aquifer pumping has had little effect on Muddy River flows, the regional water-level declines have been small and the boundary shift has been slight. Nevertheless, the proposed future pumping is sufficient to shift this boundary further outward.

To account for this phenomenon, the variable-flux module of FEMLOW3D is utilized in the model. That module specifies a boundary condition that in effect extends the model area by attaching an analytical solution representing a one-dimensional aquifer to mesh nodes at the model boundary (Durbin and Bond, 1998). The extension occurs when pumping within the modeled area causes a water-level decline at the boundary of the modeled area. The module simulates subsurface flows at the boundary that occur in response to a water-level decline at the boundary. This approach has some similarities to the general-head boundary utilized in the modeling program MODFLOW (McDonald and Harbaugh, 1988), but it differs in that the variable-flux boundary incorporates the changes in ground-water storage outside the model area.

Figure 8-24 shows the geographic locations where a variable-flux boundary is assigned to mesh nodes. That boundary condition is assigned to the carbonate aquifer using the second from the bottom node in the model mesh. At that vertical position, the aquifer thickness specified for the boundary condition is the overall thickness of the carbonate aquifer.

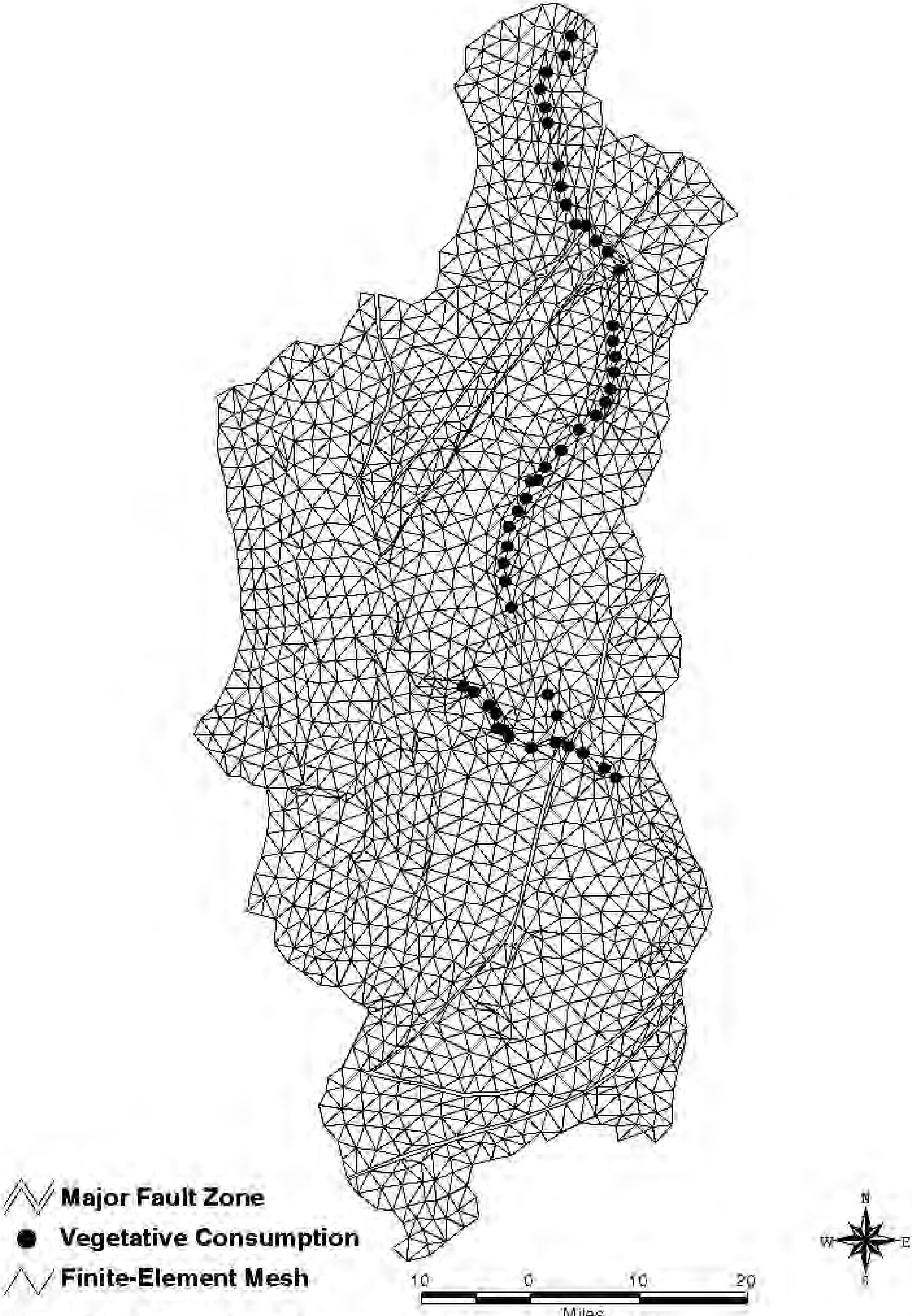

Figure 8-22. Location of vegetation consumptive use represented in model.

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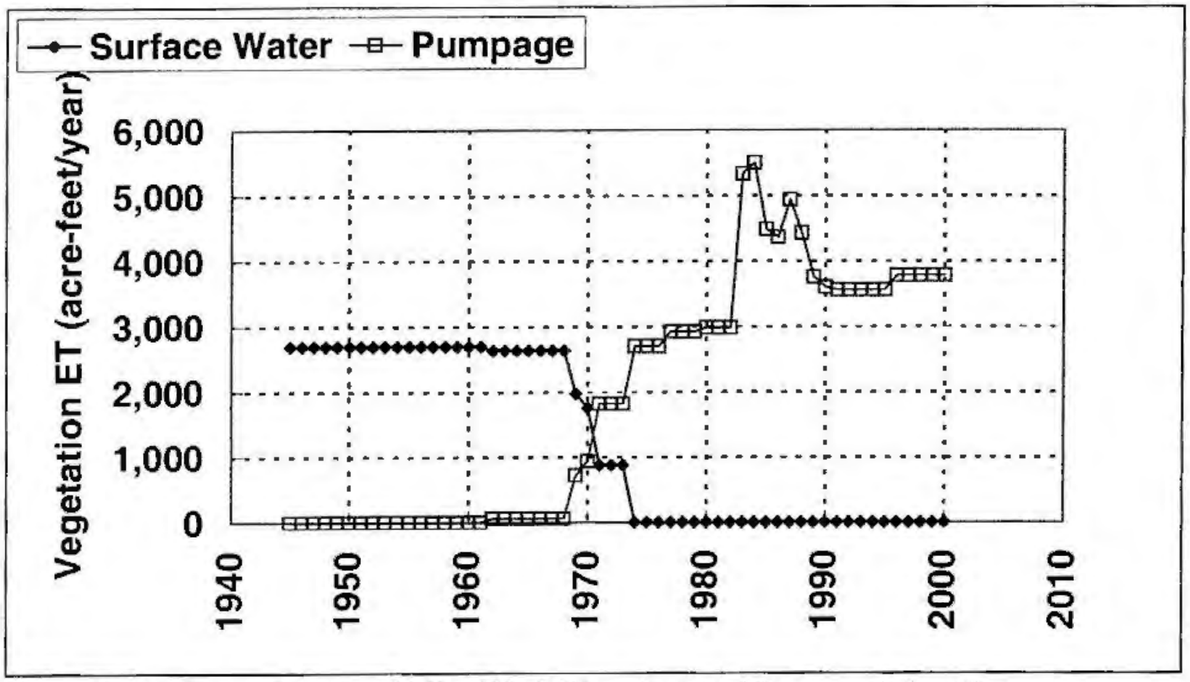

Figure 8-23a Lower Meadow Valley Wash Diversions and Pumpage below Rox.

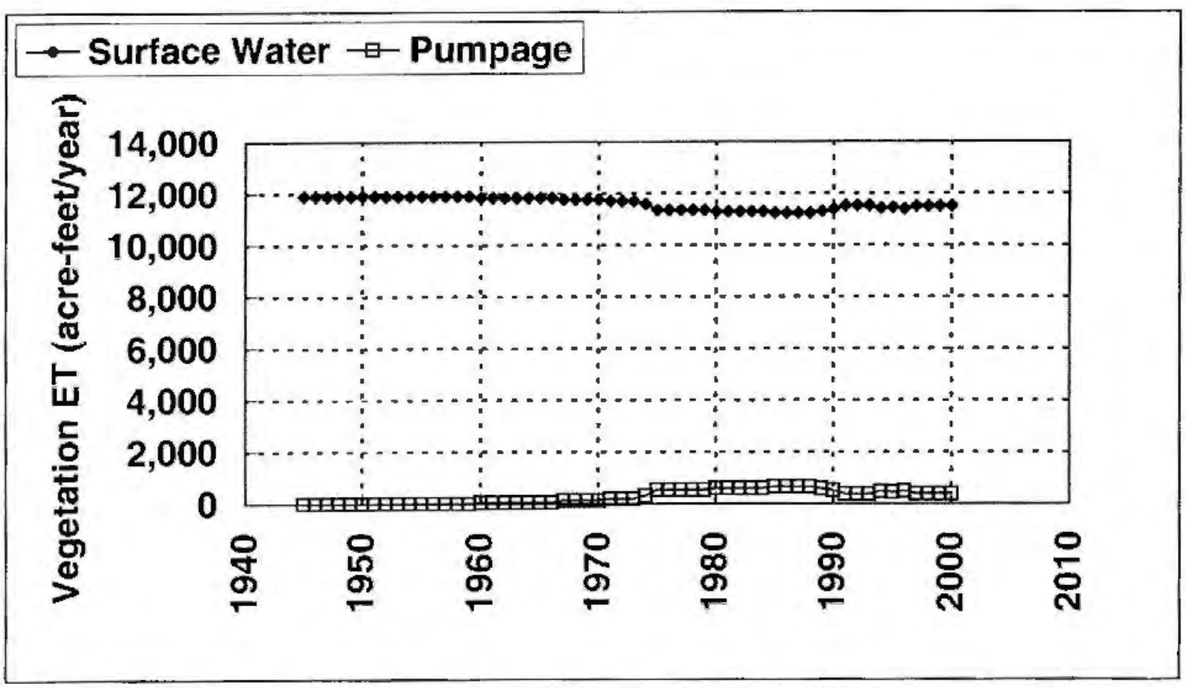

Figure 8-23b Muddy River Diversions and Pumpage Moapa to Glendale.

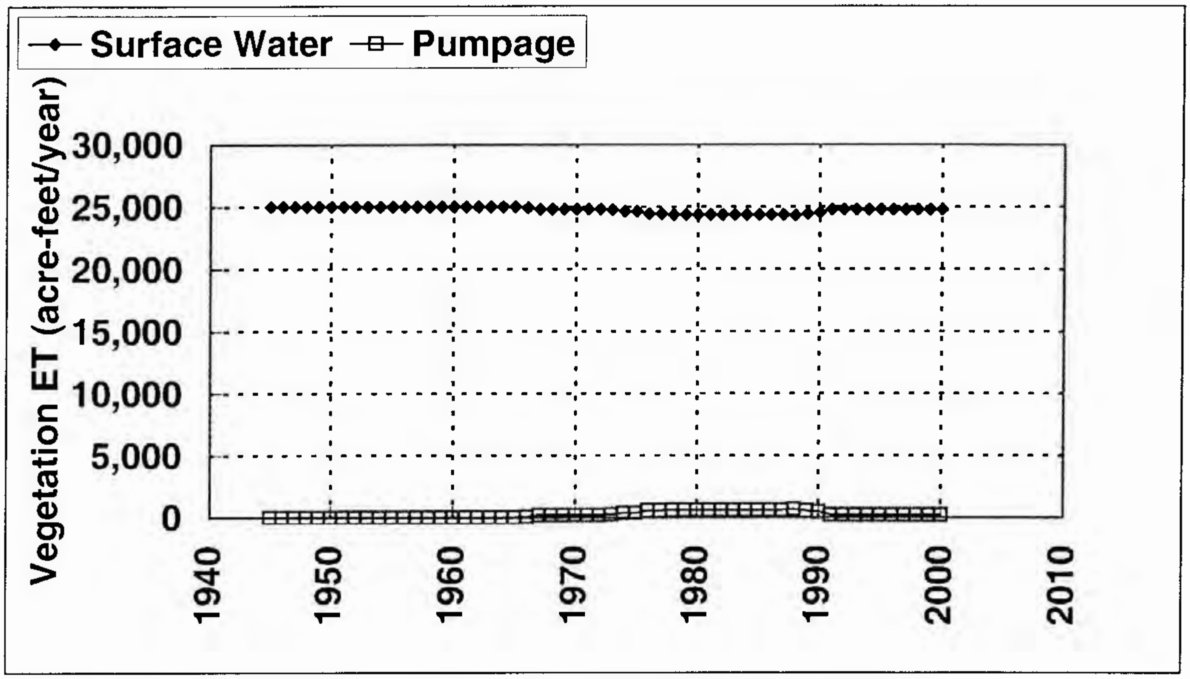

Figure 8-23c Muddy River Diversions and Pumpage Glendale to Overton.

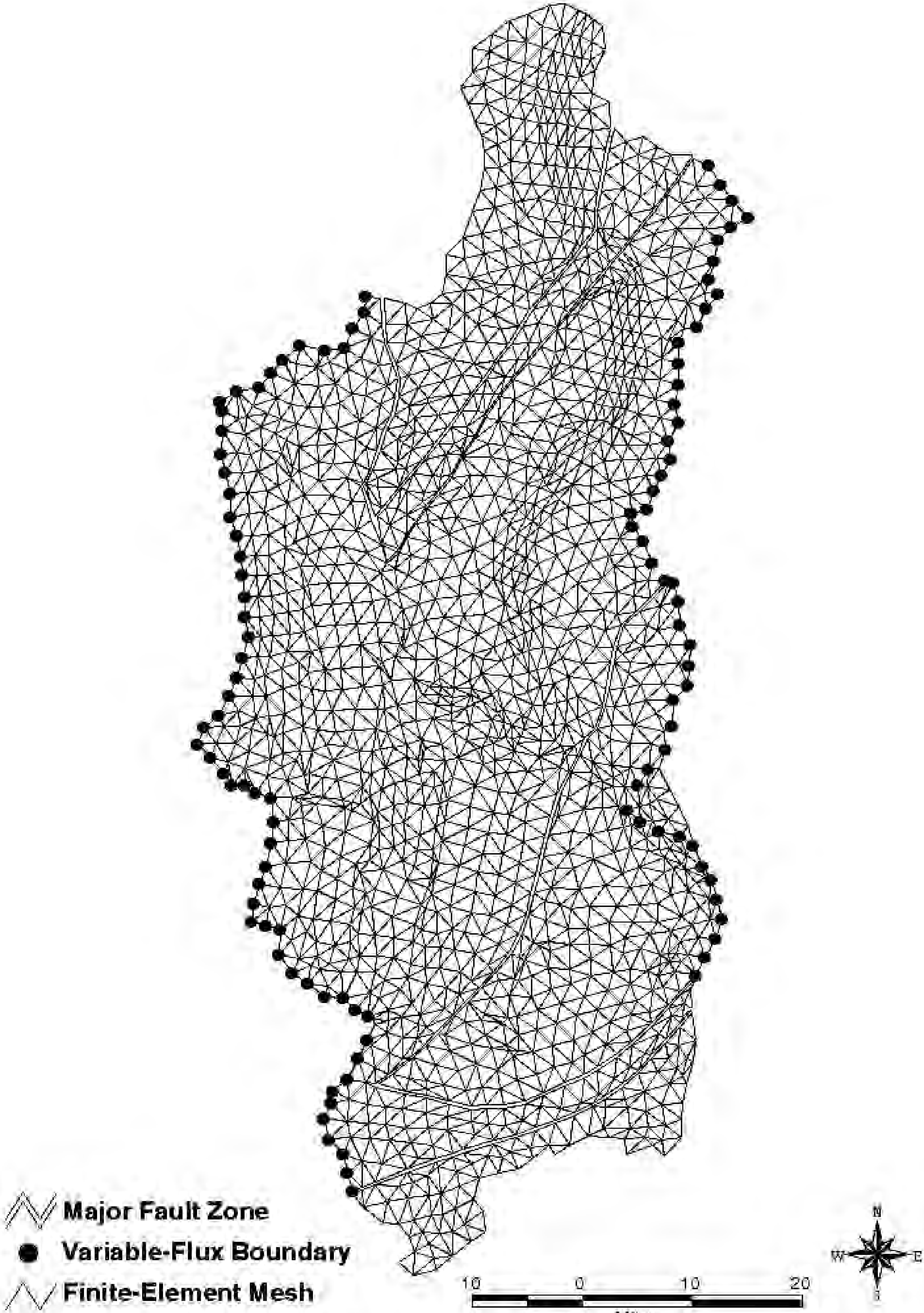

Figure 8-24. Location of variable-flux boundaries represented in model.

8.2.7 Identification of Model Parameters

8.2.7.1 Calibration Approach

Parameter values for the model were identified by calibrating the model to measured ground-water levels, spring flows, and streamflows. The model parameters include the permeability, specific storage, and specific yield for each hydrogeologic unit; the leakance for each spring or spring group; and the bed permeability for each stream channel. The calibration involved finding a set of parameter values such that the model best fit measured ground-water levels, spring flows, and streamflows. The model was used to simulate these quantities, and the simulated values were compared with the corresponding measured values in order to assess the model fit. Based on that comparison, parameter values were adjusted iteratively by a trial-and-error process to improve the model fit.

Both steady-state and transient-state simulations were used to calibrate the model. The calibration period was 1945-2000. Starting with a steady-state simulation for 1945, a transient-state simulation was made for 1946-2000. Correspondingly, the model was calibrated to the 1945 steady-state conditions and to the 1946-2000 transient-state conditions. The model was calibrated to streamflows, spring flows, and ground-water measurements representing 1945, including data collected later but nevertheless representative of 1945 conditions. Based on a steady-state simulation, these data were used to identify permeability for each hydrogeologic unit, permeability for the represented faults, and leakance for the carbonate springs. Additionally, the model was calibrated to streamflow, spring flow, and ground-water measurements during 1946-2000. Based on a transient-state simulation, these data were used to identify the specific storage and specific yield for each hydrogeologic unit.

Streamflow, spring flow, and ground-water data collected by the U. S. Geological Survey, Southern Nevada Water Authority and others were used in the model calibration. Streamflow data include those for the Caliente gage, Rox gage, Moapa gage, Glendale gage, and Overton gage. The location for these stream-gaging stations is shown on **Figure 8-5**, and annual streamflows are shown on **Figure 8-26** and **Figure 8-27** for the Moapa and Glendale gages. Spring flow data for Rogers Spring and Blue Point Spring are also included. Ground-water data include water-level measurements made by the U. S. Geological Survey and others in both valley-fill and carbonate wells. The well locations are shown on **Figure 8-25a** and **Figure 25b**, and represent wells in which repeated water-level measurements have been made over an extended period.

Ground-water levels were used to estimate hydraulic heads that were then compared to those simulated by the ground-water flow model during the calibration process. Hydraulic heads are a measure of the potential energy at a single point, and provide a measure of the driving energy that causes water to flow through permeable rocks. The difference between observed water levels and simulated hydraulic heads is a measure of how well the model simulates the ground-water flow system. Water-level data may also be used to estimate the direction of ground-water

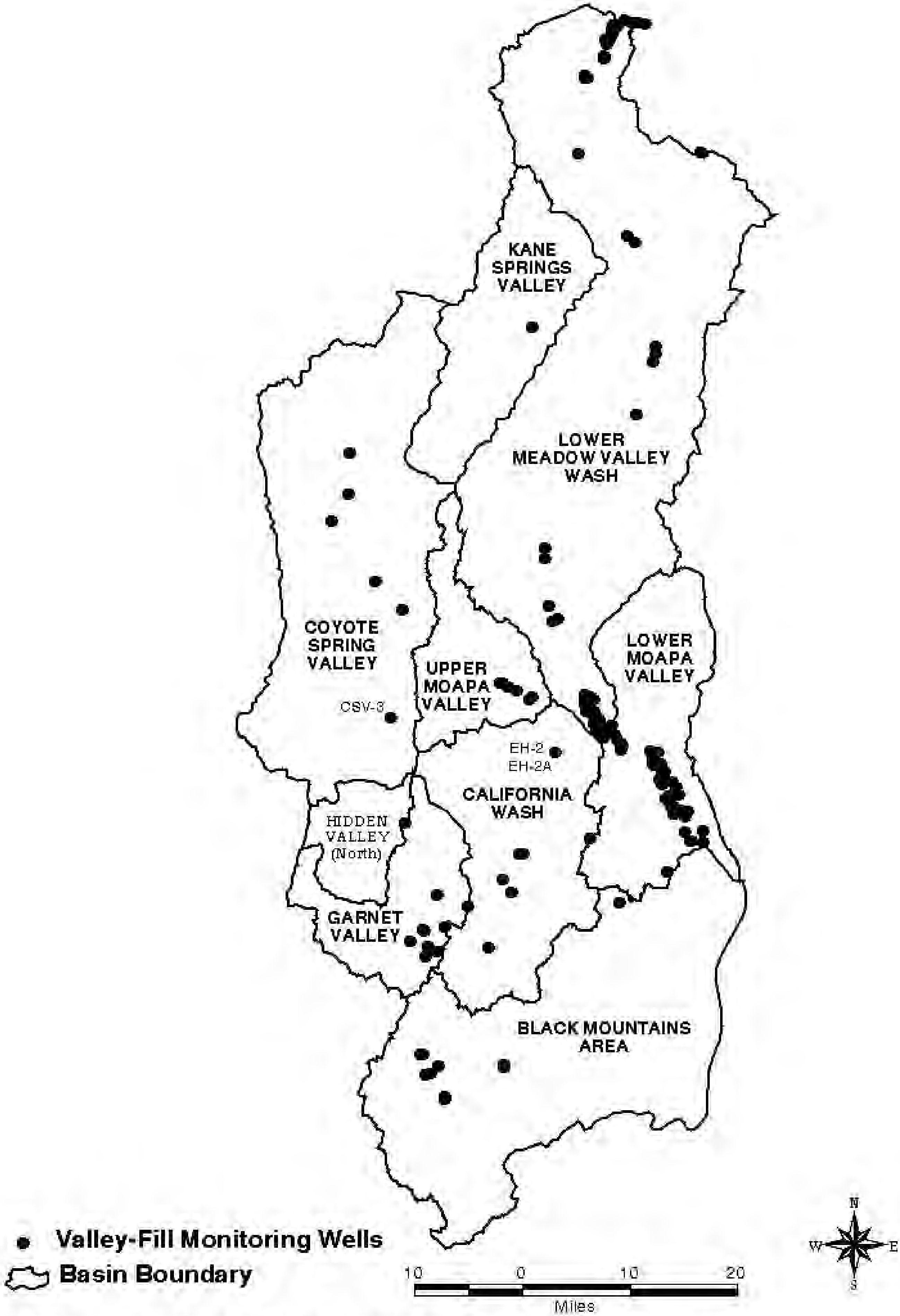

Figure 8-25a. Location of valley-fill monitoring wells used in model calibration.

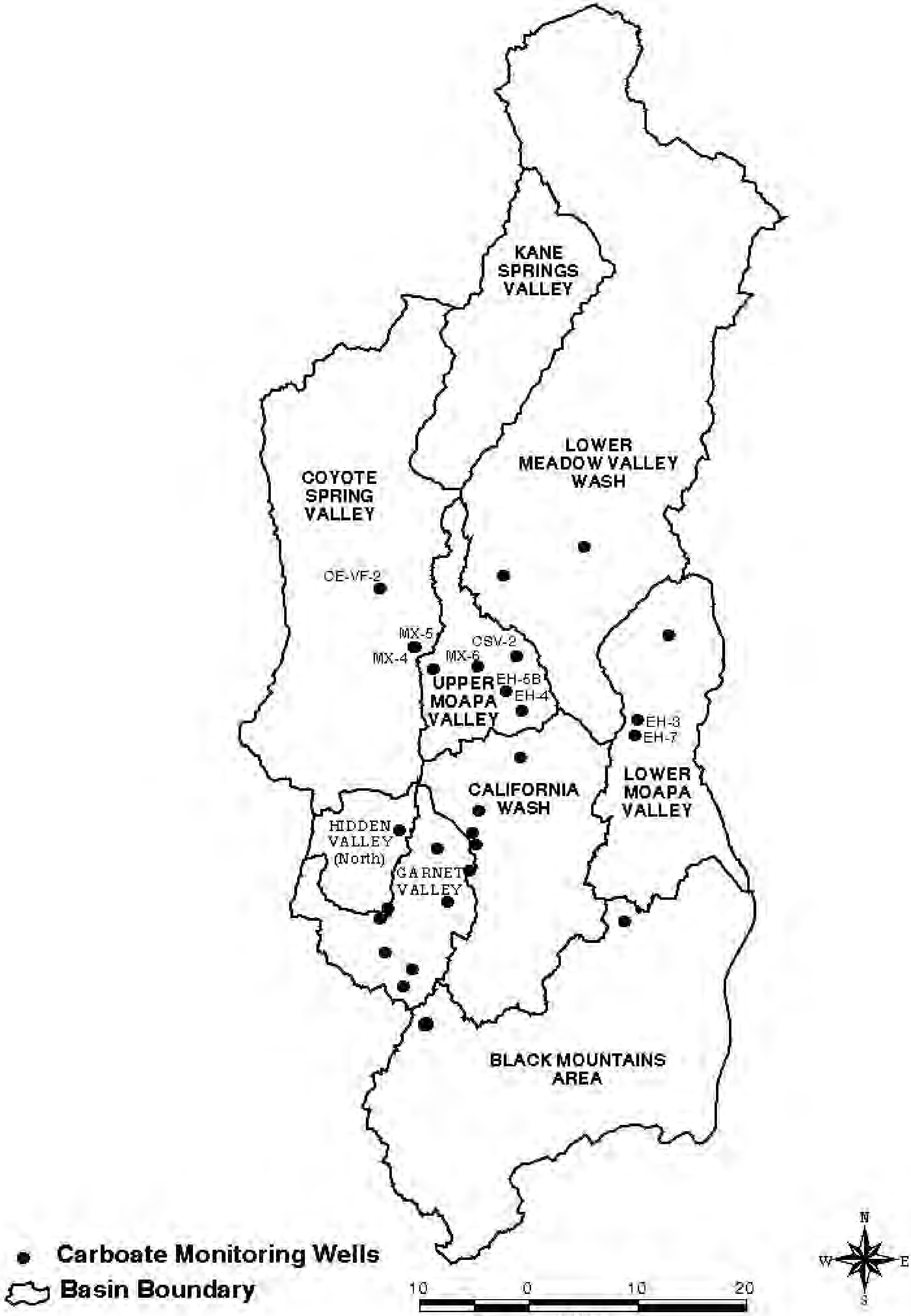

Figure 8-25b. Location of carbonate monitoring wells used in model calibration.

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flow. For these purposes, water-level data was an integral part in developing the ground-water flow model. The greater the density of quality water-level data the greater certainty in the calibration process and subsequent model results.

Water levels are typically expressed temporally and spatially as elevations above mean sea level, requiring the following known parameters: location coordinates, measuring point elevation, depth-to-water, and date and time of measurement. Each of these parameters has some inherent uncertainty. Measurement error and procedural deficiencies lead to uncertainty in depth-to-water measurements. Expressing water levels as elevations introduces additional uncertainty related to the accuracy of the methods used to determine the measuring point elevation.

Well data containing these parameters were compiled from numerous sources including data collected by SNWA and data obtained from the USGS Ground-water Site Inventory database (GWSI), NDWR Well Log Database, and various reports and maps. Data compilation focused on well data for known carbonate wells and wells known to have a significant record of depth-to-water measurements (e.g. greater than 5-years of record). As **Figure C-1** in Appendix C illustrates, nearly all of these wells are located in Coyote Spring Valley and the Muddy River Springs Area. Many of the wells have limited historical records since they were completed in the early to mid-1980s as part of USGS hydrologic investigations, the U.S. Airforce MX-Missile program, and NPC ground-water-monitoring program. Appendix C provides individual hydrographs for these wells. Site information and depth-to-water data compiled for wells within the model boundary are also included in Appendix C **(Table C-1** and **Table C-2)**.

Water-level data used to construct the hydrographs for wells ABBOTT, BEHMER, EH-2, EH-2A, EH-3, EH-4, EH-5B, EH-7, LDS-CENTRAL, LDS-WEST, LEWIS-NORTH, and LEWIS-SOUTH were compiled from NPC monitoring reports. Water-level data used to construct the hydrographs for wells CE-VF-1, CE-VF-2, CSV-1, CSV-2, CSV-3, MX-4, MX-5, and SHV-1 were compiled from SNWA records and the USGS GWSI database. Water-level data for these wells is considered good although methods by which the depth-to-water measurements were made and the accuracy of the measuring-point elevation are generally unknown.

Other well data compiled from Johnson et al. (2001, Appendix C) includes water-level data for additional carbonate monitoring wells, however many of the wells were completed in recent years and do not have a significant long-term record. Johnson et al. reported discrete carbonate water-level elevations for wells ECP-1, ECP-2, ECP-3, TH-1, TH-2, M-1, M-2, and M-3 located on the Moapa River Indian Reservation in California Wash. Also reported, were discrete water-level elevations for wells owned by Nevada Cogeneration Associates, Georgia Pacific Corporation, and U.S. Chemical Lime Company in the Black Mountains Area and Garnet Valley. These data are also provided in Appendix C in Table C-1 and C-2.

The remaining well data provided in Appendix C were compiled from individual well log records listed in the NDWR Well Log database. Few of these data were used for calibration purposes due to the high uncertainty of the methods used to determine depth-to-water and measuring point elevations. These data were used with great caution and only as a last resort to provide water-level control in areas where no other data were available.

Figure C-2 depicts the location of primary wells with significant water-level records. As stated previously, many of these wells were completed recent years in areas where ground-water development is occurring. However, due to the sparseness of quality water-level data within the model boundary, some were used during the calibration process.

8.2.7.2 Calibration Results

The parameter values produced from the model calibration are listed in **Table 8-4**. Permeability, specific storage, and specific yield values are listed separately in the table for each subarea within the modeled area, except that values are listed for northern and southern parts of the Upper Moapa Valley subarea. That subarea was subdivided to represent a region of higher permeability that occurs within a geographic band overlying the Glendale Thrust. Within this band, higher permeability is indicated by nearly flat hydraulic gradients, which presumably correspond to secondary faulting and fracturing that is associated with the Glendale Thrust.

Based on the listed parameter values, the streamflows and spring flows simulated with the calibrated model are summarized on **Figure 8-26** through **Figure 8-30**. **Figure 8-26** and **Figure 8-27** show hydrographs of computed and measured streamflow for the Moapa and Glendale gages. The simulated streamflow at the Overton gage is shown on **Figure 8-28**. There is no long-term historical record for the Overton gage. **Figure 8-29** and **Figure 8-30** show a hydrograph of computed springflow for the Muddy Springs and Rogers and Blue Point Springs. The ground-water levels simulated with the calibrated model are summarized on **Figure 8-31** through **Figure 8-33m**. **Figure 8-31** and **Figure 8-32** show scatter diagrams of measured and computed streamflow respectively for valley-fill and carbonate wells. **Figures 8-33a** through **Figure 8-33m** show hydrographs of measured and computed ground-water levels for selected valley-fill and carbonate wells.

Simulated ground-water levels for the model area are shown on **Figure 8-34** through **Figure 8-37**. **Figure 8-34** shows contours of ground-water elevation at the top of the carbonate aquifer for 1945, and **Figure 8-35** shows contours of ground-water elevation at the ground-water table. Likewise, **Figure 8-36** and **Figure 8-37** show those contours for 2000.

Table 8-4. Hydraulic properties assigned to hydrogeologic units and faults.

Material Name	Structural Block	Material	Kx ft/d	Ky ft/d	Kz ft/d	Ss 1/ft	Sy
Valley-Fill Deposits	Lake Mead Subarea	1	1.00	1.00	1.80×10^{-3}	1.00×10^{-6}	0.05
Valley-Fill Deposits	Black Mountains Subarea	2	1.00	1.00	1.80×10^{-3}	1.00×10^{-6}	0.05
Valley-Fill Deposits	Lower Moapa Subarea	3	1.00	1.00	1.80×10^{-3}	1.00×10^{-6}	0.05
Valley-Fill Deposits	Upper Moapa Subarea	4	1.00	1.00	1.80×10^{-3}	1.00×10^{-6}	0.05
Valley-Fill Deposits	Meadow Valley Mountains Subarea	5	1.00	1.00	1.80×10^{-2}	1.00×10^{-6}	0.05
Valley-Fill Deposits	Kane Springs Subarea	6	1.00	1.00	1.80×10^{-2}	1.00×10^{-6}	0.05
Volcanic Rocks	Lake Mead Subarea	7	1.50×10^{-1}	1.50×10^{-1}	2.70×10^{-2}	1.00×10^{-6}	0.01
Volcanic Rocks	Black Mountains Subarea	8	1.50×10^{-1}	1.50×10^{-1}	2.70×10^{-2}	1.00×10^{-6}	0.01
Volcanic Rocks	Lower Moapa Subarea	9	1.50×10^{-1}	1.50×10^{-1}	2.70×10^{-2}	1.00×10^{-6}	0.01
Volcanic Rocks	Upper Moapa Subarea	10	1.50×10^{-1}	1.50×10^{-1}	2.70×10^{-2}	1.00×10^{-6}	0.01
Volcanic Rocks	Meadow Valley Mountains Subarea	11	1.50×10^{-1}	1.50×10^{-1}	2.70×10^{-2}	1.00×10^{-6}	0.01
Volcanic Rocks	Kane Springs Subarea	12	1.50×10^{-1}	1.50×10^{-1}	2.70×10^{-1}	1.00×10^{-6}	0.01
Intrusive Rocks	Lake Mead Subarea	13	1.50×10^{-2}	1.50×10^{-2}	2.70×10^{-2}	1.00×10^{-6}	0.01
Intrusive Rocks	Black Mountains Subarea	14	1.50×10^{-2}	1.50×10^{-2}	2.70×10^{-2}	1.00×10^{-6}	0.01
Intrusive Rocks	Lower Moapa Subarea	15	1.50×10^{-2}	1.50×10^{-2}	2.70×10^{-2}	1.00×10^{-6}	0.01
Intrusive Rocks	Upper Moapa Subarea	16	1.50×10^{-2}	1.50×10^{-2}	2.70×10^{-2}	1.00×10^{-6}	0.01
Intrusive Rocks	Meadow Valley Mountains Subarea	17	1.50×10^{-2}	1.50×10^{-2}	2.70×10^{-2}	1.00×10^{-6}	0.01
Intrusive Rocks	Kane Springs Subarea	18	1.50×10^{-2}	1.50×10^{-2}	2.70×10^{-2}	1.00×10^{-6}	0.01
Clastic Rocks	Lake Mead Subarea	19	2.00×10^{-1}	2.00×10^{-1}	3.60×10^{-1}	1.00×10^{-6}	0.01
Clastic Rocks	Black Mountains Subarea	20	2.00×10^{-1}	2.00×10^{-1}	3.60×10^{-1}	1.00×10^{-6}	0.01
Clastic Rocks	Lower Moapa Subarea	21	2.00×10^{-1}	2.00×10^{-1}	3.60×10^{-1}	1.00×10^{-6}	0.01
Clastic Rocks	Upper Moapa Subarea	22	2.00×10^{-1}	2.00×10^{-1}	3.60×10^{-3}	1.00×10^{-6}	0.01
Clastic Rocks	Meadow Valley Mountains Subarea	23	2.00×10^{-1}	2.00×10^{-1}	3.60×10^{-1}	1.00×10^{-6}	0.01
Clastic Rocks	Kane Springs Subarea	24	2.00×10^{-1}	2.00×10^{-1}	3.60×10^{-1}	1.00×10^{-6}	0.01
Carbonate Rocks	Lake Mead Subarea	25	2.00	2.00	3.60×10^{-1}	1.00×10^{-6}	0.01
Carbonate Rocks	Black Mountains Subarea	26	2.00	2.00	3.60×10^{-1}	1.00×10^{-6}	0.01
Carbonate Rocks	Lower Moapa Subarea	27	2.00	2.00	3.60×10^{-1}	1.00×10^{-6}	0.01
Carbonate Rocks	Upper Moapa Subarea (South)	28	$2.00 \times 10^{+1}$	$2.00 \times 10^{+1}$	3.60×10^{-1}	1.00×10^{-6}	0.01
Carbonate Rocks	Upper Moapa Subarea (North)	39	3.50×10^{-1}	3.50×10^{-1}	9.00×10^{-2}	1.00×10^{-6}	0.01
Carbonate Rocks	Meadow Valley Mountains Subarea	29	3.50×10^{-1}	3.50×10^{-1}	9.00×10^{-2}	1.00×10^{-6}	0.01
Carbonate Rocks	Kane Springs Subarea	30	3.50×10^{-1}	3.50×10^{-1}	9.00×10^{-2}	1.00×10^{-6}	0.01
Overthrust Clastic Rocks	Lower Moapa Subarea	31	2.00×10^{-1}	2.00×10^{-1}	3.60×10^{-2}	1.00×10^{-6}	0.01
Overthrust Carbonate Rocks	Lower Moapa Subarea	32	2.00×10^{-1}	2.00×10^{-1}	3.60×10^{-1}	1.00×10^{-6}	0.01
South Black Mountains Fault		33	1.00×10^{-2}	1.00×10^{-2}	1.80×10^{-2}	1.00×10^{-6}	0
North Black Mountains Fault		34	1.00×10^{-2}	1.00×10^{-2}	1.80×10^{-2}	1.00×10^{-6}	0
Glendale Thrust		35	3.50×10^{-2}	3.50×10^{-2}	3.50×10^{-2}	1.00×10^{-6}	0
Meadow Valley Mountains Fault		36	2.00×10^{-1}	2.00×10^{-1}	3.60×10^{-2}	1.00×10^{-6}	0
Kane Springs Fault		37	2.00×10^{-1}	2.00×10^{-1}	3.60×10^{-2}	1.00×10^{-6}	0
Coyote Spring Fault		38	2.00×10^{-1}	2.00×10^{-1}	3.60×10^{-2}	1.00×10^{-6}	0

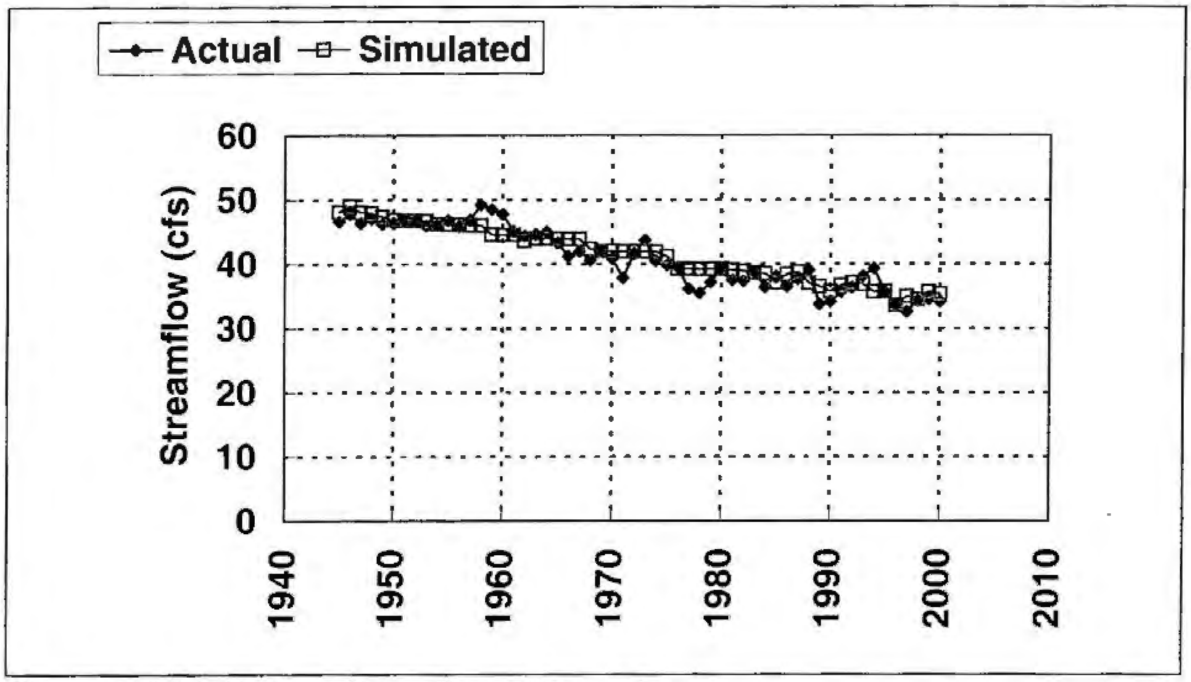

Figure 8-26 Muddy River Streamflow at Moapa Gage.

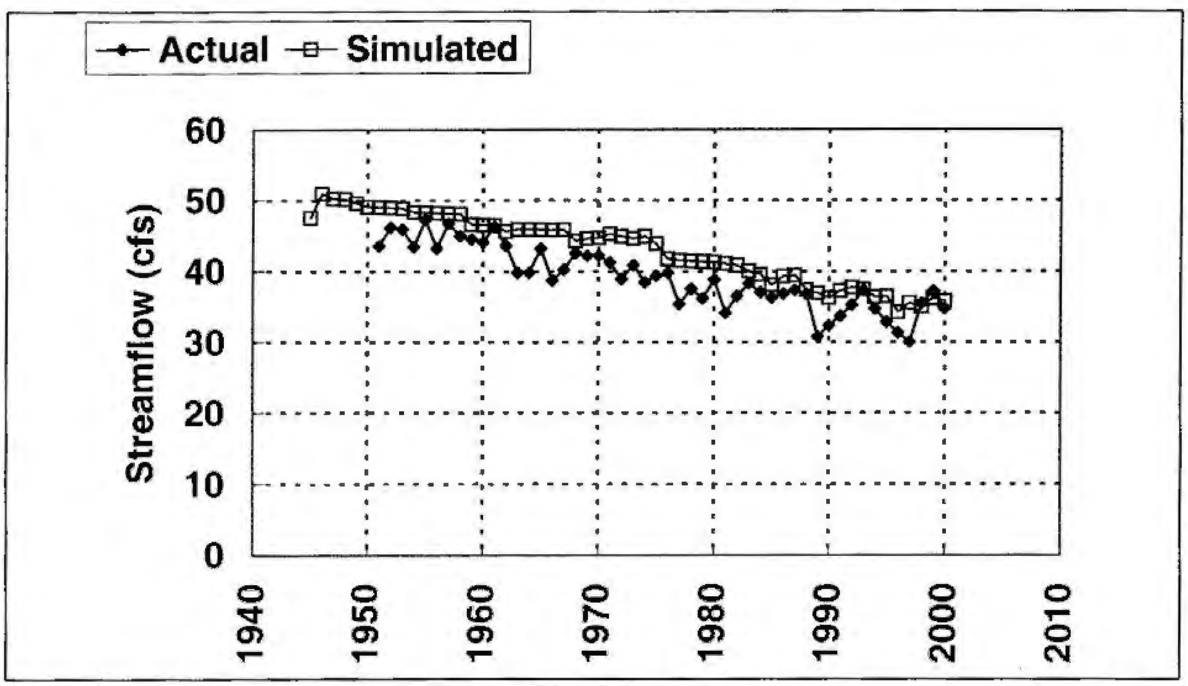

Figure 8-27 Muddy River Streamflow at Glendale Gage.

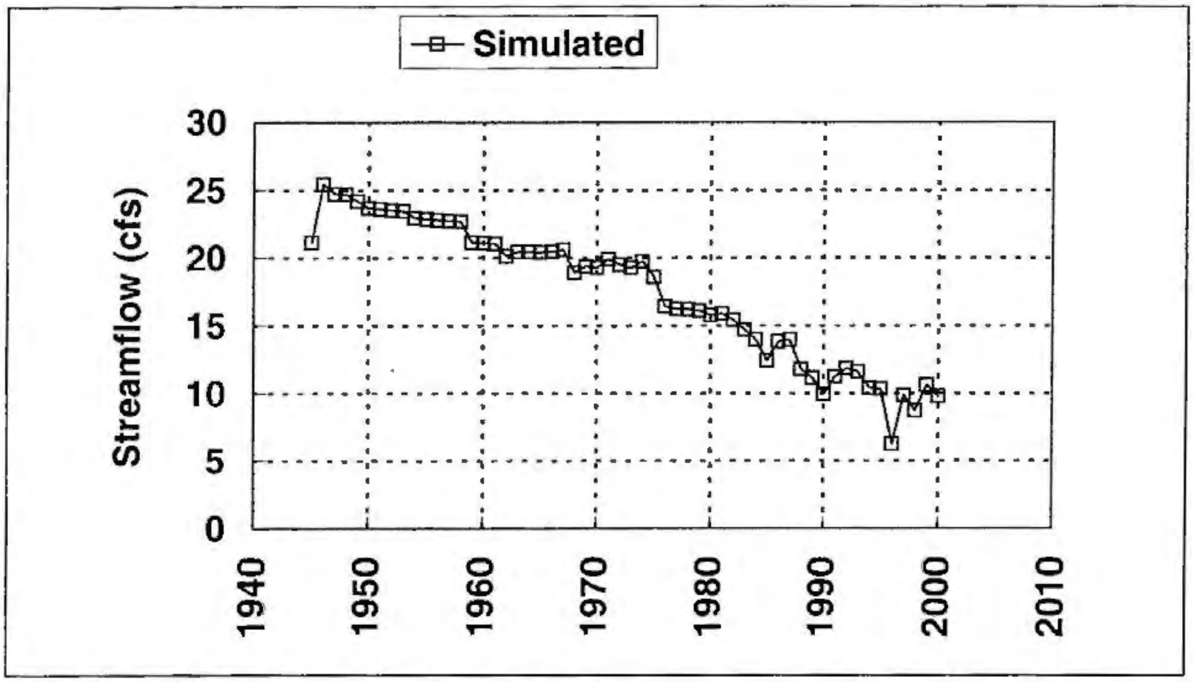

Figure 8-28 Muddy River Streamflow at Overton.

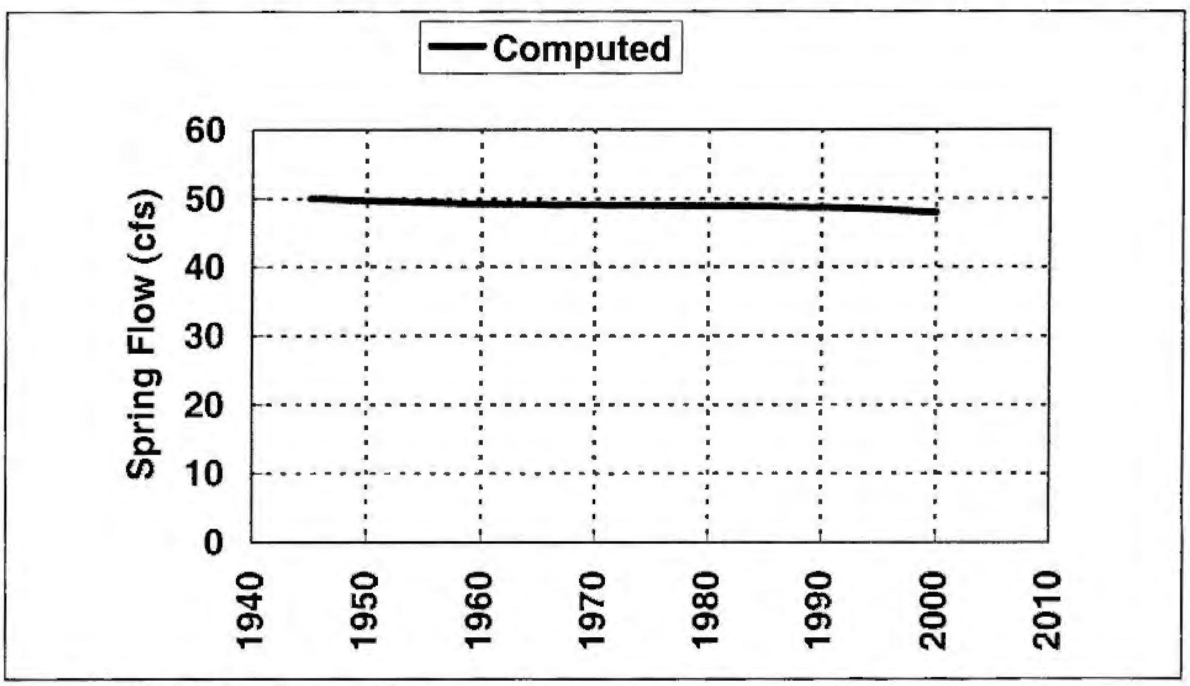

Figure 8-29 Muddy Springs Flow.

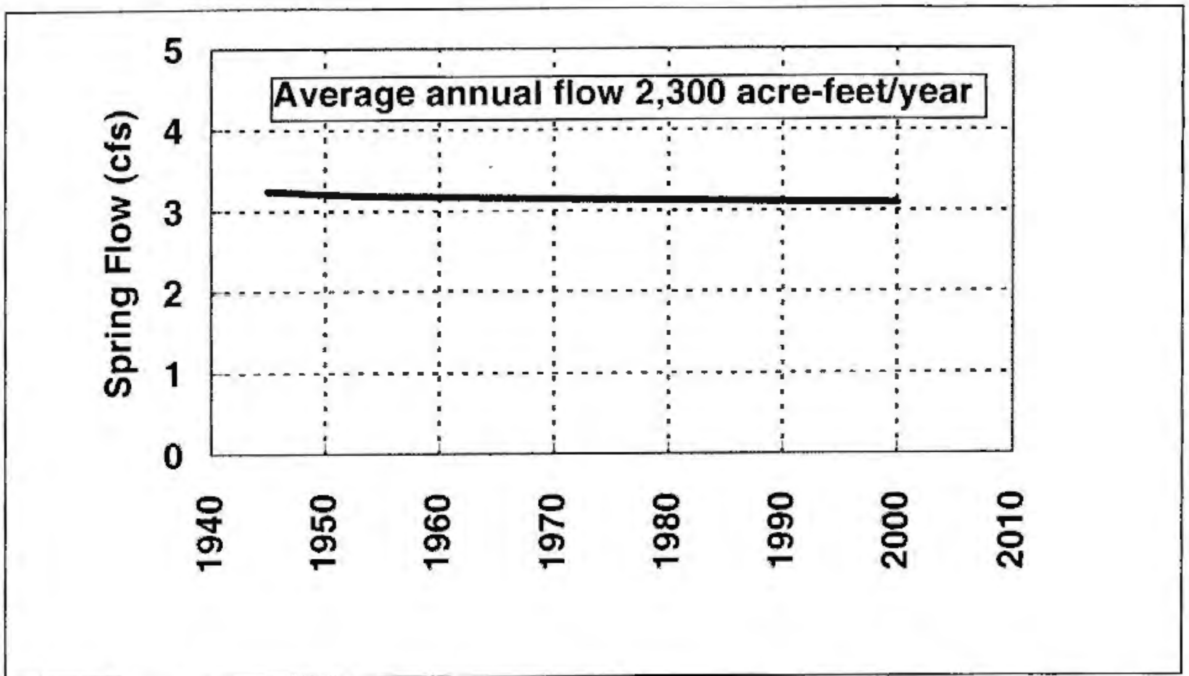

Figure 8-30 Rogers and Blue Point Springs Flow (represents North Shore Spring Complex).

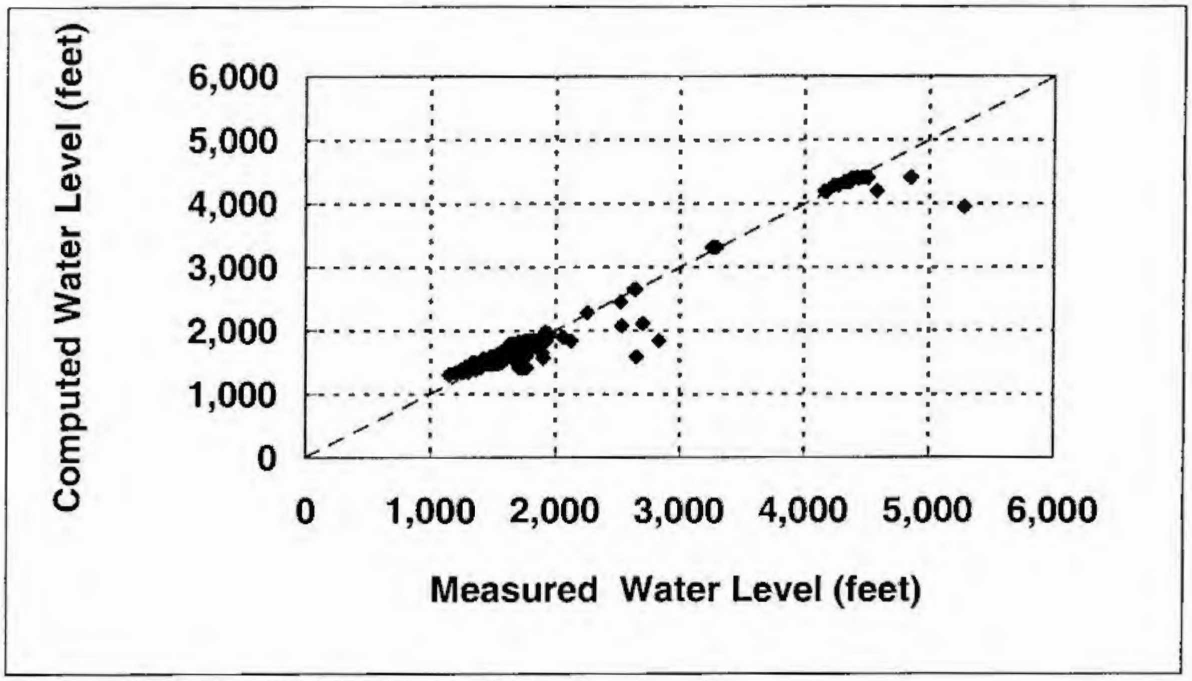

Figure 8-31 Valley-fill Wells Steady State.

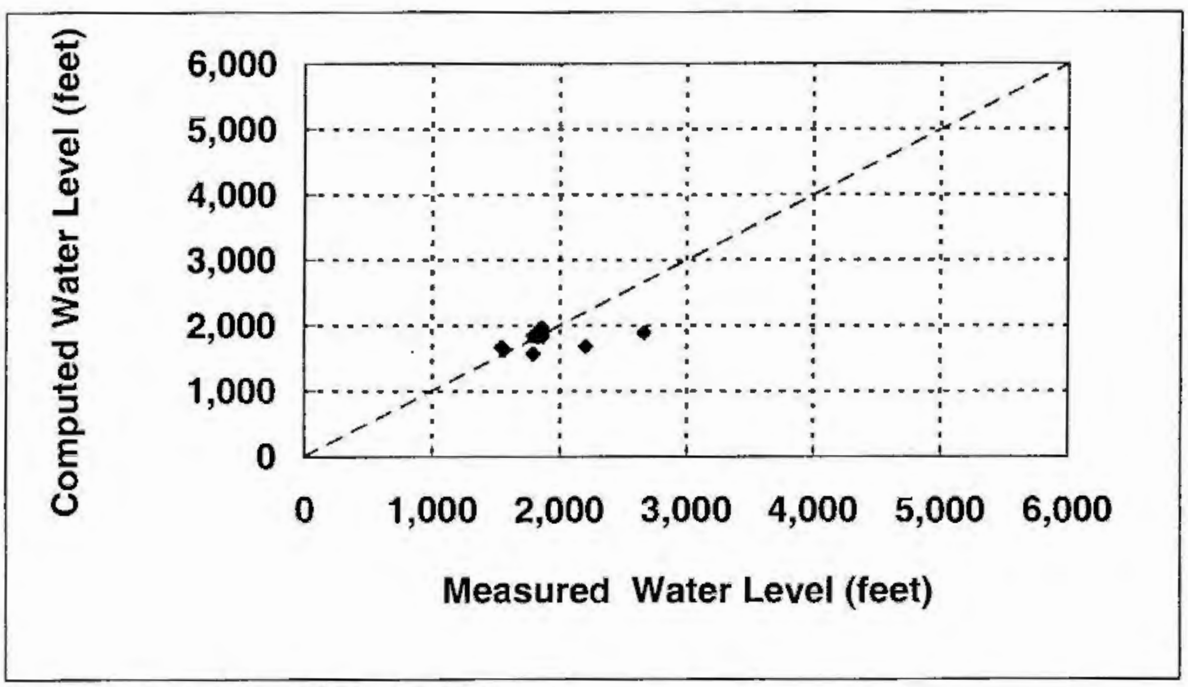

Figure 8-32 Carbonate Wells Steady State.

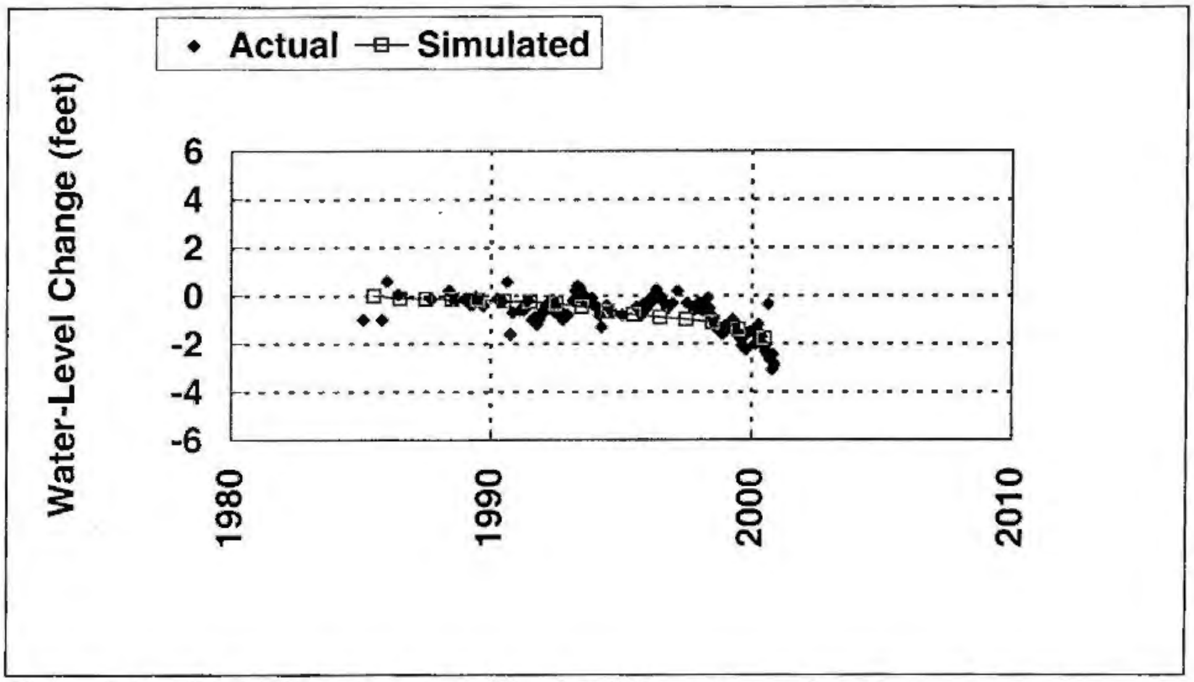

Figure 8-33a Well CSV-2 Actual and Simulated Ground-water Levels.

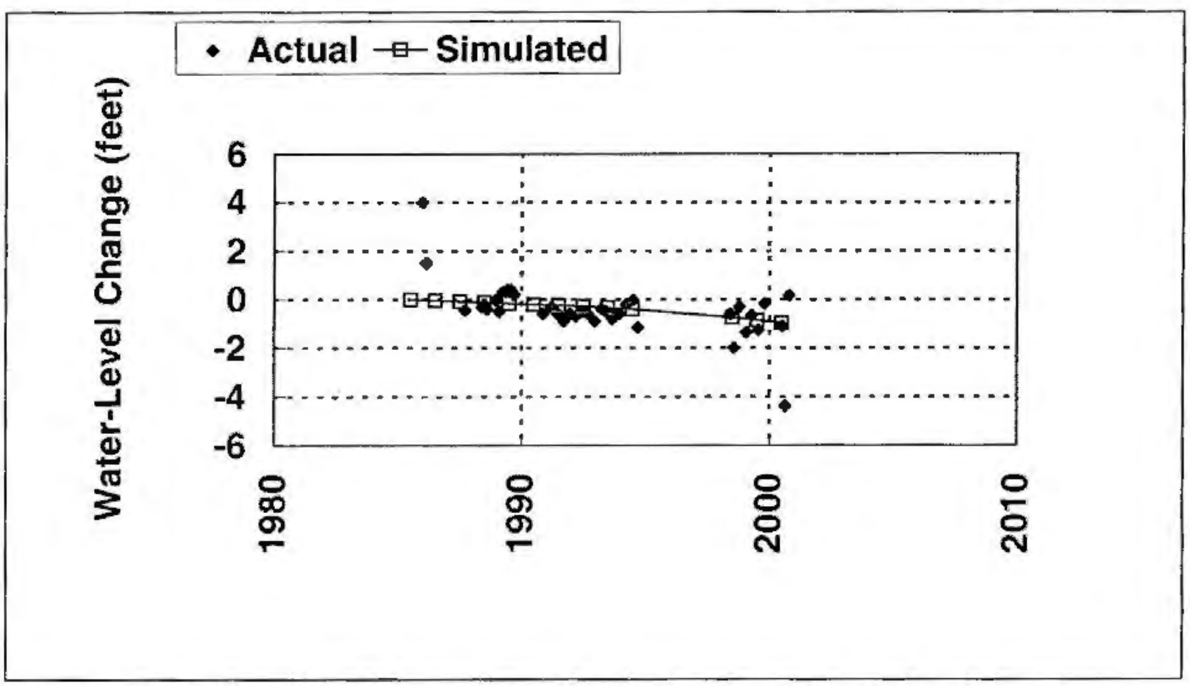

Figure 8-33b Well CSV-3 Actual and Simulated Ground-water Levels.

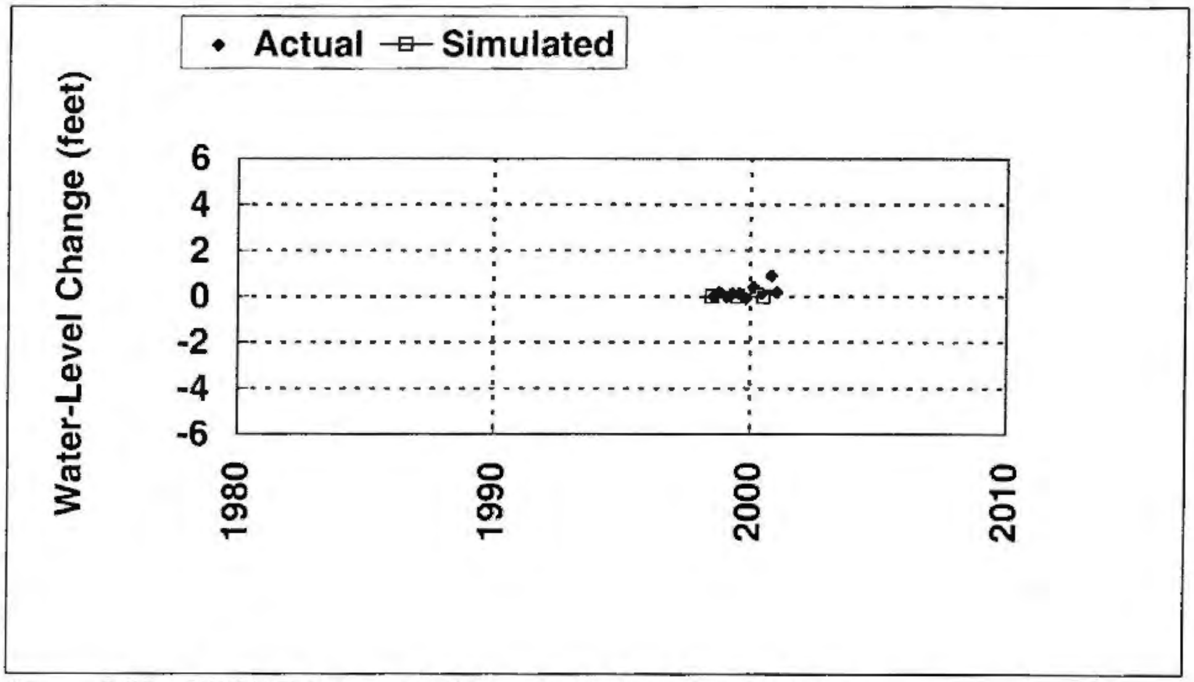

Figure 8-33c Well DF-1 Actual and Simulated Ground-water Levels.

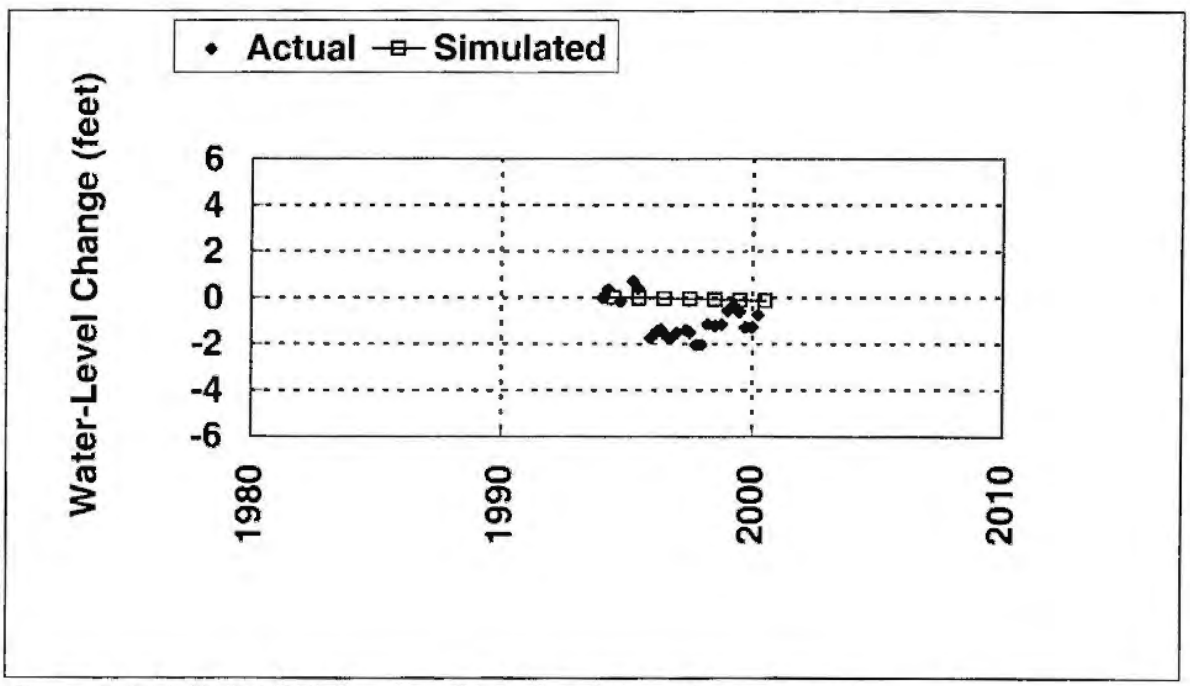

Figure 8-33d Well EH-2 Actual and Simulated Ground-water Levels.

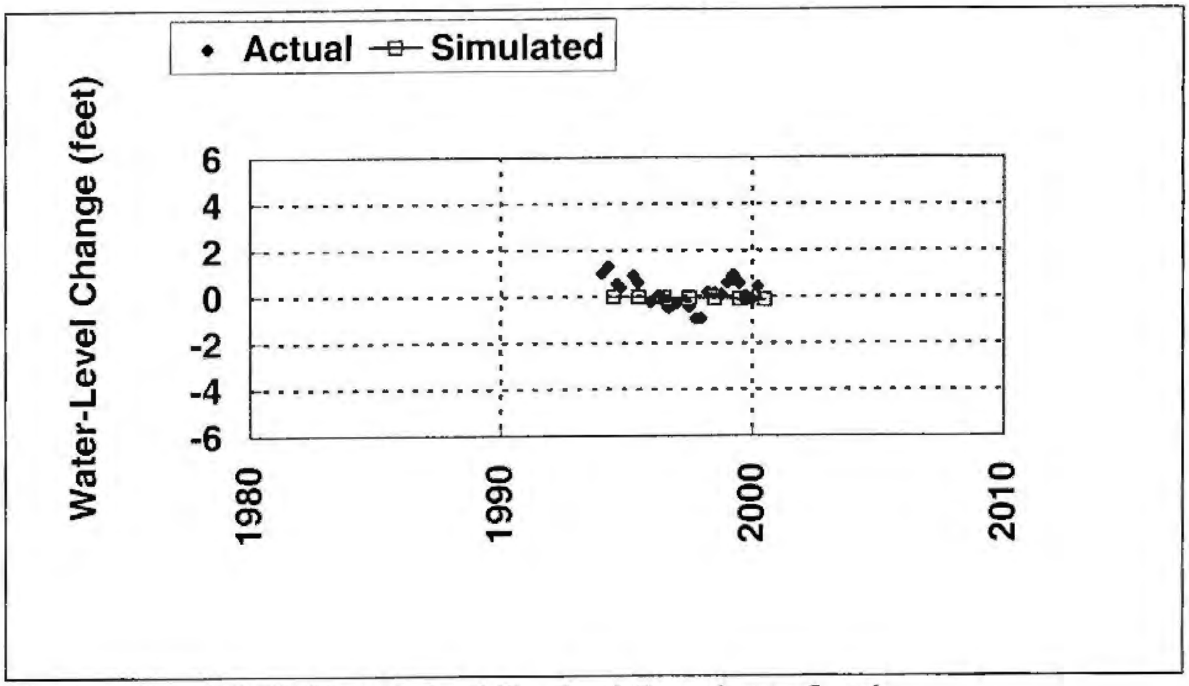

Figure 8-33e Well EH-2A Actual and Simulated Ground-water Levels.

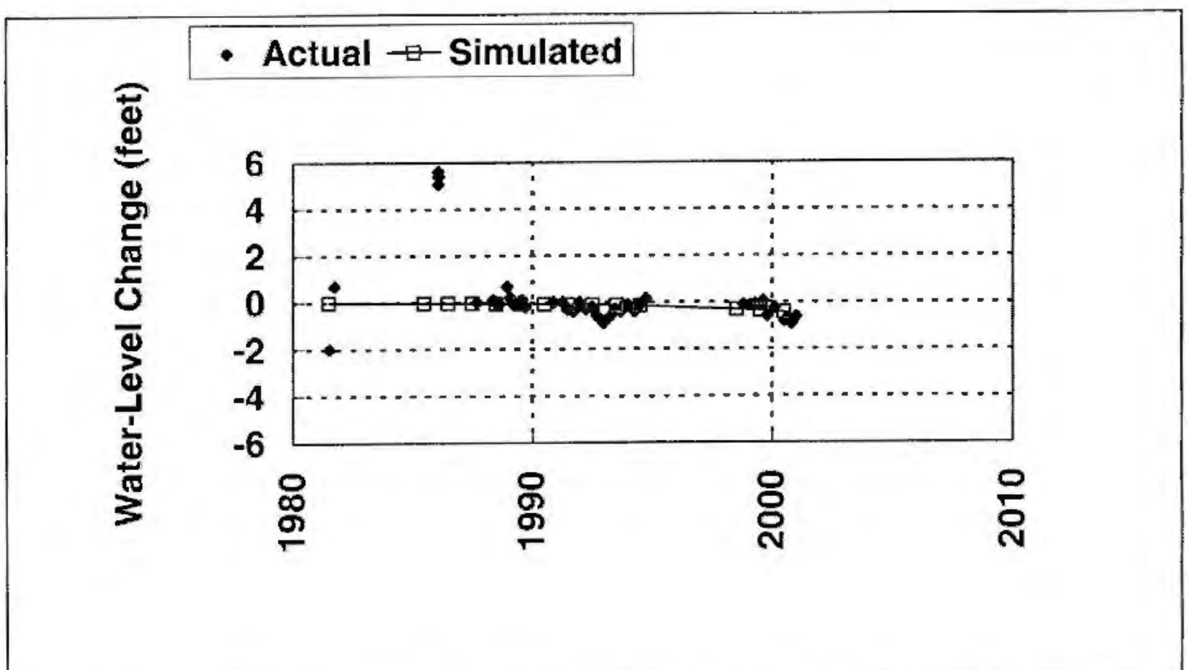

Figure 8-33f Well CE-VF-2 Actual and Simulated Ground-water Levels.

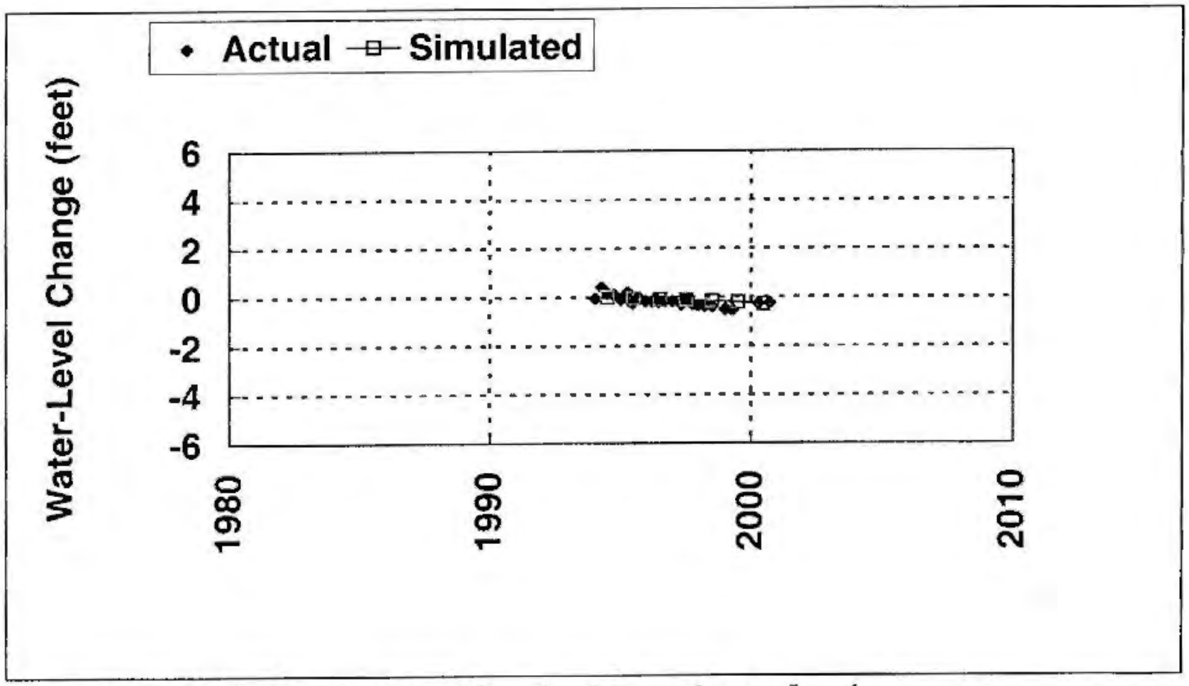

Figure 8-33g Well EH-3 Actual and Simulated Ground-water Levels.

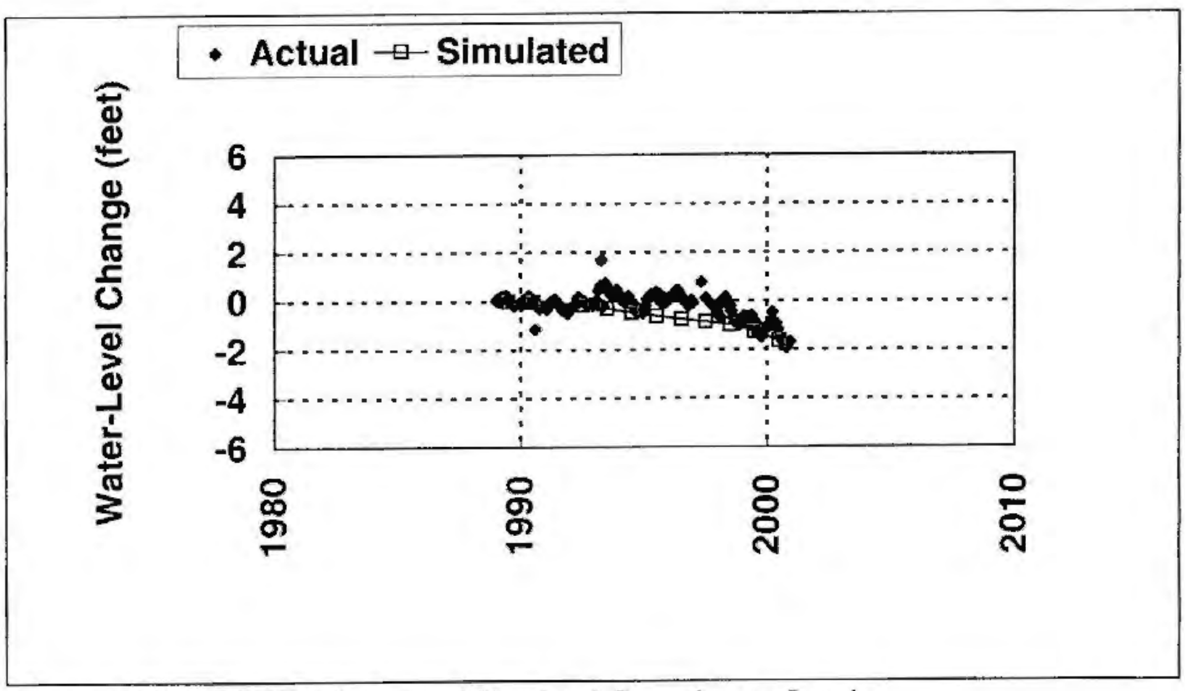

Figure 8-33h Well EH-4 Actual and Simulated Ground-water Levels.

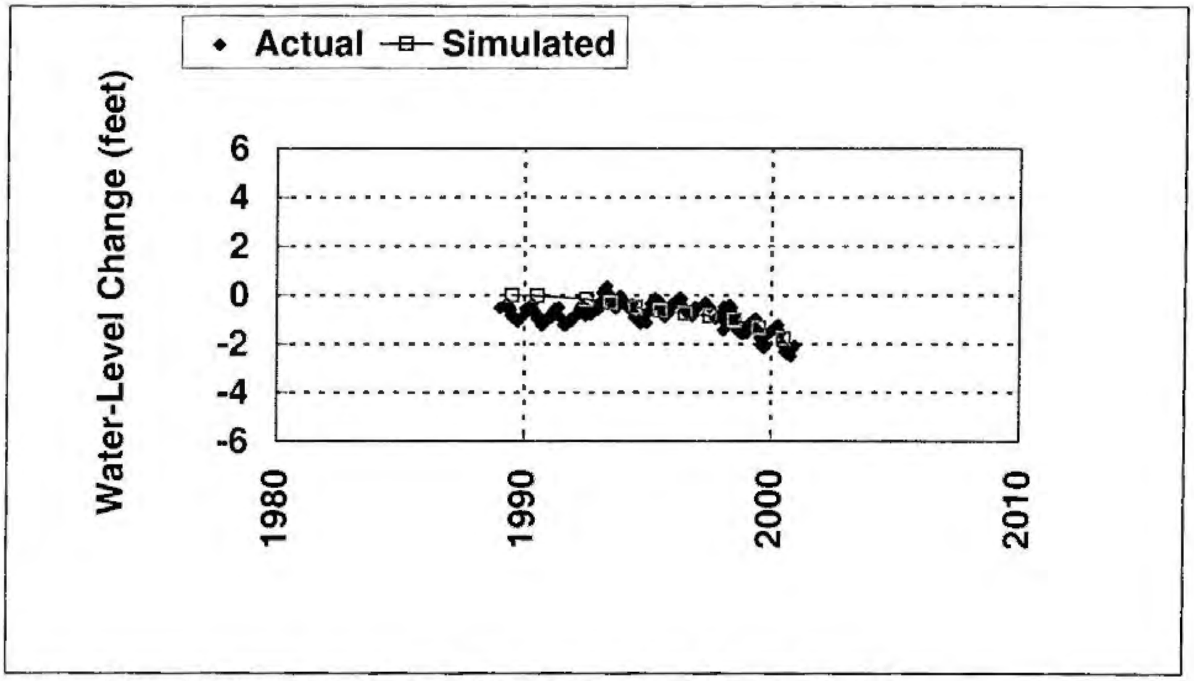

Figure 8-33i Well EH-5B Actual and Simulated Ground-water Levels.

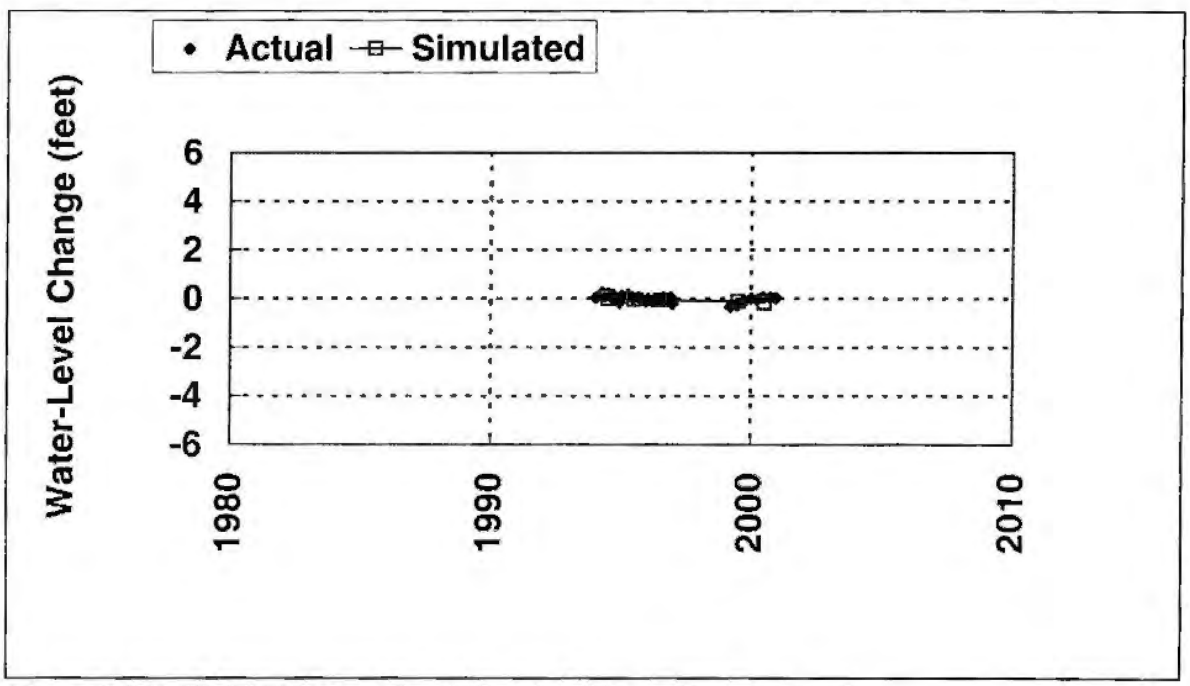

Figure 8-33j Well EH-7 Actual and Simulated Ground-water Levels.

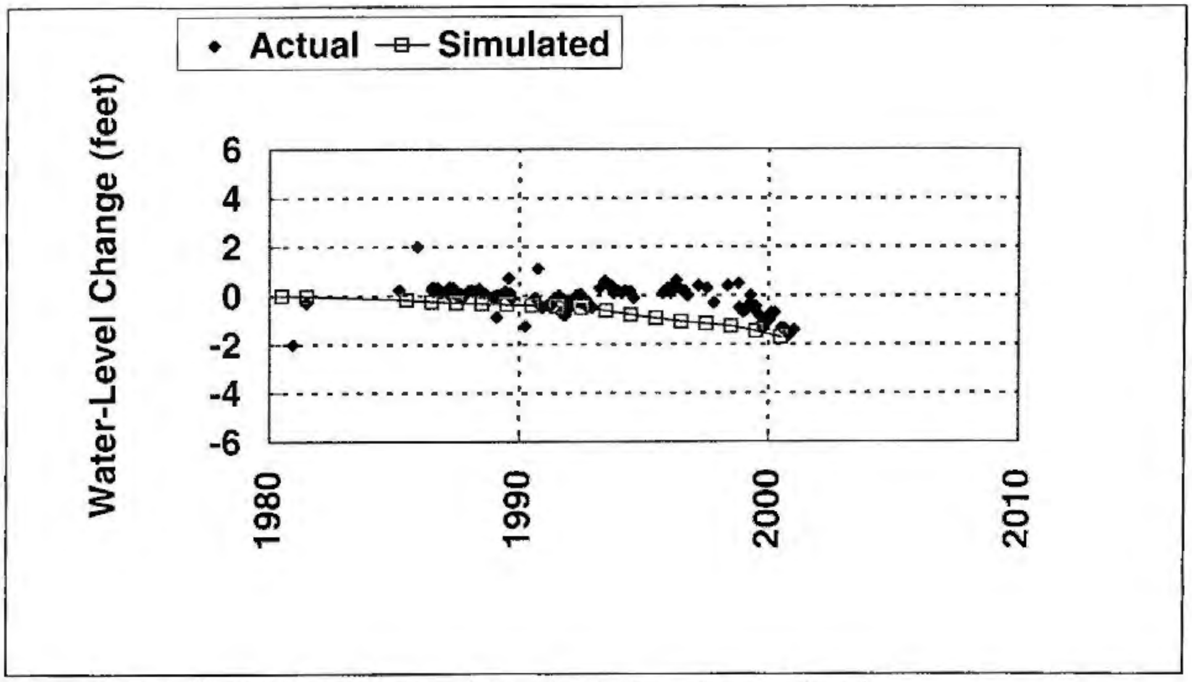

Figure 8-33k Well MX-4 Actual and Simulated Ground-water Levels.

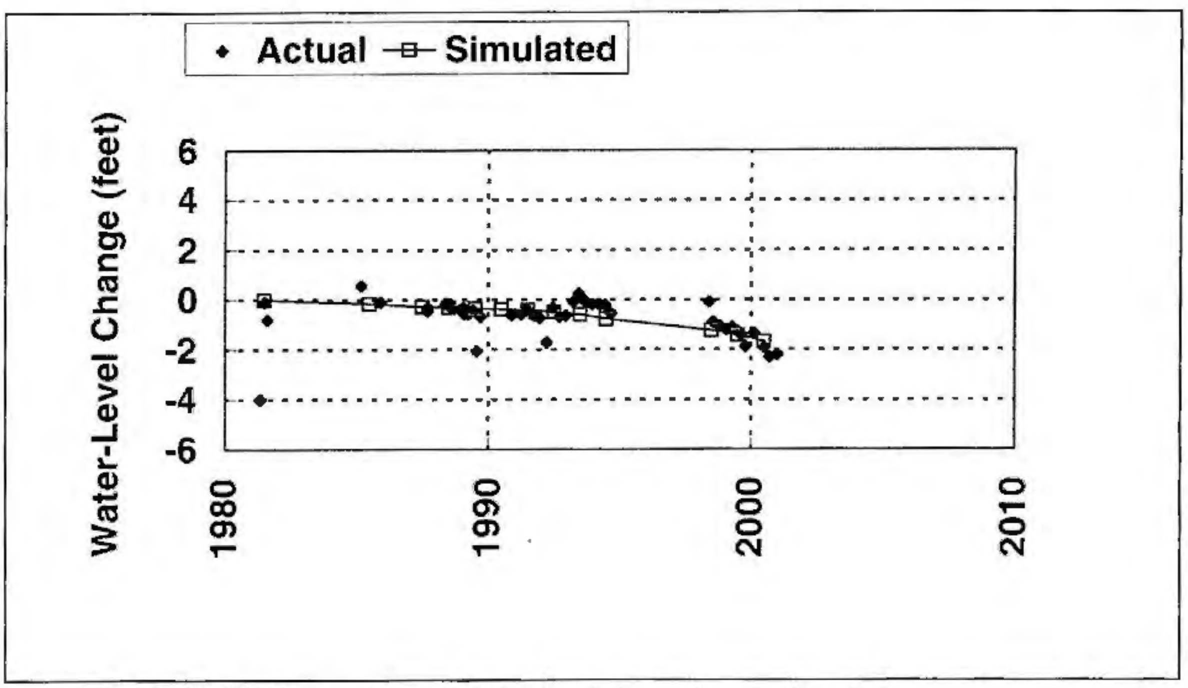

Figure 8-33l Well MX-5 Actual and Simulated Ground-water Levels.

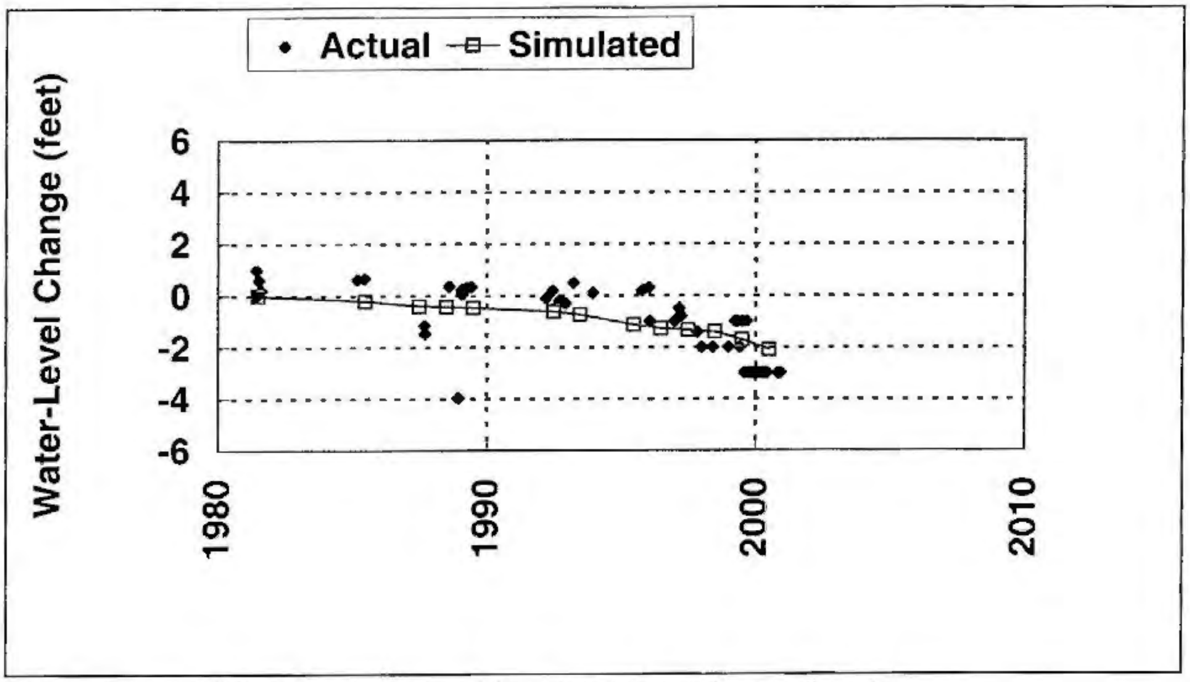

Figure 8-33m Well MX-6 Actual and Simulated Ground-water Levels.

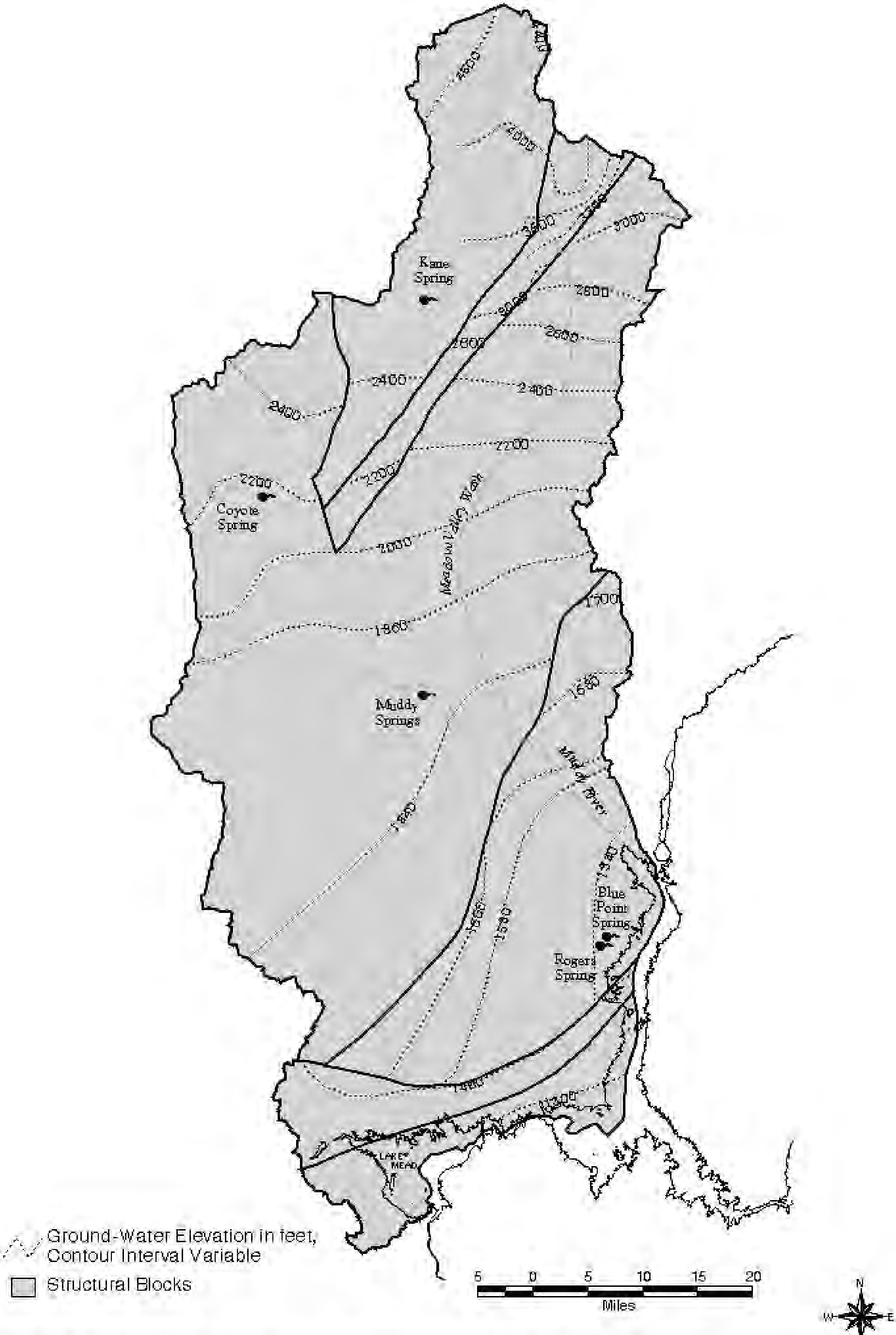

Figure 8-34. Simulated ground-water elevation at top of carbonate aquifer, 1945.

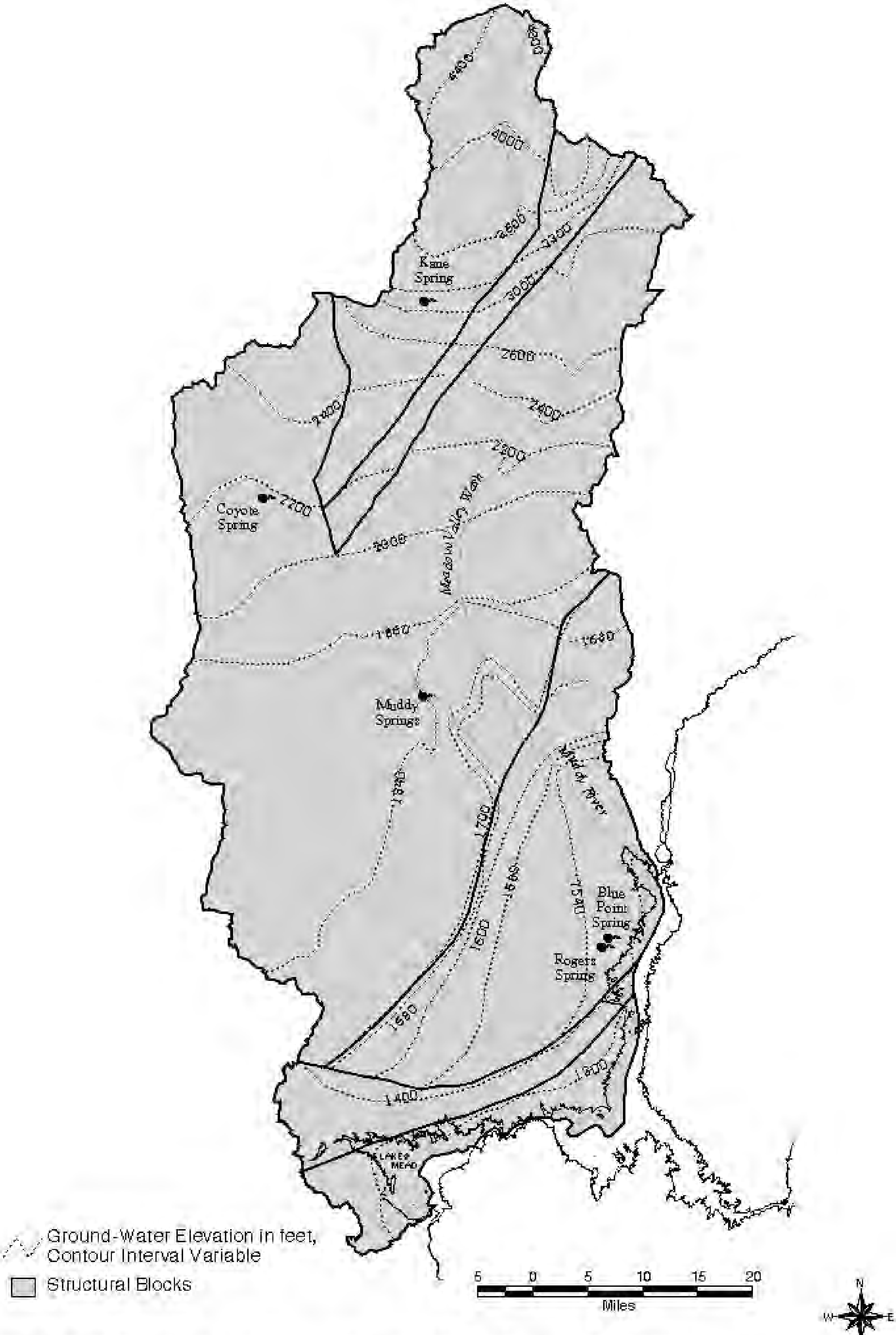

Figure 8-35. Simulated ground-water elevation of ground-water table, 1945.

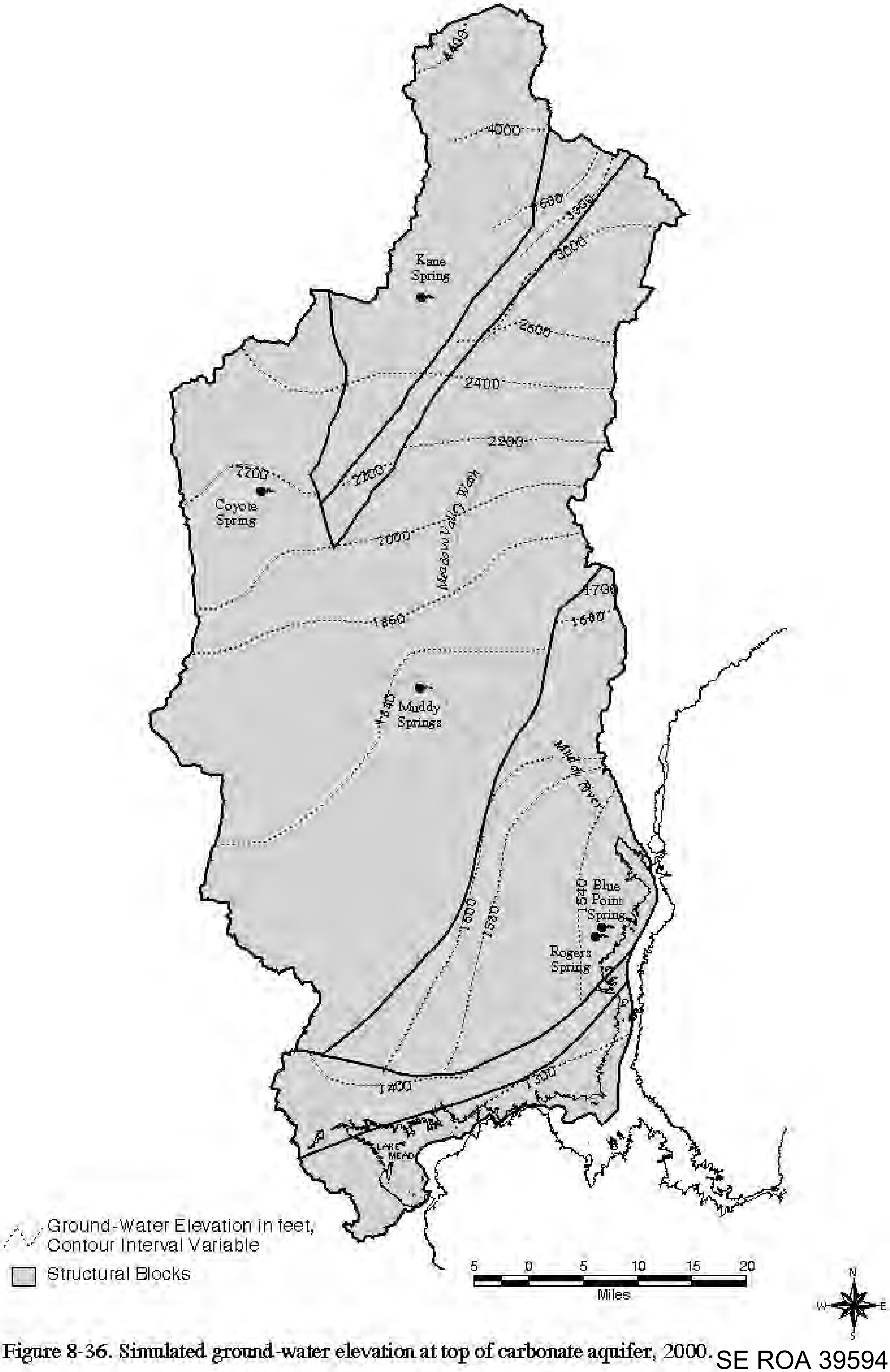

Figure 8-36. Simulated ground-water elevation at top of carbonate aquifer, 2000.

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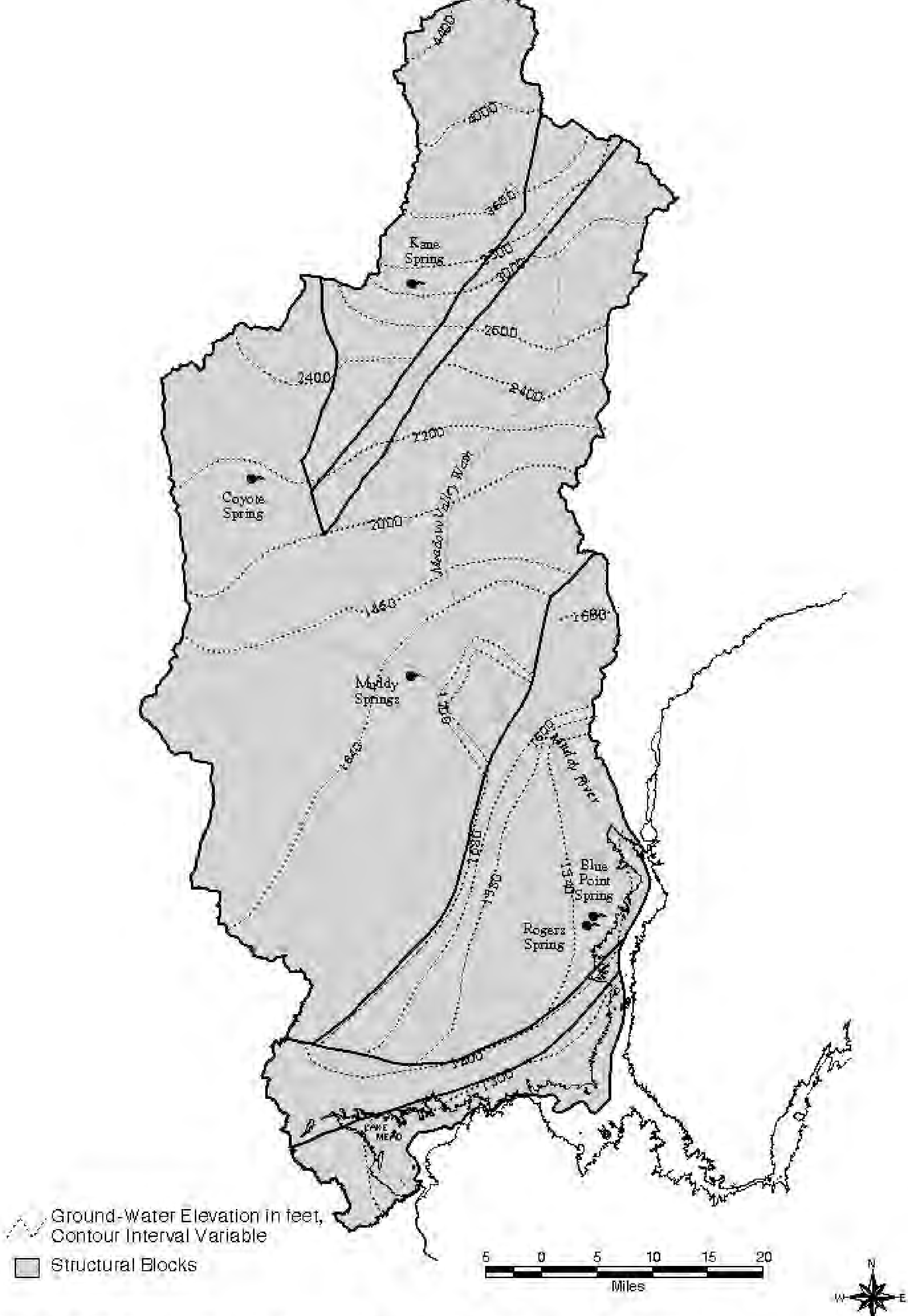

Figure 8-37. Simulated ground-water elevation of ground-water table, 2000.

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8.2.7.3 Calibration Evaluation

The adequacy of the model can be evaluated only with respect to the intended use. The principal intended use of this model is to evaluate the impact of increased regional pumping on spring flows. For that purpose, the model adequately represents the ground-water system. The reliability of the evaluation in this regard depends on the difference between two model simulations. That difference tends to contain less uncertainty than its components, because some uncertainties in the components are canceled by the subtraction process (i.e., by each other). The components adequately represent the ground-water system, and the difference correspondingly better represents the ground-water system.

The model adequately reproduces the measured streamflows. **Figure 8-26** and **Figure 8-27** show the measured annual non-flood streamflows for the Moapa and Glendale gages. These are the annual streamflows that result from filtering daily values to remove streamflows resulting from runoff events. The filtered streamflows are those resulting from spring flows, ground-water inflows, and irrigation returns. The simulated non-flood streamflows adequately match the corresponding measured streamflows with respect to both magnitude and temporal trend. For the Moapa gage, the 1945-measured streamflow is 34,000 afy, and streamflow tends to decrease 200 afy per year. Correspondingly, the 1945 computed streamflow is 35,000 afy, and the streamflow tends to decrease 200 afy per year. As described in Section 5.2 the decline in streamflow at the Moapa gage correlates to alluvial ground-water pumpage, and spring flow data suggest spring flow has remained constant. For the Glendale gage, the 1945-measured streamflow is 34,000 afy, and streamflow tends to decrease 200 afy per year. Correspondingly, the 1945 computed streamflow is 35,000 afy, and the streamflow tends to decrease 200 afy per year.

The model adequately reproduces measured spring flows. **Figure 8-29** shows the simulated Muddy Springs discharge. As shown on the figure, the simulated spring flow changes little during 1945-2000. A corresponding measured discharge is not shown because the total Muddy Springs discharge is not measured. Muddy River streamflow is measured below the springs, but the streamflow at that site is impacted by upstream diversions, pumping, and consumption. However, selected spring discharges have been measured since 1986, and the measured spring flows display no long-term trend as discussed in Section 5.2.

Figure 8-30 shows the simulated Rogers Spring and Blue Point Spring discharge. As shown on the figure, the simulated spring flow does not change during 1945-2000. The Rogers Spring discharge has been measured since 1985, and the Blue Point Spring discharge has been measured since 1997. These records indicate that the spring flows are not displaying long-term changes.

The model adequately reproduces measured ground-water levels. **Figure 8-31** and **Figure 8-32** show the simulated ground-water levels correspond to the measured levels. On this scatter diagram, the deviation of simulated ground-water levels from the measured level is represented by the vertical deviation from diagonal line shown on **Figure 8-31** and **Figure 8-32**. If the simulated ground-water level is higher than the measured level, the scatter point representing the values will be positioned above the diagonal line by the difference between the values. Likewise, if the simulated ground-water level is lower than the measured level, the scatter point representing the values will be positioned below the diagonal line by the difference between the values. Most of the simulated ground-water levels are positioned near the diagonal relative to the total range of values, which means in statistical terms that the model explains a large part of the total variance in the measured ground-water levels.

The deviations that do occur between a simulated ground-water level and the corresponding measured level result from at least three factors. They result first because the model does not represent phenomena that impact the measured ground-water level. As a first example, computed ground-water levels are extracted from the model based on the mesh node that is nearest the well with respect to both geographic location and depth. Except by chance, a mesh node will not coincide with the three-dimensional center of a well screen, and even with a perfect model, the simulated ground-water-level will deviate from the measured level. As a second example, simulated ground-water levels represent average conditions over large three-dimensional scales. The horizontal averaging is on scales of 20,000 ft or more, and the vertical averaging is on scales of 2,000 ft or more. However, the ground-water level measured in a well represents averaging over much smaller scales. Depending on the complexity of the local hydrogeologic setting, the horizontal averaging is on scales of 2,000 ft or less, and the vertical averaging is on scales of 200 ft or less. Accordingly, the model represents not every measured ground-water level, but the average of the measured ground-water levels over model scales. As a third example, the available ground-water data are noisy. While measurements of ground-water depth are likely reliable, the corresponding ground-water elevation is often unreliable because the measuring-point elevation is uncertain. Owing to that uncertainty, the simulated ground-water-level will deviate from the measured level.

In addition to being noisy, the ground-water data are so geographically sparse that ground-water levels are unknown over large parts of the model area. Ground-water data for alluvial wells are limited mostly to wells located along Meadow Valley Wash and the Muddy River. Additionally, data are available for a few locations within the modeled area. Ground-water data are available for carbonate wells at scattered locations within the modeled area. However, for large parts of the modeled area, ground-water data are absent not only for carbonate wells but also for alluvial wells. Additionally, a few monitoring wells identified as carbonate wells **(Figure 8-38)** actually may be alluvial wells.

Even though ground-water data for the modeled area are few, the model is an adequate tool for interpolating and extrapolating the available ground-water data. The model can be used spatially or temporally to interpolate between measurement points, and it can be used to extrapolate to locations and times for which data are not available. While some other approach might be used to interpret the available ground-water data, the interpolations and extrapolations based on the model have the advantage that they are based on explicit hydrogeologic and hydrologic characterizations of the ground-water system that are coupled with the mathematical laws of ground-water flow. As a result, the model simulations of ground-water levels are more constrained and correspondingly more reliable than less quantitative approaches to describing the ground-water levels. The simulated ground-water levels are constrained by not only the measured ground-water levels but also the measured streamflows and spring flows.

8.3 UTILIZATION OF THE GROUND-WATER MODEL

The calibrated ground-water model was used to simulate the effects of future pumping within the modeled area. The model was used to simulate the resulting streamflows, spring flows, and ground-water levels from existing permitted rights and LVVWD applications.

8.3.1 Description of Simulations

The simulations describe future pumping for the 61-year period 2001-2061. The simulations are similar in the assumption that the current pumping within the modeled area will continue. The simulations differ in the specification of additional pumping. The particular specifications for each simulation are as follows:

8.3.1.1 Simulation of Existing Permitted Rights

The existing-permits simulation involved the pumping of 17,660 afy of all existing water permits within the Coyote Spring Valley, Garnet Valley, Lower Meadow Valley Wash, Lower Moapa Valley, Upper Moapa Valley, and the Black Mountain Area to observe the pumping impacts on spring discharge and ground-water heads decades into the future. The total rights within the Coyote Spring Valley includes 7,500 afy of SNWA water rights for the MX-5 well, 2,500 afy of NPC rights, and 6,100 afy of CSI rights (includes 5,000 afy purchased from NPC). The Garnet Valley water rights include 2,200 afy for SNWA, and 178 afy for Dry Lake LLC. Within the Lower Meadow Valley Wash, 5,000 afy of water rights belonging to the MVWD for the PG&E power plant is included. Existing water rights in the Black Mountains area that were included in the pumping simulation are 1,392 afy for Dry Lake LLC and 1,870 afy for the Nevada Cogeneration. An additional 4,981 afy of MVWD rights for the Arrow Canyon and MX-6 wells were added in the pumping simulation.

The simulation assumes that the pumpage will be distributed to the wells shown on **Figure 8-38**. None of the wells were sited within the Moapa Paiute Indian Reservation. For the SNWA water rights, 7,500 afy was pumped out of MX-5 well and the rights of 2,200 afy within Garnet Valley were divided between two wells. We assumed that the MVWD water rights of 5,000 afy within the Lower Meadow Valley Wash is temporary and that pumping within the Lower Meadow Valley Wash will be reduced by 5,000 afy beginning in year 2031.

The representation of simulating existing permitted rights in the model is shown on **Figure 8-38**. **Figure 8-39** shows the geographic distribution of annual pumpage to regions within the modeled area.

8.3.1.2 Simulation of LVVWD Ground-Water Applications

The simulation of LVVWD applications involved the pumping from the previous simulation in addition to the 27,512 afy of LVVWD applications. The amount of 27,512 afy requested was

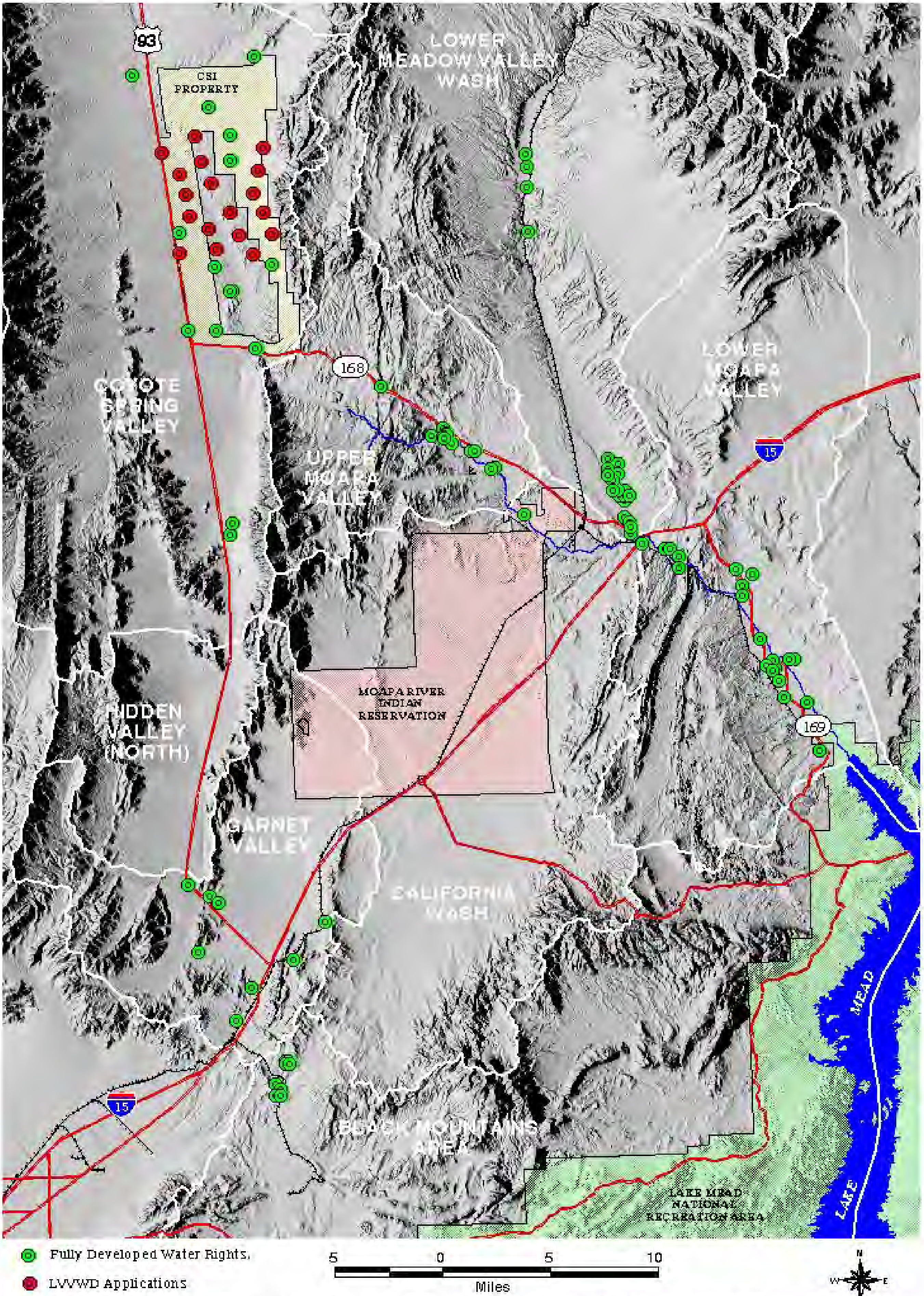

Figure 8-38. Locations of pumping wells with fully developed water rights and LVVWD Applications.

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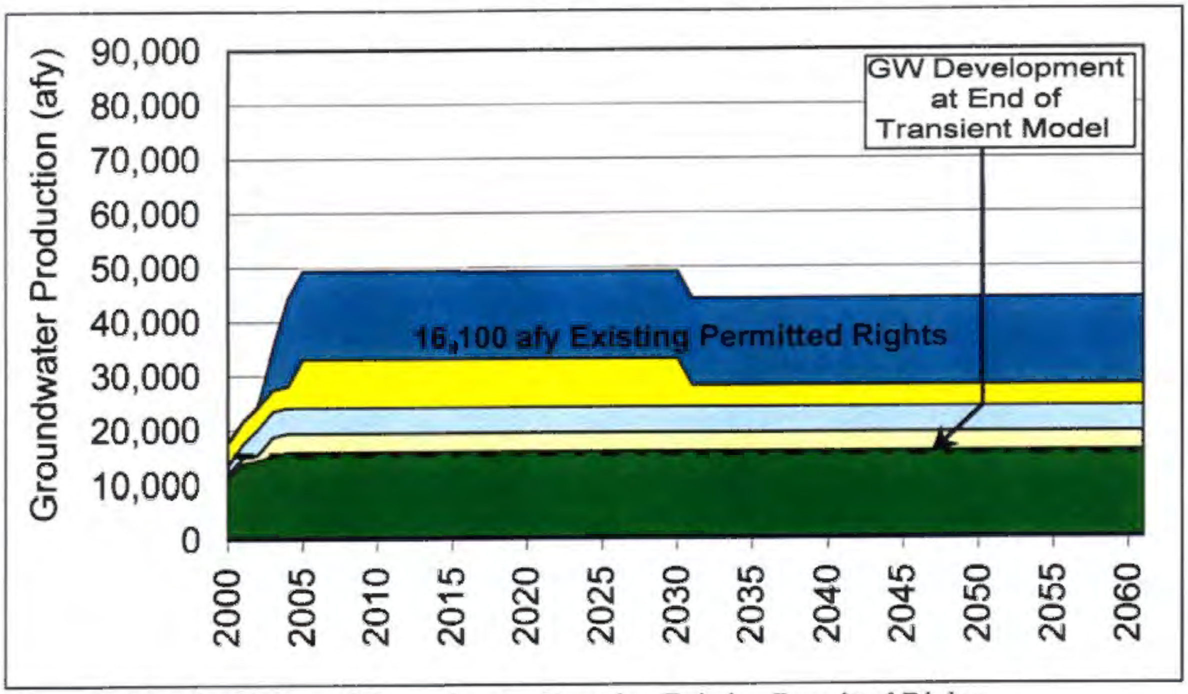
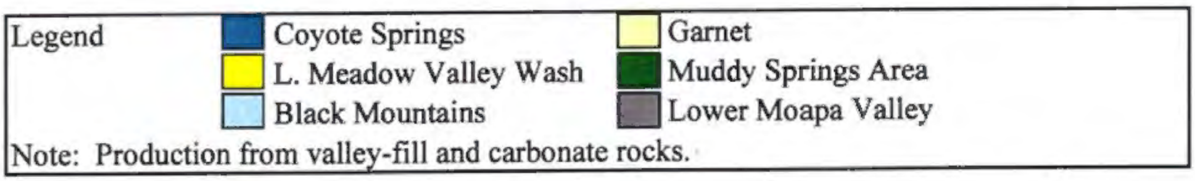


Figure 8-39 Distribution of Ground-water Pumping Existing Permitted Rights.



pumped in three-year increments of 9,171 afy starting from the year 2017. In the first year (2017), the 9171 afy was divided among six wells sited within the Coyote Spring Valley. As in the previous simulation, all the wells were sited on CSI Property with majority of them within Lincoln County. None of them were sited within the Moapa Pauite Indian Reservation. Pumpage from six additional wells with a total duty of 9,171 afy was added in the second year (2018). The final increment of 9,171 afy was again divided among six wells in the third year. As in the first simulation, 7,500 afy was pumped out of MX-5 and 2,200 afy from two other SNWA wells in Garnet Valley. The simulation assumes that the pumpage will be distributed to the wells shown on **Figure 8-38**.

The representation of simulating LVVWD applications in the model is shown on **Figure 8-38**. **Figure 8-40** shows the geographic distribution of annual pumpage to regions within the modeled area.

8.3.2 <u>Simulation Results</u>

8.3.2.1 Existing Permitted Rights

Figure 8-41 through **Figure 8-49** and **Table 8-5** summarizes the simulation of existing permitted rights. **Figure 8-41** shows contours of computed ground-water elevation at the top of the carbonate aquifer for 2061. **Figure 8-42** shows contours of computed ground-water elevation at the ground-water table. **Figure 8-43** shows contours of computed change in ground-water elevation at the top of the carbonate aquifer for 2000-2061. **Figure 8-44** shows contours of computed change in ground-water elevation at the ground-water table. **Figure 8-45** through **Figure 8-47** shows hydrographs of computed streamflow, and **Figure 8-48** and **Figure 8-49** shows hydrographs of computed spring flows. **Table 8-5** lists the components of the ground-water budget for 2061.

As indicated on **Figure 8-45** through **Figure 8-49**, spring flows and streamflows in the simulation show a decline as a result of pumping existing permits. **Figure 8-43** and **Figure 8-44** also show a slight decline in simulated ground-water levels as a result of the specified future pumping. Within Coyote Springs Valley, the maximum water-level decline at the top of the carbonate is approximately 30 ft in 2061. At Muddy Springs, the water-level decline is <10 ft. At the western boundary of the modeled area, the water-level decline is approximately 2 ft in 2061. At the eastern boundary of the modeled area, the water-level decline is approximately 3 ft.

As indicated in **Table 8-5**, water-level declines at the model boundaries induce ground-water inflow to the modeled area. The boundary inflow during 2061 is 25,000 afy.

8.3.2.2 LVVWD Ground-Water Applications

Figure 8-50 through **Figure 8-58** and **Table 8-5** summarize the simulation for LVVWD applications. **Figure 8-50** shows contours of computed ground-water elevation at the top of the carbonate aquifer for 2061. **Figure 8-51** shows contours of computed ground-water elevation at the ground-water table. **Figure 8-52** shows contours of computed change in ground-water

Table 8-5. Water budgets for streams and hydrologic systems[1].

Budget Component	Historical Pumping / Diversions 1945	Historical Pumping / Diversions 2000	Existing Permits 2061	LVVWD Applications 2061
WATER BUDGETS FOR MEADOW VALLEY WASH AND MUDDY RIVER				
Inflows – Meadow Valley Wash				
• Streamflow at model boundary	10,000	10,000	10,000	10,000
• Ground-water inflows above Rox	11,000	9,000	9,000	8,000
• Ground-water inflows Rox to mouth	4,000	3,000	2,000	2,000
Total	**25,000**	**22,000**	**21,000**	**20,000**
Outflows – Meadow Valley Wash				
• ET above Rox[2]	21,000	20,000	19,000	18,000
• ET from Rox to mouth[2]	2,000	0	0	0
• Streamflow at mouth	2,000	2,000	2,000	2,000
Total	**25,000**	**22,000**	**21,000**	**20,000**
Inflows – Muddy River				
• Meadow Valley Wash streamflow at mouth	2,000	2,000	2,000	2,000
• Ground-water inflows above Moapa	38,000	31,000[3]	27,000[3]	26,000[3]
• Ground-water inflows Moapa to Glendale	6,000	6,000	4,000	4,000
• Ground-water inflows Glendale to Overton	7,000	7,000	6,000	6,000
Total	**53,000**	**46,000**	**39,000**	**38,000**
Outflows – Muddy River				
• ET above Moapa[2]	3,000	5,000	5,000	5,000
• ET Moapa to Glendale[2]	9,000	9,000	9,000	9,000
• ET Glendale to Overton[2]	25,000	25,000	20,000	19,000
• Streamflow at Overton	16,000	8,000	6,000	5,000
Total	**53,000**	**47,000**	**40,000**	**38,000**
HYDROLOGIC SYSTEM				
Inflows				
Ground-water underflow - Pahranagat Valley	28,000	28,000	28,000	28,000
Ground-water underflow - Delemar Valley	16,000	16,000	16,000	16,000
Ground-water underflow - Panaca Valley	17,000	17,000	17,000	17,000
Ground-water underflow - Clover Valley	9,000	9,000	9,000	9,000
Meadow Valley Wash streamflow at boundary	10,000	10,000	10,000	10,000
Boundary underflows	0	0	25,000	41,000
Precipitation recharge	37,000	37,000	37,000	37,000
Total	**117,000**	**117,000**	**142,000**	**158,000**
Outflows				
Ground-water pumpage	0	18,000	44,000	72,000
Surface-water outflow - Muddy River	16,000	8,000	6,000	5,000
Ground-water discharge to Colorado River	37,000	37,000	37,000	37,000
ET – Coyote Springs	1,000	1,000	1,000	1,000
ET – Kane Springs	1,000	1,000	1,000	1,000
ET – Rogers Springs	1,000	1,000	1,000	1,000
ET – Blue Point Springs	1,000	1,000	1,000	1,000
ET – Meadow Valley Wash above Rox	21,000	20,000	19,000	18,000
ET – Meadow Valley Wash below Rox	2,000	0	0	0
ET – Muddy River above Moapa	3,000	5,000	5,000	5,000
ET – Muddy River – Moapa to Glendale	9,000	9,000	9,000	9,000
ET – Muddy River – Glendale to Overton	25,000	25,000	20,000	19,000
Total	**117,000**	**126,000**	**144,000**	**169,000**
STORAGE CHANGE	**0**	**-9,000**	**-2,000**	**-11,000**

[1] *See Figure 8-5 for definition of control volumes.*
[2] *ET includes consumption of diverted streamflow and riparian ground water.*
[3] *After-effects of diversions and ground-water pumping above Muddy River streamgaging station near Moapa.*

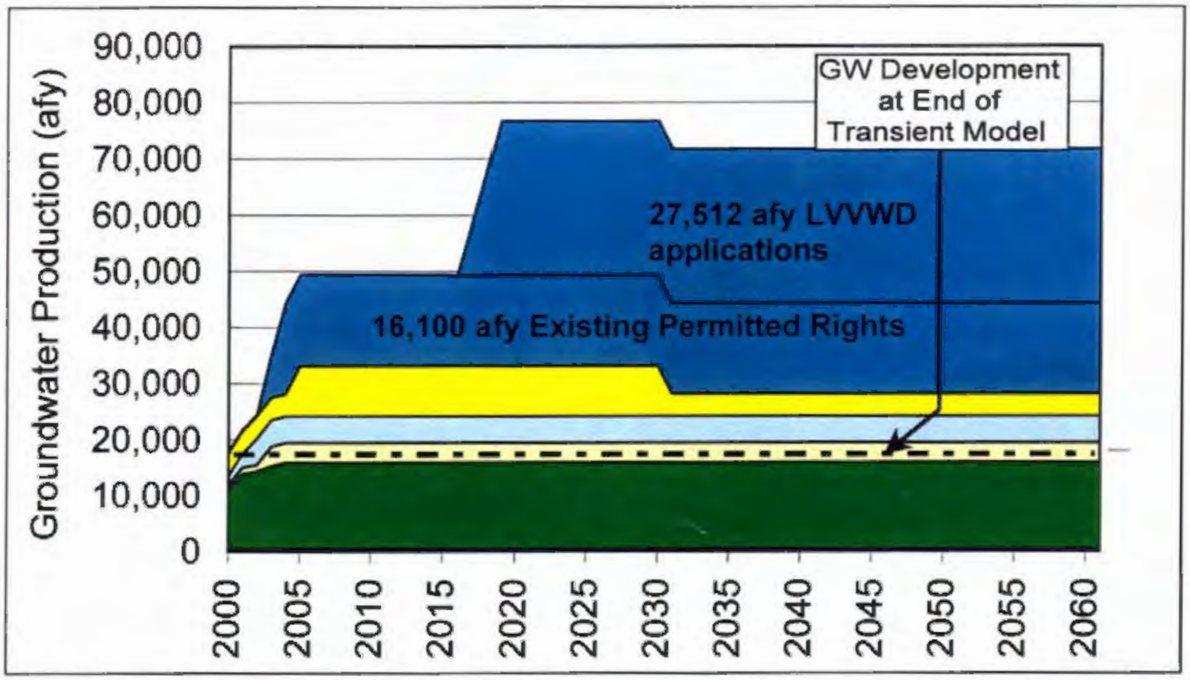


Figure 8-40 Distribution of Ground-water Pumping for LVVWD Applications.

Legend: Coyote Springs; L. Meadow Valley Wash; Black Mountains; Garnet; Muddy Springs Area; Lower Moapa Valley

Note: Production from valley-fill and carbonate rocks.

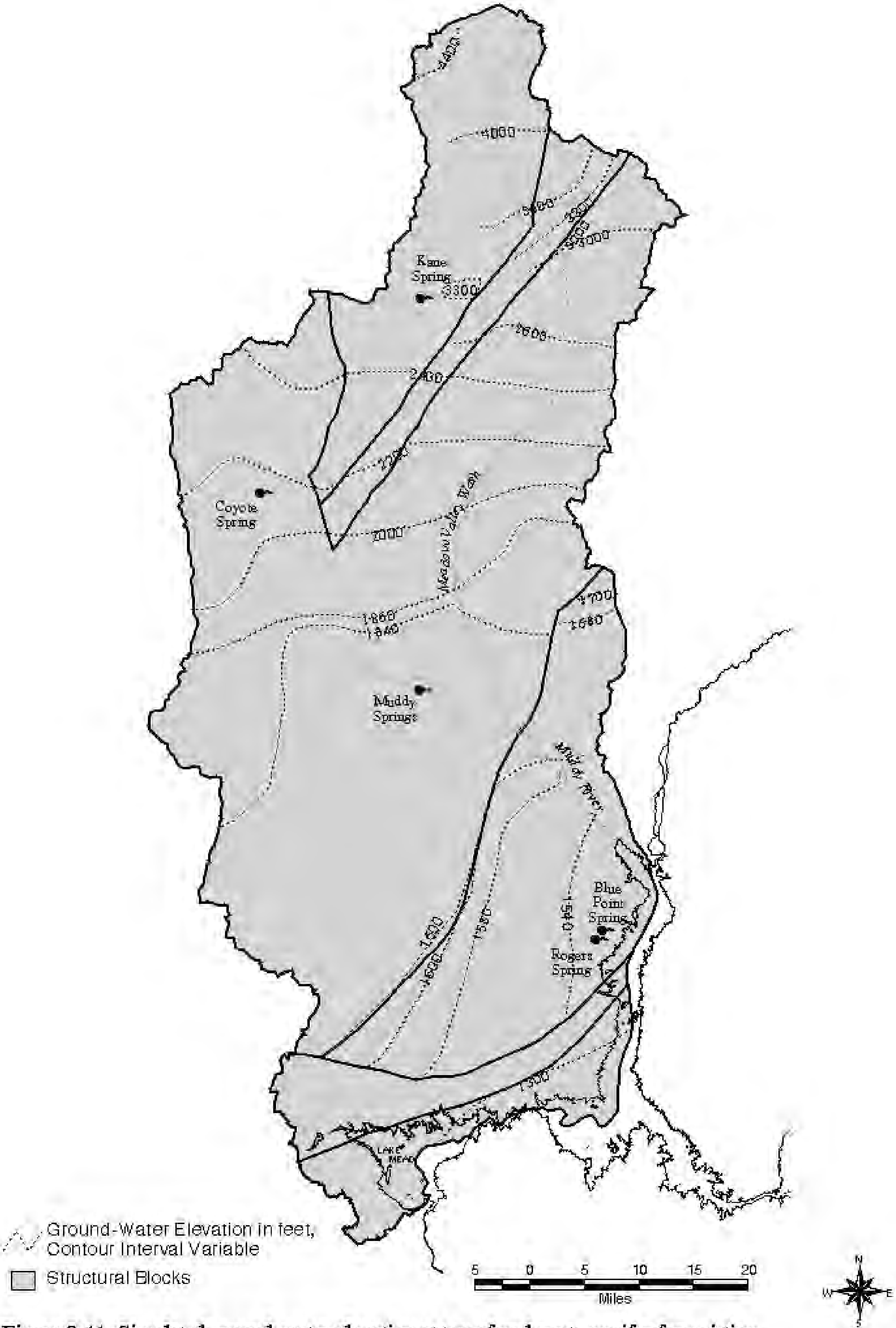


Figure 8-41. Simulated ground-water elevation at top of carbonate aquifer for existing permitted rights, 2061.

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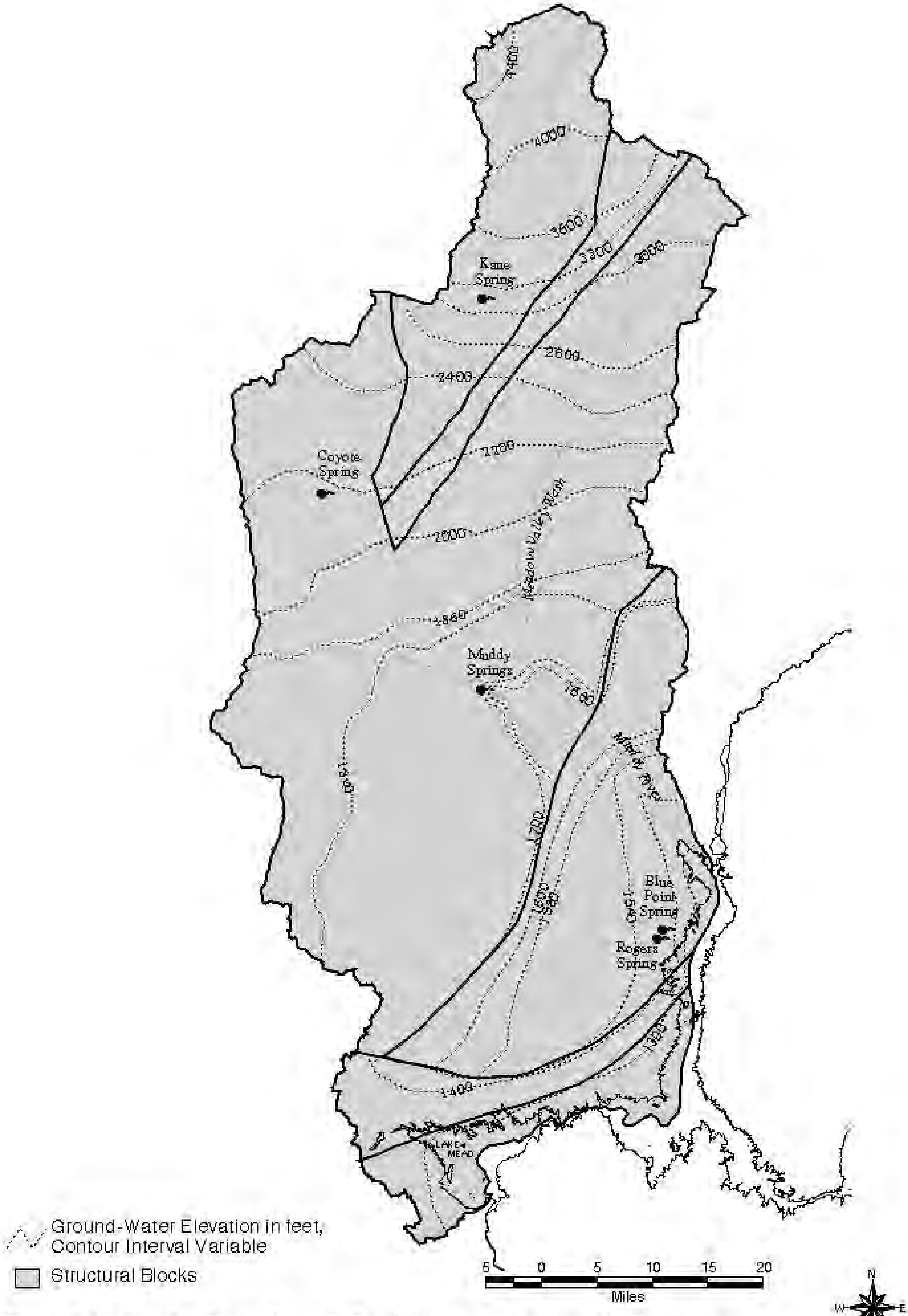

Figure 8-42. Simulated ground-water elevation at ground-water table for existing permitted rights, 2061.

SE ROA 39605

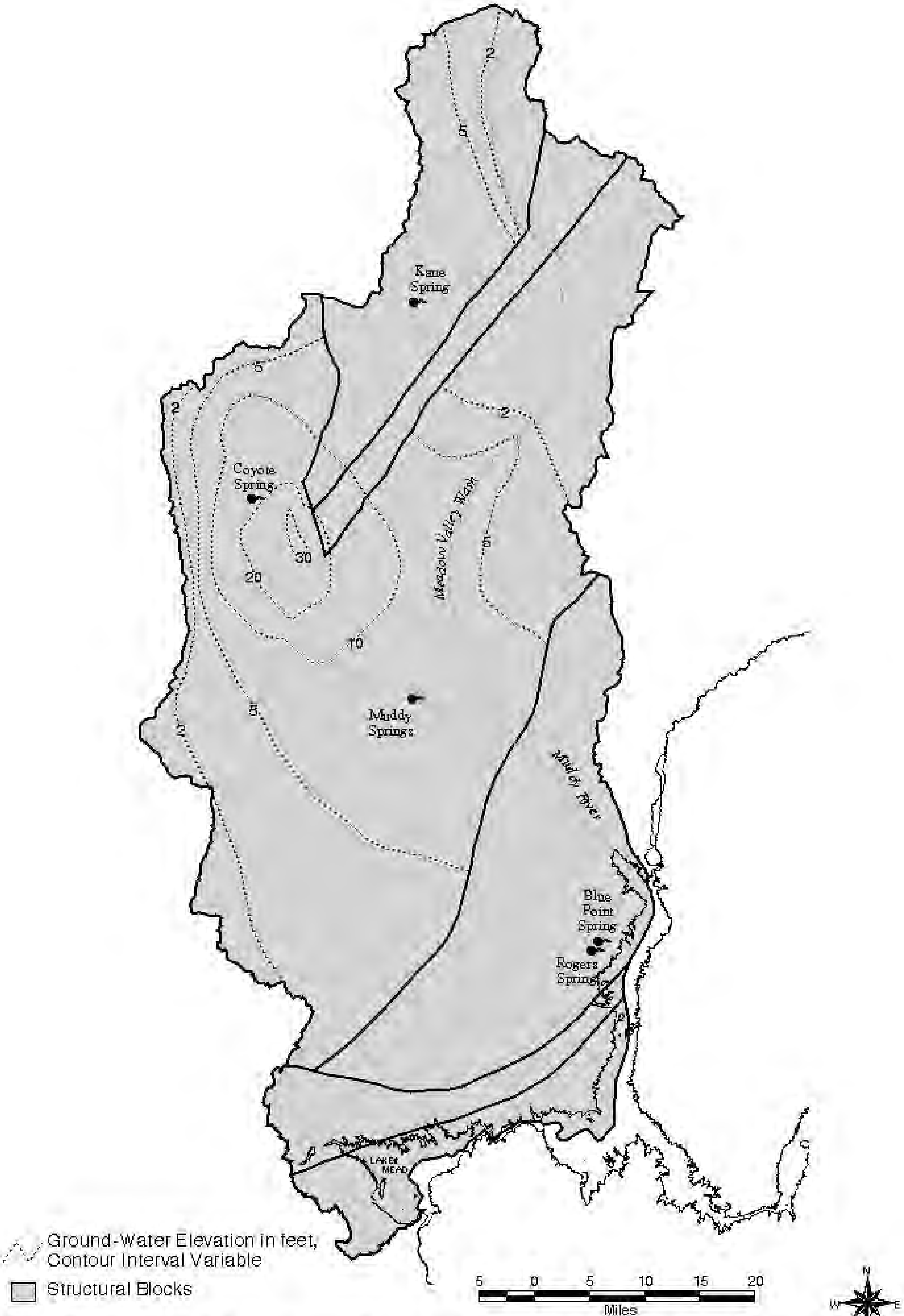

Figure 8-43. Simulated change in ground-water elevation at top of carbonate aquifer for existing permitted rights, 2000-2061.

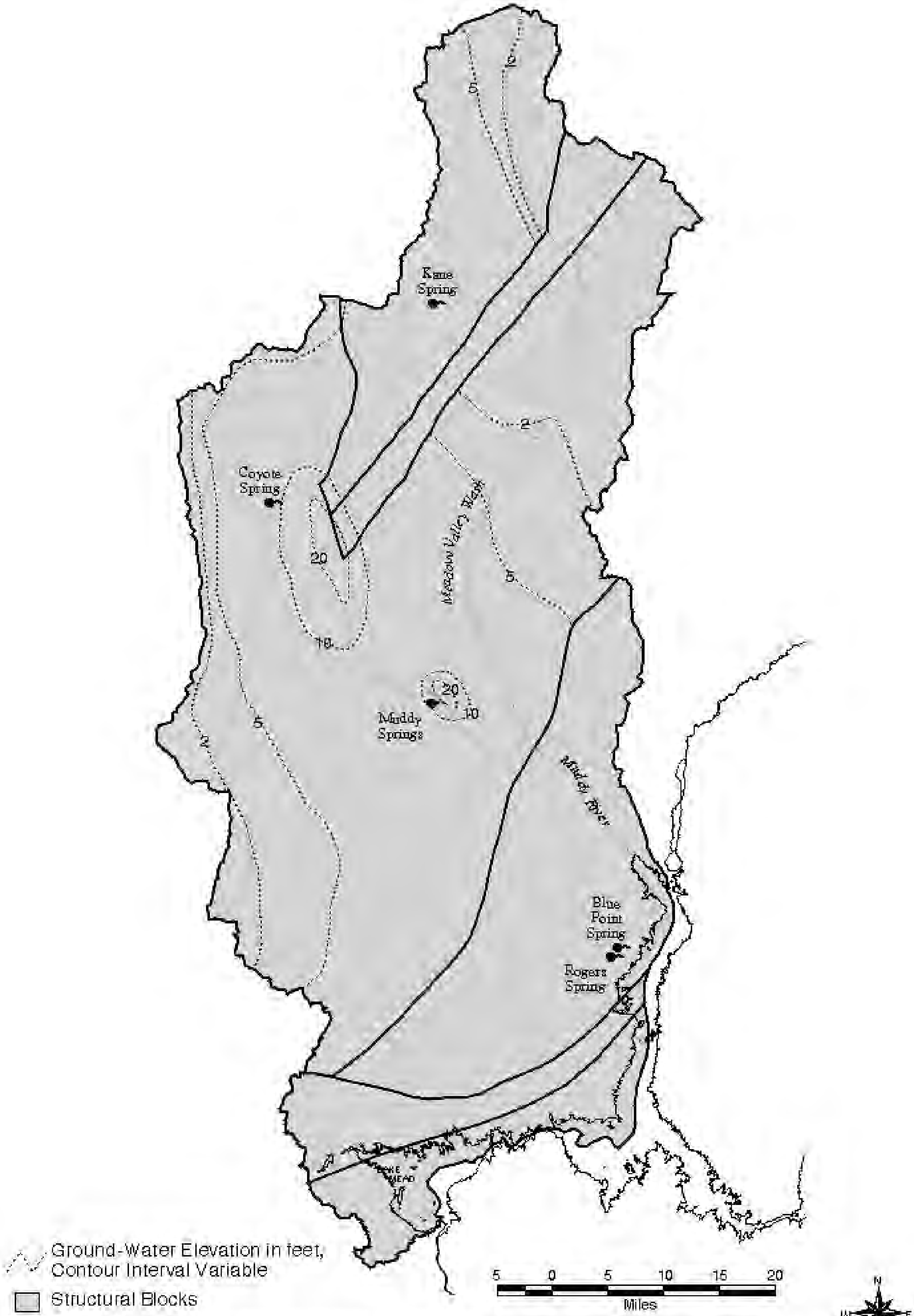

Figure 8-44. Simulated change in ground-water elevation at ground-water table for existing permitted rights, 2000-2061.

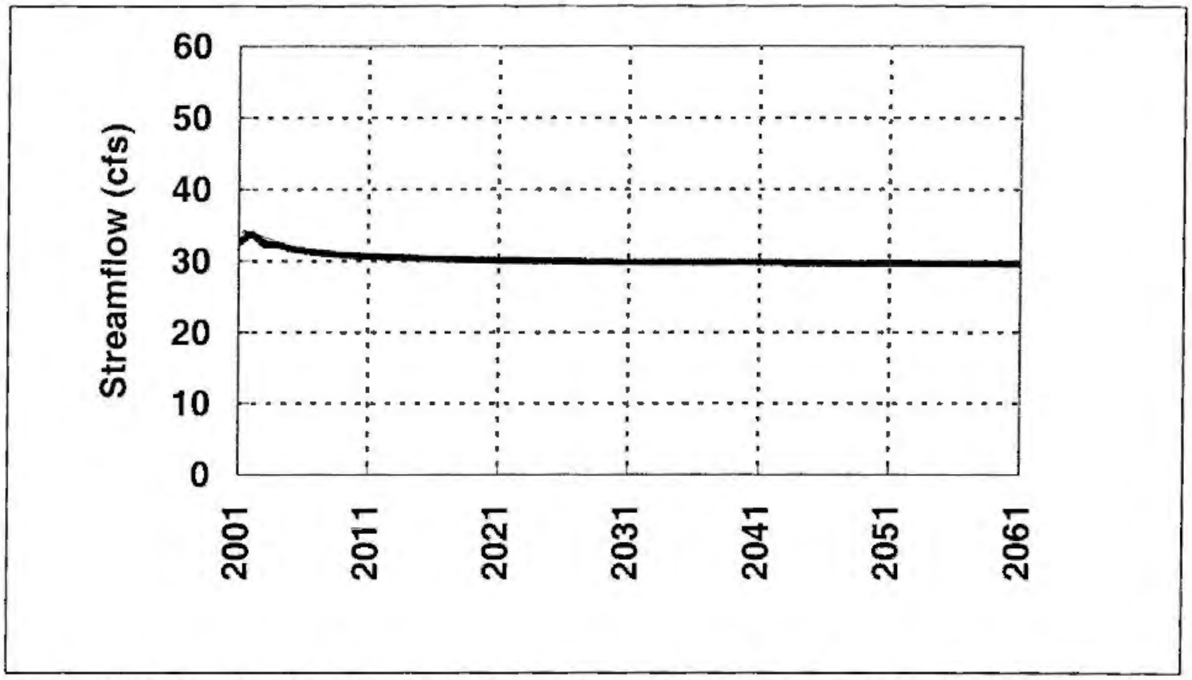

Figure 8-45 Simulated Muddy River Streamflow at Moapa Gage-Existing Permitted Rights.

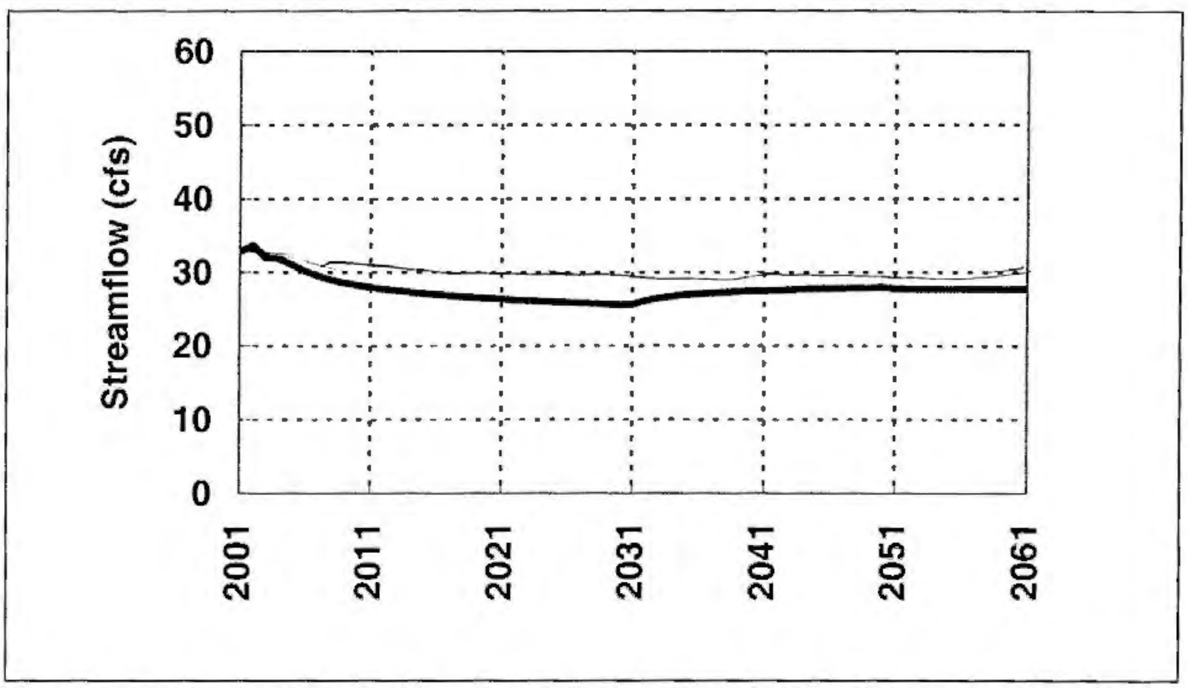

Figure 8-46 Simulated Muddy River Streamflow at Glendale Gage-Existing Permitted Rights.

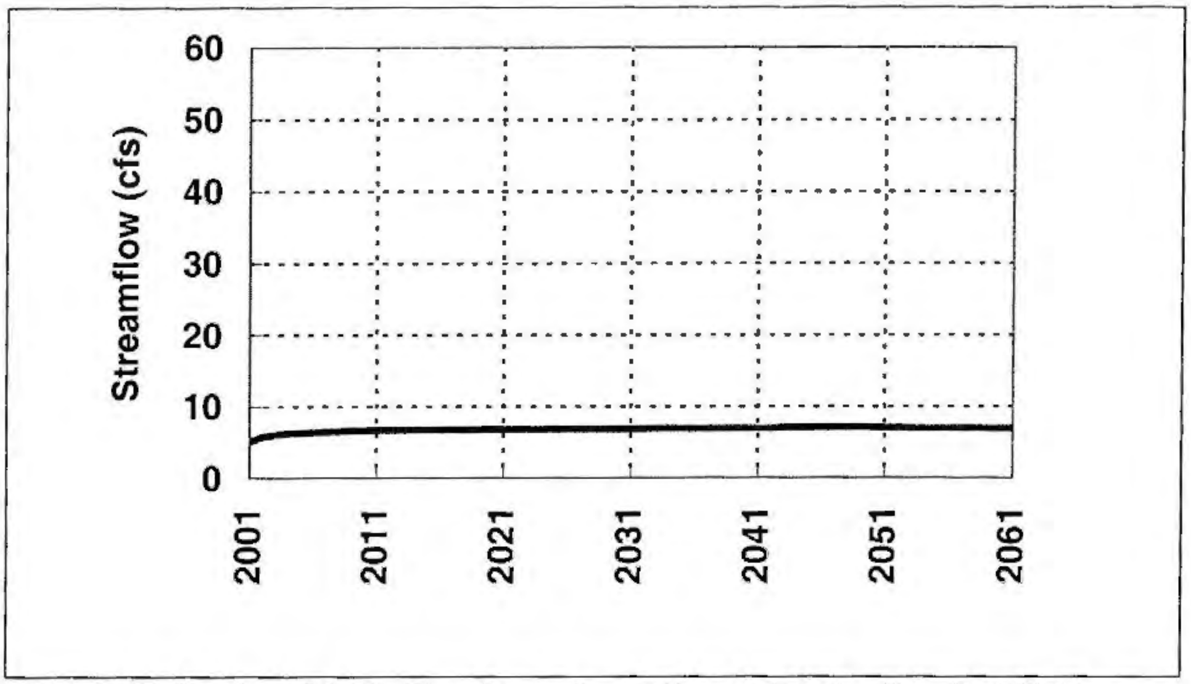

Figure 8-47 Simulated Muddy River Streamflow at Overton-Existing Permitted Rights.

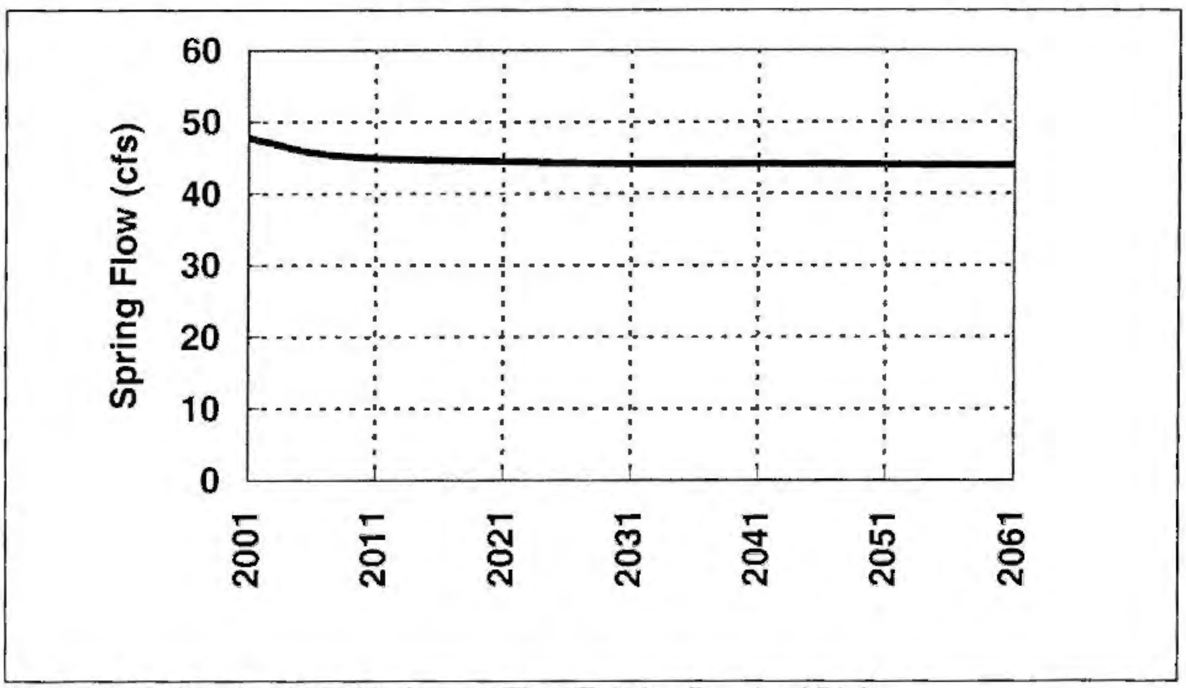

Figure 8-48 Simulated Muddy Springs Flow-Existing Permitted Rights.

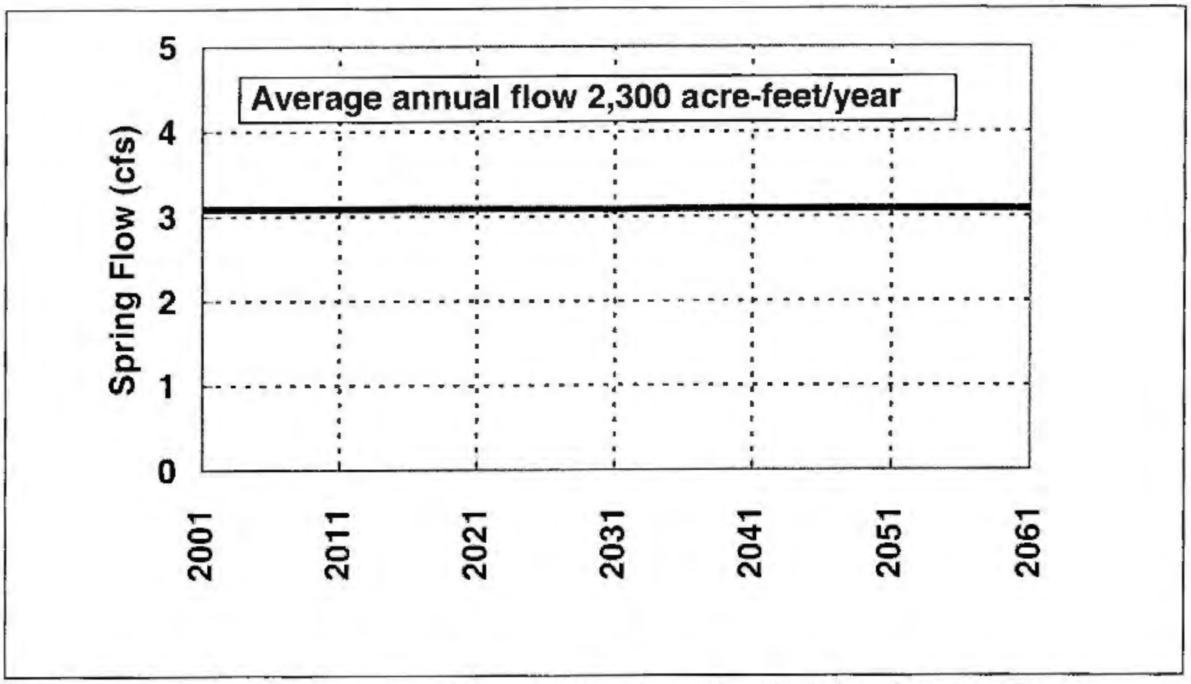

Figure 8-49 Simulated Rogers and Blue Point Springs Flow-Existing Permitted Rights. (represents North Shore Spring Complex).

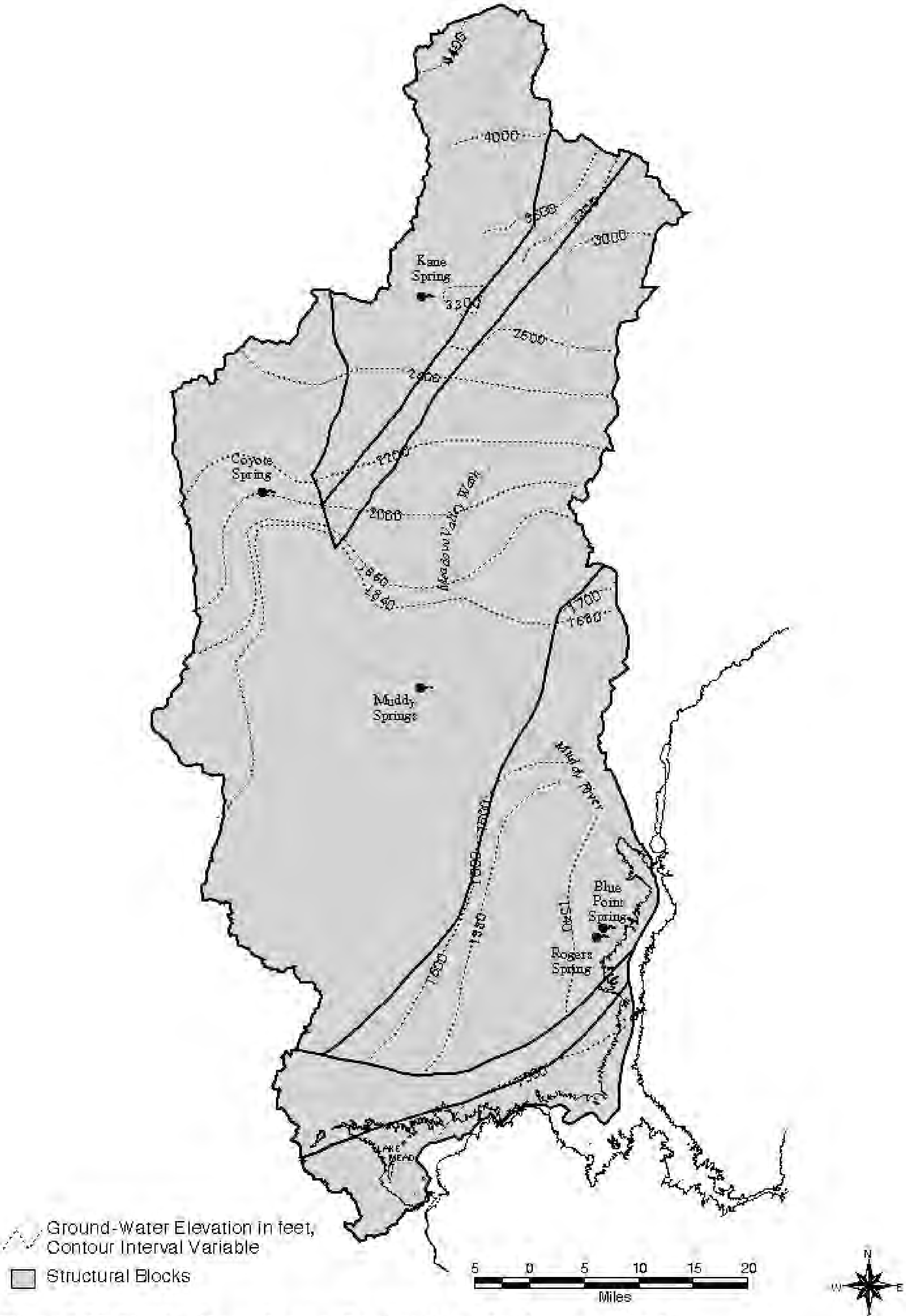

Figure 8-50. Simulated ground-water elevation at top of carbonate aquifer for LVVWD applications, 2061.

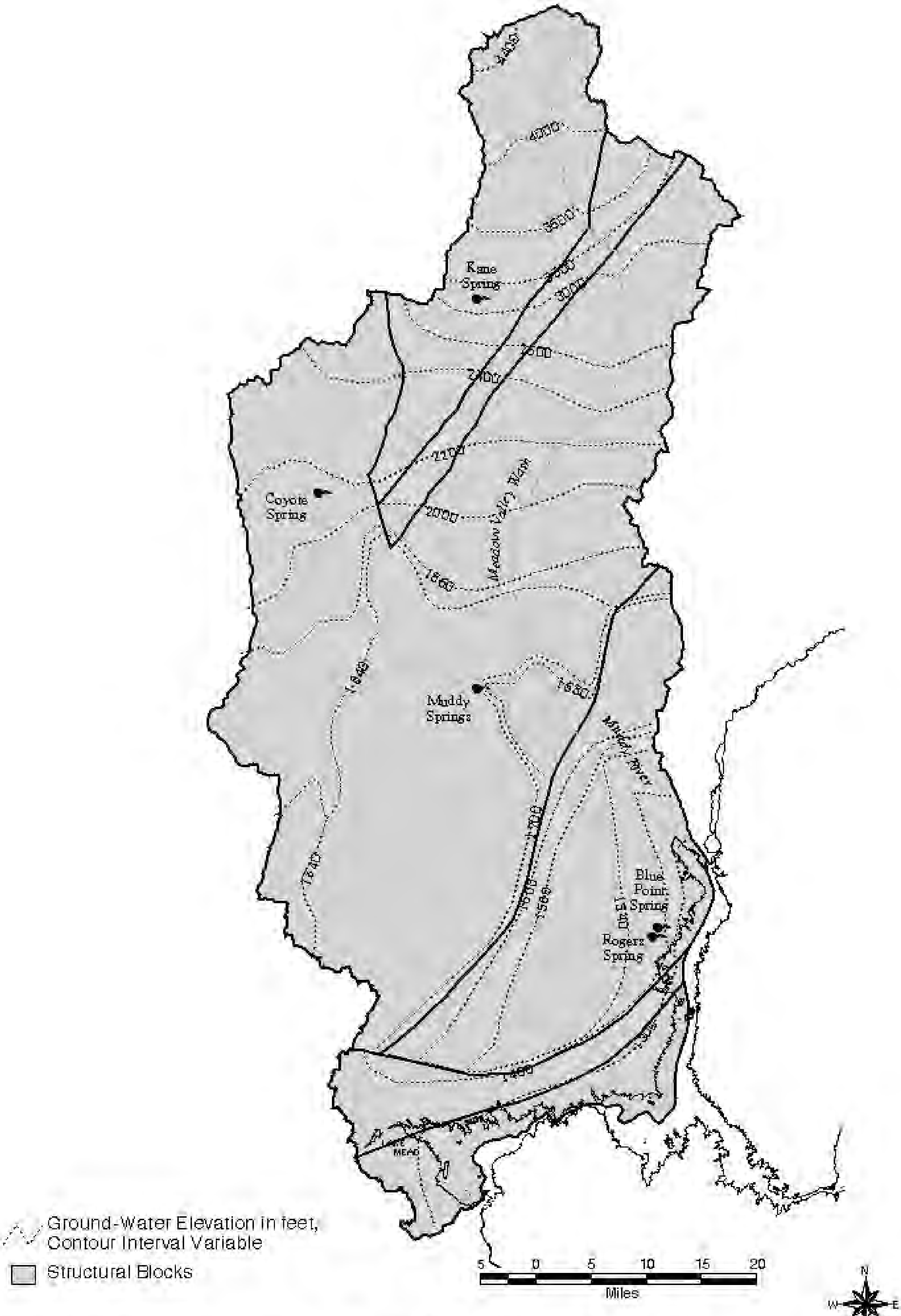

Figure 8-51. Simulated ground-water elevation for LVVWD applications, 2061.

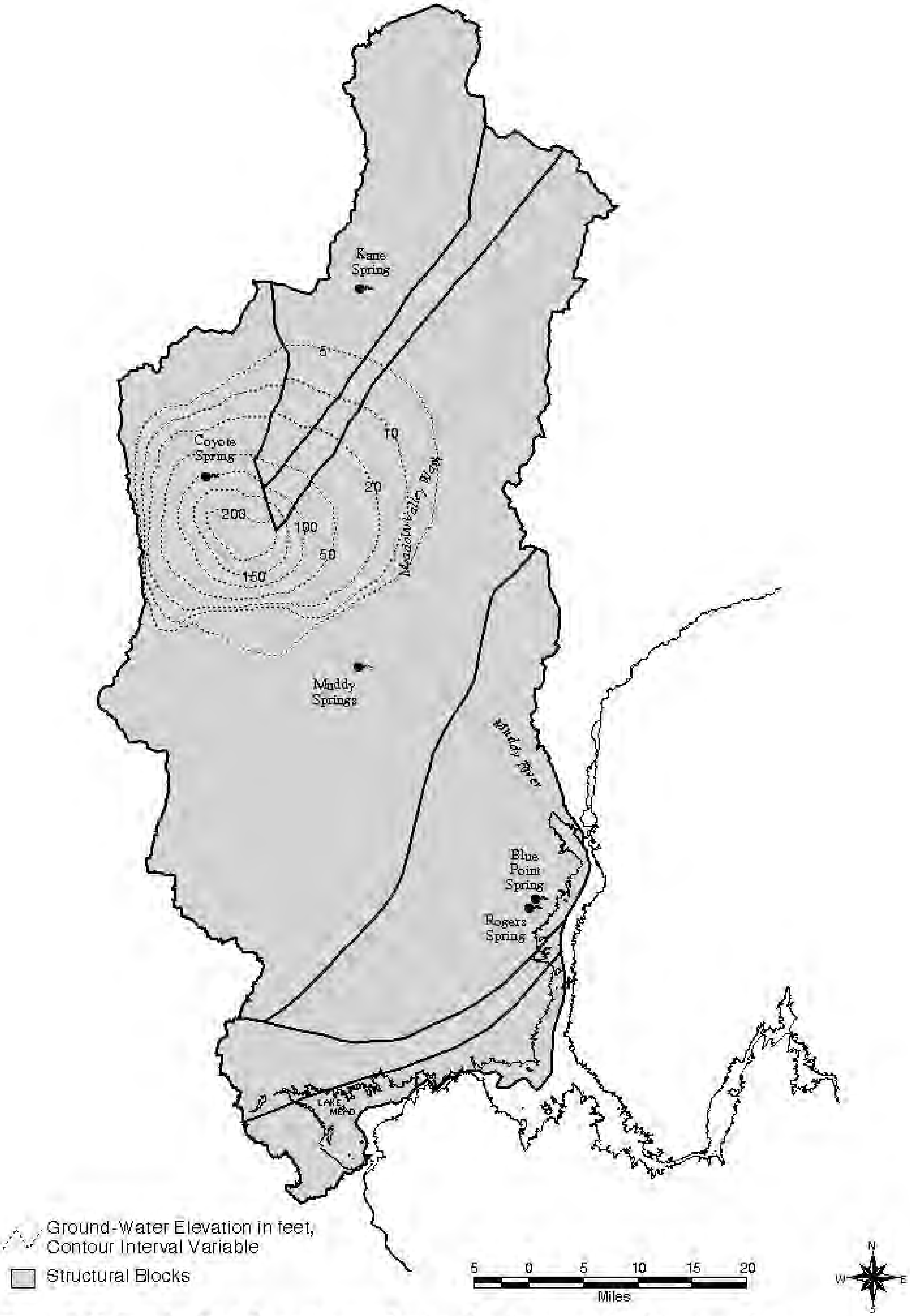

Figure 8-52. Simulated net change in ground-water elevation at top of carbonate aquifer in 2061 between existing permits and LVVWD applications.

elevation at the top of the carbonate aquifer in 2061 between existing permitted rights and LVVWD applications. **Figure 8-53** shows contours of computed change in ground-water elevation at the ground-water table in 2061 between existing permitted rights and LVVWD applications. **Figure 8-54** through **Figure 8-56** show hydrographs of computed streamflow, and **Figure 8-57** and **Figure 8-58** shows hydrographs of computed spring flows. **Table 8-5** lists the components of the ground-water budget for 2061.

As indicated on **Figure 8-54** through **Figure 8-58**, spring flows and streamflows in the simulation show a slight decline as a result of LVVWD applications compared to existing permitted rights. The Muddy Springs discharge shows a decrease from 44 to 41 cfs, but the Rogers Spring and Blue Point Springs discharges remain unchanged. Corresponding to the decrease at Muddy Springs, the Muddy River has a net decline in streamflow at the Moapa gage of approximately 2.5 cfs. The Muddy River streamflow near Glendale declines by approximately 3 cfs, and the decline of Muddy River streamflow at Overton is negligible (<0.1 cfs).

As indicated on **Figure 8-52** and **Figure 8-53**, ground-water levels in the simulation show a decline as a result of LVVWD applications compared to existing permitted rights. Within Coyote Spring Valley, the net water-level decline at the top of the carbonate aquifer is approximately 5 ft in 2061. At Muddy Springs, the net water-level decline at the top of the carbonate aquifer is approximately 2 ft. At the western boundary of the modeled area, the net water-level decline is 1 ft in 2061. At the eastern boundary of the modeled area, the net water-level decline is 2 ft.

As indicated in **Table 8-5**, water-level declines at the model boundaries induce ground-water inflow to the modeled area. The boundary inflow in year 2061 is approximately 41,000 afy.

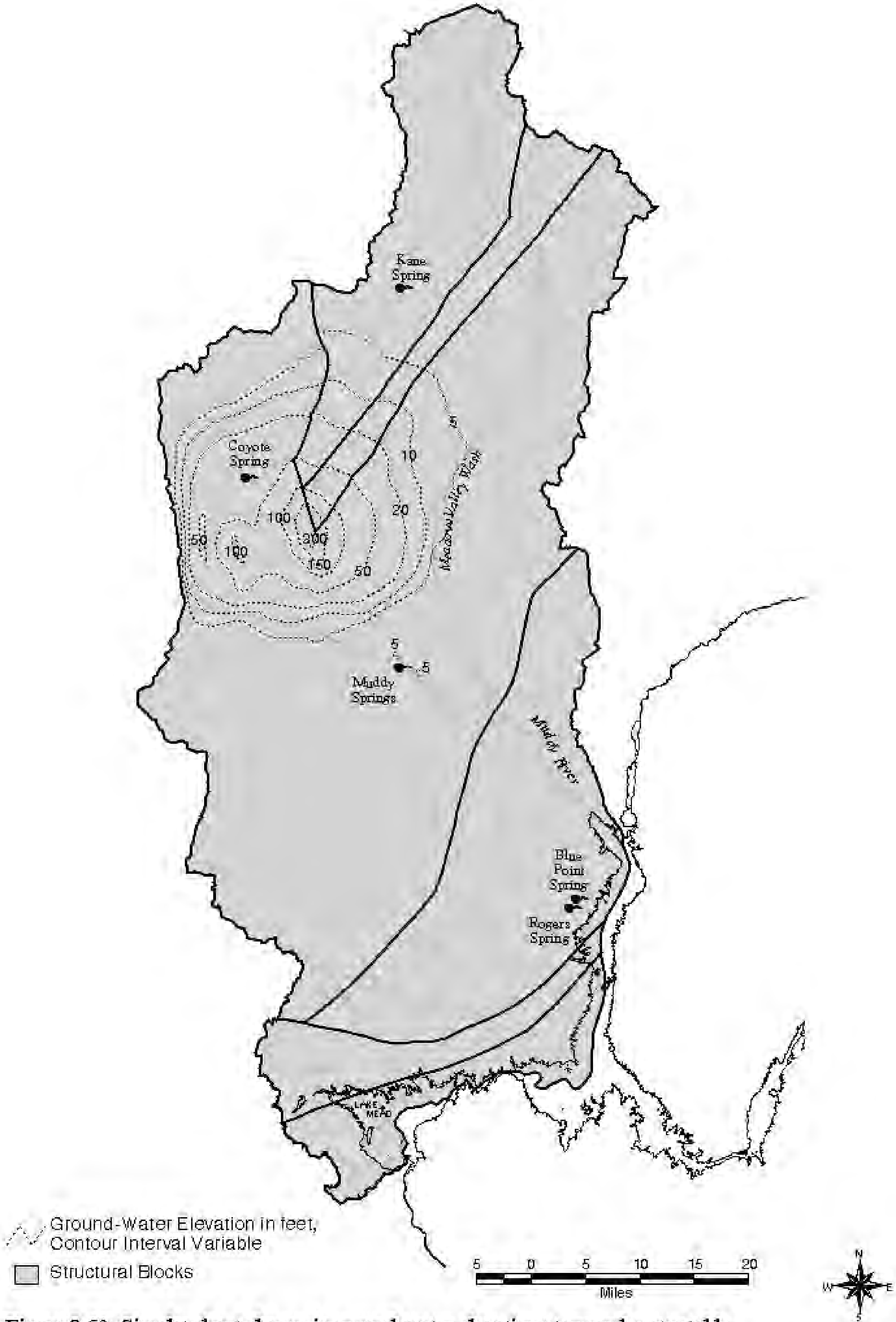

Figure 8-53. Simulated net change in ground-water elevation at ground-water table in 2061 between existing permits and LVVWD applications.

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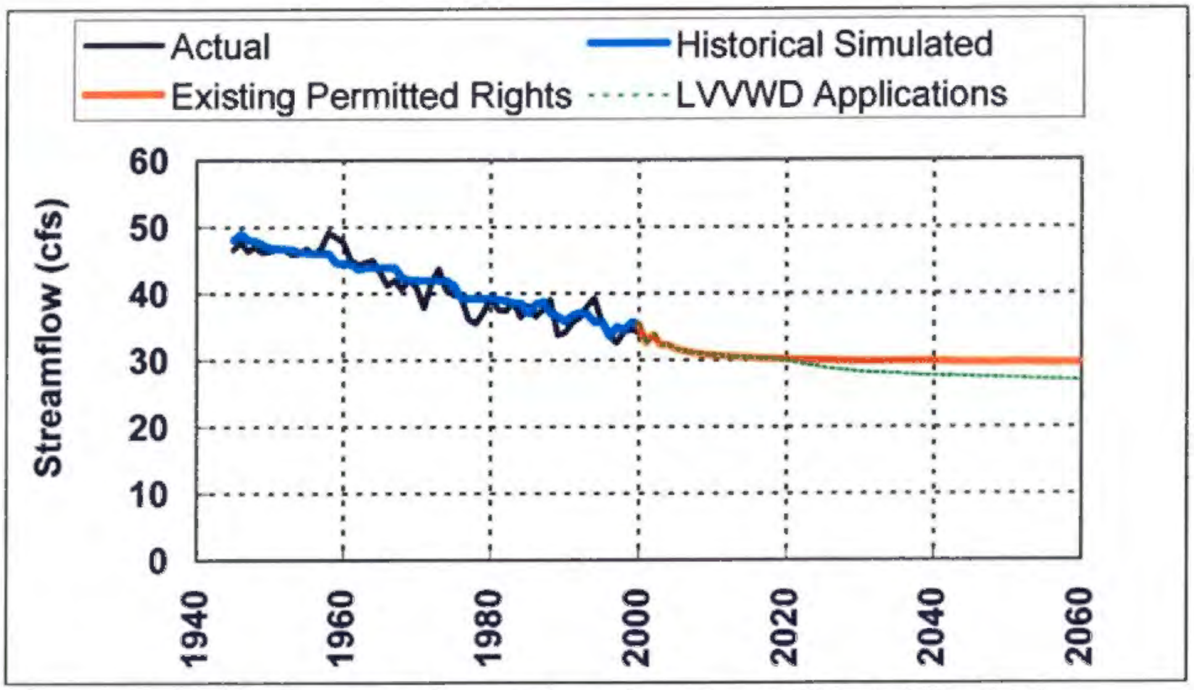

Figure 8-54 Muddy River Streamflow at Moapa Gage-Actual, Historical Simulated, Existing Permitted Rights, and LVVWD Applications.

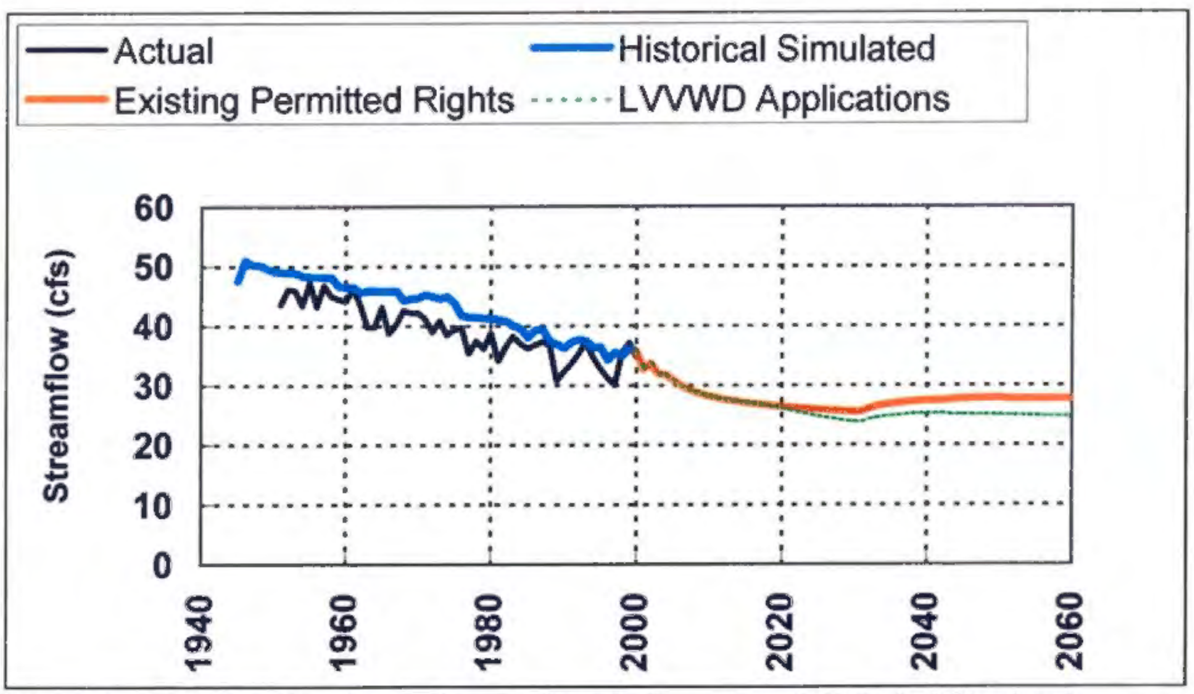

Figure 8-55 Muddy River Streamflow at Glendale Gage-Actual, Historical Simulated, Existing Permitted Rights, and LVVWD Applications.

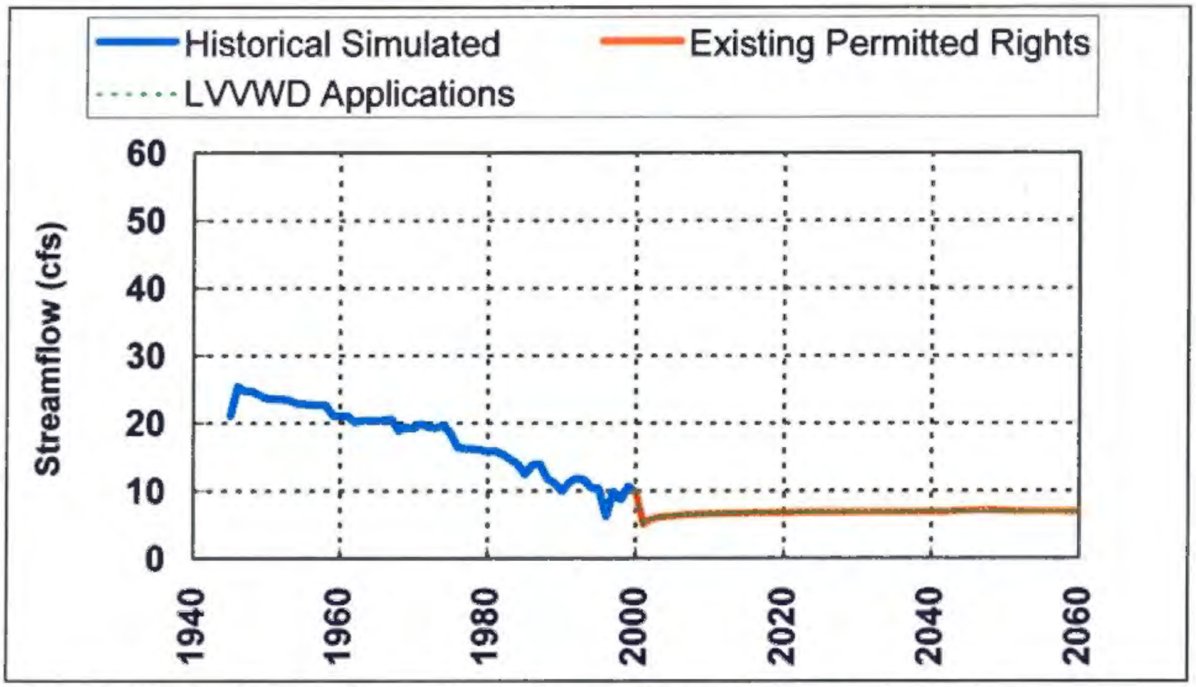

Figure 8-56 Muddy River Streamflow at Overton-Historical Simulated, Existing Permitted Rights, and LVVWD Applications.

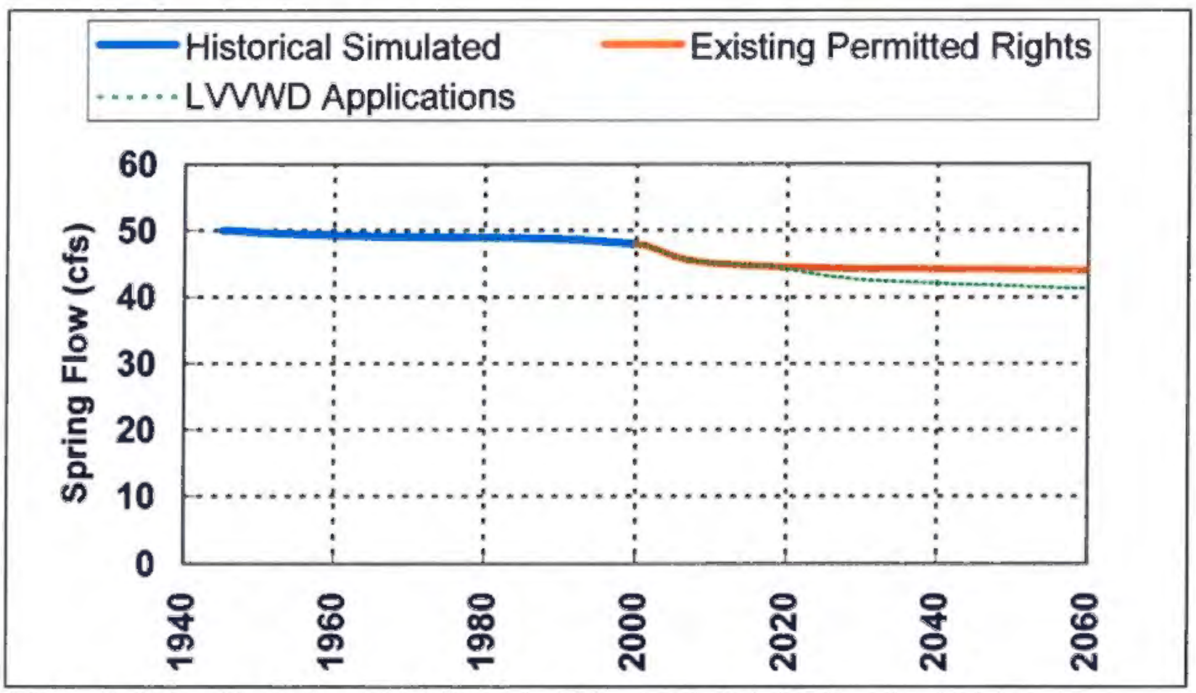

Figure 8-57 Muddy Springs Flow-Historical Simulated, Existing Permitted Rights, and LVVWD Applications.

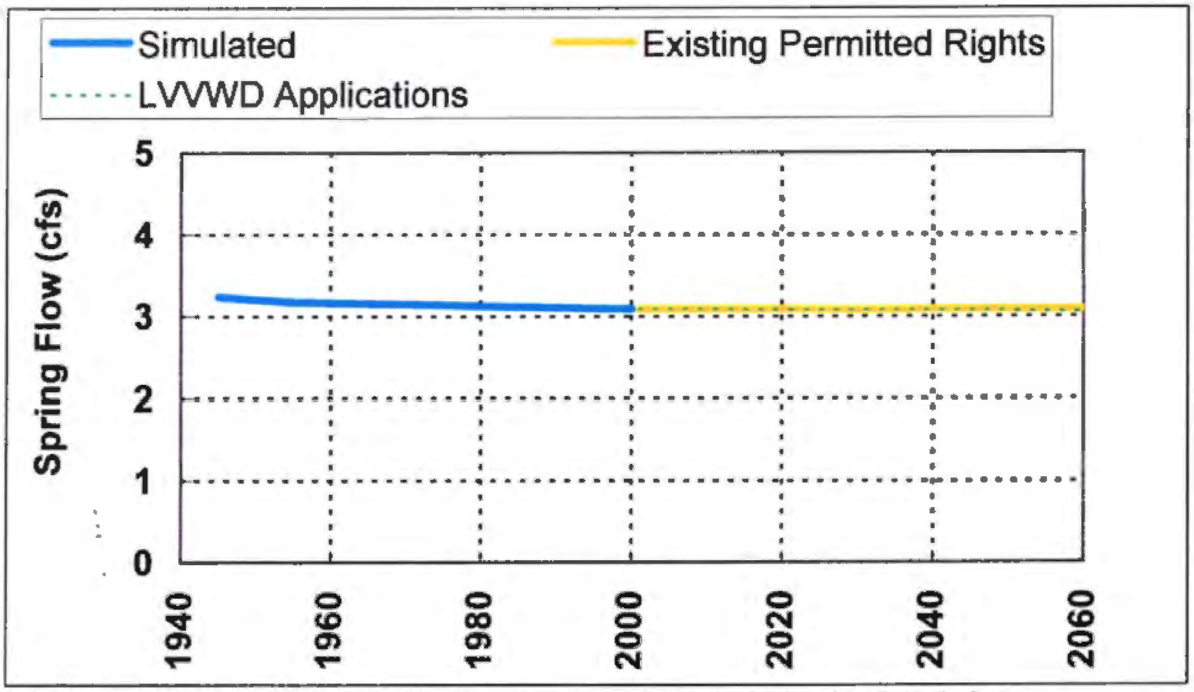

Figure 8-58 Rogers and Blue Point Springs Flow-Historical Simulated, Existing Permitted Rights and LVVWD Applications.

9 MONITORING

Timely and sound judgements regarding the effects and benefits of development of the regional carbonate aquifer can only be made through the use of monitoring combined with coordinated development. Extensive monitoring in the Muddy Springs Area and surrounding valleys is currently being conducted by NPC, MVWD, SNWA, and CSI. All these organizations have monitoring plans in place that require annual summaries to be submitted to the Nevada State Engineer for review. Monitoring is also being conducted by NDWR, USFS, USFWS, NPA, and the Moapa Band of Paiute Indians (MBPI). The parameters being monitored are ground-water levels, spring and streamflow discharges, and quantities of surface and ground-water diversions. **Table 9-1** outlines the number of wells and springs being monitored by each of these entities. This monitoring establishes a mechanism for all parties to better understand the complex aquifer system and protect vital water resources.

Ground-water development naturally occurs in stages due to capital investment of infrastructure and population growth. Development of existing and potential ground-water rights by LVVWD and SNWA will also occur in phases, with concurrent monitoring, modeling, and hydrogeologic investigations. However, the timing and quantities/volumes of these pumping stages will be variable, because future population growth and resulting water demand in the Las Vegas region and the I-15 corridor are not known at this time.

With so little actually known about causal relationships between pumping stresses, water level fluctuations, and spring discharge in the model area, monitoring is key to development of the carbonate aquifer system. LVVWD and SNWA as public agencies are committed to protecting the public interest and vital water resources in the model area.

Table 9-1. Summary of current ground-water and surface-water monitoring sites and data collected.

Area and Agency	Ground-Water Levels		Stream Flow	Diversion Amounts		
	Valley Fill	Carbonate	Spring/River	Springs	River	Wells
Upper Moapa Valley / Arrow Canyon						
NDWR (monthly)	6		5		2	12
NPC (continuous)	5	2			2	11
NPC (monthly)	6	1				
NPC (quarterly)			8			
MVWD (continuous)		2	4	2		2
USFWS (misc.)			5			
USGS (2 per year)			8			
USGS (continuous)[1]		1	4			
Black Mountains Area, California Wash, Garnet and Hidden Valleys						
MBPI (continuous)		6				
NPC (quarterly)		1				
NPS (monthly)		1?	1			
SNWA (quarterly)	2					
USGS (quarterly)	1					
Coyote Spring Valley						
SNWA (quarterly)	4	3				
USGS (continuous)		1				
USGS (quarterly)	4	3				
Lower Meadow Valley Wash / Lower Moapa Valley						
NDWR (monthly)						6
NPC (quarterly)	10					
USGS (continuous)			1			
Mesa/Weiser Wash						
NPC (quarterly)	2	2				

[1] *SNWA funds 50% of three of the USGS continuous gaging stations.*

<u>SOURCES:</u>

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Site reconnaissance conducted 4/30/01; SNWA, USGS, TNC

10 SUMMARY AND CONCLUSIONS

To support ground-water applications 54055 through 54059 (inclusive) filed by LVVWD for an annual duty of 27,512 af in Coyote Spring Valley an extensive hydrogeologic investigation was completed for the Colorado River Basin Province in Nevada, which includes all of the White River and Meadow Valley Flow Systems. Both of these systems are in hydrogeologic continuity with each other and are tributary to the Muddy River.

The water-resources budget for the model area, including Coyote Spring Valley where the applications are located, shows 117, 000 afy of inflow. The upper valleys in the White River and Meadow Valley Flow Systems contribute 44,000 afy and 36,000 afy respectively plus local recharge of 37,000 afy. This recharge is minor compared to the vast amount of water in storage in the alluvial and carbonate rock aquifers.

The analysis shows there is about 324,000 afy of ground-water recharge throughout the entire White River and Meadow Valley Flow Systems. This is slightly more than two times the amount estimated by previous investigators. Ground-water discharge through evapotranspiration is also much greater than previously estimated. Ground-water outflow from the two flow systems (the difference between recharge and discharge) is estimated at about 50,000 afy of which 10,000 to 20,000 afy is surface water in the Muddy River that actually flows into Lake Mead.

Previous studies demonstrate there is a wide range of values in the hydrologic components used to estimate natural recharge and discharge. There is also uncertainty in aquifer properties of the regional carbonate aquifer, and conceptual flow paths of this complex system are only vaguely known. These uncertainties are compounded by the lack of data over much of the area and when combined with natural variation in the hydrologic system make a definitive interpretation of the affects of ground-water development extremely difficult. Nevertheless, this study draws on all previous investigations and using the most recent data and interpretations refines estimates of the hydrogeology of the carbonate aquifer. With a better understanding of the surface- and ground-water hydrology, geology, and geochemistry a ground-water flow model was developed for the lower part of the White River and Meadow Valley Flow Systems to assess the potential affects of ground-water development of the carbonate aquifer in Coyote Spring Valley.

The model was calibrated (for the years 1945 to 2000) to measured water levels in the carbonate aquifer, spring flow of Muddy, Rogers, and Blue Point Springs, and flow in the Muddy River and Meadow Valley Wash. The calibrated model showed predicted water levels were within a few feet of observed levels and spring and river flows were matched within three percent.

During the transient simulations the model simulated a 2 cfs decline in the Muddy Springs from 1945 to 2000. However, water level and gage data collected over nearly the last 20 years does not support this simulated 2 cfs decline which means the model is conservative, slightly over predicting impacts to the ground-water system.

The most sensitive model parameter observed in model development is the value of specific storage. The range of plausible values, based on those found in the literature, vary from 1×10^{-5} to 1×10^{-7}. A value of 1×10^{-6} produced the best model calibration, and all the simulations were run with this value.

The calibrated model evaluated impacts to the ground-water system for a 61-year period. Existing ground-water pumpage of 18,000 afy is simulated in the model area plus additional permitted rights of 16,100 afy in Coyote Spring Valley, and another additional permitted 10,000 afy scattered throughout the model area for a total of 44,000 afy. Of this total 5,000 afy is utilized for a proposed power plant that is anticipated to decrease its use in 2031.

Future impacts due to the LVVWD applications in Coyote Springs Valley for the same time period has all of the permitted water pumped, 44,000 afy, plus ground-water applications filed by LVVWD in the amount of 27,512 afy for a total of about 72,000 afy. All of the pumpage for the LVVWD applications is on line in the first 20 years. The model predicts that the additional pumpage of the applications after 61 years results in: 1) A net water level decline of about 5 ft in Coyote Spring Valley, and 2) an additional 2 ft decline in water levels in the carbonate aquifer in the Muddy Springs area, which causes a decline in spring flow of about 2.5 cfs. This decrease in flow results in a similar decrease in the flow of the Muddy River. Rogers and Blue Point Springs remain unchanged.

Are these values realistic? If the hydrogeology is exactly as we have estimated the answer is yes, however, we know there is great variability in the hydrologic processes that control the movement of ground water and the associated recharge and discharge. These uncertainties suggest a staged approach to ground-water development of these applications that optimizes well locations based on ground-water exploration and aquifer testing. This program, coupled with a monitoring and mitigation plan, will provide insurance against undesirable impacts to the ground-water system.

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APPENDIX A

Appendix A, Part 1. Summary output of Altitude-Precipitation regressions using Excel software.

The four local altitude-precipitation relationships were created using the regression tool in the Excel software. Both altitude and precipitation were reported in feet. The independent variable was altitude and the dependent variable was precipitation.

Appendix A, Part 1, Table A-1. Summary of "General" altitude-precipitation relationship regression.

Regression Statistics	
Multiple R	0.886584
R Square	0.786031
Adjusted R Square	0.779345
Standard Error	0.208043
Observations	34

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.084172	0.097407	0.86	0.393946
X Variable 1	0.000153	1.41E-05	10.84	3.02E-12
(P) Precipitation in feet = 0.000153 (A) Altitude in feet + 0.084				

Appendix A, Part 1, Table A-2. Summary of "Dry" (Group 1) altitude-precipitation relationship regression.

Regression Statistics	
Multiple R	0.963492
R Square	0.928317
Adjusted R Square	0.923837
Standard Error	0.088485
Observations	18

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.042803	0.061857	0.691977	0.4988714
X Variable 1	0.000137	9.49E-06	14.3946	1.415E-10
(P) Precipitation in feet = 0.000137 (A) Altitude in feet + 0.0428				

Appendix A, Part 1, Table A-3. Summary of "Wet" (Group 2) altitude-precipitation relationship regression.

Regression Statistics	
Multiple R	0.929723
R Square	0.864386
Adjusted R Square	0.854699
Standard Error	0.181604
Observations	16

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.250518	0.117663	2.129106	0.0514792
X Variable 1	0.000152	1.61E-05	9.446368	1.883E-07
(P) Precipitation in feet = 0.000152 (A) Altitude in feet + 0.2505				

Appendix A, Part 1, Table A-4. Summary of "WRV" altitude-precipitation relationship regression.

Regression Statistics	
Multiple R	0.981701
R Square	0.963736
Adjusted R Square	0.957692
Standard Error	0.07347
Observations	8

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-0.08728	0.093259	-0.93593	0.3854332
X Variable 1	0.000176	1.39E-05	12.62755	1.511E-05
(P) Precipitation in feet = 0.000176 (A) Altitude in feet - 0.087				

APPENDIX A

Appendix A, Part 2. Estimation of precipitation and natural recharge in the study area, by valley.

Altitude Interval	Local A-P[1] Relationship	Assumed Precipitation Rate[2]		Assumed Recharge Efficiency[3]	Area	Precipitation Totals	Natural Recharge Totals
Feet		inches	feet		acres	acre-feet	acre-feet
Long Valley							
6000-7000	WRV	12.7	1.06	0.0582	315,501	333,396	19,401
7000-8000	WRV	14.8	1.23	0.0889	93,202	114,892	10,213
8000-9000	WRV	16.9	1.41	0.1283	8,217	11,576	1,485
9000-10000	WRV	19.0	1.58	0.1774	46	73	13
Long Valley Total					**416,966**	**459,937**	**31,112**
Jakes Valley							
6000-7000	WRV	12.7	1.06	0.0582	147,842	156,227	9,091
7000-8000	WRV	14.8	1.23	0.0889	102,496	126,349	11,231
8000-9000	WRV	16.9	1.41	0.1283	20,673	29,123	3,737
9000-10000	WRV	19.0	1.58	0.1774	482	763	135
Jakes Valley Total					**271,493**	**312,462**	**24,194**
White River Valley							
5000-6000	WRV	10.6	0.88	0.0353	503,848	443,749	15,646
6000-7000	WRV	12.7	1.06	0.0582	325,682	344,155	20,027
7000-8000	WRV	14.8	1.23	0.0889	127,081	156,656	13,925
8000-9000	WRV	16.9	1.41	0.1283	46,897	66,064	8,476
9000-10000	WRV	19.0	1.58	0.1774	11,473	18,182	3,225
10000-11000	WRV	21.1	1.76	0.2500	1,839	3,237	809
11000-12000	WRV	23.2	1.94	0.2500	52	100	25
White River Valley Total					**1,016,871**	**1,032,143**	**62,133**
Garden Valley							
5000-6000	WRV	10.6	0.88	0.0353	177,408	156,247	5,509
6000-7000	WRV	12.7	1.06	0.0582	81,729	86,365	5,026
7000-8000	WRV	14.8	1.23	0.0889	37,964	46,799	4,160
8000-9000	WRV	16.9	1.41	0.1283	15,336	21,604	2,772
9000-10000	WRV	19.0	1.58	0.1774	4,949	7,842	1,391
10000-11000	WRV	21.1	1.76	0.2500	649	1,142	286
11000-12000	WRV	23.2	1.94	0.2500	21	40	10
Garden Valley Total					**318,055**	**320,039**	**19,153**
Coal Valley							
4000-5000	DRY	7.9	0.66	0.0159	50,893	33,553	534
5000-6000	DRY	9.6	0.80	0.0267	170,066	135,423	3,619
6000-7000	DRY	11.2	0.93	0.0414	62,580	58,406	2,415
7000-8000	DRY	12.8	1.07	0.0603	5,990	6,411	386
8000-9000	DRY	14.5	1.21	0.0839	469	567	48
Coal Valley Total					**289,998**	**234,361**	**7,002**
Cave Valley							
5000-6000	WRV	10.6	0.88	0.0353	25,855	22,771	803
6000-7000	WRV	12.7	1.06	0.0582	114,001	120,467	7,010
7000-8000	WRV	14.8	1.23	0.0889	69,058	85,129	7,567

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Altitude Interval	Local A-P[1] Relationship	Assumed Precipitation Rate[2]		Assumed Recharge Efficiency[3]	Area	Precipitation Totals	Natural Recharge Totals
8000-9000	WRV	16.9	1.41	0.1283	17,409	24,524	3,147
9000-10000	WRV	19.0	1.58	0.1774	2,782	4,408	782
10000-11000	WRV	21.1	1.76	0.2500	650	1,145	286
Cave Valley Total					**229,755**	**258,445**	**19,595**
			Pahroc Valley				
4000-5000	DRY	7.9	0.66	0.0159	61,728	40,697	647
5000-6000	DRY	9.6	0.80	0.0267	201,272	160,273	4,283
6000-7000	DRY	11.2	0.93	0.0414	54,632	50,988	2,109
7000-8000	DRY	12.8	1.07	0.0603	7,338	7,854	473
8000-9000	DRY	14.5	1.21	0.0839	319	385	32
Pahroc Valley Total					**325,289**	**260,197**	**7,545**
			Dry Lake Valley				
4000-5000	DRY	7.9	0.66	0.0159	169,220	111,567	1,774
5000-6000	DRY	9.6	0.80	0.0267	275,992	219,772	5,874
6000-7000	DRY	11.2	0.93	0.0414	110,168	102,820	4,252
7000-8000	DRY	12.8	1.07	0.0603	15,753	16,861	1,016
8000-9000	DRY	14.5	1.21	0.0839	3,182	3,841	322
9000-10000	DRY	16.1	1.34	0.1128	102	137	15
Dry Lake Valley Total					**574,417**	**454,998**	**13,254**
			Delamar Valley				
4000-5000	DRY	7.9	0.66	0.0159	102,703	67,712	1,077
5000-6000	DRY	9.6	0.80	0.0267	90,604	72,148	1,928
6000-7000	DRY	11.2	0.93	0.0414	33,844	31,587	1,306
7000-8000	DRY	12.8	1.07	0.0603	4,431	4,742	286
Delamar Valley Total					**231,582**	**176,189**	**4,597**
			Pahranagat Valley				
3000-4000	DRY	6.3	0.52	0.0084	100,414	52,446	440
4000-5000	DRY	7.9	0.66	0.0159	231,352	152,530	2,426
5000-6000	DRY	9.6	0.80	0.0267	121,039	96,383	2,576
6000-7000	DRY	11.2	0.93	0.0414	35,356	32,998	1,365
7000-8000	DRY	12.8	1.07	0.0603	8,838	9,459	570
8000-9000	DRY	14.5	1.21	0.0839	313	378	32
Pahranagat Valley Total					**497,312**	**344,195**	**7,407**
			Kane Springs Valley				
2000-3000	WET	7.6	0.63	0.0141	1,688	1,064	15
3000-4000	WET	9.4	0.78	0.0255	61,164	47,861	1,219
4000-5000	WET	11.2	0.93	0.0415	44,562	41,643	1,728
5000-6000	WET	13.0	1.09	0.0628	25,539	27,749	1,743
6000-7000	WET	14.9	1.24	0.0900	15,783	19,547	1,760
7000-8000	WET	16.7	1.39	0.1238	1,694	2,355	292
Kane Springs Valley Total					**150,429**	**140,218**	**6,757**
			Coyote Spring Valley				
2000-3000	DRY	4.6	0.39	0.0036	132,184	50,931	185
3000-4000	DRY	6.3	0.52	0.0084	109,142	57,005	478
4000-5000	DRY	7.9	0.66	0.0159	67,259	44,344	705

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Altitude Interval	Local A-P[1] Relationship	Assumed Precipitation Rate[2]		Assumed Recharge Efficiency[3]	Area	Precipitation Totals	Natural Recharge Totals
5000-6000	DRY	9.6	0.80	0.0267	51,624	41,108	1,099
6000-7000	DRY	11.2	0.93	0.0414	21,806	20,352	842
7000-8000	DRY	12.8	1.07	0.0603	7,908	8,464	510
8000-9000	DRY	14.5	1.21	0.0839	1,512	1,826	153
9000-10000	DRY	16.1	1.34	0.1128	186	249	28
Coyote Spring Valley Total					**391,621**	**224,278**	**4,000**
Muddy River Springs Area							
1000-2000	DRY	3.0	0.25	0.0011	13,427	3,334	4
2000-3000	DRY	4.6	0.39	0.0036	52,932	20,395	74
3000-4000	DRY	6.3	0.52	0.0084	19,294	10,077	84
4000-5000	DRY	7.9	0.66	0.0159	6,648	4,383	70
5000-6000	DRY	9.6	0.80	0.0267	239	190	5
Muddy River Springs Area Total					**92,541**	**38,380**	**237**
Lower Moapa Valley							
1000-2000	WET	5.7	0.48	0.0066	80,864	38,693	255
2000-3000	WET	7.6	0.63	0.0141	80,843	50,972	717
3000-4000	WET	9.4	0.78	0.0255	9,537	7,463	190
4000-5000	WET	11.2	0.93	0.0415	3,761	3,515	146
5000-6000	WET	13.0	1.09	0.0628	599	651	41
6000-7000	WET	14.9	1.24	0.0900	52	64	6
Lower Moapa Valley Total					**175,656**	**101,358**	**1,354**
Hidden Valley							
2000-3000	DRY	4.6	0.39	0.0036	20,275	7,812	28
3000-4000	DRY	6.3	0.52	0.0084	18,405	9,613	81
4000-5000	DRY	7.9	0.66	0.0159	7,162	4,722	75
5000-6000	DRY	9.6	0.80	0.0267	5,758	4,585	123
6000-7000	DRY	11.2	0.93	0.0414	833	777	32
7000-8000	DRY	12.8	1.07	0.0603	3	3	0
Hidden Valley Total					**52,435**	**27,512**	**339**
Garnet Valley							
1000-2000	DRY	3.0	0.25	0.0011	5,778	1,435	2
2000-3000	DRY	4.6	0.39	0.0036	68,111	26,243	95
3000-4000	DRY	6.3	0.52	0.0084	14,053	7,340	62
4000-5000	DRY	7.9	0.66	0.0159	8,228	5,425	86
5000-6000	DRY	9.6	0.80	0.0267	4,383	3,490	93
6000-7000	DRY	11.2	0.93	0.0414	1,412	1,317	54
7000-8000	DRY	12.8	1.07	0.0603	17	18	1
Garnet Valley Total					**101,981**	**45,268**	**393**
California Wash							
1000-2000	DRY	3.0	0.25	0.0011	51,402	12,763	14
2000-3000	DRY	4.6	0.39	0.0036	131,151	50,533	183
3000-4000	DRY	6.3	0.52	0.0084	20,818	10,873	91
4000-5000	DRY	7.9	0.66	0.0159	2,162	1,425	23
5000-6000	DRY	9.6	0.80	0.0267	17	14	0
California Wash Total					**205,550**	**75,608**	**311**

APPENDIX A

Altitude Interval	Local A-P[1] Relationship	Assumed Precipitation Rate[2]		Assumed Recharge Efficiency[3]	Area	Precipitation Totals	Natural Recharge Totals
Lake Valley							
5000-6000	WET	13.0	1.09	0.0628	99,543	108,154	6,794
6000-7000	WET	14.9	1.24	0.0900	186,091	230,473	20,752
7000-8000	WET	16.7	1.39	0.1238	51,929	72,207	8,939
8000-9000	WET	18.5	1.54	0.1647	13,279	20,483	3,373
9000-10000	WET	20.3	1.69	0.2500	2,847	4,824	1,206
10000-11000	WET	22.2	1.85	0.2500	558	1,030	257
Lake Valley Total					**354,246**	**437,170**	**41,320**
Patterson Valley							
4000-5000	GEN	9.3	0.77	0.0246	26	20	1
5000-6000	GEN	11.1	0.93	0.0404	121,199	112,190	4,536
6000-7000	GEN	12.9	1.08	0.0616	117,689	126,948	7,817
7000-8000	GEN	14.8	1.23	0.0887	23,894	29,429	2,610
8000-9000	GEN	16.6	1.38	0.1224	4,444	6,153	753
9000-10000	GEN	18.5	1.54	0.1632	178	274	45
Patterson Valley Total					**267,430**	**275,015**	**15,761**
Spring Valley							
5000-6000	GEN	11.1	0.93	0.0404	5,285	4,893	198
6000-7000	GEN	12.9	1.08	0.0616	101,315	109,286	6,729
7000-8000	GEN	14.8	1.23	0.0887	67,312	82,906	7,352
8000-9000	GEN	16.6	1.38	0.1224	11,013	15,249	1,866
9000-10000	GEN	18.5	1.54	0.1632	20	31	5
Spring Valley Total					**184,945**	**212,364**	**16,151**
Dry Valley							
4000-5000	GEN	9.3	0.77	0.0246	36	28	1
5000-6000	GEN	11.1	0.93	0.0404	39,384	36,457	1,474
6000-7000	GEN	12.9	1.08	0.0616	30,324	32,710	2,014
7000-8000	GEN	14.8	1.23	0.0887	6,128	7,547	669
8000-9000	GEN	16.6	1.38	0.1224	467	647	79
Dry Valley Total					**76,339**	**77,388**	**4,237**
Rose Valley							
5000-6000	GEN	11.1	0.93	0.0404	5,876	5,440	220
6000-7000	GEN	12.9	1.08	0.0616	1,770	1,910	118
Rose Valley Total					**7,647**	**7,349**	**338**
Eagle Valley							
5000-6000	GEN	11.1	0.93	0.0404	8,100	7,498	303
6000-7000	GEN	12.9	1.08	0.0616	20,763	22,397	1,379
7000-8000	GEN	14.8	1.23	0.0887	4,671	5,753	510
8000-9000	GEN	16.6	1.38	0.1224	924	1,280	157
Eagle Valley Total					**34,458**	**36,927**	**2,349**
Clover Valley							
4000-5000	GEN	9.3	0.77	0.0246	12,035	9,299	229
5000-6000	GEN	11.1	0.93	0.0404	149,551	138,435	5,597
6000-7000	GEN	12.9	1.08	0.0616	69,058	74,491	4,587
7000-8000	GEN	14.8	1.23	0.0887	1,320	1,626	144

APPENDIX A

Altitude Interval	Local A-P[1] Relationship	Assumed Precipitation Rate[2]		Assumed Recharge Efficiency[3]	Area	Precipitation Totals	Natural Recharge Totals
Clover Valley Total					**231,964**	**223,852**	**10,557**
			Panaca Valley				
4000-5000	GEN	9.3	0.77	0.0246	51,990	40,171	988
5000-6000	GEN	11.1	0.93	0.0404	120,939	111,950	4,526
6000-7000	GEN	12.9	1.08	0.0616	41,111	44,345	2,731
7000-8000	GEN	14.8	1.23	0.0887	4,893	6,027	534
8000-9000	GEN	16.6	1.38	0.1224	1,419	1,965	240
9000-10000	GEN	18.5	1.54	0.1632	84	129	21
Panaca Valley Total					**220,435**	**204,587**	**9,041**
			Lower Meadow Valley Wash				
1000-2000	WET	5.7	0.48	0.0066	32,791	15,690	103
2000-3000	WET	7.6	0.63	0.0141	111,757	70,462	991
3000-4000	WET	9.4	0.78	0.0255	175,275	137,153	3,493
4000-5000	WET	11.2	0.93	0.0415	124,533	116,376	4,830
5000-6000	WET	13.0	1.09	0.0628	109,876	119,380	7,499
6000-7000	WET	14.9	1.24	0.0900	48,781	60,415	5,440
7000-8000	WET	16.7	1.39	0.1238	2,711	3,769	467
8000-9000	WET	18.5	1.54	0.1647	1	1	0
Lower Meadow Valley Wash Total					**605,723**	**523,247**	**22,823**
			Black Mountains Area				
1000-2000	DRY	3.0	0.25	0.0011	218,605	54,280	59
2000-3000	DRY	4.6	0.39	0.0036	159,897	61,608	224
3000-4000	DRY	6.3	0.52	0.0084	27,183	14,198	119
4000-5000	DRY	7.9	0.66	0.0159	2,975	1,961	31
5000-6000	DRY	9.6	0.80	0.0267	260	207	6
Black Mountains Area Total					**408,919**	**132,254**	**438**
Grand Total					**7,734,059**	**6,635,742**	**332,399**

[1] A-P = Altitude-Precipitation

[2] Precipitation calculated directly from mean altitude of 1,000 foot altitude intervals using one of the four local altitude-precipitation relationships listed in the second column and described in (Section 4.2, Precipitation)

[3] Recharge efficiency coefficient (percentage of precipitation that becomes natural recharge) was calculated from the estimate of precipitation in feet per year for the specific 1,000 foot altitude intervals by using the non-linear mathematical approximation ([$r_e = 0.05 (P)^{2.75}$] Donovan and Katzer, 2000, p. 1142), discussed in Section 4. 4. 2., of the Maxey-Eakin coefficients. Note 0.0100 = 1 percent.

APPENDIX B

B.1 BACKGROUND

Historically, ground-water development within the model boundary has generally been limited to areas located within the flood plains of the Muddy River and Lower Meadow Valley Wash in Lower Moapa Valley, Lower Meadow Valley Wash, and the Muddy River Springs area of the Upper Moapa Valley near the southeast portion of the model area. Ground water has principally been developed to supply water for agriculture in these areas. It has also been developed in the Muddy River Springs area to supply water to the Reid Gardner power-generating facility located in California Wash which is owned and operated by NPC. Pumping well locations in the area are depicted in **Figure B-1.** Until recently, there has been little to no ground-water development in the other basins comprising the remainder of the model area (Black Mountains, California Wash, Garnet Valley, Hidden Valley). However, since 1990, various commercial enterprises have been granted ground-water withdrawal permits within the Black Mountains Area, Garnet Valley, and Hidden Valley of which, only a few have been certified. The remaining sections of this appendix discuss sources of ground-water production data, methods used to compile the development history for each basin within the model boundary, and a summary of the development history and description of how the records were used in the flow model.

B.2 DATA SOURCES AND RECORD COMPILATION

Major sources of ground-water production data and information are DRI, NDWR, USGS, and various reports referenced in this appendix. Information was obtained in the form of published and unpublished documents and data sets. In addition, numerous interviews were conducted with representatives of the MVIC, MVWD, NDWR, and various consultants working within the boundaries of the model area.

Ground-water production data were compiled and transcribed into digital form for analysis and formatting such that they could be used as input into the ground-water flow model. Abstracts from the Water Rights Database administered by NDWR were used to identify permitted/certified ground-water rights. Information garnered from this process was used to construct possible ground-water production histories in areas where reported data are scarce. Much of the data for the Muddy Springs area was compiled from monitoring reports submitted to the Nevada State Engineer on behalf of MVWD and NPC. Ground-water production reports for selected wells located in the Black Mountains Area and Garnet Valley were acquired from NDWR and transcribed into digital form. Information garnered through interviews was incorporated. Land-use maps based on aerial photography and satellite imagery were developed for selected years in order to identify irrigated areas from which the magnitude of ground-water development could be approximated.

B.3 METHODS

A record of ground-water production for each basin within the model boundary was developed for the period 1945 to 2000 based on the data and informational sources noted in the previous section. Since few recorded data are available for the years prior to 1987, information garnered from literature review and the interview process, land-use maps, aerial photography, and satellite

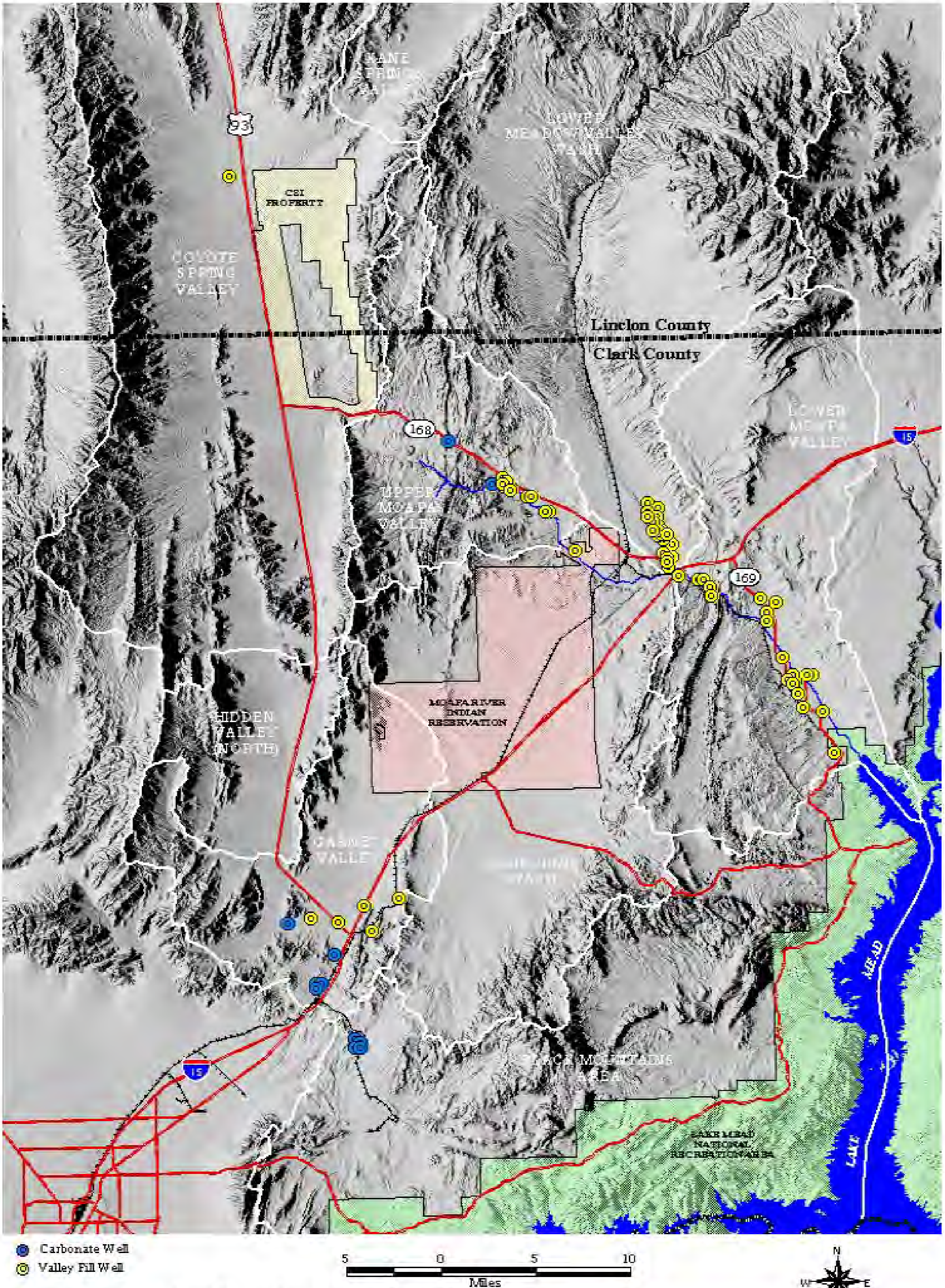

Figure B-1. Location of pumping wells within the model area.

imagery was relied upon to construct the records. The methods employed for each basin are discussed in detail in the following sections.

B.3.1 Black Mountains Area and Garnet Valley

Ground-water development in these basins began in earnest in the early 1990s to support various industrial and mining operations. The principal ground-water user in the Black Mountains Area is the Nevada Cogeneration Associates plant, and the principal users in Garnet Valley are the Chemical Lime Company, Georgia Pacific Corporation, Great Star Cement Corporation, and Republic Environmental Technologies. These users accounted for approximately 2,600 acre-feet of ground-water production in 2000.

Abstracts from NDWR's Water Rights Database were used to identify permitted rights within each basin. To construct the development history of these rights, ground-water production records were requested from NDWR. NDWR provided copies of these records for selected wells. For other wells that are known to exist in the area, information garnered from interviews with Mr. Robert Coache (Chief Engineer, NDWR) was used to estimate the extent to which the permitted rights have been developed.

B.3.2 California Wash, Coyote Spring and Hidden Valleys

California Wash, Coyote Spring and Hidden Valleys remain essentially undeveloped; however numerous ground-water permit applications have been filed with the Nevada State Engineer for proposed projects located within these basins. To date, no appreciable development has occurred.

B.3.3 Lower Meadow Valley Wash

In the southern section of Lower Meadow Valley Wash, ground water has historically been used for crop irrigation that has been generally confined to the flood plain of Lower Meadow Valley Wash. Based on interpretations of aerial photography acquired for year 2000, approximately 792 acres of cropland was irrigated in this section of the basin. Using a consumptive rate of 5 feet per acre, first published by Eakin (1964) for agriculture in the Muddy River Springs area, an estimated 3,960 acre-feet of ground water were applied in 2000. In order to distribute this quantity spatially, the volume was divided equally amongst permitted wells located on or near the irrigated fields. It was assumed that the consumptive use applied to the wells remained constant to the date the well was constructed.

In the early 1980s, NPC constructed wells at the southern tip of the basin in an effort to develop additional ground-water resources for use at their Reid Gardner facility. These wells were pumped extensively for a brief period in the early 1980s, coincident with the activation the fourth generating unit in 1983, but production was reduced in 1988 due to excessive declines in water levels and water quality (Mifflin, oral. commun. 03/2001). The annual ground-water production was reduced to approximately 310,000 gallons in 1989 as reported by Pohlmann et al. (1990, p.9). Only a negligible amount of ground water has been produced from these wells since 1990.

In the northern portions of Lower Meadow Valley Wash, above Farrier, agricultural uses are assumed to be supplied principally by surface water flowing in the wash. It is acknowledged that ground-water pumping occurs minimally in this area, but since records are non-existent or unavailable, it is assumed to be negligible for the purposes of this study.

B.3.4 Lower Moapa Valley

Records of ground-water production for this basin are either unavailable or do not exist, and therefore had to be estimated based on information garnered from the interview process. According to MVWD (03/2001, oral. commun.), ground-water development has generally been limited to selected wells located in the valley that have been used to supply water to meet peak agricultural demands during the summer months when diversions from the Muddy River have been either insufficient or untimely. Ground-water development was at its maximum between 1970 and the late-1980s, after which it began to decrease as agricultural lands were replaced with housing developments. This trend has continued to the present, and ground-water development is now much less prevalent.

The ground-water production record for this basin was developed based on an estimated consumptive use rate of 5-6 cfs for four months out of the year (MVWD, 03/2001, oral commun.). An average rate of 5.5 cfs equates to approximately 1,325 afy, which was distributed by dividing the volume equally amongst 21 permitted wells located in the valley in 1988. It was assumed that the consumptive use applied to the wells remained constant from the date the well was constructed. After 1988, the consumptive-use rate applied to each well was reduced to account for an observed increase in housing development and reduced irrigated acreage. It is assumed in the record that by 1991 the maximum consumptive use that occurred in the late-1980s had been reduced by 66 percent to account for changes in land use from agriculture to housing developments.

B.3.5 Muddy River Springs Area

Few records of ground-water production in the Muddy River Springs area existed prior to 1989 when Nevada Power Company first established their ground-water-monitoring program for the area. However, it is known that the first well was completed in the area in 1947 (NDWR Well Log Database) and it is assumed, for the purposes of this study, that little to no ground water had been developed prior to this time. After 1947, ground water was developed primarily for agricultural purposes. Eakin (1964) first estimated that 2,000 to 3,000 afy were used to irrigate 400 to 500 acres in the Muddy River Springs area prior to 1964. By 1965, NPC completed construction of its Reid Gardner facility and had acquired water rights in the Muddy River Springs area through the purchase of the Lewis wells. NPC continues to be the primary user of ground water in the area. For this report, data compilation focuses primarily on NPC and MVWD since they have been, and continue to be, the principal users of ground water in the area. It is acknowledged that there have been, and still are, other minor uses of ground water within the area. However, since these uses are small and no records exist to determine the exact amount, they were not accounted for in this study.

B.3.5.1 Nevada Power Company

Maxey et al. (1966) reported that NPC pumped 1,931 afy in 1962 and 1,681 afy in 1963 from their Lewis well field. They also reported that the total volume pumped in 1962 was the largest on record at that time, suggesting that although the area had been extensively developed for agricultural purposes, the annual production had not exceeded 1,931 afy prior to 1962. Ground-water production records for the period 1964 to 1986 either do not exist or are unavailable, and therefore had to be estimated.

Table B-1 provides data reported to the Nevada State Engineer by NPC for the period 1987 to 2000, and ground-water production estimates for the period 1945 to 1986. Included in **Table B-1** are reported NPC Muddy River diversions for the periods 1978 to 1985 (USGS, Water Resources Data for Nevada) and 1988 to 2000 (NPC), and estimated diversions for the periods 1965 to 1977 and 1986 to 1987.

The estimated values for NPC Muddy River diversions and ground-water production are based on an assumed total water demand related to the total generating capacity of the Reid Gardner facility. According to the 1994 NPC Re-filed Resource Plan, the facility's four generating units came on-line in 1965, 1968, 1976, and 1983 with the following generating capacities: No.1 110 megawatts (MW), No.2 110 MW, No.3 110 MW, and No.4 255 MW. The generating capacity of the Reid Gardner facility for the period 1989 to 2000 is estimated to have been 605 MW, during which time the average annual water use was 7,366 afy. This equates to approximately 12 acre-feet per megawatt generating capacity. Knowing the generating capacity and date each unit came on-line, this factor can then be used to estimate NPC's annual water demand for the period 1965 to 1986 by multiplying it by the generating capacity estimated for each year. NPC's annual ground-water demand can be approximated for this period by subtracting their annual surface-water diversions from their estimated annual water demand. This method takes into account typical facility operations and maintenance schedules.

Abstracts from NDWR's Water Rights Database were reviewed to develop a history of the ground-water and surface-water rights within the Muddy River Springs area. This information was used to distribute NPC's approximated annual ground-water demand to the wells listed in **Table B-1.**

B3.5.2 Moapa Valley Water District

MVWD has used ground water pumped from the Muddy River Springs area to supplement its spring diversions since 1986. In 1986, MVWD completed construction of water storage tanks and began pumping ground water from the MX-6 well to meet peak demand during four summer months (MVWD, 3/26/01, oral. commun.) MVWD estimates that from 1986 to 1992 the MX-6 well was pumped an average of 450 gpm, or approximately 245 afy. In January 1991, MVWD completed the Arrow Canyon well. Although, the well was pumped for hydraulic testing during 1991, it was not until 1992 that the well was pumped for water supply purposes. In 1992, MVWD estimates that an estimated 531 acre-feet was pumped from the well. **Table B-2** provides data reported by MVWD for the period 1993 to 2000. Included in **Table B-2** are estimates of annual ground-water withdrawals by MVWD from 1986 to 1992.

B.5 GROUND-WATER PRODUCTION DATA SET

The ground-water development history discussed in the preceding section was used to develop a data set for input into the ground-water flow model for the period 1945 to 2000. The data set is provided in **Table B-3.**

Table B-1. Estimated and reported NPC ground-water production in the Muddy River. Springs area for the period 1945 to 2000, in acre-feet per year

	NPC WATER DEMAND		SURFACE DIVERSIONS		NPC GROUND-WATER PRODUCTION				
YEAR	NPC GENERATING CAPACITY	ESTIMATED NPC WATER DEMAND[1]	MUDDY RIVER DIVERSION[2]	APPROX. NPC GROUNDWATER DEMAND[3]	BEHMER[4]	PERKINS[4]	LEWIS WELLS[5]	LDS WELLS[4]	LOWER MEADOW VALLEY WASH[6]
1945	0	0		0	0	0	0		0
1946	0	0		0	0	0	0		0
1947	0	0		0	0	855	0		0
1948	0	0		0	0	855	0		0
1949	0	0		0	0	855	329		0
1950	0	0		0	0	855	658		0
1951	0	0		0	0	855	658		0
1952	0	0		0	0	855	658		0
1953	0	0		0	0	855	658		0
1954	0	0		0	0	855	987		0
1955	0	0		0	0	855	987		0
1956	0	0		0	0	855	987		0
1957	0	0		0	0	855	987		0
1958	0	0		0	0	855	987		0
1959	0	0		0	0	855	1316		0
1960	0	0		0	0	855	1316		0
1961	0	0		0	0	855	1316		0
1962	0	0		0	0	855	**1931**		0
1963	0	0		0	0	855	**1681**		0
1964	0	0		0	0	855	1645		0
1965	110	1320	0	1320	0	855	1645		0
1966	110	1320	0	1320	0	855	1645		0
1967	110	1320	0	1320	0	855	1645		0
1968	220	2640	1200	1440	0	855	1440		0
1969	220	2640	2000	640	0	855	640		0
1970	220	2640	2000	640	0	855	640		0
1971	220	2640	2000	640	0	855	640		0
1972	220	2640	2000	640	0	855	640		0
1973	220	2640	2000	640	0	855	640		0
1974	220	2640	2000	640	0	855	640		0
1975	220	2640	2000	640	200	855	500		0
1976	330	3960	2900	1060	300	855	800		0
1977	330	3960	2900	1060	300	855	800		0
1978	330	3960	**2890**	1070	300	855	800		0
1979	330	3960	**2899**	1061	300	855	800		0
1980	330	3960	**2347**	1613	400	855	1200		0
1981	330	3960	**2805**	1155	400	855	800		0
1982	330	3960	**2752**	1208	400	855	900		0
1983	605	7260	**1885**	5375	628	855	2400		2347
1984	605	7260	**1720**	5540	628	855	2400		2512
1985	605	7260	**2731**	4529	628	855	2400		1501
1986	605	7260	2000	5260	628	855	2400		1377
1987	605	7260	3000	4260	**0**	**816**	**1188**	**300**	1956
1988	605	7260	**2164**	5096	**33**	**910**	**1524**	**1842**	787
1989	605	7260	**2012**	5248	**834**	**910**	**1679**	**1691**	**1**
1990	605	7260	**3526**	3734	**0**	**834**	**1476**	**1501**	**0**

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Table B-1. Estimated and reported NPC ground-water production in the Muddy River. Springs area for the period 1945 to 2000, in acre-feet per year

	NPC WATER DEMAND		SURFACE DIVERSIONS		NPC GROUND-WATER PRODUCTION				
YEAR	NPC GENERATING CAPACITY	ESTIMATED NPC WATER DEMAND[1]	MUDDY RIVER DIVERSION[2]	APPROX. NPC GROUNDWATER DEMAND[3]	BEHMER[4]	PERKINS[4]	LEWIS WELLS[5]	LDS WELLS[4]	LOWER MEADOW VALLEY WASH[6]
1991	605	7260	3625	3635	319	910	1179	1309	0
1992	605	7260	2942	4318	0	777	1160	1413	0
1993	605	7260	2871	4389	138	910	1410	958	0
1994	605	7260	2462	4798	0	886	2075	1467	0
1995	605	7260	2950	4310	0	581	1299	1583	0
1996	605	7260	3219	4041	224	910	1522	2097	0
1997	605	7260	2494	4766	0	726	1195	2175	0
1998	605	7260	2296	4964	0	804	2259	2903	0
1999	605	7260	2585	4675	0	482	1876	2390	0
2000	605	7260	3063	4197	573	471	1736	4705	0

Note: Shaded cells represent estimated years in which well(s) was used for agricultural water supply based on abstracts from NDWR Water Rights Database

1. *Demand based on the average annual water demand per megawatt generating capacity during the period 1989 to 2000*
2. *Diversions for 1978 to 1985 reported by USGS; 1988 to 2000 reported by NPC*
3. *Approximated as the difference between the estimated water demand ([1]) and Muddy River diversion ([2])*
4. *Data from 1987 to 2000 from NPC monitoring reports submitted to Nevada State Engineer's Office; 1945 to 1986 estimated data based abstracts from NDWR Water Rights Database*
5. *Data from 1962 and 1963 from Maxey et al. (1966); Data from 1987 to 2000 from NPC Hydrologic Impacts reports; stimated data based abstracts from NDWR Water Rights Database*
6. *Data from 1982 to 1988 estimated as the volume of water needed by NPC, in addition to other the sources, to meet their estimated water demand ([1])*

Table B-2. Estimated and reported MVWD ground-water production in the Muddy River Springs area for the period 1986 to 2000, in acre-feet per year

Year	MX-6	Arrow Canyon	Total
1986	245	-	245
1987	245	-	245
1988	245	-	245
1989	245	-	245
1990	245	-	245
1991	245	0	245
1992	245	513	758
1993	141	1,204	1,345
1994	390	504	894
1995	374	304	678
1996	431	274	705
1997	307	501	808
1998	40	1,517	1,557
1999	145	2,434	2,579
2000	130	2,777	2,908

Sources: 1986 to 1992 estimates based on MVWD interviews (MVWD, oral commun., 03/2001)
1993 to 1996 NPC Hydrologic Impacts reports
1997 to 2000 MVWD Muddy Springs Area Monitoring Reports

Table B-3. Ground-water production data set as used in the ground-water flow model.

WELL_ID	OWNER/OPERATOR	UTM_X	UTM_Y	DATE COMPLETED	ELEV	HSU	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955
MUDDY SPRINGS AREA							0	0	855	855	1184	1513	1513	1513	1513	1842	1842
ARROW_CANYON	MVWD	701233	4067521	01/25/91	1875	C											
LEWIS-1	NEVADA POWER COMPANY	702136	4068021	05/16/49	1828	VF					329	329	329	329	329	329	329
LEWIS-3	NEVADA POWER COMPANY	702424	4067549	05/15/62	1827	VF											
LEWIS-2	NEVADA POWER COMPANY	702409	4067707	07/15/59	1821	VF											
LEWIS-5	NEVADA POWER COMPANY	702248	4067290	02/16/54	1822	VF										329	329
LEWIS-4	NEVADA POWER COMPANY	702104	4067418	06/07/50	1822	VF						329	329	329	329	329	329
LDS-WEST	NEVADA POWER COMPANY	702799	4066922	1986	1787	VF											
LDS-CENTRAL	NEVADA POWER COMPANY	704189	4066366	1986	1811	VF											
LDS-EAST	NEVADA POWER COMPANY	704537	4066400	1986	1715	VF											
MX-6	MVWD	697525	4071193	05/21/81	2275	C											
BEHMER	NEVADA POWER COMPANY	706031	4065080			VF											
NPC-PP	NEVADA POWER COMPANY	705735	4065016	06/16/88	1771	VF			855	855	855	855	855	855	855	855	855
LOWER MOAPA VALLEY							0	0	0	0	0	0	0	0	0	0	0
MV-2	NEVADA POWER COMPANY	716092	4061037	08/27/62	1538	VF											
73		718701	4059068	10/12/71	1524	VF											
MV-7	LEWIS, PAUL	719123	4059078	05/31/60	1552	VF											
MV-3	EWING, JAMES L	716113	4060205	02/15/80	1544	VF											
MV-5	C X PRODUCTS CORP	717002	4059425	11/26/73	1565	VF											
MV-9	LEWIS, PAUL R & PATRICIA	719735	4058477	01/11/75	1540	VF											
MV-10	LEWIS, PAUL R & PATRICIA	719755	4057676	01/11/75	1496	VF											
MV-12	LAS VEGAS CEMENT	724010	4057508	11/18/85	1500	VF											
MV-16	FAY, BOB	725237	4057139	07/15/80	1466	VF											
MV-13	STREET, KEVIN	724463	4056317	02/10/97	1431	VF											
MV-14	MOAPA VALLEY WATER CO	724484	4055516	04/24/67	1415	VF											
MV-21	ROBINSON, L H	725836	4052344	07/01/67	1367	VF											
MV-37	STRINGHAM, STANLEY	728364	4050807	02/12/78	1368	VF											
85		727941	4050795	03/21/74	1342	VF											
MV-29	HORN, ERIC	726937	4050183	03/18/67	1314	VF											
MV-26	MARSHAL, KARL	726723	4050763	02/11/76	1314	VF											
MV-23	SEBAUGH, FRANK	726311	4050352	02/27/76	1314	VF											
MV-28	METCALF, M B	726744	4049962	12/10/66	1314	VF											
MV-30	LAHM, ROBERT LEE & EVELYN	727188	4049172	05/05/73	1304	VF											
MV-33	PERKINS, W V	727643	4047950	09/26/74	1288	VF											
MV-40	MOAPA VALLEY DAIRY FARMS	729295	4047593	03/23/88	1250	VF											
MV-42	SIMPLOT SILICON PRODUCTS	730213	4043978	05/25/76	1292	VF											
37	MVWD-1	724484	4055516	04/24/67	1415	VF											
LOWER MEADOW VALLEY WASH							0	0	0	0	0	0	0	0	0	0	0
LMVW-72	NEVADA POWER COMPANY	715252	4063822	12/31/63	1564	VF											
LMVW-75	NEVADA POWER COMPANY	716086	4062240	09/30/81	1552	VF											
LMVW-76	NEVADA POWER COMPANY	716508	4062250	11/01/63	1541	VF											
LMVW-14	NEVADA POWER COMPANY	716514	4061048	08/27/62	1532	VF											
LMVW-34	LEWIS, PAUL	715669	4063031	11/1/1971	1573	VF											
LMVW-41	WHITNEY, R C	715684	4061428	11/13/1996	1545	VF											
135	PERKINS, ROBERT	708203	4061613	1/9/1975	1660	VF											
LMVW-49	MEADOW VALLEY FARMLAND IRR CO	714407	4065806	3/25/1988	1587	VF											
LMVW-50	MEADOW VALLEY FARMLAND IRR CO	715236	4065425	2/25/1988	1584	VF											
LMVW-53	SCHLARMAN, HENRY T	715659	4063432	4/23/1971	1566	VF											
LMVW-56	HENRIE, PAUL	714402	4065004	3/1/1969	1583	VF											
LMVW-57	MEADOW VALLEY FARMLAND IRR CO	715231	4064624	3/3/1988	1561	VF											
LMVW-60	LEWIS, PAUL	715679	4062630	2/12/1974	1577	VF											
LMVW-64	EMBRY, MILTON	715247	4063020	9/13/1974	1609	VF											
LMVW-66	LEAVITT, GARY & DIANE	716092	4061037	4/1/1974	1538	VF											
LMVW-67	STEWART, MARK	715669	4063031	11/1/1971	1573	VF											
LMVW-68	PERKINS, ROBERT	715237	4063421	9/28/1971	1586	VF											
LMVW-70	LEWIS, PAUL	716102	4060636	2/19/1974	1538	VF											
LMVW-71	MCKNIGHT, JAMES D	714820	4064212	3/1/1969	1564	VF											
LMVW-74	HENRIE, PAUL	714412	4064603	3/1/1969	1574	VF											
163	STEWART, MARK	716091	4063042	2/28/1977	1565	VF											
164	CUTLER, KEITH	714840	4063411	3/18/1970	1593	VF											
GARNET VALLEY							0	0	0	0	0	0	0	0	0	0	0
46	U S LIME	685798	4029433	06/17/71	2273	VF											
47	U S LIME	688174	4029084	07/22/71	2155	VF											
GV-KERR-1	KERR-MCGEE CHEMICAL CORP	683838	4028991	02/07/90	2405	C											
49	GEORGIA PACIFIC CORP	686317	4023833	10/23/92	2464	C											
50	GEORGIA PACIFIC CORP	686716	4023842	08/19/90	2415	C											
51	GEORGIA PACIFIC CORP	686326	4023432	09/30/86	2455	C											
GV-GSC-1	GREAT STAR CEMENT CORP	693337	4031201	03/30/87	2293	VF											
GV-USLIME-1	U S LIME	690310	4030549	09/13/63	2073	VF											
GV-ET-1	ENVIRONMENTAL TECHNOLOGIES	690982	4028343	03/23/89	2321	VF											
202	U S LIME	687850	4026300	06/01/99		C											
BLACK MOUNTAINS							0	0	0	0	0	0	0	0	0	0	0
60	BONNEVILLE ENERGY	689589	4019063	12/24/91	2485	C											
BM-BE-2	BONNEVILLE ENERGY	689997	4018671	12/30/91	2434	C											
BM-BE-3	BONNEVILLE ENERGY	689606	4018262	08/16/91	2391	C											
BM-BE-1	BONNEVILLE ENERGY	690006	4018271	06/12/90	2442	C											

Table B-3. Ground-water production data set as used in the ground-water flow model.

WELL_ID	OWNER/OPERATOR	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
MUDDY SPRINGS AREA		1842	1842	1842	2171	2171	2171	2786	2536	2500	2500	2500	2500	2295	1495	1495	1495	1495	1495
ARROW_CANYON	MVWD																		
LEWIS-1	NEVADA POWER COMPANY	329	329	329	329	329	329	386	336	329	329	329	329	288	128	128	128	128	128
LEWIS-3	NEVADA POWER COMPANY							386	336	329	329	329	329	288	128	128	128	128	128
LEWIS-2	NEVADA POWER COMPANY				329	329	329	386	336	329	329	329	329	288	128	128	128	128	128
LEWIS-5	NEVADA POWER COMPANY	329	329	329	329	329	329	386	336	329	329	329	329	288	128	128	128	128	128
LEWIS-4	NEVADA POWER COMPANY	329	329	329	329	329	329	386	336	329	329	329	329	288	128	128	128	128	128
LDS-WEST	NEVADA POWER COMPANY																		
LDS-CENTRAL	NEVADA POWER COMPANY																		
LDS-EAST	NEVADA POWER COMPANY																		
MX-6	MVWD																		
BEHMER	NEVADA POWER COMPANY																		
NPC-PP	NEVADA POWER COMPANY	855	855	855	855	855	855	855	855	855	855	855	855	855	855	855	855	855	855
LOWER MOAPA VALLEY		0	0	0	0	63	63	126	126	126	126	189	378	378	378	378	441	441	567
MV-2	NEVADA POWER COMPANY							63	63	63	63	63	63	63	63	63	63	63	63
73																	63	63	63
MV-7	LEWIS, PAUL					63	63	63	63	63	63	63	63	63	63	63	63	63	63
MV-3	EWING, JAMES L																		
MV-5	C X PRODUCTS CORP																		63
MV-9	LEWIS, PAUL R & PATRICIA																		
MV-10	LEWIS, PAUL R & PATRICIA																		
MV-12	LAS VEGAS CEMENT																		
MV-16	FAY, BOB																		
MV-13	STREET, KEVIN																		
MV-14	MOAPA VALLEY WATER CO												63	63	63	63	63	63	63
MV-21	ROBINSON, L H												63	63	63	63	63	63	63
MV-37	STRINGHAM, STANLEY																		
85																			
MV-29	HORN, ERIC												63	63	63	63	63	63	63
MV-26	MARSHAL, KARL																		
MV-23	SEBAUGH, FRANK																		
MV-28	METCALF, M B											63	63	63	63	63	63	63	63
MV-30	LAHM, ROBERT LEE & EVELYN																		63
MV-33	PERKINS, W V																		
MV-40	MOAPA VALLEY DAIRY FARMS																		
MV-42	SIMPLOT SILICON PRODUCTS																		
37	MVWD-1												0	0	0	0	0	0	0
LOWER MEADOW VALLEY WASH		0	0	0	0	0	0	0	0	0	0	0	0	0	660	880	1760	1760	1760
LMVW-72	NEVADA POWER COMPANY																		
LMVW-75	NEVADA POWER COMPANY																		
LMVW-76	NEVADA POWER COMPANY																		
LMVW-14	NEVADA POWER COMPANY																		
LMVW-34	LEWIS, PAUL																220	220	220
LMVW-41	WHITNEY, R C																		
135	PERKINS, ROBERT																		
LMVW-49	MEADOW VALLEY FARMLAND IRR CO																		
LMVW-50	MEADOW VALLEY FARMLAND IRR CO																		
LMVW-53	SCHLARMAN, HENRY T																220	220	220
LMVW-56	HENRIE, PAUL														220	220	220	220	220
LMVW-57	MEADOW VALLEY FARMLAND IRR CO																		
LMVW-60	LEWIS, PAUL																		
LMVW-64	EMBRY, MILTON																		
LMVW-66	LEAVITT, GARY & DIANE																		
LMVW-67	STEWART, MARK																220	220	220
LMVW-68	PERKINS, ROBERT																220	220	220
LMVW-70	LEWIS, PAUL																		
LMVW-71	MCKNIGHT, JAMES D														220	220	220	220	220
LMVW-74	HENRIE, PAUL														220	220	220	220	220
163	STEWART, MARK																		
164	CUTLER, KEITH															220	220	220	220
GARNET VALLEY		0	0	0	0	0	0	0	50	50	50	50	50	50	50	50	150	150	150
46	U S LIME																50	50	50
47	U S LIME																50	50	50
GV-KERR-1	KERR-MCGEE CHEMICAL CORP																		
49	GEORGIA PACIFIC CORP																		
50	GEORGIA PACIFIC CORP																		
51	GEORGIA PACIFIC CORP																		
GV-GSC-1	GREAT STAR CEMENT CORP																		
GV-USLIME-1	U S LIME								50	50	50	50	50	50	50	50	50	50	50
GV-ET-1	ENVIRONMENTAL TECHNOLOGIES																		
202	U S LIME																		
BLACK MOUNTAINS		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	BONNEVILLE ENERGY																		
BM-BE-2	BONNEVILLE ENERGY																		
BM-BE-3	BONNEVILLE ENERGY																		
BM-BE-1	BONNEVILLE ENERGY																		

Table B-3. Ground-water production data set as used in the ground-water flow model.

WELL_ID	OWNER/OPERATOR	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
MUDDY SPRINGS AREA		1495	1555	1955	1955	1955	1955	2455	2055	2155	3883	3883	3883	4128	2249	4554	5359
ARROW_CANYON	MVWD																
LEWIS-1	NEVADA POWER COMPANY	128	100	160	160	160	160	240	160	180	480	480	480	480	238	305	336
LEWIS-3	NEVADA POWER COMPANY	128	100	160	160	160	160	240	160	180	480	480	480	480	238	305	336
LEWIS-2	NEVADA POWER COMPANY	128	100	160	160	160	160	240	160	180	480	480	480	480	238	305	336
LEWIS-5	NEVADA POWER COMPANY	128	100	160	160	160	160	240	160	180	480	480	480	480	238	305	336
LEWIS-4	NEVADA POWER COMPANY	128	100	160	160	160	160	240	160	180	480	480	480	480	238	305	336
LDS-WEST	NEVADA POWER COMPANY															614	564
LDS-CENTRAL	NEVADA POWER COMPANY															614	564
LDS-EAST	NEVADA POWER COMPANY															614	564
MX-6	MVWD								0	0	0	0	0	245	245	245	245
BEHMER	NEVADA POWER COMPANY		200	300	300	300	300	400	400	400	628	628	628	628	0	33	834
NPC-PP	NEVADA POWER COMPANY	855	855	855	855	855	855	855	855	855	855	855	855	855	816	910	910
LOWER MOAPA VALLEY		819	819	1008	1008	1071	1071	1197	1197	1197	1197	1197	1260	1260	1260	1323	1102
MV-2	NEVADA POWER COMPANY	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	52
73		63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-7	LEWIS, PAUL	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-3	EWING, JAMES L							63	63	63	63	63	63	63	63	63	52
MV-5	C X PRODUCTS CORP	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-9	LEWIS, PAUL R & PATRICIA	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-10	LEWIS, PAUL R & PATRICIA	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-12	LAS VEGAS CEMENT												63	63	63	63	52
MV-16	FAY, BOB							63	63	63	63	63	63	63	63	63	52
MV-13	STREET, KEVIN																
MV-14	MOAPA VALLEY WATER CO	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-21	ROBINSON, L H	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-37	STRINGHAM, STANLEY					63	63	63	63	63	63	63	63	63	63	63	52
85		63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-29	HORN, ERIC	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-26	MARSHAL, KARL			63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-23	SEBAUGH, FRANK			63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-28	METCALF, M B	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-30	LAHM, ROBERT LEE & EVELYN	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-33	PERKINS, W V	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	52
MV-40	MOAPA VALLEY DAIRY FARMS															63	52
MV-42	SIMPLOT SILICON PRODUCTS			63	63	63	63	63	63	63	63	63	63	63	63	63	52
37	MVWD-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LOWER MEADOW VALLEY WASH		2640	2860	2860	3080	3080	3080	3080	3080	3080	5427	5592	4581	4457	5036	4527	3874
LMVW-72	NEVADA POWER COMPANY										587	628	375	344	489	197	33
LMVW-75	NEVADA POWER COMPANY										587	628	375	344	489	197	33
LMVW-76	NEVADA POWER COMPANY										587	628	375	344	489	197	33
LMVW-14	NEVADA POWER COMPANY										587	628	375	344	489	197	33
LMVW-34	LEWIS, PAUL	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
LMVW-41	WHITNEY, R C																
135	PERKINS, ROBERT		220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
LMVW-49	MEADOW VALLEY FARMLAND IRR CO															220	220
LMVW-50	MEADOW VALLEY FARMLAND IRR CO															220	220
LMVW-53	SCHLARMAN, HENRY T	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
LMVW-56	HENRIE, PAUL	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
LMVW-57	MEADOW VALLEY FARMLAND IRR CO															220	220
LMVW-60	LEWIS, PAUL	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
LMVW-64	EMBRY, MILTON	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
LMVW-66	LEAVITT, GARY & DIANE	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
LMVW-67	STEWART, MARK	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
LMVW-68	PERKINS, ROBERT	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
LMVW-70	LEWIS, PAUL	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
LMVW-71	MCKNIGHT, JAMES D	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
LMVW-74	HENRIE, PAUL	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
163	STEWART, MARK				220	220	220	220	220	220	220	220	220	220	220	220	220
164	CUTLER, KEITH	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
GARNET VALLEY		150	150	150	150	150	150	150	150	150	150	150	150	200	378	378	446
46	U S LIME	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
47	U S LIME	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
GV-KERR-1	KERR-MCGEE CHEMICAL CORP																
49	GEORGIA PACIFIC CORP																
50	GEORGIA PACIFIC CORP																
51	GEORGIA PACIFIC CORP													50	50	50	50
GV-GSC-1	GREAT STAR CEMENT CORP														178	178	178
GV-USLIME-1	U S LIME	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
GV-ET-1	ENVIRONMENTAL TECHNOLOGIES																68
202	U S LIME																
BLACK MOUNTAINS		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	BONNEVILLE ENERGY																
BM-BE-2	BONNEVILLE ENERGY																
BM-BE-3	BONNEVILLE ENERGY																
BM-BE-1	BONNEVILLE ENERGY																

Table B-3. Ground-water production data set as used in the ground-water flow model.

WELL_ID	OWNER/OPERATOR	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
MUDDY SPRINGS AREA		**4056**	**3963**	**4109**	**4762**	**5322**	**4142**	**5458**	**4904**	**7524**	**7327**	**10393**
ARROW_CANYON	MVWD		0	513	1204	504	304	274	501	1517	2434	2777
LEWIS-1	NEVADA POWER COMPANY	295	236	232	282	415	260	304	239	452	375	275
LEWIS-3	NEVADA POWER COMPANY	295	236	232	282	415	260	304	239	452	375	468
LEWIS-2	NEVADA POWER COMPANY	295	236	232	282	415	260	304	239	452	375	317
LEWIS-5	NEVADA POWER COMPANY	295	236	232	282	415	260	304	239	452	375	427
LEWIS-4	NEVADA POWER COMPANY	295	236	232	282	415	260	304	239	452	375	249
LDS-WEST	NEVADA POWER COMPANY	500	437	471	319	489	528	699	725	968	797	2622
LDS-CENTRAL	NEVADA POWER COMPANY	500	437	471	319	489	528	699	725	968	797	967
LDS-EAST	NEVADA POWER COMPANY	500	437	471	319	489	528	699	725	968	797	1116
MX-6	MVWD	245	245	245	141	390	374	431	307	40	145	130
BEHMER	NEVADA POWER COMPANY	0	319	0	138	0	0	224	0	0	0	573
NPC-PP	NEVADA POWER COMPANY	834	910	777	910	886	581	910	726	804	482	471
LOWER MOAPA VALLEY		**881**	**441**	**441**	**441**	**552**	**517**	**569**	**462**	**462**	**462**	**462**
MV-2	NEVADA POWER COMPANY	42	21	21	21	21	21	21	21	21	21	21
73		42	21	21	21	21	21	21	21	21	21	21
MV-7	LEWIS, PAUL	42	21	21	21	21	21	21	21	21	21	21
MV-3	EWING, JAMES L	42	21	21	21	21	21	21	21	21	21	21
MV-5	C X PRODUCTS CORP	42	21	21	21	21	21	21	21	21	21	21
MV-9	LEWIS, PAUL R & PATRICIA	42	21	21	21	21	21	21	21	21	21	21
MV-10	LEWIS, PAUL R & PATRICIA	42	21	21	21	21	21	21	21	21	21	21
MV-12	LAS VEGAS CEMENT	42	21	21	21	21	21	21	21	21	21	21
MV-16	FAY, BOB	42	21	21	21	21	21	21	21	21	21	21
MV-13	STREET, KEVIN								21	21	21	21
MV-14	MOAPA VALLEY WATER CO	42	21	21	21	21	21	21	21	21	21	21
MV-21	ROBINSON, L H	42	21	21	21	21	21	21	21	21	21	21
MV-37	STRINGHAM, STANLEY	42	21	21	21	21	21	21	21	21	21	21
85		42	21	21	21	21	21	21	21	21	21	21
MV-29	HORN, ERIC	42	21	21	21	21	21	21	21	21	21	21
MV-26	MARSHAL, KARL	42	21	21	21	21	21	21	21	21	21	21
MV-23	SEBAUGH, FRANK	42	21	21	21	21	21	21	21	21	21	21
MV-28	METCALF, M B	42	21	21	21	21	21	21	21	21	21	21
MV-30	LAHM, ROBERT LEE & EVELYN	42	21	21	21	21	21	21	21	21	21	21
MV-33	PERKINS, W V	42	21	21	21	21	21	21	21	21	21	21
MV-40	MOAPA VALLEY DAIRY FARMS	42	21	21	21	21	21	21	21	21	21	21
MV-42	SIMPLOT SILICON PRODUCTS	42	21	21	21	21	21	21	21	21	21	21
37	MVWD-1	0	0	0	0	112	77	129	0	0	0	0
LOWER MEADOW VALLEY WASH		**3740**	**3740**	**3740**	**3740**	**3740**	**3740**	**3960**	**3960**	**3960**	**3960**	**3960**
LMVW-72	NEVADA POWER COMPANY	0	0	0	0	0	0	0	0	0	0	0
LMVW-75	NEVADA POWER COMPANY	0	0	0	0	0	0	0	0	0	0	0
LMVW-76	NEVADA POWER COMPANY	0	0	0	0	0	0	0	0	0	0	0
LMVW-14	NEVADA POWER COMPANY	0	0	0	0	0	0	0	0	0	0	0
LMVW-34	LEWIS, PAUL	220	220	220	220	220	220	220	220	220	220	220
LMVW-41	WHITNEY, R C							220	220	220	220	220
135	PERKINS, ROBERT	220	220	220	220	220	220	220	220	220	220	220
LMVW-49	MEADOW VALLEY FARMLAND IRR CO	220	220	220	220	220	220	220	220	220	220	220
LMVW-50	MEADOW VALLEY FARMLAND IRR CO	220	220	220	220	220	220	220	220	220	220	220
LMVW-53	SCHLARMAN, HENRY T	220	220	220	220	220	220	220	220	220	220	220
LMVW-56	HENRIE, PAUL	220	220	220	220	220	220	220	220	220	220	220
LMVW-57	MEADOW VALLEY FARMLAND IRR CO	220	220	220	220	220	220	220	220	220	220	220
LMVW-60	LEWIS, PAUL	220	220	220	220	220	220	220	220	220	220	220
LMVW-64	EMBRY, MILTON	220	220	220	220	220	220	220	220	220	220	220
LMVW-66	LEAVITT, GARY & DIANE	220	220	220	220	220	220	220	220	220	220	220
LMVW-67	STEWART, MARK	220	220	220	220	220	220	220	220	220	220	220
LMVW-68	PERKINS, ROBERT	220	220	220	220	220	220	220	220	220	220	220
LMVW-70	LEWIS, PAUL	220	220	220	220	220	220	220	220	220	220	220
LMVW-71	MCKNIGHT, JAMES D	220	220	220	220	220	220	220	220	220	220	220
LMVW-74	HENRIE, PAUL	220	220	220	220	220	220	220	220	220	220	220
163	STEWART, MARK	220	220	220	220	220	220	220	220	220	220	220
164	CUTLER, KEITH	220	220	220	220	220	220	220	220	220	220	220
GARNET VALLEY		**496**	**497**	**547**	**549**	**553**	**549**	**542**	**523**	**578**	**717**	**952**
46	U S LIME	50	50	50	50	50	50	50	50	50		
47	U S LIME	50	50	50	50	50	50	50	50	50		
GV-KERR-1	KERR-MCGEE CHEMICAL CORP	0	1	1	2	7	3	0	0	9	4	4
49	GEORGIA PACIFIC CORP			50	50	45	45					
50	GEORGIA PACIFIC CORP	50	50	50	50	65	65	145	126	131	149	150
51	GEORGIA PACIFIC CORP	50	50	50	50	40	40					
GV-GSC-1	GREAT STAR CEMENT CORP	178	178	178	178	178	178	178	178	178	178	178
GV-USLIME-1	U S LIME	50	50	50	50	50	50	50	50	50		
GV-ET-1	ENVIRONMENTAL TECHNOLOGIES	68	68	68	68	68	68	68	68	111	386	470
202	U S LIME										150	150
BLACK MOUNTAINS		**0**	**0**	**582**	**1400**	**1563**	**1528**	**1613**	**1429**	**1408**	**1569**	**1693**
60	BONNEVILLE ENERGY			194	350	391	382	403	357	352	392	423
BM-BE-2	BONNEVILLE ENERGY			194	350	391	382	403	357	352	392	423
BM-BE-3	BONNEVILLE ENERGY			194	350	391	382	403	357	352	392	423
BM-BE-1	BONNEVILLE ENERGY				350	391	382	403	357	352	392	423

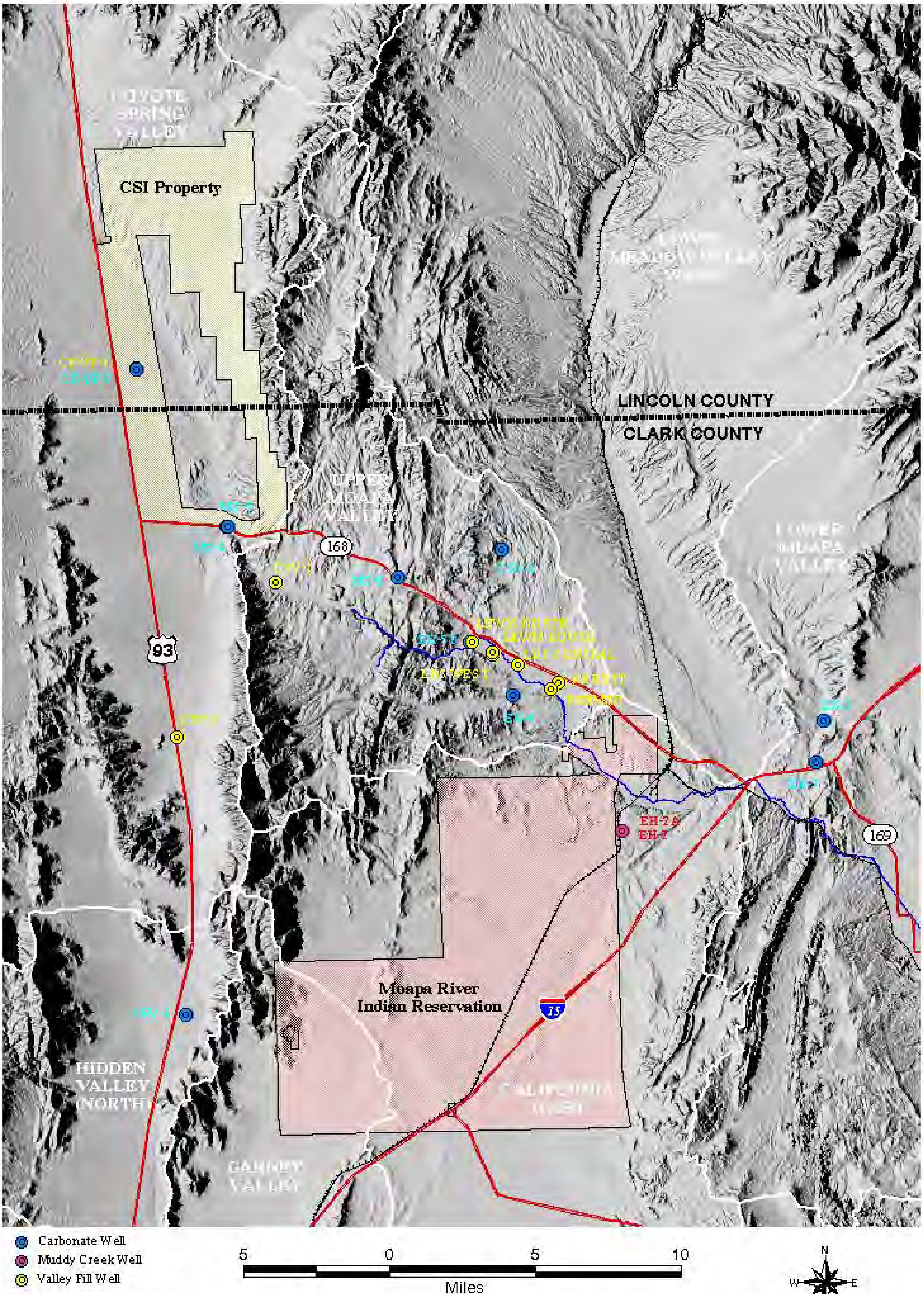


Figure C-1. Model area wells with greater than 5 years of water-level record.

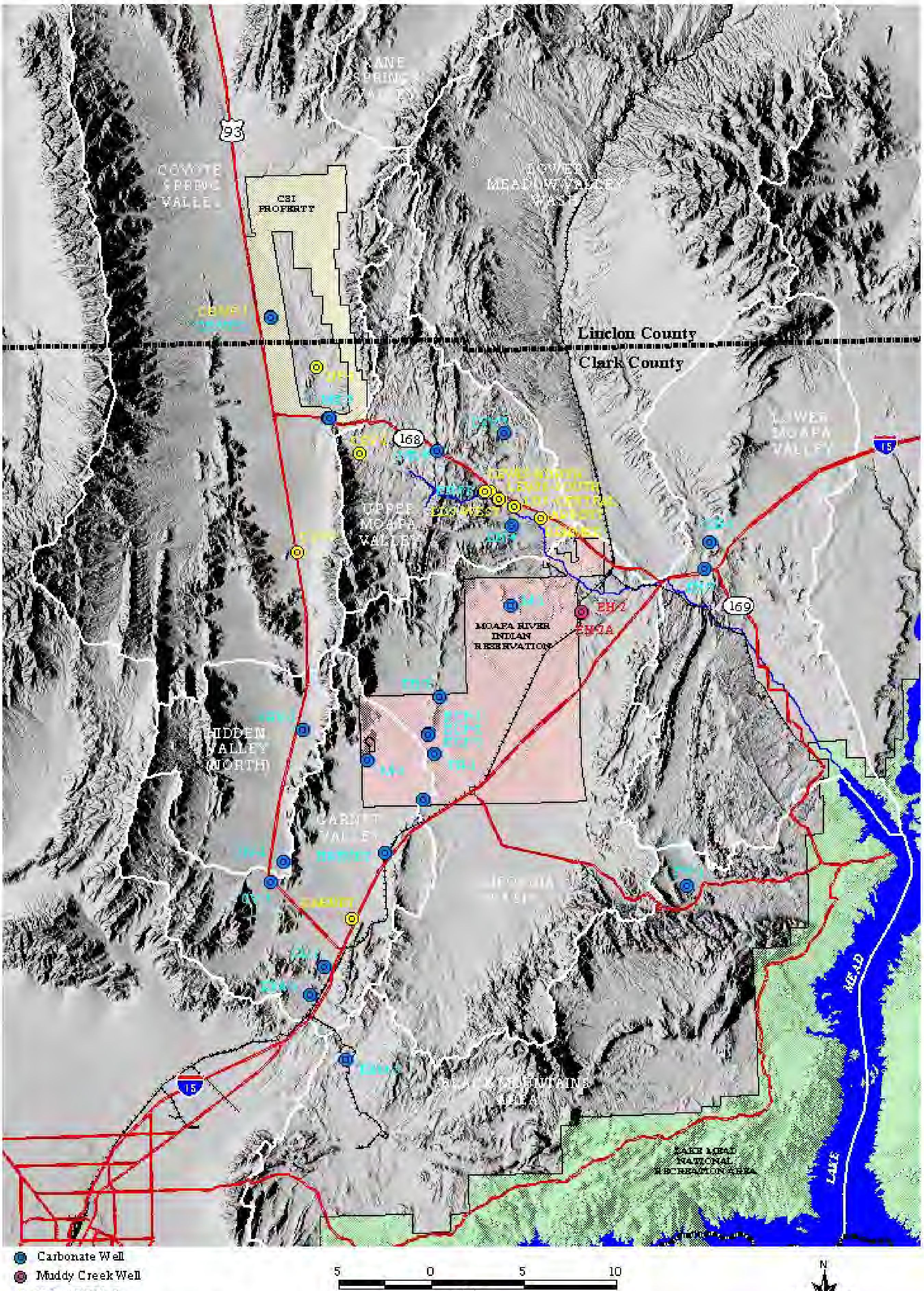
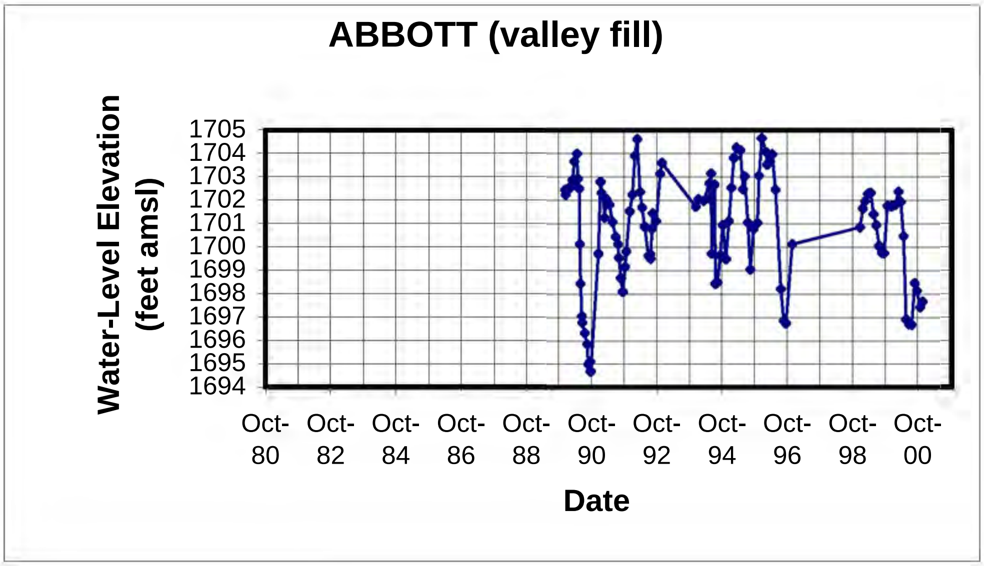
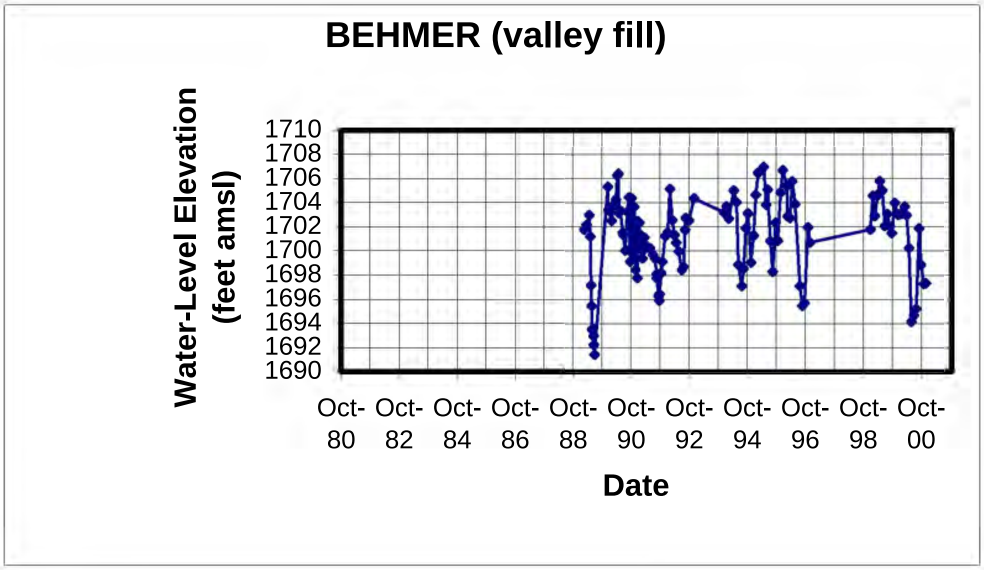


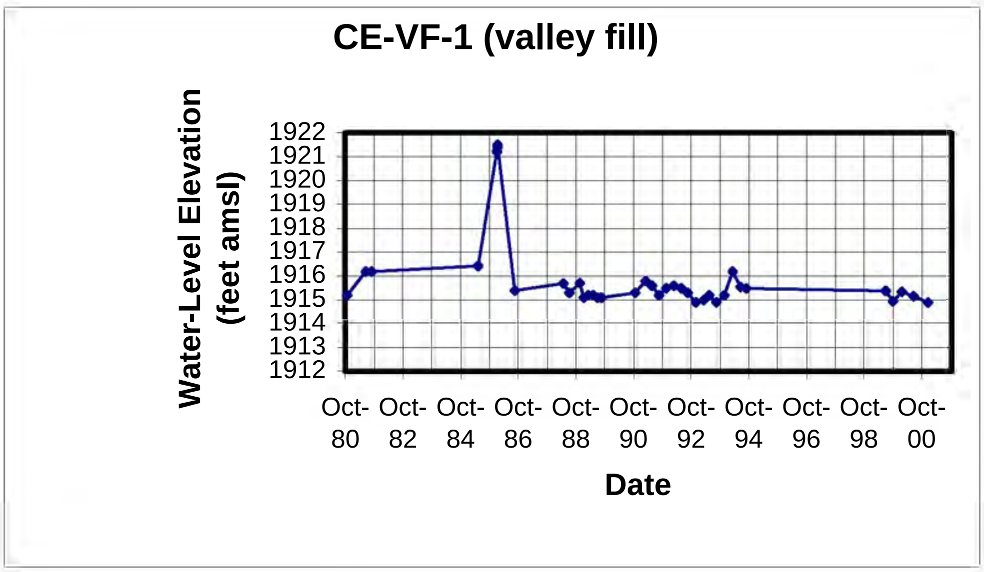
Figure C-2. Location of primary wells with significant water-level records.

APPENDIX C

Ground-water hydrographs of selected wells with greater than 5 years of record

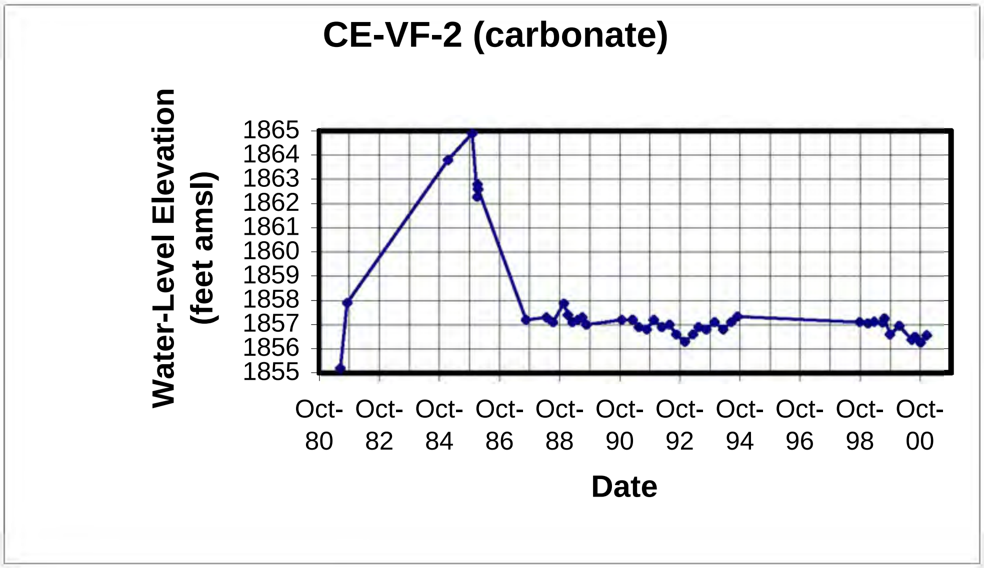


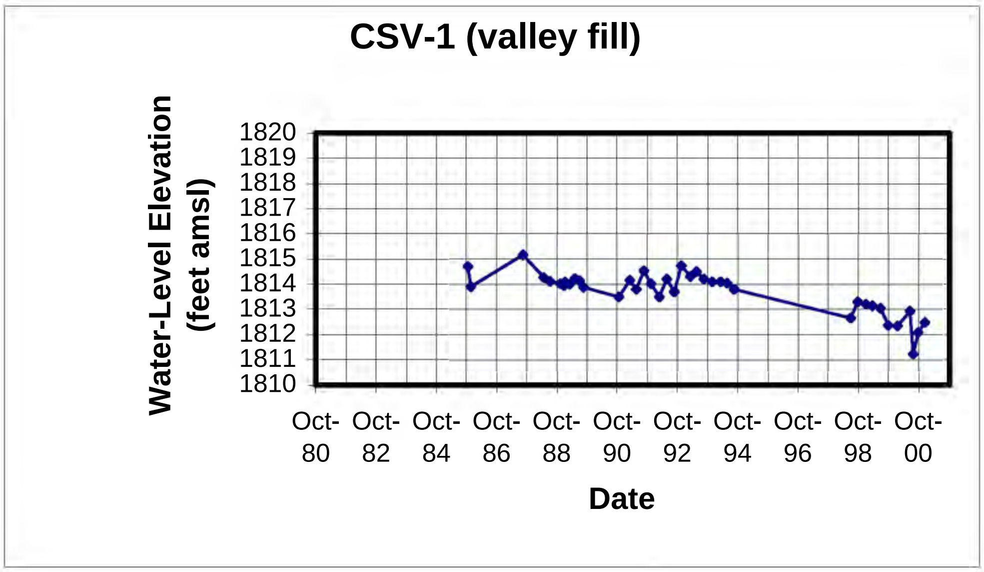


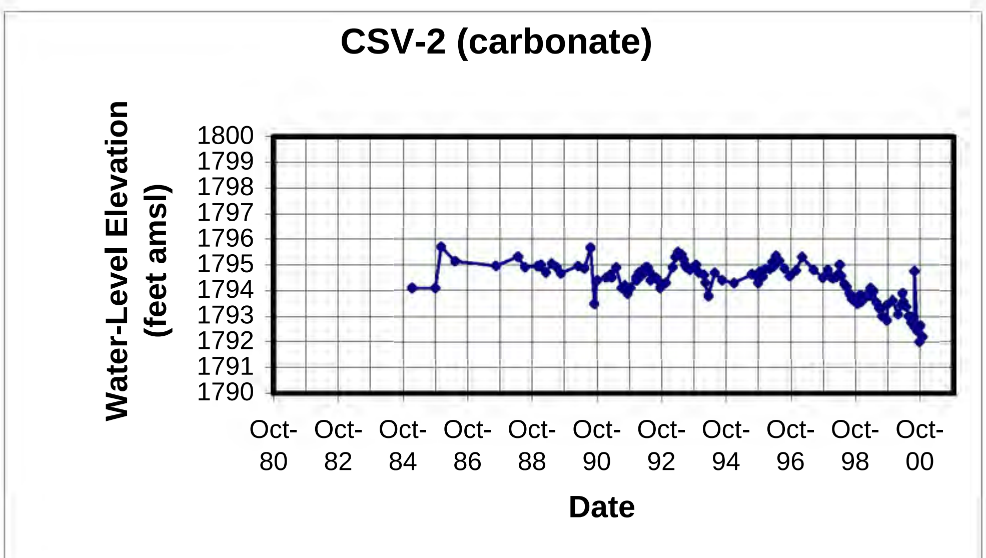


APPENDIX C

Ground-water hydrographs of selected wells with greater than 5 years of record

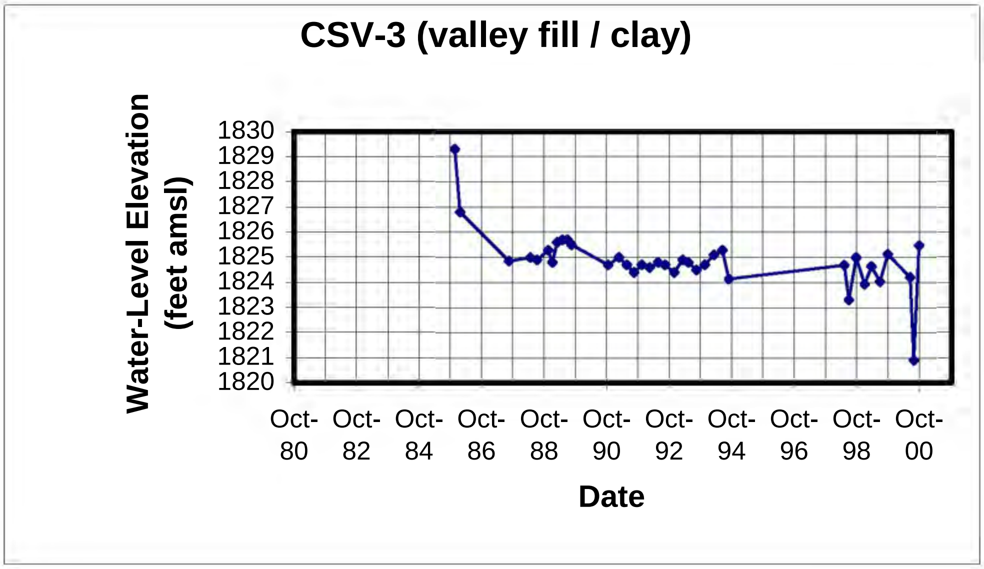


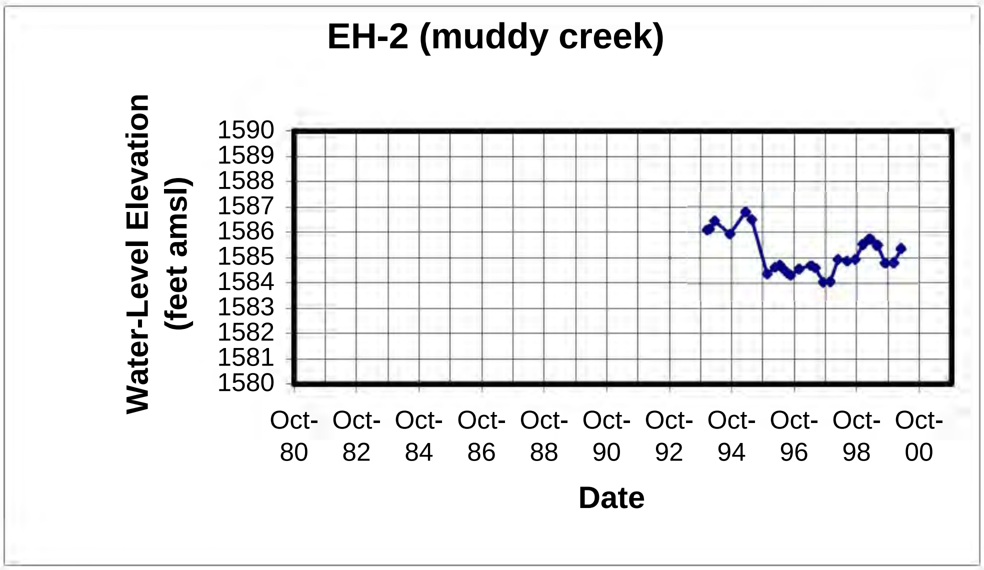


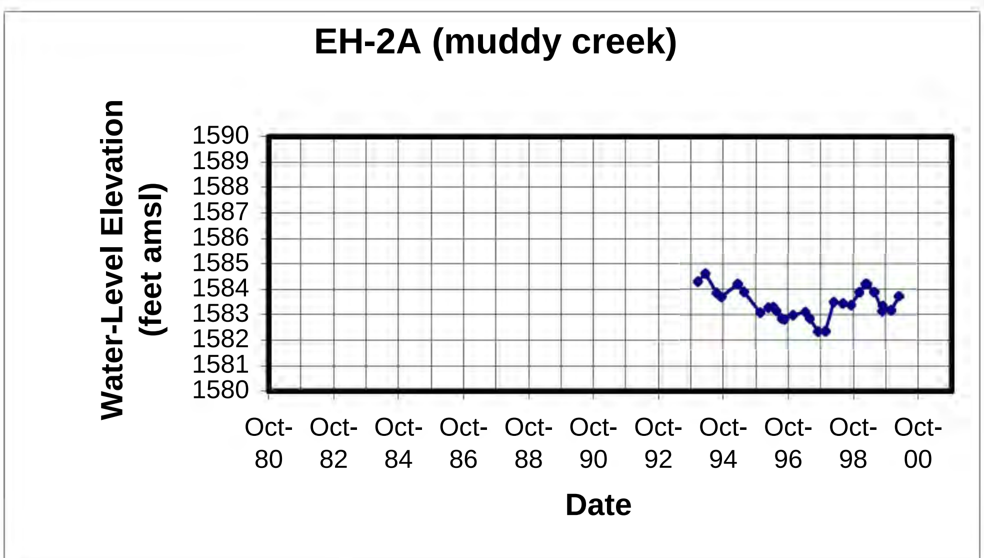


APPENDIX C

Ground-water hydrographs of selected wells with greater than 5 years of record

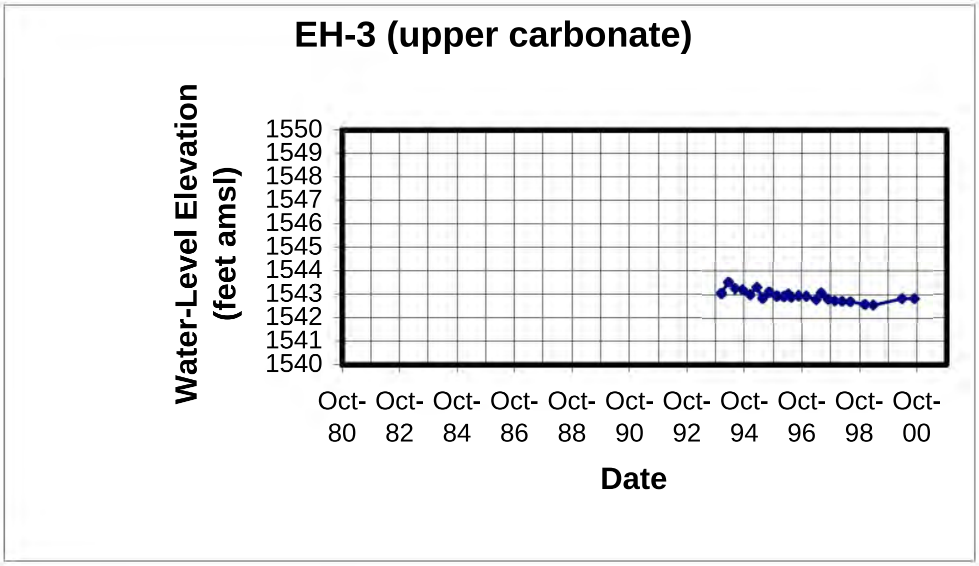


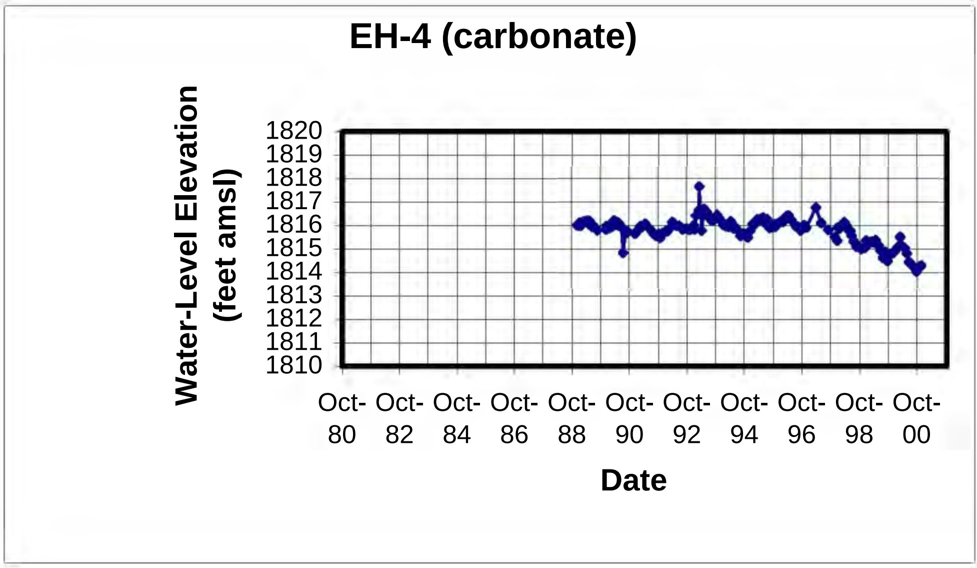


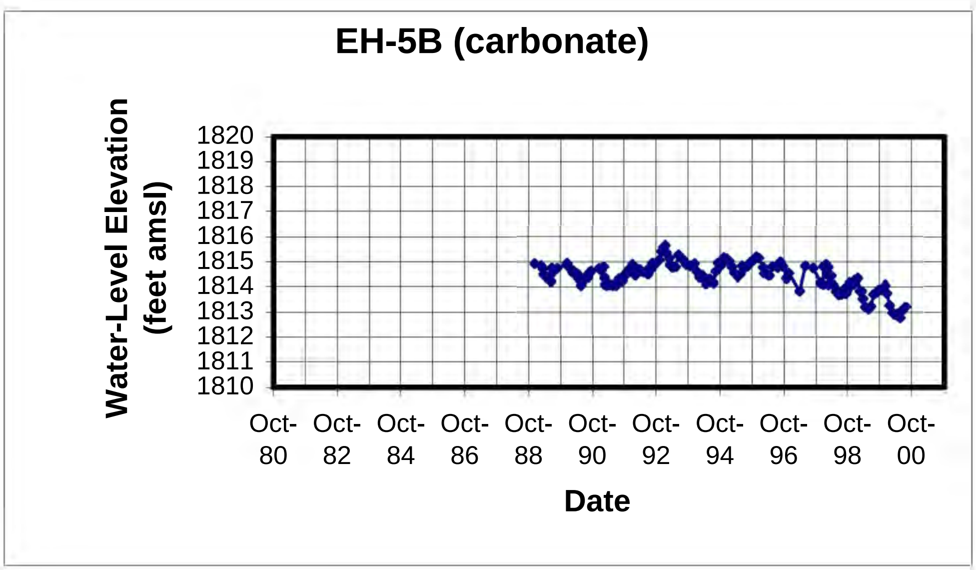


APPENDIX C

Ground-water hydrographs of selected wells with greater than 5 years of record

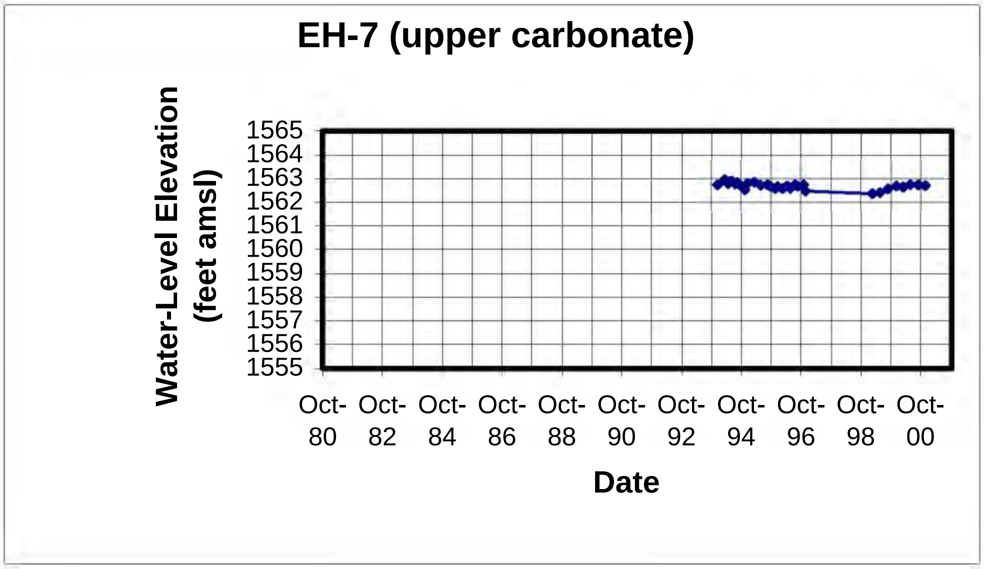


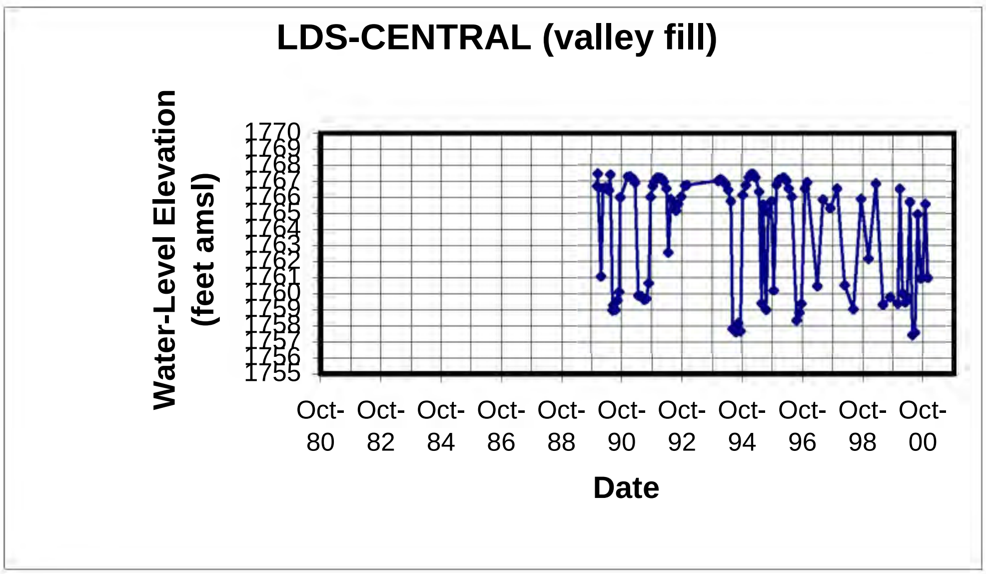


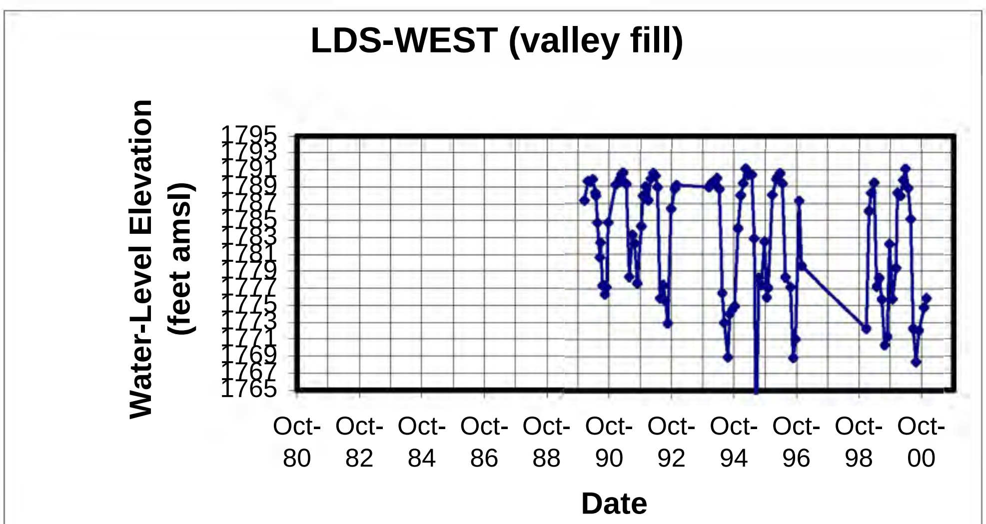


APPENDIX C

Ground-water hydrographs of selected wells with greater than 5 years of record

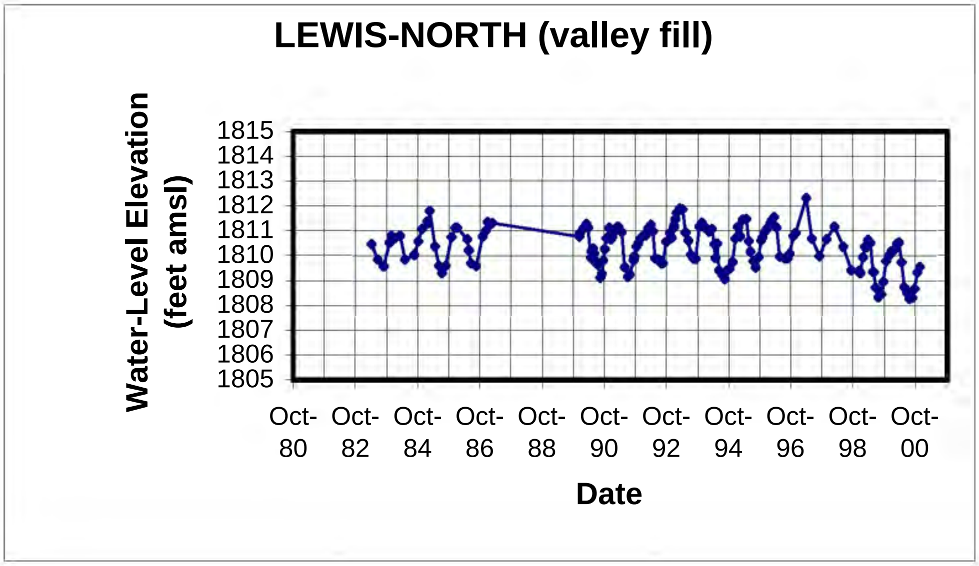


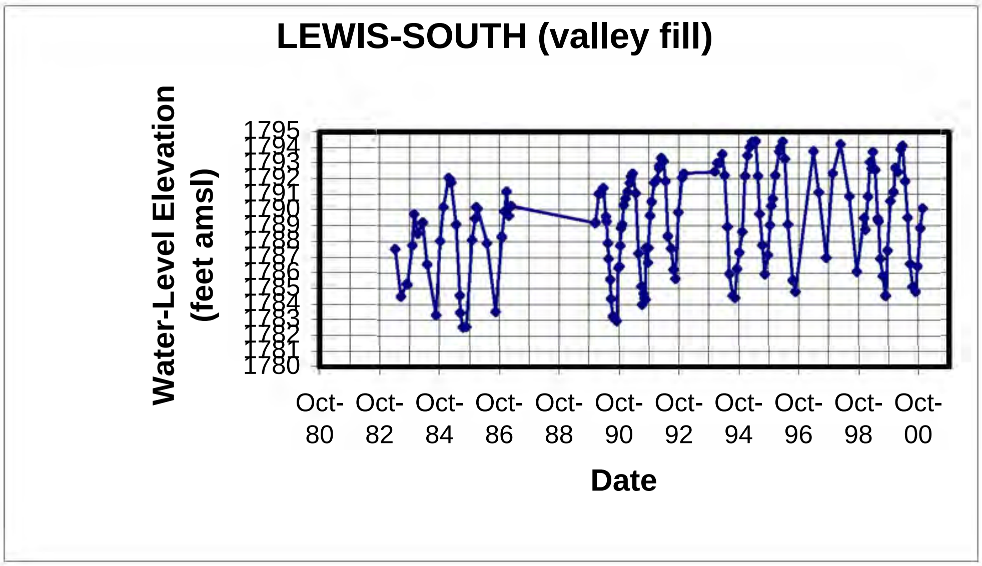


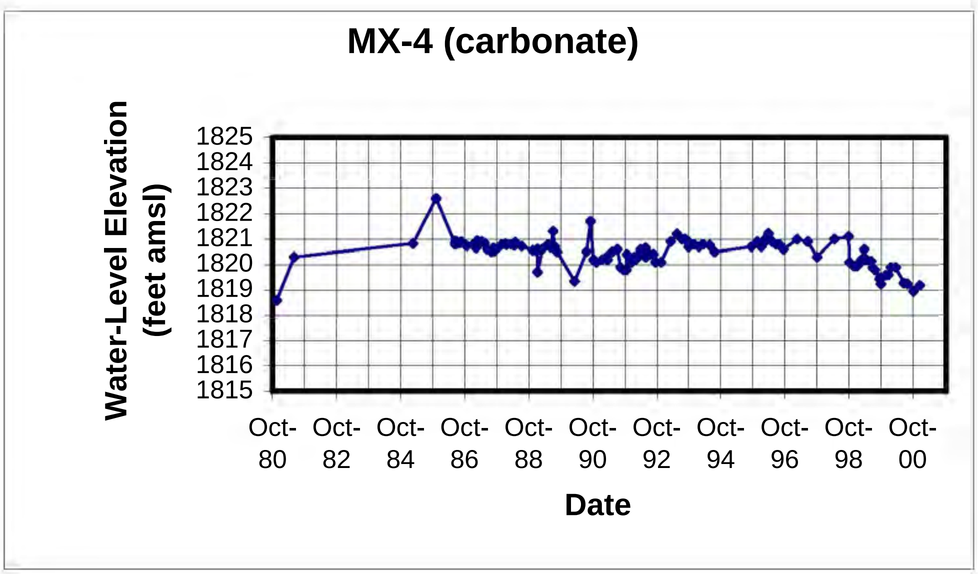


APPENDIX C

Ground-water hydrographs of selected wells with greater than 5 years of record

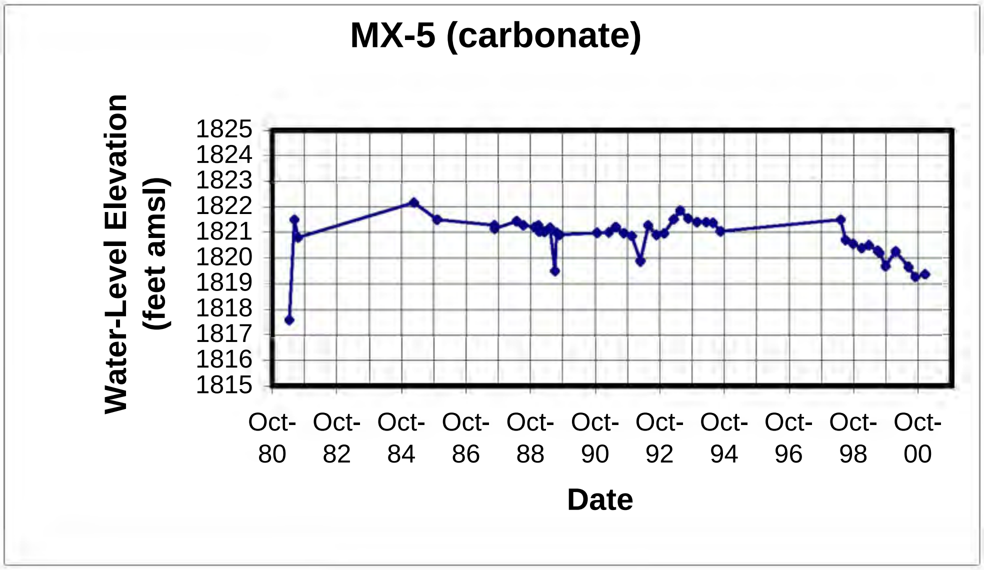


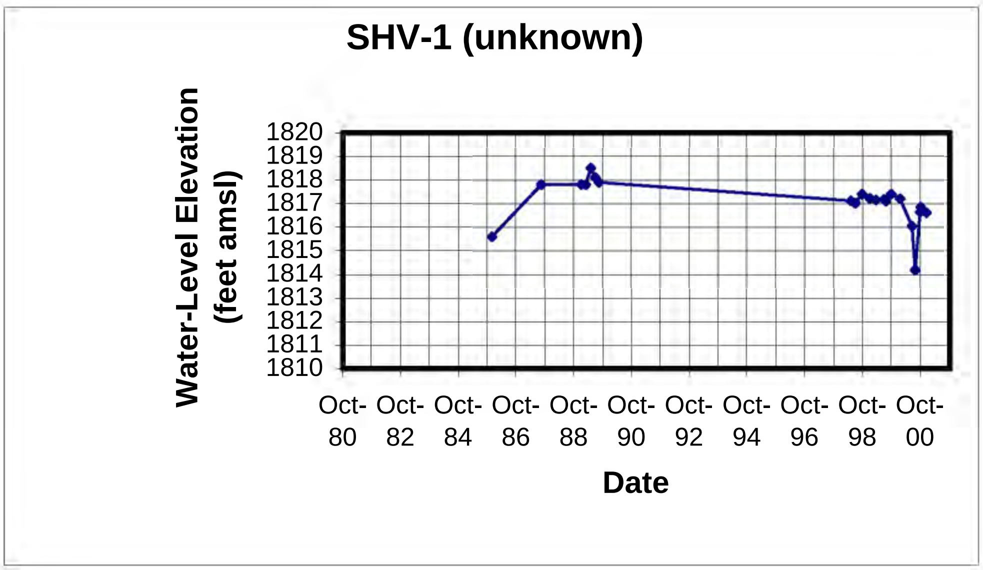




APPENDIX C

Ground-water hydrographs of selected wells with greater than 5 years of record





APPENDIX C

Table C-1. Well-Site Data

WELL_ID	ALIAS	OWNER/OPERATOR	HGU[1]	COMPLETION DATE	UTM EASTING[2] (m)	UTM NORTHING[2] (m)	ELEVATION (ft. amsl)	ELEVATION SOURCE[3]	WELL DEPTH (ft.)
ABBOTT	UM7	NPC	VF		706482	4065427	1710.83	NPC	
ACEVEDO		ACEVEDO, BEN	VF	10/30/99	729268	4045279	1273	NDWR	230
ARROW_CANYON		MVWD	C	01/25/91	701233	4067521	1875	USGS/GWSI	565
BEHMER	UM14	NPC	VF		706031	4065080	1715.77	NPC	
BM-BE-1		BONNEVILLE ENERGY	C	06/12/90	690006	4018271	2442	NDWR	1214
BM-BE-2		BONNEVILLE ENERGY	C	12/30/91	689997	4018671	2434	NDWR	960
BM-BE-3		BONNEVILLE ENERGY	C	08/16/91	689606	4018262	2391	NDWR	1241
BM-FARGO		FARGO PACIFIC	VF	5/10/1980	692376	4010399	1844	NDWR	950
BM-HEISEN-1		HEISEN, CHARLES	VF	8/4/1988	693487	4005336	1483	NDWR	440
BM-HEISEN-2		HEISEN, CHARLES	VF	11/10/1988	693478	4005737	1505	NDWR	320
BM-LIGHTFOOT-1		LIGHTFOOT, WILLIAM E	VF	11/6/1958	689739	4012191	1930	NDWR	240
BM-LIGHTFOOT-2		LIGHTFOOT, WILLIAM E	VF	10/18/1958	690608	4008973	1755	NDWR	130
BM-LIGHTFOOT-3		LIGHTFOOT, WILLIAM E	VF	9/20/1958	691204	4009171	1783	NDWR	146
BM-MARTIN		MARTIN, M B	VF	10/29/1994	693487	4005336	1483	NDWR	490
BM-ONC-1		OGLEBAY NORTON CORPORATION	VF	5/11/1995	702237.7	4010684	2110	NDWR	1291
BM-ONC-2		OGLEBAY NORTON CORPORATION	VF	5/27/1995	702247	4010283	2122	NDWR	1575
BM-SIMPLOT		SIMPLOT SILICIA PRODUCTS	VF	12/23/00	730121	4044013	1294	NDWR	203
BM-SITTON		SITTON, DORCUS	VF	11/18/1967	690138	4012200	1935	NDWR	200
CE-VF-1	365232114554401	CSI	VF	11/13/80	683135	4082805	2464.2	USGS/GWSI	714
CE-VF-2	365227114554401	CSI	C	12/15/80	683092	4082694	2466.9	USGS/GWSI	1221
CL-1		CHEM LIME	C		687748	4026564	2286.48	JOHNSON, C. et al., 2001	
CS-BUCKHORN		BUCKHORN LAND & CATTLE CO	VF	6/24/1970	678973	4095731	2573	NDWR	100
CS-GORDON		GORDON, TERRY	VF	7/11/1977	679139	4101902	2615	NDWR	500
CS-JBR		J B R ENVIRONMENTAL	VF	12/19/1996	676607	4091766	2776	NDWR	80
CSV-1	364601114514301	USGS	VF	10/16/85	690832	4070948	2158.6	USGS/GWSI	765
CSV-2	364650114432001	USGS	C	10/26/85	703269	4072746	2185.9	USGS/GWSI	478
CSV-3	364127114553001	USGS	VF	11/24/85	685386	4062380	2414.3	USGS/GWSI	780
CW-BLM-1		U S BUREAU OF LAND MANAGEMENT	VF	2/11/1949	705015.8	4042139	1976	NDWR	400
CW-BLM-2		U S BUREAU OF LAND MANAGEMENT	VF	6/17/1949	699863.7	4028081	2526	NDWR	860
CW-CLARK		CLARK, JIM	VF	7/1/1992	704617.7	4042130	1983	NDWR	680
CW-HALL		HALL, FRANK	VF	10/8/1967	702045.7	4038215	2109	NDWR	1550
CW-JONES		JONES, JOHN A	VF	12/6/1966	703286.8	4036271	2177	NDWR	500
CW-PEHLEN		PEHLEN, JACK	VF	7/3/1951	696908.3	4034150	2286	NDWR	583
CW-SCC		STEWART CONSTRUCTION CO	VF	4/24/1958	692211.1	4035863	2029	NDWR	550
DF-1	DUTCH FLAT	CSI	VF		687059	4078489	2223.6	SNWA	
EBA-1		GEORGIA PACIFIC	C	10/23/92	686513	4024108	2426.99	JOHNSON, C. et al., 2001	1598
EBM-3		NV COGEN	C		689602	4018535	2389.88	JOHNSON, C. et al., 2001	
ECP-1		CALPINE	C		696735	4046586	2233.55	JOHNSON, C. et al., 2001	1170
ECP-2		CALPINE	C		696726	4046738	2232.42	JOHNSON, C. et al., 2001	1228
ECP-3		CALPINE	C		696681	4046670	2243.63	JOHNSON, C. et al., 2001	1500
EH-2		NPC	MC	01/23/86	709965	4057216	1754	NPC	1960
EH-2A		NPC	MC		709947	4057235	1752	NPC	
EH-3	NORTH WEISER	NPC	C	02/25/86	721085	4063300	1739	NPC	793
EH-4	BATTLESHIP WASH	NPC	C	03/19/86	703929	4064736	1933.54	JOHNSON, C. et al., 2001	285
EH-5B		NPC	C	03/12/86	701569	4067619	1845.03	JOHNSON, C. et al., 2001	264

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Table C-1. Well-Site Data

WELL_ID	ALIAS	OWNER/OPERATOR	HGU[1]	COMPLETION DATE	UTM EASTING[2] (m)	UTM NORTHING[2] (m)	ELEVATION (ft. amsl)	ELEVATION SOURCE[3]	WELL DEPTH (ft.)
EH-7	SOUTH WEISER	NPC	C	04/11/86	720660	4060990	1680	NPC	440
FW-1	VALLEY OF FIRE WELL	NV STATE PARKS	C	1/15/1985	719051	4033541	2358	NDWR	1140
GARNET		NDOT	VF		690107	4030729	2066	NDWR	500
GV-1	GARNET VALLEY	DRY LAKE LLC	C	05/05/00	683063	4033946	2692.7	JOHNSON, C. et al., 2001	1400
GV-ET-1		ENVIRONMENTAL TECHNOLOGIES	VF	03/23/89	690982	4028343	2321	NDWR	560
GV-GSC-1		GREAT STAR CEMENT CORP	VF	03/30/87	693337	4031201	2293	NDWR	736
GV-KERR-1		KERR-MCGEE CHEMICAL CORP	C	02/07/90	683838	4028991	2405	NDWR	1145
GV-NDOT		STATE OF NV HIGHWAY DEPT	VF	09/10/72	690107	4030729	2066	NDWR	500
GV-SSD-1		SILVER STATE DISPOSAL	MC	06/07/96	690594	4026732	2450	NDWR	1500
GV-SSD-2		SILVER STATE DISPOSAL	VF	06/21/97	692196	4027569	2449	NDWR	940
GV-USLIME-1		U S LIME	VF	09/13/63	690310	4030549	2073	NDWR	600
GV-USLIME-2		U S LIME	VF	07/22/71	688174	4029084	2155	NDWR	500
HARVEY WELL		NPC	C		692944	4036436		NPC	575
HV-1	HIDDEN VALLEY	DRY LAKE LLC	C	06/20/00	684198	4035619	2699.85	JOHNSON, C. et al., 2001	2480
HV-HLA		HARDING LAWSON ASSOCIATES	VF	9/19/1995	687444.7	4046581	2880	NDWR	70
KS-GEYSER		GEYSER RANCH	VF	1/10/1968	706511	4120722	3590	NDWR	200
LDS-CENTRAL	UM49	NPC	VF		704189	4066366	1769.58	NPC	
LDS-WEST	UM18	NPC	VF		702799	4066922	1807.34	NPC	
LEWIS-FARM		NPC	VF		702028	4067664	1827	NPC	
LEWIS-NORTH		NPC	VF		701668	4067676	1842.42	NPC	
LEWIS-SOUTH		NPC	VF		702800	4067061	1806.45	NPC	
LMVW-1		SUMMA CORPORATION	VF	10/27/1975	718268.5	4165282	4394	NDWR	180
LMVW-10		CALIENTE PUBLIC UTILITIES	VF	11/23/1953	719067.2	4165704	4386	NDWR	190
LMVW-11		BREEDLOVE, MILDRED	VF	12/1/1962	708398.1	4086134	1962	NDWR	105
LMVW-12		NPC	VF	9/30/1981	716513.7	4061048	1532	NDWR	171
LMVW-13		NPC	VF	5/6/1981	716528.4	4061449	1538	NDWR	175
LMVW-14		NPC	VF	8/27/1962	716513.7	4061048	1532	NDWR	480
LMVW-15		PULSIPHER, BILLY H & SUSAN	VF	4/4/1974	716091.6	4061037	1538	NDWR	105
LMVW-16		BUNKERVILLE WATER USERS ASSOC	VF	1/10/1952	755231.8	4080871	2361	NDWR	265
LMVW-17		STEWART WELLS CONSTRUCTION CO	VF	12/13/1961	718420.6	4061281	1653	NDWR	190
LMVW-18		SALT LAKE & LOS ANGELES RAILRO	VF	7/10/1980	709471.5	4076724	1753	NDWR	360
LMVW-19		VANKIRK, R S & RUTH	VF	11/13/1975	723303.5	4166033	4864	NDWR	115
LMVW-2		TENNELLE, JAMES B	VF	4/20/1979	714236.3	4157989	4189	NDWR	200
LMVW-20		ATLANTA GOLD & URANIUM CO	VF	8/8/1955	731591.1	4146887	5969	NDWR	550
LMVW-21		MATTHEWS, LESTER	VF	3/25/1974	724535.4	4115508	2657	NDWR	138
LMVW-22		REYNOLDS, PATRICK	VF	7/6/1982	721876.4	4166179	4443	NDWR	108
LMVW-23	NPC-HOLE21	NPC	VF	10/28/1980	715251.5	4063822	1564	NDWR	182
LMVW-24		BRADSHAW INC	VF	4/2/1976	724873.3	4116720	2678	NDWR	141
LMVW-25		BRADSHAW, JAMES W	VF	9/3/1962	721767.5	4133356	3278	NDWR	115
LMVW-26		CONAWAY, EMORY	VF	11/24/1959	718279.1	4164881	4362	NDWR	165
LMVW-27		SUMMA CORPORATION	VF	6/3/1974	718289.7	4164480	4358	NDWR	200
LMVW-28		SUMMA CORPORATION	VF	10/26/1973	717893.8	4163668	4327	NDWR	210
LMVW-29		CONAWAY, JOHN	VF	6/2/1949	718279.1	4164881	4362	NDWR	152
LMVW-3		SUMMA CORPORATION	VF	10/31/1974	717476.9	4163657	4321	NDWR	200
LMVW-30		WISEMAN, LYLE	VF	8/7/1976	713299.8	4146615	5368	NDWR	500

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Table C-1. Well-Site Data

WELL_ID	ALIAS	OWNER/OPERATOR	HGU[1]	COMPLETION DATE	UTM EASTING[2] (m)	UTM NORTHING[2] (m)	ELEVATION (ft. amsl)	ELEVATION SOURCE[3]	WELL DEPTH (ft.)
LMVW-31		NEVADA GIRLS TRAINING CENTER	VF	6/18/1976	723303.5	4166033	4864	NDWR	120
LMVW-32		SCHLARMAN, OLIVER	VF	11/30/1961	720683	4134314	3312	NDWR	120
LMVW-33		MCKENZIE, JOHN	VF	11/21/1975	723303.5	4166033	4864	NDWR	115
LMVW-34		LEWIS, PAUL	VF	11/1/1971	715668.8	4063031	1573	NDWR	117
LMVW-35		MEADOW VALLEY PROPERTIES	VF	8/20/1981	717132.6	4160872	4264	NDWR	127
LMVW-36		OLSON, ROBERT & MARY	VF	2/12/1968	721484	4166169	4485	NDWR	123
LMVW-37		LEWIS, PAUL	VF	2/26/1974	716091.6	4061037	1538	NDWR	194
LMVW-38		BREEDLOVE, C P	VF	6/1/1963	708358	4087768	1963	NDWR	120
LMVW-39		LEWIS, RON	VF	5/1/1982	716101.7	4060636	1538	NDWR	110
LMVW-4		SUMMA CORPORATION	VF	4/16/1975	717497.1	4162886	4322	NDWR	190
LMVW-40		BRADSHAW, DON	VF	11/6/1961	724840.3	4117953	2694	NDWR	150
LMVW-41		WHITNEY, R C	VF	11/13/1996	715684.4	4061428	1545	NDWR	168
LMVW-42		STUART, ROBERT B	VF	8/9/1995	709040.1	4079149	1794	NDWR	170
LMVW-43		LONGHORN CATTLE COMPANY	VF	8/21/1994	714653.5	4158000	4603	NDWR	102
LMVW-44		HENRIE, PAUL	VF	1/6/1973	714402.4	4065004	1583	NDWR	137
LMVW-45		CUTLER, KETH	VF	5/31/1985	715236.7	4063421	1586	NDWR	200
LMVW-46		STEWART, MARK	VF	4/9/1973	715668.8	4063031	1573	NDWR	150
LMVW-47		ROARING SPRINGS RANCH	VF	10/18/1986	710279.5	4077145	1788	NDWR	111
LMVW-48		GUINN, ROBERT	VF	5/13/1974	721950.5	4107728	2538	NDWR	105
LMVW-49		MEADOW VALLEY FARMLAND IRR CO	VF	3/25/1988	714407.1	4065806	1587	NDWR	134
LMVW-5		CONAWAY, JOHN	VF	6/9/1949	717146.7	4161273	4283	NDWR	108
LMVW-50		MEADOW VALLEY FARMLAND IRR CO	VF	2/25/1988	715236	4065425	1584	NDWR	162
LMVW-51		STUART, ROBERT B	VF	4/29/1988	709040.1	4079149	1794	NDWR	150
LMVW-52		MEADOW VALLEY FARMLAND IRR CO	VF	2/16/1987	716086.2	4062240	1552	NDWR	174
LMVW-53		SCHLARMAN, HENRY T	VF	4/23/1971	715658.8	4063432	1566	NDWR	112
LMVW-54		LEWIS, ROBERT & VIVIEN	VF	4/25/1974	715678.9	4062630	1577	NDWR	130
LMVW-55		MEADOW VALLEY FARM LANES	VF	3/9/1990	715231.4	4064624	1561	NDWR	142
LMVW-56		HENRIE, PAUL	VF	3/1/1969	714402.4	4065004	1583	NDWR	139
LMVW-57		MEADOW VALLEY FARMLAND IRR CO	VF	3/3/1988	715231.4	4064624	1561	NDWR	144
LMVW-58		HENRIE, PAUL	VF	1/2/1973	714412.4	4064603	1574	NDWR	158
LMVW-59		HOUSTMA, KEN	VF	11/7/1971	714839.7	4063411	1593	NDWR	200
LMVW-6		PIOCHE PUBLIC UTILITIES	VF	8/21/1965	718448.5	4165903	4524	NDWR	595
LMVW-60		LEWIS, PAUL	VF	2/12/1974	715678.9	4062630	1577	NDWR	206
LMVW-61		LEWIS, ROBERT C & VIVIAN	VF	4/5/1983	715678.9	4062630	1577	NDWR	135
LMVW-62		PAYTAS, PAUL	VF	12/25/1971	715246.8	4063020	1609	NDWR	255
LMVW-63		PERKINS, ROBERT	VF	3/26/1973	715236.7	4063421	1586	NDWR	125
LMVW-64		EMBRY, MILTON	VF	12/28/1971	715246.8	4063020	1609	NDWR	181
LMVW-65		CALLAHAN, RALPH V	VF	6/5/1976	716101.7	4060636	1538	NDWR	150
LMVW-66		LEAVITT, GARY & DIANE	VF	4/1/1974	716091.6	4061037	1538	NDWR	173
LMVW-67		STEWART, MARK	VF	11/1/1971	715668.8	4063031	1573	NDWR	117
LMVW-68		PERKINS, ROBERT	VF	9/28/1971	715236.7	4063421	1586	NDWR	117
LMVW-69		WRIGHT, LEONARD	VF	4/20/1971	714819.6	4064212	1564	NDWR	109
LMVW-7		OLSON, ROBERT & MARY	VF	3/7/1968	722293.2	4166191	4535	NDWR	115
LMVW-70		LEWIS, PAUL	VF	2/19/1974	716101.7	4060636	1538	NDWR	205
LMVW-71		MCKNIGHT, JAMES D	VF	3/1/1969	714819.6	4064212	1564	NDWR	112

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Table C-1. Well-Site Data

WELL_ID	ALIAS	OWNER/OPERATOR	HGU[1]	COMPLETION DATE	UTM EASTING[2] (m)	UTM NORTHING[2] (m)	ELEVATION (ft. amsl)	ELEVATION SOURCE[3]	WELL DEPTH (ft.)
LMVW-72		NPC	VF	12/31/1963	715251.5	4063822	1564	NDWR	180
LMVW-73		FOLEY, RUSS	VF	1/5/1972	715658.8	4063432	1566	NDWR	141
LMVW-74		HENRIE, PAUL	VF	3/1/1969	714412.4	4064603	1574	NDWR	119
LMVW-75		NPC	VF	9/30/1981	716086.2	4062240	1552	NDWR	167
LMVW-76		NPC	VF	11/1/1963	716508.1	4062250	1541	NDWR	235
LMVW-77		BALLOW, JOE	VF	3/22/1973	714417.8	4063400	1610	NDWR	219
LMVW-78		COLE, JOE	VF	1/13/1973	714839.7	4063411	1593	NDWR	215
LMVW-79		STEELE, BOYD & WOOLEY, BOBBY F	VF	5/7/1971	715643.1	4065035	1574	NDWR	115
LMVW-8		CALIENTE PUBLIC UTILITIES	VF	3/5/1966	720247.4	4166537	4524	NDWR	195
LMVW-80	NPC-HOLE07	NPC	VF	10/23/1980	716528.4	4061449	1538	NDWR	204
LMVW-81	NPC-HOLE12	NPC	VF	10/26/1980	716508.1	4062250	1541	NDWR	204
LMVW-82	NPC-HOLE31	NPC	VF	11/7/1980	715684.4	4061428	1545	NDWR	104
LMVW-83		TENNILE, GEORGE	VF	1/26/1999	714226	4158390	4192	NDWR	130
LMVW-84	NPC-HOLE03	NPC	VF	10/14/1980	716936.6	4061027	1534	NDWR	204
LMVW-85	NPC-HOLE02	NPC	VF	10/16/1980	716946.7	4060627	1525	NDWR	160
LMVW-9		OLSON, ROBERT & MARY	VF	11/11/1965	722293.2	4166191	4535	NDWR	112
LMVW-PERKINS[4]			C		713096	4088869	2732	USGS DEM	
LMVW-TEXACO[4]			C		701232	4084759	3877	USGS DEM	
M-1		MOAPA PAIUTES	C		703851	4057823	1898.11	JOHNSON, C. et al., 2001	403
M-2		MOAPA PAIUTES	C		696307	4041041	2111.02	JOHNSON, C. et al., 2001	683
M-3		MOAPA PAIUTES	C		691446	4044464	2238.03	JOHNSON, C. et al., 2001	673
MV-1		HUGES, ROGER	VF	4/1/1983	715067.1	4044389	2673	NDWR	118
MV-10		LEWIS, PAUL R & PATRICIA	VF	1/11/1975	719755.2	4057676	1496	NDWR	135
MV-11		JENSEN, R M	VF	12/20/1959	719938.8	4058267	1507	NDWR	400
MV-12		LAS VEGAS CEMENT	VF	11/18/1985	724009.6	4057508	1500	NDWR	423
MV-13		STREET, KEVIN	VF	2/10/1997	724463.3	4056317	1431	NDWR	160
MV-14		MOAPA VALLEY WATER CO	VF	5/28/1967	724484.2	4055516	1415	NDWR	163
MV-15		ADAMS, LOUIS	VF	11/14/1957	724687.9	4055336	1410	NDWR	120
MV-16		FAY, BOB	VF	7/15/1980	725237.2	4057139	1466	NDWR	275
MV-17		LANGFORD, F H	VF	8/27/1966	725304.1	4055537	1415	NDWR	200
MV-18		CLARK COUNTY	VF	8/5/1973	725392.1	4053134	1375	NDWR	120
MV-19		LANGFORD, F H	VF	7/28/1958	725701.7	4055548	1446	NDWR	112
MV-2		NPC	VF	8/27/1962	716091.6	4061037	1538	NDWR	480
MV-20		WHITNEY, BERT N & ANNA C	VF	9/18/1971	725768.6	4053946	1403	NDWR	120
MV-21		ROBINSON, L H	VF	7/1/1967	725835.6	4052344	1367	NDWR	151
MV-22		WOOLSTON, ROBERT & IRENE	VF	9/13/1971	726155.7	4054357	1427	NDWR	120
MV-23		SEBAUGH, FRANK	VF	2/27/1976	726310.8	4050352	1314	NDWR	140
MV-24		CITY OF LOGANDALE	VF	11/21/1957	726415.8	4052976	1381	NDWR	100
MV-25		J R SIMPLOT CO	VF	3/31/1988	726672.3	4039443	1837	NDWR	525
MV-26		MARSHAL, KARL	VF	2/11/1976	726722.9	4050763	1314	NDWR	140
MV-27		BATES, D L	VF	8/26/1972	726733.5	4050363	1314	NDWR	143
MV-28		METCALF, M B	VF	12/10/1966	726744	4049962	1314	NDWR	140
MV-29		HORN, ERIC	VF	3/18/1967	726937.2	4050183	1314	NDWR	130
MV-3		EWING, JAMES L	VF	2/15/1980	716112.6	4060205	1544	NDWR	198
MV-30		LAHM, ROBERT LEE & EVELYN	VF	5/5/1973	727187.8	4049172	1304	NDWR	150

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Table C-1. Well-Site Data

WELL_ID	ALIAS	OWNER/OPERATOR	HGU[1]	COMPLETION DATE	UTM EASTING[2] (m)	UTM NORTHING[2] (m)	ELEVATION (ft. amsl)	ELEVATION SOURCE[3]	WELL DEPTH (ft.)
MV-31		LONG, SIMON & BERNICE	VF	7/27/1982	727440.5	4052787	1418	NDWR	250
MV-32		RAMOS, MIKE	VF	3/26/1976	727585.6	4049182	1295	NDWR	150
MV-33		PERKINS, W V	VF	3/24/1978	727643.1	4047950	1288	NDWR	127
MV-34		PERKINS, W V	VF	3/24/1978	727691.2	4048013	1287	NDWR	220
MV-35		MCANICH, LEWIS	VF	7/22/1983	727884.2	4051997	1396	NDWR	120
MV-36		MATHIS, EARNEST G	VF	4/30/1977	728018.8	4048793	1285	NDWR	104
MV-37		STRINGHAM, STANLEY	VF	2/12/1978	728363.5	4050807	1368	NDWR	328
MV-38		ESTRADO, JUAN & SENAIDA	VF	4/29/1977	728452.2	4048403	1275	NDWR	104
MV-39		CLARK COUNTY	VF	5/19/1971	728646.2	4048594	1274	NDWR	120
MV-4		NEVADA SILICA CORP	VF		716544.8	4059815	1514	NDWR	150
MV-40		MOAPA VALLEY DAIRY FARMS	VF	3/23/1988	729294.9	4047593	1250	NDWR	145
MV-41		PERKINS, JACK	VF	2/23/1975	729670.6	4048436	1315	NDWR	242
MV-42		SIMPLOT SILICON PRODUCTS	VF	5/25/1976	730212.8	4043978	1292	NDWR	100
MV-43		U S NATIONAL PARK SERVICE	VF	6/26/1956	731965.8	4045444	1279	NDWR	300
MV-44		STEVENS, BERT	VF	2/4/1954	732009	4043841	1213	NDWR	106
MV-45		BUNKERVILLE WATER USERS ASSOC	VF	9/15/1960	755457.3	4070851	1744	NDWR	300
MV-5		C X PRODUCTS CORP	VF	11/26/1973	717001.9	4059425	1565	NDWR	360
MV-6		HESTER, CHARLIE	VF	1/14/1975	718655.5	4059868	1591	NDWR	200
MV-7		LEWIS, PAUL	VF	5/31/1960	719122.9	4059078	1552	NDWR	170
MV-8		STATE OF NEVADA	VF	4/3/1978	719443	4034784	2236	NDWR	500
MV-9		LEWIS, PAUL R & PATRICIA	VF	1/11/1975	719734.7	4058477	1540	NDWR	135
MV-UNKNOWN[4]			C		725591	4075915	2595	USGS DEM	
MX-4	364743114533101	CSI	C	11/20/80	688085	4074033	2172.6	USGS/GWSI	669
MX-5	364741114532801	SNWA	C	04/14/81	688166	4074024	2170	USGS/GWSI	628
MX-6	364604114471301	MVWD	C	05/21/81	697525	4071193	2274.6	USGS/GWSI	937
SHV-1	363308114553001	BLM	C		685831	4047059	2648.8	USGS/GWSI	920
TH-1		MOAPA PAIUTES	C		697237	4044962	2169.95	JOHNSON, C. et al., 2001	1100
TH-2		MOAPA PAIUTES	C		697687	4049913	2341.7	JOHNSON, C. et al., 2001	1198

1. *HGU (hydrogeologic unit) designations: C = Carbonate Aquifer; VF = Valley Fill Aquifer; MC = Muddy Creek Formation*
2. *UTM Zone 11, NAD 27*
3. *Elevation sources: JOHNSON, C. et al., 2001 = Johnson et al., 2001, Hydrogeologic and groundwater modeling analyses for the Moapa Paiute Energy Center, 78 p.*
   NDWR = NDWR Well Log Database
   NPC = Nevada Power Company
   SNWA = Southern Nevada Water Authority
   USGS DEM = USGS Seamless Digital Elevation Model
   USGS/GWSI = USGS Ground-water Site Inventory Database
4. *Site location from unpublished map by Buqo, T. (2001, oral commun.)*

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
ABBOTT	UM7	01/04/90	1710.83	8.38	1702.45	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	01/12/90	1710.83	8.58	1702.25	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	02/20/90	1710.83	8.32	1702.51	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	03/16/90	1710.83	8.19	1702.64	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	03/28/90	1710.83	7.96	1702.87	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	04/16/90	1710.83	7.16	1703.67	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	05/18/90	1710.83	6.84	1703.99	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	05/25/90	1710.83	7.9	1702.93	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	06/12/90	1710.83	8.32	1702.51	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	06/18/90	1710.83	10.7	1700.13	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	06/26/90	1710.83	12.39	1698.44	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	07/10/90	1710.83	13.77	1697.06	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	07/18/90	1710.83	14.05	1696.78	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	08/10/90	1710.83	14.5	1696.33	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	09/07/90	1710.83	14.97	1695.86	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	09/20/90	1710.83	15.84	1694.99	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	10/12/90	1710.83	15.71	1695.12	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	10/16/90	1710.83	16.14	1694.69	M.D. MIFFLIN, MAY 1991
ABBOTT	UM7	01/11/91	1710.83	11.11	1699.72	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	02/05/91	1710.83	8.03	1702.80	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	02/14/91	1710.83	8.5	1702.33	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	03/06/91	1710.83	8.65	1702.18	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	03/21/91	1710.83	9.56	1701.27	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	04/08/91	1710.83	8.76	1702.07	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	05/16/91	1710.83	9	1701.83	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	06/18/91	1710.83	9.75	1701.08	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	07/25/91	1710.83	10.39	1700.44	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	08/20/91	1710.83	10.7	1700.13	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	08/29/91	1710.83	11.29	1699.54	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	09/20/91	1710.83	12.15	1698.68	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	10/11/91	1710.83	12.73	1698.10	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	11/06/91	1710.83	11.67	1699.16	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	11/20/91	1710.83	11.01	1699.82	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	12/27/91	1710.83	9.29	1701.54	M.D. MIFFLIN, MAY 1992
ABBOTT	UM7	01/27/92	1710.83	8.58	1702.25	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	02/24/92	1710.83	6.92	1703.91	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	03/20/92	1710.83	6.21	1704.62	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	04/21/92	1710.83	8.47	1702.36	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	05/13/92	1710.83	9.13	1701.70	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	06/12/92	1710.83	9.95	1700.88	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	07/23/92	1710.83	11.2	1699.63	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	08/13/92	1710.83	11.12	1699.71	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	08/18/92	1710.83	11.32	1699.51	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	09/02/92	1710.83	10.05	1700.78	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	09/10/92	1710.83	9.37	1701.46	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	10/19/92	1710.83	9.71	1701.12	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	12/01/92	1710.83	7.69	1703.14	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	12/23/92	1710.83	7.23	1703.60	M.D. MIFFLIN, APRIL 1993
ABBOTT	UM7	01/05/94	1710.83	9.09	1701.74	KARL F. POHLMANN, JUNE 1995
ABBOTT	UM7	02/04/94	1710.83	8.77	1702.06	KARL F. POHLMANN, JUNE 1995
ABBOTT	UM7	04/03/94	1710.83	8.84	1701.99	KARL F. POHLMANN, JUNE 1995
ABBOTT	UM7	06/05/94	1710.83	8.09	1702.74	KARL F. POHLMANN, JUNE 1995
ABBOTT	UM7	06/09/94	1710.83	8.74	1702.09	KARL F. POHLMANN, JUNE 1995
ABBOTT	UM7	06/25/94	1710.83	7.68	1703.15	KARL F. POHLMANN, JUNE 1995
ABBOTT	UM7	07/02/94	1710.83	11.1	1699.73	KARL F. POHLMANN, JUNE 1995
ABBOTT	UM7	08/04/94	1710.83	8.15	1702.68	KARL F. POHLMANN, JUNE 1995
ABBOTT	UM7	08/12/94	1710.83	12.39	1698.44	KARL F. POHLMANN, JUNE 1995

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
ABBOTT	UM7	09/06/94	1710.83	12.34	1698.49	KARL F. POHLMANN, JUNE 1995
ABBOTT	UM7	10/04/94	1710.83	11.17	1699.66	KARL F. POHLMANN, JUNE 1995
ABBOTT	UM7	11/01/94	1710.83	9.89	1700.94	KARL F. POHLMANN, JUNE 1995
ABBOTT	UM7	12/08/94	1710.83	11.33	1699.5	KARL F. POHLMANN, JUNE 1995
ABBOTT	UM7	01/09/95	1710.83	9.72	1701.11	KARL F. POHLMANN, MAY 1996
ABBOTT	UM7	02/08/95	1710.83	8.29	1702.54	KARL F. POHLMANN, MAY 1996
ABBOTT	UM7	03/08/95	1710.83	7	1703.83	KARL F. POHLMANN, MAY 1996
ABBOTT	UM7	04/05/95	1710.83	6.57	1704.26	KARL F. POHLMANN, MAY 1996
ABBOTT	UM7	05/18/95	1710.83	6.69	1704.14	KARL F. POHLMANN, MAY 1996
ABBOTT	UM7	06/16/95	1710.83	8.35	1702.48	KARL F. POHLMANN, MAY 1996
ABBOTT	UM7	07/05/95	1710.83	7.8	1703.03	KARL F. POHLMANN, MAY 1996
ABBOTT	UM7	08/09/95	1710.83	9.77	1701.06	KARL F. POHLMANN, MAY 1996
ABBOTT	UM7	09/07/95	1710.83	11.79	1699.04	KARL F. POHLMANN, MAY 1996
ABBOTT	UM7	10/12/95	1710.83	10.05	1700.78	KARL F. POHLMANN, MAY 1996
ABBOTT	UM7	11/09/95	1710.83	9.85	1700.98	KARL F. POHLMANN, MAY 1996
ABBOTT	UM7	11/24/95	1710.83	9.79	1701.04	KARL F. POHLMANN, MAY 1996
ABBOTT	UM7	12/14/95	1710.83	7.77	1703.06	KARL F. POHLMANN, MAY 1996
ABBOTT	UM7	01/12/96	1710.83	6.17	1704.66	KARL F. POHLMANN, MARCH 1997
ABBOTT	UM7	03/01/96	1710.83	6.76	1704.07	KARL F. POHLMANN, MARCH 1997
ABBOTT	UM7	03/14/96	1710.83	7.29	1703.54	KARL F. POHLMANN, MARCH 1997
ABBOTT	UM7	04/11/96	1710.83	7.16	1703.67	KARL F. POHLMANN, MARCH 1997
ABBOTT	UM7	05/08/96	1710.83	6.86	1703.97	KARL F. POHLMANN, MARCH 1997
ABBOTT	UM7	06/14/96	1710.83	8.37	1702.46	KARL F. POHLMANN, MARCH 1997
ABBOTT	UM7	08/13/96	1710.83	12.61	1698.22	KARL F. POHLMANN, MARCH 1997
ABBOTT	UM7	09/13/96	1710.83	13.96	1696.87	KARL F. POHLMANN, MARCH 1997
ABBOTT	UM7	10/10/96	1710.83	14.08	1696.75	KARL F. POHLMANN, MARCH 1997
ABBOTT	UM7	12/18/96	1710.83	10.7	1700.13	KARL F. POHLMANN, MARCH 1997
ABBOTT	UM7	01/15/99	1710.83	9.98	1700.85	CONVERSE, 02/25/00
ABBOTT	UM7	02/16/99	1710.83	9.17	1701.66	CONVERSE, 02/25/00
ABBOTT	UM7	03/12/99	1710.83	8.86	1701.97	CONVERSE, 02/25/00
ABBOTT	UM7	04/15/99	1710.83	8.54	1702.29	CONVERSE, 02/25/00
ABBOTT	UM7	05/14/99	1710.83	8.5	1702.33	CONVERSE, 02/25/00
ABBOTT	UM7	06/15/99	1710.83	9.42	1701.41	CONVERSE, 02/25/00
ABBOTT	UM7	07/15/99	1710.83	9.89	1700.94	CONVERSE, 02/25/00
ABBOTT	UM7	08/16/99	1710.83	10.78	1700.05	CONVERSE, 02/25/00
ABBOTT	UM7	09/16/99	1710.83	11.06	1699.77	CONVERSE, 02/25/00
ABBOTT	UM7	10/12/99	1710.83	11.08	1699.75	CONVERSE, 02/25/00
ABBOTT	UM7	11/16/99	1710.83	9.06	1701.77	CONVERSE, 02/25/00
ABBOTT	UM7	12/28/99	1710.83	9.07	1701.76	CONVERSE, 02/25/00
ABBOTT	UM7	01/14/00	1710.83	9.06	1701.77	CONVERSE, 02/15/01
ABBOTT	UM7	02/15/00	1710.83	9.01	1701.82	CONVERSE, 02/15/01
ABBOTT	UM7	03/21/00	1710.83	8.46	1702.37	CONVERSE, 02/15/01
ABBOTT	UM7	04/14/00	1710.83	8.89	1701.94	CONVERSE, 02/15/01
ABBOTT	UM7	05/15/00	1710.83	10.36	1700.47	CONVERSE, 02/15/01
ABBOTT	UM7	06/14/00	1710.83	13.91	1696.92	CONVERSE, 02/15/01
ABBOTT	UM7	07/14/00	1710.83	14.12	1696.71	CONVERSE, 02/15/01
ABBOTT	UM7	08/15/00	1710.83	14.14	1696.69	CONVERSE, 02/15/01
ABBOTT	UM7	09/19/00	1710.83	12.37	1698.46	CONVERSE, 02/15/01
ABBOTT	UM7	10/13/00	1710.83	12.69	1698.14	CONVERSE, 02/15/01
ABBOTT	UM7	11/16/00	1710.83	13.39	1697.44	CONVERSE, 02/15/01
ABBOTT	UM7	12/15/00	1710.83	13.16	1697.67	CONVERSE, 02/15/01
ACEVEDO		10/30/99	1273.13	26	1247	NDWR
BEHMER	UM14	03/15/89	1715.77	14	1701.77	M.D. MIFFLIN, MAY 1991
BEHMER	UM14	04/14/89	1715.77	13.6	1702.17	M.D. MIFFLIN, MAY 1991
BEHMER	UM14	05/16/89	1715.77	12.8	1702.97	M.D. MIFFLIN, MAY 1991
BEHMER	UM14	05/31/89	1715.77	14.59	1701.18	M.D. MIFFLIN, MAY 1991
BEHMER	UM14	06/09/89	1715.77	18.59	1697.18	M.D. MIFFLIN, MAY 1991

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
BEHMER	UM14	06/16/89	1715.77	20.31	1695.46	M.D. MIFFLIN, MAY 1991
BEHMER	UM14	06/22/89	1715.77	22.28	1693.49	M.D. MIFFLIN, MAY 1991
BEHMER	UM14	06/28/89	1715.77	22.19	1693.58	M.D. MIFFLIN, MAY 1991
BEHMER	UM14	07/10/89	1715.77	22.79	1692.98	M.D. MIFFLIN, MAY 1991
BEHMER	UM14	07/14/89	1715.77	23.53	1692.24	M.D. MIFFLIN, MAY 1991
BEHMER	UM14	07/21/89	1715.77	24.34	1691.43	M.D. MIFFLIN, MAY 1991
BEHMER	UM14	01/04/90	1715.77	10.45	1705.32	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	01/12/90	1715.77	12.37	1703.4	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	02/20/90	1715.77	13.27	1702.5	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	03/16/90	1715.77	11.98	1703.79	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	04/16/90	1715.77	11.52	1704.25	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	05/04/90	1715.77	9.52	1706.25	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	05/18/90	1715.77	9.38	1706.39	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	05/25/90	1715.77	12.63	1703.14	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	06/12/90	1715.77	12.44	1703.33	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	07/10/90	1715.77	14.25	1701.52	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	07/18/90	1715.77	14.43	1701.34	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	08/10/90	1715.77	15.72	1700.05	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	09/07/90	1715.77	12.53	1703.24	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	09/27/90	1715.77	11.33	1704.44	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	10/11/90	1715.77	16.65	1699.12	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	10/16/90	1715.77	15.54	1700.23	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	10/30/90	1715.77	11.41	1704.36	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	11/08/90	1715.77	15.96	1699.81	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	11/19/90	1715.77	14.54	1701.23	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	12/03/90	1715.77	12.11	1703.66	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	12/20/90	1715.77	17.31	1698.46	KARL F. POHLMANN, JUNE 1991
BEHMER	UM14	01/11/91	1715.77	18	1697.77	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	01/17/91	1715.77	13.3	1702.47	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	02/05/91	1715.77	13.42	1702.35	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	02/14/91	1715.77	14.41	1701.36	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	03/06/91	1715.77	15.4	1700.37	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	03/15/91	1715.77	16.38	1699.39	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	03/21/91	1715.77	15.73	1700.04	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	04/08/91	1715.77	14.65	1701.12	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	05/16/91	1715.77	15.39	1700.38	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	06/18/91	1715.77	15.54	1700.23	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	07/25/91	1715.77	16.08	1699.69	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	08/20/91	1715.77	16.38	1699.39	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	09/09/91	1715.77	17.67	1698.10	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	09/13/91	1715.77	18.02	1697.75	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	10/03/91	1715.77	19.5	1696.27	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	10/11/91	1715.77	19.86	1695.91	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	10/17/91	1715.77	19.32	1696.45	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	11/06/91	1715.77	17.58	1698.19	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	11/20/91	1715.77	16.66	1699.11	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	12/27/91	1715.77	14.54	1701.23	M.D. MIFFLIN, MAY 1992
BEHMER	UM14	01/27/92	1715.77	14.22	1701.55	M.D. MIFFLIN, APRIL 1993
BEHMER	UM14	02/24/92	1715.77	10.63	1705.14	M.D. MIFFLIN, APRIL 1993
BEHMER	UM14	03/24/92	1715.77	13.21	1702.56	M.D. MIFFLIN, APRIL 1993
BEHMER	UM14	04/21/92	1715.77	14.44	1701.33	M.D. MIFFLIN, APRIL 1993
BEHMER	UM14	05/13/92	1715.77	15.08	1700.69	M.D. MIFFLIN, APRIL 1993
BEHMER	UM14	06/12/92	1715.77	15.8	1699.97	M.D. MIFFLIN, APRIL 1993
BEHMER	UM14	07/23/92	1715.77	17.32	1698.45	M.D. MIFFLIN, APRIL 1993
BEHMER	UM14	08/13/92	1715.77	17.1	1698.67	M.D. MIFFLIN, APRIL 1993
BEHMER	UM14	09/02/92	1715.77	14.02	1701.75	M.D. MIFFLIN, APRIL 1993
BEHMER	UM14	09/10/92	1715.77	13.04	1702.73	M.D. MIFFLIN, APRIL 1993

APPENDIX C

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
BEHMER	UM14	10/19/92	1715.77	13.24	1702.53	M.D. MIFFLIN, APRIL 1993
BEHMER	UM14	12/23/92	1715.77	11.41	1704.36	M.D. MIFFLIN, APRIL 1993
BEHMER	UM14	01/05/94	1715.77	12.58	1703.19	KARL F. POHLMANN, JUNE 1995
BEHMER	UM14	02/04/94	1715.77	12.08	1703.69	KARL F. POHLMANN, JUNE 1995
BEHMER	UM14	03/04/94	1715.77	13.08	1702.69	KARL F. POHLMANN, JUNE 1995
BEHMER	UM14	05/06/94	1715.77	10.76	1705.01	KARL F. POHLMANN, JUNE 1995
BEHMER	UM14	06/09/94	1715.77	11.75	1704.02	KARL F. POHLMANN, JUNE 1995
BEHMER	UM14	07/02/94	1715.77	16.9	1698.87	KARL F. POHLMANN, JUNE 1995
BEHMER	UM14	08/12/94	1715.77	18.65	1697.12	KARL F. POHLMANN, JUNE 1995
BEHMER	UM14	09/06/94	1715.77	17.22	1698.55	KARL F. POHLMANN, JUNE 1995
BEHMER	UM14	10/04/94	1715.77	13.88	1701.89	KARL F. POHLMANN, JUNE 1995
BEHMER	UM14	11/01/94	1715.77	12.65	1703.12	KARL F. POHLMANN, JUNE 1995
BEHMER	UM14	12/08/94	1715.77	16.72	1699.05	KARL F. POHLMANN, JUNE 1995
BEHMER	UM14	01/09/95	1715.77	14.5	1701.27	KARL F. POHLMANN, MAY 1996
BEHMER	UM14	02/08/95	1715.77	11.12	1704.65	KARL F. POHLMANN, MAY 1996
BEHMER	UM14	03/08/95	1715.77	9.3	1706.47	KARL F. POHLMANN, MAY 1996
BEHMER	UM14	04/05/95	1715.77	9.15	1706.62	KARL F. POHLMANN, MAY 1996
BEHMER	UM14	05/18/95	1715.77	8.81	1706.96	KARL F. POHLMANN, MAY 1996
BEHMER	UM14	06/18/95	1715.77	11.95	1703.82	KARL F. POHLMANN, MAY 1996
BEHMER	UM14	07/05/95	1715.77	10.69	1705.08	KARL F. POHLMANN, MAY 1996
BEHMER	UM14	08/09/95	1715.77	14.95	1700.82	KARL F. POHLMANN, MAY 1996
BEHMER	UM14	09/07/95	1715.77	17.47	1698.3	KARL F. POHLMANN, MAY 1996
BEHMER	UM14	10/12/95	1715.77	13.42	1702.35	KARL F. POHLMANN, MAY 1996
BEHMER	UM14	11/09/95	1715.77	14.92	1700.85	KARL F. POHLMANN, MAY 1996
BEHMER	UM14	12/14/95	1715.77	10.93	1704.84	KARL F. POHLMANN, MAY 1996
BEHMER	UM14	01/12/96	1715.77	9.09	1706.68	KARL F. POHLMANN, MARCH 1997
BEHMER	UM14	03/01/96	1715.77	10.36	1705.41	KARL F. POHLMANN, MARCH 1997
BEHMER	UM14	03/14/96	1715.77	12.89	1702.88	KARL F. POHLMANN, MARCH 1997
BEHMER	UM14	04/11/96	1715.77	13.02	1702.75	KARL F. POHLMANN, MARCH 1997
BEHMER	UM14	05/08/96	1715.77	10.01	1705.76	KARL F. POHLMANN, MARCH 1997
BEHMER	UM14	06/14/96	1715.77	11.9	1703.87	KARL F. POHLMANN, MARCH 1997
BEHMER	UM14	08/13/96	1715.77	18.65	1697.12	KARL F. POHLMANN, MARCH 1997
BEHMER	UM14	09/13/96	1715.77	20.28	1695.49	KARL F. POHLMANN, MARCH 1997
BEHMER	UM14	10/10/96	1715.77	20.06	1695.71	KARL F. POHLMANN, MARCH 1997
BEHMER	UM14	11/22/96	1715.77	13.8	1701.97	KARL F. POHLMANN, MARCH 1997
BEHMER	UM14	12/18/96	1715.77	15.06	1700.71	KARL F. POHLMANN, MARCH 1997
BEHMER	UM14	01/15/99	1715.77	13.98	1701.79	CONVERSE, 02/25/00
BEHMER	UM14	02/16/99	1715.77	11.21	1704.56	CONVERSE, 02/25/00
BEHMER	UM14	03/12/99	1715.77	12.86	1702.91	CONVERSE, 02/25/00
BEHMER	UM14	04/15/99	1715.77	11.14	1704.63	CONVERSE, 02/25/00
BEHMER	UM14	05/14/99	1715.77	9.98	1705.79	CONVERSE, 02/25/00
BEHMER	UM14	06/14/99	1715.77	10.75	1705.02	CONVERSE, 02/25/00
BEHMER	UM14	07/15/99	1715.77	13.69	1702.08	CONVERSE, 02/25/00
BEHMER	UM14	08/16/99	1715.77	12.71	1703.06	CONVERSE, 02/25/00
BEHMER	UM14	09/16/99	1715.77	13.73	1702.04	CONVERSE, 02/25/00
BEHMER	UM14	10/12/99	1715.77	14.29	1701.48	CONVERSE, 02/25/00
BEHMER	UM14	11/16/99	1715.77	11.79	1703.98	CONVERSE, 02/25/00
BEHMER	UM14	12/28/99	1715.77	12.76	1703.01	CONVERSE, 02/25/00
BEHMER	UM14	01/14/00	1715.77	12.73	1703.04	CONVERSE, 02/15/01
BEHMER	UM14	02/15/00	1715.77	12.67	1703.1	CONVERSE, 02/15/01
BEHMER	UM14	03/21/00	1715.77	12.08	1703.69	CONVERSE, 02/15/01
BEHMER	UM14	04/14/00	1715.77	12.79	1702.98	CONVERSE, 02/15/01
BEHMER	UM14	05/15/00	1715.77	15.51	1700.26	CONVERSE, 02/15/01
BEHMER	UM14	06/14/00	1715.77	21.61	1694.16	CONVERSE, 02/15/01
BEHMER	UM14	07/14/00	1715.77	21.09	1694.68	CONVERSE, 02/15/01
BEHMER	UM14	08/15/00	1715.77	20.55	1695.22	CONVERSE, 02/15/01
BEHMER	UM14	09/19/00	1715.77	13.89	1701.88	CONVERSE, 02/15/01

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
BEHMER	UM14	10/13/00	1715.77	16.94	1698.83	CONVERSE, 02/15/01
BEHMER	UM14	11/16/00	1715.77	18.48	1697.29	CONVERSE, 02/15/01
BEHMER	UM14	12/12/00	1715.77	18.42	1697.35	CONVERSE, 02/15/01
BM-BE-1		06/12/90	2442.46	575	1867	NDWR
BM-BE-2		12/30/91	2434.21	608	1826	NDWR
BM-BE-3		08/16/91	2391.14	559	1832	NDWR
BM-FARGO		05/10/80	1844.35	137	1707	NDWR
BM-HEISEN-1		08/04/88	1483.37	155	1328	NDWR
BM-HEISEN-2		11/10/88	1505.27	150	1355	NDWR
BM-LIGHTFOOT-1		11/06/58	1930.28	40	1890	NDWR
BM-LIGHTFOOT-2		10/18/58	1754.62	20	1735	NDWR
BM-LIGHTFOOT-3		09/20/58	1783.48	14	1769	NDWR
BM-MARTIN		10/29/94	1483.37	180	1303	NDWR
BM-ONC-1		05/11/95	2109.93	344.09	1766	NDWR
BM-ONC-2		05/27/95	2121.92	549.55	1572	NDWR
BM-SIMPLOT		12/23/00	1293.85	25	1269	NDWR
BM-SITTON		11/18/67	1935.45	44	1891	NDWR
CE-VF-1	365232114554401	11/22/80	2464.20	549	1915.2	USGS
CE-VF-1	365232114554401	07/14/81	2464.20	548	1916.2	USGS
CE-VF-1	365232114554401	09/29/81	2464.20	548	1916.2	USGS
CE-VF-1	365232114554401	06/06/85	2464.20	547.77	1916.43	USGS
CE-VF-1	365232114554401	01/28/86	2464.20	542.98	1921.22	BERGER et al., 1988
CE-VF-1	365232114554401	01/29/86	2464.20	543	1921.2	USGS
CE-VF-1	365232114554401	02/05/86	2464.20	542.8	1921.4	USGS
CE-VF-1	365232114554401	02/06/86	2464.20	542.7	1921.5	USGS
CE-VF-1	365232114554401	09/13/86	2464.20	548.8	1915.4	USGS
CE-VF-1	365232114554401	05/17/88	2464.20	548.5	1915.7	USGS
CE-VF-1	365232114554401	08/04/88	2464.20	548.9	1915.3	USGS
CE-VF-1	365232114554401	12/13/88	2464.20	548.48	1915.72	USGS
CE-VF-1	365232114554401	01/31/89	2464.20	549.1	1915.1	USGS
CE-VF-1	365232114554401	03/28/89	2464.20	549	1915.2	USGS
CE-VF-1	365232114554401	05/30/89	2464.20	549	1915.2	USGS
CE-VF-1	365232114554401	07/26/89	2464.20	549.1	1915.1	USGS
CE-VF-1	365232114554401	09/12/89	2464.20	549.1	1915.1	USGS
CE-VF-1	365232114554401	11/13/90	2464.20	548.9	1915.3	USGS
CE-VF-1	365232114554401	03/26/91	2464.20	548.4	1915.8	USGS
CE-VF-1	365232114554401	06/13/91	2464.20	548.6	1915.6	USGS
CE-VF-1	365232114554401	09/12/91	2464.20	549	1915.2	USGS
CE-VF-1	365232114554401	12/10/91	2464.20	548.7	1915.5	USGS
CE-VF-1	365232114554401	03/18/92	2464.20	548.6	1915.6	USGS
CE-VF-1	365232114554401	06/17/92	2464.20	548.7	1915.5	USGS
CE-VF-1	365232114554401	09/08/92	2464.20	548.9	1915.3	USGS
CE-VF-1	365232114554401	12/21/92	2464.20	549.3	1914.9	USGS
CE-VF-1	365232114554401	03/31/93	2464.20	549.2	1915	USGS
CE-VF-1	365232114554401	06/07/93	2464.20	549	1915.2	USGS
CE-VF-1	365232114554401	09/07/93	2464.20	549.3	1914.9	USGS
CE-VF-1	365232114554401	12/15/93	2464.20	549	1915.2	USGS
CE-VF-1	365232114554401	03/31/94	2464.20	548	1916.2	USGS
CE-VF-1	365232114554401	07/07/94	2464.20	548.65	1915.55	USGS
CE-VF-1	365232114554401	09/20/94	2464.20	548.71	1915.49	USGS
CE-VF-1	365232114554401	07/19/99	2464.20	548.81	1915.39	SNWA
CE-VF-1	365232114554401	10/19/99	2464.20	549.25	1914.95	SNWA
CE-VF-1	365232114554401	02/09/00	2464.20	548.85	1915.35	SNWA
CE-VF-1	365232114554401	07/07/00	2464.20	549.04	1915.16	SNWA
CE-VF-1	365232114554401	01/05/01	2464.20	549.3	1914.9	SNWA
CE-VF-2	365227114554401	07/11/81	2466.90	611.7	1855.2	BERGER et al., 1988
CE-VF-2	365227114554401	09/29/81	2466.90	609	1857.9	USGS

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
CE-VF-2	365227114554401	02/05/85	2466.90	603.1	1863.8	USGS
CE-VF-2	365227114554401	11/25/85	2466.90	602	1864.9	USGS
CE-VF-2	365227114554401	01/28/86	2466.90	604.62	1862.28	BERGER et al., 1988
CE-VF-2	365227114554401	01/29/86	2466.90	604.1	1862.8	USGS
CE-VF-2	365227114554401	02/04/86	2466.90	604.3	1862.6	USGS
CE-VF-2	365227114554401	02/05/86	2466.90	604.3	1862.6	USGS
CE-VF-2	365227114554401	02/06/86	2466.90	604.3	1862.6	TUMBUSCH et al., 1996
CE-VF-2	365227114554401	09/13/87	2466.90	609.7	1857.2	USGS
CE-VF-2	365227114554401	05/17/88	2466.90	609.6	1857.3	USGS
CE-VF-2	365227114554401	08/04/88	2466.90	609.8	1857.1	USGS
CE-VF-2	365227114554401	12/13/88	2466.90	609.02	1857.88	USGS
CE-VF-2	365227114554401	01/31/89	2466.90	609.5	1857.4	USGS
CE-VF-2	365227114554401	03/28/89	2466.90	609.8	1857.1	USGS
CE-VF-2	365227114554401	05/30/89	2466.90	609.7	1857.2	USGS
CE-VF-2	365227114554401	07/26/89	2466.90	609.6	1857.3	USGS
CE-VF-2	365227114554401	09/12/89	2466.90	609.9	1857	USGS
CE-VF-2	365227114554401	11/13/90	2466.90	609.7	1857.2	USGS
CE-VF-2	365227114554401	03/26/91	2466.90	609.7	1857.2	USGS
CE-VF-2	365227114554401	06/13/91	2466.90	610	1856.9	USGS
CE-VF-2	365227114554401	09/12/91	2466.90	610.1	1856.8	USGS
CE-VF-2	365227114554401	12/10/91	2466.90	609.7	1857.2	USGS
CE-VF-2	365227114554401	03/18/92	2466.90	610	1856.9	USGS
CE-VF-2	365227114554401	06/17/92	2466.90	609.9	1857	USGS
CE-VF-2	365227114554401	09/08/92	2466.90	610.3	1856.6	USGS
CE-VF-2	365227114554401	12/21/92	2466.90	610.6	1856.3	USGS
CE-VF-2	365227114554401	03/31/93	2466.90	610.3	1856.6	USGS
CE-VF-2	365227114554401	06/07/93	2466.90	610	1856.9	USGS
CE-VF-2	365227114554401	09/07/93	2466.90	610.1	1856.8	USGS
CE-VF-2	365227114554401	12/15/93	2466.90	609.8	1857.1	USGS
CE-VF-2	365227114554401	03/31/94	2466.90	610.1	1856.8	USGS
CE-VF-2	365227114554401	07/07/94	2466.90	609.79	1857.11	USGS
CE-VF-2	365227114554401	09/20/94	2466.90	609.56	1857.34	USGS
CE-VF-2	365227114554401	10/16/98	2466.90	609.8	1857.1	SNWA
CE-VF-2	365227114554401	01/22/99	2466.90	609.85	1857.05	SNWA
CE-VF-2	365227114554401	04/12/99	2466.90	609.78	1857.12	SNWA
CE-VF-2	365227114554401	07/19/99	2466.90	609.82	1857.08	SNWA
CE-VF-2	365227114554401	08/12/99	2466.90	609.65	1857.25	USGS
CE-VF-2	365227114554401	10/19/99	2466.90	610.3	1856.6	SNWA
CE-VF-2	365227114554401	02/09/00	2466.90	609.95	1856.95	SNWA
CE-VF-2	365227114554401	07/07/00	2466.90	610.52	1856.38	SNWA
CE-VF-2	365227114554401	08/17/00	2466.90	610.4	1856.5	USGS
CE-VF-2	365227114554401	10/24/00	2466.90	610.64	1856.26	SNWA
CE-VF-2	365227114554401	01/05/01	2466.90	610.34	1856.56	SNWA
CL-1	CHEM LIME	05/21/99		471.1	1815.38	JOHNSON, C. et al., 2001
CS-BUCKHORN		06/24/70	2573.21	37	2536	NDWR
CS-GORDON		07/11/77	2614.82	360	2255	NDWR
CS-JBR		12/19/96	2776.18	72	2704	NDWR
CSV-1	364601114514301	11/11/85	2158.60	343.9	1814.7	BERGER et al., 1988
CSV-1	364601114514301	12/17/85	2158.60	344.7	1813.9	BERGER et al., 1988
CSV-1	364601114514301	09/11/87	2158.60	343.44	1815.16	BERGER et al., 1988
CSV-1	364601114514301	05/18/88	2158.60	344.33	1814.27	USGS
CSV-1	364601114514301	08/03/88	2158.60	344.49	1814.11	USGS
CSV-1	364601114514301	12/08/88	2158.60	344.58	1814.02	USGS
CSV-1	364601114514301	01/20/89	2158.60	344.66	1813.94	USGS
CSV-1	364601114514301	01/31/89	2158.60	344.52	1814.08	USGS
CSV-1	364601114514301	03/28/89	2158.60	344.6	1814	USGS
CSV-1	364601114514301	05/30/89	2158.60	344.38	1814.22	USGS

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
CSV-1	364601114514301	07/26/89	2158.60	344.46	1814.14	USGS
CSV-1	364601114514301	09/12/89	2158.60	344.72	1813.88	USGS
CSV-1	364601114514301	11/13/90	2158.60	345.1	1813.5	USGS
CSV-1	364601114514301	03/26/91	2158.60	344.44	1814.16	USGS
CSV-1	364601114514301	06/13/91	2158.60	344.8	1813.8	USGS
CSV-1	364601114514301	09/12/91	2158.60	344.07	1814.53	USGS
CSV-1	364601114514301	12/10/91	2158.60	344.59	1814.01	USGS
CSV-1	364601114514301	03/18/92	2158.60	345.1	1813.5	USGS
CSV-1	364601114514301	06/15/92	2158.60	344.4	1814.2	USGS
CSV-1	364601114514301	09/14/92	2158.60	344.9	1813.7	USGS
CSV-1	364601114514301	12/09/92	2158.60	343.87	1814.73	USGS
CSV-1	364601114514301	03/30/93	2158.60	344.3	1814.3	USGS
CSV-1	364601114514301	06/08/93	2158.60	344.1	1814.5	USGS
CSV-1	364601114514301	09/09/93	2158.60	344.4	1814.2	USGS
CSV-1	364601114514301	12/17/93	2158.60	344.5	1814.1	USGS
CSV-1	364601114514301	03/31/94	2158.60	344.5	1814.1	USGS
CSV-1	364601114514301	06/16/94	2158.60	344.56	1814.04	USGS
CSV-1	364601114514301	09/08/94	2158.60	344.8	1813.8	USGS
CSV-1	364601114514301	07/22/98	2158.60	345.94	1812.66	SNWA
CSV-1	364601114514301	10/16/98	2158.60	345.3	1813.3	SNWA
CSV-1	364601114514301	01/22/99	2158.60	345.4	1813.2	SNWA
CSV-1	364601114514301	04/12/99	2158.60	345.45	1813.15	SNWA
CSV-1	364601114514301	07/19/99	2158.60	345.55	1813.05	SNWA
CSV-1	364601114514301	10/19/99	2158.60	346.22	1812.38	SNWA
CSV-1	364601114514301	02/09/00	2158.60	346.25	1812.35	SNWA
CSV-1	364601114514301	07/07/00	2158.60	345.67	1812.93	SNWA
CSV-1	364601114514301	08/17/00	2158.60	347.36	1811.24	USGS
CSV-1	364601114514301	10/17/00	2158.60	346.51	1812.09	SNWA
CSV-1	364601114514301	01/05/01	2158.60	346.11	1812.49	SNWA
CSV-2	364650114432001	02/06/85	2185.90	391.8	1794.1	USGS
CSV-2	364650114432001	10/27/85	2185.90	391.8	1794.1	USGS
CSV-2	364650114432001	12/30/85	2185.90	390.21	1795.69	USGS
CSV-2	364650114432001	06/07/86	2185.90	390.76	1795.14	USGS
CSV-2	364650114432001	09/11/87	2185.90	390.94	1794.96	USGS
CSV-2	364650114432001	05/17/88	2185.90	390.59	1795.31	USGS
CSV-2	364650114432001	08/03/88	2185.90	390.99	1794.91	USGS
CSV-2	364650114432001	12/21/88	2185.90	390.95	1794.95	USGS
CSV-2	364650114432001	01/20/89	2185.90	390.96	1794.94	USGS
CSV-2	364650114432001	01/31/89	2185.90	390.9	1795	USGS
CSV-2	364650114432001	03/28/89	2185.90	391.2	1794.7	USGS
CSV-2	364650114432001	05/30/89	2185.90	390.85	1795.05	USGS
CSV-2	364650114432001	07/26/89	2185.90	390.99	1794.91	USGS
CSV-2	364650114432001	09/12/89	2185.90	391.23	1794.67	USGS
CSV-2	364650114432001	03/29/90	2185.90	390.94	1794.96	USGS
CSV-2	364650114432001	06/08/90	2185.90	391.04	1794.86	USGS
CSV-2	364650114432001	08/14/90	2185.90	390.24	1795.66	USGS
CSV-2	364650114432001	09/28/90	2185.90	392.4	1793.5	USGS
CSV-2	364650114432001	10/29/90	2185.90	391.5	1794.4	USGS
CSV-2	364650114432001	02/06/91	2185.90	391.4	1794.5	USGS
CSV-2	364650114432001	03/26/91	2185.90	391.28	1794.62	USGS
CSV-2	364650114432001	04/09/91	2185.90	391.4	1794.5	USGS
CSV-2	364650114432001	05/30/91	2185.90	391	1794.9	USGS
CSV-2	364650114432001	07/30/91	2185.90	391.8	1794.1	USGS
CSV-2	364650114432001	09/04/91	2185.90	391.7	1794.2	USGS
CSV-2	364650114432001	10/08/91	2185.90	392	1793.9	USGS
CSV-2	364650114432001	11/08/91	2185.90	391.8	1794.1	USGS
CSV-2	364650114432001	01/10/92	2185.90	391.4	1794.5	USGS

APPENDIX C

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
CSV-2	364650114432001	01/14/92	2185.90	391.5	1794.4	USGS
CSV-2	364650114432001	02/12/92	2185.90	391.2	1794.7	USGS
CSV-2	364650114432001	03/18/92	2185.90	391.3	1794.6	USGS
CSV-2	364650114432001	04/21/92	2185.90	391	1794.9	USGS
CSV-2	364650114432001	04/29/92	2185.90	391	1794.9	USGS
CSV-2	364650114432001	05/12/92	2185.90	391.1	1794.8	USGS
CSV-2	364650114432001	05/19/92	2185.90	391	1794.9	USGS
CSV-2	364650114432001	05/20/92	2185.90	391	1794.9	USGS
CSV-2	364650114432001	06/15/92	2185.90	391.2	1794.7	USGS
CSV-2	364650114432001	06/18/92	2185.90	391.5	1794.4	USGS
CSV-2	364650114432001	07/29/92	2185.90	391.4	1794.5	USGS
CSV-2	364650114432001	08/18/92	2185.90	391.4	1794.5	USGS
CSV-2	364650114432001	09/14/92	2185.90	391.5	1794.4	USGS
CSV-2	364650114432001	10/07/92	2185.90	391.8	1794.1	USGS
CSV-2	364650114432001	12/09/92	2185.90	391.6	1794.3	USGS
CSV-2	364650114432001	02/25/93	2185.90	391	1794.9	USGS
CSV-2	364650114432001	03/30/93	2185.90	390.6	1795.3	USGS
CSV-2	364650114432001	04/26/93	2185.90	390.4	1795.5	USGS
CSV-2	364650114432001	06/08/93	2185.90	390.5	1795.4	USGS
CSV-2	364650114432001	07/02/93	2185.90	390.7	1795.2	USGS
CSV-2	364650114432001	07/15/93	2185.90	390.9	1795	USGS
CSV-2	364650114432001	07/29/93	2185.90	391	1794.9	USGS
CSV-2	364650114432001	09/09/93	2185.90	391.1	1794.8	USGS
CSV-2	364650114432001	10/14/93	2185.90	391	1794.9	USGS
CSV-2	364650114432001	11/18/93	2185.90	390.9	1795	USGS
CSV-2	364650114432001	12/17/93	2185.90	391.2	1794.7	USGS
CSV-2	364650114432001	02/14/94	2185.90	391.3	1794.6	USGS
CSV-2	364650114432001	03/01/94	2185.90	391.6	1794.3	USGS
CSV-2	364650114432001	04/05/94	2185.90	392.1	1793.8	USGS
CSV-2	364650114432001	06/15/94	2185.90	391.21	1794.69	USGS
CSV-2	364650114432001	09/08/94	2185.90	391.5	1794.4	USGS
CSV-2	364650114432001	01/19/95	2187.20	392.91	1794.29	KARL F. POHLMANN, 1996
CSV-2	364650114432001	08/09/95	2187.20	392.57	1794.63	KARL F. POHLMANN, 1996
CSV-2	364650114432001	10/19/95	2187.20	392.91	1794.29	
CSV-2	364650114432001	11/09/95	2187.20	392.46	1794.74	KARL F. POHLMANN, 1996
CSV-2	364650114432001	11/24/95	2187.20	392.66	1794.54	KARL F. POHLMANN, 1996
CSV-2	364650114432001	12/14/95	2187.20	392.66	1794.54	KARL F. POHLMANN, 1996
CSV-2	364650114432001	01/12/96	2187.20	392.36	1794.84	KARL F. POHLMANN, MARCH 1997
CSV-2	364650114432001	03/01/96	2187.20	392.36	1794.84	KARL F. POHLMANN, MARCH 1997
CSV-2	364650114432001	03/14/96	2187.20	392.31	1794.89	KARL F. POHLMANN, MARCH 1997
CSV-2	364650114432001	03/29/96	2185.90	390.8	1795.1	USGS
CSV-2	364650114432001	04/11/96	2187.20	392.26	1794.94	KARL F. POHLMANN, MARCH 1997
CSV-2	364650114432001	05/08/96	2187.20	391.85	1795.35	KARL F. POHLMANN, MARCH 1997
CSV-2	364650114432001	06/14/96	2187.20	392.05	1795.15	KARL F. POHLMANN, MARCH 1997
CSV-2	364650114432001	08/13/96	2187.20	392.35	1794.85	KARL F. POHLMANN, MARCH 1997
CSV-2	364650114432001	10/10/96	2187.20	392.64	1794.56	KARL F. POHLMANN, MARCH 1997
CSV-2	364650114432001	12/18/96	2187.20	392.42	1794.78	KARL F. POHLMANN, MARCH 1997
CSV-2	364650114432001	02/26/97	2185.90	390.6	1795.3	USGS
CSV-2	364650114432001	07/08/97	2185.90	391.1	1794.8	USGS
CSV-2	364650114432001	10/20/97	2185.90	391.4	1794.5	USGS
CSV-2	364650114432001	12/15/97	2185.90	391.1	1794.8	USGS
CSV-2	364650114432001	01/21/98	2187.20	392.69	1794.51	MVWD, APRIL 1998
CSV-2	364650114432001	02/12/98	2187.20	392.72	1794.48	MVWD, APRIL 1998
CSV-2	364650114432001	03/18/98	2187.20	392.69	1794.51	MVWD, APRIL 1998
CSV-2	364650114432001	04/16/98	2187.20	392.54	1794.66	MVWD, APRIL 1998
CSV-2	364650114432001	04/28/98	2185.90	390.9	1795	USGS
CSV-2	364650114432001	05/15/98	2187.20	392.64	1794.56	MVWD, APRIL 1998

APPENDIX C

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
CSV-2	364650114432001	06/17/98	2187.20	392.94	1794.26	
CSV-2	364650114432001	07/14/98	2187.20	393.06	1794.14	
CSV-2	364650114432001	08/13/98	2187.20	393.3	1793.9	MVWD 1998
CSV-2	364650114432001	09/15/98	2187.20	393.52	1793.68	
CSV-2	364650114432001	10/15/98	2187.20	393.58	1793.62	
CSV-2	364650114432001	10/27/98	2185.90	392.2	1793.7	USGS
CSV-2	364650114432001	11/13/98	2187.20	393.7	1793.5	
CSV-2	364650114432001	12/16/98	2187.20	393.64	1793.56	MVWD 1998
CSV-2	364650114432001	12/17/98	2185.90	392.06	1793.84	USGS
CSV-2	364650114432001	01/15/99	2187.20	393.53	1793.67	CONVERSE, 02/25/00
CSV-2	364650114432001	01/15/99	2187.20	393.53	1793.67	
CSV-2	364650114432001	02/16/99	2187.20	393.4	1793.8	CONVERSE, 02/25/00
CSV-2	364650114432001	02/16/99	2187.20	393.4	1793.8	
CSV-2	364650114432001	03/12/99	2187.20	393.38	1793.82	CONVERSE, 02/25/00
CSV-2	364650114432001	03/12/99	2187.20	393.38	1793.82	MVWD 1998
CSV-2	364650114432001	04/08/99	2185.90	391.8	1794.1	USGS
CSV-2	364650114432001	04/15/99	2187.20	393.38	1793.82	CONVERSE, 02/25/00
CSV-2	364650114432001	05/14/99	2187.20	393.22	1793.98	CONVERSE, 02/25/00
CSV-2	364650114432001	06/15/99	2187.20	393.64	1793.56	CONVERSE, 02/25/00
CSV-2	364650114432001	07/15/99	2187.20	393.84	1793.36	CONVERSE, 02/25/00
CSV-2	364650114432001	07/28/99	2185.90	392.6	1793.3	USGS
CSV-2	364650114432001	08/16/99	2187.20	394.18	1793.02	CONVERSE, 02/25/00
CSV-2	364650114432001	09/16/99	2187.20	394.24	1792.96	CONVERSE, 02/25/00
CSV-2	364650114432001	10/12/99	2187.20	394.34	1792.86	CONVERSE, 02/25/00
CSV-2	364650114432001	10/14/99	2185.90	392.44	1793.46	USGS
CSV-2	364650114432001	12/13/99	2185.90	392.28	1793.62	USGS
CSV-2	364650114432001	02/15/00	2187.20	394.11	1793.09	CONVERSE, 02/15/01
CSV-2	364650114432001	03/21/00	2187.20	393.74	1793.46	CONVERSE, 02/15/01
CSV-2	364650114432001	04/05/00	2185.90	392	1793.9	USGS
CSV-2	364650114432001	04/14/00	2187.20	393.62	1793.58	CONVERSE, 02/15/01
CSV-2	364650114432001	05/15/00	2187.20	393.81	1793.39	CONVERSE, 02/15/01
CSV-2	364650114432001	06/14/00	2187.20	394.18	1793.02	CONVERSE, 02/15/01
CSV-2	364650114432001	07/07/00	2185.90	392.9	1793	USGS
CSV-2	364650114432001	07/14/00	2187.20	394.44	1792.76	CONVERSE, 02/15/01
CSV-2	364650114432001	08/15/00	2187.20	394.58	1792.62	CONVERSE, 02/15/01
CSV-2	364650114432001	08/17/00	2185.90	391.15	1794.75	USGS
CSV-2	364650114432001	09/19/00	2187.20	394.75	1792.45	CONVERSE, 02/15/01
CSV-2	364650114432001	10/13/00	2187.20	395.18	1792.02	CONVERSE, 02/15/01
CSV-2	364650114432001	10/24/00	2185.90	393.25	1792.65	USGS
CSV-2	364650114432001	11/16/00	2187.20	394.98	1792.22	CONVERSE, 02/15/01
CSV-3	364127114553001	12/20/85	2414.30	585	1829.3	USGS
CSV-3	364127114553001	02/19/86	2414.30	587.5	1826.8	USGS
CSV-3	364127114553001	09/13/87	2414.30	589.45	1824.85	USGS
CSV-3	364127114553001	05/18/88	2414.30	589.3	1825	USGS
CSV-3	364127114553001	08/04/88	2414.30	589.4	1824.9	USGS
CSV-3	364127114553001	12/13/88	2414.30	589.02	1825.28	USGS
CSV-3	364127114553001	01/31/89	2414.30	589.5	1824.8	USGS
CSV-3	364127114553001	03/28/89	2414.30	588.7	1825.6	USGS
CSV-3	364127114553001	05/30/89	2414.30	588.6	1825.7	USGS
CSV-3	364127114553001	07/26/89	2414.30	588.6	1825.7	USGS
CSV-3	364127114553001	09/12/89	2414.30	588.8	1825.5	USGS
CSV-3	364127114553001	11/13/90	2414.30	589.6	1824.7	USGS
CSV-3	364127114553001	03/19/91	2414.30	589.3	1825	USGS
CSV-3	364127114553001	06/18/91	2414.30	589.6	1824.7	USGS
CSV-3	364127114553001	09/12/91	2414.30	589.9	1824.4	USGS
CSV-3	364127114553001	12/10/91	2414.30	589.6	1824.7	USGS
CSV-3	364127114553001	03/11/92	2414.30	589.7	1824.6	USGS

APPENDIX C

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
CSV-3	364127114553001	06/17/92	2414.30	589.5	1824.8	USGS
CSV-3	364127114553001	09/08/92	2414.30	589.6	1824.7	USGS
CSV-3	364127114553001	12/21/92	2414.30	589.9	1824.4	USGS
CSV-3	364127114553001	03/31/93	2414.30	589.4	1824.9	USGS
CSV-3	364127114553001	06/07/93	2414.30	589.5	1824.8	USGS
CSV-3	364127114553001	09/07/93	2414.30	589.8	1824.5	USGS
CSV-3	364127114553001	12/15/93	2414.30	589.6	1824.7	USGS
CSV-3	364127114553001	03/31/94	2414.30	589.2	1825.1	USGS
CSV-3	364127114553001	07/07/94	2414.30	589.02	1825.28	USGS
CSV-3	364127114553001	09/20/94	2414.30	590.16	1824.14	USGS
CSV-3	364127114553001	05/29/98	2414.30	589.61	1824.69	SNWA
CSV-3	364127114553001	07/22/98	2414.30	590.99	1823.31	SNWA
CSV-3	364127114553001	10/16/98	2414.30	589.31	1824.99	SNWA
CSV-3	364127114553001	01/22/99	2414.30	590.36	1823.94	SNWA
CSV-3	364127114553001	04/12/99	2414.30	589.66	1824.64	SNWA
CSV-3	364127114553001	07/19/99	2414.30	590.27	1824.03	SNWA
CSV-3	364127114553001	10/19/99	2414.30	589.18	1825.12	SNWA
CSV-3	364127114553001	07/07/00	2414.30	590.1	1824.2	USGS
CSV-3	364127114553001	08/17/00	2414.30	593.39	1820.91	USGS
CSV-3	364127114553001	10/17/00	2416.90	591.43	1825.47	SNWA
CW-BLM-1		02/11/49	1975.62	340	1636	NDWR
CW-BLM-2		06/17/49	2526.24	825	1701	NDWR
CW-CLARK		07/01/92	1983.27	321	1662	NDWR
CW-HALL		10/08/67	2108.65	212	1897	NDWR
CW-JONES		12/06/66	2177.05	258	1919	NDWR
CW-PEHLEN		07/03/51	2286.37	160	2126	NDWR
CW-SCC		04/24/58	2028.63	272	1757	NDWR
DF-1	DUTCHFLAT	07/22/98	2223.60	164.63	2058.97	SNWA
DF-1	DUTCHFLAT	10/16/98	2223.60	164.45	2059.15	SNWA
DF-1	DUTCHFLAT	01/22/99	2223.60	164.65	2058.95	SNWA
DF-1	DUTCHFLAT	04/12/99	2223.60	164.5	2059.1	SNWA
DF-1	DUTCHFLAT	07/19/99	2223.60	164.51	2059.09	SNWA
DF-1	DUTCHFLAT	10/19/99	2223.60	164.73	2058.87	SNWA
DF-1	DUTCHFLAT	02/09/00	2223.60	164.22	2059.38	SNWA
DF-1	DUTCHFLAT	06/07/00	2223.60	164.49	2059.11	SNWA
DF-1	DUTCHFLAT	10/24/00	2223.60	163.72	2059.88	SNWA
DF-1	DUTCHFLAT	01/05/01	2223.60	164.46	2059.14	SNWA
EBA-1	GEORGIA PACIFIC	06/12/05		607	1819.99	JOHNSON, C. et al., 2001
EBM-3	NV COGEN	08/21/00		577.05	1812.83	JOHNSON, C. et al., 2001
ECP-1	CALPINE	12/05/00		417.94	1815.61	JOHNSON, C. et al., 2001
ECP-2	CALPINE	12/05/00		416.86	1815.56	JOHNSON, C. et al., 2001
ECP-3	CALPINE	12/05/00		428.53	1815.1	JOHNSON, C. et al., 2001
EH-2	EH-2	01/11/94	1754.00	167.92	1586.08	KARL F. POHLMANN, JUNE 1995
EH-2	EH-2	02/08/94	1754.00	167.88	1586.12	KARL F. POHLMANN, JUNE 1995
EH-2	EH-2	04/08/94	1754.00	167.56	1586.44	KARL F. POHLMANN, JUNE 1995
EH-2	EH-2	10/04/94	1754.00	168.08	1585.92	KARL F. POHLMANN, JUNE 1995
EH-2	EH-2	04/05/95	1754.00	167.2	1586.8	KARL F. POHLMANN, 1996
EH-2	EH-2	06/16/95	1754.00	167.5	1586.5	KARL F. POHLMANN, 1996
EH-2	EH-2	12/14/95	1754.00	169.64	1584.36	KARL F. POHLMANN, 1996
EH-2	EH-2	03/14/96	1754.00	169.37	1584.63	KARL F. POHLMANN, MARCH 1997
EH-2	EH-2	05/08/96	1754.00	169.28	1584.72	KARL F. POHLMANN, MARCH 1997
EH-2	EH-2	06/14/96	1754.00	169.42	1584.58	KARL F. POHLMANN, MARCH 1997
EH-2	EH-2	08/13/96	1754.00	169.62	1584.38	KARL F. POHLMANN, MARCH 1997
EH-2	EH-2	09/13/96	1754.00	169.69	1584.31	KARL F. POHLMANN, MARCH 1997
EH-2	EH-2	12/18/96	1754.00	169.44	1584.56	KARL F. POHLMANN, MARCH 1997
EH-2	EH-2	05/06/97	1754.00	169.3	1584.7	KLEINFELDER, 02/17/00
EH-2	EH-2	06/25/97	1754.00	169.4	1584.6	KLEINFELDER, 02/17/00

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
EH-2	EH-2	09/24/97	1754.00	169.96	1584.04	KLEINFELDER, 02/17/00
EH-2	EH-2	12/16/97	1754.00	169.94	1584.06	KLEINFELDER, 02/17/00
EH-2	EH-2	03/18/98	1754.00	169.06	1584.94	KLEINFELDER, 02/17/00
EH-2	EH-2	06/30/98	1754.00	169.13	1584.87	KLEINFELDER, 02/17/00
EH-2	EH-2	10/02/98	1754.00	169.06	1584.94	KLEINFELDER, 02/17/00
EH-2	EH-2	12/31/98	1754.00	168.48	1585.52	KLEINFELDER, 02/17/00
EH-2	EH-2	03/12/99	1754.00	168.28	1585.72	CONVERSE, 02/25/00
EH-2	EH-2	03/30/99	1754.00	168.28	1585.72	KLEINFELDER, 02/17/00
EH-2	EH-2	06/14/99	1754.00	168.52	1585.48	CONVERSE, 02/25/00
EH-2	EH-2	06/24/99	1754.00	168.52	1585.48	KLEINFELDER, 02/17/00
EH-2	EH-2	09/16/99	1754.00	169.2	1584.8	CONVERSE, 02/25/00
EH-2	EH-2	09/21/99	1754.00	169.2	1584.8	KLEINFELDER, 02/17/00
EH-2	EH-2	12/21/99	1754.00	169.19	1584.81	KLEINFELDER, 02/17/00
EH-2	EH-2	12/28/99	1754.00	169.19	1584.81	CONVERSE, 02/25/00
EH-2	EH-2	03/21/00	1754.00	168.64	1585.36	CONVERSE, 02/15/01
EH-2A	EH-2A	01/11/94	1752.00	167.7	1584.3	KARL F. POHLMANN, JUNE 1995
EH-2A	EH-2A	04/08/94	1752.00	167.39	1584.61	KARL F. POHLMANN, JUNE 1995
EH-2A	EH-2A	08/12/94	1752.00	168.15	1583.85	KARL F. POHLMANN, JUNE 1995
EH-2A	EH-2A	10/04/94	1752.00	168.3	1583.7	KARL F. POHLMANN, JUNE 1995
EH-2A	EH-2A	04/05/95	1752.00	167.8	1584.2	KARL F. POHLMANN, 1996
EH-2A	EH-2A	06/16/95	1752.00	168.1	1583.9	KARL F. POHLMANN, 1996
EH-2A	EH-2A	12/14/95	1752.00	168.92	1583.08	KARL F. POHLMANN, 1996
EH-2A	EH-2A	03/14/96	1752.00	168.72	1583.28	KARL F. POHLMANN, MARCH 1997
EH-2A	EH-2A	05/08/96	1752.00	168.7	1583.3	KARL F. POHLMANN, MARCH 1997
EH-2A	EH-2A	06/14/96	1752.00	168.85	1583.15	KARL F. POHLMANN, MARCH 1997
EH-2A	EH-2A	08/13/96	1752.00	169.15	1582.85	KARL F. POHLMANN, MARCH 1997
EH-2A	EH-2A	09/13/96	1752.00	169.18	1582.82	KARL F. POHLMANN, MARCH 1997
EH-2A	EH-2A	12/18/96	1752.00	169.01	1582.99	KARL F. POHLMANN, MARCH 1997
EH-2A	EH-2A	05/06/97	1752.00	168.9	1583.1	KLEINFELDER, 02/17/00
EH-2A	EH-2A	06/25/97	1752.00	169.15	1582.85	KLEINFELDER, 02/17/00
EH-2A	EH-2A	09/24/97	1752.00	169.66	1582.34	KLEINFELDER, 02/17/00
EH-2A	EH-2A	12/16/97	1752.00	169.65	1582.35	KLEINFELDER, 02/17/00
EH-2A	EH-2A	03/18/98	1752.00	168.51	1583.49	KLEINFELDER, 02/17/00
EH-2A	EH-2A	06/30/98	1752.00	168.56	1583.44	KLEINFELDER, 02/17/00
EH-2A	EH-2A	10/02/98	1752.00	168.62	1583.38	KLEINFELDER, 02/17/00
EH-2A	EH-2A	12/31/98	1752.00	168.12	1583.88	KLEINFELDER, 02/17/00
EH-2A	EH-2A	03/12/99	1752.00	167.79	1584.21	CONVERSE, 02/25/00
EH-2A	EH-2A	03/30/99	1752.00	167.79	1584.21	KLEINFELDER, 02/17/00
EH-2A	EH-2A	06/14/99	1752.00	168.11	1583.89	CONVERSE, 02/25/00
EH-2A	EH-2A	06/24/99	1752.00	168.11	1583.89	KLEINFELDER, 02/17/00
EH-2A	EH-2A	09/16/99	1752.00	168.86	1583.14	CONVERSE, 02/25/00
EH-2A	EH-2A	09/21/99	1752.00	168.66	1583.34	KLEINFELDER, 02/17/00
EH-2A	EH-2A	12/21/99	1752.00	168.83	1583.17	KLEINFELDER, 02/17/00
EH-2A	EH-2A	12/28/99	1752.00	168.83	1583.17	CONVERSE, 02/25/00
EH-2A	EH-2A	03/21/00	1752.00	168.28	1583.72	CONVERSE, 02/15/01
EH-3	NORTH WEISER	01/11/94	1739.00	195.95	1543.05	KARL F. POHLMANN, JUNE 1995
EH-3	NORTH WEISER	04/08/94	1739.00	195.48	1543.52	KARL F. POHLMANN, JUNE 1995
EH-3	NORTH WEISER	07/02/94	1739.00	195.75	1543.25	KARL F. POHLMANN, JUNE 1995
EH-3	NORTH WEISER	10/04/94	1739.00	195.8	1543.2	KARL F. POHLMANN, JUNE 1995
EH-3	NORTH WEISER	01/09/95	1739.00	196	1543	KARL F. POHLMANN, 1996
EH-3	NORTH WEISER	04/05/95	1739.00	195.7	1543.3	KARL F. POHLMANN, 1996
EH-3	NORTH WEISER	06/16/95	1739.00	196.15	1542.85	KARL F. POHLMANN, 1996
EH-3	NORTH WEISER	09/07/95	1739.00	195.9	1543.1	KARL F. POHLMANN, 1996
EH-3	NORTH WEISER	12/14/95	1739.00	196.07	1542.93	KARL F. POHLMANN, 1996
EH-3	NORTH WEISER	03/14/96	1739.00	196.08	1542.92	KARL F. POHLMANN, MARCH 1997
EH-3	NORTH WEISER	05/08/96	1739.00	195.99	1543.01	KARL F. POHLMANN, MARCH 1997
EH-3	NORTH WEISER	06/14/96	1739.00	196.1	1542.9	KARL F. POHLMANN, MARCH 1997

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
EH-3	NORTH WEISER	09/13/96	1739.00	196.05	1542.95	KARL F. POHLMANN, MARCH 1997
EH-3	NORTH WEISER	12/18/96	1739.00	196.07	1542.93	KARL F. POHLMANN, MARCH 1997
EH-3	NORTH WEISER	04/25/97	1739.00	196.2	1542.8	KLEINFELDER, 02/17/00
EH-3	NORTH WEISER	06/25/97	1739.00	195.94	1543.06	KLEINFELDER, 02/17/00
EH-3	NORTH WEISER	09/24/97	1739.00	196.18	1542.82	KLEINFELDER, 02/17/00
EH-3	NORTH WEISER	12/15/97	1739.00	196.25	1542.75	KLEINFELDER, 02/17/00
EH-3	NORTH WEISER	03/18/98	1739.00	196.27	1542.73	KLEINFELDER, 02/17/00
EH-3	NORTH WEISER	06/30/98	1739.00	196.29	1542.71	KLEINFELDER, 02/17/00
EH-3	NORTH WEISER	12/31/98	1739.00	196.41	1542.59	KLEINFELDER, 02/17/00
EH-3	NORTH WEISER	04/15/99	1739.00	196.44	1542.56	CONVERSE, 02/25/00
EH-3	NORTH WEISER	04/14/00	1739.00	196.17	1542.83	CONVERSE, 02/15/01
EH-3	NORTH WEISER	09/20/00	1739.00	196.16	1542.84	CONVERSE, 02/15/01
EH-4	BATTLESHIP WASH	01/06/89	1932.77	116.75	1816.02	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	01/25/89	1932.77	116.77	1816	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	02/03/89	1932.77	116.64	1816.13	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	02/21/89	1932.77	116.77	1816	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	03/09/89	1932.77	116.66	1816.11	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	03/17/89	1932.77	116.61	1816.16	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	04/07/89	1932.77	116.6	1816.17	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	04/14/89	1932.77	116.58	1816.19	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	05/02/89	1932.77	116.59	1816.18	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	05/16/89	1932.77	116.56	1816.21	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	05/19/89	1932.77	116.62	1816.15	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	05/31/89	1932.77	116.7	1816.07	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	06/09/89	1932.77	116.57	1816.2	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	06/16/89	1932.77	116.6	1816.17	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	07/10/89	1932.77	116.75	1816.02	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	07/14/89	1932.77	116.81	1815.96	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	07/21/89	1932.77	116.8	1815.97	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	08/16/89	1932.77	116.83	1815.94	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	09/19/89	1932.77	116.96	1815.81	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	01/04/90	1932.77	116.93	1815.84	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	01/12/90	1932.77	116.77	1816	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	02/20/90	1932.77	116.86	1815.91	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	03/16/90	1932.77	116.82	1815.95	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	03/28/90	1932.77	116.62	1816.15	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	04/16/90	1932.77	116.55	1816.22	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	05/04/90	1932.77	116.73	1816.04	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	05/18/90	1932.77	116.62	1816.15	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	05/25/90	1932.77	116.7	1816.07	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	06/12/90	1932.77	116.65	1816.12	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	06/18/90	1932.77	116.76	1816.01	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	06/26/90	1932.77	116.72	1816.05	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	07/18/90	1932.77	116.83	1815.94	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	08/10/90	1932.77	116.92	1814.85	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	09/07/90	1932.77	117.03	1815.74	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	09/27/90	1932.77	117.08	1815.69	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	10/10/90	1932.77	117.02	1815.75	M.D. MIFFLIN, MAY 1991
EH-4	BATTLESHIP WASH	01/11/91	1932.77	117.11	1815.66	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	02/05/91	1932.77	116.97	1815.80	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	02/14/91	1932.77	116.95	1815.82	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	03/15/91	1932.77	116.79	1815.98	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	03/21/91	1932.77	116.81	1815.96	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	04/08/91	1932.77	116.81	1815.96	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	05/17/91	1932.77	116.69	1816.08	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	06/18/91	1932.77	116.82	1815.95	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	07/25/91	1932.77	116.94	1815.83	M.D. MIFFLIN, MAY 1992

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
EH-4	BATTLESHIP WASH	08/20/91	1932.77	117.06	1815.71	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	08/29/91	1932.77	117.12	1815.65	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	10/03/91	1932.77	117.2	1815.57	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	10/11/91	1932.77	117.18	1815.59	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	10/17/91	1932.77	117.15	1815.62	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	11/06/91	1932.77	117.12	1815.65	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	11/20/91	1932.77	117.28	1815.49	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	11/26/91	1932.77	117.13	1815.64	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	12/27/91	1932.77	117.08	1815.69	M.D. MIFFLIN, MAY 1992
EH-4	BATTLESHIP WASH	01/27/92	1932.77	117.01	1815.76	M.D. MIFFLIN, APRIL 1993
EH-4	BATTLESHIP WASH	02/24/92	1932.77	116.99	1815.78	M.D. MIFFLIN, APRIL 1993
EH-4	BATTLESHIP WASH	03/24/92	1932.77	116.87	1815.90	M.D. MIFFLIN, APRIL 1993
EH-4	BATTLESHIP WASH	04/21/92	1932.77	116.62	1816.15	M.D. MIFFLIN, APRIL 1993
EH-4	BATTLESHIP WASH	05/13/92	1932.77	116.65	1816.12	M.D. MIFFLIN, APRIL 1993
EH-4	BATTLESHIP WASH	06/12/92	1932.77	116.76	1816.01	M.D. MIFFLIN, APRIL 1993
EH-4	BATTLESHIP WASH	07/22/92	1932.77	116.78	1815.99	M.D. MIFFLIN, APRIL 1993
EH-4	BATTLESHIP WASH	08/18/92	1932.77	116.85	1815.92	M.D. MIFFLIN, APRIL 1993
EH-4	BATTLESHIP WASH	09/02/92	1932.77	116.92	1815.85	M.D. MIFFLIN, APRIL 1993
EH-4	BATTLESHIP WASH	09/10/92	1932.77	116.91	1815.86	M.D. MIFFLIN, APRIL 1993
EH-4	BATTLESHIP WASH	10/19/92	1932.77	116.89	1815.88	M.D. MIFFLIN, APRIL 1993
EH-4	BATTLESHIP WASH	12/01/92	1932.77	116.95	1815.82	M.D. MIFFLIN, APRIL 1993
EH-4	BATTLESHIP WASH	12/23/92	1932.77	116.9	1815.87	M.D. MIFFLIN, APRIL 1993
EH-4	BATTLESHIP WASH	01/13/93	1932.77	116.78	1815.99	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	01/21/93	1932.77	116.75	1816.02	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	02/05/93	1932.77	116.92	1815.85	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	02/19/93	1932.77	116.34	1816.43	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	03/24/93	1932.77	116.13	1816.64	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	04/02/93	1932.77	115.1	1817.67	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	04/30/93	1932.77	116.98	1815.79	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	06/03/93	1932.77	116.05	1816.72	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	07/07/93	1932.77	116.21	1816.56	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	08/02/93	1932.77	116.42	1816.35	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	09/03/93	1932.77	116.54	1816.23	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	10/01/93	1932.77	116.53	1816.24	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	11/12/93	1932.77	116.31	1816.46	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	12/10/93	1932.77	116.45	1816.32	M.D. MIFFLIN, APRIL 1994
EH-4	BATTLESHIP WASH	01/05/94	1932.77	116.58	1816.19	KARL F. POHLMANN, JUNE 1995
EH-4	BATTLESHIP WASH	02/04/94	1932.77	116.74	1816.03	KARL F. POHLMANN, JUNE 1995
EH-4	BATTLESHIP WASH	03/04/94	1932.77	116.79	1815.98	KARL F. POHLMANN, JUNE 1995
EH-4	BATTLESHIP WASH	04/08/94	1932.77	116.82	1815.95	KARL F. POHLMANN, JUNE 1995
EH-4	BATTLESHIP WASH	05/06/94	1932.77	116.58	1816.19	KARL F. POHLMANN, JUNE 1995
EH-4	BATTLESHIP WASH	05/19/94	1932.77	116.74	1816.03	KARL F. POHLMANN, JUNE 1995
EH-4	BATTLESHIP WASH	06/09/94	1932.77	116.89	1815.88	KARL F. POHLMANN, JUNE 1995
EH-4	BATTLESHIP WASH	07/02/94	1932.77	116.83	1815.94	KARL F. POHLMANN, JUNE 1995
EH-4	BATTLESHIP WASH	08/12/94	1932.77	117	1815.77	KARL F. POHLMANN, JUNE 1995
EH-4	BATTLESHIP WASH	09/06/94	1932.77	117.21	1815.56	KARL F. POHLMANN, JUNE 1995
EH-4	BATTLESHIP WASH	10/04/94	1932.77	117.11	1815.66	KARL F. POHLMANN, JUNE 1995
EH-4	BATTLESHIP WASH	11/01/94	1932.77	117.12	1815.65	KARL F. POHLMANN, JUNE 1995
EH-4	BATTLESHIP WASH	12/08/94	1932.77	117.27	1815.5	KARL F. POHLMANN, JUNE 1995
EH-4	BATTLESHIP WASH	01/09/95	1932.77	116.98	1815.79	KARL F. POHLMANN, 1996
EH-4	BATTLESHIP WASH	02/08/95	1932.77	116.7	1816.07	KARL F. POHLMANN, 1996
EH-4	BATTLESHIP WASH	03/08/95	1932.77	116.7	1816.07	KARL F. POHLMANN, 1996
EH-4	BATTLESHIP WASH	04/05/95	1932.77	116.5	1816.27	KARL F. POHLMANN, 1996
EH-4	BATTLESHIP WASH	05/18/95	1932.77	116.49	1816.28	KARL F. POHLMANN, 1996
EH-4	BATTLESHIP WASH	06/16/95	1932.77	116.42	1816.35	KARL F. POHLMANN, 1996
EH-4	BATTLESHIP WASH	07/05/95	1932.77	116.64	1816.13	KARL F. POHLMANN, 1996
EH-4	BATTLESHIP WASH	08/09/95	1932.77	116.49	1816.28	KARL F. POHLMANN, 1996

APPENDIX C

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
EH-4	BATTLESHIP WASH	09/07/95	1932.77	116.86	1815.91	KARL F. POHLMANN, 1996
EH-4	BATTLESHIP WASH	10/12/95	1932.77	116.85	1815.92	KARL F. POHLMANN, 1996
EH-4	BATTLESHIP WASH	11/09/95	1932.77	116.72	1816.05	KARL F. POHLMANN, 1996
EH-4	BATTLESHIP WASH	11/24/95	1932.77	116.81	1815.96	KARL F. POHLMANN, 1996
EH-4	BATTLESHIP WASH	12/14/95	1932.77	116.69	1816.08	KARL F. POHLMANN, 1996
EH-4	BATTLESHIP WASH	01/12/96	1932.77	116.63	1816.14	M.D. MIFFLIN, JANUARY 1997
EH-4	BATTLESHIP WASH	03/01/96	1932.77	116.6	1816.17	M.D. MIFFLIN, JANUARY 1997
EH-4	BATTLESHIP WASH	03/14/96	1932.77	116.45	1816.32	M.D. MIFFLIN, JANUARY 1997
EH-4	BATTLESHIP WASH	04/11/96	1932.77	116.36	1816.41	M.D. MIFFLIN, JANUARY 1997
EH-4	BATTLESHIP WASH	05/08/96	1932.77	116.34	1816.43	M.D. MIFFLIN, JANUARY 1997
EH-4	BATTLESHIP WASH	06/14/96	1932.77	116.53	1816.24	M.D. MIFFLIN, JANUARY 1997
EH-4	BATTLESHIP WASH	08/13/96	1932.77	116.8	1815.97	M.D. MIFFLIN, JANUARY 1997
EH-4	BATTLESHIP WASH	09/13/96	1932.77	116.83	1815.94	M.D. MIFFLIN, JANUARY 1997
EH-4	BATTLESHIP WASH	10/10/96	1932.77	116.97	1815.8	KARL F. POHLMANN, MARCH 1997
EH-4	BATTLESHIP WASH	11/22/96	1932.77	116.74	1816.03	KARL F. POHLMANN, MARCH 1997
EH-4	BATTLESHIP WASH	12/18/96	1932.77	116.85	1815.92	KARL F. POHLMANN, MARCH 1997
EH-4	BATTLESHIP WASH	04/20/97	1932.77	116	1816.77	KLEINFELDER, 02/17/00
EH-4	BATTLESHIP WASH	06/26/97	1932.77	116.65	1816.12	KLEINFELDER, 02/17/00
EH-4	BATTLESHIP WASH	09/24/97	1932.77	116.94	1815.83	KLEINFELDER, 02/17/00
EH-4	BATTLESHIP WASH	12/15/97	1932.77	117.25	1815.52	KLEINFELDER, 02/17/00
EH-4	BATTLESHIP WASH	01/15/98	1932.77	117.4	1815.37	MVWD 1999
EH-4	BATTLESHIP WASH	01/21/98	1932.77	116.85	1815.92	MVWD 1999
EH-4	BATTLESHIP WASH	02/12/98	1932.77	116.9	1815.87	MVWD 1999
EH-4	BATTLESHIP WASH	03/18/98	1932.77	116.75	1816.02	KLEINFELDER, 02/17/00
EH-4	BATTLESHIP WASH	03/18/98	1932.77	116.75	1816.02	MVWD 1999
EH-4	BATTLESHIP WASH	04/16/98	1932.77	116.62	1816.15	MVWD 1999
EH-4	BATTLESHIP WASH	05/15/98	1932.77	116.79	1815.98	MVWD 1999
EH-4	BATTLESHIP WASH	06/17/98	1932.77	116.99	1815.78	MVWD 1999
EH-4	BATTLESHIP WASH	07/01/98	1932.77	116.99	1815.78	KLEINFELDER, 02/17/00
EH-4	BATTLESHIP WASH	07/14/98	1932.77	117.2	1815.57	MVWD 1999
EH-4	BATTLESHIP WASH	08/13/98	1932.77	117.44	1815.33	MVWD 1999
EH-4	BATTLESHIP WASH	09/15/98	1932.77	117.66	1815.11	MVWD 1999
EH-4	BATTLESHIP WASH	10/02/98	1932.77	117.66	1815.11	KLEINFELDER, 02/17/00
EH-4	BATTLESHIP WASH	10/15/98	1932.77	117.63	1815.14	MVWD 1999
EH-4	BATTLESHIP WASH	11/13/98	1932.77	117.77	1815	MVWD 1999
EH-4	BATTLESHIP WASH	12/16/98	1932.77	117.71	1815.06	MVWD 1999
EH-4	BATTLESHIP WASH	12/31/98	1932.77	117.71	1815.06	KLEINFELDER, 02/17/00
EH-4	BATTLESHIP WASH	01/15/99	1932.77	117.4	1815.37	CONVERSE, 02/25/00
EH-4	BATTLESHIP WASH	02/16/99	1932.77	117.48	1815.29	CONVERSE, 02/25/00
EH-4	BATTLESHIP WASH	03/12/99	1932.77	117.46	1815.31	CONVERSE, 02/25/00
EH-4	BATTLESHIP WASH	03/30/99	1932.77	117.46	1815.31	KLEINFELDER, 02/17/00
EH-4	BATTLESHIP WASH	04/15/99	1932.77	117.48	1815.29	CONVERSE, 02/25/00
EH-4	BATTLESHIP WASH	05/14/99	1932.77	117.38	1815.39	CONVERSE, 02/25/00
EH-4	BATTLESHIP WASH	06/15/99	1932.77	117.61	1815.16	CONVERSE, 02/25/00
EH-4	BATTLESHIP WASH	06/24/99	1932.77	117.61	1815.16	KLEINFELDER, 02/17/00
EH-4	BATTLESHIP WASH	07/15/99	1932.77	117.82	1814.95	CONVERSE, 02/25/00
EH-4	BATTLESHIP WASH	08/16/99	1932.77	118.13	1814.64	CONVERSE, 02/25/00
EH-4	BATTLESHIP WASH	09/16/99	1932.77	117.89	1814.88	CONVERSE, 02/25/00
EH-4	BATTLESHIP WASH	09/21/99	1932.77	117.89	1814.88	KLEINFELDER, 02/17/00
EH-4	BATTLESHIP WASH	10/12/99	1932.77	118.27	1814.5	CONVERSE, 02/25/00
EH-4	BATTLESHIP WASH	11/16/99	1932.77	118.01	1814.76	CONVERSE, 02/25/00
EH-4	BATTLESHIP WASH	12/21/99	1932.77	117.92	1814.85	KLEINFELDER, 02/17/00
EH-4	BATTLESHIP WASH	12/28/99	1932.77	117.92	1814.85	CONVERSE, 02/25/00
EH-4	BATTLESHIP WASH	01/14/00	1932.77	117.85	1814.92	CONVERSE, 02/15/01
EH-4	BATTLESHIP WASH	02/15/00	1932.77	117.69	1815.08	CONVERSE, 02/15/01
EH-4	BATTLESHIP WASH	03/21/00	1932.77	117.25	1815.52	CONVERSE, 02/15/01
EH-4	BATTLESHIP WASH	04/14/00	1932.77	117.63	1815.14	CONVERSE, 02/15/01

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
EH-4	BATTLESHIP WASH	05/15/00	1932.77	117.71	1815.06	CONVERSE, 02/15/01
EH-4	BATTLESHIP WASH	06/14/00	1932.77	117.95	1814.82	CONVERSE, 02/15/01
EH-4	BATTLESHIP WASH	07/14/00	1932.77	118.32	1814.45	CONVERSE, 02/15/01
EH-4	BATTLESHIP WASH	08/15/00	1932.77	118.43	1814.34	CONVERSE, 02/15/01
EH-4	BATTLESHIP WASH	09/19/00	1932.77	118.54	1814.23	CONVERSE, 02/15/01
EH-4	BATTLESHIP WASH	10/13/00	1932.77	118.71	1814.06	CONVERSE, 02/15/01
EH-4	BATTLESHIP WASH	11/16/00	1932.77	118.51	1814.26	CONVERSE, 02/15/01
EH-4	BATTLESHIP WASH	12/15/00	1932.77	118.47	1814.3	CONVERSE, 02/15/01
EH-5B		01/06/89	1842.69	27.91	1814.78	M.D. MIFFLIN, MAY 1991
EH-5B		03/17/89	1842.69	27.83	1814.86	M.D. MIFFLIN, MAY 1991
EH-5B		04/07/89	1842.69	27.76	1814.93	M.D. MIFFLIN, MAY 1991
EH-5B		04/14/89	1842.69	27.77	1814.92	M.D. MIFFLIN, MAY 1991
EH-5B		04/17/89	1842.69	27.77	1814.92	M.D. MIFFLIN, MAY 1991
EH-5B		05/16/89	1842.69	27.85	1814.84	M.D. MIFFLIN, MAY 1991
EH-5B		05/19/89	1842.69	27.98	1814.71	M.D. MIFFLIN, MAY 1991
EH-5B		06/09/89	1842.69	27.97	1814.72	M.D. MIFFLIN, MAY 1991
EH-5B		06/16/89	1842.69	28.2	1814.49	M.D. MIFFLIN, MAY 1991
EH-5B		07/10/89	1842.69	28.3	1814.39	M.D. MIFFLIN, MAY 1991
EH-5B		07/14/89	1842.69	28.32	1814.37	M.D. MIFFLIN, MAY 1991
EH-5B		07/21/89	1842.69	28.33	1814.36	M.D. MIFFLIN, MAY 1991
EH-5B		08/16/89	1842.69	28.32	1814.37	M.D. MIFFLIN, MAY 1991
EH-5B		09/19/89	1842.69	28.48	1814.21	M.D. MIFFLIN, MAY 1991
EH-5B		01/04/90	1842.69	28.18	1814.51	M.D. MIFFLIN, MAY 1991
EH-5B		01/12/90	1842.69	27.95	1814.74	M.D. MIFFLIN, MAY 1991
EH-5B		02/20/90	1842.69	28.02	1814.67	M.D. MIFFLIN, MAY 1991
EH-5B		03/16/90	1842.69	27.96	1814.73	M.D. MIFFLIN, MAY 1991
EH-5B		03/28/90	1842.69	27.82	1814.87	M.D. MIFFLIN, MAY 1991
EH-5B		04/16/90	1842.69	27.76	1814.93	M.D. MIFFLIN, MAY 1991
EH-5B		05/04/90	1842.69	27.97	1814.72	M.D. MIFFLIN, MAY 1991
EH-5B		05/18/90	1842.69	28.12	1814.57	M.D. MIFFLIN, MAY 1991
EH-5B		05/25/90	1842.69	28.08	1814.61	M.D. MIFFLIN, MAY 1991
EH-5B		06/12/90	1842.69	28.19	1814.5	M.D. MIFFLIN, MAY 1991
EH-5B		06/18/90	1842.69	28.17	1814.52	M.D. MIFFLIN, MAY 1991
EH-5B		06/26/90	1842.69	28.35	1814.34	M.D. MIFFLIN, MAY 1991
EH-5B		07/18/90	1842.69	28.35	1814.34	M.D. MIFFLIN, MAY 1991
EH-5B		08/10/90	1842.69	28.44	1814.25	M.D. MIFFLIN, MAY 1991
EH-5B		09/07/90	1842.69	28.63	1814.06	M.D. MIFFLIN, MAY 1991
EH-5B		09/27/90	1842.69	28.59	1814.1	M.D. MIFFLIN, MAY 1991
EH-5B		10/10/90	1842.69	28.42	1814.27	M.D. MIFFLIN, MAY 1991
EH-5B		01/11/91	1842.69	28.3	1814.39	M.D. MIFFLIN, MAY 1992
EH-5B		01/25/91	1842.69	28.31	1814.38	M.D. MIFFLIN, MAY 1992
EH-5B		02/05/91	1842.69	28.11	1814.58	M.D. MIFFLIN, MAY 1992
EH-5B		03/06/91	1842.69	28.07	1814.62	M.D. MIFFLIN, MAY 1992
EH-5B		03/15/91	1842.69	27.96	1814.73	M.D. MIFFLIN, MAY 1992
EH-5B		03/21/91	1842.69	27.99	1814.70	M.D. MIFFLIN, MAY 1992
EH-5B		04/08/91	1842.69	28.04	1814.65	M.D. MIFFLIN, MAY 1992
EH-5B		05/17/91	1842.69	27.9	1814.79	M.D. MIFFLIN, MAY 1992
EH-5B		06/18/91	1842.69	28.33	1814.36	M.D. MIFFLIN, MAY 1992
EH-5B		07/25/91	1842.69	28.59	1814.10	M.D. MIFFLIN, MAY 1992
EH-5B		07/26/91	1842.69	28.62	1814.07	M.D. MIFFLIN, MAY 1992
EH-5B		08/01/91	1842.69	28.61	1814.08	M.D. MIFFLIN, MAY 1992
EH-5B		08/20/91	1842.69	28.62	1814.07	M.D. MIFFLIN, MAY 1992
EH-5B		08/29/91	1842.69	28.63	1814.06	M.D. MIFFLIN, MAY 1992
EH-5B		10/03/91	1842.69	28.55	1814.14	M.D. MIFFLIN, MAY 1992
EH-5B		10/11/91	1842.69	28.52	1814.17	M.D. MIFFLIN, MAY 1992
EH-5B		10/17/91	1842.69	28.5	1814.19	M.D. MIFFLIN, MAY 1992
EH-5B		11/06/91	1842.69	28.36	1814.33	M.D. MIFFLIN, MAY 1992

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
EH-5B		11/20/91	1842.69	28.45	1814.24	M.D. MIFFLIN, MAY 1992
EH-5B		11/26/91	1842.69	28.34	1814.35	M.D. MIFFLIN, MAY 1992
EH-5B		12/27/91	1842.69	28.27	1814.42	M.D. MIFFLIN, MAY 1992
EH-5B		01/27/92	1842.69	28.24	1814.45	M.D. MIFFLIN, APRIL 1993
EH-5B		02/24/92	1842.69	28.19	1814.50	M.D. MIFFLIN, APRIL 1993
EH-5B		02/28/92	1842.69	28.11	1814.58	M.D. MIFFLIN, APRIL 1993
EH-5B		03/20/92	1842.69	27.96	1814.73	M.D. MIFFLIN, APRIL 1993
EH-5B		04/21/92	1842.69	27.8	1814.89	M.D. MIFFLIN, APRIL 1993
EH-5B		05/13/92	1842.69	27.93	1814.76	M.D. MIFFLIN, APRIL 1993
EH-5B		06/12/92	1842.69	28.24	1814.45	M.D. MIFFLIN, APRIL 1993
EH-5B		07/22/92	1842.69	27.98	1814.71	M.D. MIFFLIN, APRIL 1993
EH-5B		07/23/92	1842.69	28.01	1814.68	M.D. MIFFLIN, APRIL 1993
EH-5B		08/05/92	1842.69	28.08	1814.61	M.D. MIFFLIN, APRIL 1993
EH-5B		08/18/92	1842.69	28.11	1814.58	M.D. MIFFLIN, APRIL 1993
EH-5B		09/02/92	1842.69	28.19	1814.50	M.D. MIFFLIN, APRIL 1993
EH-5B		09/10/92	1842.69	28.16	1814.53	M.D. MIFFLIN, APRIL 1993
EH-5B		10/19/92	1842.69	27.96	1814.73	M.D. MIFFLIN, APRIL 1993
EH-5B		12/01/92	1842.69	27.93	1814.76	M.D. MIFFLIN, APRIL 1993
EH-5B		12/23/92	1842.69	27.98	1814.71	M.D. MIFFLIN, APRIL 1993
EH-5B		01/13/93	1842.69	27.76	1814.93	M.D. MIFFLIN, APRIL 1994
EH-5B		01/21/93	1842.69	27.75	1814.94	M.D. MIFFLIN, APRIL 1994
EH-5B		02/05/93	1842.69	27.62	1815.07	M.D. MIFFLIN, APRIL 1994
EH-5B		02/19/93	1842.69	27.29	1815.4	M.D. MIFFLIN, APRIL 1994
EH-5B		03/24/93	1842.69	27.12	1815.57	M.D. MIFFLIN, APRIL 1994
EH-5B		04/02/93	1842.69	27.13	1815.56	M.D. MIFFLIN, APRIL 1994
EH-5B		04/30/93	1842.69	27.04	1815.65	M.D. MIFFLIN, APRIL 1994
EH-5B		06/03/93	1842.69	27.35	1815.34	M.D. MIFFLIN, APRIL 1994
EH-5B		07/07/93	1842.69	27.55	1815.14	M.D. MIFFLIN, APRIL 1994
EH-5B		08/02/93	1842.69	27.82	1814.87	M.D. MIFFLIN, APRIL 1994
EH-5B		09/03/93	1842.69	27.92	1814.77	M.D. MIFFLIN, APRIL 1994
EH-5B		10/01/93	1842.69	27.9	1814.79	M.D. MIFFLIN, APRIL 1994
EH-5B		11/12/93	1842.69	27.42	1815.27	M.D. MIFFLIN, APRIL 1994
EH-5B		12/10/93	1842.69	27.54	1815.15	M.D. MIFFLIN, APRIL 1994
EH-5B		01/05/94	1842.69	27.64	1815.05	KARL F. POHLMANN, JUNE 1995
EH-5B		02/04/94	1842.69	27.81	1814.88	KARL F. POHLMANN, JUNE 1995
EH-5B		03/04/94	1842.69	27.86	1814.83	KARL F. POHLMANN, JUNE 1995
EH-5B		04/08/94	1842.69	27.84	1814.85	KARL F. POHLMANN, JUNE 1995
EH-5B		05/06/94	1842.69	27.77	1814.92	KARL F. POHLMANN, JUNE 1995
EH-5B		05/19/94	1842.69	28.09	1814.6	KARL F. POHLMANN, JUNE 1995
EH-5B		06/09/94	1842.69	28.3	1814.39	KARL F. POHLMANN, JUNE 1995
EH-5B		07/02/94	1842.69	28.23	1814.46	KARL F. POHLMANN, JUNE 1995
EH-5B		08/12/94	1842.69	28.4	1814.29	KARL F. POHLMANN, JUNE 1995
EH-5B		09/09/94	1842.69	28.56	1814.13	KARL F. POHLMANN, JUNE 1995
EH-5B		10/04/94	1842.69	28.44	1814.25	KARL F. POHLMANN, JUNE 1995
EH-5B		11/04/94	1842.69	28.38	1814.31	KARL F. POHLMANN, JUNE 1995
EH-5B		12/08/94	1842.69	28.53	1814.16	KARL F. POHLMANN, JUNE 1995
EH-5B		01/09/95	1842.69	28.08	1814.61	KARL F. POHLMANN, 1996
EH-5B		02/08/95	1842.69	27.75	1814.94	KARL F. POHLMANN, 1996
EH-5B		03/08/95	1842.69	27.84	1814.85	KARL F. POHLMANN, 1996
EH-5B		04/05/95	1842.69	27.53	1815.16	KARL F. POHLMANN, 1996
EH-5B		05/18/95	1842.69	27.58	1815.11	KARL F. POHLMANN, 1996
EH-5B		06/16/95	1842.69	27.68	1815.01	KARL F. POHLMANN, 1996
EH-5B		07/05/95	1842.69	27.89	1814.8	KARL F. POHLMANN, 1996
EH-5B		08/09/95	1842.69	28.13	1814.56	KARL F. POHLMANN, 1996
EH-5B		09/07/95	1842.69	28.29	1814.4	KARL F. POHLMANN, 1996
EH-5B		10/12/95	1842.69	28.17	1814.52	KARL F. POHLMANN, 1996
EH-5B		11/09/95	1842.69	27.86	1814.83	KARL F. POHLMANN, 1996

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
EH-5B		11/24/95	1842.69	27.92	1814.77	KARL F. POHLMANN, 1996
EH-5B		12/14/95	1842.69	27.87	1814.82	KARL F. POHLMANN, 1996
EH-5B		01/12/96	1842.69	27.7	1814.99	M.D. MIFFLIN, JANUARY 1997
EH-5B		03/01/96	1842.69	27.64	1815.05	M.D. MIFFLIN, JANUARY 1997
EH-5B		03/14/96	1842.69	27.56	1815.13	M.D. MIFFLIN, JANUARY 1997
EH-5B		04/11/96	1842.69	27.49	1815.2	M.D. MIFFLIN, JANUARY 1997
EH-5B		05/08/96	1842.69	27.55	1815.14	M.D. MIFFLIN, JANUARY 1997
EH-5B		06/14/96	1842.69	27.91	1814.78	M.D. MIFFLIN, JANUARY 1997
EH-5B		08/13/96	1842.69	28.16	1814.53	M.D. MIFFLIN, JANUARY 1997
EH-5B		09/13/96	1842.69	28.18	1814.51	M.D. MIFFLIN, JANUARY 1997
EH-5B		10/10/96	1842.69	28.25	1814.44	KARL F. POHLMANN, MARCH 1997
EH-5B		11/22/96	1842.69	27.89	1814.8	KARL F. POHLMANN, MARCH 1997
EH-5B		12/18/96	1842.69	27.93	1814.76	KARL F. POHLMANN, MARCH 1997
EH-5B		04/21/97	1842.69	27.7	1814.99	KLEINFELDER, 02/17/00
EH-5B		06/26/97	1842.69	27.88	1814.81	KLEINFELDER, 02/17/00
EH-5B		09/24/97	1842.69	28.35	1814.34	KLEINFELDER, 02/17/00
EH-5B		12/16/97	1842.69	28.15	1814.54	KLEINFELDER, 02/17/00
EH-5B		01/15/98	1842.69	28.84	1813.85	MVWD 1999
EH-5B		01/21/98	1842.69	27.86	1814.83	MVWD 1999
EH-5B		02/12/98	1842.69	27.95	1814.74	MVWD 1999
EH-5B		02/16/98	1842.69	28.52	1814.17	MVWD 1999
EH-5B		03/12/98	1842.69	28.58	1814.11	MVWD 1999
EH-5B		03/18/98	1842.69	27.88	1814.81	KLEINFELDER, 02/17/00
EH-5B		03/18/98	1842.69	27.88	1814.81	MVWD 1999
EH-5B		04/16/98	1842.69	27.8	1814.89	MVWD 1999
EH-5B		05/15/98	1842.69	27.91	1814.78	MVWD 1999
EH-5B		06/14/98	1842.69	28.61	1814.08	MVWD98
EH-5B		06/17/98	1842.69	28.25	1814.44	MVWD 1999
EH-5B		07/01/98	1842.69	28.25	1814.44	KLEINFELDER, 02/17/00
EH-5B		07/14/98	1842.69	28.61	1814.08	MVWD 1999
EH-5B		08/13/98	1842.69	28.85	1813.84	MVWD 1999
EH-5B		09/15/98	1842.69	28.83	1813.86	MVWD 1999
EH-5B		10/02/98	1842.69	28.83	1813.86	KLEINFELDER, 02/17/00
EH-5B		10/15/98	1842.69	28.99	1813.7	MVWD 1999
EH-5B		11/13/98	1842.69	28.98	1813.71	MVWD 1999
EH-5B		12/16/98	1842.69	28.75	1813.94	MVWD 1999
EH-5B		12/31/98	1842.69	28.95	1813.74	KLEINFELDER, 02/17/00
EH-5B		01/15/99	1842.69	28.84	1813.85	CONVERSE, 02/25/00
EH-5B		02/16/99	1842.69	28.52	1814.17	CONVERSE, 02/25/00
EH-5B		03/12/99	1842.69	28.58	1814.11	CONVERSE, 02/25/00
EH-5B		03/30/99	1842.69	28.58	1814.11	KLEINFELDER, 02/17/00
EH-5B		04/15/99	1842.69	28.41	1814.28	CONVERSE, 02/25/00
EH-5B		05/14/99	1842.69	28.35	1814.34	CONVERSE, 02/25/00
EH-5B		06/15/99	1842.69	28.85	1813.84	CONVERSE, 02/25/00
EH-5B		06/24/99	1842.69	28.85	1813.84	KLEINFELDER, 02/17/00
EH-5B		07/15/99	1842.69	29.15	1813.54	CONVERSE, 02/25/00
EH-5B		08/16/99	1842.69	29.48	1813.21	CONVERSE, 02/25/00
EH-5B		09/16/99	1842.69	29.55	1813.14	CONVERSE, 02/25/00
EH-5B		09/21/99	1842.69	29.55	1813.14	KLEINFELDER, 02/17/00
EH-5B		10/12/99	1842.69	29.45	1813.24	CONVERSE, 02/25/00
EH-5B		11/16/99	1842.69	28.98	1813.71	CONVERSE, 02/25/00
EH-5B		12/21/99	1842.69	28.89	1813.8	KLEINFELDER, 02/17/00
EH-5B		12/28/99	1842.69	28.89	1813.8	CONVERSE, 02/25/00
EH-5B		01/14/00	1842.69	28.81	1813.88	CONVERSE, 02/15/01
EH-5B		02/15/00	1842.69	28.8	1813.89	CONVERSE, 02/15/01
EH-5B		03/21/00	1842.69	28.65	1814.04	CONVERSE, 02/15/01
EH-5B		04/14/00	1842.69	28.62	1814.07	CONVERSE, 02/15/01

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
EH-5B		05/15/00	1842.69	28.94	1813.75	CONVERSE, 02/15/01
EH-5B		06/14/00	1842.69	29.42	1813.27	CONVERSE, 02/15/01
EH-5B		07/14/00	1842.69	29.71	1812.98	CONVERSE, 02/15/01
EH-5B		08/15/00	1842.69	29.79	1812.9	CONVERSE, 02/15/01
EH-5B		09/19/00	1842.69	29.75	1812.94	CONVERSE, 02/15/01
EH-5B		10/13/00	1842.69	29.9	1812.79	CONVERSE, 02/15/01
EH-5B		11/16/00	1842.69	29.59	1813.1	CONVERSE, 02/15/01
EH-5B		12/15/00	1842.69	29.47	1813.22	CONVERSE, 02/15/01
EH-7	SOUTH WEISER	01/11/94	1680.00	117.26	1562.74	KARL F. POHLMANN, JUNE 1995
EH-7	SOUTH WEISER	04/08/94	1680.00	117.04	1562.96	KARL F. POHLMANN, JUNE 1995
EH-7	SOUTH WEISER	05/19/94	1680.00	117.2	1562.8	KARL F. POHLMANN, JUNE 1995
EH-7	SOUTH WEISER	05/25/94	1680.00	117.13	1562.87	KARL F. POHLMANN, JUNE 1995
EH-7	SOUTH WEISER	07/02/94	1680.00	117.1	1562.9	KARL F. POHLMANN, JUNE 1995
EH-7	SOUTH WEISER	08/12/94	1680.00	117.22	1562.78	KARL F. POHLMANN, JUNE 1995
EH-7	SOUTH WEISER	09/06/94	1680.00	117.16	1562.84	KARL F. POHLMANN, JUNE 1995
EH-7	SOUTH WEISER	10/04/94	1680.00	117.25	1562.75	KARL F. POHLMANN, JUNE 1995
EH-7	SOUTH WEISER	12/08/94	1680.00	117.46	1562.54	KARL F. POHLMANN, JUNE 1995
EH-7	SOUTH WEISER	01/09/95	1680.00	117.2	1562.8	KARL F. POHLMANN, 1996
EH-7	SOUTH WEISER	04/05/95	1680.00	117.15	1562.85	KARL F. POHLMANN, 1996
EH-7	SOUTH WEISER	06/16/95	1680.00	117.27	1562.73	KARL F. POHLMANN, 1996
EH-7	SOUTH WEISER	09/07/95	1680.00	117.25	1562.75	KARL F. POHLMANN, 1996
EH-7	SOUTH WEISER	10/12/95	1680.00	117.31	1562.69	KARL F. POHLMANN, 1996
EH-7	SOUTH WEISER	12/14/95	1680.00	117.41	1562.59	KARL F. POHLMANN, 1996
EH-7	SOUTH WEISER	01/12/96	1680.00	117.33	1562.67	KARL F. POHLMANN, MARCH 1997
EH-7	SOUTH WEISER	03/14/96	1680.00	117.41	1562.59	KARL F. POHLMANN, MARCH 1997
EH-7	SOUTH WEISER	05/08/96	1680.00	117.31	1562.69	KARL F. POHLMANN, MARCH 1997
EH-7	SOUTH WEISER	06/14/96	1680.00	117.4	1562.6	KARL F. POHLMANN, MARCH 1997
EH-7	SOUTH WEISER	08/13/96	1680.00	117.25	1562.75	KARL F. POHLMANN, MARCH 1997
EH-7	SOUTH WEISER	09/13/96	1680.00	117.31	1562.69	KARL F. POHLMANN, MARCH 1997
EH-7	SOUTH WEISER	11/22/96	1680.00	117.25	1562.75	KARL F. POHLMANN, MARCH 1997
EH-7	SOUTH WEISER	12/18/96	1680.00	117.52	1562.48	KARL F. POHLMANN, MARCH 1997
EH-7	SOUTH WEISER	03/12/99	1680.00	117.63	1562.37	CONVERSE, 02/25/00
EH-7	SOUTH WEISER	06/14/99	1680.00	117.58	1562.42	CONVERSE, 02/25/00
EH-7	SOUTH WEISER	09/16/99	1680.00	117.43	1562.57	CONVERSE, 02/25/00
EH-7	SOUTH WEISER	12/28/99	1680.00	117.3	1562.7	CONVERSE, 02/25/00
EH-7	SOUTH WEISER	03/21/00	1680.00	117.35	1562.65	CONVERSE, 02/15/01
EH-7	SOUTH WEISER	06/15/00	1680.00	117.25	1562.75	CONVERSE, 02/15/01
EH-7	SOUTH WEISER	09/20/00	1680.00	117.26	1562.74	CONVERSE, 02/15/01
EH-7	SOUTH WEISER	12/15/00	1680.00	117.29	1562.71	CONVERSE, 02/15/01
GARNET		10/23/97	2066.00	282.8	1783.20	SNWA
GARNET		11/28/97	2066.00	283.58	1782.42	SNWA
GARNET		01/05/98	2066.00	281.88	1784.12	SNWA
GARNET		04/09/98	2066.00	278.56	1787.44	SNWA
GARNET		05/29/98	2066.00	282.71	1783.29	SNWA
GARNET		06/11/98	2066.00	275.05	1790.95	SNWA
GARNET		07/01/98	2066.00	275.62	1790.38	SNWA
GARNET		08/19/98	2066.00	283.4	1782.60	SNWA
GARNET		01/22/99	2066.00	283.4	1782.60	SNWA
GARNET		04/12/99	2066.00	282.7	1783.30	SNWA
GARNET		08/06/99	2066.00	283.77	1782.23	SNWA
GARNET		10/19/99	2066.00	284.15	1781.85	SNWA
GARNET		06/09/00	2066.00	283.84	1782.16	SNWA
GARNET		01/05/01	2066.00	284.5	1781.50	SNWA
GV-1	DRY LAKE LLC	06/04/00	2692.70	880.5	1812.2	JOHNSON, C. et al., 2001
GV-ET-1		03/23/89	2321.41	453	1868	NDWR
GV-GSC-1		03/30/87	2293.41	485	1808	NDWR
GV-KERR-1		02/07/90	2404.60	578	1827	NDWR

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
GV-NDOT		09/10/72	2066.37	240	1826	NDWR
GV-SSD-1		06/07/96	2450.12	645	1805	NDWR
GV-SSD-2		06/21/97	2449.17	610	1839	NDWR
GV-USLIME-1		09/13/63	2073.16	230	1843	NDWR
GV-USLIME-2		07/22/71	2155.33	338	1817	NDWR
HARVEY WELL		04/15/99	2066.80	253.79	1813.01	CONVERSE, 02/25/00
HARVEY WELL		06/14/99	2066.80	253.91	1812.89	CONVERSE, 02/25/00
HARVEY WELL		09/16/99	2066.80	254.43	1812.37	CONVERSE, 02/25/00
HARVEY WELL		12/28/99	2066.80	254.19	1812.61	CONVERSE, 02/25/00
HARVEY WELL		03/21/00	2066.80	254.1	1812.7	CONVERSE, 02/15/01
HARVEY WELL		06/15/00	2066.80	254.35	1812.45	CONVERSE, 02/15/01
HARVEY WELL		08/09/00	2066.80	254.8	1812	CONVERSE, 02/15/01
HARVEY WELL		08/15/00	2066.80	254.85	1811.95	CONVERSE, 02/15/01
HARVEY WELL		09/19/00	2066.80	254.84	1811.96	CONVERSE, 02/15/01
HARVEY WELL		12/15/00	2066.80	254.82	1811.98	CONVERSE, 02/15/01
HV-1	DRY LAKE LLC	05/10/00		882.5	1817.35	JOHNSON, C. et al., 2001
HV-HLA		09/19/95	2879.97	46	2834	NDWR
KS-GEYSER		01/10/68	3590.13	55	3535	NDWR
LDS-CENTRAL	UM49	01/04/90	1769.58	2.89	1766.69	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	01/12/90	1769.58	2.12	1767.46	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	02/20/90	1769.58	8.5	1761.08	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	03/16/90	1769.58	3.02	1766.56	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	04/16/90	1769.58	2.96	1766.62	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	05/04/90	1769.58	3.08	1766.5	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	05/18/90	1769.58	3.09	1766.49	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	05/25/90	1769.58	3.16	1766.42	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	06/12/90	1769.58	2.18	1767.4	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	07/10/90	1769.58	10.59	1758.99	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	07/18/90	1769.58	10.27	1759.31	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	08/10/90	1769.58	10.57	1759.01	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	09/07/90	1769.58	9.98	1759.6	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	09/27/90	1769.58	9.46	1760.12	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	10/12/90	1769.58	3.58	1766	M.D. MIFFLIN, MAY 1991
LDS-CENTRAL	UM49	01/11/91	1769.58	2.3	1767.28	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	02/05/91	1769.58	2.29	1767.29	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	03/06/91	1769.58	2.42	1767.16	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	03/21/91	1769.58	2.51	1767.07	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	04/06/91	1769.58	2.68	1766.90	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	05/16/91	1769.58	9.68	1759.90	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	06/18/91	1769.58	9.72	1759.86	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	07/25/91	1769.58	9.94	1759.64	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	08/20/91	1769.58	9.87	1759.71	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	09/20/91	1769.58	8.92	1760.66	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	10/11/91	1769.58	3.56	1766.02	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	11/06/91	1769.58	2.9	1766.68	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	11/26/91	1769.58	2.61	1766.97	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	12/27/91	1769.58	2.36	1767.22	M.D. MIFFLIN, MAY 1992
LDS-CENTRAL	UM49	01/27/92	1769.58	2.37	1767.21	M.D. MIFFLIN, APRIL 1993
LDS-CENTRAL	UM49	02/24/92	1769.58	2.41	1767.17	M.D. MIFFLIN, APRIL 1993
LDS-CENTRAL	UM49	03/20/92	1769.58	2.61	1766.97	M.D. MIFFLIN, APRIL 1993
LDS-CENTRAL	UM49	04/21/92	1769.58	3.04	1766.54	M.D. MIFFLIN, APRIL 1993
LDS-CENTRAL	UM49	05/13/92	1769.58	7.01	1762.57	M.D. MIFFLIN, APRIL 1993
LDS-CENTRAL	UM49	06/12/92	1769.58	3.7	1765.88	M.D. MIFFLIN, APRIL 1993
LDS-CENTRAL	UM49	07/23/92	1769.58	4.24	1765.34	M.D. MIFFLIN, APRIL 1993
LDS-CENTRAL	UM49	08/13/92	1769.58	4.41	1765.17	M.D. MIFFLIN, APRIL 1993
LDS-CENTRAL	UM49	09/10/92	1769.58	4	1765.58	M.D. MIFFLIN, APRIL 1993
LDS-CENTRAL	UM49	10/19/92	1769.58	3.54	1766.04	M.D. MIFFLIN, APRIL 1993

APPENDIX C

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
LDS-CENTRAL	UM49	12/01/92	1769.58	2.86	1766.72	M.D. MIFFLIN, APRIL 1993
LDS-CENTRAL	UM49	12/23/92	1769.58	2.82	1766.76	M.D. MIFFLIN, APRIL 1993
LDS-CENTRAL	UM49	01/05/94	1769.58	2.55	1767.03	KARL F. POHLMANN, JUNE 1995
LDS-CENTRAL	UM49	02/04/94	1769.58	2.46	1767.12	KARL F. POHLMANN, JUNE 1995
LDS-CENTRAL	UM49	03/04/94	1769.58	2.56	1767.02	KARL F. POHLMANN, JUNE 1995
LDS-CENTRAL	UM49	04/08/94	1769.58	2.78	1766.8	KARL F. POHLMANN, JUNE 1995
LDS-CENTRAL	UM49	05/06/94	1769.58	3.12	1766.46	KARL F. POHLMANN, JUNE 1995
LDS-CENTRAL	UM49	06/09/94	1769.58	3.82	1765.76	KARL F. POHLMANN, JUNE 1995
LDS-CENTRAL	UM49	07/02/94	1769.58	11.75	1757.83	KARL F. POHLMANN, JUNE 1995
LDS-CENTRAL	UM49	08/12/94	1769.58	11.95	1757.63	KARL F. POHLMANN, JUNE 1995
LDS-CENTRAL	UM49	09/06/94	1769.58	11.38	1758.2	KARL F. POHLMANN, JUNE 1995
LDS-CENTRAL	UM49	10/04/94	1769.58	11.9	1757.68	KARL F. POHLMANN, JUNE 1995
LDS-CENTRAL	UM49	11/01/94	1769.58	3.45	1766.13	KARL F. POHLMANN, JUNE 1995
LDS-CENTRAL	UM49	12/08/94	1769.58	2.83	1766.75	KARL F. POHLMANN, JUNE 1995
LDS-CENTRAL	UM49	01/09/95	1769.58	2.35	1767.23	KARL F. POHLMANN, 1996
LDS-CENTRAL	UM49	02/08/95	1769.58	2.15	1767.43	KARL F. POHLMANN, 1996
LDS-CENTRAL	UM49	03/08/95	1769.58	2.15	1767.43	KARL F. POHLMANN, 1996
LDS-CENTRAL	UM49	04/05/95	1769.58	2.35	1767.23	KARL F. POHLMANN, 1996
LDS-CENTRAL	UM49	05/18/95	1769.58	3.24	1766.34	KARL F. POHLMANN, 1996
LDS-CENTRAL	UM49	06/16/95	1769.58	10.17	1759.41	KARL F. POHLMANN, 1996
LDS-CENTRAL	UM49	07/05/95	1769.58	4.04	1765.54	KARL F. POHLMANN, 1996
LDS-CENTRAL	UM49	08/09/95	1769.58	10.56	1759.02	KARL F. POHLMANN, 1996
LDS-CENTRAL	UM49	09/07/95	1769.58	4.52	1765.06	KARL F. POHLMANN, 1996
LDS-CENTRAL	UM49	10/12/95	1769.58	3.81	1765.77	KARL F. POHLMANN, 1996
LDS-CENTRAL	UM49	11/09/95	1769.58	9.37	1760.21	KARL F. POHLMANN, 1996
LDS-CENTRAL	UM49	12/14/95	1769.58	2.8	1766.78	KARL F. POHLMANN, 1996
LDS-CENTRAL	UM49	01/12/96	1769.58	2.48	1767.1	KARL F. POHLMANN, MARCH 1997
LDS-CENTRAL	UM49	03/01/96	1769.58	2.36	1767.22	KARL F. POHLMANN, MARCH 1997
LDS-CENTRAL	UM49	03/14/96	1769.58	2.37	1767.21	KARL F. POHLMANN, MARCH 1997
LDS-CENTRAL	UM49	04/11/96	1769.58	2.56	1767.02	KARL F. POHLMANN, MARCH 1997
LDS-CENTRAL	UM49	05/08/96	1769.58	3.03	1766.55	KARL F. POHLMANN, MARCH 1997
LDS-CENTRAL	UM49	06/14/96	1769.58	3.55	1766.03	KARL F. POHLMANN, MARCH 1997
LDS-CENTRAL	UM49	08/13/96	1769.58	11.21	1758.37	KARL F. POHLMANN, MARCH 1997
LDS-CENTRAL	UM49	09/13/96	1769.58	10.75	1758.83	KARL F. POHLMANN, MARCH 1997
LDS-CENTRAL	UM49	10/10/96	1769.58	10.2	1759.38	KARL F. POHLMANN, MARCH 1997
LDS-CENTRAL	UM49	11/22/96	1769.58	3.05	1766.53	KARL F. POHLMANN, MARCH 1997
LDS-CENTRAL	UM49	12/18/96	1769.58	2.65	1766.93	KARL F. POHLMANN, MARCH 1997
LDS-CENTRAL	UM49	04/21/97	1769.58	9.1	1760.48	KLEINFELDER, 02/17/00
LDS-CENTRAL	UM49	06/26/97	1769.58	3.72	1765.86	KLEINFELDER, 02/17/00
LDS-CENTRAL	UM49	09/24/97	1769.58	4.26	1765.32	KLEINFELDER, 02/17/00
LDS-CENTRAL	UM49	12/16/97	1769.58	3.04	1766.54	KLEINFELDER, 02/17/00
LDS-CENTRAL	UM49	03/18/98	1769.58	9.04	1760.54	KLEINFELDER, 02/17/00
LDS-CENTRAL	UM49	07/01/98	1769.58	10.52	1759.06	KLEINFELDER, 02/17/00
LDS-CENTRAL	UM49	10/02/98	1769.58	3.7	1765.88	KLEINFELDER, 02/17/00
LDS-CENTRAL	UM49	12/31/98	1769.58	7.4	1762.18	KLEINFELDER, 02/17/00
LDS-CENTRAL	UM49	03/30/99	1769.58	2.72	1766.86	KLEINFELDER, 02/17/00
LDS-CENTRAL	UM49	06/24/99	1769.58	10.24	1759.34	KLEINFELDER, 02/17/00
LDS-CENTRAL	UM49	09/21/99	1769.58	9.78	1759.8	KLEINFELDER, 02/17/00
LDS-CENTRAL	UM49	12/22/99	1769.58	10.19	1759.39	KLEINFELDER, 02/17/00
LDS-CENTRAL	UM49	01/14/00	1769.58	3.06	1766.52	CONVERSE, 02/15/01
LDS-CENTRAL	UM49	02/15/00	1769.58	9.55	1760.03	CONVERSE, 02/15/01
LDS-CENTRAL	UM49	03/21/00	1769.58	10.1	1759.48	CONVERSE, 02/15/01
LDS-CENTRAL	UM49	04/14/00	1769.58	9.77	1759.81	CONVERSE, 02/15/01
LDS-CENTRAL	UM49	05/15/00	1769.58	3.87	1765.71	CONVERSE, 02/15/01
LDS-CENTRAL	UM49	06/14/00	1769.58	12.14	1757.44	CONVERSE, 02/15/01
LDS-CENTRAL	UM49	07/14/00	1769.58	11.96	1757.62	CONVERSE, 02/15/01
LDS-CENTRAL	UM49	08/15/00	1769.58	4.63	1764.95	CONVERSE, 02/15/01

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
LDS-CENTRAL	UM49	09/19/00	1769.58	8.63	1760.95	CONVERSE, 02/15/01
LDS-CENTRAL	UM49	10/13/00	1769.58	8.56	1761.02	CONVERSE, 02/15/01
LDS-CENTRAL	UM49	11/16/00	1769.58	3.99	1765.59	CONVERSE, 02/15/01
LDS-CENTRAL	UM49	12/15/00	1769.58	8.58	1761	CONVERSE, 02/15/01
LDS-WEST	UM18	01/12/90	1807.34	19.98	1787.36	M.D. MIFFLIN, MAY 1991
LDS-WEST	UM18	02/20/90	1807.34	17.71	1789.63	M.D. MIFFLIN, MAY 1991
LDS-WEST	UM18	03/16/90	1807.34	17.81	1789.53	M.D. MIFFLIN, MAY 1991
LDS-WEST	UM18	04/16/90	1807.34	17.49	1789.85	M.D. MIFFLIN, MAY 1991
LDS-WEST	UM18	05/18/90	1807.34	19.07	1788.27	M.D. MIFFLIN, MAY 1991
LDS-WEST	UM18	05/25/90	1807.34	19.44	1787.9	M.D. MIFFLIN, MAY 1991
LDS-WEST	UM18	06/12/90	1807.34	22.6	1784.74	M.D. MIFFLIN, MAY 1991
LDS-WEST	UM18	07/10/90	1807.34	26.71	1780.63	M.D. MIFFLIN, MAY 1991
LDS-WEST	UM18	07/18/90	1807.34	24.96	1782.38	M.D. MIFFLIN, MAY 1991
LDS-WEST	UM18	08/10/90	1807.34	29.95	1777.39	M.D. MIFFLIN, MAY 1991
LDS-WEST	UM18	09/07/90	1807.34	31	1776.34	M.D. MIFFLIN, MAY 1991
LDS-WEST	UM18	09/27/90	1807.34	30.16	1777.18	M.D. MIFFLIN, MAY 1991
LDS-WEST	UM18	10/16/90	1807.34	22.55	1784.79	M.D. MIFFLIN, MAY 1991
LDS-WEST	UM18	01/11/91	1807.34	18.12	1789.22	M.D. MIFFLIN, MAY 1992
LDS-WEST	UM18	02/25/91	1807.34	17.82	1789.52	M.D. MIFFLIN, MAY 1992
LDS-WEST	UM18	03/06/91	1807.34	17.36	1789.98	M.D. MIFFLIN, MAY 1992
LDS-WEST	UM18	03/21/91	1807.34	16.88	1790.46	M.D. MIFFLIN, MAY 1992
LDS-WEST	UM18	04/08/91	1807.34	16.72	1790.62	M.D. MIFFLIN, MAY 1992
LDS-WEST	UM18	05/16/91	1807.34	18.04	1789.30	M.D. MIFFLIN, MAY 1992
LDS-WEST	UM18	06/18/91	1807.34	28.97	1778.37	M.D. MIFFLIN, MAY 1992
LDS-WEST	UM18	07/25/91	1807.34	24.05	1783.29	M.D. MIFFLIN, MAY 1992
LDS-WEST	UM18	08/20/91	1807.34	25.08	1782.26	M.D. MIFFLIN, MAY 1992
LDS-WEST	UM18	09/20/91	1807.34	29.72	1777.62	M.D. MIFFLIN, MAY 1992
LDS-WEST	UM18	11/06/91	1807.34	23.02	1784.32	M.D. MIFFLIN, MAY 1992
LDS-WEST	UM18	11/26/91	1807.34	19.43	1787.91	M.D. MIFFLIN, MAY 1992
LDS-WEST	UM18	12/27/91	1807.34	18.31	1789.03	M.D. MIFFLIN, MAY 1992
LDS-WEST	UM18	01/27/92	1807.34	19.98	1787.36	M.D. MIFFLIN, APRIL 1993
LDS-WEST	UM18	02/24/92	1807.34	17.41	1789.93	M.D. MIFFLIN, APRIL 1993
LDS-WEST	UM18	03/24/92	1807.34	16.75	1790.59	M.D. MIFFLIN, APRIL 1993
LDS-WEST	UM18	04/21/92	1807.34	17.05	1790.29	M.D. MIFFLIN, APRIL 1993
LDS-WEST	UM18	05/13/92	1807.34	18.41	1788.93	M.D. MIFFLIN, APRIL 1993
LDS-WEST	UM18	06/12/92	1807.34	31.46	1775.88	M.D. MIFFLIN, APRIL 1993
LDS-WEST	UM18	07/22/92	1807.34	29.94	1777.40	M.D. MIFFLIN, APRIL 1993
LDS-WEST	UM18	08/13/92	1807.34	31.76	1775.58	M.D. MIFFLIN, APRIL 1993
LDS-WEST	UM18	09/10/92	1807.34	34.44	1772.90	M.D. MIFFLIN, APRIL 1993
LDS-WEST	UM18	10/19/92	1807.34	20.95	1786.39	M.D. MIFFLIN, APRIL 1993
LDS-WEST	UM18	12/01/92	1807.34	18.58	1788.76	M.D. MIFFLIN, APRIL 1993
LDS-WEST	UM18	12/23/92	1807.34	18.16	1789.18	M.D. MIFFLIN, APRIL 1993
LDS-WEST	UM18	01/05/94	1807.34	18.39	1788.95	KARL F. POHLMANN, JUNE 1995
LDS-WEST	UM18	02/04/94	1807.34	17.94	1789.4	KARL F. POHLMANN, JUNE 1995
LDS-WEST	UM18	03/04/94	1807.34	17.83	1789.51	KARL F. POHLMANN, JUNE 1995
LDS-WEST	UM18	04/08/94	1807.34	17.32	1790.02	KARL F. POHLMANN, JUNE 1995
LDS-WEST	UM18	05/06/94	1807.34	18.63	1788.71	KARL F. POHLMANN, JUNE 1995
LDS-WEST	UM18	06/09/94	1807.34	30.83	1776.51	KARL F. POHLMANN, JUNE 1995
LDS-WEST	UM18	07/02/94	1807.34	34.35	1772.99	KARL F. POHLMANN, JUNE 1995
LDS-WEST	UM18	08/12/94	1807.34	38.4	1768.94	KARL F. POHLMANN, JUNE 1995
LDS-WEST	UM18	09/06/94	1807.34	33.3	1774.04	KARL F. POHLMANN, JUNE 1995
LDS-WEST	UM18	10/04/94	1807.34	32.8	1774.54	KARL F. POHLMANN, JUNE 1995
LDS-WEST	UM18	11/01/94	1807.34	32.4	1774.94	KARL F. POHLMANN, JUNE 1995
LDS-WEST	UM18	12/08/94	1807.34	23.26	1784.08	KARL F. POHLMANN, JUNE 1995
LDS-WEST	UM18	01/09/95	1807.34	19.38	1787.96	KARL F. POHLMANN, 1996
LDS-WEST	UM18	02/08/95	1807.34	17.97	1789.37	KARL F. POHLMANN, 1996
LDS-WEST	UM18	03/08/95	1807.34	16.24	1791.1	KARL F. POHLMANN, 1996

APPENDIX C

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
LDS-WEST	UM18	04/05/95	1807.34	16.96	1790.38	KARL F. POHLMANN, 1996
LDS-WEST	UM18	05/18/95	1807.34	16.94	1790.4	KARL F. POHLMANN, 1996
LDS-WEST	UM18	06/16/95	1807.34	24.48	1782.86	KARL F. POHLMANN, 1996
LDS-WEST	UM18	07/05/95	1807.34	48	1759.34	KARL F. POHLMANN, 1996
LDS-WEST	UM18	08/09/95	1807.34	29.1	1778.24	KARL F. POHLMANN, 1996
LDS-WEST	UM18	09/07/95	1807.34	29.9	1777.44	KARL F. POHLMANN, 1996
LDS-WEST	UM18	10/12/95	1807.34	24.84	1782.5	KARL F. POHLMANN, 1996
LDS-WEST	UM18	11/09/95	1807.34	31.38	1775.96	KARL F. POHLMANN, 1996
LDS-WEST	UM18	11/24/95	1807.34	30.25	1777.09	KARL F. POHLMANN, 1996
LDS-WEST	UM18	01/12/96	1807.34	19.33	1788.01	KARL F. POHLMANN, MARCH 1997
LDS-WEST	UM18	03/01/96	1807.34	17.46	1789.88	KARL F. POHLMANN, MARCH 1997
LDS-WEST	UM18	03/14/96	1807.34	17.17	1790.17	KARL F. POHLMANN, MARCH 1997
LDS-WEST	UM18	04/11/96	1807.34	16.79	1790.55	KARL F. POHLMANN, MARCH 1997
LDS-WEST	UM18	05/08/96	1807.34	17.99	1789.35	KARL F. POHLMANN, MARCH 1997
LDS-WEST	UM18	06/14/96	1807.34	29.05	1778.29	KARL F. POHLMANN, MARCH 1997
LDS-WEST	UM18	08/13/96	1807.34	30.14	1777.2	KARL F. POHLMANN, MARCH 1997
LDS-WEST	UM18	09/13/96	1807.34	38.5	1768.84	KARL F. POHLMANN, MARCH 1997
LDS-WEST	UM18	10/10/96	1807.34	36.25	1771.09	KARL F. POHLMANN, MARCH 1997
LDS-WEST	UM18	11/22/96	1807.34	20.04	1787.3	KARL F. POHLMANN, MARCH 1997
LDS-WEST	UM18	12/18/96	1807.34	27.7	1779.64	KARL F. POHLMANN, MARCH 1997
LDS-WEST	UM18	01/15/99	1807.34	35.05	1772.29	CONVERSE, 02/25/00
LDS-WEST	UM18	02/16/99	1807.34	21.22	1786.12	CONVERSE, 02/25/00
LDS-WEST	UM18	03/12/99	1807.34	19.1	1788.24	CONVERSE, 02/25/00
LDS-WEST	UM18	04/15/99	1807.34	17.89	1789.45	CONVERSE, 02/25/00
LDS-WEST	UM18	05/14/99	1807.34	30.08	1777.26	CONVERSE, 02/25/00
LDS-WEST	UM18	06/14/99	1807.34	29.14	1778.2	CONVERSE, 02/25/00
LDS-WEST	UM18	07/15/99	1807.34	31.59	1775.75	CONVERSE, 02/25/00
LDS-WEST	UM18	08/16/99	1807.34	36.98	1770.36	CONVERSE, 02/25/00
LDS-WEST	UM18	09/16/99	1807.34	35.99	1771.35	CONVERSE, 02/25/00
LDS-WEST	UM18	10/12/99	1807.34	25.12	1782.22	CONVERSE, 02/25/00
LDS-WEST	UM18	11/16/99	1807.34	31.55	1775.79	CONVERSE, 02/25/00
LDS-WEST	UM18	12/28/99	1807.34	27.95	1779.39	CONVERSE, 02/25/00
LDS-WEST	UM18	01/14/00	1807.34	19.06	1788.28	CONVERSE, 02/15/01
LDS-WEST	UM18	02/15/00	1807.34	19.44	1787.9	CONVERSE, 02/15/01
LDS-WEST	UM18	03/21/00	1807.34	17.58	1789.76	CONVERSE, 02/15/01
LDS-WEST	UM18	04/14/00	1807.34	16.26	1791.08	CONVERSE, 02/15/01
LDS-WEST	UM18	05/15/00	1807.34	18.52	1788.82	CONVERSE, 02/15/01
LDS-WEST	UM18	06/14/00	1807.34	22.16	1785.18	CONVERSE, 02/15/01
LDS-WEST	UM18	07/14/00	1807.34	35.04	1772.3	CONVERSE, 02/15/01
LDS-WEST	UM18	08/15/00	1807.34	38.98	1768.36	CONVERSE, 02/15/01
LDS-WEST	UM18	09/19/00	1807.34	35.27	1772.07	CONVERSE, 02/15/01
LDS-WEST	UM18	11/16/00	1807.34	32.56	1774.78	CONVERSE, 02/15/01
LDS-WEST	UM18	12/15/00	1807.34	31.47	1775.87	CONVERSE, 02/15/01
LEWIS-FARM		01/05/94	1827.00	24.4	1802.60	KARL F. POHLMANN, JUNE 1995
LEWIS-FARM		02/04/94	1827.00	24.35	1802.65	KARL F. POHLMANN, JUNE 1995
LEWIS-FARM		03/04/94	1827.00	24.6	1802.40	KARL F. POHLMANN, JUNE 1995
LEWIS-FARM		04/08/94	1827.00	24.17	1802.83	KARL F. POHLMANN, JUNE 1995
LEWIS-FARM		05/06/94	1827.00	27.54	1799.46	KARL F. POHLMANN, JUNE 1995
LEWIS-FARM		05/19/94	1827.00	27.96	1799.04	KARL F. POHLMANN, JUNE 1995
LEWIS-FARM		06/09/94	1827.00	28.16	1798.84	KARL F. POHLMANN, JUNE 1995
LEWIS-FARM		07/02/94	1827.00	28.16	1798.84	KARL F. POHLMANN, JUNE 1995
LEWIS-FARM		08/12/94	1827.00	28.14	1798.86	KARL F. POHLMANN, JUNE 1995
LEWIS-FARM		09/06/94	1827.00	28.17	1798.83	KARL F. POHLMANN, JUNE 1995
LEWIS-FARM		10/04/94	1827.00	28.04	1798.96	KARL F. POHLMANN, JUNE 1995
LEWIS-FARM		11/01/94	1827.00	28.02	1798.98	KARL F. POHLMANN, JUNE 1995
LEWIS-FARM		12/08/94	1827.00	27.24	1799.76	KARL F. POHLMANN, JUNE 1995
LEWIS-FARM		01/09/95	1827.00	25	1802.00	KARL F. POHLMANN, JUNE 1996

APPENDIX C

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
LEWIS-FARM		02/08/95	1827.00	24.06	1802.94	KARL F. POHLMANN, JUNE 1996
LEWIS-FARM		03/08/95	1827.00	26.68	1800.32	KARL F. POHLMANN, JUNE 1996
LEWIS-FARM		04/05/95	1827.00	23.59	1803.41	KARL F. POHLMANN, JUNE 1996
LEWIS-FARM		05/18/95	1827.00	23.55	1803.45	KARL F. POHLMANN, JUNE 1996
LEWIS-FARM		06/16/95	1827.00	27.34	1799.66	KARL F. POHLMANN, JUNE 1996
LEWIS-FARM		07/05/95	1827.00	27.82	1799.18	KARL F. POHLMANN, JUNE 1996
LEWIS-FARM		08/09/95	1827.00	27.97	1799.03	KARL F. POHLMANN, JUNE 1996
LEWIS-FARM		09/07/95	1827.00	28.04	1798.96	KARL F. POHLMANN, JUNE 1996
LEWIS-FARM		10/12/95	1827.00	27.34	1799.66	KARL F. POHLMANN, JUNE 1996
LEWIS-FARM		10/19/95	1827.00	27.14	1799.86	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	05/05/83	1842.42	31.96	1810.46	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	07/14/83	1842.42	32.56	1809.86	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	09/21/83	1842.42	32.83	1809.59	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	11/30/83	1842.42	31.9	1810.52	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	12/23/83	1842.42	31.62	1810.80	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	02/03/84	1842.42	31.71	1810.71	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	04/03/84	1842.42	31.62	1810.80	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	05/29/84	1842.42	32.55	1809.87	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	09/14/84	1842.42	32.37	1810.05	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	11/02/84	1842.42	31.85	1810.57	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	12/14/84	1842.42	31.35	1811.07	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	02/15/85	1842.42	31.04	1811.38	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	03/01/85	1842.42	31.12	1811.30	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	03/16/85	1842.42	30.62	1811.80	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	05/17/85	1842.42	32.05	1810.37	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	07/02/85	1842.42	32.81	1809.61	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	08/07/85	1842.42	33.1	1809.32	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	09/18/85	1842.42	32.8	1809.62	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	11/26/85	1842.42	31.68	1810.74	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	01/08/86	1842.42	31.3	1811.12	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	01/31/86	1842.42	31.3	1811.12	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	05/29/86	1842.42	31.76	1810.66	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	06/17/86	1842.42	32.2	1810.22	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	07/14/86	1842.42	32.71	1809.71	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	09/11/86	1842.42	32.82	1809.60	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	11/26/86	1842.42	31.66	1810.76	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	12/31/86	1842.42	31.42	1811.00	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	01/23/87	1842.42	31.07	1811.35	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	02/20/87	1842.42	31.17	1811.25	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	03/19/87	1842.42	31.11	1811.31	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-NORTH	UM45	01/04/90	1842.42	31.66	1810.76	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	01/12/90	1842.42	31.51	1810.91	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	02/20/90	1842.42	31.32	1811.10	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	03/16/90	1842.42	31.26	1811.16	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	03/28/90	1842.42	31.14	1811.28	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	04/16/90	1842.42	31.29	1811.13	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	05/18/90	1842.42	32.49	1809.93	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	05/25/90	1842.42	32.24	1810.18	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	06/12/90	1842.42	32.13	1810.29	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	06/26/90	1842.42	32.3	1810.12	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	07/10/90	1842.42	32.59	1809.83	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	07/18/90	1842.42	32.68	1809.74	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	08/10/90	1842.42	32.77	1809.65	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	09/07/90	1842.42	33.28	1809.14	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	09/27/90	1842.42	33.13	1809.29	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	10/11/90	1842.42	32.6	1809.82	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	10/30/90	1842.42	32.15	1810.27	KARL F. POHLMANN, JUNE 1991

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
LEWIS-NORTH	UM45	11/19/90	1842.42	31.73	1810.69	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	12/03/90	1842.42	31.69	1810.73	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	12/20/90	1842.42	31.3	1811.12	KARL F. POHLMANN, JUNE 1991
LEWIS-NORTH	UM45	01/11/91	1842.42	31.77	1810.65	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	01/25/91	1842.42	31.67	1810.75	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	02/05/91	1842.42	31.5	1810.92	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	03/06/91	1842.42	31.35	1811.07	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	03/21/91	1842.42	31.28	1811.14	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	04/08/91	1842.42	31.26	1811.16	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	05/17/91	1842.42	31.48	1810.94	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	06/18/91	1842.42	32.86	1809.56	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	07/25/91	1842.42	33.25	1809.17	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	08/20/91	1842.42	33.16	1809.26	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	10/03/91	1842.42	32.58	1809.84	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	10/11/91	1842.42	32.43	1809.99	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	11/06/91	1842.42	32.06	1810.36	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	11/26/91	1842.42	31.93	1810.49	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	12/27/91	1842.42	31.71	1810.71	M.D. MIFFLIN, MAY 1992
LEWIS-NORTH	UM45	01/27/92	1842.42	31.61	1810.81	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	02/24/92	1842.42	31.61	1810.81	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	02/28/92	1842.42	31.52	1810.90	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	03/20/92	1842.42	31.32	1811.10	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	03/24/92	1842.42	31.33	1811.09	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	03/25/92	1842.42	31.37	1811.05	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	04/21/92	1842.42	31.18	1811.24	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	05/13/92	1842.42	31.42	1811.00	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	05/15/92	1842.42	31.44	1810.98	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	06/12/92	1842.42	32.51	1809.91	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	07/22/92	1842.42	32.55	1809.87	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	07/23/92	1842.42	32.57	1809.85	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	08/05/92	1842.42	32.59	1809.83	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	08/13/92	1842.42	32.66	1809.76	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	08/18/92	1842.42	32.7	1809.72	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	09/10/92	1842.42	32.7	1809.72	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	10/19/92	1842.42	31.87	1810.55	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	12/01/92	1842.42	31.51	1810.91	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	12/23/92	1842.42	31.7	1810.72	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	12/23/92	1842.42	31.7	1810.72	M.D. MIFFLIN, APRIL 1993
LEWIS-NORTH	UM45	01/13/93	1842.42	31.3	1811.12	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	01/19/93	1842.42	31.21	1811.21	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	01/20/93	1842.42	31.29	1811.13	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	02/01/93	1842.42	30.98	1811.44	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	02/05/93	1842.42	30.93	1811.49	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	02/19/93	1842.42	30.7	1811.72	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	03/24/93	1842.42	30.52	1811.90	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	04/02/93	1842.42	30.56	1811.86	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	04/30/93	1842.42	30.56	1811.86	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	06/03/93	1842.42	31.49	1810.93	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	07/07/93	1842.42	31.82	1810.60	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	08/02/93	1842.42	32.36	1810.06	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	09/03/93	1842.42	32.52	1809.90	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	10/01/93	1842.42	32.53	1809.89	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	11/12/93	1842.42	31.26	1811.16	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	12/10/93	1842.42	31.1	1811.32	KARL F. POHLMANN, APRIL 1994
LEWIS-NORTH	UM45	01/05/94	1842.42	31.26	1811.16	KARL F. POHLMANN, JUNE 1995
LEWIS-NORTH	UM45	02/04/94	1842.42	31.32	1811.10	KARL F. POHLMANN, JUNE 1995
LEWIS-NORTH	UM45	03/04/94	1842.42	31.45	1810.97	KARL F. POHLMANN, JUNE 1995

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
LEWIS-NORTH	UM45	04/08/94	1842.42	31.35	1811.07	KARL F. POHLMANN, JUNE 1995
LEWIS-NORTH	UM45	05/06/94	1842.42	31.96	1810.46	KARL F. POHLMANN, JUNE 1995
LEWIS-NORTH	UM45	05/19/94	1842.42	32.49	1809.93	KARL F. POHLMANN, JUNE 1995
LEWIS-NORTH	UM45	06/09/94	1842.42	31.93	1810.49	KARL F. POHLMANN, JUNE 1995
LEWIS-NORTH	UM45	07/02/94	1842.42	32.99	1809.43	KARL F. POHLMANN, JUNE 1995
LEWIS-NORTH	UM45	08/12/94	1842.42	33.18	1809.24	KARL F. POHLMANN, JUNE 1995
LEWIS-NORTH	UM45	09/06/94	1842.42	33.33	1809.09	KARL F. POHLMANN, JUNE 1995
LEWIS-NORTH	UM45	10/04/94	1842.42	33	1809.42	KARL F. POHLMANN, JUNE 1995
LEWIS-NORTH	UM45	11/01/94	1842.42	32.92	1809.50	KARL F. POHLMANN, JUNE 1995
LEWIS-NORTH	UM45	12/08/94	1842.42	32.65	1809.77	KARL F. POHLMANN, JUNE 1995
LEWIS-NORTH	UM45	01/09/95	1842.42	31.73	1810.69	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	02/08/95	1842.42	31.26	1811.16	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	03/08/95	1842.42	31.66	1810.76	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	04/05/95	1842.42	30.97	1811.45	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	05/18/95	1842.42	30.94	1811.48	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	06/16/95	1842.42	31.83	1810.59	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	07/05/95	1842.42	32.25	1810.17	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	08/09/95	1842.42	32.62	1809.80	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	09/07/95	1842.42	32.88	1809.54	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	10/12/95	1842.42	32.46	1809.96	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	11/09/95	1842.42	31.82	1810.60	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	11/24/95	1842.42	31.7	1810.72	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	12/14/95	1842.42	31.5	1810.92	KARL F. POHLMANN, JUNE 1996
LEWIS-NORTH	UM45	01/12/96	1842.42	31.36	1811.06	KARL F. POHLMANN, MARCH 1997
LEWIS-NORTH	UM45	03/01/96	1842.42	31.11	1811.31	KARL F. POHLMANN, MARCH 1997
LEWIS-NORTH	UM45	03/14/96	1842.42	30.99	1811.43	KARL F. POHLMANN, MARCH 1997
LEWIS-NORTH	UM45	04/11/96	1842.42	30.87	1811.55	KARL F. POHLMANN, MARCH 1997
LEWIS-NORTH	UM45	05/08/96	1842.42	31.3	1811.12	KARL F. POHLMANN, MARCH 1997
LEWIS-NORTH	UM45	06/14/96	1842.42	32.44	1809.98	KARL F. POHLMANN, MARCH 1997
LEWIS-NORTH	UM45	08/13/96	1842.42	32.51	1809.91	KARL F. POHLMANN, MARCH 1997
LEWIS-NORTH	UM45	09/13/96	1842.42	32.51	1809.91	KARL F. POHLMANN, MARCH 1997
LEWIS-NORTH	UM45	10/10/96	1842.42	32.32	1810.10	KARL F. POHLMANN, MARCH 1997
LEWIS-NORTH	UM45	11/22/96	1842.42	31.64	1810.78	KARL F. POHLMANN, MARCH 1997
LEWIS-NORTH	UM45	12/18/96	1842.42	31.51	1810.91	KARL F. POHLMANN, MARCH 1997
LEWIS-NORTH	UM45	04/21/97	1842.42	30.1	1812.32	KLEINFELDER, FEBRUARY 2000
LEWIS-NORTH	UM45	06/26/97	1842.42	31.74	1810.68	KLEINFELDER, FEBRUARY 2000
LEWIS-NORTH	UM45	09/24/97	1842.42	32.42	1810.00	KLEINFELDER, FEBRUARY 2000
LEWIS-NORTH	UM45	12/16/97	1842.42	31.76	1810.66	KLEINFELDER, FEBRUARY 2000
LEWIS-NORTH	UM45	03/18/98	1842.42	31.26	1811.16	KLEINFELDER, FEBRUARY 2000
LEWIS-NORTH	UM45	07/01/98	1842.42	32.06	1810.36	KLEINFELDER, FEBRUARY 2000
LEWIS-NORTH	UM45	10/02/98	1842.42	32.99	1809.43	KLEINFELDER, FEBRUARY 2000
LEWIS-NORTH	UM45	12/31/98	1842.42	33.01	1809.41	KLEINFELDER, FEBRUARY 2000
LEWIS-NORTH	UM45	01/15/99	1842.42	33.1	1809.32	CONVERSE, 02/25/00
LEWIS-NORTH	UM45	02/16/99	1842.42	32.47	1809.95	CONVERSE, 02/25/00
LEWIS-NORTH	UM45	03/12/99	1842.42	32.06	1810.36	CONVERSE, 02/25/00
LEWIS-NORTH	UM45	03/30/99	1842.42	32.06	1810.36	KLEINFELDER, FEBRUARY 2000
LEWIS-NORTH	UM45	04/15/99	1842.42	31.78	1810.64	CONVERSE, 02/25/00
LEWIS-NORTH	UM45	05/14/99	1842.42	31.91	1810.51	CONVERSE, 02/25/00
LEWIS-NORTH	UM45	06/15/99	1842.42	33.06	1809.36	CONVERSE, 02/25/00
LEWIS-NORTH	UM45	06/24/99	1842.42	33.06	1809.36	KLEINFELDER, FEBRUARY 2000
LEWIS-NORTH	UM45	07/15/99	1842.42	33.68	1808.74	CONVERSE, 02/25/00
LEWIS-NORTH	UM45	08/16/99	1842.42	34.07	1808.35	CONVERSE, 02/25/00
LEWIS-NORTH	UM45	09/16/99	1842.42	33.95	1808.47	CONVERSE, 02/25/00
LEWIS-NORTH	UM45	09/21/99	1842.42	33.95	1808.47	KLEINFELDER, FEBRUARY 2000
LEWIS-NORTH	UM45	10/12/99	1842.42	33.45	1808.97	CONVERSE, 02/25/00
LEWIS-NORTH	UM45	11/16/99	1842.42	32.62	1809.80	CONVERSE, 02/25/00
LEWIS-NORTH	UM45	12/21/99	1842.42	32.37	1810.05	KLEINFELDER, FEBRUARY 2000

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
LEWIS-NORTH	UM45	12/28/99	1842.42	32.37	1810.05	CONVERSE, 02/25/00
LEWIS-NORTH	UM45	01/14/00	1842.42	32.25	1810.17	CONVERSE, 02/15/01
LEWIS-NORTH	UM45	02/15/00	1842.42	32.18	1810.24	CONVERSE, 02/15/01
LEWIS-NORTH	UM45	03/21/00	1842.42	31.94	1810.48	CONVERSE, 02/15/01
LEWIS-NORTH	UM45	04/14/00	1842.42	31.89	1810.53	CONVERSE, 02/15/01
LEWIS-NORTH	UM45	05/15/00	1842.42	32.66	1809.76	CONVERSE, 02/15/01
LEWIS-NORTH	UM45	06/14/00	1842.42	33.66	1808.76	CONVERSE, 02/15/01
LEWIS-NORTH	UM45	07/14/00	1842.42	33.88	1808.54	CONVERSE, 02/15/01
LEWIS-NORTH	UM45	08/15/00	1842.42	34.13	1808.29	CONVERSE, 02/15/01
LEWIS-NORTH	UM45	09/19/00	1842.42	34.09	1808.33	CONVERSE, 02/15/01
LEWIS-NORTH	UM45	10/13/00	1842.42	33.73	1808.69	CONVERSE, 02/15/01
LEWIS-NORTH	UM45	11/16/00	1842.42	33.07	1809.35	CONVERSE, 02/15/01
LEWIS-NORTH	UM45	12/15/00	1842.42	32.86	1809.56	CONVERSE, 02/15/01
LEWIS-SOUTH	UM43	05/05/83	1806.45	18.92	1787.53	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	07/14/83	1806.45	21.94	1784.51	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	09/21/83	1806.45	21.12	1785.33	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	09/30/83	1806.45	21.18	1785.27	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	11/30/83	1806.45	18.67	1787.78	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	12/23/83	1806.45	16.72	1789.73	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	02/03/84	1806.45	17.93	1788.52	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	04/03/84	1806.45	17.25	1789.20	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	05/29/84	1806.45	19.88	1786.57	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	09/14/84	1806.45	23.13	1783.32	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	11/02/84	1806.45	18.39	1788.06	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	12/13/84	1806.45	16.27	1790.18	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	02/15/85	1806.45	14.41	1792.04	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	03/01/85	1806.45	14.48	1791.97	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	03/16/85	1806.45	14.7	1791.75	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	05/17/85	1806.45	17.38	1789.07	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	07/02/85	1806.45	21.88	1784.57	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	07/05/85	1806.45	22.98	1783.47	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	08/07/85	1806.45	23.89	1782.56	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	09/18/85	1806.45	23.87	1782.58	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	11/26/85	1806.45	18.33	1788.12	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	01/06/86	1806.45	17	1789.45	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	01/14/86	1806.45	16.27	1790.18	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	01/31/86	1806.45	16.36	1790.09	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	05/29/86	1806.45	18.53	1787.92	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	09/11/86	1806.45	22.92	1783.53	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	11/26/86	1806.45	18.15	1788.30	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	12/31/86	1806.45	16.55	1789.90	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	01/23/87	1806.45	15.28	1791.17	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	02/20/87	1806.45	16.82	1789.63	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	03/20/87	1806.45	16.2	1790.25	M.D. MIFFLIN, FEBRUARY 1989
LEWIS-SOUTH	UM43	01/04/90	1806.45	17.27	1789.18	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	01/12/90	1806.45	17.25	1789.20	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	02/20/90	1806.45	15.43	1791.02	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	03/16/90	1806.45	15.36	1791.09	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	04/16/90	1806.45	15.05	1791.40	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	05/18/90	1806.45	16.87	1789.58	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	05/25/90	1806.45	17.18	1789.27	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	06/12/90	1806.45	18.54	1787.91	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	06/18/90	1806.45	19.53	1786.92	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	07/10/90	1806.45	20.84	1785.61	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	07/18/90	1806.45	22.08	1784.37	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	08/10/90	1806.45	23.2	1783.25	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	09/07/90	1806.45	23.39	1783.06	KARL F. POHLMANN, JUNE 1991

APPENDIX C

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
LEWIS-SOUTH	UM43	09/27/90	1806.45	23.5	1782.95	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	10/16/90	1806.45	20.11	1786.34	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	10/30/90	1806.45	20.01	1786.44	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	11/08/90	1806.45	18.68	1787.77	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	11/19/90	1806.45	17.61	1788.84	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	12/03/90	1806.45	17.37	1789.08	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	12/20/90	1806.45	16.13	1790.32	KARL F. POHLMANN, JUNE 1991
LEWIS-SOUTH	UM43	01/11/91	1806.45	15.73	1790.72	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	02/05/91	1806.45	15.3	1791.15	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	03/06/91	1806.45	14.74	1791.71	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	03/21/91	1806.45	14.31	1792.14	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	04/08/91	1806.45	14.13	1792.32	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	05/16/91	1806.45	15.37	1791.08	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	06/18/91	1806.45	19.18	1787.27	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	07/25/91	1806.45	21.28	1785.17	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	08/01/91	1806.45	22.46	1783.99	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	08/20/91	1806.45	21.76	1784.69	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	08/29/91	1806.45	22.04	1784.41	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	09/13/91	1806.45	22.11	1784.34	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	09/17/91	1806.45	18.83	1787.62	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	10/11/91	1806.45	19.77	1786.68	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	10/17/91	1806.45	18.83	1787.62	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	11/06/91	1806.45	16.81	1789.64	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	11/26/91	1806.45	15.93	1790.52	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	12/27/91	1806.45	14.73	1791.72	M.D. MIFFLIN, MAY 1992
LEWIS-SOUTH	UM43	01/27/92	1806.45	14.51	1791.94	M.D. MIFFLIN, APRIL 1993
LEWIS-SOUTH	UM43	02/24/92	1806.45	13.77	1792.68	M.D. MIFFLIN, APRIL 1993
LEWIS-SOUTH	UM43	02/28/92	1806.45	13.62	1792.83	M.D. MIFFLIN, APRIL 1993
LEWIS-SOUTH	UM43	03/24/92	1806.45	13.13	1793.32	M.D. MIFFLIN, APRIL 1993
LEWIS-SOUTH	UM43	04/21/92	1806.45	13.33	1793.12	M.D. MIFFLIN, APRIL 1993
LEWIS-SOUTH	UM43	05/13/92	1806.45	14.62	1791.83	M.D. MIFFLIN, APRIL 1993
LEWIS-SOUTH	UM43	06/12/92	1806.45	18.1	1788.35	M.D. MIFFLIN, APRIL 1993
LEWIS-SOUTH	UM43	07/22/92	1806.45	18.87	1787.58	M.D. MIFFLIN, APRIL 1993
LEWIS-SOUTH	UM43	08/18/92	1806.45	20.21	1786.24	M.D. MIFFLIN, APRIL 1993
LEWIS-SOUTH	UM43	09/10/92	1806.45	20.79	1785.66	M.D. MIFFLIN, APRIL 1993
LEWIS-SOUTH	UM43	10/19/92	1806.45	16.6	1789.85	M.D. MIFFLIN, APRIL 1993
LEWIS-SOUTH	UM43	12/01/92	1806.45	14.4	1792.05	M.D. MIFFLIN, APRIL 1993
LEWIS-SOUTH	UM43	12/23/92	1806.45	14.12	1792.33	M.D. MIFFLIN, APRIL 1993
LEWIS-SOUTH	UM43	01/05/94	1806.45	14.02	1792.43	KARL F. POHLMANN, JUNE 1995
LEWIS-SOUTH	UM43	02/04/94	1806.45	13.46	1792.99	KARL F. POHLMANN, JUNE 1995
LEWIS-SOUTH	UM43	03/04/94	1806.45	13.45	1793.00	KARL F. POHLMANN, JUNE 1995
LEWIS-SOUTH	UM43	04/08/94	1806.45	12.89	1793.56	KARL F. POHLMANN, JUNE 1995
LEWIS-SOUTH	UM43	05/06/94	1806.45	14.24	1792.21	KARL F. POHLMANN, JUNE 1995
LEWIS-SOUTH	UM43	06/09/94	1806.45	17.53	1788.92	KARL F. POHLMANN, JUNE 1995
LEWIS-SOUTH	UM43	07/02/94	1806.45	20.49	1785.96	KARL F. POHLMANN, JUNE 1995
LEWIS-SOUTH	UM43	08/12/94	1806.45	21.88	1784.57	KARL F. POHLMANN, JUNE 1995
LEWIS-SOUTH	UM43	09/06/94	1806.45	22.02	1784.43	KARL F. POHLMANN, JUNE 1995
LEWIS-SOUTH	UM43	10/04/94	1806.45	20.15	1786.30	KARL F. POHLMANN, JUNE 1995
LEWIS-SOUTH	UM43	11/01/94	1806.45	19.11	1787.34	KARL F. POHLMANN, JUNE 1995
LEWIS-SOUTH	UM43	12/08/94	1806.45	17.84	1788.61	KARL F. POHLMANN, JUNE 1995
LEWIS-SOUTH	UM43	01/09/95	1806.45	14.27	1792.18	KARL F. POHLMANN, JUNE 1996
LEWIS-SOUTH	UM43	02/08/95	1806.45	12.97	1793.48	KARL F. POHLMANN, JUNE 1996
LEWIS-SOUTH	UM43	03/08/95	1806.45	12.44	1794.01	KARL F. POHLMANN, JUNE 1996
LEWIS-SOUTH	UM43	04/05/95	1806.45	12.08	1794.37	KARL F. POHLMANN, JUNE 1996
LEWIS-SOUTH	UM43	05/18/95	1806.45	12.06	1794.39	KARL F. POHLMANN, JUNE 1996
LEWIS-SOUTH	UM43	06/16/95	1806.45	14.28	1792.17	KARL F. POHLMANN, JUNE 1996
LEWIS-SOUTH	UM43	07/05/95	1806.45	16.7	1789.75	KARL F. POHLMANN, JUNE 1996

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
LEWIS-SOUTH	UM43	08/09/95	1806.45	18.65	1787.80	KARL F. POHLMANN, JUNE 1996
LEWIS-SOUTH	UM43	09/07/95	1806.45	20.5	1785.95	KARL F. POHLMANN, JUNE 1996
LEWIS-SOUTH	UM43	10/12/95	1806.45	19.28	1787.17	KARL F. POHLMANN, JUNE 1996
LEWIS-SOUTH	UM43	11/09/95	1806.45	17.42	1789.03	KARL F. POHLMANN, JUNE 1996
LEWIS-SOUTH	UM43	11/24/95	1806.45	16.2	1790.25	KARL F. POHLMANN, JUNE 1996
LEWIS-SOUTH	UM43	12/14/95	1806.45	15.75	1790.70	KARL F. POHLMANN, JUNE 1996
LEWIS-SOUTH	UM43	01/12/96	1806.45	14.24	1792.21	KARL F. POHLMANN, MARCH 1997
LEWIS-SOUTH	UM43	03/01/96	1806.45	12.71	1793.74	KARL F. POHLMANN, MARCH 1997
LEWIS-SOUTH	UM43	03/14/96	1806.45	12.45	1794.00	KARL F. POHLMANN, MARCH 1997
LEWIS-SOUTH	UM43	04/11/96	1806.45	12.08	1794.37	KARL F. POHLMANN, MARCH 1997
LEWIS-SOUTH	UM43	05/08/96	1806.45	13.19	1793.26	KARL F. POHLMANN, MARCH 1997
LEWIS-SOUTH	UM43	06/14/96	1806.45	17.37	1789.08	KARL F. POHLMANN, MARCH 1997
LEWIS-SOUTH	UM43	08/13/96	1806.45	20.88	1785.57	KARL F. POHLMANN, MARCH 1997
LEWIS-SOUTH	UM43	09/13/96	1806.45	21.63	1784.82	KARL F. POHLMANN, MARCH 1997
LEWIS-SOUTH	UM43	04/21/97	1806.45	12.7	1793.75	KLEINFELDER, FEBRUARY 2000
LEWIS-SOUTH	UM43	06/26/97	1806.45	15.33	1791.12	KLEINFELDER, FEBRUARY 2000
LEWIS-SOUTH	UM43	09/24/97	1806.45	19.46	1786.99	KLEINFELDER, FEBRUARY 2000
LEWIS-SOUTH	UM43	12/15/97	1806.45	14.12	1792.33	KLEINFELDER, FEBRUARY 2000
LEWIS-SOUTH	UM43	03/18/98	1806.45	12.25	1794.20	KLEINFELDER, FEBRUARY 2000
LEWIS-SOUTH	UM43	07/01/98	1806.45	15.58	1790.87	KLEINFELDER, FEBRUARY 2000
LEWIS-SOUTH	UM43	10/02/98	1806.45	20.35	1786.10	KLEINFELDER, FEBRUARY 2000
LEWIS-SOUTH	UM43	12/31/98	1806.45	16.95	1789.50	KLEINFELDER, FEBRUARY 2000
LEWIS-SOUTH	UM43	01/15/99	1806.45	17.71	1788.74	CONVERSE, 02/25/00
LEWIS-SOUTH	UM43	02/16/99	1806.45	15.59	1790.86	CONVERSE, 02/25/00
LEWIS-SOUTH	UM43	03/12/99	1806.45	13.38	1793.07	CONVERSE, 02/25/00
LEWIS-SOUTH	UM43	03/30/99	1806.45	13.8	1792.65	KLEINFELDER, FEBRUARY 2000
LEWIS-SOUTH	UM43	04/15/99	1806.45	12.75	1793.70	CONVERSE, 02/25/00
LEWIS-SOUTH	UM43	05/14/99	1806.45	13.89	1792.56	CONVERSE, 02/25/00
LEWIS-SOUTH	UM43	06/15/99	1806.45	17.02	1789.43	CONVERSE, 02/25/00
LEWIS-SOUTH	UM43	06/24/99	1806.45	17.17	1789.28	KLEINFELDER, FEBRUARY 2000
LEWIS-SOUTH	UM43	07/15/99	1806.45	19.53	1786.92	CONVERSE, 02/25/00
LEWIS-SOUTH	UM43	08/16/99	1806.45	20.63	1785.82	CONVERSE, 02/25/00
LEWIS-SOUTH	UM43	09/16/99	1806.45	21.89	1784.56	CONVERSE, 02/25/00
LEWIS-SOUTH	UM43	09/21/99	1806.45	21.89	1784.56	KLEINFELDER, FEBRUARY 2000
LEWIS-SOUTH	UM43	10/12/99	1806.45	18.99	1787.46	CONVERSE, 02/25/00
LEWIS-SOUTH	UM43	11/16/99	1806.45	15.89	1790.56	CONVERSE, 02/25/00
LEWIS-SOUTH	UM43	12/22/99	1806.45	15.31	1791.14	KLEINFELDER, FEBRUARY 2000
LEWIS-SOUTH	UM43	12/28/99	1806.45	15.31	1791.14	CONVERSE, 02/25/00
LEWIS-SOUTH	UM43	01/14/00	1806.45	13.75	1792.70	CONVERSE, 02/15/01
LEWIS-SOUTH	UM43	02/15/00	1806.45	14.03	1792.42	CONVERSE, 02/15/01
LEWIS-SOUTH	UM43	03/21/00	1806.45	12.58	1793.87	CONVERSE, 02/15/01
LEWIS-SOUTH	UM43	04/14/00	1806.45	12.35	1794.10	CONVERSE, 02/15/01
LEWIS-SOUTH	UM43	05/15/00	1806.45	14.62	1791.83	CONVERSE, 02/15/01
LEWIS-SOUTH	UM43	06/14/00	1806.45	16.94	1789.51	CONVERSE, 02/15/01
LEWIS-SOUTH	UM43	07/14/00	1806.45	19.85	1786.60	CONVERSE, 02/15/01
LEWIS-SOUTH	UM43	08/15/00	1806.45	21.31	1785.14	CONVERSE, 02/15/01
LEWIS-SOUTH	UM43	09/19/00	1806.45	21.62	1784.83	CONVERSE, 02/15/01
LEWIS-SOUTH	UM43	10/13/00	1806.45	20.01	1786.44	CONVERSE, 02/15/01
LEWIS-SOUTH	UM43	11/16/00	1806.45	17.62	1788.83	CONVERSE, 02/15/01
LEWIS-SOUTH	UM43	12/15/00	1806.45	16.35	1790.10	CONVERSE, 02/15/01
LMVW-1		10/27/75	4393.71	30	4364	NDWR
LMVW-10		11/23/53	4386.40	14	4372	NDWR
LMVW-11		12/01/62	1961.66	11	1951	NDWR
LMVW-12		09/30/81	1532.45	20	1512	NDWR
LMVW-13		05/06/81	1537.60	19	1519	NDWR
LMVW-14		08/27/62	1532.45	17	1515	NDWR
LMVW-15		04/04/74	1537.60	18	1520	NDWR

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
LMVW-16		01/10/52	2361.19	170	2191	NDWR
LMVW-17		12/13/61	1653.13	16	1637	NDWR
LMVW-18		07/10/80	1753.01	50	1703	NDWR
LMVW-19		11/13/75	4863.89	10	4854	NDWR
LMVW-2		04/20/79	4188.98	10	4179	NDWR
LMVW-20		08/08/55	5969.19	210	5759	NDWR
LMVW-21		03/25/74	2657.48	25	2632	NDWR
LMVW-22		07/06/82	4442.57	24	4419	NDWR
LMVW-23		10/28/80	1564.10	29.4	1535	NDWR
LMVW-24		04/02/76	2678.39	33	2645	NDWR
LMVW-25		09/03/62	3278.09	20	3258	NDWR
LMVW-26		11/24/59	4361.62	26	4336	NDWR
LMVW-27		06/03/74	4358.30	13	4345	NDWR
LMVW-28		10/26/73	4327.45	7	4320	NDWR
LMVW-29		06/02/49	4361.62	34	4328	NDWR
LMVW-3		10/31/74	4320.86	8	4313	NDWR
LMVW-30		08/07/76	5367.74	86	5282	NDWR
LMVW-31		06/18/76	4863.89	12	4852	NDWR
LMVW-32		11/30/61	3311.82	21	3291	NDWR
LMVW-33		11/21/75	4863.89	15	4849	NDWR
LMVW-34		11/01/71	1573.42	19	1554	NDWR
LMVW-35		08/20/81	4263.76	36	4228	NDWR
LMVW-36		02/12/68	4485.25	21	4464	NDWR
LMVW-37		02/26/74	1537.60	22	1516	NDWR
LMVW-38		06/01/63	1962.74	22	1941	NDWR
LMVW-39		05/01/82	1537.60	21	1517	NDWR
LMVW-4		04/16/75	4322.13	5	4317	NDWR
LMVW-40		11/06/61	2694.48	51	2643	NDWR
LMVW-41		11/13/96	1544.56	67	1478	NDWR
LMVW-42		08/09/95	1794.24	55	1739	NDWR
LMVW-43		08/21/94	4603.28	21	4582	NDWR
LMVW-44		01/06/73	1583.24	21	1562	NDWR
LMVW-45		05/31/85	1585.69	55	1531	NDWR
LMVW-46		04/09/73	1573.42	42	1531	NDWR
LMVW-47		10/18/86	1787.97	80	1708	NDWR
LMVW-48		05/13/74	2538.31	14	2524	NDWR
LMVW-49		03/25/88	1586.54	30	1557	NDWR
LMVW-5		06/09/49	4283.41	15	4268	NDWR
LMVW-50		02/25/88	1583.55	30	1554	NDWR
LMVW-51		04/29/88	1794.24	12	1782	NDWR
LMVW-52		02/16/87	1551.72	30	1522	NDWR
LMVW-53		04/23/71	1566.33	20	1546	NDWR
LMVW-54		04/25/74	1577.21	20	1557	NDWR
LMVW-55		03/09/90	1560.57	20	1541	NDWR
LMVW-56		03/01/69	1583.24	23	1560	NDWR
LMVW-57		03/03/88	1560.57	30	1531	NDWR
LMVW-58		01/02/73	1573.51	24	1550	NDWR
LMVW-59		11/07/71	1592.54	28	1565	NDWR
LMVW-6		08/21/65	4523.83	93	4431	NDWR
LMVW-60		02/12/74	1577.21	22	1555	NDWR
LMVW-61		04/05/83	1577.21	22	1555	NDWR
LMVW-62		12/25/71	1608.72	64	1545	NDWR
LMVW-63		03/26/73	1585.69	34	1552	NDWR
LMVW-64		12/28/71	1608.72	28	1581	NDWR
LMVW-65		06/05/76	1537.60	55	1483	NDWR
LMVW-66		04/01/74	1537.60	18	1520	NDWR
LMVW-67		11/01/71	1573.42	19	1554	NDWR

APPENDIX C

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
LMVW-68		09/28/71	1585.69	20	1566	NDWR
LMVW-69		04/20/71	1563.77	19	1545	NDWR
LMVW-7		03/07/68	4535.13	29	4506	NDWR
LMVW-70		02/19/74	1537.60	22	1516	NDWR
LMVW-71		03/01/69	1563.77	18	1546	NDWR
LMVW-72		12/31/63	1564.10	23	1541	NDWR
LMVW-73		01/05/72	1566.33	31	1535	NDWR
LMVW-74		03/01/69	1573.51	20	1554	NDWR
LMVW-75		09/30/81	1551.72	25	1527	NDWR
LMVW-76		11/01/63	1541.49	20	1521	NDWR
LMVW-77		03/22/73	1609.78	76	1534	NDWR
LMVW-78		01/13/73	1592.54	61	1532	NDWR
LMVW-79		05/07/71	1573.59	20	1554	NDWR
LMVW-8		03/05/66	4524.20	18	4506	NDWR
LMVW-80		10/23/80	1537.60	20.4	1517	NDWR
LMVW-81		10/26/80	1541.49	24	1517	NDWR
LMVW-82		11/07/80	1544.56	27	1518	NDWR
LMVW-83		01/26/99	4191.54	35	4157	NDWR
LMVW-84		10/14/80	1534.19	15.4	1519	NDWR
LMVW-85		10/16/80	1525.37	15.44	1510	NDWR
LMVW-9		11/11/65	4535.13	36	4499	NDWR
M-1		12/04/00		82.28	1815.83	JOHNSON, C. et al., 2001
M-2		12/04/00		298.05	1812.97	JOHNSON, C. et al., 2001
M-3		12/04/00		423	1815.03	JOHNSON, C. et al., 2001
MV-1		04/01/83	2672.68	21	2652	NDWR
MV-10		01/11/75	1496.05	40	1456	NDWR
MV-11		12/20/59	1507.44	30	1477	NDWR
MV-12		11/18/85	1499.73	165	1335	NDWR
MV-13		02/10/97	1430.77	35	1396	NDWR
MV-14		05/28/67	1415.38	22	1393	NDWR
MV-15		11/14/57	1409.60	21	1389	NDWR
MV-16		07/15/80	1466.09	47	1419	NDWR
MV-17		08/27/66	1414.81	17	1398	NDWR
MV-18		08/05/73	1375.34	20	1355	NDWR
MV-19		07/28/58	1446.48	5	1441	NDWR
MV-2		08/27/62	1537.60	17	1521	NDWR
MV-20		09/18/71	1402.80	48	1355	NDWR
MV-21		07/01/67	1366.77	10	1357	NDWR
MV-22		09/13/71	1427.44	65	1362	NDWR
MV-23		02/27/76	1314.45	12	1302	NDWR
MV-24		11/21/57	1381.01	22	1359	NDWR
MV-25		03/31/88	1836.69	174	1663	NDWR
MV-26		02/11/76	1314.45	12	1302	NDWR
MV-27		08/26/72	1314.45	25	1289	NDWR
MV-28		12/10/66	1314.45	6	1308	NDWR
MV-29		03/18/67	1314.45	12	1302	NDWR
MV-3		02/15/80	1544.45	33	1511	NDWR
MV-30		05/05/73	1304.38	3	1301	NDWR
MV-31		07/27/82	1418.04	85	1333	NDWR
MV-32		03/26/76	1295.29	7	1288	NDWR
MV-33		03/24/78	1288.29	8	1280	NDWR
MV-34		03/24/78	1286.86	6	1281	NDWR
MV-35		07/22/83	1396.11	70	1326	NDWR
MV-36		04/30/77	1285.02	18	1267	NDWR
MV-37		02/12/78	1367.63	61	1307	NDWR
MV-38		04/29/77	1275.08	20	1255	NDWR
MV-39		05/19/71	1273.57	2	1272	NDWR

APPENDIX C

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
MV-4			1514.04	10	1504	NDWR
MV-40		03/23/88	1249.89	6	1244	NDWR
MV-41		02/23/75	1314.89	10	1305	NDWR
MV-42		05/25/76	1291.63	23	1269	NDWR
MV-43		06/26/56	1279.47	83	1196	NDWR
MV-44		02/04/54	1212.75	67	1146	NDWR
MV-45		09/15/60	1744.35	180	1564	NDWR
MV-5		11/26/73	1564.64	8	1557	NDWR
MV-6		01/14/75	1591.26	14	1577	NDWR
MV-7		05/31/60	1551.80	12	1540	NDWR
MV-8		04/03/78	2236.47	336	1900	NDWR
MV-9		01/11/75	1539.93	40	1500	NDWR
MX-4	364743114533101	12/12/80	2172.60	354	1818.6	BERGER et al., 1988
MX-4	364743114533101	06/28/81	2172.60	352.3	1820.3	BERGER et al., 1988
MX-4	364743114533101	03/14/85	2172.60	351.77	1820.83	BERGER et al., 1988
MX-4	364743114533101	12/04/85	2172.60	350	1822.6	BERGER et al., 1988
MX-4	364743114533101	07/09/86	2172.60	351.8	1820.8	USGS
MX-4	364743114533101	07/10/86	2172.60	351.74	1820.86	USGS
MX-4	364743114533101	07/14/86	2172.60	351.66	1820.94	USGS
MX-4	364743114533101	08/20/86	2172.60	351.77	1820.83	USGS
MX-4	364743114533101	09/18/86	2172.60	351.69	1820.91	USGS
MX-4	364743114533101	11/17/86	2172.60	351.87	1820.73	USGS
MX-4	364743114533101	02/10/87	2172.60	351.77	1820.83	USGS
MX-4	364743114533101	03/03/87	2172.60	351.94	1820.66	USGS
MX-4	364743114533101	03/13/87	2172.60	351.66	1820.94	USGS
MX-4	364743114533101	05/07/87	2172.60	351.7	1820.9	USGS
MX-4	364743114533101	06/03/87	2172.60	351.75	1820.85	USGS
MX-4	364743114533101	07/10/87	2172.60	352	1820.6	USGS
MX-4	364743114533101	08/27/87	2172.60	352.09	1820.51	USGS
MX-4	364743114533101	09/11/87	2172.60	351.99	1820.61	TUMBUSCH et al., 1996
MX-4	364743114533101	09/13/87	2172.60	351.95	1820.65	TUMBUSCH et al., 1996
MX-4	364743114533101	09/30/87	2172.60	352.06	1820.54	USGS
MX-4	364743114533101	10/29/87	2172.60	351.95	1820.65	USGS
MX-4	364743114533101	12/18/87	2172.60	351.81	1820.79	USGS
MX-4	364743114533101	01/29/88	2172.60	351.79	1820.81	USGS
MX-4	364743114533101	02/12/88	2172.60	351.82	1820.78	USGS
MX-4	364743114533101	04/07/88	2172.60	351.8	1820.8	USGS
MX-4	364743114533101	05/12/88	2172.60	351.85	1820.75	USGS
MX-4	364743114533101	05/18/88	2172.60	351.72	1820.88	USGS
MX-4	364743114533101	08/03/88	2172.60	351.88	1820.72	USGS
MX-4	364743114533101	12/08/88	2172.60	352.04	1820.56	USGS
MX-4	364743114533101	01/17/89	2172.60	352.06	1820.54	USGS
MX-4	364743114533101	01/30/89	2172.60	351.99	1820.61	USGS
MX-4	364743114533101	01/31/89	2172.60	352.89	1819.71	USGS
MX-4	364743114533101	03/28/89	2172.60	351.98	1820.62	USGS
MX-4	364743114533101	05/30/89	2172.60	351.82	1820.78	USGS
MX-4	364743114533101	07/03/89	2172.60	351.93	1820.67	USGS
MX-4	364743114533101	07/26/89	2172.60	351.29	1821.31	USGS
MX-4	364743114533101	08/14/89	2172.60	351.9	1820.7	USGS
MX-4	364743114533101	09/12/89	2172.60	352.1	1820.5	USGS
MX-4	364743114533101	03/29/90	2172.60	353.25	1819.35	USGS
MX-4	364743114533101	08/14/90	2172.60	352.09	1820.51	USGS
MX-4	364743114533101	09/27/90	2172.60	350.9	1821.7	USGS
MX-4	364743114533101	10/29/90	2172.60	352.4	1820.2	USGS
MX-4	364743114533101	12/03/90	2172.60	352.5	1820.1	USGS
MX-4	364743114533101	02/07/91	2172.60	352.4	1820.2	USGS
MX-4	364743114533101	03/26/91	2172.60	352.3	1820.3	USGS

APPENDIX C

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
MX-4	364743114533101	04/09/91	2172.60	352.4	1820.2	USGS
MX-4	364743114533101	05/30/91	2172.60	352.1	1820.5	USGS
MX-4	364743114533101	07/30/91	2172.60	352	1820.6	USGS
MX-4	364743114533101	09/05/91	2172.60	352.7	1819.9	USGS
MX-4	364743114533101	10/08/91	2172.60	352.8	1819.8	USGS
MX-4	364743114533101	11/08/91	2172.60	352.8	1819.8	USGS
MX-4	364743114533101	11/14/91	2172.60	352.2	1820.4	USGS
MX-4	364743114533101	01/10/92	2172.60	352.5	1820.1	USGS
MX-4	364743114533101	02/12/92	2172.60	352.3	1820.3	USGS
MX-4	364743114533101	02/21/92	2172.60	352.4	1820.2	USGS
MX-4	364743114533101	03/18/92	2172.60	352.3	1820.3	USGS
MX-4	364743114533101	04/21/92	2172.60	352	1820.6	USGS
MX-4	364743114533101	04/29/92	2172.60	352.1	1820.5	USGS
MX-4	364743114533101	05/12/92	2172.60	352.1	1820.5	USGS
MX-4	364743114533101	06/15/92	2172.60	351.94	1820.66	USGS
MX-4	364743114533101	06/18/92	2172.60	352.3	1820.3	USGS
MX-4	364743114533101	07/29/92	2172.60	352.2	1820.4	USGS
MX-4	364743114533101	09/14/92	2172.60	352.2	1820.4	USGS
MX-4	364743114533101	10/07/92	2172.60	352.5	1820.1	USGS
MX-4	364743114533101	12/09/92	2172.60	352.5	1820.1	USGS
MX-4	364743114533101	03/30/93	2172.60	351.7	1820.9	USGS
MX-4	364743114533101	06/08/93	2172.60	351.4	1821.2	USGS
MX-4	364743114533101	08/04/93	2172.60	351.6	1821	USGS
MX-4	364743114533101	09/09/93	2172.60	351.6	1821	USGS
MX-4	364743114533101	10/14/93	2172.60	351.7	1820.9	USGS
MX-4	364743114533101	10/19/93	2172.60	351.9	1820.7	USGS
MX-4	364743114533101	11/10/93	2172.60	351.8	1820.8	USGS
MX-4	364743114533101	11/18/93	2172.60	351.8	1820.8	USGS
MX-4	364743114533101	12/17/93	2172.60	351.8	1820.8	USGS
MX-4	364743114533101	02/14/94	2172.60	351.9	1820.7	USGS
MX-4	364743114533101	03/31/94	2172.60	351.8	1820.8	USGS
MX-4	364743114533101	06/16/94	2172.60	351.84	1820.76	USGS
MX-4	364743114533101	08/09/94	2172.60	352.1	1820.5	USGS
MX-4	364743114533101	10/04/95	2172.60	351.9	1820.7	USGS
MX-4	364743114533101	12/12/95	2172.60	351.7	1820.9	USGS
MX-4	364743114533101	01/19/96	2172.60	351.8	1820.8	USGS
MX-4	364743114533101	01/26/96	2172.60	351.9	1820.7	USGS
MX-4	364743114533101	03/05/96	2172.60	351.7	1820.9	USGS
MX-4	364743114533101	03/12/96	2172.60	351.6	1821	USGS
MX-4	364743114533101	04/16/96	2172.60	351.38	1821.22	USGS
MX-4	364743114533101	05/31/96	2172.60	351.7	1820.9	USGS
MX-4	364743114533101	07/11/96	2172.60	351.8	1820.8	USGS
MX-4	364743114533101	08/15/96	2172.60	351.8	1820.8	USGS
MX-4	364743114533101	10/04/96	2172.60	352	1820.6	USGS
MX-4	364743114533101	03/07/97	2172.60	351.6	1821	USGS
MX-4	364743114533101	07/08/97	2172.60	351.7	1820.9	USGS
MX-4	364743114533101	10/20/97	2172.60	352.3	1820.3	USGS
MX-4	364743114533101	05/07/98	2172.60	351.6	1821	USGS
MX-4	364743114533101	10/16/98	2172.60	351.5	1821.1	SNWA
MX-4	364743114533101	10/27/98	2172.60	352.5	1820.1	USGS
MX-4	364743114533101	12/17/98	2172.60	352.66	1819.94	USGS
MX-4	364743114533101	01/22/99	2172.60	352.65	1819.95	SNWA
MX-4	364743114533101	02/19/99	2172.60	352.5	1820.1	USGS
MX-4	364743114533101	03/02/99	2172.60	352.5	1820.1	USGS
MX-4	364743114533101	03/11/99	2172.60	352.4	1820.2	USGS
MX-4	364743114533101	04/12/99	2172.60	352	1820.6	SNWA
MX-4	364743114533101	05/07/99	2172.60	352.4	1820.2	USGS

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
MX-4	364743114533101	07/02/99	2172.60	352.46	1820.14	USGS
MX-4	364743114533101	07/19/99	2172.60	352.71	1819.89	SNWA
MX-4	364743114533101	08/12/99	2172.60	352.8	1819.8	USGS
MX-4	364743114533101	10/07/99	2172.60	353.16	1819.44	USGS
MX-4	364743114533101	10/08/99	2172.60	353.11	1819.49	USGS
MX-4	364743114533101	10/19/99	2172.60	353.35	1819.25	SNWA
MX-4	364743114533101	12/13/99	2172.60	353.01	1819.59	USGS
MX-4	364743114533101	01/11/00	2172.60	353	1819.6	USGS
MX-4	364743114533101	02/09/00	2172.60	352.7	1819.9	SNWA
MX-4	364743114533101	04/05/00	2172.60	352.7	1819.9	USGS
MX-4	364743114533101	07/07/00	2172.60	353.32	1819.28	SNWA
MX-4	364743114533101	08/17/00	2172.60	353.35	1819.25	USGS
MX-4	364743114533101	10/24/00	2172.60	353.64	1818.96	SNWA
MX-4	364743114533101	01/05/01	2172.60	353.41	1819.19	SNWA
MX-5	364741114532801	05/06/81	2170.00	352.4	1817.6	BERGER et al., 1988
MX-5	364741114532801	07/04/81	2170.00	348.5	1821.5	BERGER et al., 1988
MX-5	364741114532801	08/13/81	2170.00	349.2	1820.8	BERGER et al., 1988
MX-5	364741114532801	03/14/85	2170.00	347.84	1822.16	BERGER et al., 1988
MX-5	364741114532801	12/03/85	2170.00	348.5	1821.5	BERGER et al., 1988
MX-5	364741114532801	09/11/87	2170.00	348.72	1821.28	BERGER et al., 1988
MX-5	364741114532801	09/13/87	2170.00	348.86	1821.14	BERGER et al., 1988
MX-5	364741114532801	05/18/88	2170.00	348.57	1821.43	TUMBUSCH et al., 1996
MX-5	364741114532801	08/03/88	2170.00	348.72	1821.28	TUMBUSCH et al., 1996
MX-5	364741114532801	12/08/88	2170.00	348.8	1821.2	TUMBUSCH et al., 1996
MX-5	364741114532801	01/20/89	2170.00	348.73	1821.27	TUMBUSCH et al., 1996
MX-5	364741114532801	01/30/89	2170.00	348.97	1821.03	TUMBUSCH et al., 1996
MX-5	364741114532801	01/31/89	2170.00	348.88	1821.12	TUMBUSCH et al., 1996
MX-5	364741114532801	03/28/89	2170.00	348.98	1821.02	TUMBUSCH et al., 1996
MX-5	364741114532801	05/30/89	2170.00	348.83	1821.17	TUMBUSCH et al., 1996
MX-5	364741114532801	07/26/89	2170.00	350.48	1819.52	TUMBUSCH et al., 1996
MX-5	364741114532801	08/14/89	2170.00	349.01	1820.99	TUMBUSCH et al., 1996
MX-5	364741114532801	09/12/89	2170.00	349.1	1820.9	TUMBUSCH et al., 1996
MX-5	364741114532801	11/13/90	2170.00	349.02	1820.98	TUMBUSCH et al., 1996
MX-5	364741114532801	03/26/91	2170.00	349	1821	TUMBUSCH et al., 1996
MX-5	364741114532801	06/13/91	2170.00	348.8	1821.2	TUMBUSCH et al., 1996
MX-5	364741114532801	09/12/91	2170.00	349.03	1820.97	TUMBUSCH et al., 1996
MX-5	364741114532801	12/10/91	2170.00	349.14	1820.86	TUMBUSCH et al., 1996
MX-5	364741114532801	03/18/92	2170.00	350.12	1819.88	TUMBUSCH et al., 1996
MX-5	364741114532801	06/15/92	2170.00	348.73	1821.27	TUMBUSCH et al., 1996
MX-5	364741114532801	09/14/92	2170.00	349.1	1820.9	TUMBUSCH et al., 1996
MX-5	364741114532801	12/09/92	2170.00	349.04	1820.96	TUMBUSCH et al., 1996
MX-5	364741114532801	03/30/93	2170.00	348.49	1821.51	TUMBUSCH et al., 1996
MX-5	364741114532801	06/08/93	2170.00	348.15	1821.85	TUMBUSCH et al., 1996
MX-5	364741114532801	09/09/93	2170.00	348.46	1821.54	TUMBUSCH et al., 1996
MX-5	364741114532801	12/17/93	2170.00	348.6	1821.4	TUMBUSCH et al., 1996
MX-5	364741114532801	03/31/94	2170.00	348.6	1821.4	TUMBUSCH et al., 1996
MX-5	364741114532801	06/16/94	2170.00	348.62	1821.38	TUMBUSCH et al., 1996
MX-5	364741114532801	09/08/94	2170.00	348.96	1821.04	TUMBUSCH et al., 1996
MX-5	364741114532801	05/29/98	2170.00	348.5	1821.5	SNWA
MX-5	364741114532801	07/22/98	2170.00	349.3	1820.7	SNWA
MX-5	364741114532801	10/16/98	2170.00	349.45	1820.55	SNWA
MX-5	364741114532801	01/22/99	2170.00	349.61	1820.39	SNWA
MX-5	364741114532801	04/12/99	2170.00	349.5	1820.5	SNWA
MX-5	364741114532801	07/19/99	2170.00	349.72	1820.28	SNWA
MX-5	364741114532801	08/13/99	2170.00	349.81	1820.19	USGS
MX-5	364741114532801	10/19/99	2170.00	350.3	1819.7	SNWA
MX-5	364741114532801	02/09/00	2170.00	349.75	1820.25	SNWA

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
MX-5	364741114532801	07/07/00	2170.00	350.34	1819.66	SNWA
MX-5	364741114532801	09/17/00	2170.00	350.72	1819.28	SNWA
MX-5	364741114532801	01/05/01	2170.00	350.61	1819.39	SNWA
MX-6	364604114471301	06/03/81	2274.60	458	1816.6	BERGER et al., 1988
MX-6	364604114471301	06/06/81	2274.60	457	1817.6	BERGER et al., 1988
MX-6	364604114471301	07/11/81	2274.60	457.4	1817.2	BERGER et al., 1988
MX-6	364604114471301	08/11/81	2274.60	457.8	1816.8	BERGER et al., 1988
MX-6	364604114471301	03/14/85	2274.60	457.37	1817.23	BERGER et al., 1988
MX-6	364604114471301	06/18/85	2274.60	457.34	1817.26	BERGER et al., 1988
MX-6	364604114471301	09/11/87	2274.60	459.16	1815.44	BERGER et al., 1988
MX-6	364604114471301	09/13/87	2274.60	459.47	1815.13	BERGER et al., 1988
MX-6	364604114471301	08/03/88	2274.60	457.63	1816.97	USGS
MX-6	364604114471301	12/08/88	2274.60	461.96	1812.64	USGS
MX-6	364604114471301	01/20/89	2274.60	457.77	1816.83	USGS
MX-6	364604114471301	01/31/89	2274.60	457.95	1816.65	USGS
MX-6	364604114471301	03/28/89	2274.60	457.7	1816.9	USGS
MX-6	364604114471301	05/30/89	2274.60	457.66	1816.94	USGS
MX-6	364604114471301	03/18/92	2274.60	458.1	1816.5	USGS
MX-6	364604114471301	06/15/92	2274.60	457.8	1816.8	USGS
MX-6	364604114471301	09/14/92	2274.60	458.2	1816.4	USGS
MX-6	364604114471301	12/09/92	2274.60	458.3	1816.3	USGS
MX-6	364604114471301	03/30/93	2274.60	457.5	1817.1	USGS
MX-6	364604114471301	12/17/93	2274.60	457.9	1816.7	USGS
MX-6	364604114471301	10/18/95	2274.60	457.8	1816.8	USGS
MX-6	364604114471301	01/16/96	2274.60	457.7	1816.9	USGS
MX-6	364604114471301	02/01/96	2274.60	459	1815.6	USGS
MX-6	364604114471301	04/01/96	2274.60	440	1834.6	USGS
MX-6	364604114471301	12/31/96	2274.60	459	1815.6	USGS
MX-6	364604114471301	01/31/97	2274.60	458.9	1815.7	USGS
MX-6	364604114471301	02/28/97	2274.60	458.5	1816.1	USGS
MX-6	364604114471301	04/01/97	2274.60	458.8	1815.8	USGS
MX-6	364604114471301	05/01/97	2274.60	508	1766.6	USGS
MX-6	364604114471301	06/02/97	2274.60	507	1767.6	USGS
MX-6	364604114471301	07/01/97	2274.60	508	1766.6	USGS
MX-6	364604114471301	08/01/97	2274.60	507	1767.6	USGS
MX-6	364604114471301	09/02/97	2274.60	507	1767.6	USGS
MX-6	364604114471301	11/03/97	2274.60	459.4	1815.2	USGS
MX-6	364604114471301	12/31/97	2274.60	460	1814.6	USGS
MX-6	364604114471301	06/01/98	2274.60	460	1814.6	USGS
MX-6	364604114471301	12/31/98	2274.60	460	1814.6	USGS
MX-6	364604114471301	02/01/99	2274.60	516	1758.6	USGS
MX-6	364604114471301	03/01/99	2274.60	516	1758.6	USGS
MX-6	364604114471301	04/01/99	2274.60	459	1815.6	USGS
MX-6	364604114471301	04/30/99	2274.60	459	1815.6	USGS
MX-6	364604114471301	06/01/99	2274.60	460	1814.6	USGS
MX-6	364604114471301	07/01/99	2274.60	459	1815.6	USGS
MX-6	364604114471301	08/02/99	2274.60	461	1813.6	USGS
MX-6	364604114471301	09/01/99	2274.60	459	1815.6	USGS
MX-6	364604114471301	10/01/99	2274.60	461	1813.6	USGS
MX-6	364604114471301	10/29/99	2274.60	461	1813.6	USGS
MX-6	364604114471301	12/01/99	2274.60	461	1813.6	USGS
MX-6	364604114471301	12/30/99	2274.60	461	1813.6	USGS
MX-6	364604114471301	02/01/00	2274.60	461	1813.6	USGS
MX-6	364604114471301	03/01/00	2274.60	461	1813.6	USGS
MX-6	364604114471301	04/03/00	2274.60	461	1813.6	USGS
MX-6	364604114471301	05/02/00	2274.60	461	1813.6	USGS
MX-6	364604114471301	06/01/00	2274.60	461	1813.6	USGS

Table C-2. Depth-to-Water Measurement Data

WELL ID	ALIAS	DATE	MP ELEVATION (ft. amsl)	DTW (ft.)	WL ELEV (ft. amsl)	DATA SOURCE[1]
MX-6	364604114471301	06/29/00	2274.60	475	1799.6	USGS
MX-6	364604114471301	07/31/00	2274.60	479	1795.6	USGS
MX-6	364604114471301	08/31/00	2274.60	484	1790.6	USGS
MX-6	364604114471301	09/29/00	2274.60	484	1790.6	USGS
MX-6	364604114471301	10/26/00	2274.60	461	1813.6	USGS
MX-6	364604114471301	11/30/00	2274.60	461	1813.6	USGS
SHV-1	363308114553001	12/30/85	2648.80	833.2	1815.6	BERGER et al., 1988
SHV-1	363308114553001	09/13/87	2648.80	831	1817.8	BERGER et al., 1988
SHV-1	363308114553001	01/31/89	2648.80	831	1817.8	USGS
SHV-1	363308114553001	03/28/89	2648.80	831	1817.8	USGS
SHV-1	363308114553001	05/30/89	2648.80	830.3	1818.5	USGS
SHV-1	363308114553001	07/26/89	2648.80	830.7	1818.1	USGS
SHV-1	363308114553001	09/12/89	2648.80	830.9	1817.9	USGS
SHV-1	363308114553001	05/29/98	2648.80	831.68	1817.12	SNWA
SHV-1	363308114553001	07/22/98	2648.80	831.78	1817.02	SNWA
SHV-1	363308114553001	10/16/98	2648.80	831.4	1817.4	SNWA
SHV-1	363308114553001	01/22/99	2648.80	831.58	1817.22	SNWA
SHV-1	363308114553001	04/12/99	2648.80	831.65	1817.15	SNWA
SHV-1	363308114553001	07/19/99	2648.80	831.63	1817.17	SNWA
SHV-1	363308114553001	08/12/99	2648.80	831.7	1817.1	USGS
SHV-1	363308114553001	10/19/99	2648.80	831.4	1817.4	SNWA
SHV-1	363308114553001	02/09/00	2648.80	831.6	1817.2	SNWA
SHV-1	363308114553001	07/07/00	2648.80	832.75	1816.05	SNWA
SHV-1	363308114553001	08/17/00	2648.80	834.6	1814.2	USGS
SHV-1	363308114553001	10/17/00	2648.80	832.16	1816.64	SNWA
SHV-1	363308114553001	10/24/00	2648.80	831.95	1816.85	SNWA
SHV-1	363308114553001	01/05/01	2648.80	832.19	1816.61	SNWA
TH-1		12/01/00		354.83	1815.12	JOHNSON, C. et al., 2001
TH-2		12/01/00		526.15	1815.55	JOHNSON, C. et al., 2001
xtal-2		08/21/00		256.34		JOHNSON, C. et al., 2001

1. NDWR - NDWR Well Log Database
   SNWA - Southern Nevada Water Authority Records
   USGS - USGS Ground-Water Site Inventory Database

ERRATA TO:

WATER RESOURCES AND GROUND-WATER MODELING IN THE WHITE RIVER AND MEADOW VALLEY FLOW SYSTEMS
CLARK, LINCOLN, NYE AND WHITE PINE COUNTIES, NEVADA

by
Las Vegas Valley Water District
June 2001

1) Table of Contents

Revision: Corrected table of contents to match body of document

2) Figure 6-1. Generalized ground-water recharge, evapotranspiration, and inter-basin flow of the White River and Meadow Valley Flow Systems, units in thousands of acre-feet per year**.**

Revision: Ground-water outflow from: Jakes Valley = 35,000 afy, Coyote Spring Valley to Upper Moapa Valley = 37,000 afy, and California Wash to Lower Moapa Valley = 41,000 afy

3) Table 8-4. Hydraulic properties assigned to hydrogeologic units and faults.

Revision: Corrected values for K_x and K_y for material 28 (Carbonate Rocks, Upper Moapa Subarea (South)). Correct values are $2.00x10^{+1}$.

4) Figures 8-26, 8-27, 8-28, 8-29, 8-30, 8-45, 8-46, 8-47, 8-48, 8-49, 8-54, 8-55, 8-56, 8-57, and 8-58.

Revision: Charts revised to reflect minor changes in model output as a result of correcting the placement of two well locations used to pump existing permitted rights in Lower Meadow Valley Wash and Lower Moapa Valley. The revision does not change the relative differences between the compared variables or change the conclusions stated in the report.

5) Appendix B Added list of reference inadvertently excluded in report.

6) Appendix C Added list of reference inadvertently excluded in report.

GENERALIZED GEOLOGIC MAP OF MODEL AREA WITH CROSS-SECTIONS

Data Sources: Longwell et al., 1965
Tschanz and Pampeyan, 1970
Ekren et al., 1977
Page, 1992
Page and Pampeyan, 1996
Schmidt et al., 1996
Page, 1998

Plate 1

SE ROA 39704

JA_10864

GENERALIZED HYDROGEOLOGIC MAP OF MODEL AREA WITH CROSS-SECTIONS

Plate 2

SE ROA 39705

JA_10865

MEMORANDUM 100418.0

STETSON ENGINEERS INC.

785 Grand Ave, Suite 202, Carlsbad, California 92008
TEL: (760) 730-0701 FAX: (415) 457-1638 e-mail: stever@stetsonengineers.com

TO:	Coyote Springs Investment, LLC	DATE:	October 4, 2018
FROM:	Stetson Engineers Inc.	JOB NO:	2674

RE: Proposed Groundwater Pumping for the 6-Basin Area Addressed in the Nevada State Engineer's September 19, 2018 Draft Order

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The purpose of this memorandum is to address the proposed total groundwater pumping from the 6-Basin area addressed in the Nevada State Engineer's (NSE) September 19, 2018 Draft Order (Draft Order). The Draft Order proposes: "The total allowable groundwater pumping in the Lower White River Flow System shall not exceed 9,318 acre-feet annual." (page 11). The NSE's basis for quantifying total groundwater pumping is that since the completion of the Order 1169 aquifer test, "..groundwater levels and spring flows have remained relative flat and precipitation has been about average" (page 8). Furthermore, the Draft Order then calculates that groundwater pumping in the LWRFS over the last three years has averaged 9,318 acre-feet annually.

Although the NSE states that groundwater levels have been relative flat for five years, the Draft Order does not provide the rationale of why only the recent three years are being used to quantify total pumping. The Draft Order does not appear to account for regional climate, geologic structure, localized pumping effects, or hydrogeologic factors that affect the flow and occurrence of groundwater in the 6-basin area.

The regional climate can be described by the relatively long-term rainfall station at the Praharanagat Wildlife Refuge, located upgradient from the 6-basin area. The cumulative departure from mean curve shows that there have been extended wet and dry cycles over the 1966 to 2017 period of record (Figure 1). Beginning in 2000, an extended dry period occurred until 2013, except for above average rainfall in 2004 and 2005. The cumulative decline in rainfall dropped from over 122% above normal to 160% below normal in 2012, based on a period of record. The end of the extended dry period in 2012 corresponds with the end of the Order 1169 aquifer test.

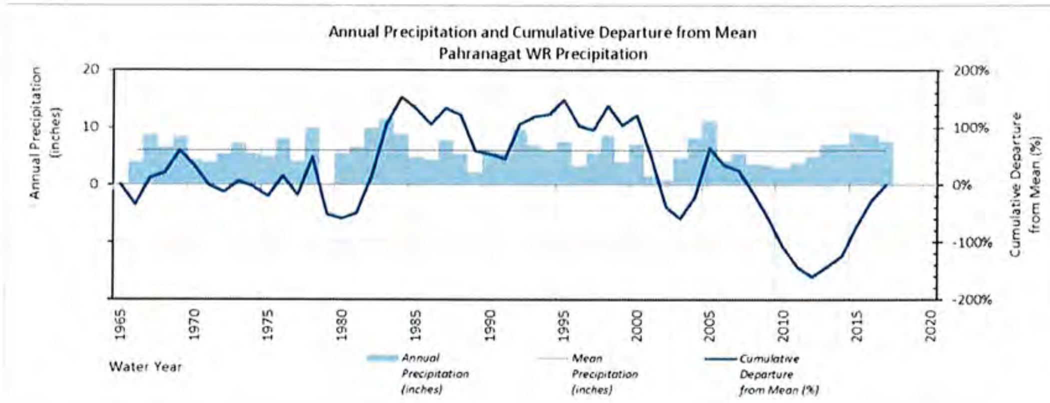

Figure 1. Cumulative Departure from Mean at Paharanagat Wildlife Refuge, period of record 1966 to 2017.

The impact from climate is reflected in the groundwater levels in the Muddy River Springs Area (MRSA) as recorded at well EH-4. Groundwater levels from 2000 through 2013 show a regional decline as depicted by the green line in Figure 2. The relatively wet years of 2004 and 2005 show an upward response in groundwater levels due to above average rainfall and recharge. The blue dots represent annual groundwater pumping from the carbonate wells in the MRSA. Two immediate observations can be made from Figure 2: First, groundwater levels decline from 2000 to 2011 as pumping declines; and, secondly, groundwater levels remain flat as groundwater pumping is

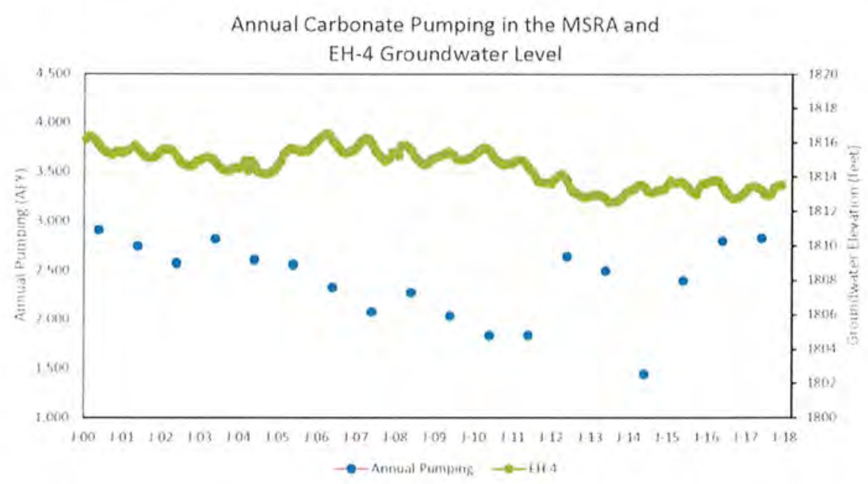

Figure 2. Annual Carbonate Pumping in the MSRA and EH-4 Groundwater Levels

significantly increased from 2012 through 2017. Based on these data, a direct correlation between groundwater pumping in the MRSA and groundwater levels can not be made without considering additional factors such as climate, geologic structure, and relationship between alluvial and carbonate pumping.

Similar to pumping in the MSRA, it is difficult to observe a direct relationship between pumping in Coyote Springs Valley (CSV) and groundwater levels in the MSRA (Figure 3) without considering other factors. Groundwater levels in the MSRA decline from 2000 through 2004 when there was no pumping in CSV. As groundwater pumping increases in 2005 through 2012, a similar slope in groundwater level decline is observed compared to that which existed when there was no pumping. Pumping in 2013 through 2017, at rates between 2,990 acre-feet per year and 1,120 acre-feet per year in CSV do not appear to have an effect on groundwater levels in the MRSA. The effect of faults, groundwater barriers, and hydrogeologic parameters between CSV pumping and the MSRA likely play a significant role when analyzing pumping in one basin to groundwater levels in the other.

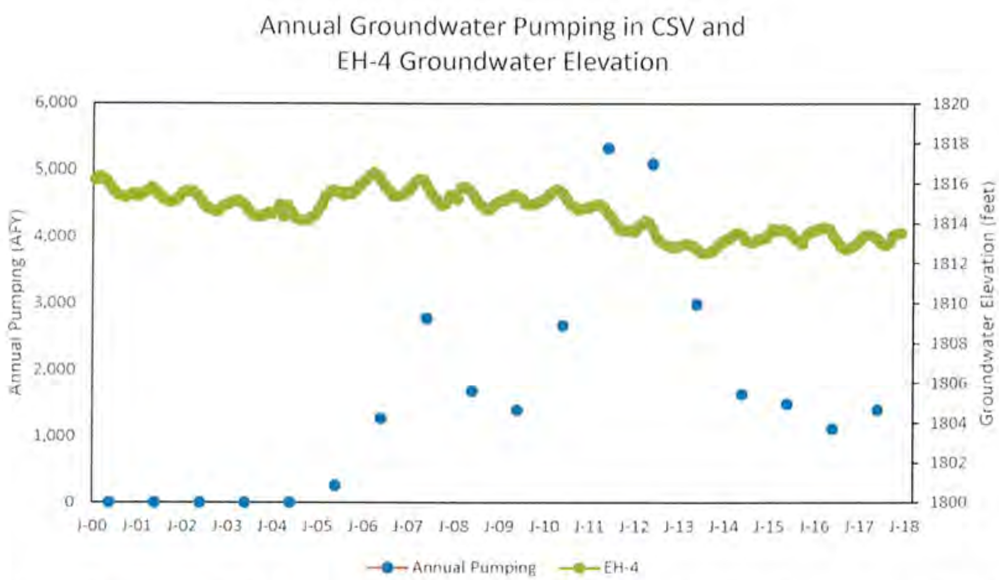

Figure 3. Annual Carbonate Pumping in the MSRA and EH-4 Groundwater Levels.

The relationship between climate, groundwater levels, and spring flow at the Pedersen Spring Complex in the MSRA for the period 1986 through 2017 is shown in Figure 4. During the period between 1986 and 2000, spring flow generally reflected climate; spring flow decreased during dry years and increased during wet years. The cumulative departure from mean curve shows that the conditions were about "normal" as reflected by an average rainfall of 5 inches per year. Spring flow decreased from 2000 to 2004 before reversing their trend due to the wet years of 2004 and 2005. Beginning in 2006, spring flow continued its decline through 2013, consistent with the extended dry climatic cycle shown in the cumulative departure form mean curve (bottom half of Figure 4).

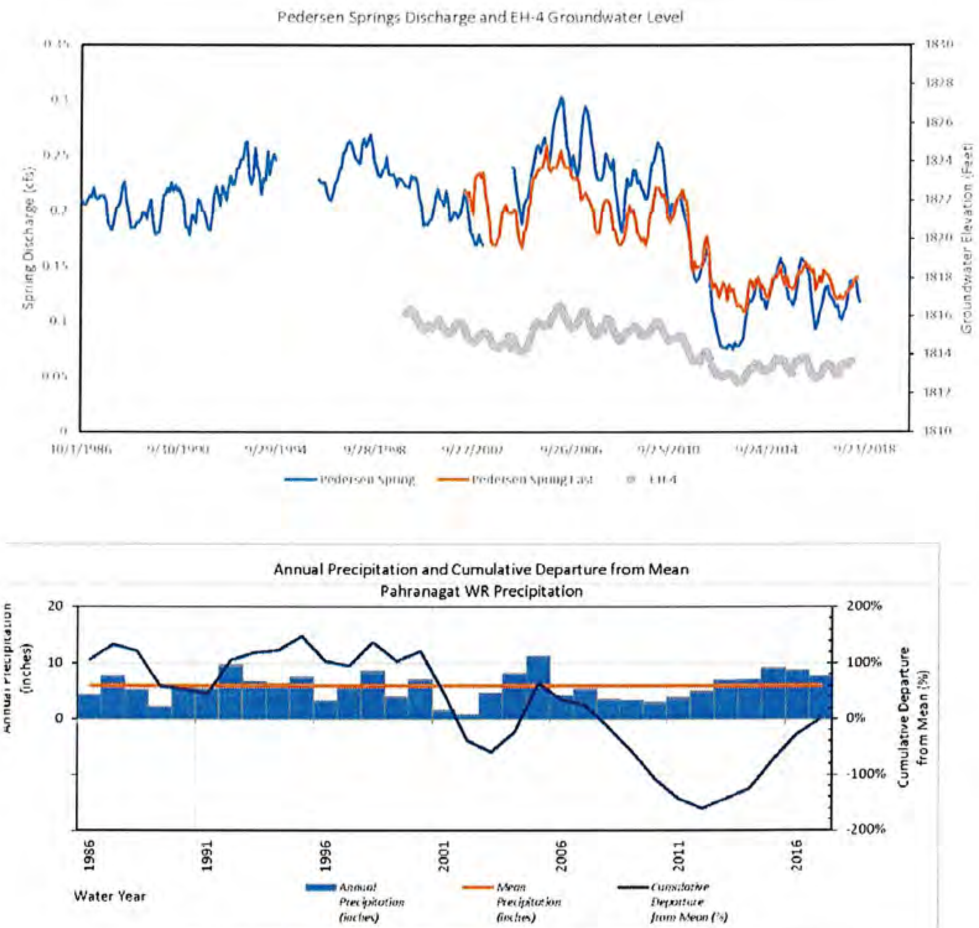

Figure 4. Climate, Spring Flow and Carbonate Groundwater levels in the MRSA

Spring flow at the Pedersen Spring complex has been relatively flat since 2013 although climate has shown above normal conditions. Although there are likely many explanations, two possible reasons for this may be due to impact of localized pumping and rainfall intensity. Groundwater pumping from carbonate wells in the MRSA increased from 1,840 acre-feet per year in 2011 to 2,820 acre-feet per year in 2017 (Figure 2), potentially impacting the recovery of groundwater levels and associated spring flow (Figure 4). Additionally, recharge from rainfall is likely dependent on intensity and temporal distribution during the rainy period. For example, recharge may not occur if storm events are short in duration or they are separated by long dry periods. An investigation of hourly or daily rainfall during 1992, 2004, 2005, 2015, and 2016 would yield an understanding of the relationship between rainfall and recharge.

Conclusions and Recommendations

The Draft Order draws a conclusion that the recent three years of pumping will support average groundwater levels and spring discharge in the MRSA. The data presented in this memorandum suggest that the relationship is much more complex. The hydrogeologic relationship between pumping and groundwater levels are dependent on the inflow and outflow of the groundwater budget that affects the entire 6-basin area, as well as the connection between each of the six basins. The 6-basin area requires the development of a conceptual hydrogeologic model, groundwater budget, and numerical model to simulate the impact of the various factors that affect the occurrence and movement of groundwater. Some of the conclusions, as well as questions, that can be reached from this analysis include.

- The observed data does not substantiate a direct relationship between the recent three years of pumping and "relatively flat" groundwater levels and spring discharge that support groundwater pumping of 9,318 acre-feet per year for the 6-Basin area.

- An extended 14-year dry period, including two wetter than normal years, occurred from 2000 through 2012.

- Climate and climatic cycles plays a significant role in assessing available water supply.

- Discharge at the Pedersen Spring Complex is affected by local and regional recharge as shown by response to 1-year and multi-year climatic conditions.

- The relationship between local carbonate pumping and groundwater levels in the MSRA is affected by recharge and long-term climate. The impact to water levels from pumping in other basins is not defined.

- The effect of pumping in CSV on carbonate groundwater levels in MSRA may be affected by groundwater barriers and geologic structure.

- Groundwater levels were declining in the MSRA at the early part of this century when there was no pumping in the CSV.

- Rainfall intensity and temporal distribution affect recharge and subsequent groundwater levels in the 6-Basin area.

The 9,318 acre-feet per year of groundwater pumping suggested in the Draft Order could be too restrictive and limit the use of Nevada's water resources. For example, the Draft Order notes that the average groundwater pumping during the calendar years 2007 through 2010 and 2013 through 2017 averaged 11,400 acre-feet per year without mention of impact to high elevation springs. Assessment of both short-term and long-term climatic conditions, groundwater recharge, and pumping that affect the groundwater resources is required to establish a starting point from which to adaptively manage the 6-Basin area. The data suggests a starting point of 11,400 acre-feet per year of groundwater pumping could be established for the 6-Basin area as the State Engineer proceeds with the following tasks to support sustainable groundwater management:

- Climate Investigation
- Hydrogeologic Conceptual Model showing boundary conditions and inter-basin flow
- Groundwater Budget
- Numerical Model

Implementation of these recommendations would allow the NSE to develop a technical basis for assessing the relationship between groundwater pumping, groundwater levels, and high elevation spring flow. Until these tasks are performed, it is premature to limit pumping in the 6-Basin area based only on the recent three years of pumping and unspecified observed groundwater levels and spring discharge.

IN THE OFFICE OF THE STATE ENGINEER

OF THE STATE OF NEVADA

IN THE MATTER OF THE ADMINISTRATION AND MANAGEMENT OF THE LOWER WHITE RIVER FLOW SYSTEM WITHIN COYOTE SPRING VALLEY HYDROGRAPHIC BASIN (210), A PORTION OF BLACK MOUNTAINS AREA HYDROGRAPHIC BASIN (215), GARNET VALLEY HYDROGRAPHIC BASIN (216), HIDDEN VALLEY HYDROGRAPHIC BASIN (217), CALIFORNIA WASH HYDROGRAPHIC BASIN (218), AND MUDDY RIVER SPRINGS AREA (AKA UPPER MOAPA VALLEY) HYDROGRAPHIC BASIN (219). LINCOLN AND CLARK COUNTIES, NEVADA.	)	**INTERIM ORDER 1303**

<u>MUDDY VALLEY IRRIGATION COMPANY</u>
<u>SUMMARY OF WITNESS TESTIMONY</u>
<u>MR. TODD ROBISON</u>

Mr. Todd Robison is the Chairman of the Board of Directors of MVIC. Mr. Robison signed the Rebuttal Report in his capacity as Chairman and is knowledgeable in matters concerning MVIC's history and operations. The Rebuttal Report shall serve as pre-filed direct written testimony of Mr. Robison.

Mr. Robison can testify concerning MVIC's history, its irrigation facilities and the water rights adjudicated in the Muddy River Decree. Mr. Robison can testify concerning MVIC's responsibilities to its shareholders, which obligate it to preserve and protect its senior decreed Muddy River water rights.

IN THE OFFICE OF THE STATE ENGINEER

OF THE STATE OF NEVADA

IN THE MATTER OF THE ADMINISTRATION AND MANAGEMENT OF THE LOWER WHITE RIVER FLOW SYSTEM WITHIN COYOTE SPRING VALLEY HYDROGRAPHIC BASIN (210), A PORTION OF BLACK MOUNTAINS AREA HYDROGRAPHIC BASIN (215), GARNET VALLEY HYDROGRAPHIC BASIN (216), HIDDEN VALLEY HYDROGRAPHIC BASIN (217), CALIFORNIA WASH HYDROGRAPHIC BASIN (218), AND MUDDY RIVER SPRINGS AREA (AKA UPPER MOAPA VALLEY) HYDROGRAPHIC BASIN (219). LINCOLN AND CLARK COUNTIES, NEVADA.	**INTERIM ORDER 1303**

MUDDY VALLEY IRRIGATION COMPANY
EXHIBIT NO. 1
REBUTTAL REPORT ATTACHED

Muddy Valley Irrigation Company
P. O. Box 665
Overton, NV 89040

August 15, 2019

Mr. Tim Wilson, P. E.
Acting State Engineer
Nevada Division of Water Resources
Department of Conservation and Natural Resources
301 South Carson Street, Suite 2002
Carson City, Nv 89701
twilson@water.nv.gov

RE: Muddy Valley Irrigation Company's Rebuttal
Report: Interim Order 1303

Dear Mr. Wilson:

As requested in Order 1303, the Muddy Valley Irrigation Company (hereafter "MVIC or "Company") submits this Rebuttal in response to the Reports filed on July 3, 2019. Said July 3, 2019 Reports were filed by twelve entities who expressed various opinions on the questions presented relative to the amount of groundwater that may be pumped within the Lower White River Flow System ("LWRFS") without conflicting with the fully appropriated and adjudicated waters of the Muddy River.

As a preface to its Rebuttal responses MVIC first observes that pursuant to NRS 533.024(1)(e), Order 1303's goal (p 11) seems to be for LWRFS groundwater permittees to propose a conjunctive management plan remedy. Such a plan, if amenable to senior surface water right holders, could mitigate impacts caused by groundwater pumping which is currently diminishing Muddy River spring and river flows. This goal, if not achieved, arguably limits the State Engineer's options in view of appears to be the present stakeholder consensus that pumping of groundwater (alluvial and carbonate) within the LWRFS has a direct connectivity with Muddy River flows.

MVIC's Rebuttal hereinbelow per Order 1303's direction addresses some of the specific (whether individual stakeholder report or combined stakeholder reports) conclusions relative to MVIC's interests in this proceeding.

I. <u>Introduction</u>

MVIC owns the majority of the Muddy River decreed surface water rights, which rights are senior to all groundwater rights within the LWRFS. A summary of MVIC's history rights and responsibilities follows:

MVIC has been in existence as a Nevada corporation since 1895 for purposes which include the acquisition of water rights and the construction operation and maintenance of their associated irrigation works of diversion and distribution for the Company's and its shareholders "beneficial use of Muddy River water within the Moapa Valley.

All Muddy River water rights including MVIC's were adjudicated in Muddy Valley Irrigation Company v. Moapa and Salt Lake Produce Company et al ("Decree") in 1920 by the 10th Judicial District Court, (now the Eighth District) for the State of Nevada ("Court"). The Decree is very explicit in its adjudication of any and every right and to the certain parties entitled to the use of Muddy River water.

The Decree determined that with the exception of the rights of the other named defendants, that MVIC is the holder of all rights in the Muddy River and all of said water rights are vested rights acquired by valid appropriation and beneficial use prior to March 1, 1905. That they are also considered as equal in rank without one having priority over any other, that the Muddy River is to be operationally divided into two parts (as far as practicable) the upper and the lower, and that the Muddy River is fully adjudicated; specifically holding:

> "Muddy Valley Irrigation Company is declared and decreed to have acquired by valid appropriation and beneficial use and to be entitled to divert and use... all of the waters of said Muddy River, its head waters, sources of supply and tributaries said water sources, supply save and accept the several amounts and rights hereinbefore specified and described as awarded and decreed...". Decree, p 20, par 7.

Not only did the Court hold that MVIC owns all the water rights not decreed to others, but that the Company is to divert all those waters for the use of the shareholders.

The Court provides for the State Engineer to supervise the Muddy River with the administration and control of the lower Muddy River provided by MVIC:

> "The Muddy Valley Irrigation Company, although under the supervision and control of the state engineer and commissioner shall subject to said supervision and general control, distribute and control the distribution of the waters diverted and conveyed by its works to its stockholders and other persons obtaining waters by means thereof." Decree, p 21, par 9,

and further:

> "That the aggregate volume of the several amounts and quantities of water awarded and allocated to the parties...**is the total available flow of the said Muddy River and consumes and exhausts all of the available flow in the said Muddy River, the head water, sources of supply and tributaries"** (emphasis added) Decree, p 22, par12.

The Court also ordered a perpetual restraint and injunction against any party from interfering with any adjudicated rights and grants the State Engineer authority to enforce the adjudicated Muddy River water rights. Decree, p21, par 14.

The above history of the Company's and the other senior surface water rights adjudicated and protected by the Decree is provided as context for MVIC's interests with respect to LWRFS groundwater development determinations in this proceeding.

There are currently just over 250 individual shareholders holding shares in the Company. As a Nevada corporation MVIC has a duty to preserve and protect its valuable Nevada water rights. Said water rights are assets of the Company acquired for the benefit of the shareholders. The shareholders are the equitable owners of MVIC's Muddy River water rights in their respective proportionate interest (shares owned) in the Company.

II. Rebuttal Response Order 1303

a. The geographic boundary of the hydrologically connected groundwater and surface water systems comprising the LWRFS

MVIC does not disagree with the Nevada State Engineer ("NSE") Order 1303 geographic boundary determinations for the LWRFS.

b. The information obtained from the Order 1169 aquifer test and subsequent to the aquifer test and Muddy River headwater spring flow as it relates to aquifer recovery since the completion of the aquifer test.

MVIC concurs with the discussion points at Section 8.2 of the Southern Nevada Water Authority ("SNWA") Report.

c. The long-term annual quantity of groundwater that may be purged from the Lower White River Flow System, including the relationship between the location of pumping on discharge to the Muddy River springs and the capture of Muddy River flow.

MVIC concurs with the technical analysis and conclusions in the SNWA Report at Section 8.2-8.4, where SNWA states that groundwater production in the MRSA and to a lesser extent the rest of the LWRFS has depleted Muddy River stream flows and thus conflicts with Muddy River Decree senior surface water rights.

d. The effects of movement of water rights between alluvial wells and carbonate wells on deliveries of senior rights to the Muddy River.

MVIC concurs with the SNWA Report at Section 8.4 changing points of diversion from the MRSA alluvial reservoir to locations in the carbonate aquifer will delay but not prevent reduced spring discharges and Muddy River flows.

As part of its Order 1303, section d filing, the MBP's Report (p 24, par 2) observes that groundwater allocations in the MRSA beginning in 1948 are not consonant with the Decree because the alluvial aquifer is intimately connected with the Muddy River. Based on the now available technical information related pumping data, this is certainly an accurate statement. There is however a statement further down in the same paragraph that should be noted for correction that reads: "Groundwater rights in the MRSA are nearly all junior to those who hold surface water rights under the Muddy River Decree". Rights to the entire Muddy River, including all waters, sources and flows were adjudicated by the Court, which determined that all surface water rights therein vested prior to March 1, 1905 (Decree, p 20, par 8). Muddy River surface water rights are senior in priority to all LWRFS groundwater rights.

e. Any other matters believed to be relevant to the State Engineer's analysis.

MVIC concurs with the conclusions presented by the SNWA Report at Section 8.5. MVIC restates its initial comments above (p1, par2) that absent a mutually agreeable LWRFS conjunctive management plan, the remedy options available to the State Engineer in this Order 1303 proceeding are limited.

Sincerely,

Todd Robison
MVIC'S Chairman of the Board

IN THE OFFICE OF THE STATE ENGINEER

OF THE STATE OF NEVADA

IN THE MATTER OF THE ADMINISTATION AND MANAGEMENT OF THE LOWER WHITE RIVER FLOWSYSTEM WITHIN COYOTE SPRING VALLEY HYDROGRAPHIC BASIN (210), A PORTIOHJ OF BLACK MOUNTIANS AREA HYDROGRAPHIC BASIN (215), GARNET VALLEY HYDROGRAPHIC BASIN (216), HIDDEN VALLEY HYDROGRAPHIC BASIN (217), CALIFORNIA WASH HYDROGRAPHIC BASIN (218), AND MUDDY RIVER SPRINGS AREA (AKA UPPER MOAPA VALLEY) HYDROGRAPHIC BASIN (219).

WITNESS LIST, EXHIBIT LIST, AND SUMMARY OF ANTICIPATED TESTIMONY OF WITNESSES FOR NEVADA COGENERATION ASSOCIATES NOS. 1 AND 2

Nevada Cogeneration Associates Nos. 1 and 2 (collectively "NCA," and separately "NCA 1" and "NCA 2"), provides the following witness list, exhibit list and summary of anticipated testimony in the above referenced proceedings before the Nevada State Engineer in compliance with the requirements of the Amended Notice of Hearing regarding Order 1303, provided August 26, 2019, which hearings are scheduled to commence September 23, 2019, in connection with the administration and management of the Lower White River Flow System (the "LWRFS").

NCA lists Jay Dixon, P.E., WRS, of Dixon Hydrologic PLLC, 10299 Culican Pass Trail, Reno, Nevada 89521, Robert Coache, P.E., WRS, who is working in association with Dixon Hydrologic on this matter, and whose address is 4280 N. Tioga Way, Las Vegas, Nevada 89129, Hugh Ricci of Ricci Engineering, Ltd., 12540 Creek Crest Dr., Reno, Nevada 89511. For the purposes of this phase of the proceeding and the upcoming hearing, each of these

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witnesses is offered as an expert in the areas of groundwater and surface water hydrology, water rights, and to the extent necessary hererin the application of Nevada water law as affecting Nevada water rights.

Mr. Dixon has been qualified as an expert before the Nevada State Engineer in hydrology and water rights. His CV is attached and will be presented as NCA Exhibit 44.

Messrs. Coache and Ricci have not been qualified before the Nevada State Engineer in a formal hearing, however they have extensive qualifications and should be allowed to testify as experts in the above listed areas. Their CVs are attached as NCA Exhibits 45 and 46, respectively. Mr. Coache has been qualified in the Eighth Judicial District Court as an expert in Nevada water law and water rights while he was employed by the Division of Water Resources.

Mr. Ricci is not expected to provide direct testimony, but as an author of NCA's Rebuttal Report (NCA Ex. 1), he will be available for cross-examination as required by the Amended Notice of Hearing regarding Order 1303.

Mr. Dixon is anticipated to testify in support of the conclusions stated in NCA's Rebuttal Report, NCA Ex. 1, as well as the following topics:

- The implementation of Nevada's Revised Statutes, particularly Chapters 533 and 534, and their impacts with regards to the administration and management of the Lower White River Flow System
- Order 1169 pump test and results of said pump test
- Ground water hydrology of the Lower White River Flow System, Black Mountains Area and Lower Meadow Valley Wash
- Surface water hydrology of the Lower White River Flow System and Black Mountains Area
- The interaction of ground water and surface water within the Lower White River Flow

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System, Black Mountains Area and Lower Meadow Valley Wash

Mr. Coache is anticipated to testify in support of the conclusions stated in NCA's Rebuttal Report, NCA Ex. 1, as well as the following topics:

- The implementation of Nevada's Revised Statutes, particularly Chapters 533 and 534, and their impacts with regards to the administration and management of the Lower White River Flow System and Kane Springs Valley
- The origin and purpose of Order 1169
- Order 1169 pump test and results of said pump test
- Ground water hydrology of the Lower White River Flow System, Kane Springs Valley, and Black Mountains Area
- Surface water hydrology of the Lower White River Flow System, Kane Springs Valley and Black Mountains Area
- The interaction of ground water and surface water within the Lower White River Flow System, Kane Springs Valley, and Black Mountains Area

The exhibits that will be utilized by NCA are those that are shown on the attached Nevada Cogeneration Association's exhibit list.

Date: September 6, 2019.

KAEMPFER CROWELL

BY: ______________________

Alex J. Flangas
Nevada Bar No. 664
50 West Liberty Street, Suite 700
Reno, NV 89501
Attorneys for Nevada Cogeneration Associates Nos. 1 and 2

CERTIFICATE OF SERVICE

I hereby certify that I am an employee of KEMPFER CROWELL, and on this date, I caused the foregoing document to be served via electronic transmission as follows:

8milelister@gmail.com; ablack@mcdonaldcarano.com; admin.mbop@moapabandofpaiutes.org; aflangas@kcnvlaw.com alaskajulie12@gmail.com; andrew.burns@snwa.com; barbnwalt325@gmail.com; bbaldwin@ziontzchestnut.com; bostajohn@gmail.com; bvann@ndow.org; chair.mbop@moapabandofpaiutes.org; chris.benkman@nsgen.com; Colby.pellegrino@snwa.com; Coop@opd5.com; coopergs@ldschurch.org; craig.primas@snvgrowers.com; craig.wilkinson@pabcogypsum.com; dan.peressini@lasvegaspaving.com; david_stone@fws.gov; Dbrown@ldalv.com; dennis.barrett10@gmail.com; derekm@westernelite.com; devaulr@cityofnorthlasvegas.com; dfrehner@lincolncountynv.gov; dixonjm@gmail.com; dorothy@vidlerwater.com; doug@nvfb.org; dvossmer@republicservices.com; dwight.smith@interflowhydro.com; edna@comcast.net; emilia.cargill@coyotesprings.com; EveryoneWaterResources@water.nv.gov; fan4philly@gmail.com; gary_karst@nps.gov; gbushner@vidlerwater.com; glen_knowles@fws.gov; gmorrison@parsonsbehle.com; golden@apexindustrialpark.com; golds@nevcogen.com; greatsam@usfds.com; greg.walch@lvvwd.com; hartthethird@gmail.com;	jmordhorst@water.nv.gov; joe@moapawater.com; Karen.glasgow@sol.doi.gov; kbrown@vvh2o.com; Kevin_Desroberts@fws.gov; kimberley.jenkins@clarkcountynv.gov; kingmont@charter.net; kpeterson@allisonmackenzie.com; krobison@rssblaw.com; kurthlawoffice@gmail.com; lazarus@glorietageo.com; lbelenky@biologicaldiversity.org; lbenezet@yahoo.com; liamleavitt@hotmail.com; Lindseyd@mvdsl.com; Lisa@ldalv.com; lle@mvdsl.com; lon@moapawater.com; lroy@broadbentinc.com; LuckyDirt@icloud.com; luke.miller@sol.doi.gov; martinmifflin@yahoo.com mfairbank@water.nv.gov mlflatley@water.nv.gov MBHoffice@earthlink.net; Michael_schwemm@fws.gov; mjohns@nvenergy.com; mmmiller@cox.net; moapalewis@gmail.com; moorea@cityofnorthlasvegas.com; muddyvalley@mvdsl.com; oldnevadanwater@gmail.com; onesharp1@gmail.com; paul@legaltnt.com; pdonnelly@biologicaldiversity.org; progress@mvdsl.com; rafelling@charter.net; raymond.roessel@bia.gov; rberley@ziontzchestnut.com; rhoerth@vidlerwater.com; robert.dreyfus@gmail.com; Rott@nvenergy.com;

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whitfam@mvdsl.com;
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RShaffer@parsonsbehle.com

Additionally, a copy of this document was delivered via facsimile to the Division of Water Resources this same day.

DATED this 6th day of September, 2019.

Employee of Kaempfer Crowell

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50 West Liberty Street, Suite 700
Reno, Nevada 89501

Nevada Cogeneration Associates

Company	Type	#	Description	Bates Nos.
NCA	Ex. No.	1	NCA Rebuttal Report Pertaining to Interim Order 1303 August 16, 2019	1-26
NCA	Ex. No.	2	City of North Las Vegas, Garnet Valley Groundwater Review for APEX Industrial Complex, City of North Las Vegas, Clark County, Nevada. Interflow Hydrology, Inc., July 2, 2019	27-80
NCA	Ex. No.	3	Tetra Tech, July 3, 2019. Prediction of the Effects of Changing the Spatial Distribution of Pumping in the Lower White River Flow System.	81-109
NCA	Ex. No.	4	Castor, S.B., Faulds, J.E., Rowland, S.M., and dePolo, G.M., 2000, Geologic map of the Frenchman Mountain Quadrangle, Clark County, Nevada: Nevada Bureau of Mines and Geology M-127	110-135
			Intentionally Omitted	(None)
NCA	Ex. No.	6	USFWS Issues Related to Conjunctive Management of the Lower White River Flow System. Presentation to the Office of the Nevada State Engineer in Response to Order 1303. July 3, 2019	136-217
NCA	Ex. No.	7	Wilson, J.W., 2019, Drilling, construction, water chemistry, water levels, and regional potentiometric surface of the upper carbonate-rock aquifer in Clark County, Nevada, 2009–2015: U.S. Geological Survey Scientific Investigations Map 3434, scale 1:500,000, https://doi.org/10.3133/sim3434	218-234

Company	Type	#	Description	Bates Nos.
NCA	Ex. No.	8	Converse Consultants, 2010. Groundwater Level Monitoring Program, 2009 Annual Report. Prepared for NV Energy.	235-317
NCA	Ex. No.	9	LVVWD Water Resources and Ground Water Modeling in the White River and Meadow Valley Flow Systems, AKA Ex 55 LVVWD Coyote Spring 2001 Hearing	318-542
NCA	Ex. No.	10	Page, W.R., Scheirer, D.S., Langenheim, V.E., and Berger, M.A.,2011, Revised Geological Cross Sections of Parts of the Colorado, White River, and Death Valley Regional Groundwater Flow Systems, Nevada, Utah, and Arizona: U.S. Geological Survey Open-File Report 2006-1040, 1 sheet, 25 p. pamphlet.	543-568
NCA	Ex. No.	11	Burbey, T. J., 1997, Hydrogeology and potential for ground-water development, Carbonate-Rock Aquifers, southern Nevada and southeastern California: U. S. Geological Survey Water Resources Investigations 95-4168, 65 p.	569-638
NCA	Ex. No.	12	Rowley, P.D., G.L. Dixon, E.A. ManKinen, K.T. Pari, D.K. McPhee, E.H. KcKee, A.G. Burns, J.M. Watrus, E.B. Ekren, W.G. Patrick, and J.M. Bandt, 2017. Geology and geophysics of White Pine and Lincoln counties, Nevada, and adjacent parts of Nevada and Utah—the geologic framework of regional groundwater flow systems. Nevada Bureau of Mines and Geology Report 56. Scale 1:250,000, 4 plates.	639-789
NCA	Ex. No.	13	Lower White River Flow System Interim Order #1303 Report Focused on the Northern Boundary of the Proposed Administrative Unit. Lincoln County Water District and Vidler Water Company. July 3, 2019.	790-839
NCA	Ex. No.	14	NSE Ex. No. 12 - Ruling 5712	840-862

Company	Type	#	Description	Bates Nos.
NCA	Ex. No.	15	Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response. SNWA. June 2019.	863-1005
NCA	Ex. No.	16	NSE Ex. No. 14 - Ruling 6254	1006-1034
NCA	Ex. No.	17	Lincoln Vidler Interim Order 1303 Transmittal Letter dated July 3, 2019	1035-1036
NCA	Ex. No.	18	Water-Level Decline in the LWRFS: Managing for Sustainable Groundwater Development. Initial Report of Moapa Band of Paiutes in Response to Order #1303. Johnson, C. and M. Mifflin. July 3, 2019.	1037-1120
NCA	Ex. No.	19	CSI Evaluation of Basin Hydrology and Assessment of Sustainable Yield in the Lower White River Flow System, Southeastern Nevada July 3, 2019	1121-1233
NCA	Ex. No.	20	CSI Rebuttal to Order 1303 Reports Submitted to the Nevada State Engineer August 08, 2019	1234-1324
NCA	Ex. No.	21	Rebuttal Submittal by Lincoln-Vidler to the Interim Order 1303 Reports submitted on July 3, 2019, dated August 16, 2019	1325-1475

Company	Type	#	Description	Bates Nos.
NCA	Ex. No.	22	Rebuttal Report Submitted on behalf of the City of North Las Vegas to Interim Order 1303 Submittals of July 3, 2019	1476-1479
NCA	Ex. No.	23	Rebuttal Report of Moapa Band of Paiutes in Response to Stakeholder Technical Reports Filed under Order #1303	1480-1506
NCA	Ex. No.	24	USFWS Rebuttal Report - Water-Level Decline in the LWRFS: Managing for Sustainable Groundwater Development August 16, 2019	1507-1522
NCA	Ex. No.	25	NV Energy Rebuttal Report to State Engineer's Order 1303 Initial Reports by Respondents, August 16, 2019	1523-1534
NCA	Ex. No.	26	NCA Comments Pertaining to a Draft Order for the LWRFS as Distributed During Working Group Meeting in Overton, NV on Sept. 19, 2018	1535-1536
NCA	Ex. No.	27	Lincoln-Vidler Hydrologic Assessment of Kane Springs Valley, AKA Ex 20 Lincoln-Vidler Kane Springs 2006 Hearing	1537-1594
NCA	Ex. No.	28	CSI Groundwater Modeling Evaluation of Coyote Spring Valley, AKA Ex 26 CSI Coyote Spring 2001 Hearing	1595-1657

Company	Type	#	Description	Bates Nos.
NCA	Ex. No.	29	Nation Park Service - The Potential Impacts of Proposed Ground Water Pumping in Coyote Spring Valley on the Water Resources of LMNRA, AKA Ex 65 CSI Coyote Spring 2001 Hearing	1658-1735
NCA	Ex. No.	30	Lake Las Vegas EarthTech Exploration and Testing Files	1736-2035
NCA	Ex. No.	31	Lake Las Vegas Phase 1 Tech Memo 060514. HydroGeo Group, 2014.	2036-2107
NCA	Ex. No.	32	NSE Ex. No. 225 - 2016 Hydrologic Review Team Annual Determination Report with Appendicies	
NCA	Ex. No.	33	NSE Ex. No. 226 - 2017 Hydrologic Review Team Annual Determination Report	
NCA	Ex. No.	34	NSE Ex. No. 228 - 2018 Hydrologic Review Team Annual Determination Report with Appended Moapa Valley Water District and Moapa Band of Paiutes Reports	
NCA	Ex. No.	35	NSE Ex. No. 236 - 2006 Memorandum of Agreement between the Southern Nevada Water Authority. United States Fish and Wildlife Service. Coyote Springs Investment LLC. Moapa Band of Paiute Indians and Moapa Valley Water District	

Company	Type	#	Description	Bates Nos.
NCA	Ex. No.	36	NSE Ex. No. 237 - 2001 Stipulation for Dismissal of Protests between Las Vegas Valley Water District. Southern Nevada Water Authority and Federal Bureaus	
NCA	Ex. No.	37	NSE Ex. No. 238 - 4/2012006 Southern Nevada Water Authority Agenda Item Re: Memorandum of Agreement. Water Supply Agreement and Back-Up Water Rights Agreement	
NCA	Ex. No.	38	NSE Ex. No. 261 - Federal Bureaus Order 1169 Report Selected References: It Is the Discharge, Bredehoeft, 2007	
NCA	Ex. No.	39	NSE Ex. No. 276 - Federal Bureaus Order 1169 Report Selected References: Geology of White Pine and Lincoln Counties and Adjacent Areas, Nevada and Utah: The Geologic Framework of Regional Groundwater Flow Systems, Southern Nevada Water Authority, 2007.	
NCA	Ex. No.	40	NSE Ex. No. 319 - Lincoln County/Vidler Water Company Response to National Park Service	
NCA	Ex. No.	41	NSE Ex. No. 320 - Settlement Agreement between the Nevada State Engineer, Lincoln County and Vidler Water Company	
NCA	Ex. No.	42	NSE Ex. No. 331 - March 5, 2018, Memorandum by Stetson Engineer Inc. to Coyote Spring Investment, LLC Re: Review of Nevada State Engineer's Ruling #6255 and Order 1169 Pumping Test in the Coyote Spring Valley	

Company	Type	#	Description	Bates Nos.
NCA	Ex. No.	43	NSE Ex. No. 331 - March 5, 2018, Memorandum by Stetson Engineer Inc. to Coyote Spring Investment, LLC Re: Review of Nevada State Engineer's Ruling #6255 and Order 1169 Pumping Test in the Coyote Spring Valley	
NCA	Ex. No.	44	Expert Witness Jay Dixon, P.E. CV	2108-2115
NCA	Ex. No.	45	Expert Witness Robert Coache, P.E., WRS CV	2116-2119
NCA	Ex. No.	46	Expert Witness Hugh Ricci, P.E. CV	2120-2121
NCA	Ex. No.	47	Water Permits	2122-2141

Rebuttal Report Pertaining to Interim Order 1303

Prepared on behalf of:

Nevada Cogeneration Associates
420 N. Nellis Blvd., #A3-400
Las Vegas, Nevada 89110

Prepared by:

PROFESSIONAL ENGINEER • STATE OF NEVADA
JASON M. DIXON
Exp. 12-31-20
CIVIL
No. 15553

8-16-2019

This Rebuttal Report is being submitted containing the signature and stamp of Jay Dixon, one of three authors of this Report, and is thus in compliance with NAC 625.612 as Jay Dixon is the licensee who has responsible charge for this Rebuttal Report. The other two authors of this Report were travelling on this day and, because of the impending deadline for submission of Rebuttal Reports, were unavailable to physically place their signatures and stamp on the Report – but they will provide a separate page containing their signatures and stamp upon their return within the following week (August 19-23).

Jason Dixon, P.E.	Robert Coache, P.E.	Hugh Ricci, P.E.

Rebuttal Report Pertaining to Interim Order 1303

Prepared on behalf of:

Nevada Cogeneration Associates
420 N. Nellis Blvd., #A3-400
Las Vegas, Nevada 89110

Prepared by:

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REGISTERED PROFESSIONAL ENGINEER STATE OF NEVADA
HUGH H. RICCI
Exp 12-31-19
CIVIL
No. 4131
8-22-2019

Jason Dixon, P.E.

Robert Coache, P.E.

Hugh Ricci, P.E.

Rebuttal Report Pertaining to Interim Order 1303

Prepared by Jay Dixon, P.E., Robert Coache, P.E. and Hugh Ricci, P.E. (on behalf of NCA-1 and 2)

August 16, 2019

Overview

Nevada Cogeneration Associates Nos. 1 and 2 (NCA 1 and 2, or NCA) operate combined cycle gas-fired cogeneration facilities located at the southern end of the Lower White River Flow System (LWRFS). NCA 1 and NCA 2 began commercial operations in June 1992 and February 1993, respectively. Collectively, the two plants account for 170 MW in baseload generation capacity. NCA sells 100% of its electric output to NV Energy under the terms of a long-term Power Purchase Agreement and both facilities supply hot exhaust gas and chilled water to Georgia Pacific (GP) and Pacific Coast Building Products' (PABCO) gypsum facilities under the terms of an Energy Purchase Agreement. NCA 2 supplies chilled water to nearby PABCO via a closed loop. NCA 1 supplies chilled water to GP, which sends water back (directly) from their well.

The NCA facilities have played an integral role in economic output in the region for more than 25 years. NCA's water rights have been placed to continuous use since construction of facilities in 1992 and 1993. The continued access of their certificated water rights is critical for NCA's sustained operations.

The following discussion points are being provided as a representation of NCA's position relative to Interim Order 1303 (Order 1303) issued by the Nevada State Engineer (NSE). These points form the basis for NCA's rebuttal to issues identified by various stakeholders who submitted Reports in July 2019 as required per Order 1303. This Rebuttal Report is being submitted on behalf of NCA as the companies are stakeholder with interests that may be directly affected by any future water right developments and management decisions implemented by the State Engineer appurtenant to the LWRFS.

Rebuttal Comments

1. **Standing of Non-Governmental Organizations Without Water Rights:**

NCA objects to the inclusion and participation of Non-Governmental Agencies (NGO), such as the Center for Biological Diversity (CBD) and Great Basin Water Network (GBWN). In consideration of these NGOs as representing "interested persons," and with respect to a determination of a state water engineer or agency, a participant challenging such a determination must be asserting its own rights and interests, not those of a third party, and must demonstrate an injury in fact sufficient to confer common-law standing. *94 C.J.S (Corpus Juris Secundum) Waters § (458).* Historically, it is the understanding of these authors that the NSE has required participants in hearings before the NSE to demonstrate an interest in either the affected real property that is directly affected by the water involved or, more often, in the water rights themselves in order to demonstrate such "standing" to participate in challenging or questioning any hydrologic determinations made by the State Engineer involving water rights in a particular basin. In this matter, the purpose of this portion of the proceeding, as was explained by Deputy Administrator Micheline Fairbank at the Prehearing Conference held on August 8, 2019, is to "determine what the sustainability is…" for the *stakeholders.*

These NGO participants are not "stakeholders." Furthermore, the NGOs do not own or control any water rights within the Muddy Rivers Spring Area (MRSA) or the LWRFS and do not own or control any property containing the habitat for threatened or endangered species. The threatened and endangered species of the MRSA and the springs to support these species are under the jurisdiction of the United States Fish and Wildlife Service (USFWS). The threatened and endangered species of Blue Point and Rogers Springs and the springs to support these species are under the jurisdiction of the United States National Park Service (NPS).

"Aggrieved" parties in a hearing process typically involve an applicant or protestant in a contested water right application determination. The NGOs here do not own land or water rights that would be affected by the NSE decisions within the LWRFS. Moreover, Order 1303 has not yet resulted in any decisions that provide the basis for a stakeholder to be "aggrieved" per the traditional understanding of that term; therefore, the NGOs have nothing to protest. Because the NGOs do not own land or water rights within the LWRFS and the basis for a grievance or protest does not exist, the NGOs do not have any legal standing in this process.

Given the obvious lack of legal standing and the limited hearing time allowed for this process, providing any significant time to these participants beyond mere public comment is a significant departure from prior State Engineer process and procedure.

2. Proposal by the NPS to include all of the Black Mountains Area Basin in the LWRFS.

The NPS is the only known stakeholder recommending that the LWRFS boundary currently proposed by the State Engineer be modified to include the entire Black Mountains Area (BMA), Basin 215. As currently proposed, the LWRFS includes a small portion of the northwest corner of the BMA north of the Las Vegas Shear Zone on the basis that NCA carbonate production wells appear to be hydraulically connected to the same sedimentary rocks that are present in southern Garnet Valley (Interflow, 2019[1]).

The position taken by the NPS for this recommendation appears to be based on an unsubstantiated flow path from Garnet Valley, beneath California Wash and the Black Mountain Area basins that discharges at Rogers and Blue Point Springs located within the Lake Mead National Recreation Area (Tetra Tech, 2012[2]). However, if true, groundwater from the Paleozoic carbonate aquifer would have to pass through Mesozoic clastic sediments and the Tertiary basin-fill evaporites (Muddy Creek and/or Horse Spring) in the lower thrust plate; a theory that is not supported by observed groundwater elevations in Garnet, Black Mountains and California Wash as described by Interflow (2019). Furthermore, differences between regional carbonate groundwater water chemistry and measurements from Roger and Blue Point Springs substantiate the lack of a direct connection between these springs and the regional carbonate aquifer.

Further justification for excluding the eastern portion of the BMA is supported by significantly different geology observed in wells completed near Lake Las Vegas. In this area, subsurface conditions are dominated by the Muddy Creek Formation, which consists of gypsum and siltstone conglomerates. The only potential groundwater resource in the southeastern portion of BMA (outside of the portion included within the LWRFS) may be the Tertiary Thumb Member of the Horse Spring Formation, which consists of sandstone and volcanic breccia (Castor, et.al., 2000[3] and Sitton, 2010[4]).

In summary, various discontinuities observed in the mapped geology, subsurface structures, potentiometric surfaces and groundwater geochemistry fully support the State Engineer's decision to include only the northwestern portion of the BMA. The portion of the BMA basin currently included within the proposed LWRFS boundary should remain as designated.

[1] Interflow Hydrology, Inc., 2019. Garnet Valley Groundwater Review for APEX Industrial Complex, City of North Las Vegas, Clark County, Nevada.

[2] Tetra Tech GEO, 2012. Predictions of the Effects of Groundwater Pumping in the Colorado Regional Groundwater System, Southeastern Nevada, 28p. plus figures and 2 appendices.

[3] Castor, S.B., Faulds, J.E., Rowland, S.M., and dePolo, G.M., 2000, Geologic map of the Frenchman Mountain Quadrangle, Clark County, Nevada: Nevada Bureau of Mines and Geology.

[4] Sitton, M.E., 2010, Stratigraphic analysis of the lower Horse Spring Formation in the Frenchman Mountain Block, Lake Mead domain: Insights into paleogeography and ties to the Gold Butte Block: GSA Abstracts w/programs, v. 42, n.5, p. 471.

3. Proposal by the USFWS to include the Lower Meadow Valley Wash Basin in the LWRFS.

The Lower Meadow Valley Wash (LMVW), Basin 205, should continue to be managed outside of the LWRFS. As part of the Order 1303 report submitted by the USFWS[5] a proposal was made to include LMVW basin within the LWRFS. The USFWS noted that carbonate aquifer monitoring in the vicinity of LMVW is sparse, but Wilson (2019)[6] interpreted the upper carbonate potentiometric surface to be higher than observed alluvial aquifer levels from NV Energy wells near the southern basin boundary. These wells were pumped extensively up through the latter part of the 1980s and have not been used since. While alluvial aquifer levels continue to recover from the historic pumping, the water chemistry has not recovered, with TDS observations in the range of 3,000 mg/l (Converse Consultants, 2010[7]). The nearest carbonate groundwater levels are monitored in wells EH-3 and EH-7. EH-7 is situated within Weiser Wash and proximal to the Glendale Thrust Fault located only 1 mile southeast of the LMVW hydrographic basin boundary (Figure 1). There is obvious communication between the alluvial aquifer levels in the LMVW and carbonate levels as reflected in the hydrographs for EH-8a and 8b (Figures 2 and 3). EH-8a is completed in the lower alluvial aquifer and the EH-8b is completed within the underlying Muddy Creek formation. Both hydrographs exhibit continuous recovery from historical pumping by NV Energy within their LMVW wellfield.

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[5] USFWS, 2019. Issues Related to Conjunctive Management of the Lower White River Flow System. Presentation to the Office of the Nevada State Engineer in Response to Order 1303.

[6] Wilson, J.W., 2019, Drilling, construction, water chemistry, water levels, and regional potentiometric surface of the upper carbonate-rock aquifer in Clark County, Nevada, 2009–2015: U.S. Geological Survey Scientific Investigations Map 3434, scale 1:500,000, https://doi.org/10.3133/sim3434

[7] Converse Consultants, 2010. Groundwater Level Monitoring Program, 2009 Annual Report. Prepared for NV Energy.

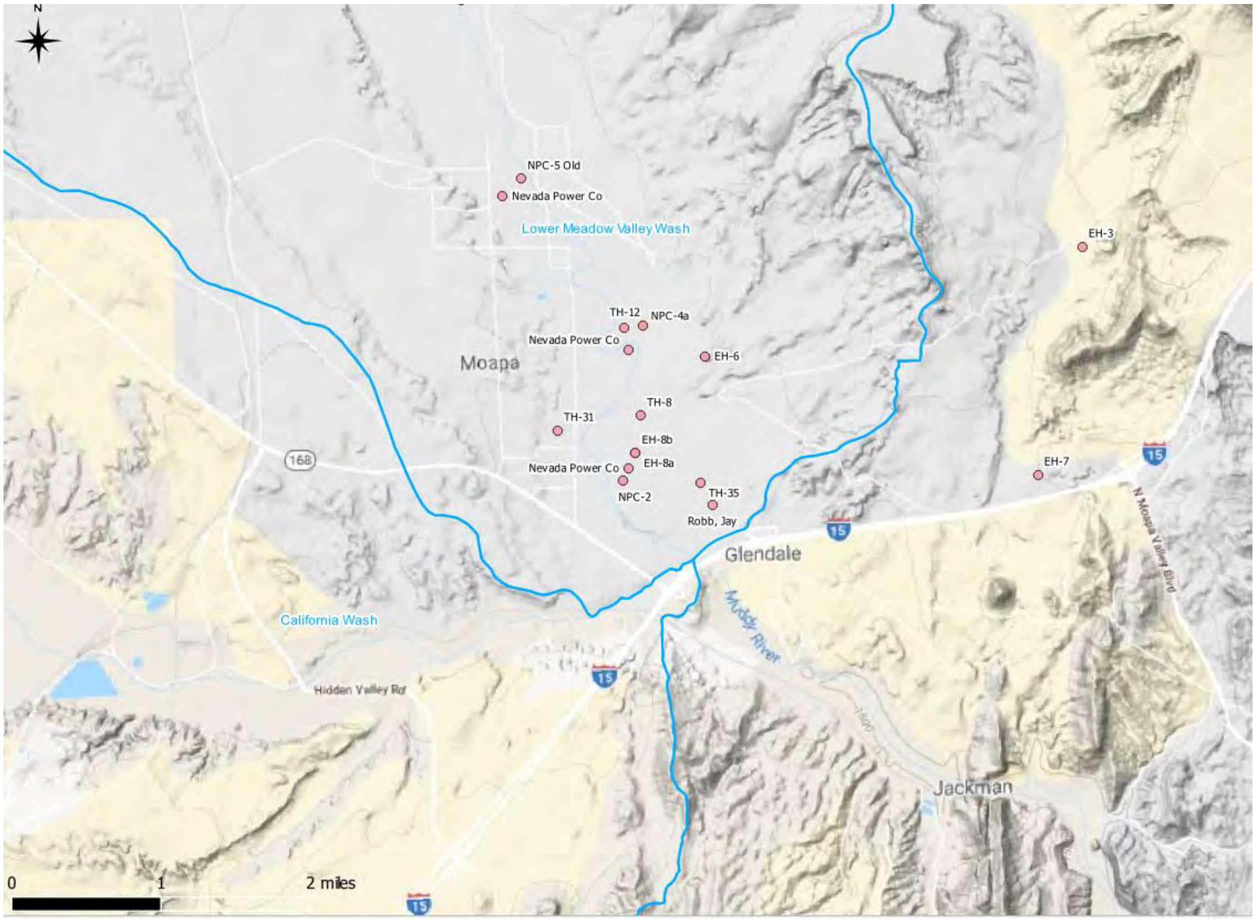

Figure 3. Southern portion of the Lower Meadow Valley Wash Basin and monitoring well locations.

Site Name	205 S14 E66 35CABA1	**Perforations From:**	
Well Name:	EH-8a	**Perforations To:**	
Owner:	Nevada Power Company	**Latitude (Decimal Degrees NAD 83):**	36.67357
Elevation:	1534.03	**Longtitude (Decimal Degrees NAD 83):**	-114.57781
USGS Site ID:		**Location Accuracy:**	
Well Log(s):		**Status:**	Active
Depth:		**Permit Number:**	

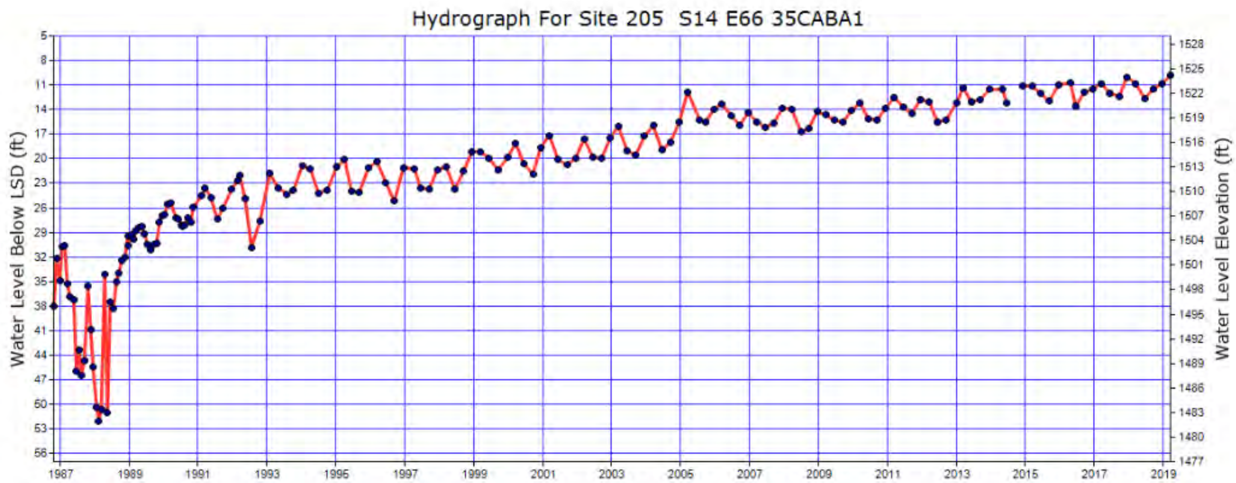

Figure 2. NV Energy monitoring well EH-8a located in southern Lower Meadow Valley Wash basin. The well is screen within the Muddy Creek Formation (NDWR, 2019).

Site Name	205 S14 E66 35CABA2	**Perforations From:**	
Well Name:	EH-8b	**Perforations To:**	
Owner:	Nevada Power Company	**Latitude (Decimal Degrees NAD 83):**	36.67357
Elevation:	1534.03	**Longtitude (Decimal Degrees NAD 83):**	-114.57781
USGS Site ID:		**Location Accuracy:**	1
Well Log(s):		**Status:**	Active
Depth:		**Permit Number:**	

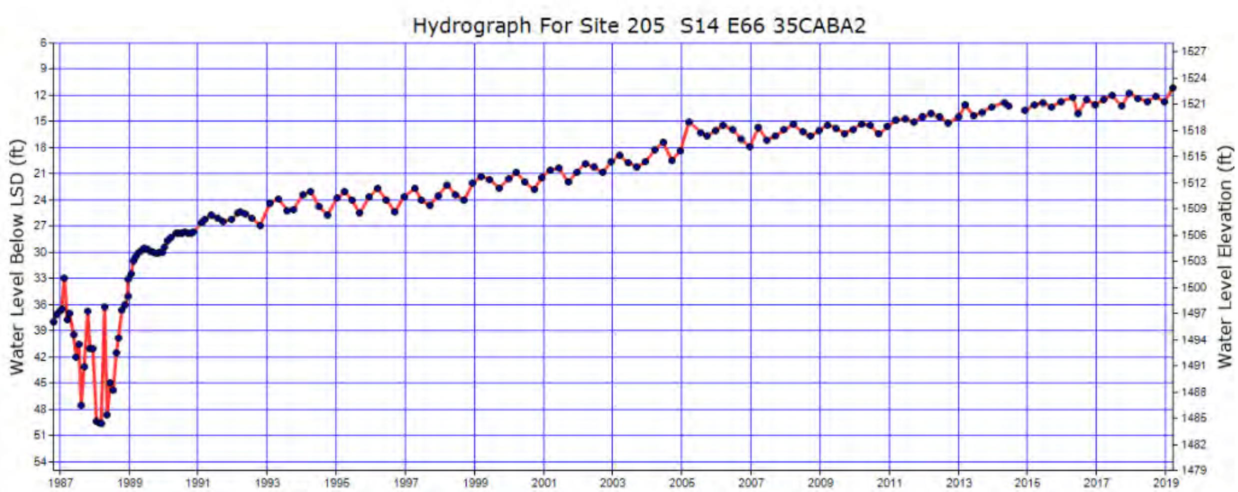

Figure 3. NV Energy monitoring well EH-8b located in southern Lower Meadow Valley Wash basin. The well is screen within the alluvial aquifer; nested monitoring well screened below EH-8a in the underlying Muddy Creek sediments (NDWR, 2019).

A similar recovery (to the LMVW alluvial aquifer) is observed in the EH-3 and EH-7 hydrographs (Figures 4 and 5) with no apparent response to the regional signal exhibited in other carbonate wells near the Muddy River Springs area such as EH-4 and 5b. The lack of continuity between water level trends observed in the LMVW when compared to alluvial and carbonate water levels is supported by geologic descriptions provided in LVVWD (2001)[8] and Page et. al. (2006)[9]. Within the southern portion of the LMVW basin, the entire Paleozoic section has been folded and thrust faulted from the west to the east through compressional forces, which caused folding and overturning of the original flat-lying beds. The shearing resulted in older rock overlying younger rock units in some locations such as along the Glendale Thrust to the east. These structures help explain the apparent lack of a consistent (LWRFS) regional response in carbonate water levels and Muddy Creek and alluvial groundwater levels at the south end of the LMVW basin.

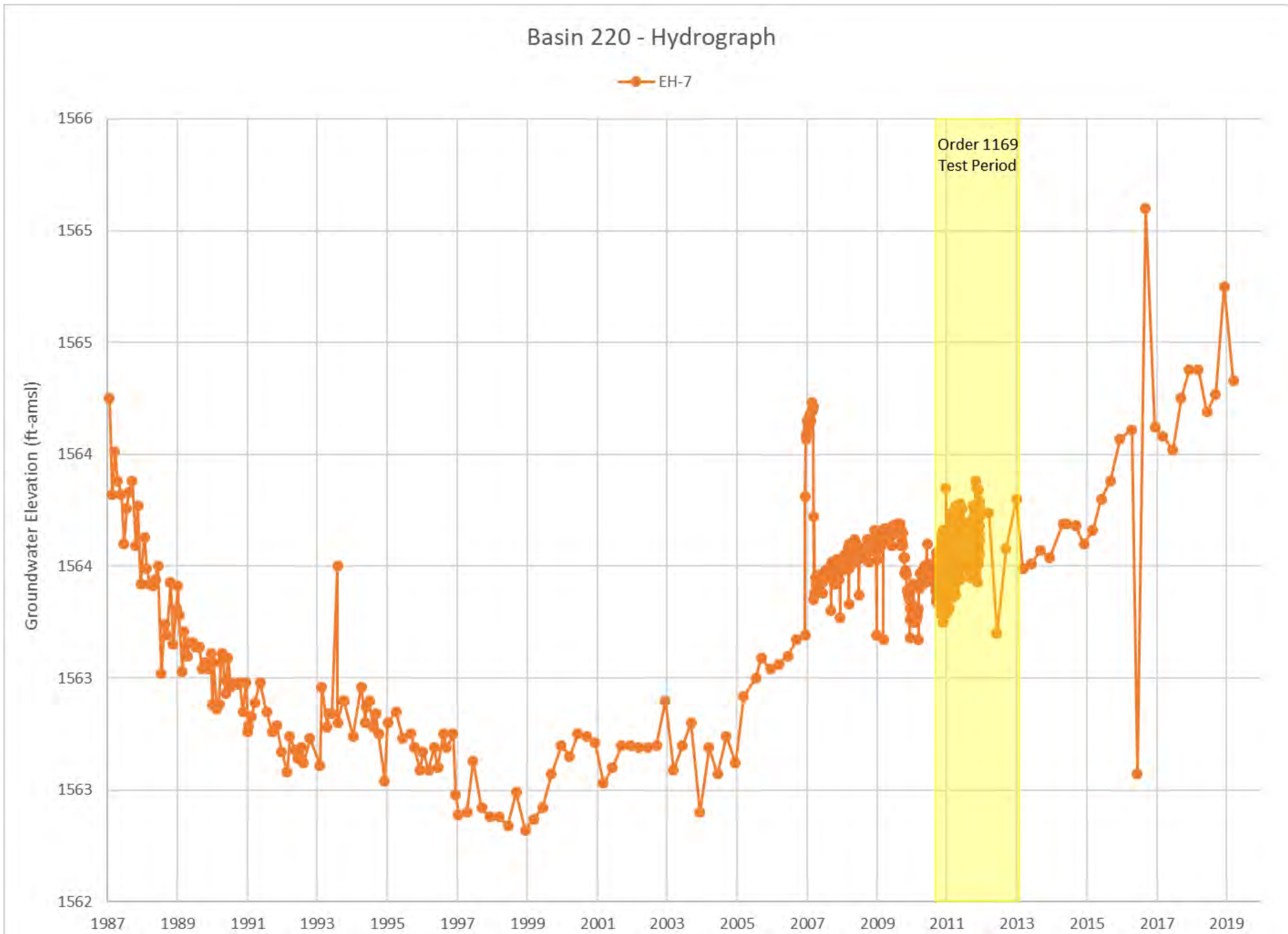

Figure 4. Carbonate monitoring well located approximately 1 mile east of the LMVW basin boundary (NDWR, 2019).

[8] Las Vegas Valley Water District (LVVWD), 2001, Water Resources and Ground-Water Modeling in the White River and Meadow Valley Flow Systems, Clark, Lincoln, Nye and White Pine Counties, Nevada.

[9] Page, W.R., Scheirer, D.S., Langenheim, V.E., and Berger, M.A.,2011, Revised Geological Cross Sections of Parts of the Colorado, White River, and Death Valley Regional Groundwater Flow Systems, Nevada, Utah, and Arizona: U.S. Geological Survey Open-File Report 2006-1040, 1 sheet, 25 p. pamphlet.

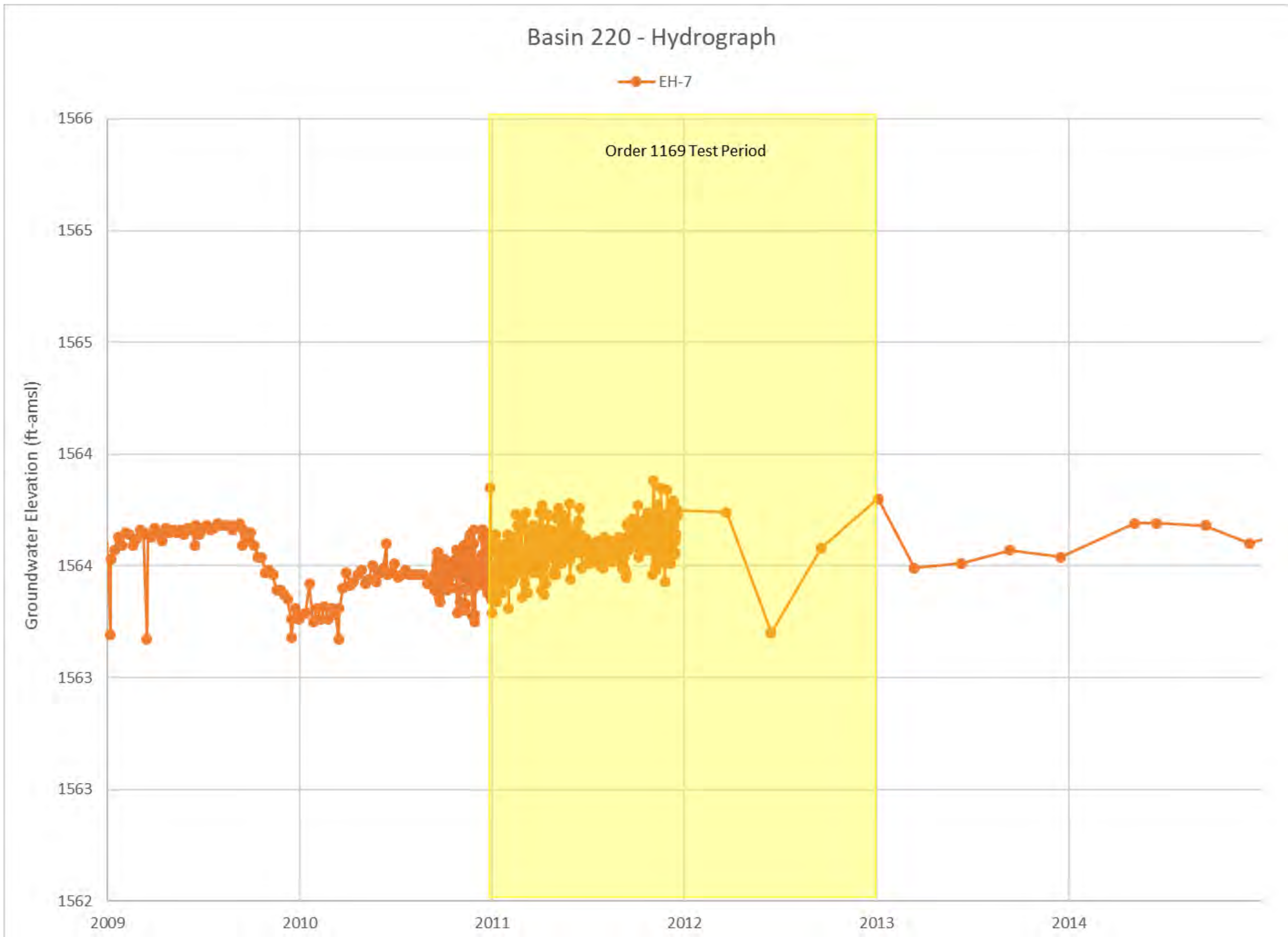

Figure 5. Carbonate monitoring well located approximately 1 mile east of the LMVW basin boundary. Hydrograph reflects water levels during the 2 years leading up, during and following the Order 1169 aquifer test. Note absence of any regional carbonate response (NDWR, 2019).

While some flux of shallow alluvial aquifer water may occur through the southern boundary of the LMVW aquifer it is probably limited, and future alluvial groundwater development is unlikely due to the poor water chemistry. Furthermore, as explained in Burbey (1997)[10] and shown in geologic sections included in Rowley, et. al. (2017)[11], development of a carbonate aquifer source in the LMVW (anywhere near the southern boundary) would require a well completed to a depth of approximately 4,000 ft, which is highly unlikely. For these reasons and due to the lack of continuity between observed water levels within the LMVW compared with regional trends observed within the LWRFS, it is our recommendation that the NSE continue managing the LMVW separately from the LWRFS.

[10] Burbey, T. J., 1997, Hydrogeology and potential for ground-water development, Carbonate-Rock Aquifers, southern Nevada and southeastern California: U. S. Geological Survey Water Resources Investigations 95-4168, 65 p.

[11] Rowley, P.D., G.L. Dixon, E.A. ManKinen, K.T. Pari, D.K. McPhee, E.H. KcKee, A.G. Burns, J.M. Watrus, E.B. Ekren, W.G. Patrick, and J.M. Bandt, 2017. Geology and geophysics of White Pine and Lincoln counties, Nevada, and adjacent parts of Nevada and Utah—the geologic framework of regional groundwater flow systems. Nevada Bureau of Mines and Geology Report 56. Scale 1:250,000, 4 plates.

4. Proposal to include the Kane Springs Basin in the LWRFS.

As currently proposed by the NSE, Order 1303 does not include Kane Springs Valley (KSV). However, there is significant correlation between KMW-1 and impacts from pumpage within the LWRFS with effects from present day pumpage within the LWRFS observed in well KMW-1. Therefore, it stands to reason that KSV be added to the LWRFS to protect existing senior rights.

In response to the NSE's Interim Order 1303 Lincoln County Water District and Vidler Water Company (Lincoln/Vidler) submitted a report titled "Lower White River Flow System Interim Order #1303 Report Focused on the Northern Boundary of the Proposed Administrative Unit" dated July 3, 2019 (Lincoln/Vidler Report).

Lincoln/Vidler makes a number of assertions in the Lincoln/Vidler Report[12] with regards to the pumpage of groundwater within Kane Springs Valley (KSV), which conflict with the results of the Order 1169 aquifer test conducted within the LWRFS.[13] NCA disagrees with the following points from the Lincoln/Vidler report:

- The effects of pumping from KSV would not be felt for over 100 years outside of KSV.
- There is no discernible trend/pattern in water levels overtime between production well KPW-1 and pumping trends.
- There is no correspondence between the water level trends in wells in KSV/northern Coyote Spring Valley (CSV), and wells located in southern CSV.
- The trend in water levels in both KMW-1 and CSVM-4 indicate water levels are still being affected by the 2005 precipitation event.

Based on the these points, Lincoln/Vidler concluded in part that:[14]

> "*…there is no evidence-based reason to impose that plan on basins outside of the Order No. 1169 geographic area. In fact, and on the contrary, there are science-based reasons to exclude KSV/northern CSV from the LWRFS as identified in this report*."

Additionally, based on the key points and conclusion, Lincoln/Vidler makes two main recommendations as follows[15]:

A. Continue to exclude KSV from the LWRFS administrative unit.
   The scientific data supports excluding KSV from the LWRFS administrative unit. The most salient point is that the carbonate wells KPW-1 in southern KSV and CSVM-4 in northern CSV have different hydraulic heads than other heads further south in the LWRFS. This was explained by the new geophysical data that was collected from northern CSV, which shows there are several structural controls, including faults that occur in the northern CSV and would represent impediments for groundwater flowing from KSV/northern CSV into the LWRFS groundwater basins. There is no

[12] Pages 6-1 and 6-2 of Lincoln/Vidler Report Titled "Lower White River Flow System Interim Order #1303 Report Focused on the Northern Boundary of the Proposed Administrative Unit" dated July 3, 2019

[13] Pages 6-1 and 6-2 of Lincoln/Vidler Report Titled "Lower White River Flow System Interim Order #1303 Report Focused on the Northern Boundary of the Proposed Administrative Unit" dated July 3, 2019

[14] Page 6-2 of Lincoln/Vidler Report Titled "Lower White River Flow System Interim Order #1303 Report Focused on the Northern Boundary of the Proposed Administrative Unit" dated July 3, 2019

[15] Page 7-1 and 7-2 of Lincoln/Vidler Report Titled "Lower White River Flow System Interim Order #1303 Report Focused on the Northern Boundary of the Proposed Administrative Unit" dated July 3, 2019

indication from the water level data of either KMW-1 or CSVM-4 that there were any noticeable effects from the Order No. 1169 aquifer test. What was observed and was significant was the dissipating effects of an over-arching precipitation event in 2005 that affected water levels in these wells for years.

In support of the conclusions and subsequent recommendation that the NSE continue to exclude KSV and the northern portion of CSV from the LWRFS administrative unit, Lincoln/Vidler appears to misrepresent statements contained in Rulings issued prior to the availability of Order 1169 aquifer test data and misrepresents the Order 1169 data. The most significant of these misrepresentations or contradictions are discussed below.

B. The NSE did not include KSV in the Order No. 1169 aquifer test.
The statement, while true, is misleading, as Order 1169 was issued by the NSE on March 8, 2002, at which time there were no active groundwater permits or viable applications within KSV. Therefore, there were no uses or wells to be monitored at the time Order 1169 was issued by the NSE and subsequently there was no reason to include a hydrologic basin that had no uses or wells to monitor.

C. Lincoln/Vidler makes the claim that the NSE has already ruled on the issue of whether the appropriation of groundwater from KSV would affect the Muddy River Springs Area (MRSA) Hydrographic Basin, or for that matter other springs of interest. To validate this claim Lincoln/Vidler cites excerpts from Ruling 5712 as follows:

> "*The State Engineer finds there is not substantial evidence that the appropriation of the limited quantity [of water] being granted under this ruling will likely impair the flow at Muddy River Springs, Rogers Springs or Blue Point Springs*."[16]

To further support their claim Lincoln/Vidler cites NSE Ruling 5712 as follows[17]:

> "*The State Engineer finds there is not substantial evidence that the appropriation of a limited quantity of water in Kane Springs Valley Hydrographic Basin will have any measurable impact on Muddy River Springs that warrants the inclusion of Kane Springs Valley in Order No. 1169*."

Ruling 5712 was issued on February 2, 2007, approximately seven years prior to the conclusion of the Order 1169 aquifer test resulting in observed impacts within the LWRFS directly attributable to the test at MX-5. As reported in SNWA's report titled Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response dated Assessment (SNWA Assessment Report), the pumping stresses imposed during the Order 1169 aquifer test were very apparent and by the end of the 2-year aquifer test, discharge from Pederson Spring was reduced to about one-third of its pre-test flow, from 0.21 to 0.07 cfs and discharge measured at the Warm Springs West gage declined about 8 percent, from 3.70 to 3.41 cfs. Both springs are located within the complex referred to as the MRSA. Additionally, after the pump test was halted discharge at the Warm Springs West gage continued to decline and, had the

[16] Page 20 of Ruling 5712 dated February 02, 2007
[17] Page 21 of Ruling 5712 dated February 02, 2007

pump test or operation of the MX-5 well continued, the initial trigger of 3.2 cfs at the Warm Springs West gage would have been reached before the end of 2014. [18]

More concerning than the actual impacts caused by the Order 1169 aquifer test is the observation that the carbonate-aquifer water levels have not recovered to pre-test levels, spring flows measured at the Pederson Spring and Warm Springs West gages have not recovered to pre-test levels and system recovery achieved its maximum levels between early 2015 and early 2016, with both carbonate aquifer water levels and spring flow trending lower.

D. Lincoln/Vidler claims that the NSE's determination that there would be no impairment from pumping in KSV as referenced above was affirmed seven years later in Ruling 6254 and quotes the NSE as follows:

> "*…the State Engineer found that where no significant effects would be felt for hundreds of years, the upgradient water could be appropriated."*[19]

Based on this truncated excerpt Lincoln/Vidler claims that "KSV groundwater can be developed because there will be no significant impact, if any, from appropriation of the groundwater for hundreds of years."[20] The Lincoln/Vidler stated claim based on a truncated finding in Ruling 6254 is a misrepresentation of the actual finding by the NSE in Ruling 6254.

The full finding in the NSE Ruling 6254 states as follows:

> "*For basins similar to Coyote Spring Valley, where there is no groundwater evapotranspiration and all of the groundwater flows in the subsurface to an adjacent basin, recent rulings have limited the perennial yield to the portion of recharge from precipitation in that basin that was not needed to satisfy rights in the immediate downgradient basin. In State Engineer's Ruling Nos. 6165, 6166, and 6167, there was a consideration for how long it might take for an existing water right to be impacted, and the State Engineer found that where no significant effects would be felt for hundreds of years, the upgradient groundwater could be appropriated….*
>
> *The vast majority of the scientific literature supports the premise that, unlike other separate and distinct basins in Nevada that do not feature carbonate-rock aquifers, all of the Order 1169 basins share virtually all of the same supply of water. The Order 1169 pumping test further supports the conclusion that pumping from any of the five basins with a close hydrologic connection (Coyote Spring Valley, Muddy River Springs Area, Hidden Valley, Garnet Valley and California Wash) will have a similar impact on water levels in the five-basin area and on the Muddy River spring flows. Therefore, because these basins share a unique and close hydrological connection and share virtually all of the same source and supply of water, unlike other basins in Nevada, these five basins will be jointly managed. The perennial yield of these basins cannot be more than the total annual supply of 50,000 acre-feet. Because the Muddy River and Muddy River*

[18] Pages 5-13 SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019.
[19] Page 23 of Ruling 6254 dated January 29, 2014
[20] Page 2-3 of Lincoln/Vidler Report Titled "Lower White River Flow System Interim Order #1303 Report Focused on the Northern Boundary of the Proposed Administrative Unit" dated July 3, 2019

springs also utilize this supply, and are the most senior water rights in the region, the perennial yield is further reduced to an amount less than 50,000 acre-feet. The State Engineer finds that the amount and location of groundwater that can be developed without capture of and conflict with senior water rights on the Muddy River and springs remains unclear, but the evidence is overwhelming that unappropriated water does not exist."[21]

Rulings 6165, 6166 and 6167 referenced by Ruling 6254 are appurtenant to Cave Valley, Dry Lake Valley and Delamar Valley, all of which are hydrologically different than CSV and KSV. Additionally, the reason for referencing Ruling 6254 was to acknowledge how the NSE had previously managed basin groundwater outflow and impacts to down gradient basin. In the case of NSE Ruling 6254 the NSE found that pumping from any of the five basins that were part of the Order 1169 aquifer test has a similar impact on water level in the five-basin area and on the Muddy River spring flows.

In addition to truncating the full finding by the NSE, Lincoln/Vidler fails to acknowledge the finding in the previously stated Ruling 5712 relevant to their applications which states:[22]

"*Given the unique hydrologic connection between the Kane Springs Valley Hydrographic Basin and the Coyote Spring Valley Hydrographic Basin, the development of ground water within Kane Springs Valley will ultimately affect water levels and flows in the White River regional carbonate-rock aquifer system. However, the State Engineer believes a small amount of water can be developed in the Kane Springs Valley and not unreasonably impact existing rights in the discharge areas of the White River carbonate-rock aquifer system, which are already fully appropriated. Well KMW-1 lies within 1,000 feet of Coyote Spring Valley and pumping simulations by the Applicant show a cone of depression extending well into Coyote Spring Valley…"*

E. The Lincoln/Vidler transmittal letter dated July 3, 2019[23], states in part that:

"*Groundwater pumping from Kane Springs Valley is extremely remote from the Muddy River Springs Area, and based on the available data during the State Engineer Order 1169 Aquifer Test, there were no effects that resulted in a change in water level in southern Kane Springs Valley*."

As previously stated, Ruling 5712 was issued on February 2, 2007 approximately seven years prior to the conclusion of the Order 1169 aquifer test which resulted in the significant impacts to the LWRFS. While there was no pumpage from KMW-1 during the Order 1169 aquifer test pumping simulations provided by Lincoln/Vidler at the April 2006 KSV hearing and referenced in Ruling 5712 show a cone of depression extending well into Coyote Spring Valley.

In the SNWA Assessment Report (2019), SNWA found that there was a high correlation between well EH-4 and spring discharge; based on this high correlation between EH-4 and spring discharge SNWA determined that it stood to reason that the observed carbonate well responses could be correlated to that of EH-4 to assess if their responses are caused by the same stresses affecting the spring

[21] Page 23 and 24 of Ruling 6254 dated January 29, 2014
[22] Page 15 of Ruling 5712 dated February 2, 2007
[23] Lincoln Vidler Interim Order 1303 Transmittal Letter dated July 3, 2019

discharge. SNWA also stated that high correlations would also further confirm the hydraulic connectivity of the LWRFS.[24] SNWA then used the average monthly values of hydraulic head from water-level elevation records of the representative carbonate wells, including CSVM-4. These values for CSVM-4 were then plotted against EH-4 for the period of 2003 to 2019.[25] See Figure 6.

[24] Page 5-11 of SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019.

[25] Page 5-12 of SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019.

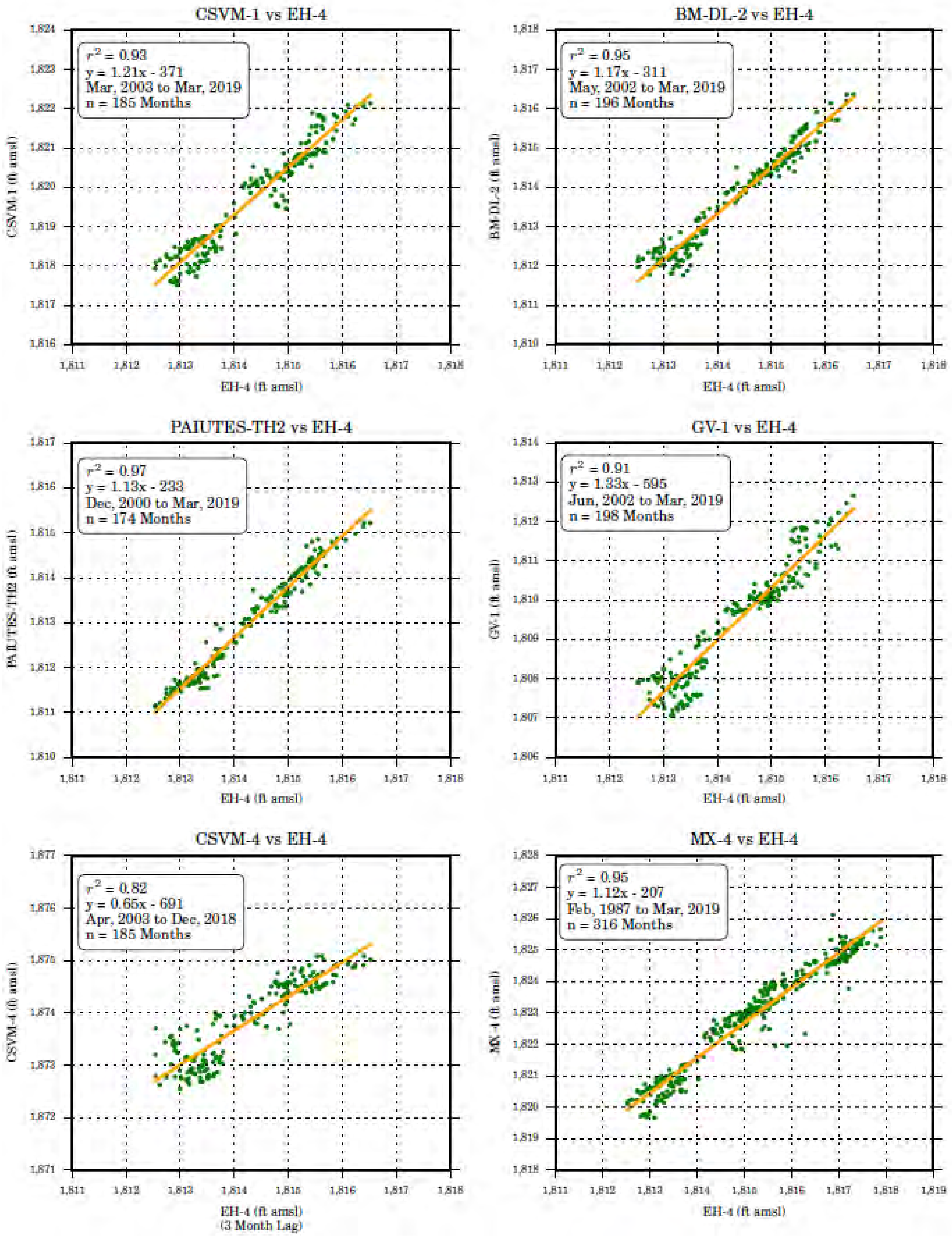

Figure 6. Correlation of Hydraulic Heads at Well EH-4 with Hydraulically Connected Carbonate Wells (SNWA, 2019).

There was a high correlation between all the carbonate wells plotted against EH-4 with the correlation of CSVW-4 and EH-4 resulting in a R_2 value of 0.82. These high correlations between carbonate wells in the LWRFS indicate a high level of hydraulic connectivity across all the basins within the LWRFS.

While SNWA did not calculate a correlation between EH-4 and KMW-1, SNWA did provide a figure identified as Figure 7 (below), which illustrates hydrographs for both CSVM-4 and KMW-1 at the same scale for both date and elevation axis's for easy comparison.[26]

[26] Page 5-14 of SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019.

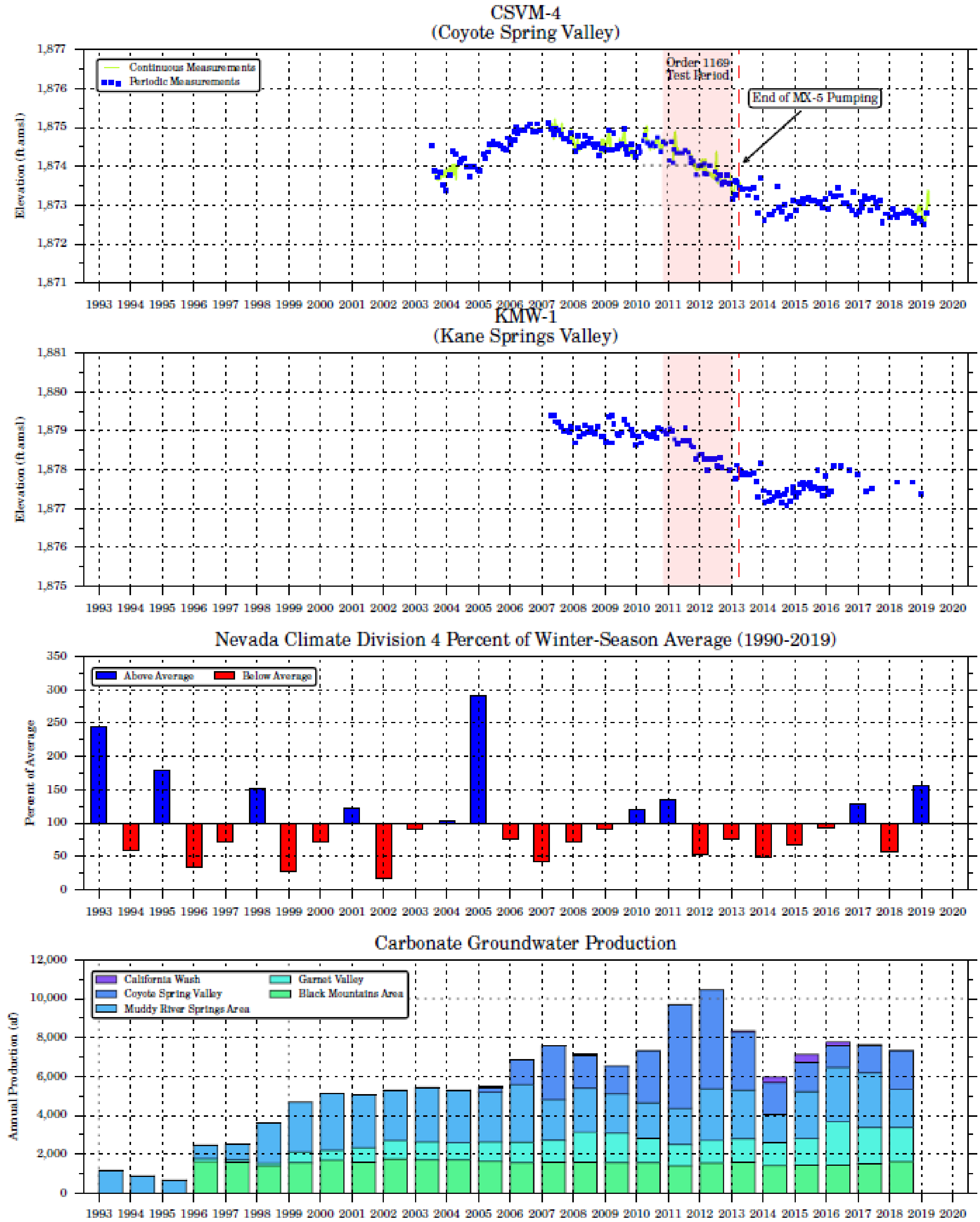

Figure 7. Carbonate-Aquifer water levels and groundwater production (SNWA, 2019).

It should be noted that an attempt to produce a graph illustrating the correlation between EH-4 and KMW-1 and the correlation between CSVM-4 and KMW-1 was made, however the data for KMW-1 could not be located as part of the 1169 data and Lincoln/Vidler does not include a table with this data in their report. Additionally, there seems to be a discrepancy in the elevation datum used for KSM-1 between SNWA and Lincoln/Vidler in that the data reported by Lincoln/Vidler is shifted approximately 0.5 feet higher than that of SNWA. This apparent difference in the elevation datum used does not affect a correlation comparison or a visual hydrograph comparison but would have an impact on any flow analysis based on elevation gradients.

A direct visual comparison of the hydrographs of CSVM-4 and KMW-1 was done for the time frame that data is available for KSM-1, (pre, during and post Order 1169 aquifer test time frame) which indicates the hydrographs for CSVM-4 and KMW-1 are virtually identical for the pre Order 1169 aquifer test, the ≈ two year span of the Order 1169 aquifer test and post Order 1169 aquifer test recovery. This indicates a high correlation between CSVM-4 and KMW-1, with an estimated R_2 value > 0.9, which in turn indicates a high correlation between KMW-1 and carbonate wells in the LWRFS with a high level of hydraulic connectivity across all of the basins within the LWRFS. Additionally, well KMW-1 lies within 1,000 feet of Coyote Spring Valley and Lincoln/Vidler's own well pumping simulations show a cone of depression extending well into Coyote Spring Valley.

The Order 1169 aquifer test data does not indicate that there were no effects that resulted in a change in water level in southern Kane Springs Valley. The contrary is true in that there is a high correlation between KMW-1 and carbonate wells in the LWRFS with a high level of hydraulic connectivity across all of the basins within the LWRFS, including KSV.

The SNWA Assessment Report is neutral with regards to the inclusion of Kane Springs Valley (KSV). However, the SNWA assessment report does make various references that are supportive to the inclusion of KSV within the LWRFS. The SNWA Assessment Report, states that KSV is included in the assessments because it is tributary to the LWRFS and contributes to the local recharge.[27]

Based on a review of all of the data, most hydrographs exhibit very similar patterns. The only apparent exception is within Coyote Spring Valley for wells CSVM-3, CSVM-4, and CSVM-5, and within Kane Springs Valley for well KMW-1. Wells CSVM-4 and KMW-1 are completed within the Kane Springs fault zone, however the responses of wells CSVM-4 and KMW-1 are similar to those of other wells in the basin, but appear to be slightly attenuated by the Kane Springs fault. [28]

As reported in the SNWA Assessment Report, SNWA found that the relationships between the hydraulic head of carbonate wells in the LWRFS are linear and have very high correlations that range from R2=0.82 to R2=0.97. As these charts illustrate, groundwater levels respond in the same manner to natural and anthropogenic stresses throughout the LWRFS. The responses are indicative of a high degree of hydraulic connection within the aquifer and across all of the basins.[29]

[27] Page 1-1, SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019

[28] Page 5-6, SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019

[29] Page 5-11-5-12, SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019

These points can be summarized as follows:

- Kane Springs Valley is included in the assessments because it is tributary to the LWRFS and contributes to the local recharge.[30]
- The responses of wells CSVM-4 and KMW-1 are similar to those of other wells in the basin, but appear to be slightly attenuated by the Kane Springs fault.[31]
- The relationships between the hydraulic head of the carbonate wells in the LWRFS are linear and have very high correlations. The correlation R_2 value for CSVM-4 = 0.82. The groundwater levels respond in the same manner to natural and anthropogenic stresses throughout the LWRFS. The responses are indicative of a high degree of hydraulic connection within the aquifer and across all of the basins.[32]

In the event that Lincoln/Vidler develops water from KMW-1 or other wells within KSV and the NSE continues to exclude KSV from the LWRFS, the existing rights owned and controlled by NCA and other (more) senior water right users within the LWRFS could be impaired. The Lincoln/Vidler ground water rights are junior in priority to approximately 98% of the ground water rights within the LWRFS and during any curtailment of pumpage within the LWRFS, these rights would be among the first to be subject to curtailment. If KSV is excluded from the LWRFS, any pumpage from KMW-1 or other wells operated by Lincoln/Vidler within KSV would not be included in the pumpage from the LWRFS; however, the impacts from said pumpage would, most likely impact flow to the MRSA and Muddy River. In the event there are significant impacts to flows of the MRSA and Muddy River, water rights senior to the Lincoln/Vidler water rights in KSV would be curtailed while the most junior rights within the LWRFS would be allowed to continue pumpage.

It is clear that there is a high correlation between KMW-1 and impacts from pumpage within the LWRFS, present day pumpage within the LWRFS continues to impact KMW-1. Therefore, it stands to reason that Kane Springs Valley should be added to the LWRFS to protect existing senior rights.

5. <u>Proposal to exclude the northern portion of Coyote Springs Valley</u>**.**
NCA believes that the hydrologic data from the Order 1169 aquifer test clearly indicates that carbonate pumpage from the northern portion of CSV and KSW-1 within KSV will impact carbonate aquifer hydraulic head within the LWRFS, which in turn will increase impacts to springs flows within the MRSA and be detrimental to the existing groundwater rights held by NCA. It is evident that there is a high correlation between CSVM-4 and KMW-1 which in turn indicates a high correlation between CSVM-4 and KMW-1 and carbonate wells in the LWRFS with a high level of hydraulic connectivity across all the basins within the LWRFS. Therefore, there is no basis to exclude the northern portion of CSV.

Lincoln/Vidler recommend that in addition to KSV remaining excluded from the LWRFS administrative unit, the northern portion of CSV should also be excluded from the LWRFS administrative unit based upon the geophysical data and groundwater level data, geochemistry data, and groundwater temperature data.

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[30] Page 1-1, SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019

[31] Page 5-6, SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019

[32] Page 5-11-5-12, SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019

As stated by SNWA (2019), most hydrographs within the LWRFA exhibit very similar patterns. The only apparent exception is within CSV for wells CSVM-3, CSVM-4, and CSVM-5, and within Kane Springs Valley for well KMW-1. Wells CSVM-4 and KMW-1 are completed within the Kane Springs fault zone, however the responses of wells CSVM-4 and KMW-1 are similar to those of other wells in the basin but appear to be slightly attenuated by the Kane Springs fault. [33]

As reported in the SNWA Assessment Report, SNWA found that the relationships between the hydraulic head of carbonate wells in the LWRFS are linear and have very high correlations. Specifically, the correlation of CSVW-4 and EH-4 resulted in a R_2 value of 0.82. As these charts illustrate, groundwater levels respond in the same manner to natural and anthropogenic stresses throughout the LWRFS. The responses are indicative of a high degree of hydraulic connection within the aquifer and across all of the basins within the LWRFS.[34]

While SNWA did not calculate a correlation between EH-4 and KMW-1, SNWA did provide a figure identified as Figure 5-11 which illustrates hydrographs for both CSVM-4 and KMW-1 at the same scale for both date and elevation axis's for easy comparison.[35]

A direct visual comparison of the hydrographs of CSVM-4 and KMW-1 was done for the time frame data is available for KSM-1, (pre, during and post Order 1169 aquifer test), which indicates the hydrographs for CSVM-4 and KMW-1 are virtually identical for the pre Order 1169 aquifer test, the ≈ two year span of the Order 1169 aquifer test and post Order 1169 aquifer test recovery. This indicates a high correlation between CSVM-4 and KMW-1, with an estimated R_2 value > 0.9, which in turn indicates a high correlation between KMW-1 and carbonate wells in the LWRFS with a high level of hydraulic connectivity across all of the basins within the LWRFS.

These points can be summarized as follows:

- The responses of wells CSVM-4 and KMW-1 are similar to those of other wells in the basin, but appear to be slightly attenuated by the Kane Springs fault.[36]
- The relationships between the hydraulic head of the carbonate wells in the LWRFS are linear and have very high correlations. The correlation R_2 value for CSVM-4 = 0.82. The groundwater levels respond in the same manner to natural and anthropogenic stresses throughout the LWRFS. The responses are indicative of a high degree of hydraulic connection within the aquifer and across all the basins.[37]

NCA believes the hydrologic data from the Order 1169 aquifer test clearly indicates that carbonate pumpage from the northern portion of CSV and KSW-1 within KSV will impact carbonate aquifer hydraulic head within the LWRFS, which in turn will increase impacts to springs flows within the MRSA and be detrimental to the existing groundwater rights held by NCA.

[33] Page 5-6, SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019

[34] Page 5-11-5-12, SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019

[35] Page 5-14 of SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019

[36] Page 5-6, SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019

[37] Page 5-11-5-12, SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019

6. Proposal by the GBWN to include the entire White River Flow System.

The Great Basin Water Network, participating in the Order 1303 process as an NGO, appears to have proposed that the State Engineer consider the entire White River Flow System when administering water resources within the LWRFS as currently proposed. This recommendation was made with no scientific basis. The Pahranagat Shear zone (north Coyote Spring Valley) creates a substantial barrier that warrants the exclusion of the hydrographic basins north of the basin. Furthermore, the LWRFS includes the Muddy River Springs, which are the regional terminus of the White River Flow System. Hydrologic data submitted by the overwhelming majority of stakeholders with valid water rights and vested interests in the LWRFS clearly suggests that if groundwater development is managed at sustainable levels within the LWRFS, Moapa Dace habitat will be protected as will spring flows that support decreed rights on the Muddy River. If these obligations are met within MRSA there is no evidence suggesting impacts would propagate north of and beyond the LWRFS boundary as currently proposed by the State Engineer.

7. Recommended LWRFS annual pumping.

NCA supports the NSE current sustainable target of 9,318 acre-feet annually. NCA recognizes that other users within the LWRFS have recommended various changes both higher and lower to the limits established by the NSE. While NCA agrees with recommendations made by SNWA (2019)[38] regarding regulatory oversight to prevent and mitigate impacts to senior water-right holders. NCA believes there is currently insufficient data to warrant a reduction or increase from the target level currently suggested by the NSE. As such, NCA supports recommendations for management plans based on the conjunctive use of surface, alluvial and carbonate water sources within an adaptive management framework.

8. Consideration regarding the movement of water rights between alluvial and carbonate wells.

NCA agrees that there is a high correlation between carbonate wells in the LWRFS which indicates a high level of hydraulic connectivity across all the basins within the LWRFS, because, as the data indicate, the MRSA is hydraulically connected to the other hydrographic basins within the LWRFS. As such, NCA does not support the transfer of alluvium ground water rights within the MRSA to the carbonate system within the LWRFS as the supply source for new or future uses. The transfer of alluvial ground water rights within the MRSA to the carbonate system within the LWRFS will not mitigate impacts to the MRSA, but in fact will intensify the impacts caused by carbonate pumpage based on impacts to the springs that feed the Muddy River.

The City of North Las Vegas (CNLV) and the Moapa Band of Paiutes (MBOP) July 2019 reports both provide information supporting transfers of alluvial groundwater rights from the MRSA to the carbonate rock as a benefit to the carbonate system.

The CNLV (Interflow, 2019[39]) defines its position supporting the transfer alluvium groundwater rights from the MRSA to the carbonate rock as follows:

- Transferring senior groundwater rights from the Muddy River Springs Area to the APEX portion of Garnet Valley appears to have merit in two regards: 1.) removing senior pumping from within the Muddy River Springs Area that appears to have historically impacted flows of the Muddy

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[38] SNWA, 2019. "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019.

[39] Interflow Hydrology, Inc., 2019. Garnet Valley Groundwater Review for APEX Industrial Complex, City of North Las Vegas, Clark County, Nevada.

River, and 2.) securing more senior water rights for the APEX municipal system, in the event that groundwater rights become regulated by priority date in the LWRFS.

- The Church's wells tap the shallow alluvium (~200 ft thick) overlying the carbonate rock along the Muddy River Springs corridor. Pumping from the alluvium has been interpreted by SNWA (2013) to create a nearly 1:1 capture of Muddy River flow, as measured at the down-stream Moapa Gage.

- In recognition of the effects of pumping from established points of diversion for the Church's water rights in the alluvium along the Muddy River Springs corridor, ceasing to pump these water rights at the existing points of diversion will mitigate potential impacts to existing decreed water rights on the Muddy River, and perhaps provide an advantage to sustaining spring flows on the valley floor. This could in turn benefit the Moapa Dace habitat.

The Interflow (2019) states "…*it appears that pumping at 1500 AF/yr and possibly up to 2000 AF/yr in the APEX area has not caused detrimental water level declines…In summary, transferring of senior water rights to the APEX facilities should not be viewed as enabling greater pumping from the basin, but rather, as adding some degree of assurance to the ability to maintain pumping in APEX should future actions require management of groundwater rights by priority date, under current Nevada water law."*

NCA believes, as does Interflow/CNLV, that transfers of senior alluvial water rights should be used as a management tool to offset existing pumping from carbonate wells relying on junior water rights.

Mifflin & Associates (MAI)[40] / MBOP claims that *"…current production levels have demonstrated no impacts on MRSA flows*." The MBOP approach to the transferring alluvium groundwater rights from the MRSA to the carbonate aquifer is as follows:

- Moving the MRSA alluvial water rights to carbonate-aquifer production will produce similar (proportional to pumping) levels of impacts on the MRSA flows as already documented for the carbonate-aquifer production in Coyote Spring Valley and Arrow Canyon Wells. A move of the alluvial rights to carbonate-aquifer production in down-gradient basins (California Wash and basins to the south) where current production levels have demonstrated no impacts on MRSA flows, is the likely strategy to maximize the extent of development without unacceptable impacts on MRSA flows.

The MBOP report appears to be taking an area limited approach to the transfer of alluvium groundwater rights from the MRSA to the carbonate, in that, these transfers can be made to the location of the entities facilities as a way to get senior ground water rights, as there is limited to no impact of carbonate pumpage at each entities location on water level declines or reduction in spring flow within the MRSA.

Within the SNWA Assessment Report, SNWA makes a number of observations and conclusions with regard to ground water pumpage from the alluvium aquifer within the MRSA[41]. The most significant of these observations and conclusions from NCA's perspective are listed below. In some cases, the

[40] Johnson, C. and M. Mifflin, Mifflin & Associates (MAI), 2019. Water-Level Decline in the LWRFS: Managing for Sustainable Groundwater Development. Initial Report of Moapa Band of Paiutes in Response to Order #1303.

[41] Pages 8-3-8-5 SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019.

observation or comments have been abbreviated and where appurtenant, comments relative to NCA's position are provided:

- Groundwater production from the MRSA alluvial reservoir depletes Muddy River streamflow on a 1:1 basis.
- Groundwater production from MRSA carbonate wells deplete Muddy River streamflow approaching a 1:1 basis. Groundwater production from other carbonate wells in the LWRFS deplete streamflow; however, their effect cannot be readily detected from the measurements.
- A significant increase in carbonate groundwater production, such as that which occurred during the NSE Order 1169 aquifer test, will cause sharp declines in carbonate-aquifer water levels and spring discharges.
- The results of the Order 1169 aquifer test demonstrate that for the areas directly upgradient of the MRSA (i.e., Arrow Canyon and Coyote Spring Valley), impacts propagate to the high-elevation springs within a matter of weeks or months. In the long-term, the location of the production wells does not matter as groundwater withdrawn anywhere within the connected carbonate aquifer or the MRSA alluvial reservoir will impact the MRSA discharge and, consequently, deplete Muddy River streamflow.
- The data indicates that pumping simply cannot occur without conflicting with senior rights. While it is unreasonable to assume that all pumping in the LWRFS would be eliminated, it should not be permitted to continue without strict regulatory oversight and appropriate mitigation to effected senior water-right holders and adequate protections for the Moapa dace.
- Production wells completed in the alluvial reservoir adjacent to the Muddy River capture groundwater that would otherwise discharge to the river. In addition, MRSA production wells completed in the carbonate aquifer capture water that would otherwise replenish the alluvial reservoir through diffuse subsurface flow or discharge from discrete springs. Capturing this groundwater depletes the source of supply to the alluvial reservoir and springs, thereby, depleting the streamflow. In each case, this groundwater production conflicts with senior Muddy River water rights.
- Changing points of diversion to move groundwater production from the MRSA alluvial reservoir to locations sourced by the carbonate aquifer will not mitigate these conflicts, only delay their inevitable occurrence. Such changes would exacerbate issues associated with the already over-appropriated carbonate aquifer by accelerating the timing of impacts to the high-elevation springs due to the additional groundwater production. The timing of impacts will vary based on the magnitude, duration, and location of groundwater production. The impacts may occur relatively quickly, within weeks or months, if additional groundwater production were to occur in areas directly upgradient from the MRSA. Groundwater production in areas farther away, may take longer, but the properties of the aquifer are such that these impacts will eventually result in reduced spring discharge and depletions of Muddy River streamflow.

In the SNWA Assessment Report, SNWA found that there was a high correlation between well EH-4 and spring discharge, based on this high correlation between EH-4 and spring discharge SNWA determined that it stood to reason that the observed carbonate well responses could be correlated to that of EH-4 to assess if their responses are caused by the same stresses affecting the spring discharge. SNWA also stated that high correlations would also further confirm the hydraulic connectivity of the LWRFS.[42] SNWA then used the average monthly values of hydraulic head from water-level elevation records of the representative carbonate wells the average monthly hydraulic head of a number of wells, including

[42] Pages 5-6-5-12 of SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019.

Paiutes-TH2 located in California Wash and GV-1 located in Garnet Valley. These values for Paiutes-TH2 and GV-1 were then plotted against EH-4 for the period of 2000 to 2019 and 2002 to 2019.[43] See Figure 6.

There was a high correlation between all the carbonate wells plotted against EH-4 with the correlation of Paiutes-TH2 and EH-4 resulting in a R_2 value of 0.97 and GV-1 and EH-4 resulting in a R_2 value of 0.91. These high correlations between carbonate wells in the LWRFS indicate a high level of hydraulic connectivity across all of the basins within the LWRFS.

The high correlations between carbonate wells in the LWRFS indicate a high level of hydraulic connectivity across all of the basins within the LWRFS. While the timing of impacts from carbonate pumpage located outside the MRSA such as Garnet Valley and California Wash may take a little longer, the properties of the carbonate aquifer are such that these impacts as seen during the Order 1169 aquifer test will impact the MRSA, because, as the data indicates, the MRSA is hydraulically connected to the other hydrographic basins within the LWRFS. The results of the Order 1169 aquifer test indicate that the impacts from carbonate pumpage within the LWRFS are the sum of all the parts, no matter size or location.

During the Order 1169 aquifer test there were significant impacts to high altitude springs in the MRSA caused by a lowering of the hydraulic head in the carbonate aquifer as a result of carbonate pumpage. Additionally, there were limited impacts to the flows of the Muddy River resulting from carbonate pumpage and a 1:1 impact to flows of the Muddy River from alluvial pumpage. Over time it is expected that carbonate pumpage within the LWRFS will capture flow to alluvial reservoir which in turn will ultimately capture spring discharge within the MRSA and Muddy River stream flow.

As demonstrated by SNWA there is a 1:1 impact to flows of the Muddy River from alluvial pumpage. Therefore, the transfer of alluvium water rights located within the MRSA to the carbonate system within the LWRFS as the supply source for new or future uses will not mitigate impacts to the MRSA, but in fact increases the impacts caused by carbonate pumpage. The reason for this is straight forward. Once pumpage from the alluvium for quantity X ceases the flow of the Muddy River increases by quantity X and conversely, once pumpage from the alluvium for quantity X begins, Muddy River flow decreases by quantity X, therefore the alluvium pumpage has neither a positive or negative impact on springs within the MRSA. While pumpage from the alluvium aquifer within the MRSA impacts senior Muddy River water rights these impacts can be mitigated by simply leasing or purchasing Muddy River shares to account for the impacts resulting in a form of conjunctive management to benefit both parties and the resource. The same cannot be said for the transfer of alluvium water rights located within the MRSA to the carbonate system within the LWRFS as supply source for new or future uses. When this transfer is made, the opportunity for conjunctive management of quantity X from the alluvium aquifer within the MRSA and the Muddy River no longer exists. Additionally, the pumpage of quantity X of alluvium water rights from the LWRFS carbonate system will result in a proportional lowering of the carbonate aquifer hydraulic head, equivalent to quantity X, as there is a high degree of hydraulic connection within the carbonate aquifer and across all of the basins resulting in additional impacts to the MRSA. The loss of the opportunity to conjunctively manage quantity X and the proportional lowering of the carbonate aquifer hydraulic head, equivalent to quantity X results in a impact twice that of quantity X to the resource.

[43] Page 5-12 of SNWA report "Assessment of Lower White River Flow System Water Resource Conditions and Aquifer Response" dated June 2019

NCA agrees with the observation that production wells completed in the alluvial reservoir adjacent to the Muddy River capture groundwater that would otherwise discharge to the Muddy River. Additionally, NCA believes that moving groundwater production from the MRSA alluvial reservoir to locations sourced by the carbonate aquifer for new or future uses will not mitigate conflicts to the MRSA, only delay their inevitable occurrence. Such changes would exacerbate issues associated with the already over-appropriated carbonate aquifer by accelerating the timing of impacts to the high-elevation springs due to the additional groundwater production.

Conclusions and Recommendations

1. Standing of Non-Governmental Organizations Without Water Rights

NCA objects to the inclusion and participation of NGOs at this point of the administrative process based on the obvious lack of legal standing. Considering the limited hearing time allowed for this process, providing any significant time to these participants beyond mere public comment is a significant departure from prior State Engineer process and procedure.

2. Proposal by the NPS to include all of the Black Mountains Area Basin in the LWRFS

NCA supports the LWRFS boundary with inclusion of only the northwestern portion of the Black Mountain Area Hydrographic Basin as currently described in Order 1303; no changes are recommended. There is substantial geological, hydrologic and geochemical evidence to justify the inclusion of only the northwestern portion as currently described.

3. Proposal by the USFWS to include the Lower Meadow Valley Wash Basin in the LWRFS

Order 1303 does not include the Lower Meadow Valley Wash (LMVW) Hydrologic Basin as part of the LWRFS. As discussed within this rebuttal report observed water level trends within alluvial, Muddy Creek and nearby carbonate monitoring wells reflect a clear disconnect with observed trends in the LWRFS regional carbonate levels. Furthermore, the likelihood of development of carbonate water sources within the basin are slim based on the extreme depth of carbonate geology and mapped structural features that separate the basin from the LWRFS.

4. Proposal to include the Kane Springs Basin in the LWRFS

Currently Order 1303 does not include Kane Springs Valley (KSV). However, there is significant correlation between KMW-1 and impacts from pumpage within the LWRFS with effects from present day pumpage within the LWRFS observed in well KMW-1. Therefore, it stands to reason that KSV be added to the LWRFS to protect existing senior rights.

5. Proposal to exclude the northern portion of Coyote Springs Valley.

NCA believes that the hydrologic data from the Order 1169 aquifer test clearly indicates that carbonate pumpage from the northern portion of CSV and KSW-1 within KSV will impact carbonate aquifer hydraulic head within the LWRFS, which in turn will increase impacts to springs flows within the MRSA and be detrimental to the existing groundwater rights held by NCA. It is evident that there is a high correlation between CSVM-4 and KMW-1 which in turn indicates a high correlation between CSVM-4 and KMW-1 and carbonate wells in the LWRFS with a high level of hydraulic connectivity across all the basins within the LWRFS. Therefore, there is no basis to exclude the northern portion of CSV.

6. Proposal by the GBWN to Include the entire White River Flow System

NCA does not support the inclusion of the entire White River Flow System (WRFS) as joint management unit. The Pahranagat Shear zone (north Coyote Spring Valley) creates a substantial barrier that warrants the exclusion of the hydrographic basins north of the basin. The LWRFS includes the Muddy River Springs, which are the regional terminus of the regional WRFS. Hydrologic data submitted by the overwhelming majority of stakeholders with valid water rights and vested interests in the LWRFS suggests that if groundwater development is managed at sustainable levels within the LWRFS, Moapa Dace habitat will be protected as will spring flows that support decreed rights on the Muddy River. If these obligations are met within the MRSA there is no evidence that suggests impacts would propagate north of and beyond the LWRFS boundary as currently proposed by the State Engineer.

7. Recommended LWRFS annual pumping

NCA supports the State Engineer's current system yield target of 9,318 acre-feet annually for the LWRFS. NCA recognizes that other users within the LWRFS have suggested a lower perennial yield target and while NCA did not touch on the sustainable yield in this rebuttal report, the company believes there is insufficient data at this time to warrant a reduction or increase from the current target level. As such, NCA supports recommendations for management plans based on the conjunctive use of surface, alluvial and carbonate water sources within an adaptive management framework.

8. Considerations regarding the movement of water rights between alluvial and carbonate wells

NCA agrees that there is a high correlation between carbonate wells in the LWRFS which indicates a high level of hydraulic connectivity across all the basins within the LWRFS, because, as the data indicate, the MRSA is hydraulically connected to the other hydrographic basins within the LWRFS. As such, NCA does not support the transfer of alluvium ground water rights within the MRSA to the carbonate system within the LWRFS as the supply source for new or future uses. The transfer of alluvial ground water rights within the MRSA to the carbonate system within the LWRFS will not mitigate impacts to the MRSA, but in fact intensify the impacts caused by carbonate pumpage based on impacts to the springs that feed the Muddy River.

InterFlow Hydrology, Inc.
Hydrogeology and Water Resources Consulting

MEMORANDUM

To: Mr. Robert A. McLaughlin, PE, City of North Las Vegas, Manager, Development & Flood Control

Date: August 12, 2019

RE: **Addendum No. 1 - Garnet Valley Groundwater Pumping Review for APEX Industrial Complex, City of North Las Vegas, Clark County, Nevada, dated July 2, 2019**

From: Dwight L. Smith, PE, PG, Principal Hydrogeologist

Figure 10 in the above reference report should be replaced with the following amended Figure 10, which has municipal (MUN) water usage added for years 2002-2005. This is a correction made in accordance with the remarks in the NDWR basin inventory published for basin 216 for year 2006, regarding prior absent reported pumping under LVVWD water right permit number 54073 (permit issued on April 13, 2001). This addendum is being made for accuracy of reporting, and does not change any of the analyses or conclusions provided in the above referenced report.

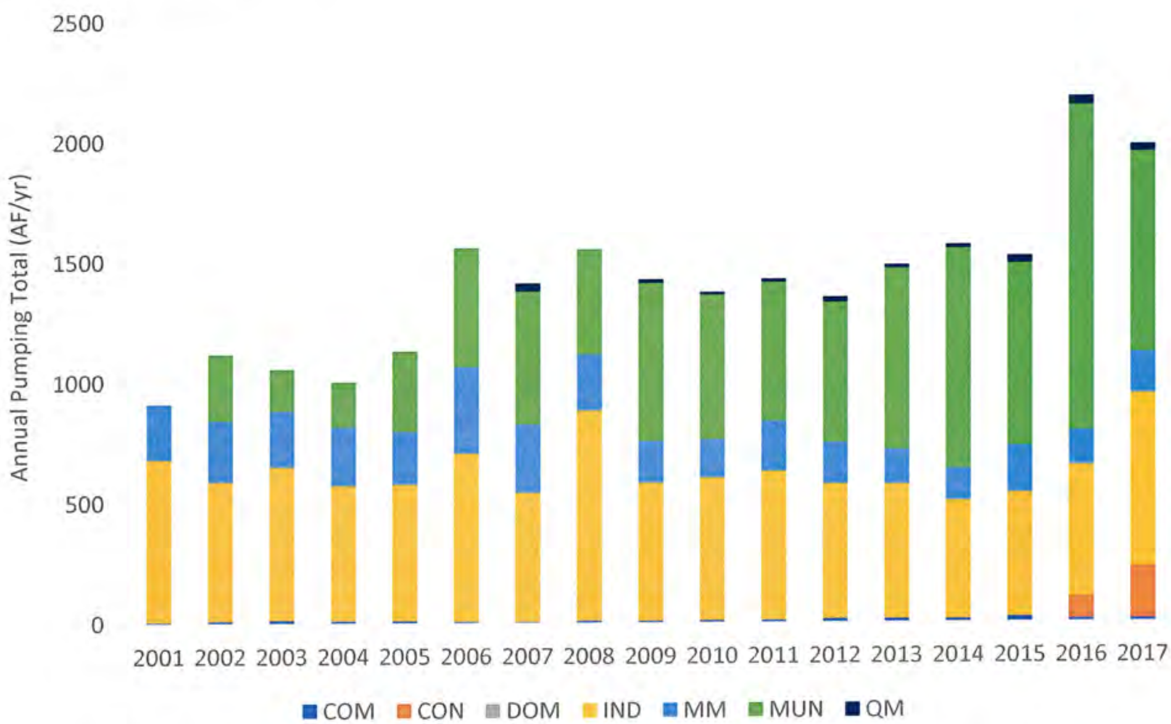


Figure 10 (Amended) – Historical Pumping from Wells in Garnet Valley (data from NDWR Pumping Inventories)

InterFlow Hydrology, Inc.
Hydrogeology and Water Resources Consulting

Technical MEMORANDUM

To: Mr. Randall E. DeVaul, PE, City of North Las Vegas, Director of Utilities
Mr. Robert A. McLaughlin, PE, City of North Las Vegas, Manager, Development & Flood Control

Date: July 2, 2019

RE: **Garnet Valley Groundwater Pumping Review for APEX Industrial Complex, City of North Las Vegas, Clark County, Nevada**

From: Dwight L. Smith, PE, PG, Principal Hydrogeologist
Alexa Terrell, MSc., Hydrogeologist

A.T.

PROFESSIONAL ENGINEER - STATE OF NEVADA
DWIGHT L. SMITH
GEOLOGICAL
EXP. 6/30/20
No. 11906

Executive Summary

Garnet Valley is situated in the southern end of the Lower White River Flow System, which is a collection of 6 hydrographic basins that have groundwater connection through the regional carbonate aquifer. The Lower White River Flow System (LWRFS) encompasses Coyote Spring Valley (210), Muddy River Springs Area (219), Hidden Valley (217), California Wash (218), Garnet Valley (216), and a smaller northwestern portion of the Black Mountains Area (215). State Engineer Interim Order 1303 was issued on January 11, 2019 designating the basins as one collective administrative area. This is the first designation of this type in the State of Nevada.

Most groundwater flow in the LWRFS basins discharges at the Muddy River Springs. Some groundwater appears to travel south to Garnet Valley based on water level elevations. As presently understood, the quantity of flow to Garnet Valley is small. Data are not sufficient to quantify an exact amount. Test modeling conducted in this study estimates groundwater inflow to northern Garnet Valley from southern Coyote Spring Valley and/or northern Hidden Valley at approximately 450 AF/yr. A unique finding of this study is that there appears to be groundwater flow from Las Vegas Valley (212) into southern Garnet Valley. Modeling suggests the magnitude may be about 700 AF/yr, but there is considerable uncertainty, and the gradient from Las Vegas Valley to Garnet Valley has not been clearly defined. This potential inflow needs to be investigated further by measuring water level elevations near the boundary between the basins, which will likely necessitate drilling and installation of two or more water level monitoring wells.

Along with the estimated in-basin recharge by precipitation falling in the Las Vegas Range, the groundwater inflows support existing pumping in Garnet Valley, which has historically been around 1500 AF/yr. There is little evidence of a significant magnitude of groundwater outflow from Garnet Valley to California Wash. It is interpreted in this study that the basin is in a state near to equilibrium with the magnitude of current groundwater pumping. There is a long-term declining water trend in Garnet Valley of approximately 0.3 ft per year, but this trend is observed throughout the LWRFS at similar magnitudes, and is interpreted to be a regional background condition. The declining trend began in the late 1990s. A wet year in 2005 interrupted the declining trend, as did the 2-year Order 1169 pumping test in Coyote Spring Valley in 2011-2012. Increases in pumping in Garnet Valley in 2016-2017 do not appear to have caused observable changes in the water level trends.

Ultimately, there is a pumping threshold in Garnet Valley that could cause undesirable levels of drawdown to propagate northward in the LWRFS, but this threshold has not been characterized by current pumping rates. Manageable levels of drawdown in Garnet Valley need to be achieved to avoid interference with decreed water rights of the Muddy River and Muddy River Springs, and spring discharges that support the endangered species Moapa Dace. Concurrent with the City's construction of the pipeline to deliver Colorado River water to APEX, there should be ample opportunity to test the groundwater pumping component of the water supply and adjust long-term management of water resources as needed to address LWRFS issues while maintaining municipal service.

Pumping groundwater at a higher rate of approximately 2000 AF/yr occurred from APEX in 2016 and 2017, under use of Southern Nevada Water Authority water rights, without noticeable impacts. Additional pumping may be sustainable, but should be tested in increments and supported by adequate monitoring. Water level monitoring in Hidden Valley to the north of APEX is sparse, and occurring at only one well (SHV-1) which is believed to be completed in alluvium rather than the carbonate aquifer. Two additional monitoring well installations are recommended in Hidden Valley, both completed in the carbonate aquifer, and one in the southern part of the basin.

There are existing water rights in Garnet Valley to pump up to 3715 AF/yr, with SNWA holding 2275 AF/yr of these rights (adjusted for combined duties). The SNWA water rights are however some of the most junior water rights in the LWRFS. Transferring senior groundwater rights from the Muddy River Springs Area to the APEX portion of Garnet Valley appears to have merit in two regards: 1.) removing senior pumping from within the Muddy River Springs Area that appears to have historically impacted flows of the Muddy River, and 2.) securing more senior water rights for the APEX municipal system, in the event that groundwater rights become regulated by priority date in the LWRFS. The latter is a concern because the total permitted duty of groundwater rights granted in the LWRFS is approximately 39,700 AF/yr, but the non-committed groundwater resources after considering commitments of spring discharges is probably no greater than 10,000 AF/yr.

A LWRFS Groundwater Management Plan is expected in the future, the specific details of which have not been determined. It is likely that the development of a Groundwater Management Plan will require several years of work between the LWRFS stakeholders and the State Engineer, and potentially more time in the courts, if the plan is appealed. In summary, transferring of senior water rights to the APEX facilities should not be viewed as enabling greater pumping from the basin, but rather, as adding some degree of assurance to the ability to maintain pumping in APEX should future actions require management of groundwater rights by priority date, under current Nevada water law. Transferring of senior water rights to APEX is also not guaranteed to be approved, because applications will need to go through the water right transfer process and could be protested, and will be subject to a State Engineer determination.

Introduction

This memorandum has been prepared as a review of groundwater pumping in Garnet Valley and at the APEX Industrial Park (APEX). APEX is located along the Interstate 15 corridor northeast of Las Vegas, and is incorporated into the City of North Las Vegas. The southern-most portion of APEX resides in Las Vegas Valley, while the majority of APEX is within Garnet Valley. APEX is bound by public lands on most sides, and by US Route 93 on the northeast (Figure 1). Bureau of Land Management utility corridors bisect portions of APEX.

Following the explosion at the Pacific Engineering and Production Company of Nevada (PEPCON) on May 4, 1988, Nevada leaders working with the United States Congress designated roughly 18,000 acres of land as a new heavy industrial area for Southern Nevada's future. Through a series of subsequent BLM auctions the land was acquired by private investors and developers. This large industrial area became known generally as APEX Industrial Park and although its vast land provides a unique opportunity for industrial development, because it lacked the utilities necessary for businesses to locate it remains largely vacant tracts of land almost 20 years later.

Today, APEX Industrial Park is a 20 square mile area annexed into the City in 2008 with approximately 7,500 developable acres. It is located along I-15 and US Route 93, has access to Union Pacific Railroad and dry utilities including electric transmission and distribution service and natural gas pipelines. The area is currently zoned M2 throughout the industrial park under the APEX Overlay allowing most industrial and ancillary uses. APEX is the home of the Hyperloop One's Propulsion Open Air Test Track to develop a new high speed, intercity transportation system which uses passenger and cargo capsules inside a reduced-pressure tube system that would reach a top speed of 760 miles per hour. Other businesses committing to the APEX include medical marijuana grow facilities and UNEV Pipeline, LLC's North Las Vegas terminal for their $300,000,000 petroleum pipeline with an initial capacity of 62,000 barrels of product per day and maximum capacity of 118,000 barrels of product per day.

In 2010, the City took over operation of a private water system serving the existing customers located in the APEX Industrial Park. This system remains in operation and will continue to remain in operation until the final water system improvements are completed.

APEX Industrial Park is currently underserved by an inadequate water system. The APEX Master Water and Sewer Plan was approved by City Council in 2012. The goal of the plan was to map out needed water and sewer facilities to make APEX Industrial Park the premier industrial park in Nevada. The master plan indicates a need for an average day water demand of 3.36 million gallons per day (MGD), maximum day demand of 4.57 MGD and peak hour demand of 7.02 MGD. The master plan for water calls for a 14-mile water pipeline and series of water reservoirs and pump stations connecting an existing 24-inch water line in Hollywood Boulevard to the existing groundwater system operated by the City of North Las Vegas Utilities Department.

In September 2014, North Las Vegas engaged Brookings Mountain West to identify the economic and regional significance of APEX Industrial Park. Their economic impact analysis indicated that APEX, when built out, could create 116,000 direct, indirect and induced jobs, generate $193 billion dollars in regional economic impact, and generate $670 million in new annual tax revenue for state and local government. However, the challenge of providing infrastructure to the promising park remained.

In April 2018, the City entered into an oversizing agreement with a private developer to construct the first 10.4 miles of a proposed 25 mile water pipeline to bring water from the City's primary water system to APEX and create a backbone water system to serve all of APEX Industrial Park. The first 7,700 LF of pipe is in the ground and the next 19,000 LF of pipe is scheduled for construction beginning in mid-August 2019. While a funding plan for the final 15 miles of pipeline is not complete, an artificial recharge well is proposed after phase 2 construction is complete that could permit recharging of the Garnet Valley Aquifer to support increased pumping from wells in northern APEX and as a long-term aquifer management tool.

APEX Industrial Park was the proposed site of the Faraday Future electric car manufacturing facility. In 2016 and 2017, I-15 interchange facilities, widening of US Route 93, and a 700-acre super-pad were completed prior to Faraday Future announcing withdrawal from the proposed project.

While the City of North Las Vegas provides water service to APEX, most facilities currently use individual water supply wells. The City of North Las Vegas operates two wells in the northern part of APEX which are equipped for municipal water supply. The Playa well was drilled in 2016 to 2000 ft in depth and has a yield up to 600 gallons per minute (gpm) (West Yost, 2016). The Kapex well was drilled to 1145 ft in depth in 1990 by the Kerr-McGee Chemical Company, and has a yield of approximately 200 gpm.

The City of North Las Vegas currently owns 10.02 acre-feet per year (AF/yr) of water rights under permit 77745, with a point of diversion at the Kapex well. The Southern Nevada Water Authority (SNWA) owns 2,274.57 AF/yr of groundwater rights in the APEX area, under multiple water right permits, which have been available for permanent and temporary transfers to wells in APEX, primarily for power generating facilities. The City has an agreement with SNWA to lease up to 900 AF/yr. SNWA permit 83490 has been issued for 300 AF/yr for use by the City of North Las Vegas for municipal purposes in APEX, with a point of diversion at the Kapex well. A temporary transfer of water rights is currently active for 350 AF/yr at the Playa well (permit 88011T).

Phase 1 of the water pipeline project extends into the southern end of APEX, and will terminate approximately 1 mile from the Garnet Valley hydrographic basin boundary. Phase 2 of the pipeline will extend another 3.3 miles into southern Garnet Valley and south-central APEX. Phases 3-6 will complete the water distribution system to the northern portion of APEX (Figure 2).

The water conveyed in the new pipeline to APEX has a primary source from Lake Mead (~90%), and secondarily, comingled groundwater pumped from Las Vegas Valley (~10%). Applications 88821-88825 have been filed by the City to expand the place of use of groundwater rights in Las Vegas Valley to include the APEX service area in Garnet Valley. The total combined duty of these applications is approximately 847 AF/yr. The build-out water demand for APEX is estimated to be 3,761 AF/yr (Poggemeyer, 2012) and is based on a predicted water use of 0.5 AF/yr/acre of developable land. The actual water demand could vary significantly depending on type of industrial facilities built. The City's master plan is for water service to be provided from both groundwater pumping within Garnet Valley combined with the piped water being ~90% Colorado River source and ~10% Las Vegas Valley groundwater source.

A complicating water management issue for the Garnet Valley groundwater source is connection with other hydrographic basins to the north, including the Muddy River Springs Area, via the regional carbonate aquifer. The State Engineer issued Interim Order 1303 in January 2019 combining six hydrographic basins into one management area, being called the Lower White River Flow System (LWRFS). Groundwater pumped from basins in the LWRFS has the potential to create drawdown in neighboring basins, as was observed in the Order 1169 aquifer pumping test of wells in Coyote Spring Valley conducted by SNWA in 2011 and 2012 (SNWA, 2013). The Muddy River Springs Area (aka Upper Moapa Valley Basin) is notably sensitive to drawdown, due to the potential impacts to spring flow and the associated habitat of the Moapa Dace, and interference with decreed water rights of the Muddy River. Interim Order 1303 also places a temporary moratorium on State Engineer approvals of new development, unless the applicant can show an adequate and sustainable supply of water to meet water demands over the anticipated life of the development. Permanent change applications for existing groundwater rights are also being held in abeyance, pending further determinations for administration of water rights in the LWRFS, although temporary transfers may be granted.

This technical memorandum examines historical, current, and potential future pumping within the APEX portion of Garnet Valley. An examination of the potential water budget and sustainable pumping yield from Garnet Valley is presented, using currently available data. The City of North Las Vegas is negotiations for an agreement to lease senior groundwater rights from the Muddy River Springs Area to transfer to the APEX facilities. Advantages and issues associated with a transfer of these senior water rights will be reviewed.

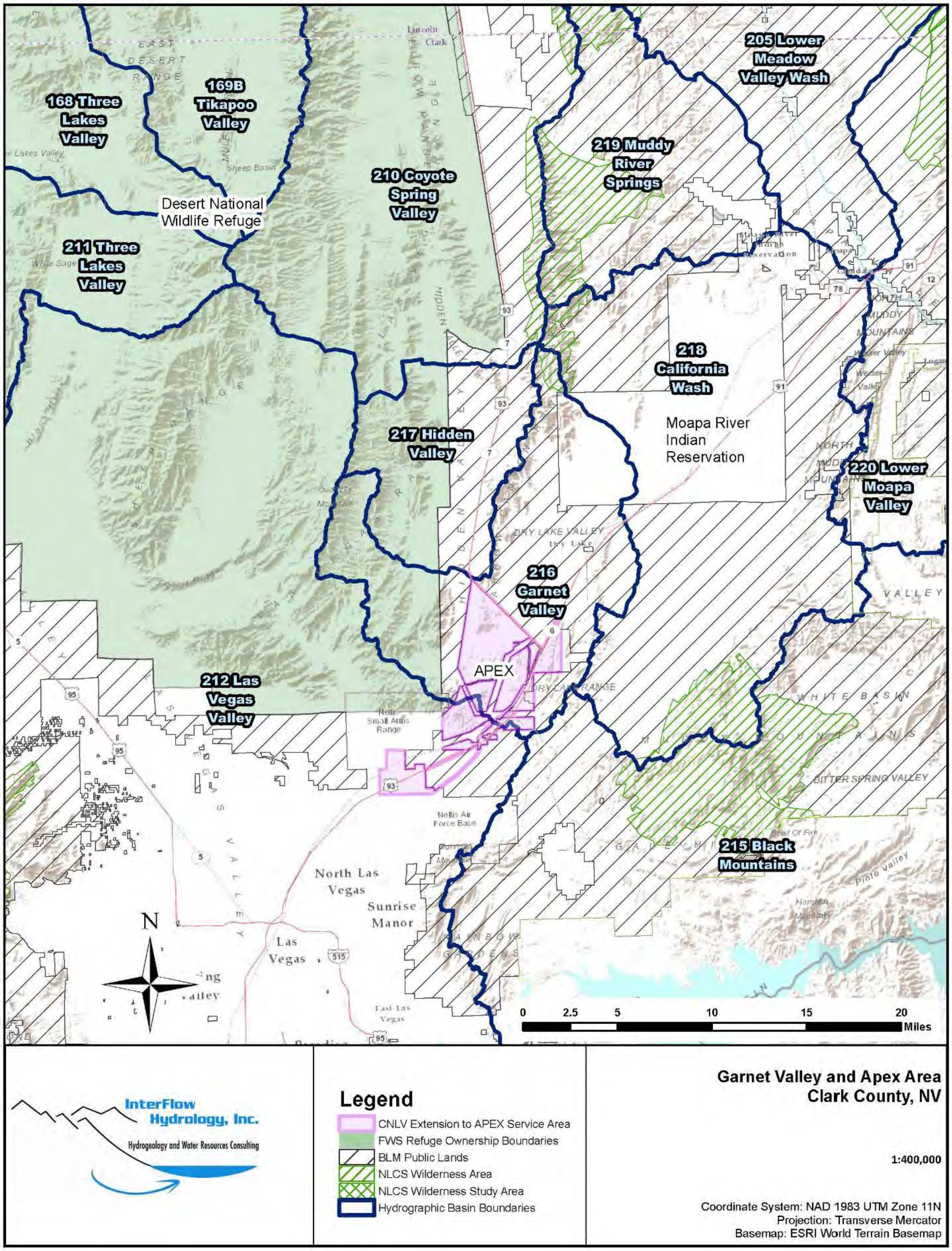


Figure 1 – Location Map

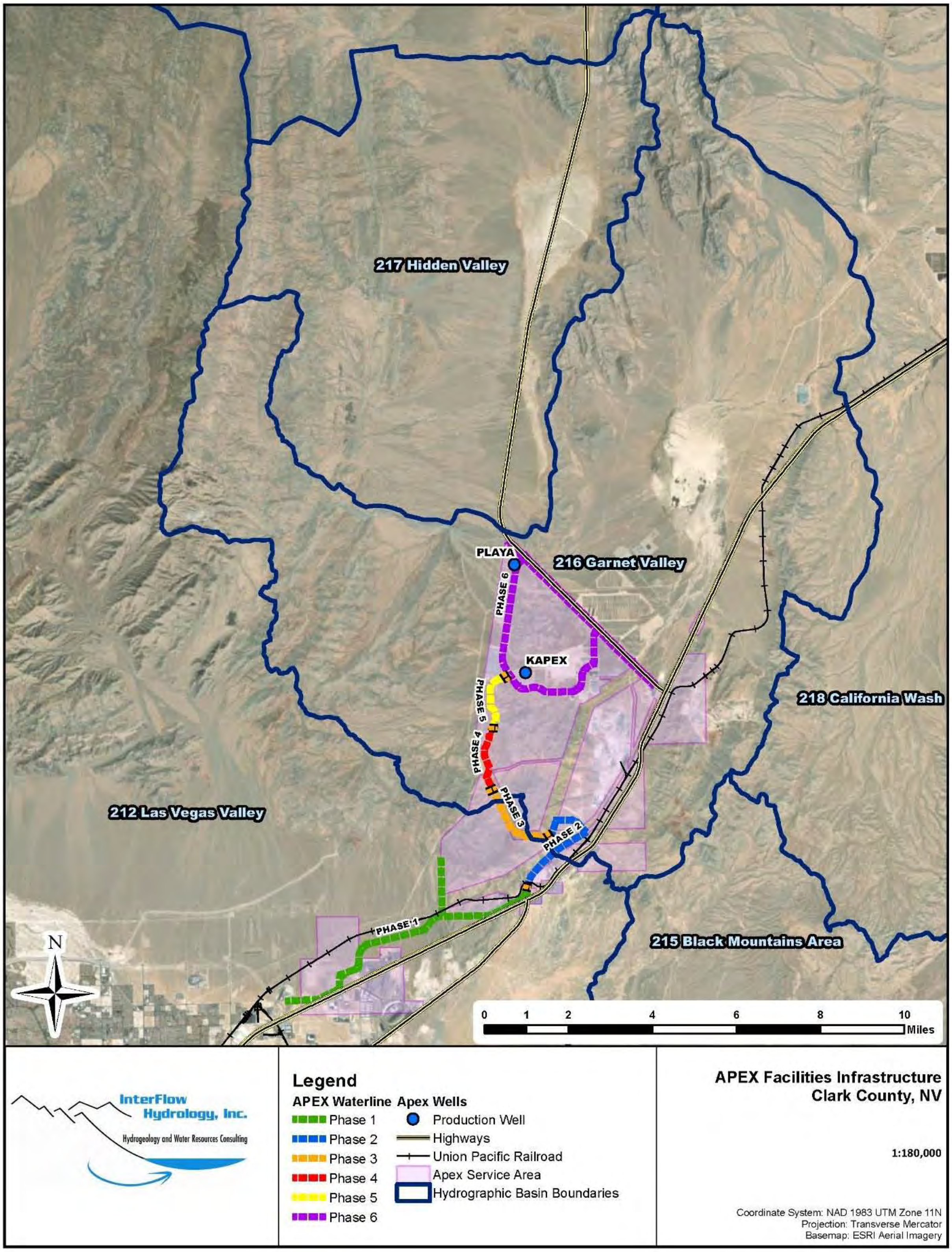


Figure 2 – APEX Planned Water Supply Infrastructure

Regional Hydrogeologic Setting

APEX is located in south-central Garnet Valley, which comprises one of six hydrographic basins in the LWRFS. Hydrographic basins included in the LWRFS are Coyote Spring Valley (210), Muddy River Springs Area (219), Hidden Valley (217), Garnet Valley (216), California Wash (218), and a small portion of the Black Mountains Area (215), as shown in Figure 3. These basins are hydrologically connected by a thick, but complexly folded and faulted, sequence of Paleozoic sedimentary rocks. The Paleozoic rocks are comprised of both carbonate (limestone and dolomite) rock types and clastic (sandstone, siltstone, quartzite and shale) rocks. The units of carbonate rock can be hundreds to thousands of feet thick and can exhibit high permeability due to faulting and dissolution of the limestone.

Figure 4 shows the regional geology for the LWRFS basins published by Page et al (2005), and Figure 5 is a geologic cross-section trending east-west through Garnet Valley (Page et al, 2011). Figure 6 is a legend for the geologic map units. The thickness of Paleozoic sedimentary rocks is interpreted to be about 20,000 to 25,000 feet beneath Garnet Valley. The Grace Petroleum Arrow Canyon #1 exploration well that was drilled in 1982 on the east side of APEX and encountered 17,110 ft of Paleozoic sedimentary rocks (Garside et al, 1988). This petroleum exploration hole encountered older Devonian to Cambrian age sedimentary rocks overlying younger Permian and Mississippian sedimentary rocks to approximately 9,000 ft in depth. The older rocks were displaced over the younger by the Dry Lake Thrust Fault.

Potentiometric water levels in the carbonate aquifer are monitored by the Southern Nevada Water Authority (SNWA), with contributions from other stakeholders in the LWRFS. Water level and pumping data are recorded on the NDWR website. Water levels reported for the LWRFS in November 2018 are shown in Figure 7. Directions of groundwater flow can be generally described, however, data in some portions of the LWRFS are sparse and interpretations of groundwater flow directions uncertain. Figure 7 shows interpreted directions of groundwater flow from this study.

Groundwater inflow to the LWRFS is understood to originate from hydrographic basins to the north along the White River Flow System. Many investigators have studied the flow system. This study shall build upon their work and not reiterate prior findings. In summary, groundwater flow enters Coyote Spring Valley from the north, and from Kane Spring Valley to the northeast, comingles with recharge from the Sheep Range bounding the west side of the basin, and flows out through the eastern side of the basin to discharge at the Muddy River Springs.

Groundwater in southern Coyote Spring Valley appears to flow northerly to the MX-5 area, and also southerly to Hidden Valley. But data are too sparse in Hidden Valley to clearly understand flow directions through that basin. Subsurface outflow through the Arrow Canyon Range to northern Garnet Valley is possible, as is southerly outflow to the APEX area. The single active monitoring well in Hidden Valley (SHV-1) is suspected to be completed in alluvium rather than the carbonate aquifer, due to unique water level variability as contrasted with other carbonate wells in the LWRFS, complicating the regional flow interpretations. Replacement of this well with a known completion in the carbonate aquifer would be helpful in making regional flow interpretations.

Groundwater flow from Hidden Valley to the APEX area and southern Garnet Valley is postulated, but there is a lack of water level in Hidden Valley to confirm. Well HV-1 is located in southern-most Hidden Valley, but has not been actively monitored since 2000, and the well may no longer be in an adequate condition for monitoring, as it has been "used" for target practice (personal communication, SNWA, 2019). Future groundwater monitoring, potentially associated with managed pumping from northern APEX, should consider installing a monitoring well in southern Hidden Valley, or refurbishing HV-1 if possible.

Regardless of groundwater flow directions, the gradients over much of the regional carbonate aquifer in the LWRFS are shallow, reflecting the high transmissivity of the carbonate aquifer. There are a few known barriers to groundwater flow within the LWRFS basins, including the Kane Springs Fault Zone in northern Coyote Spring Valley, and an unnamed fault on the west side of Coyote Spring Valley. These barriers are not however impermeable, but rather features with lower transmissivity than the adjacent portions of the regional carbonate aquifer.

The Order 1169 pumping test in central Coyote Spring Valley had pumping centered at the MX-5 well and Coyote Springs Golf Club wells, and enabled interpretations of hydrologic connections through the regional carbonate aquifer (SNWA, 2013; USFWS et al, 2013; Mifflin & Associates, 2013). Interpreted drawdown responses were observed in several Garnet Valley monitoring wells. The geologic environment and continuity along with the water level monitoring observations support Garnet Valley being included within the LWRFS groundwater management area.

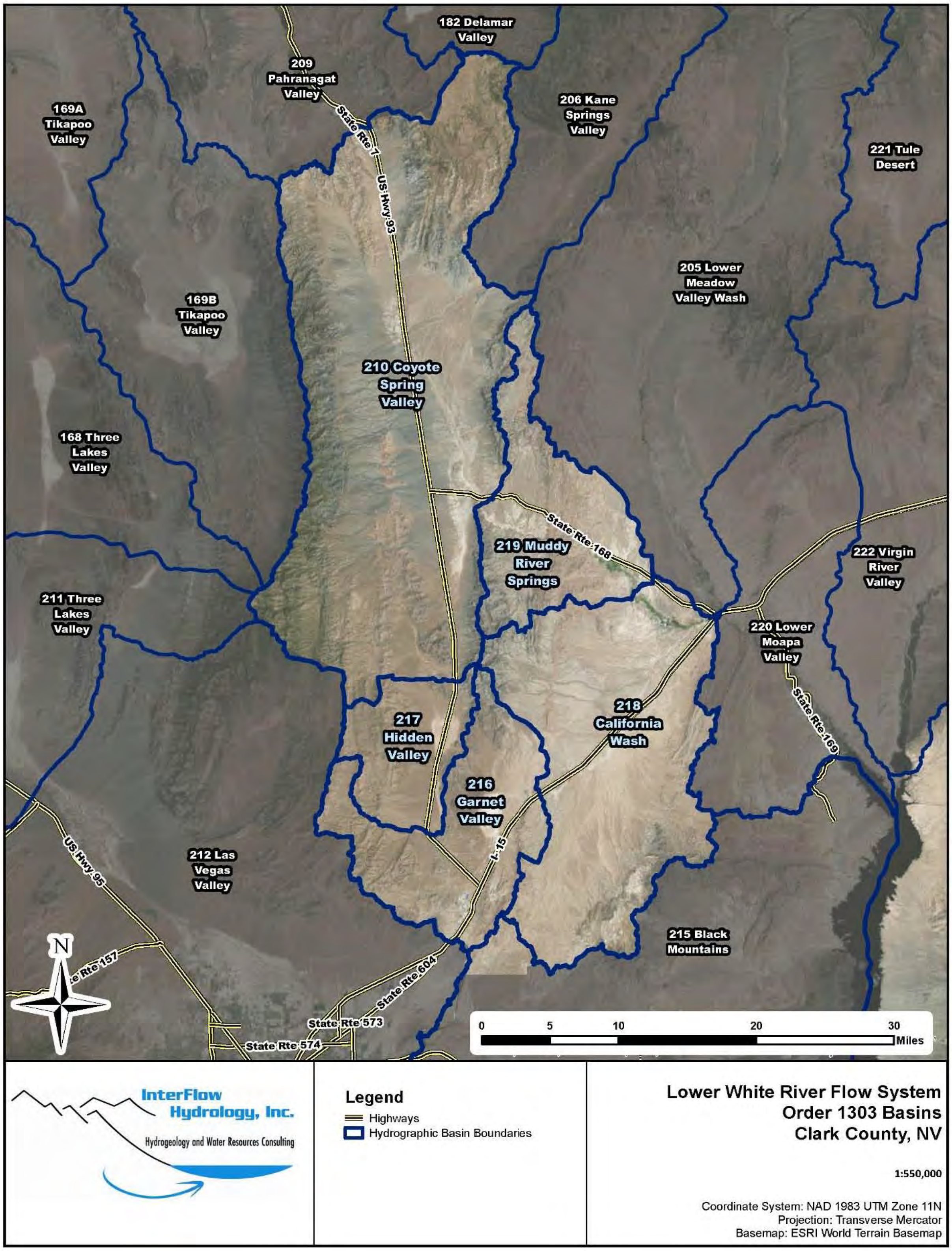


Figure 3 – LRWFS Basins Map

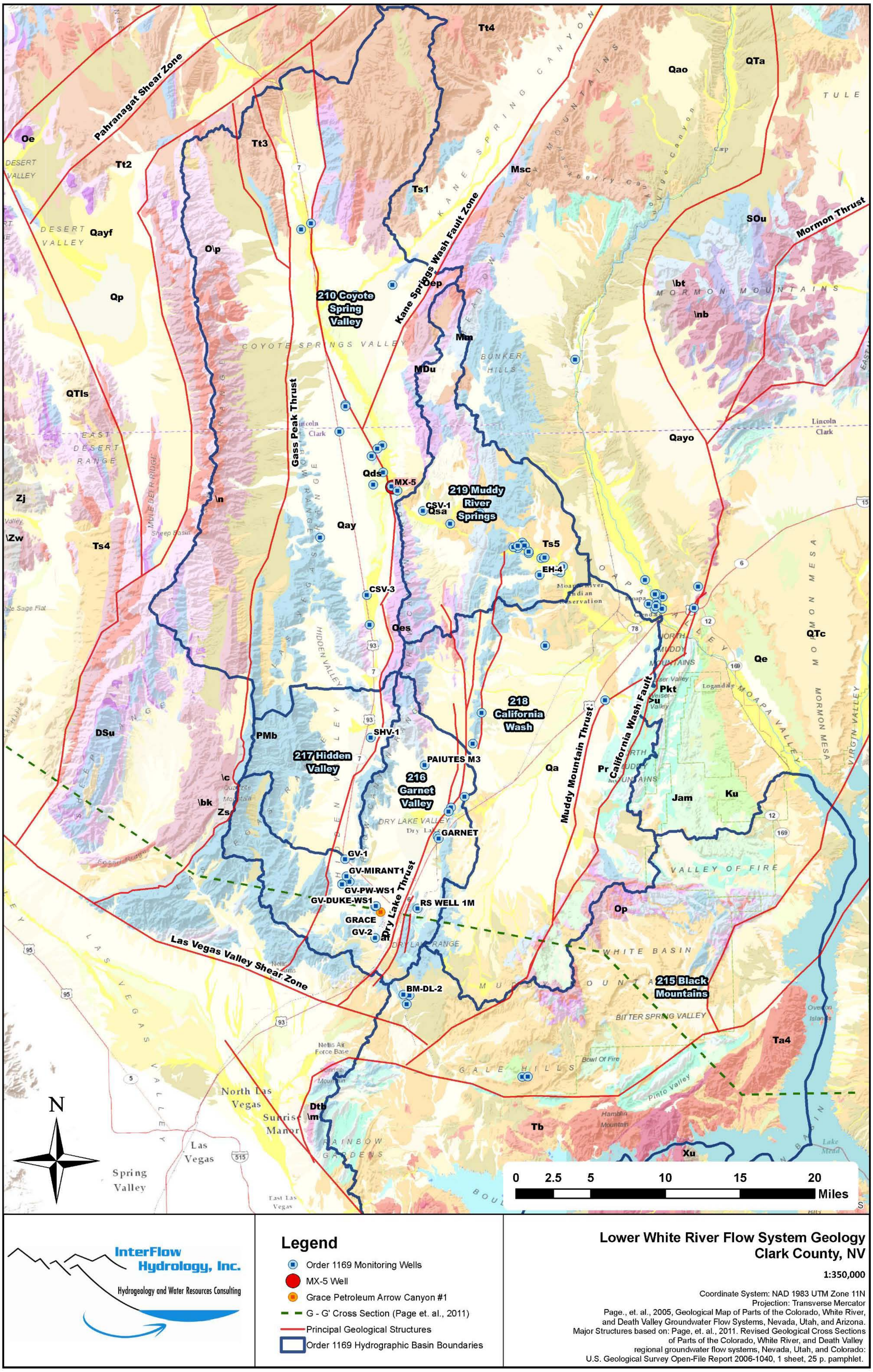
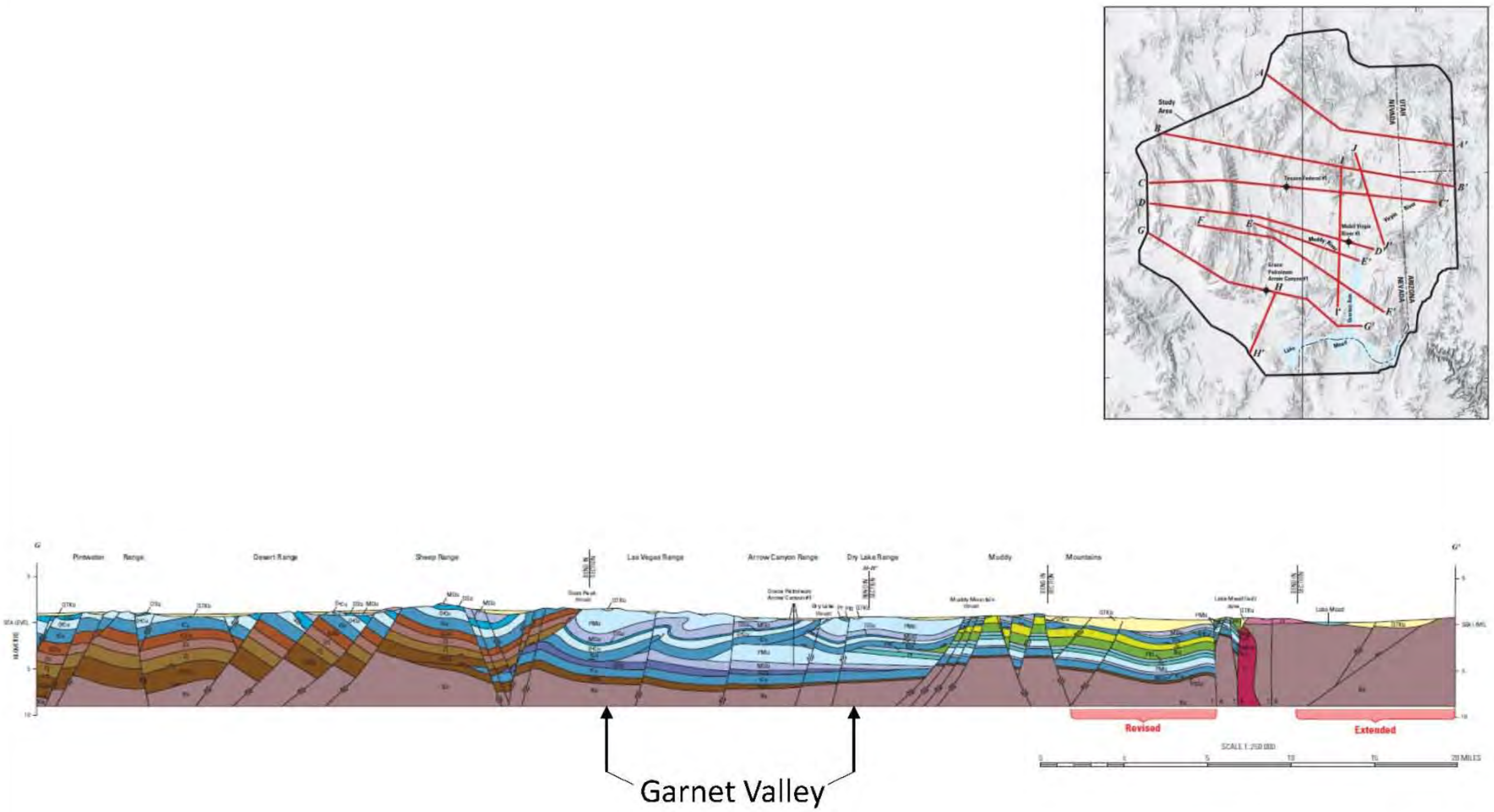


Figure 4 – Regional Geology of the LWRFS Basins (Page, et al, 2005)



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Geological Cross Section G-G' through the Garnet Valley and Surroundings Geological Formations

Page, et. al., 2011. Revised Geological Cross Sections of Parts of the Colorado, White River, and Death Valley regional groundwater flow systems, Nevada, Utah, and Colorado: U.S. Geological Survey Open-File Report 2006-1040, 1 sheet, 25 p. pamphlet.

Figure 5 – Geologic Cross-Section (E-W) through Garnet Valley (Page, et al, 2001)

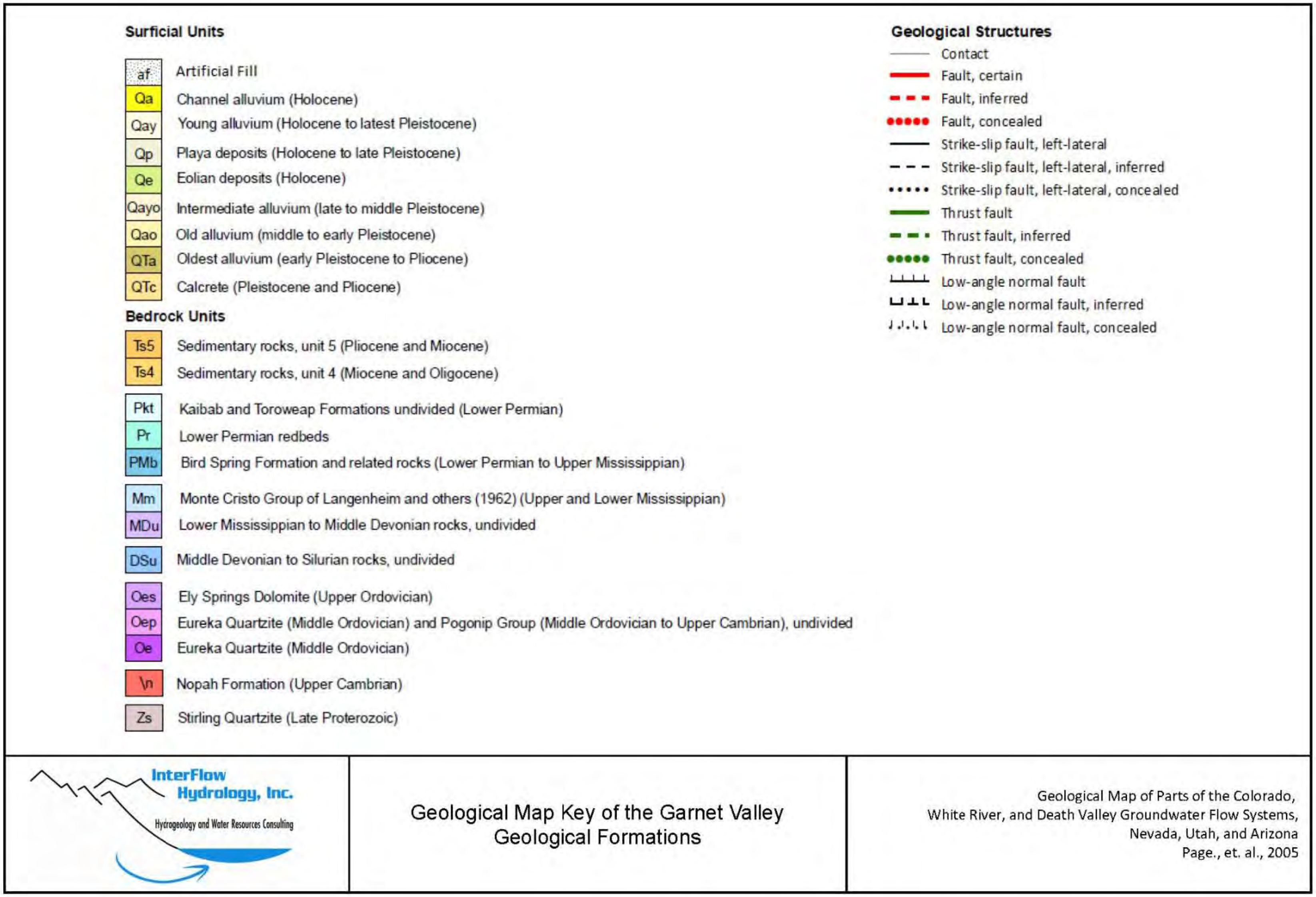

Figure 6 – Geologic Map Explanation

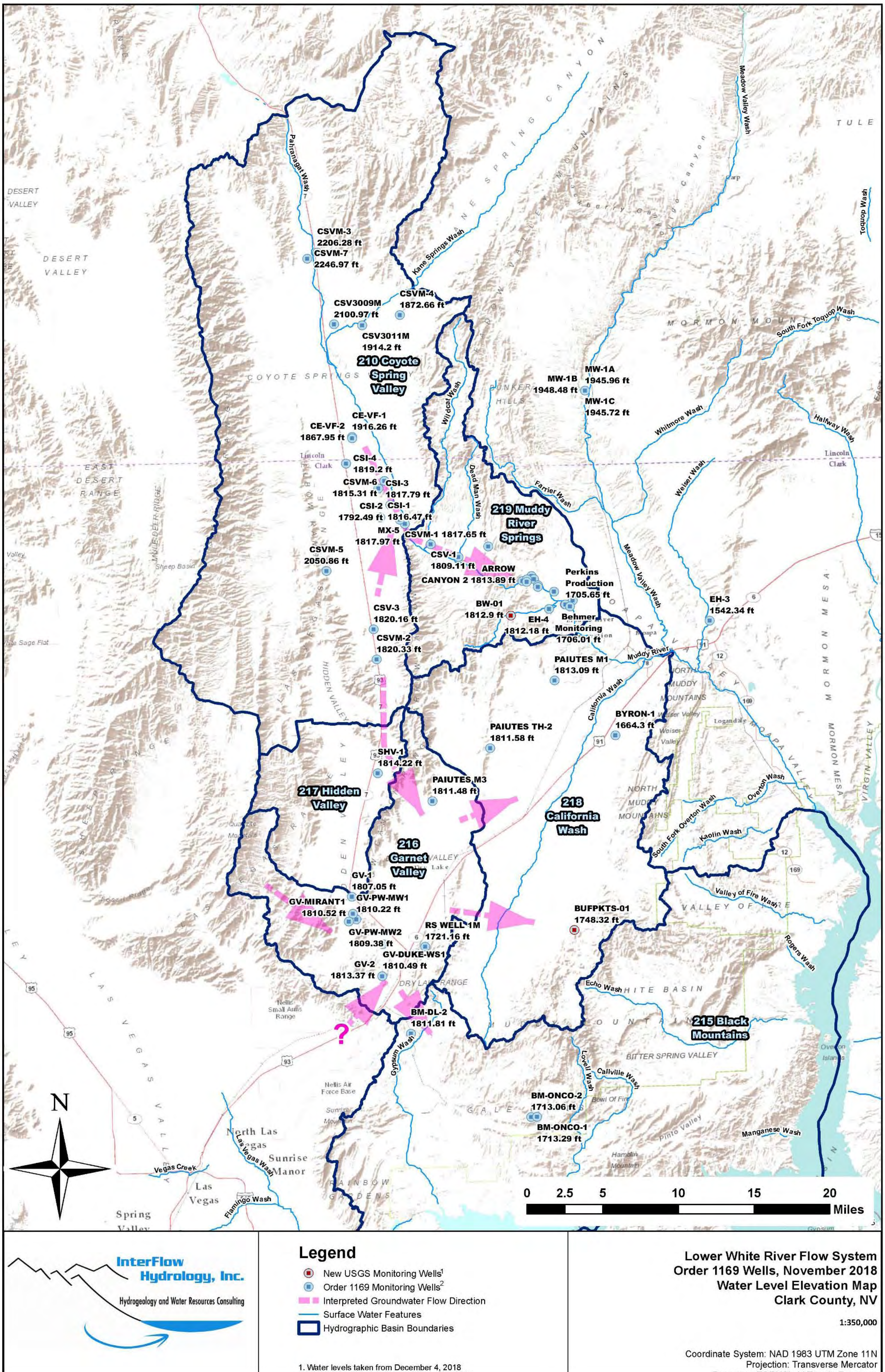

Figure 7 – Groundwater Potentiometric Levels and Potential Regional Flow Directions

Garnet Valley Hydrogeology

Geologic Setting

Groundwater in Garnet Valley primarily occurs in the Paleozoic age sedimentary rocks, which are comprised of significant amounts of carbonate rocks. Groundwater also occurs in some locations in Garnet Valley in the alluvium that overlies the Paleozoic sedimentary rocks, but much of the alluvium is unsaturated. The thickness of alluvium and depths to the top of the carbonate rock (limestone) in Garnet Valley range from zero (bedrock at surface) to approximately 1600 ft, based on available Well Driller's Reports, also called well logs, on file with NDWR (Figure 8). Alluvial sediments that overlie the carbonate rocks are interbedded deposits of gravel, sands, cemented sediments, fresh-water limestones, and silts and clays. Saturated alluvium is tapped by a few wells in Garnet Valley, including an NDOT well along I-15 and wells used by US Lime (drilled in the 1960-70s). The majority of wells in Garnet Valley tap the upper Paleozoic sedimentary rocks for water supply.

The Permian-Mississippian Bird Spring Formation (PMb) comprises the bedrock outcropping over much of APEX and the mountains bounding the west side of Garnet Valley, including the Arrow Canyon Range and Las Vegas Range (Figure 8). The Bird Spring Formation also comprises portions of the Dry Lake Range bounding the southeastern side of Garnet Valley. This formation consists of limestones, dolostone, siltstones, sandstones and shales (Page et al, 2005), with a considerable portion being carbonate rocks. On the eastern side of APEX and the far northern part of Garnet Valley, older Mississippian-Devonian rocks outcrop (MDu unit, Figure 8), which are carbonate rocks, with non-carbonate (clastic) rocks, such as shale and quartzite.

The Dry Lake Thrust Fault daylights in a N-S direction along the east side of Garnet Valley (Figure 8). This thrust fault may be a hydraulic barrier to easterly groundwater outflow from Garnet Valley to California Wash, and may also define an eastern boundary to the LRWRS. The Las Vegas Shear Zone may form a southern boundary to the LWRFS. In this case, the shear zone incorporates a small portion of the Black Mountains Area within the LWRFS.

Wells and Groundwater Pumping

There are approximately 50 well logs on file with NDWR for Garnet Valley as summarized in Table 1, with locations shown in Figure 9. Seventeen logs are for abandonment of a well. Wells in Garnet Valley are primarily used for industrial and commercial water supply, and nine wells are for monitoring wells. Well depths range between 423 to 2480 ft (excluding one well drilled to 50 ft which did not encounter groundwater). The average well depth is 988 ft and the median is 736 ft. Well yields are reported for 20 well logs, ranging from 28 to 1500 gpm, with an average of 350 gpm, and a median rate of 135 gpm.

Groundwater being pumped by wells in APEX is primarily from the upper-most 1,000 feet of saturated thickness in the carbonate aquifer. NDWR pumping inventories have been conducted in Garnet Valley since 2001. Annual water use from 2001 to 2005 was approximately 850 AF/yr (Figure 10). In 2006, water use increased due to new power generating facilities and remained relatively constant at an annual volume of approximately 1470 AF/yr through 2015. In 2016 and 2017, groundwater pumping increased to 2081 AF/yr and 1981 AF/yr, respectively, as a result of highway and Faraday Future construction actives. As of the date of this report, the pumping inventory report for 2018 had not yet been published by NDWR for Garnet Valley, but annual pumping is anticipated to be similar to 2006-2015 volumes.

In forthcoming evaluations in this report, year 2015 pumping and associated water levels were chosen to represent current conditions, rather than 2016 or 2017, which experienced temporary increases in pumping, and 2018 which followed that increase. In the representative year 2015, 16 wells pumped a total of 1520 acre-feet, as summarized in Table 2. Of the 1520 AF pumped in Garnet Valley in 2015, 1277.43 AF were from wells reporting as part of the Order 1169 monitoring network. Mining and industrial usage was 710.03 AF, and municipal and commercial uses made up 810.06 AF. No irrigation or domestic use was reported for the 2015 pumpage inventory in Garnet Valley. The majority of the pumped wells are located in the south-central part of Garnet Valley, with the exception of RW-1 which is approximately 5 miles to the northeast. The pumping distribution for 2015 is shown in Figure 11.

Potentiometric Water Levels and Gradients

Wells which were monitored for water levels during 2015 are summarized in Table 2. Water level data were collected from the Order 1169 monitoring network. The average water level elevations were differentiated between static or pumping times, as determined by review of the period of recorded water level hydrographs. There are fifteen wells with water level elevation data for 2015, seven of which contain both pumping and non-pumping water level data, or are next to a pumping well and likely affected by pumping.

The potentiometric water levels in Garnet Valley are shown in Figure 12. Directions of flow are complicated to interpret due to pumping that occurs in the basin. In general, water level elevations are relatively flat through Garnet Valley, except during times of pumping. The water elevations during non-pumping times range from 1797.16 (Rep well #7) to 1814.35 (GV-2) ft above mean sea level (amsl). Rep Well #7 is near to Rep Well #1 which appeared to be pumping during the monitoring periods, and static water levels at Rep Well #7 are probably influenced by pumping. Much of the basin exhibits a static water level around 1811 ft amsl, plus or minus ~3 feet. An anomalously high water level reported at GV-PW-WS-1(~1840 ft) was removed from the dataset as it is suspected to be in error. The well is in poor condition and confident water level measurements cannot be made (personal communications, Andrew Burns, SNWA,2019).

The water level data in the southern-most part of the basin suggests a gradient from the Las Vegas Valley boundary northeasterly toward south-central Garnet Valley (from GV-2 toward central and northern APEX wells). The water level in GV-1 (1808.1 ft amsl) is lower than most static water levels in central-northern APEX, which seems counter to the hypothesis of groundwater inflow from southern Hidden Valley. An apparent potentiometric gradient exists between Hidden Valley and northern Garnet Valley, supporting possible groundwater flow through the Arrow Canyon Range.

Hydrographs for the period of recorded water level measurements in several wells in Garnet Valley are shown in Figures 13 and 14. A long-term declining water level trend is observed from 2007 to 2018. This trend is similarly observed in monitoring wells throughout the LWRFS. The long-term declining trend appears to be potentially associated with changes in long-term climate, due to the consistency of the trend over the LWRFS and over periods of varying magnitudes of regional pumping.

Seasonal variations in water levels may be due to annual pumping cycles, with increases in summer water use causing short-term declines. The stronger than normal seasonal decline in water levels in 2011-2012, followed by rebounding water levels in 2013-2014 (Figure 14) are interpreted to be the influence of increased pumping under Order 1169 in Coyote Spring Valley. This pumping influence, while subtle in magnitude, was observed in many other wells in the LWRFS, and clearly observed in spring discharge at Pederson Spring in the Muddy River Springs complex (see graph in Interim Order 1303).

Carbonate Aquifer Transmissivity

Aquifer transmissivity (T) is the rate of flow through a unit width of the aquifer under a unit hydraulic gradient (Todd, 1980). The transmissivity of the upper-most carbonate aquifer is estimated using reported pumping and drawdown data (specific capacity) in Well Driller's Reports available from the NDWR (2019) database. The specific capacity (SC) is the production rate of a well per unit drawdown. Two equations for approximating transmissivity were used, as published by Mace (1997) and Driscoll (1986). The approximation equations are presented below.

Mace (1997) for fractured karstic carbonate aquifers in the range of 1-1x10^5 m^2/day:

$$\text{Transmissivity}_{Mace}\, {ft^2}\!/_{day} = 0.76 \times (\text{Specific Capacity } (m^2/\text{day}))^{1.08} \times\ 10.7639\ (\frac{ft^2}{m^2})$$

Driscoll (1986) equation:

$$\text{Transmissivity}_{Driscoll}\, {ft^2}\!/_{day} = \text{Specific capacity } \left({gpm}/_{ft}\right) \times\ 2000\ \times 0.160544 (\frac{ft^3}{gal} \times \frac{min}{day})$$

Results from the two calculations were averaged to get an estimated transmissivity at each well location in Garnet Valley, as summarized in Table 3 and presented in Figure 15.

The average T for fifteen wells is 5275 ft^2/day, based on an average SC of 17.25 gpm/ft. The median is lower at 1334 ft^2/day based on a median SC of 2.53 gpm/ft, and the geometric mean is similar to the median at 1366 ft^2/day. The average estimated T is significantly increased by one notably high value (50,300 ft^2/day) in southern Garnet Valley at the Georgia Pacific Corporation facility (Figure 15). Well log #34528 reports a production rate of 140 gpm, with only 10 inches of drawdown at this well, resulting in a SC value of 168 gpm/ft. The accuracy of this information is uncertain.

The average saturated thickness for the fifteen wells with specific capacity data is 858 ft, with a median of 808 ft. The computed hydraulic conductivity (K) for the aquifer is the transmissivity divided by the aquifer thickness, and averages 8.7 ft/day, with a median of 1.1 ft/day and geometric mean of 2.0 ft/day.

Three wells with specific capacity data are completed in saturated alluvium rather than the carbonate aquifer. The average T for these three wells is 710 ft^2/day. The average T for the twelve wells completed in the carbonate aquifer is 6416 ft^2/day, with a median of 1520 ft^2/day and geometric mean of 1797 ft^2/day. K values for the carbonate aquifer average 10.0 ft/day, with a median of 1.1 ft/day and a geometric mean of 2.0 ft/day.

<u>Groundwater Budget</u>

Rush (1968) published a water budget for Garnet Valley, and several other basins in the region, including Hidden Valley, California Wash and the Black Mountains Area. Recharge from precipitation falling on the Garnet Valley hydrographic basin, in the higher altitude Las Vegas Range, is estimated at 400 AF/yr. California Wash and the Black Mountains Area are both estimated to receive <100 AF/yr of recharge by precipitation, and Hidden Valley is estimated to receive 400 AF/yr. Reconnaissance estimates of recharge to Coyote Spring Valley (includes Kane Spring Valley) and the Muddy Springs Area is 2,600 AF/yr (Eakin, 1964). Recharge by direct precipitation to the LWRFS is estimated at 3,400 AF/yr summing the reconnaissance estimates.

Groundwater discharge from Garnet Valley was interpreted by Rush (1968) to occur as subsurface outflow to California Wash. No playa or phreatophyte discharge of groundwater occurs, due the depth of groundwater below land surface. The perennial yield presently acknowledged by NDWR in Garnet Valley is 400 AF/yr.

In Coyote Spring Valley, NDWR presently lists the perennial yield as 1,900 to 18,000 AF/yr; Muddy River Springs Area at 100 to 36,000 AF/yr; Hidden Valley at 200 AF/yr, and California Wash at 2200 AF/yr. The perennial yield values consider regional groundwater flow into and between basins. However, under State Engineer Interim Order 1303, the basins of the LWRFS will be managed as one hydrographic area. The combined recharge and subsurface inflow to the LWRFS basins is stated to be not greater than 50,000 AF/yr and pre-development discharge of groundwater to the Muddy River Springs is estimated at 36,000 AF/yr. By difference, the maximum that could be sustained from the LWRFS is 14,000 AF/yr, but more realistically, is perhaps around 10,000 AF/yr. Pumping of groundwater will also need to occur in a manner that does not diminish existing decreed water rights of the Muddy River and Muddy River Springs, or jeopardize habitat in the springs that support the endangered species Moapa Dace. To date, there have been approximately 39,700

AF/yr of water rights issued in the LWRFS (NDWR, 2017). Pumping since 2015 in the LWRFS has ranged between 9,090 to 9,637 AF/yr (NDWR, 2019; Interim Order 1303).

Existing Water Rights in Garnet Valley

A summary of current water rights in Garnet Valley is presented in Table 4, and locations of points of diversion are shown in Figure 16. Currently there are 3715.55 AF/yr of permitted water rights in the basin (NDWR, 2019, adjusted for combined duties). Municipal rights total 2274.57 AF/yr, industrial totals 615.15 AF/yr, 350 AF/yr are in a construction manner of use, 283.81 AF/yr in mining and milling, 178.00 AF/yr in quasi-municipal, and 14.02 AF/yr are in a commercial manner of use.

Water rights in Garnet Valley are predominantly considered "junior" relative to other water rights that have been issued in the LWRFS. A potential perennial yield for the LWRFS may be approximately 10,000 AF/yr, derived from basin recharge and subsurface inflow that is not allocated to Muddy River and Muddy River Springs (NDWR, 2018). This would place a priority cutoff date at 1983, if regulation of groundwater rights under the prior appropriation statutes were to occur.

Potential "senior" water rights (pre-1983) in Garnet Valley include Chemical Lime rights for 233.81 AF/yr with 1967 and 1981 priority dates, Republic Environmental Technologies rights for 194 AF/yr with 1981 priority, Nevada Power Company rights for 74.57 AF/yr with a 1981 priority date, the City of North Las Vegas rights for 10.02 AF/yr with a 1981 priority date, and Western Mining & Minerals rights for 4 AF/yr with a 1981 priority date. These totals have been adjusted to account for total combined duties of permits (NDWR, 2017). Total "senior" priority water rights in Garnet Valley are estimated to be 516.4 AF/yr.

SNWA holds the greatest duty of water rights in Garnet Valley (Table 4). The total combined duty of multiple water right permits is 2274.57 AF/yr. These water rights have a priority date of 1989, and are junior for the LWRFS. There are approximately 28,500 AF/yr of water right issued in the LWRFS that have a more senior priority as compared to SNWA's 1989 priority rights in Garnet Valley (NDWR, 2017). Some of these water rights are SNWA rights in Coyote Spring Valley, with a priority date of 1985. The Coyote Spring Valley water rights are junior to approximately 13,400 AF/yr of more senior issued rights (NDWR, 2017).

Table 1 - Summary of Wells in Garnet Valley (NDWR database, 2019)

Well Log #	Name	UTM X (ft)	UTM Y (ft)	Date Drilled	Depth Drilled (ft)	Static Water (ft)	Well Type	Aquifer Type	Owner
4105		2270784	13240978	4/24/1958	550	272	Production	Carbonate	STEWART CONSTRUCTION
4106		2274147	13240446	6/12/1958	575	260	Abandoned	Carbonate	STEWART CONSTRUCTION
10682		2264548	13223542	9/13/1963	600	230	Production	Valley Fill	U S LIME
11655		2249744	13219883	6/17/1971	712	408	Abandoned	Carbonate	U S LIME
11891	OLD	2257020	13219570	7/22/1971	500	338	Production	Valley Fill	Chemical Lime Co.
27975		2251475	13200195	9/30/1986	1205	660	Abandoned	Carbonate	GEORGIA PACIFIC CORP
28575		2273169	13225655	1/24/1987	700	ND	Abandoned	Carbonate	FRU-CON CONSTRUCTION CORP
28576		2274477	13225684	3/30/1987	736	485	Abandoned	Valley Fill	GREAT STAR CEMENT CORP
33206	KAPEX	2243314	13218430	2/7/1990	1145	578	Production	Carbonate	LVVWD
34528		2251447	13201510	10/23/1992	1598	606	Abandoned	No Data	GEORGIA PACIFIC CORP
36318		2251447	13201513	8/19/1990	960	608	Production	No Data	GEORGIA PACIFIC CORP
37990		2251475	13200195	12/30/1991	1205	660	Abandoned	No Data	GEORGIA PACIFIC CORP
42438	WELL #2	2265986	13214836	9/3/1993	983	596	Production	Carbonate	Republic Env. Tech.
43500		2274147	13240446	6/23/1993	500	360	Abandoned	No Data	LAS VEGAS PAVING CORP
46755		2266752	13216308	3/23/1989	560	453	Production	Valley Fill	ENVIRONMENTAL TECHNOLOGIES
52733		2272743	13244764	8/25/1982	500	244	Production	Valley Fill	UNION PACIFIC RAILROAD
52867		2265478	13211019	6/7/1996	1500	645	Production	Carbonate	SILVER STATE DISPOSAL
58956	REPWELL#5	2267230	13220531	12/13/1996	720	405	Production	Carbonate	Republic Env. Tech.
60603		2254281	13218058	5/25/1982	687	460	Production	Valley Fill	GRACE PETROLEUM
60605	GARNET	2273768	13242713	9/10/1972	500	240	Abandoned	Valley Fill	SNWA
60607		2265275	13220220	1/6/1975	423	340	Abandoned	Carbonate	UNIVERSAL ATLAS CEMENT
60608		2265275	13220220	9/24/1976	625	332	Abandoned	Carbonate	UNIVERSAL ATLAS CEMENT
65222	WELL #6	2265586	13209678	5/26/1997	1150	650	Production	Carbonate	Republic Env. Tech.
66619	REPWELL#7	2270735	13213766	6/21/1997	940	610	Production	Carbonate	Republic Env. Tech.
68098		2258903	13216136	10/11/1997	725	377	Production	Valley Fill	WESTERN GYPSUM INC
72577	CRYSTAL 2	2277377	13252218	9/30/1998	497	256	Monitor	Carbonate	NPC (NV Energy)

Well Log #	Name	UTM X (ft)	UTM Y (ft)	Date Drilled	Depth Drilled (ft)	Static Water (ft)	Well Type	Aquifer Type	Owner
72578	CRYSTAL 1	2278175	13253635	9/30/1998	565	230	Monitor	Carbonate	NPC (NV Energy)
75351	NEW	2256387	13210482	6/1/1999	860	471	Production	Carbonate	Chemical Lime Co.
79487	GV-1	2240753	13235351	5/5/2000	1400	888	Monitor	Carbonate	SNWA
80086		2245415	13238806	6/20/2000	2480	882	Production	Carbonate	DRY LAKE WATER CO
82303		2284396	13256964	10/21/2000	680	500	Production	Carbonate	MARTY MIFFLIN & ASSOCIATES
82443	PAIUTES-M3	2268814	13268681	10/20/2000	670	580	Monitor	Carbonate	MBPI
83301		2274147	13240446	5/17/2001	903	No Data	Abandoned	Carbonate	NEVADA POWER COMPANY
83302		2274147	13240446	5/18/2001	903	No Data	Abandoned	Carbonate	NEVADA POWER COMPANY
83508	GV-RW1	2273381	13243559	7/3/2001	870	260	Production	Carbonate	NPC (NV Energy)
83771	GV-2	2251393	13207618	7/19/2001	1232	620	Monitor	Carbonate	SNWA
85526	GV-PW-MW2	2239667	13226640	12/14/2001	1500	716	Monitor	Carbonate	SNWA
85610	GV-DUKE-WS1	2251591	13218820	12/7/2001	685	426	Production	Carbonate	SNWA
85894	GV-MIRANT1	2241186	13229363	3/1/2002	2007	754.95	Production	Carbonate	SNWA
86905	GV-PW-WS1	2239674	13226548	7/25/2002	2020	684	Production	Carbonate	SNWA
86906	GV-PW-MW1	2242318	13227434	1/22/2002	1500	692	Monitor	Carbonate	SNWA
87079	GV-DUKE-WS2	2251305	13218795	5/23/2002	2020	431.69	Abandoned	Carbonate	SNWA/NPC (NVEnergy)
91028		2274147	13240446	7/7/2003	575	No data	Abandoned	Carbonate	NEVADA POWER CO
96487		2248883	13202770	4/5/2005	50	No Data	Monitor	Carbonate	G P GYPSUM CORP
99336		2260240	13214850	4/21/2006	650	408	Production	Carbonate	INDUSTRIAL PROPERTIES DEVELOPMENT
107394	REPWELL#1	2266367	13217956	12/31/2008	860	487	Monitor	Clastic Rock	Republic Env. Tech.
107395		2266612	13217302	1/13/2009	560	505	Abandoned	No Data	REPUBLIC DUMPCO
113362		2274477	13225684	2/9/2011	736	200	Abandoned	No Data	U S BUREAU OF LAND MANAGEMENT
125987	GV-LENZIE-3	2251301	13218803	10/15/2016	1960	433	Production	Carbonate	NV Energy
127359	PLAYA	2241892	13232025	10/27/2016	2000	793	Production	Carbonate	First Solar/Playa Solar LLC

Table 2 - Pumping and Water Level Measurements for Wells in Garnet Valley in Year 2015 (data compiled from NDWR, 2019)

Well Name	Pumped Amount in 2015 (AF/yr)	UTM X (ft)	UTM Y (ft)	Average 2015 Water Level Elevation (ft amsl)	Water Level Measurement Frequency	Remark	Average Water Level during Pumping (ft amsl)	Average Water Level during Non-Pumping (ft amsl)
REPWELL #1	20.17	2266371	13217983	1726.52	monthly	Avg of monthly 2015 recordings	1720.21	1730.13
GV-1		2240759	13235378	1808.10	daily	Avg of daily recordings for 2015		
GV-PW-MW2		2239673	13226669	1810.04	monthly	Avg of monthly 2015 recordings		
CRYSTAL 1		2278179	13253662	1811.38	yearly	1 recording - 3/19/2015		
GV-PW-MW1		2242323	13227460	1810.97	daily	Avg of daily recordings for 2015		
CRYSTAL 2		2277383	13252246	1811.68	yearly	1 recording - 3/19/2015		
PAIUTES-M3		2268818	13268706	1812.19	daily	Avg of daily recordings for 2015		
GV-2		2251399	13207644	1814.35	monthly	Avg of monthly 2015 recordings		
REPWELL #5	119.67	2267234	13220558			First recording 1/17/18		
GV-PW-WS1	153.82	2239678	13226577	1800.48	monthly	Avg of monthly (Jan, July, Oct, Nov, Dec), Feb, May, June ,Aug, Sept avg. 1738.65	1738.65	1800.48
GV-DUKE-WS1	71.2	2251596	13218847	1811.66	monthly	Avg of July - Dec 2015 monthly. WLs were 1657-1675 in April-May	1666.35	1811.66
GV-DUKE-WS2	205.44	2252394	13218651	1813.24	monthly	Avg of monthly (April, May, July, Aug, Nov, Dec) June, Sept, Oct were 1711.17-1731.81 ft	1718.82	1813.24
REPWELL #7	16.54	2270739	13213792	1797.16*	monthly	Avg of Monthly Jan-July 2015 recorded WL		
GV-MIRANT1	56.54	2241190	13229392	1810.41	monthly	Most common WL Elevation recorded	1755.04	1809.90
GV-RW1	346.84	2273385	13243588	1791.33	yearly	1 recording - 3/19/2015	1791.33	
KERR	17.72	2243202	13218909			No Data		
NEW	121.51	2256391	13210509			No Data		
OLD	72.63	2257024	13219597			No Data		
REPWELL #6	130.98	2265591	13209705			No Data		
REPWELL #2	36.67	2265991	13214863			No Data		
GARNET		2273774	13242739	1810.51	yearly	1 recording - 2/9/2015		
Georgia Pacific	117.24	2252464	13202457			No Data		
Western MM	3.42	2260206	13217461			No Data		
Dry Lake Water, LLC	29.67	2259367	13215503			No Data		

* Water level probably effected by nearby pumping from REP Well#1

Table 3 – Summary of Estimated T Computations for Garnet Valley using NDWR Well Log Data (2019)

Site ID	Name	UTM X (ft)	UTM Y (ft)	Well Log No.	Perfs From (ft)	Perfs To (ft)	Well Drilled Depth (ft)	Depth to Limestone (ft)	Static WL (ft)	Saturated Thickness (ft)	Drawdown (ft)	Pump Rate (gpm)	Pump Duration (hrs)	Specific Capacity (gpm/ft)	Mace T (ft^2/day)	Driscoll T (ft^2/day)	Average Estimated T (ft^2/day)	Estimated K (ft/day)
216 S18 E64 07BB	NDOT	690032	4030724	60605	350	500	500	N/A	240	260	140	60	24	0.43	73.8	137.6	105.7	0.41
216 S18 E63 15AACD1	GV-DUKE-WS1	686286	4029104	85610	537	685	685	460	426	259	194	225	24	1.16	216.3	372.4	294.3	1.14
216 S18 E63 04CBBA1	GV-PW-MW1	683460	4031730	86906	900	1500	1500	10	692	808	29	50	1	1.72	331.8	553.6	442.7	0.55
216 S17 E63 33CBCB1	PLAYA (FIRST SOLAR)	683330	4033129	127359	1218	1969	2000	870	793	1207	322	600	24	1.86	360.9	598.3	479.6	0.40
216 S18 E63 14AABD1	US LIME (1971)	687941	4029333	11891	350	500	500	N/A	338	162	38	96	8	2.53	501.3	811.2	656.3	4.05
216 S18 E64 18CA	SILVER STATE DISPOSAL	690519	4026727	52867	1040	1480	1500	0	645	855	325	50	8	0.15	1611.3	49.4	830.3	0.97
216 S18 E63 15AACC1	GV-DUKE-WS2	686199	4029097	87079	877	1944	2020	370	431.69	1588	204.3	1000	24	4.89	1024.1	1571.6	1297.9	0.82
216 S18 E63 15AA	GV-LENZIE-3	686198	4029099	125987	900	1900	1940	--	433	1507	199	1000	24	5.03	1053.6	1613.5	1333.6	0.88
216 S18 E64 07B	US LIME (1963)	690236	4030544	10682	250	490	600	N/A	230	260	450	110	0	0.24	2656.8	78.5	1367.6	5.26
216 S17 E63 21DC	DRY LAKE WATER CO	684404	4035196	80086	--	--	2480	260	882	1598	1000	300	336	0.30	3314.4	96.3	1705.4	1.07
216 S18 E63 05AADB1	GV-MIRANT1	683115	4032318	85894	1197	1979	2007	610	754.95	1252	138.6	1000	72	7.22	1557.2	2316.7	1936.9	1.55
216 S18 E63 05DBCD1	GV-PW-WS1	682654	4031460	86905	1240	1980	2020	1600	684	1336	29	235	20	8.10	1765.2	2601.9	2183.6	1.63
216 S18 E63 16BB	KAPEX (KERR-MCGEE CHEM)	683763	4028986	33206	700	1145	1145	375	578	567	21	200	48	9.52	2101.6	3058.0	2579.8	4.55
216 S18 E63 34AC	GEORGIA PACIFIC CORP	686242	4023828	34528	0	0	1200	--	606	594	0.83	140	4	168.67	46844.1	54159.4	50501.8	85.02
216 S17 E64 21CBBD1	GV-RW1	692928	4036645	83508	553	833	870	495	260	610	32	1500	72	46.88	11750.5	15051.0	13400.8	21.97

Table 4 – Summary of Active Underground Water Rights in Garnet Valley (NDWR database, 2019, not adjusted for combined duty limits)

Application #	Change Of Application	Certificate #	Priority Date	Application Status	Source	Type of Use	Duty (AF/yr)	Owner of Record	Site Name
83553	18140		7/24/1959	PER	UG	IND	3	TECHNICHROME	216 S19 E63 03ADDD1
64880	26277	16864	7/24/1967	CER	UG	MM	150.38	CHEMICAL LIME COMPANY	216 S18 E63 23DCAA1
74399	60022	17531	7/20/1981	CER	UG	IND	74.57	NEVADA POWER COMPANY	216 S17 E64 21CBBD1
63261	55674	16751	10/20/1981	CER	UG	COM	100	CHEMICAL LIME COMPANY OF ARIZONA	216 S18 E63 14AABD1
63348	55674	15682	10/20/1981	CER	UG	COM	4	WESTERN MINING & MINERALS, INC.	216 S18 E63 13CAAA1
77745	55674	19642	10/20/1981	CER	UG	COM	10.02	NORTH LAS VEGAS-CITY	216 S18 E63 16BBDA1
83714	67718	21127	10/20/1981	CER	UG	IND	157	REPUBLIC ENVIRONMENTAL TECHNOLOGIES INC	216 S18 E64 19CDDD1
83715	67718		10/20/1981	PER	UG	IND	37	REPUBLIC ENVIRONMENTAL TECHNOLOGIES INC	216 S18 E64 19ABBB1
56855	50316	14449	10/28/1986	CER	UG	IND	144.15	GEORGIA PACIFIC CORPORATION	216 S18 E63 34ADAB1
66784	50663		3/6/1987	PER	UG	QM	178	DRY LAKE WATER, LLC	216 S18 E63 27ACAD1
83707	67711	21125	10/3/1988	CER	UG	IND	0.11	REPUBLIC ENVIRONMENTAL TECHNOLOGIES INC	216 S18 E64 18ACDB1
83708	67712		10/3/1988	PER	UG	IND	68.5	REPUBLIC ENVIRONMENTAL TECHNOLOGIES INC	216 S18 E64 18ACDB1
83709	67713		10/3/1988	PER	UG	IND	0.11	REPUBLIC ENVIRONMENTAL TECHNOLOGIES INC	216 S18 E64 07DDCB1
83710	67714	21126	10/3/1988	CER	UG	IND	0.11	REPUBLIC ENVIRONMENTAL TECHNOLOGIES INC	216 S18 E64 20BABA1
83711	67715		10/3/1988	PER	UG	IND	40.78	REPUBLIC ENVIRONMENTAL TECHNOLOGIES INC	216 S18 E64 19ABBB1
83712	67716		10/3/1988	PER	UG	IND	3.7	REPUBLIC ENVIRONMENTAL TECHNOLOGIES INC	216 S18 E64 19ABBB1
83713	67717		10/3/1988	PER	UG	IND	23.8	REPUBLIC ENVIRONMENTAL TECHNOLOGIES INC	216 S18 E64 19ABBB1
83716	67719		10/3/1988	PER	UG	IND	68.5	REPUBLIC ENVIRONMENTAL TECHNOLOGIES INC	216 S18 E64 18ACDB1
83717	67720	21128	10/3/1988	CER	UG	IND	68.39	REPUBLIC ENVIRONMENTAL TECHNOLOGIES INC	216 S18 E64 07DDCC1

Application #	Change Of Application	Certificate #	Priority Date	Application Status	Source	Type of Use	Duty (AF/yr)	Owner of Record	Site Name
54073			10/17/1989	PER	UG	MUN	2200	SOUTHERN NEVADA WATER AUTHORITY	216 S17 E63 32CCCB1
79001	68822		10/17/1989	PER	UG	MUN	350	SOUTHERN NEVADA WATER AUTHORITY	216 S18 E63 05AADB1
79002	72798		10/17/1989	PER	UG	MUN	349.8	SOUTHERN NEVADA WATER AUTHORITY	216 S18 E63 05DACC1
79003	73149		10/17/1989	PER	UG	MUN	233.33	SOUTHERN NEVADA WATER AUTHORITY	216 S17 E64 21CBBD1
79004	73150		10/17/1989	PER	UG	MUN	233.33	SOUTHERN NEVADA WATER AUTHORITY	216 S18 E63 15AACD1
79005	73151		10/17/1989	PER	UG	MUN	233.33	SOUTHERN NEVADA WATER AUTHORITY	216 S18 E63 15AACC1
83490	54073		10/17/1989	PER	UG	MUN	300	SOUTHERN NEVADA WATER AUTHORITY	216 S18 E63 16BBDA1
88011T	68822		10/17/1989	PER	UG	CON	350	SOUTHERN NEVADA WATER AUTHORITY	216 S17 E63 33CBCB1
66785			8/25/2000	PER	UG	QM	178	DRY LAKE WATER, LLC	216 S17 E63 32AABA1
72098	66785	19102	8/25/2000	CER	UG	QM	13.17	DRY LAKE WATER, LLC	216 S18 E63 13CDBC1
77389	66785		8/25/2000	PER	UG	QM	80	DRY LAKE WATER, LLC	216 S18 E63 33DBBA1
79948	66785		8/25/2000	PER	UG	QM	30	DRY LAKE WATER LLC	216 S18 E63 13CDBC1
81344	74064		8/25/2000	PER	UG	QM	8	DRY LAKE WATER LLC	216 S18 E63 13CDBC1
76862			3/27/2008	PER	EFF	STO	278.73	NEVADA COGENERATION ASSOCIATES #1	216 S18 E63 34ADAC1
79010			11/2/2009	PER	UG	MUN	233.33	SOUTHERN NEVADA WATER AUTHORITY	216 S18 E63 15AACC1

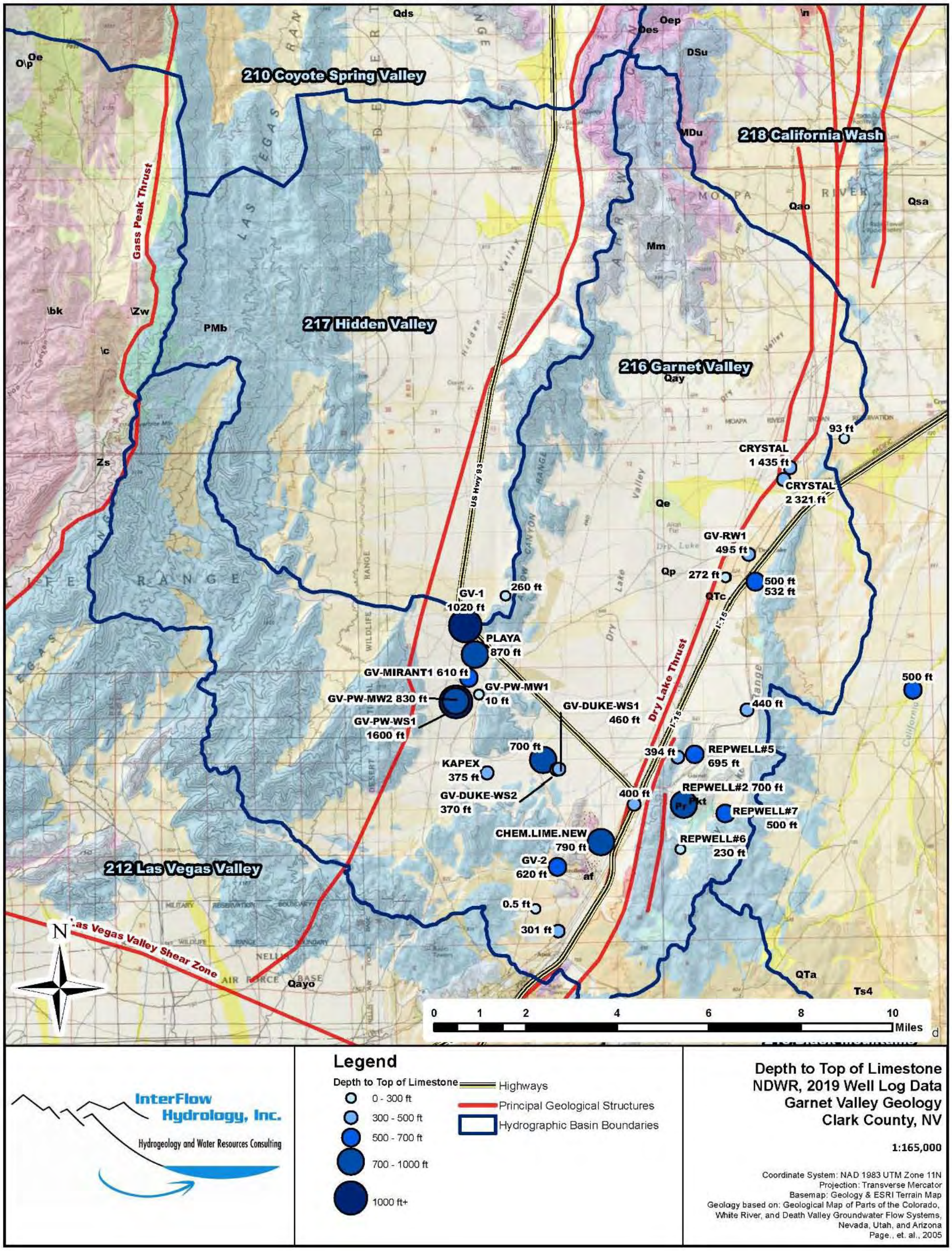

Figure 8 – Geologic Map of Garnet Valley with Interpreted Depth to Top of Carbonate Rock

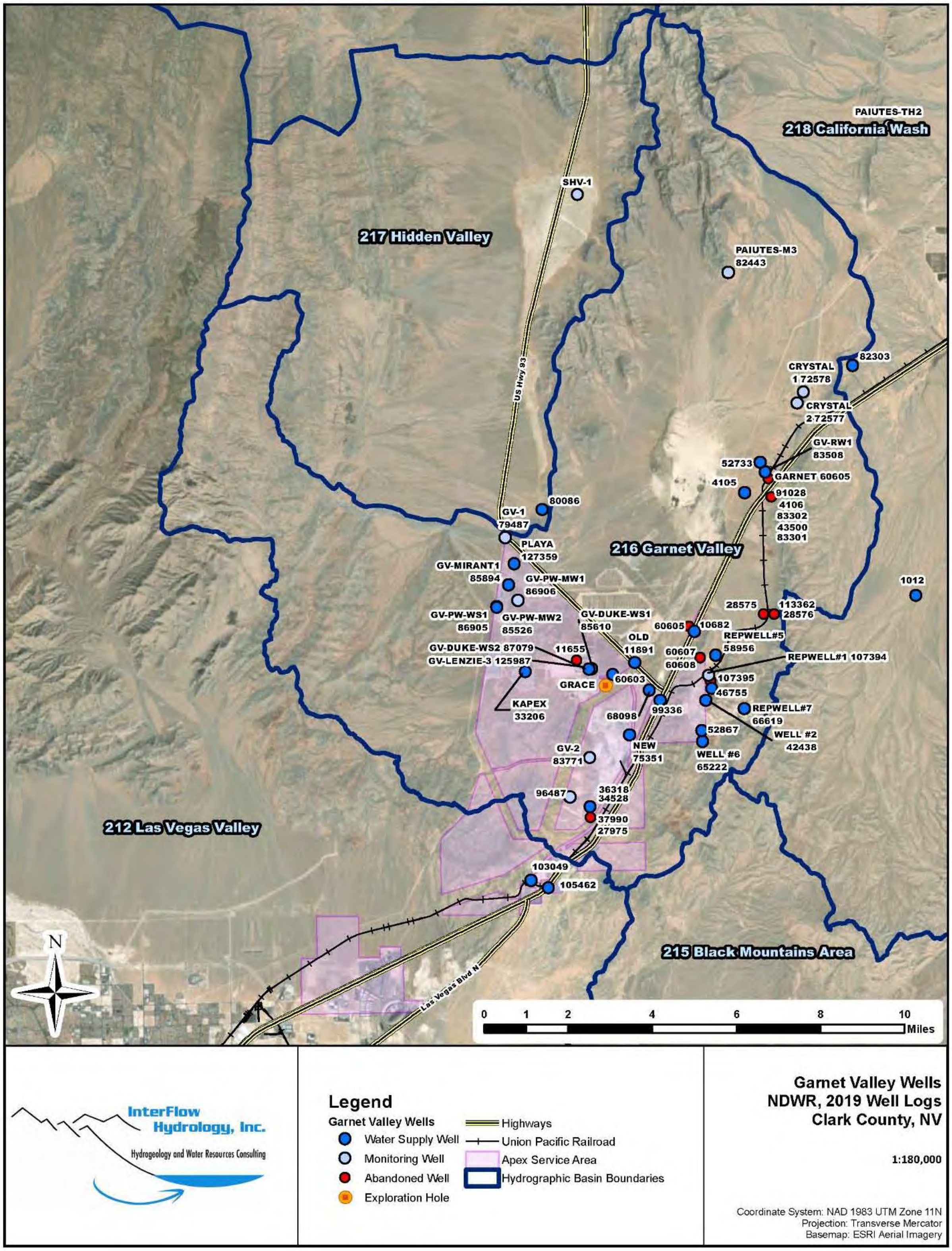

Figure 9 – Recorded Wells in Garnet Valley

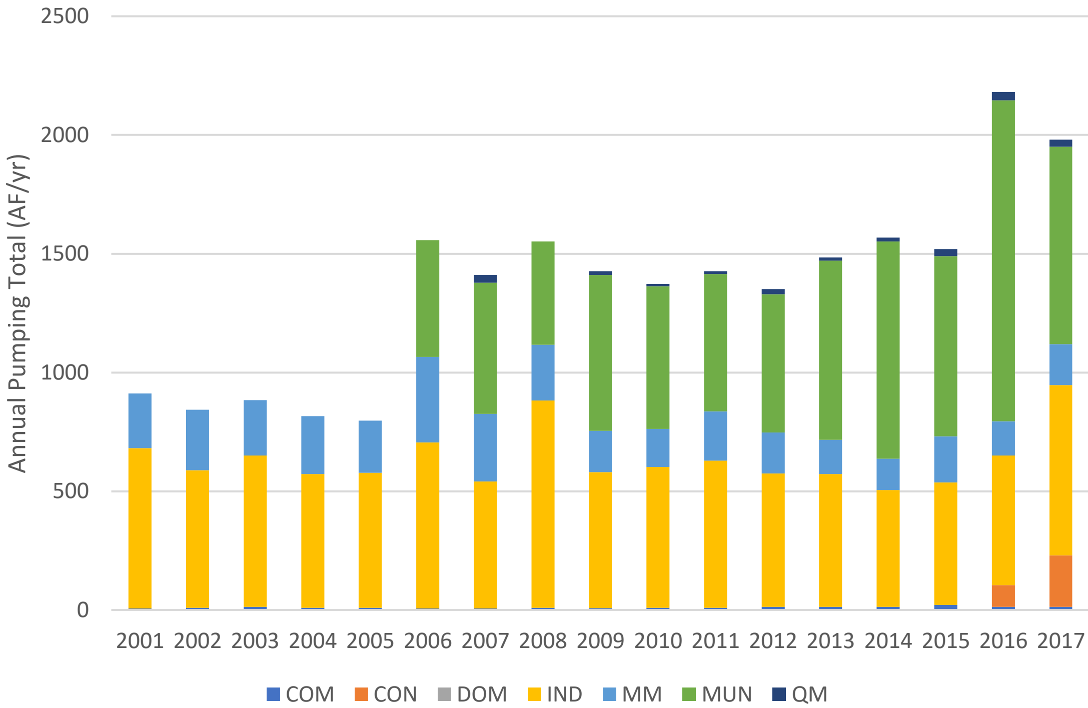

Figure 10 – Historical Pumping from Wells in Garnet Valley (data from NDWR Pumping Inventories)

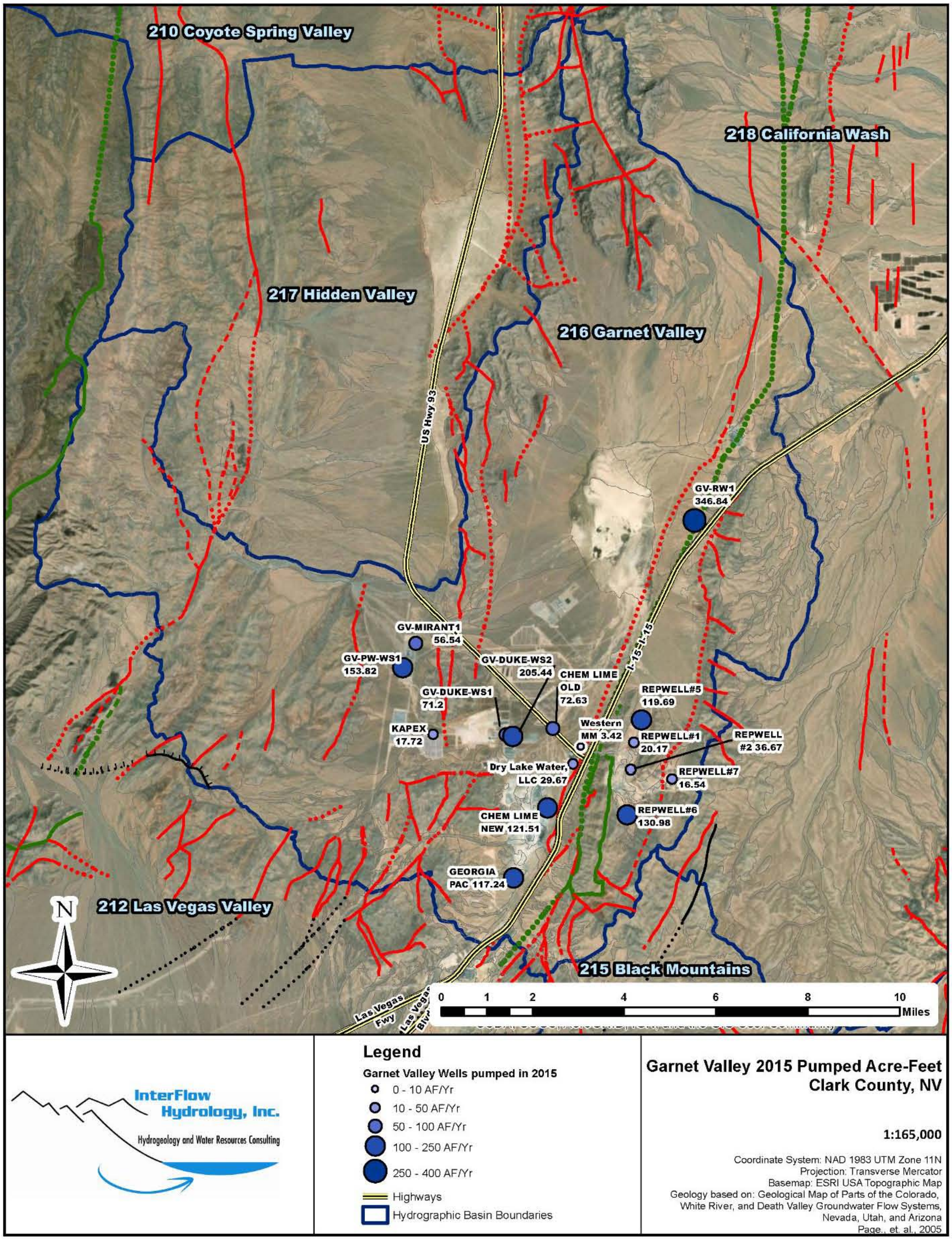

Figure 11 – Distribution of Pumping in Garnet Valley in Year 2015

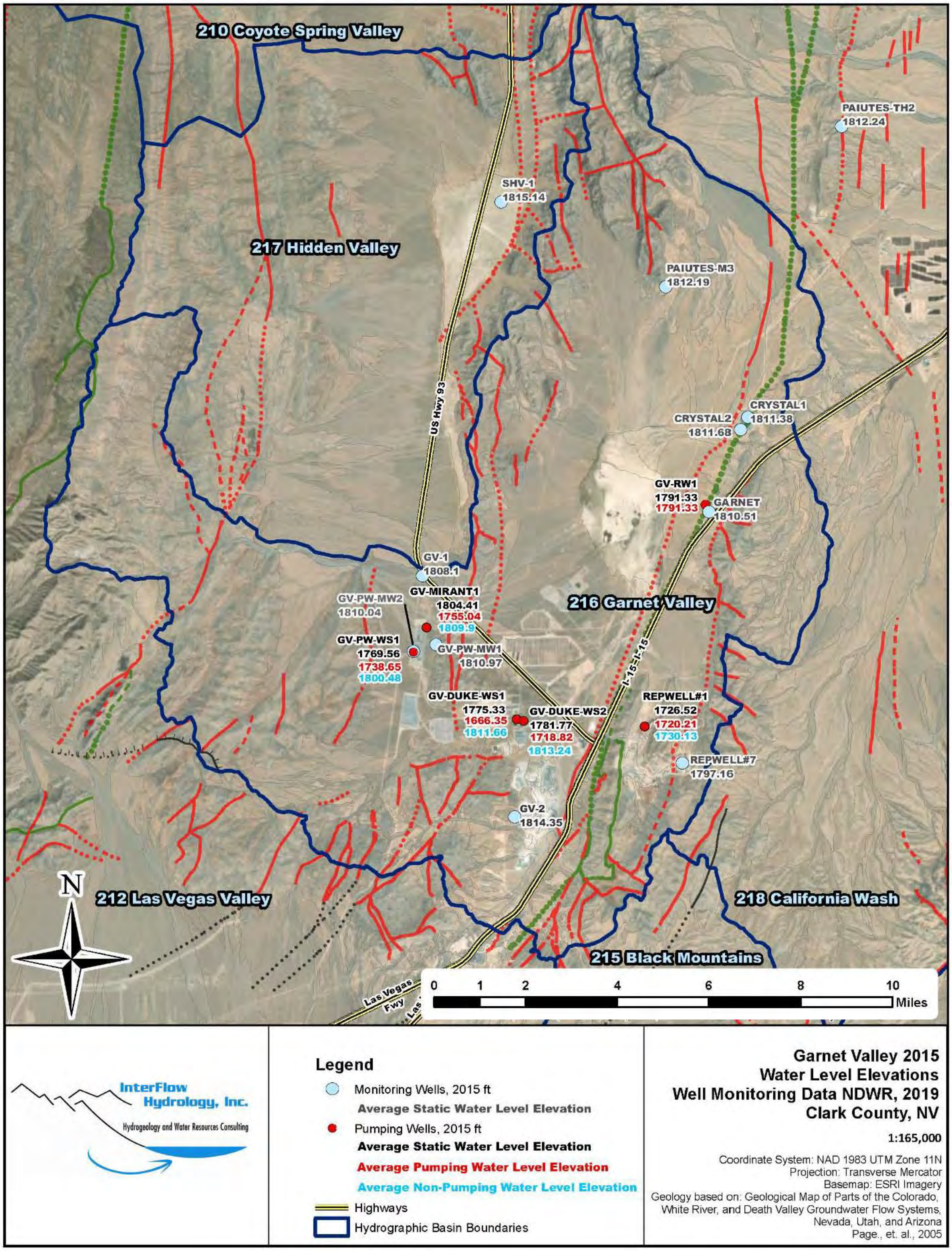

Figure 12 – Potentiometric Water Levels in Garnet Valley in Year 2015

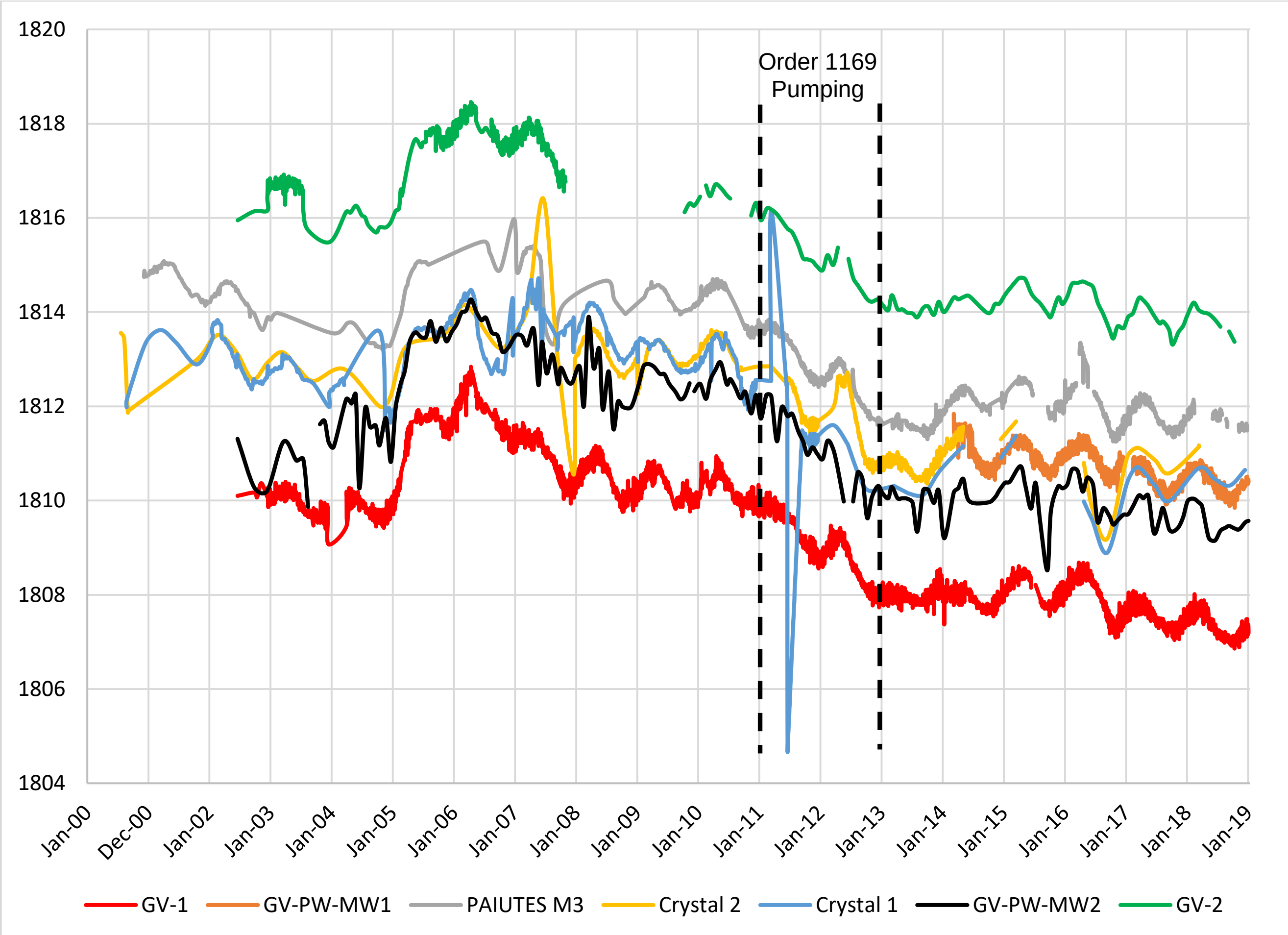

Figure 13 – Selected Hydrographs in Garnet Valley

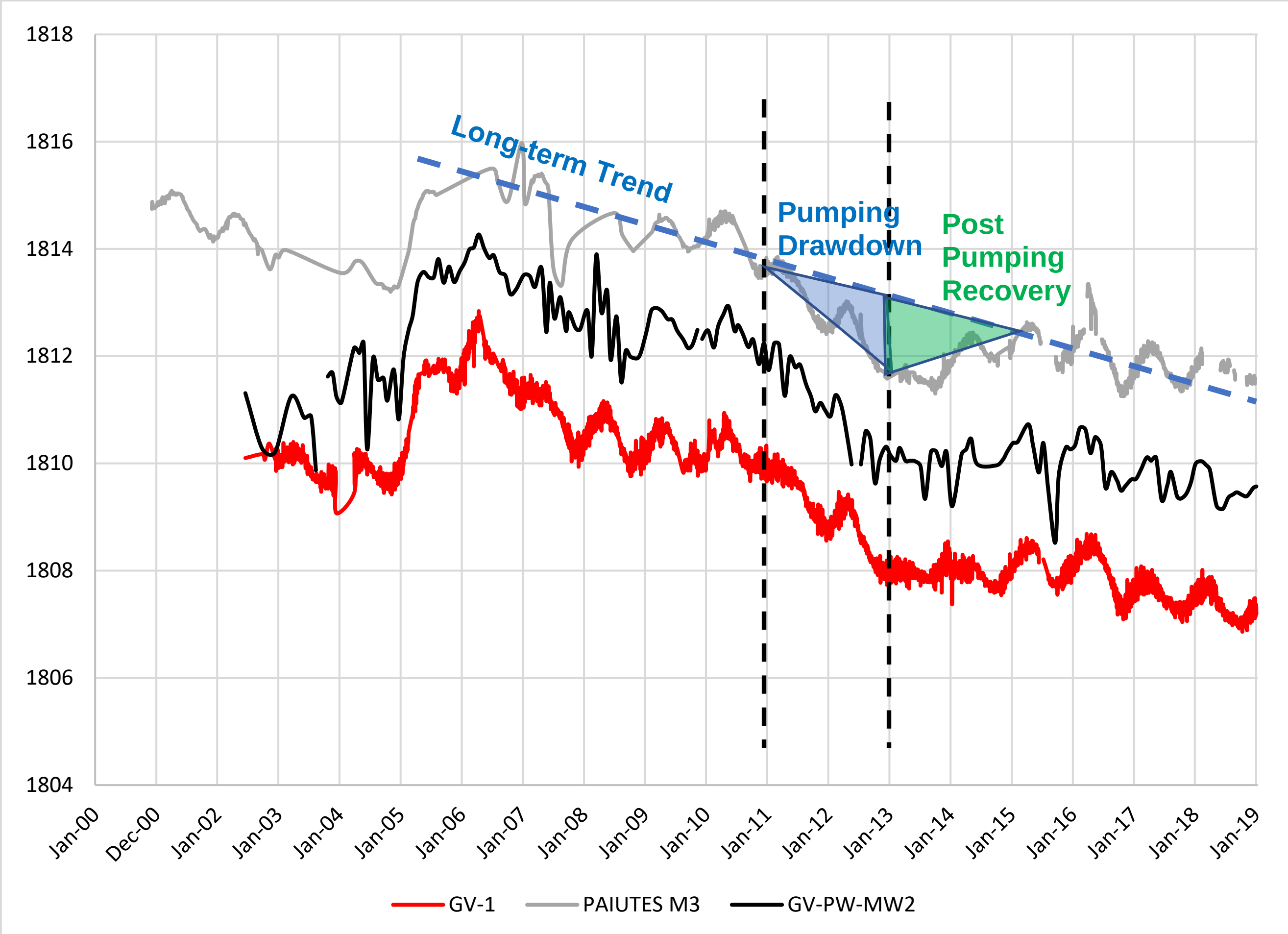

Figure 14 – Selected Hydrographs in Garnet Valley, Long-Term Trend, and Order 1169 Pumping Influence

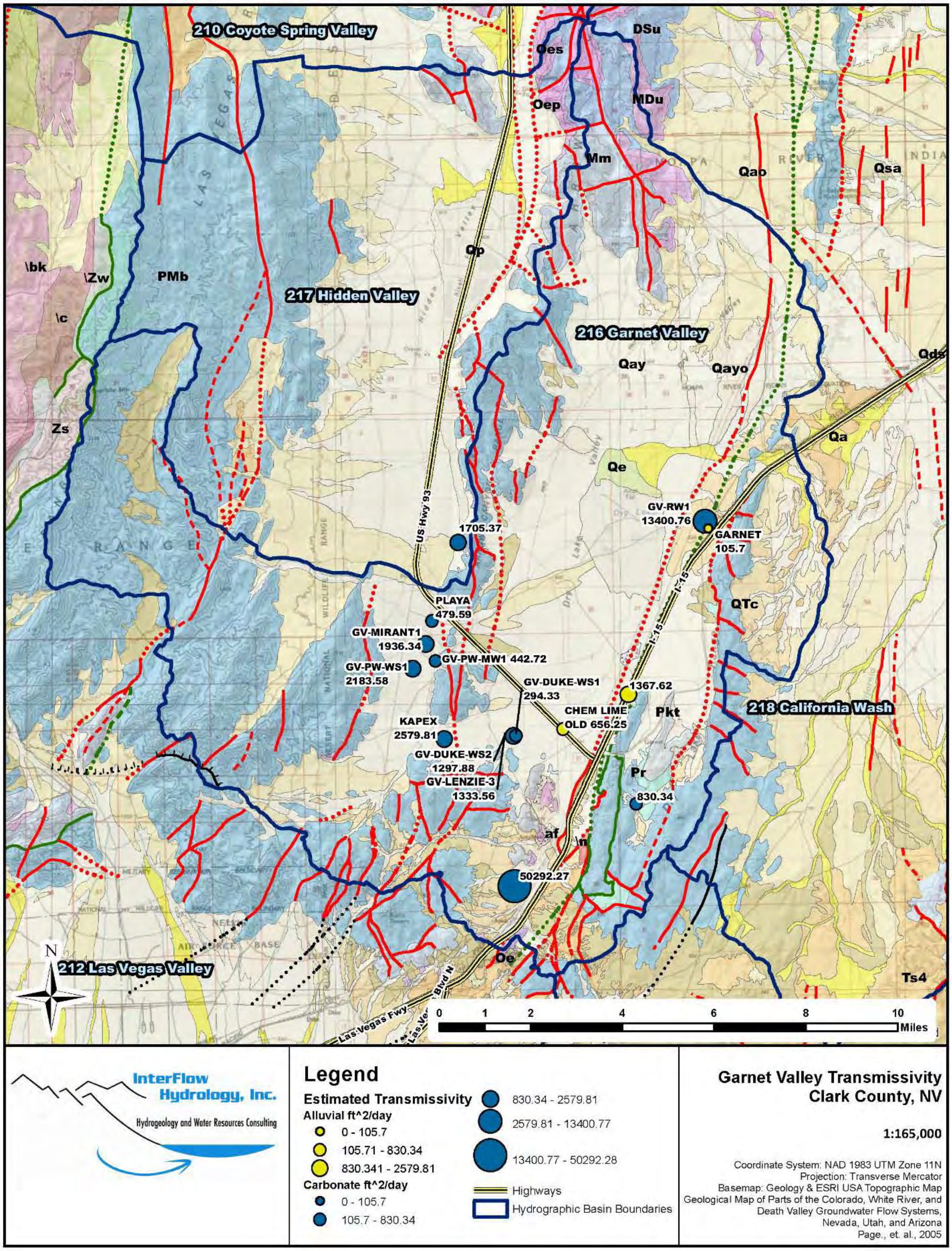

Figure 15 – Estimated Transmissivity of the Carbonate Aquifer in Garnet Valley

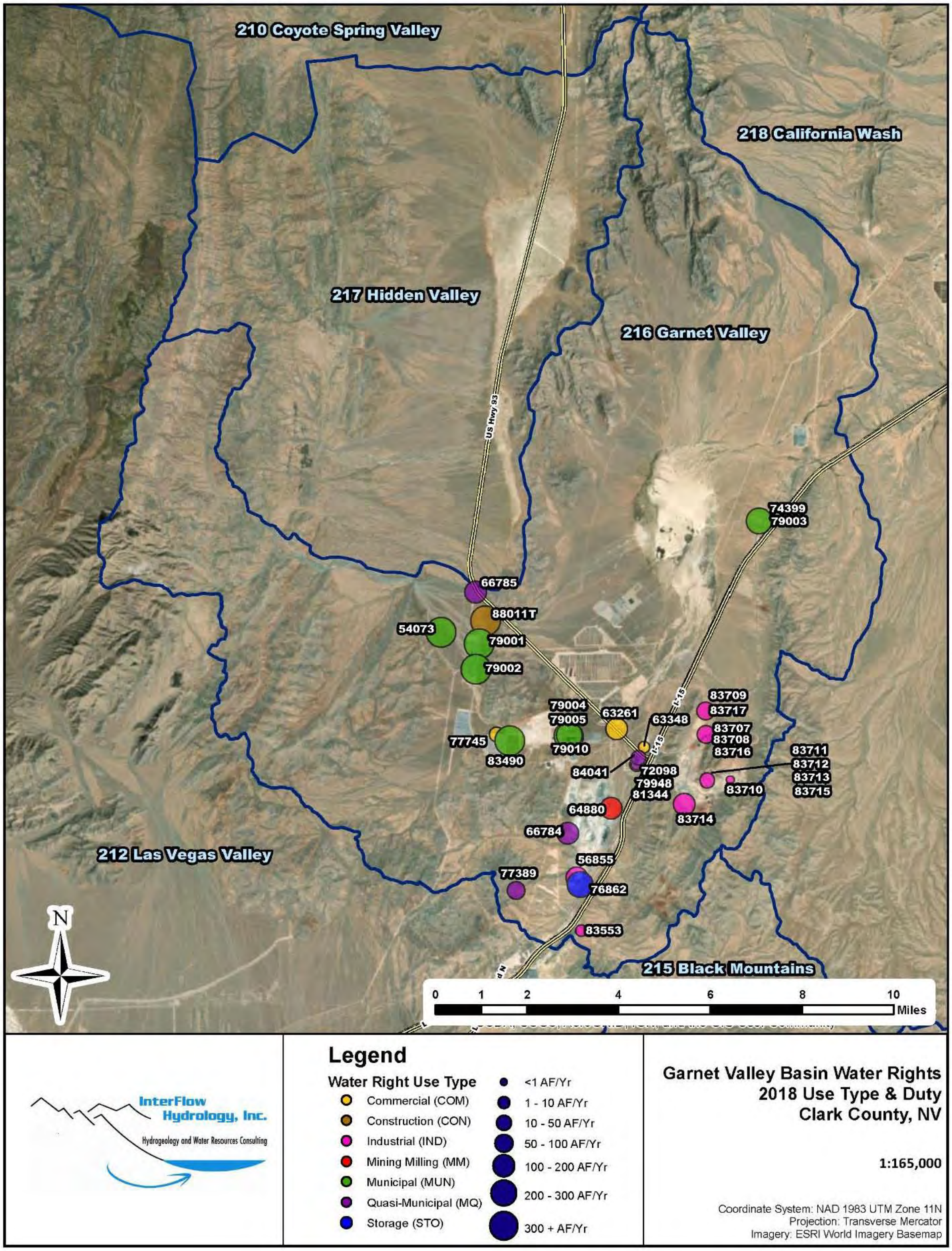

Figure 16 – Existing Water Rights Points of Diversion and Duties in Garnet Valley

Review of Garnet Valley Boundary Conditions

Las Vegas Valley Boundary

Groundwater flow between Garnet Valley and Las Vegas Valley is not clearly defined. The water level elevation in the southern-most monitoring well in Garnet Valley (GV-2) being the highest observed in the basin (1814 ft amsl) has prompted further examination of the boundary condition.

Dedicated water level monitoring wells are not known to exist at the northeastern-most edge of Las Vegas Valley. In order to gain a preliminary understanding of groundwater elevations and potential groundwater flow direction, well logs on file with NDWR were examined for the general area of Township 19 South, Ranges 62 and 63 East. Well logs selected for evaluation were chosen by their availability of accurate location information, with a preference given to deeper drilled wells, assuming that deeper wells may be more representative of carbonate aquifer water levels. Data analysis using the well logs static water levels needs to consider the date drilled, which spans over several decades from 1962 to 2016. Depth to water can vary seasonally and over the long-term due to climate, pumping, and artificial recharge taking place in Las Vegas Valley, so the date of the well completion and reported static water level reading was noted. Well log data that have been compiled are summarized in Table 5.

The well locations were determined in varyingly accurate ways. Some locations could only be determined to the nearest Quarter-Quarter Section, and are the least accurate. Some well logs contain locations coordinates and with review of map imagery, are assumed to be located more accurately. Some non-domestic wells could also be associated with a water right point of diversion, which provides an accurate location, provided the well was drilled at or near the defined point of diversion. Figure 17 shows the locations of well logs assembled, with color coding for the location plotting method.

Once the well locations were determined as accurately as possible using office methods, the land surface elevation at each well was determined from USGS lidar imagery, if available, or otherwise from ASTER satellite digital elevation model (DEM) at a 30 meter resolution. Groundwater elevations were then calculated based on the depth to water reported in the well log (Table 5).

The resulting map of water level elevations from driller logs (Figure 17) is not definitive. Inaccuracies in groundwater elevations, owing in part to the location and elevation derivation methods, are more likely due to the accuracy of reported static water levels in the well logs, along with the varying time span over which the measurements were made. In order to gain an overview of the compiled data, the average and median groundwater elevations were determined. The average groundwater elevation from the compiled dataset containing 22 groundwater elevation estimates in northeastern-most Las Vegas Valley is 1809.3 ft amsl, and the median is 1821.6 ft amsl. This contrasts with the water level measurements in southern Garnet Valley at GV-2 ranging from 1813.31 to 1818.46 ft amsl (Figure 18), measured between June 2002 to October 2018. The average water level elevation at GV-2 over this time span is 1817.2 ft amsl.

Based on the existing data in northeastern Las Vegas Valley, it is not possible to accurately determine the direction of groundwater flow. The Bird Spring Formation carbonate rocks separate the two basins and provide adequate permeability to facilitate meaningful groundwater flow. The median elevation in northeastern-most Las Vegas Valley is believed to be more reliable than the average, because a few outliers observed in the dataset may unduly bias the average statistic. If the median is representative of groundwater elevations, then the apparent groundwater flow direction is from Las Vegas Valley to Garnet Valley. Monitoring wells with accurate water level measurements and surveyed reference points are needed to confirm this preliminary interpretation.

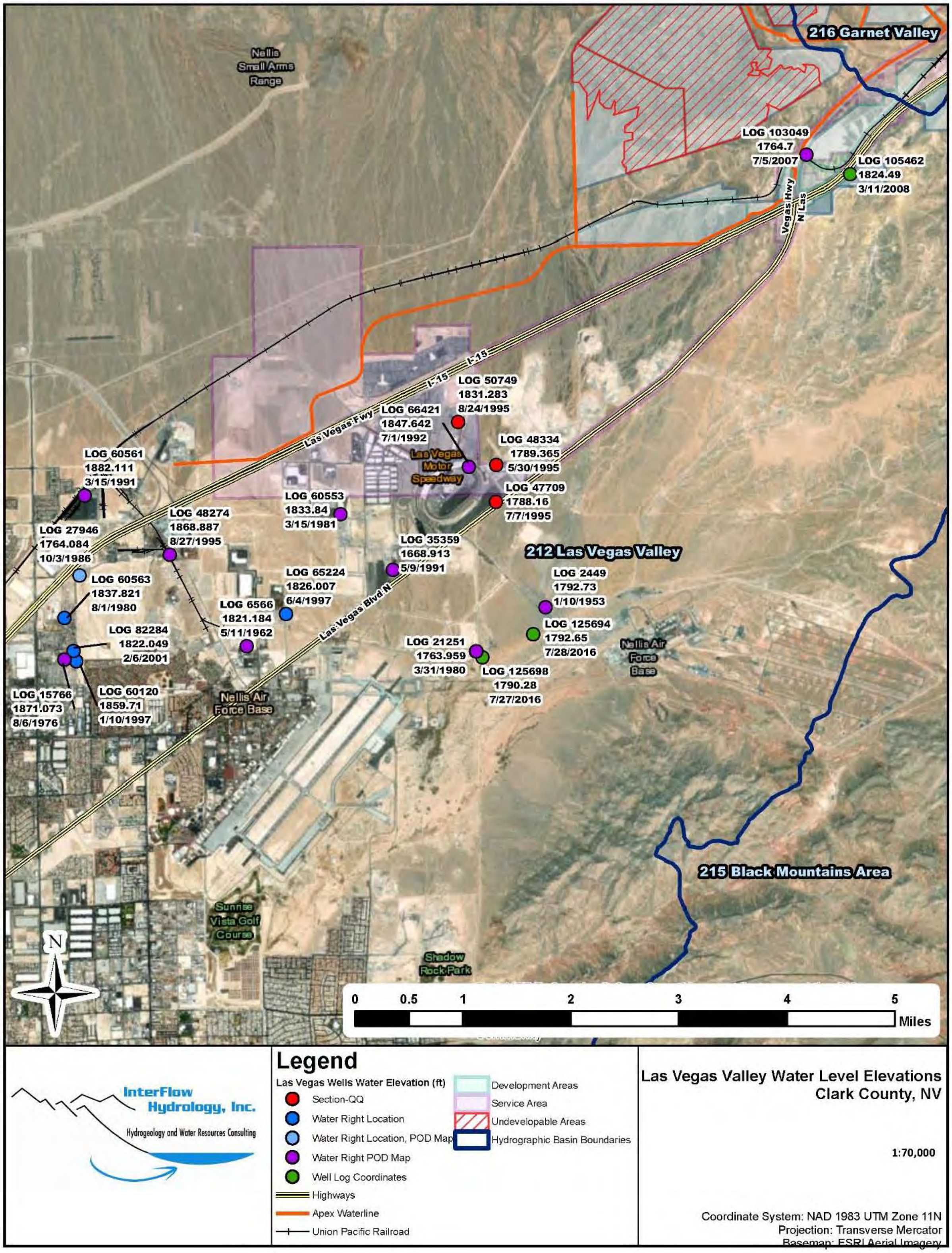

Figure 17 – Interpreted Water Level Elevations in Northeastern Las Vegas Valley

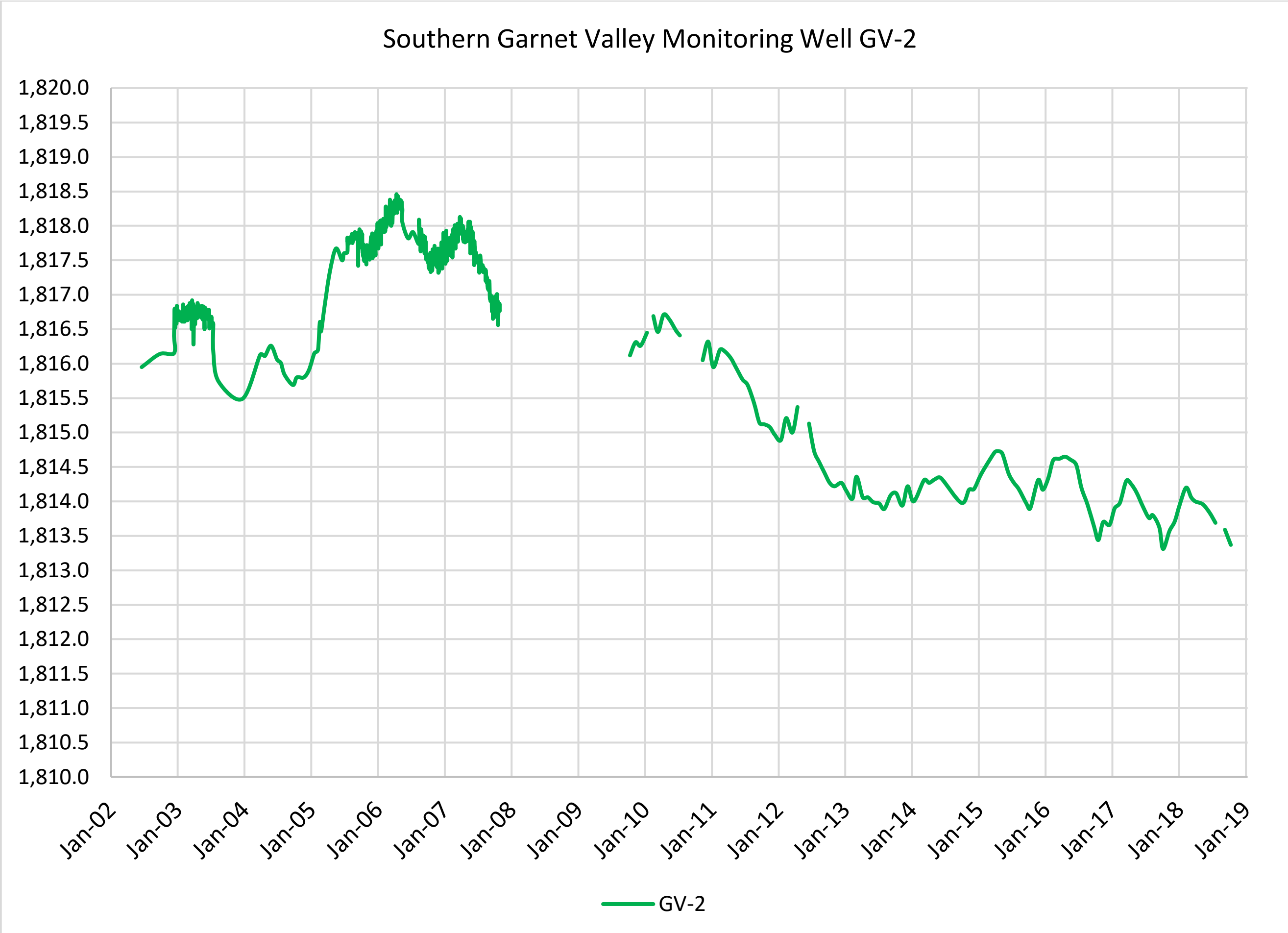

Figure 18 – Water Level Elevations at Monitoring Well GV-2

Table 5 – Summary of Estimated Water Level Elevations in Northeastern Las Vegas Valley using NDWR Well Log Data (2019)

Well Log	UTM X (ft)	UTM Y (ft)	Location Basis	Reported Depth to Water (ft)	Date Static Water Level Reported	Land Surface Elevation (ft amsl)	Water Elevation Calculated (ft amsl)
2449	2231287.61	13170171.60	Water Right POD	120	1/10/1953	1912.73	1792.7
6566	2216664.37	13168258.29	Water Right POD	92	5/11/1962	1913.18	1821.2
15766	2207770.93	13167610.59	Water Right POD	50	8/6/1976	1921.07	1871.1
21251	2227891.22	13168003.19	Water Right POD	110	3/31/1980	1873.70	1763.7
21251	2227895.47	13168010.27	Water Right POD	110	3/31/1980	1873.96	1764.0
27946	2208514.546	13171714.86	Water Right POD	200	10/3/1986	1964.08	1764.1
35359	2223813.87	13171993.69	Water Right POD	250	5/9/1991	1918.91	1668.9
47709	2228859.80	13175328.46	Section Quarter-Quarter	186	7/7/1995	1974.16	1788.2
48274	2212933.04	13172731.45	Water Right POD	90	8/27/1995	1958.89	1868.9
48334	2228877.98	13177137.31	Section Quarter-Quarter	220	5/30/1995	2009.37	1789.4
50749	2227015.97	13179227.94	Section Quarter-Quarter	204	8/24/1995	2035.28	1831.3
60120	2208358.444	13167533.05	Water Right POD	55	1/10/1997	1914.71	1859.7
60553	2221245.53	13174711.79	Water Right POD	143	3/15/1981	1976.84	1833.8
60561	2208761.10	13175640.13	Water Right POD	133	3/15/1991	2015.11	1882.1
60563	2207781.018	13169648.86	Water Right POD	100	8/1/1980	1937.82	1837.8
65224	2218583.489	13169837.18	Water Right POD	99	6/4/1997	1925.01	1826.0
66421	2227538.05	13177040.82	Water Right POD	124	7/1/1992	1971.64	1847.6
82284	2208217.368	13168025.83	Water Right POD	102	2/6/2001	1924.05	1822.0
103049	2244014.57	13192269.94	Water Right POD	650	7/5/2007	2414.70	1764.7
105462	2246169.344	13191329.032	Well Log Coordinates, Imagery	541	3/11/2008	2365.49	1824.5
125694	2230688.87	13168841.83	Well Log Coordinates, Imagery	116.8	7/28/2016	1909.45	1792.7
125698	2228201.37	13167716.06	Well Log Coordinates, Imagery	79.8	7/27/2016	1870.08	1790.3

Testing of Boundary Conditions using Numerical Flow Modeling

In order to examine and test potential boundary conditions and surface inflow and outflow from Garnet Valley, a simple 2D numerical flow model was developed using MODFLOW (Langevin, et al, 2017). The model grid is comprised of 1000 ft square cells and incorporates the entire hydrographic basin area (Figure 19). The model has one layer, approximately 1000 ft in thickness, to represent the upper-most saturated thickness of the carbonate aquifer that is tapped by wells in Garnet Valley.

General head boundary (GHB) conditions were established around the periphery of the model at postulated locations of subsurface inflow or outflow (Figure 19). The GHBs derive a flow based on the gradient across the boundary, which is established from a water level elevation at a projected distance beyond the boundary. A conductance term regulates the ease of flow across the boundary, which is derived from the hydraulic conductivity (K) assigned to the boundary. Table 6 summarizes the GHB assumptions, and values assigned for the GHB K, which were determined during model calibration.

Recharge was input into the model on the western-most edge of Garnet Valley (Figure 19), corresponding to the highest altitude portions of the Las Vegas Range. The recharge quantity was set equal to 400 AF/yr, based on the estimate of Rush (1968).

The hydraulic conductivity of the upper carbonate aquifer represented by the model layer was initially set to 2 ft/day (geometric mean of well specific capacity analysis), but adjusted upward to 5.5 ft/day during model calibration to provide a better fit to measured potentiometric heads in the basin. This K value is mid-range between the average carbonate aquifer K (10 ft/day) and median K (1.1 ft/day) as derived from the well log specific capacity analysis.

Pumping was input in the model based on the year 2015 distribution and volumes, as shown in Figure 20. Year 2015 was selected because the yearly pumping amount had been constant for 10-years at approximately 1,500 AF/yr. The pumping is assumed to have reached a state of equilibrium (steady-state) in the groundwater system, for model calibration and boundary testing purposes.

Calibration of the steady-state model was to average 2015 water level elevations at fifteen wells in Garnet Valley, as summarized in Table 2. Potentiometric water level elevation targets are called "head targets" in the modeling. Seven head targets are water levels recorded at pumping wells. In these cases, the average water level over the entire year, including both pumping and non-pumping periods, was input as the head target. The averaged head targets correspond to the average annual pumping simulated in the model. This approach ignores well efficiency and radial flow convergence effects within a model cell. As a result, the model should tend to simulate higher water level elevations than the head targets at the seven pumping wells. But these points are still important to the model calibration, because data are sparse in Garnet Valley. To reflect the greater potential error in pumping well head targets, they are assigned $1/10^{th}$ weight during calibration as contrasted with head targets from non-pumping monitoring wells (assigned a weight of 1).

Calibration of the model included adjustments to GHB K values to loosen or tighten the hydraulic properties regulating flow across each defined boundary, combined with reviews of GHB sensitivity to model calibration. Automated calibration adjustments to the GHB K values was accomplished in part using PEST (Doherty, 2010), which runs iterations of the parameters to derive a solution providing the statistical best fit to the data. GHB calibrated K values are presented in Table 6. Boundary sensitivity to GHB conductance variations are plotted in Figure 21. The flatter the GHB conductance curve, the lower the sensitivity of the boundary to model calibration. A qualitative description GHB sensitivity observed during calibration is provided in Table 6.

The model calibration results are reviewed by comparing the match between observed and simulated water levels at the calibration head targets. The difference between the observed (measured) and simulated water level is called the residual. Residuals and calibration statistics are reported applying the head target weighting reported above. The residual mean for head targets (average difference) is 0.26 ft. The scaled residual standard deviation and scaled RMS error are 3.6%. Models calibrated to achieve within 10% are generally acceptable for use, and within 5% is generally considered good. For a simplistic 2D model, the calibration statistics are considered good. Model calibration statistics are presented in Table 7, and a plot of simulated versus measured water level elevations is presented as Figure 22. Simulated potentiometric water level elevations and head target residuals are shown in Figure 23.

Test Model Results and Observations

This modeling exercise was undertaken to examine and test potential inflows and outflows that would provide a reasonable match to observed potentiometric water levels in Garnet Valley. The model simulates flows across the boundaries of Garnet Valley as summarized in Table 8. The total subsurface inflow is simulated at 1217 AF/yr. The test model derives 518 AF/yr of inflow to the northern-most part of Garnet Valley from Southern Coyote Spring Valley and/or northern Hidden Valley. The test model derives significant inflow from Las Vegas Valley at 698 AF/yr. Outflows are simulated at 111 AF/yr, primarily from the northern-most part of Garnet Valley to northwestern California Wash. No outflow is simulated across the eastern Garnet Valley boundary to central and southern California Wash.

The test model results should not be interpreted as quantification of a water budget for the Garnet Valley basin, but rather should be viewed as a conceptual test of boundary conditions with the following general observations:

- Significant subsurface inflow likely occurs from Southern Coyote Spring Valley and/or Northern Hidden Valley into Garnet Valley, through the Arrow Canyon Range, and the model boundary condition exhibits moderate sensitivity to achieve calibration to observed water level elevations.

- Significant subsurface inflow to Garnet Valley likely occurs from Las Vegas Valley, and the boundary condition exhibits high sensitivity to achieve satisfactory model calibration.

- Groundwater inflow from southern Hidden Valley to Garnet Valley appears low, however there could be offsetting scenarios with recharge simulated on the western edge in the Las Vegas Range and the magnitude of inflow at this boundary. The sensitivity of this boundary to achieve satisfactory calibration is moderate.

- Groundwater outflow from Garnet Valley to central California Wash appears to be low, and the model boundary exhibits high sensitivity to high conductance values that would allow for significant groundwater outflow.

- Groundwater outflow from Garnet Valley to northern California Wash is supported by the model; however, the model boundary sensitivity is low, and the magnitude of outflow is uncertain.

Table 6 – General Head Boundary Assumptions and Values

Model Reach No.	Flow From	Flow To	GHB Elevation (ft amsl)	GHB Distance (ft)	Explanation for GHB Parameters	Calibrated Boundary K (ft/day)	Relative Sensitivity of Boundary
2	Las Vegas Valley	Garnet Valley	1821.6	10000	Median elevation from review of LV well logs	5.3	High
1	Hidden Valley – South	Garnet Valley	1815	42000	Water level at SHV-1	1.0	Moderate
0	Hidden Valley – Central	Garnet Valley	1815	19000-42000	Water level at SHV-1	1.9	Moderate-High
7	Hidden Valley – North and/or Coyote Spring Valley - South	Garnet Valley	1820	26000	Water level at CSVM-2	38.4	Moderate
3	Garnet Valley	Black Mountain	1813	6000	Water level at BM-DL-2	1.0	Low
6	Garnet Valley	Black Mountain and CALIFORNIA Wash - South	1713	60000	Water level at BM-ONCO-1	1.5e-05	Low - Moderate
4	Garnet Valley	CALIFORNIA Wash - Central	1664	48000	Water level at BYRON-1	8.5e-06	High to increase in K Only
5	Garnet Valley	CALIFORNIA Wash - North	1812	13000	Water level at Paiutes TH-2	10.8	Low

Table 7 – Garnet Valley Boundary Test Model Calibration Summary

Calibration Statistic	Value
Residual Mean	0.258 ft
Absolute Residual Mean	2.209 ft
Residual Std. Deviation	3.127 ft
Sum of Squares	147.68 ft
RMS Error	3.138 ft
Min. Residual	-7.864 ft
Max. Residual	6.195 ft
Number of Observations	15
Range in Observations	87.83 ft
Scaled Residual Std. Deviation	0.0356
Scaled Absolute Residual Mean	0.0252
Scaled RMS Error	0.0357
Scaled Residual Mean	0.0029

Table 8 – Summary of Model Simulated Groundwater Flows at Garnet Valley Boundaries

Flow From	Flow To	Model Reach No.	Simulated Steady-State Flow Across Boundary (AF/yr)
Las Vegas Valley	Garnet Valley	2	698
Hidden Valley – South	Garnet Valley	1	1.4
Hidden Valley – Central	Garnet Valley	0	61
Hidden Valley – North and/or Coyote Spring Valley - South	Garnet Valley	7	456
Garnet Valley	Black Mountain	3	7.5
Garnet Valley	Black Mountain and CALIFORNIA Wash - South	6	0
Garnet Valley	CALIFORNIA Wash - Central	4	0
Garnet Valley	CALIFORNIA Wash - North	5	103

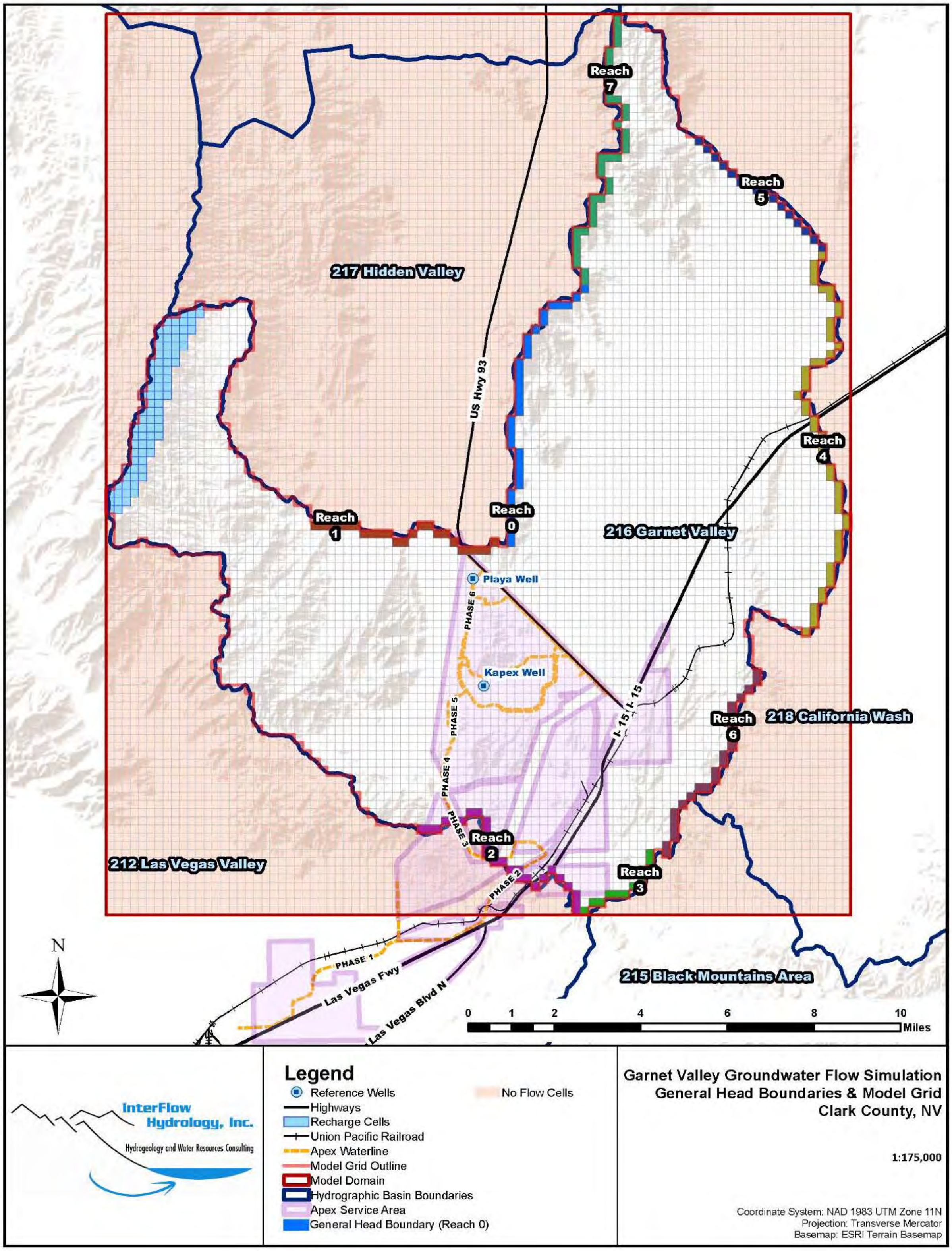

Figure 19 – Garnet Valley Test Model Grid and Boundary Conditions

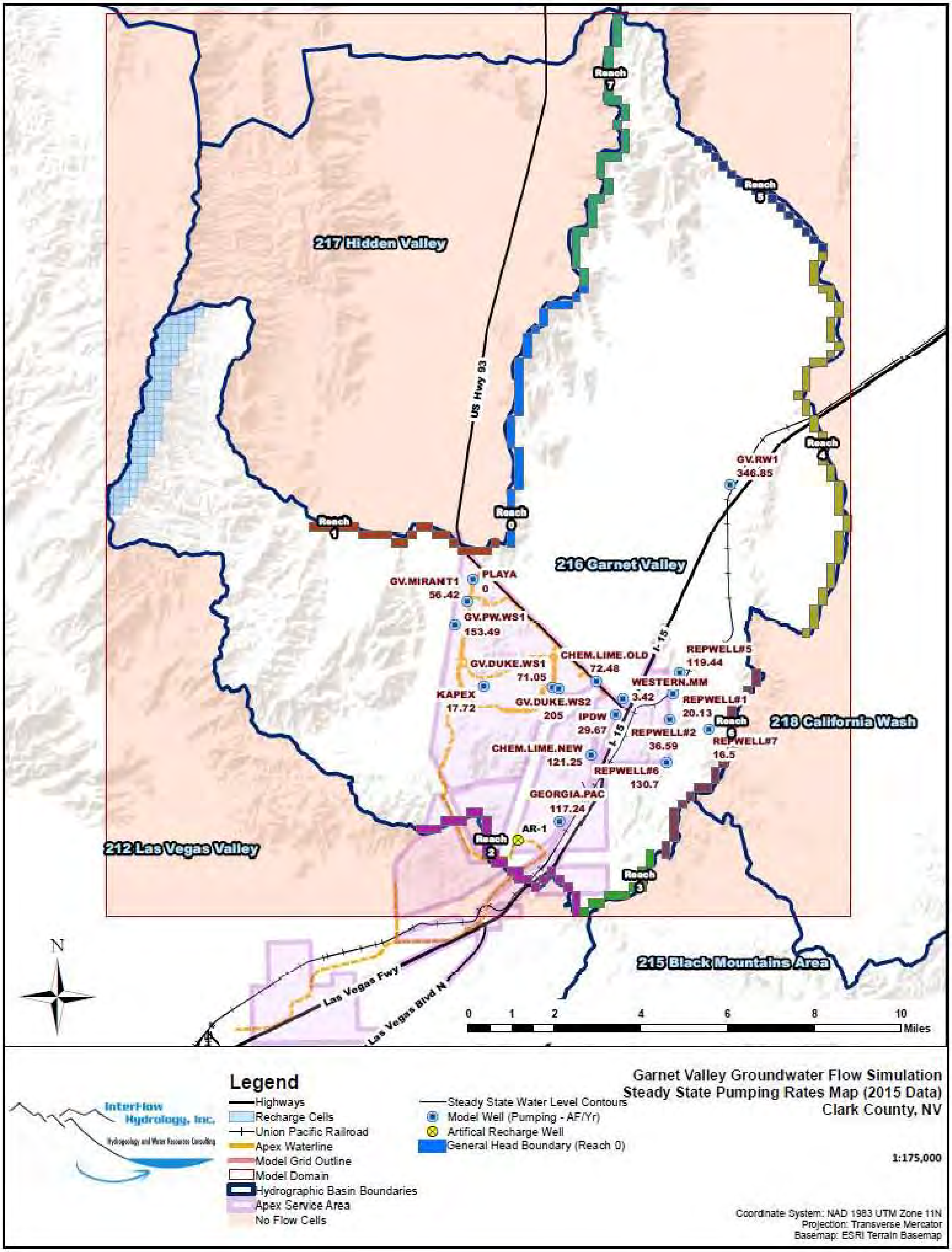

Figure 20 – Simulated Pumping Distribution

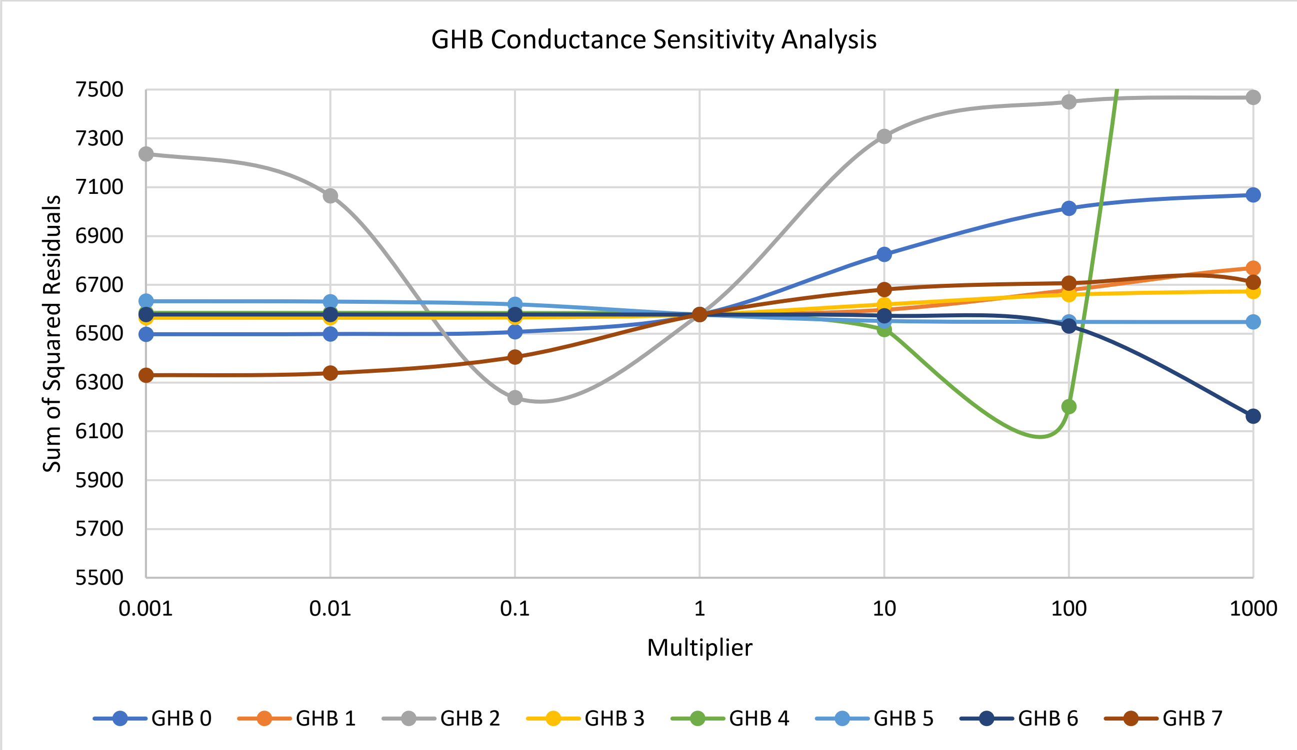

Figure 21 - GHB Conductance Sensitivity Plot

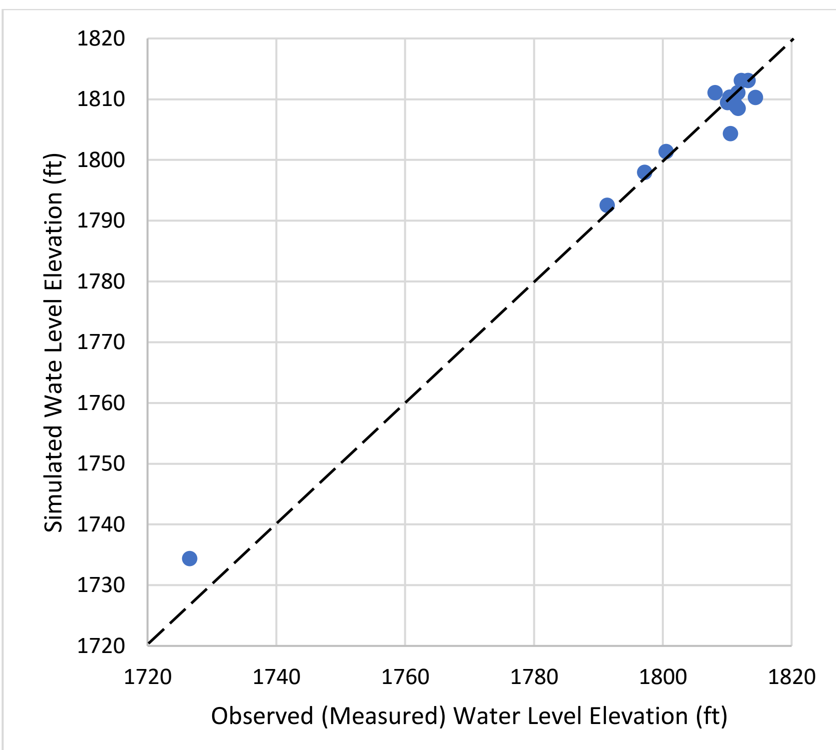

Figure 22 - Plot of Simulated versus Observed Groundwater Elevations at Model Head Targets

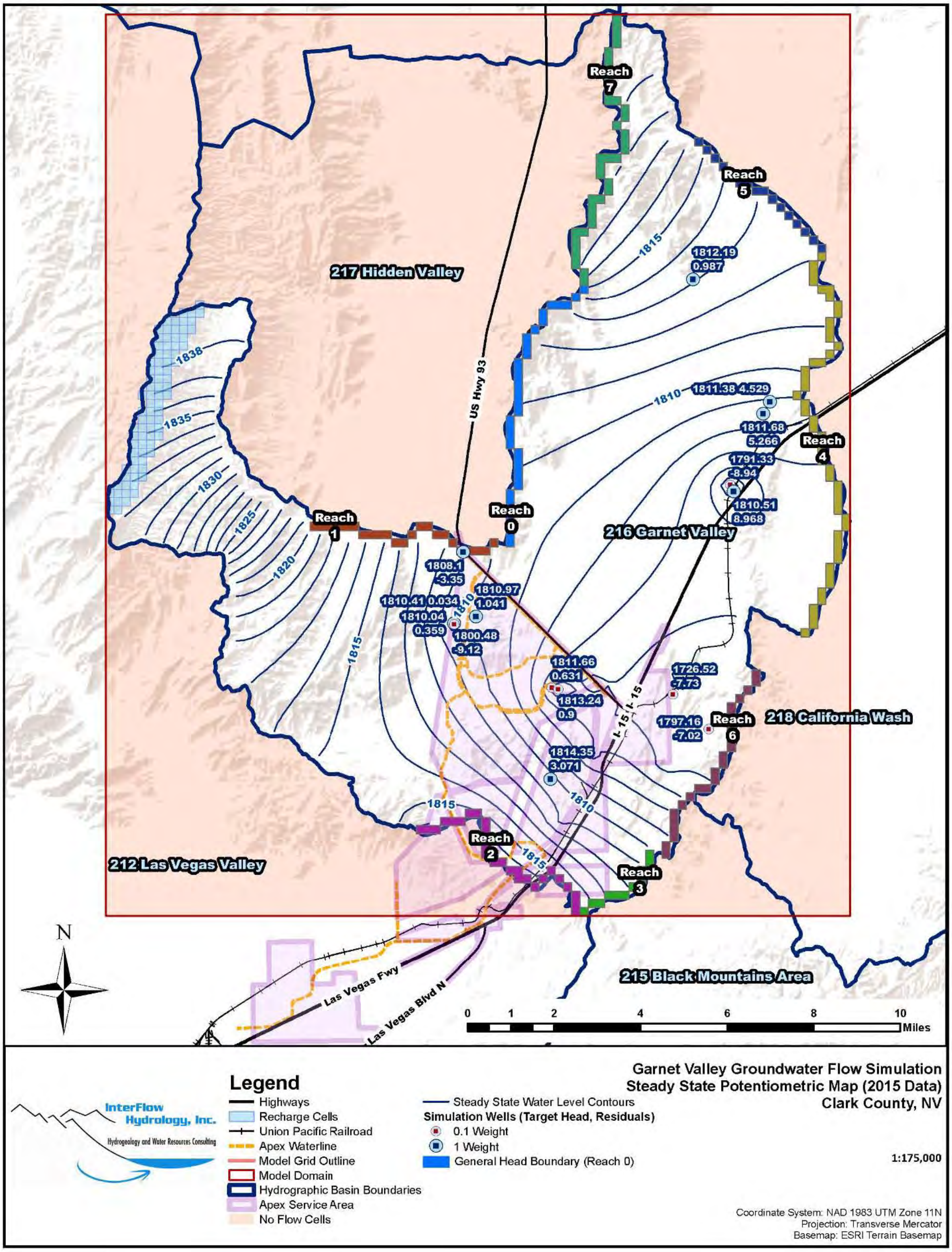

Figure 23 – Simulated Potentiometric Water Levels

Conceptual Review of Groundwater Yield in Garnet Valley

Sources of groundwater to Garnet Valley include locally derived recharge (~400 AF/yr), and based on the boundary test modeling, subsurface inflow from southern Coyote Spring Valley and/or northern Hidden Valley through the Arrow Canyon Range (~450 AF/yr), and subsurface inflow from northeastern Las Vegas Valley to southern Garnet Valley (~700 AF/yr). These estimates carry notable uncertainty, as data are limited for model calibration.

The model reflects a simple uniform hydraulic conductivity over the entire model area, and only the upper 1000 ft of saturated thickness of the carbonate aquifer. Higher transmissivities and greater thicknesses would accommodate greater flows. However, the ability to capture the deeper groundwater by wells has practical limitations. Data on aquifer transmissivity is sparse in portions of Garnet Valley, particularly the northern portion. The represented transmissivity in the model is however consistent with the available information and produces a reasonable model calibration to observed water level elevations.

In-basin recharge from precipitation is estimated on a reconnaissance level at 400 AF/yr by Rush (1968). This recharge supports a portion of pumping from APEX wells. What appears potentially unaccounted for is precipitation recharge occurring in Hidden Valley, which is estimated by Rush (1968) to also be 400 AF/yr. This recharge would be expected to discharge via subsurface outflow to southern or central Garnet Valley. The boundary testing did not suggest significant inflow from southern Hidden Valley to Garnet Valley is required to produce adequate model calibration. The lack of quantification of outflow could however be due in large part to the lack of the available data in Hidden Valley. Additional monitoring wells in Hidden Valley would aid in understanding gradients and refining interpretations, to possibly account for the Hidden Valley recharge.

There is a long-term declining water level trend in Garnet Valley, but this trend mimics water level trends throughout much of the LWRFS (Figure 24). In Garnet Valley, the declining trend is about 0.3 ft/yr, and has been observed since the beginning of groundwater monitoring in 2000, but was interrupted by a high recharge year in 2005. After the wet period, the declining water level trend resumed. The Order 1169 pumping interrupted the trend in 2011-2014, during the pumping and recovery periods (Figure 25). Otherwise the declining trend has been present throughout the period of record from 2000-2018 in Garnet Valley and from 1998 to present at other LWRFS locations (Figure 24).

The pumping responses in the Order 1169 testing were observed to spread rapidly in the system (SNWA, 2013), being identified within a couple months, including in Garnet Valley, due to high transmissivity and the confined nature of the aquifer. The rapid propagation of drawdown also produced a similarly rapid commencement of spring discharge capture, at Pederson Spring. This observation supports the interpretation that the LWRFS responds rapidly to pumping by reduced spring discharge, and pumping capture of spring discharge is not a highly delayed. This important characteristic of the carbonate aquifer leads to the conclusion that the long-term uniform declining trends in water levels throughout the LWRFS are likely due to other stresses on the system, presumably long-term climate, rather than a delayed response to pumping.

In years 2016 and 2017, pumping from APEX wells increased to ~2,000 AF/yr due to highway and Faraday Future construction activities. A noticeable response to this increase in pumping, however, is not visible in the Garnet Valley water level hydrographs. Conversely, water levels near the Muddy River Springs showed some indication of leveling (note EH-4, Figure 25). It may be that the increase in pumping was not sufficient to have caused a large amount of aquifer storage depletion. A controlled long-term aquifer test, possibly integrated with pumping in APEX to bridge the gap in time for APEX pipeline construction, would be beneficial to understanding the system and potential thresholds for pumping. For example, pumping from the City's Playa and Kapex wells might be increased in increments between 500 AF/yr to 1000 AF/yr, while responses are monitored. Should pumping results indicate unacceptable drawdown, then the proposed artificial recharge (AR) as reviewed in Interflow (2019) can be implemented, and/or a conversion from groundwater use to Colorado

River water supply can take place. Ideally some test pumping would occur prior to implementation of an AR program, to simplify interpretations.

The above observations suggest that partitioning of climate and pumping responses needs to continue to be reviewed and considered when interpreting water level trends in the LWRFS, and in Garnet Valley. Smith et al (2004), and others, have reviewed the importance of differentiating climate versus pumping trends.

In summary, it appears that pumping at 1500 AF/yr and possibly up to 2000 AF/yr in the APEX area has not caused detrimental water level declines. As a water development and management strategy for APEX, a controlled pumping test with increased pumping from the Playa and Kapex wells up to 1000 AF/yr could reveal more information, from which a sustainable pumping volume in the APEX area may be determined. Additional monitoring wells should complement the pumping, especially in Hidden Valley. Under the City's water supply strategy of using both groundwater and imported Colorado River water to provide a conjunctive water supply, along with artificial recharge to help manage groundwater pumping drawdown and potentially return treated wastewater to the beneficial use (Interflow, 2019), there will be ample flexibility and a backstop to manage use of groundwater resources, and to accommodate short-term increased pumping to determine a sustainable groundwater pumping volume in the basin.

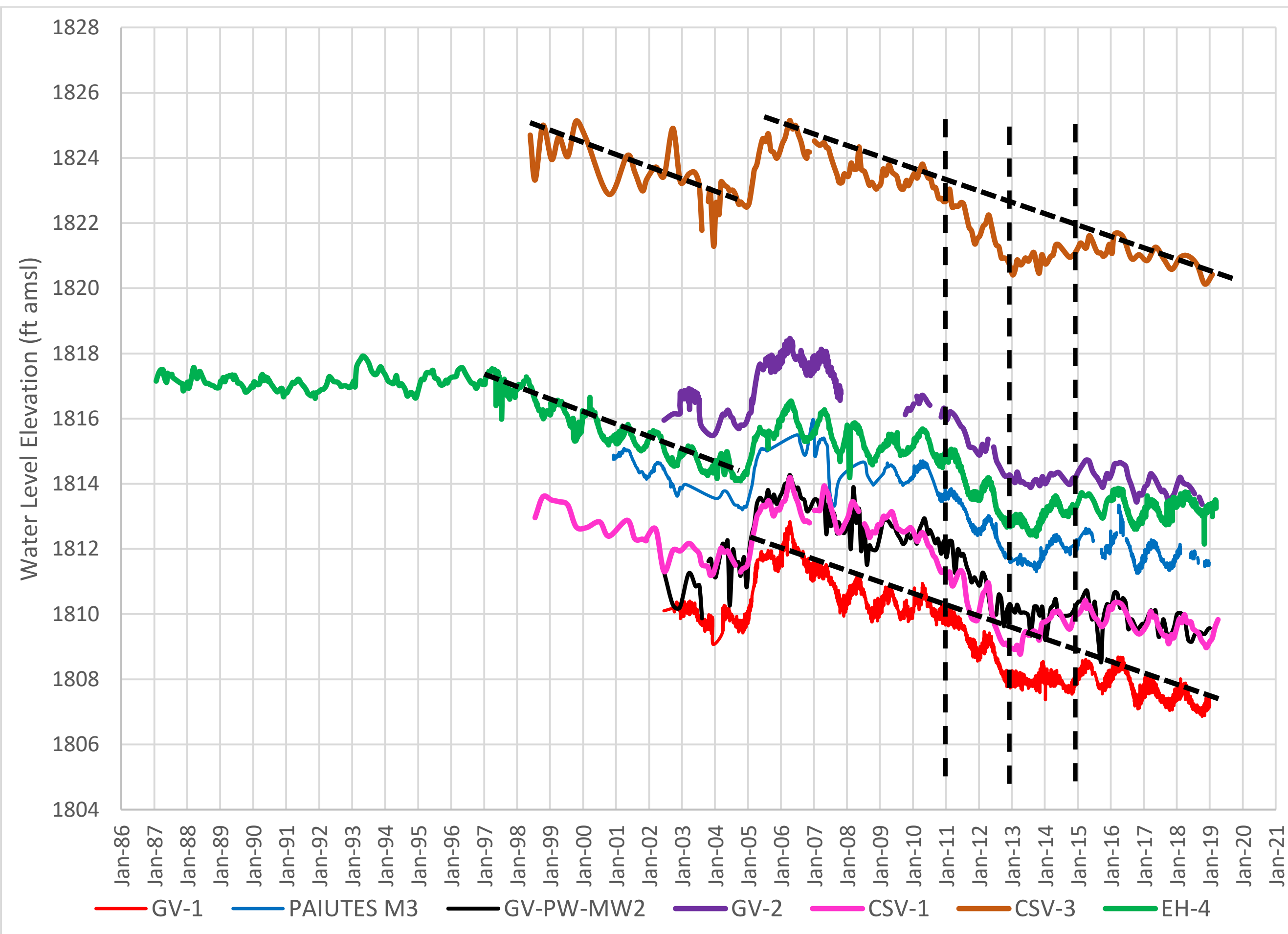

Figure 24 – Hydrograph Comparison of Garnet Valley Water Level Trends with other LWRFS Locations

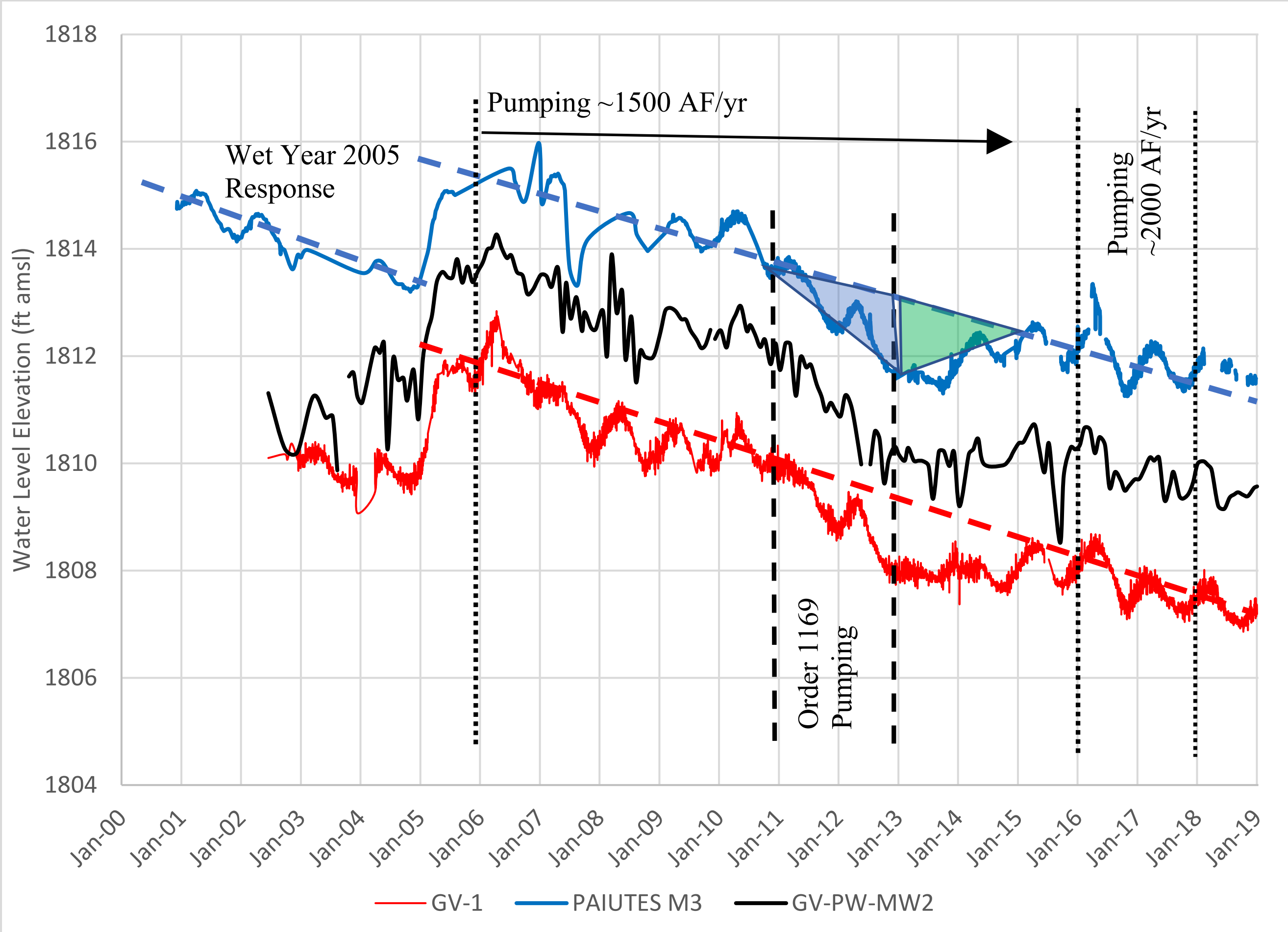

Figure 25 – Hydrograph Interpretations in Garnet Valley

Review of Senior Water Rights Transfers to APEX

The City of North Las Vegas is in negotiations with the Church of Jesus Christ of Latter Day Saints (Church) to lease senior groundwater water rights from the Muddy River Springs Area, with plans to transfer the rights to the Playa and Kapex wells in Garnet Valley, subject to State Engineer approval.

The Church's groundwater rights in the Muddy River Springs Area have a priority date of 1947 for permits 50723, 50728-29, and 50731-33; a priority date of 1949 for permit 50724; and a priority date of 1965 for permits 50725-27, and 50730. The 1947 year water rights are some of the most senior underground water rights in the LWRFS, with only 343 AF/yr of more senior rights (NDWR, 2017). The 1949 year right has 3507 AF/yr of more senior water rights, but including 1952 AF/yr of the 1947 rights. The 1965 priority water rights have 4531 AF/yr of senior water rights, including the other LDS rights which total approximately 2330 AF/yr. The points of diversion for the active permits currently reside at Church wells: LDS East, LDS West and LDS Central, as shown in Figure 26.

The manner of use of the Church water rights is currently designated as industrial, with change applications granted in 1988 for the water supply to the Reid-Gardner Station power plant. The 1988 permit date does not change the base water right priority date. These groundwater rights were under a lease agreement with NV

Energy until April 2017. Prior to use for power generation, these water rights were used for irrigation in the Muddy River Springs Area.

Under the joint administration the LWRFS basins, transfers of points of diversion between basins may be permitted, however, permanent change applications are currently being held in abeyance under Interim Order 1303. Assuming future administration of groundwater rights by the State Engineer in the LWRFS will accept permanent transfers, the water right change applications will be subject to administrative reviews under NRS 533. Applications to change water rights are filed with the office of the State Engineer (NDWR), publicly advertised, open to protest for a period of time, and then go through a review and determination process by the State Engineer, which may include a water right hearing if the applications are protested. Rulings issued by the State Engineer may also be appealed, furthering the time required to obtain a permit. There is no guarantee that change applications will be approved until the process has been successfully completed. Terms of granted permits may include restrictions and a monitoring plan.

In the case of the Church owned water rights, the applications to change the water rights to serve the City of North Las Vegas' wells in Garnet Valley will require changes to the points of diversion, manner of use, and place of use. Applications for temporary changes of water right permits (1-year duration) may initially be needed. Temporary change applications do not require public advertisement and can commonly be issued within a couple months. Permanent change applications may require 6-12 months to go through the permitting process, but will require the condition of Interim Order 1303 to hold permanent changes application in abeyance to be lifted.

Benefits to Transferring the Church's Underground Water Rights out of the Muddy River Springs Area

The Church's wells tap the shallow alluvium (~200 ft thick) overlying the carbonate rock along the Muddy River Springs corridor. Pumping from the alluvium has been interpreted by SNWA (2013) to create a nearly 1:1 capture of Muddy River flow, as measured at the down-stream Moapa Gage (Figure 26). This interpretation is supported by a relatively straightforward accounting of historical pumped volumes from the Muddy River Springs Area and total flow at the Moapa Gage, beginning at pre-pumping conditions in the 1940s and working forward in time, as presented in Figure 27.

The exact process of stream flow capture by pumping is not clearly known, and could be due to direct lowering of the water table adjacent to the stream bed (classic stream flow capture), or could be by indirect means of capture of flow from springs that discharge through the alluvium on the valley floor, producing discharge to the Muddy River. The springs that discharge through the alluvium have an established conduit of flow through the alluvium that may be hydraulically supported by a high water table and saturated alluvium outside the conduit. When the water table is lowered, leakage from the conduit occurs back into the alluvium, rather than discharging to land surface. This condition has been observed at other springs in Nevada where water table drawdown has affected the discharge of springs occurring through alluvial conduits. For example, springs in Diamond Valley, such as Sulphur, Tule, Bailey, Shipley and Eva once derived flow from an underlying carbonate aquifer, discharging through thin alluvial cover to land surface (Smith, 2013; Smith, 2019). Drawdown in the alluvium in Diamond Valley upset the hydraulic balance between the conduits and alluvium, and depleted spring flows. In summary, pumping of the Church's wells may potentially capture flow of the Muddy River as measured at the down-stream Moapa Gage by both induction of river flow and by indirect means of capture of spring discharge tributary to the river.

In recognition of the effects of pumping from established points of diversion for the Church's water rights in the alluvium along the Muddy River Springs corridor, ceasing to pump these water rights at the existing points of diversion will mitigate potential impacts to existing decreed water rights on the Muddy River, and perhaps provide an advantage to sustaining spring flows on the valley floor. This could in turn benefit the Moapa Dace habitat.

Benefits to Securing Senior Water Rights to Support APEX Pumping

It appears that there are currently sufficient underground water rights in Garnet Valley to support municipal service to APEX in the future. The total permitted water rights are 3715 AF/yr (NDWR, 2019) of which SNWA holds approximately 2275 AF/yr (total combined duty). It is not certain if the SNWA water rights (up to 900 AF/yr) will remain available to pump from the City of North Las Vegas wells.

However, if regulation by priority date occurs in the LWRFS, then the SNWA water rights will be considered junior. It is likely that administrative actions in the LWRFS would first declare the basins a Critical Management Area (CMA), initiating opportunity for stakeholders to craft and submit a Groundwater Management Plan (GMP). The GMP would need to be approved by a majority of water right owners, and be approved by the State Engineer within 10 years of the declaration as a CMA. A GMP could conceivably work around the prior appropriations system of water rights administration, but may initiate challenges in court. The future of GPMs in this regard is unclear and untested to the point of a GMP being fully implemented.

It seems unlikely that curtailment of water rights based on water right priority would occur until the 10-yr timeframe for completion of a GMP has expired, and only in the case that the GMP failed to deliver an acceptable solution. However, if Muddy River Springs discharge diminishes to the point that actions are required, or dictated by the courts, to protect the Moapa Dace, then regulation by priority date is one of the only tools legally available to the State Engineer. While the future of underground water rights and potential regulation by priority date in the LWRFS is uncertain, there might be an advantage to transferring senior water rights to APEX to provide an increased level of certainty in water right holdings in support of municipal water service from the groundwater source in Garnet Valley, particularly over the period of time needed to rely upon wells until the Colorado River water pipeline is completed throughout APEX.

Beyond the bridge period for completion of the pipeline, the City of North Las Vegas could be in a more secure position going into the uncertain future regarding underground water rights. However, the Colorado River water source being brought into Garnet Valley also provides a viable supply of water along with long-term use of groundwater in the LWRFS.

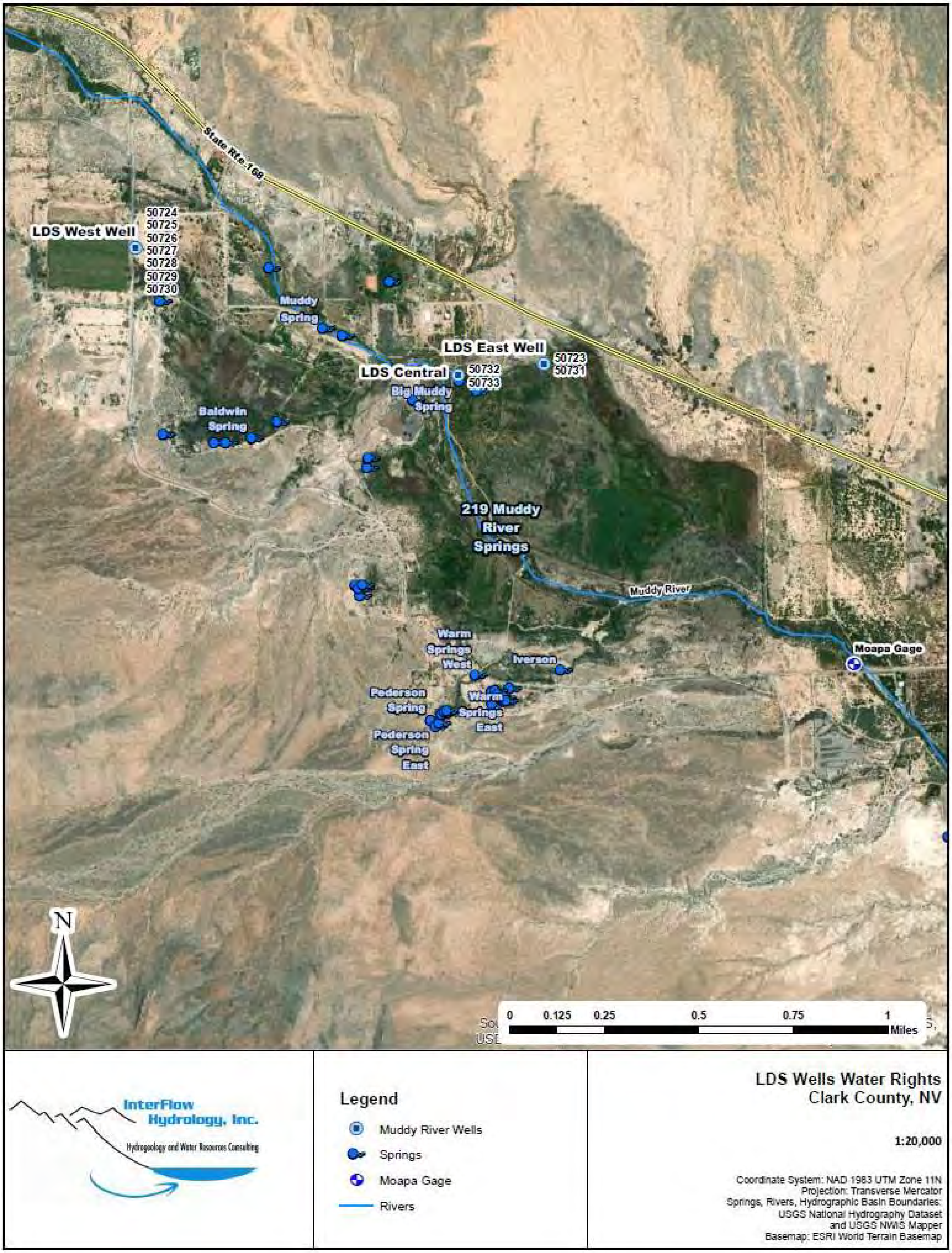

Figure 26 – Locations of the LDS East, LDS West, and LDS Central Wells

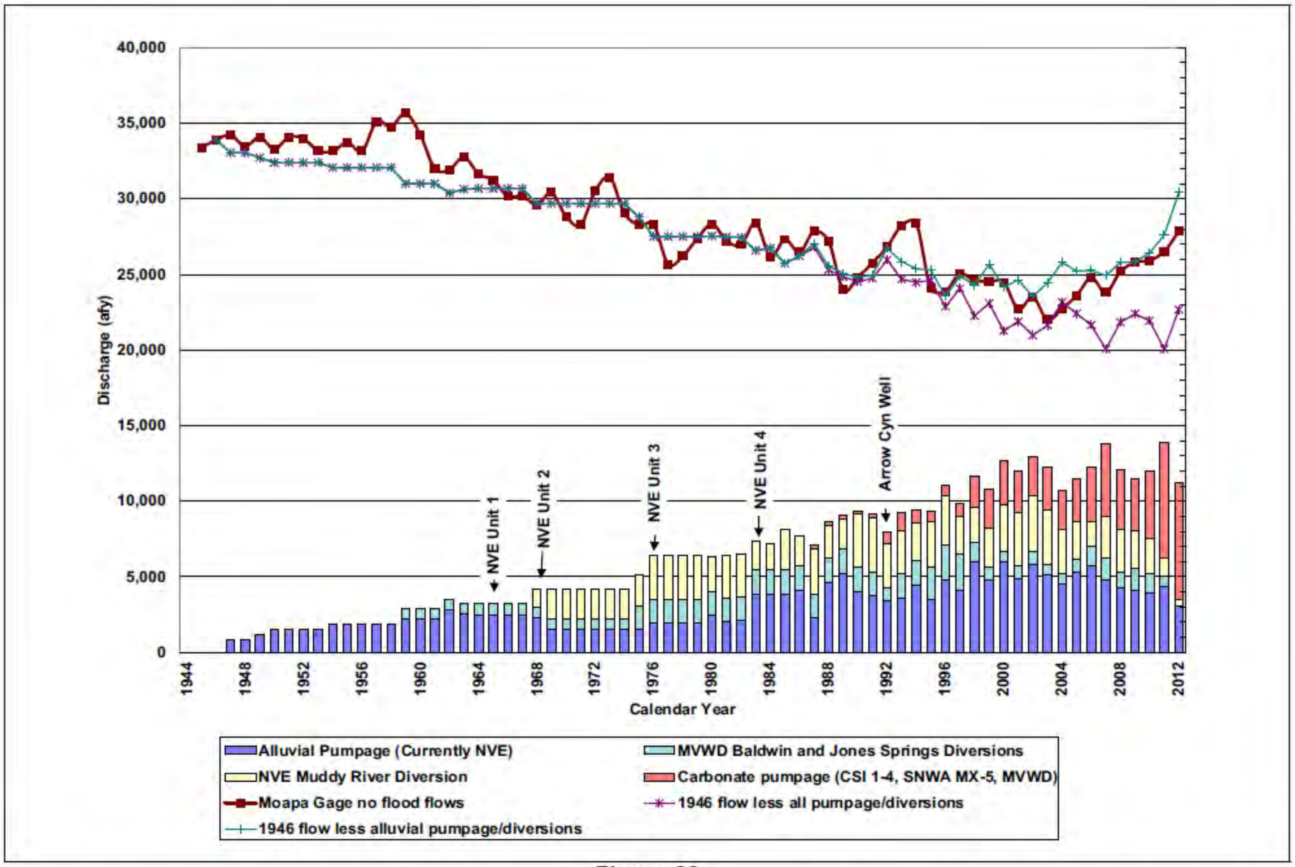

Figure 28
Comparison Between Decline in Flow at the Moapa Gage and Alluvial vs.Carbonate Groundwater Pumpage and Surface-Water Diversions

Figure 27 - SNWA (2013) Exhibit Demonstrating Alluvial Pumping Capture of Muddy River Flow

Summary and Recommendations

Conceptual review of groundwater flow at the boundaries of Garnet Valley suggest that inflow occurs from southern Coyote Spring Valley and/or northern Hidden Valley, and from Las Vegas Valley. Along with estimated recharge of 400 AF/yr, the current pumping of ~1500 AF/yr may be in near equilibrium with inflow and recharge. A portion of groundwater outflow to northern California Wash is perhaps not captured by existing pumping. Some uncertainty exists however as to the potential upper limit of the quantity of groundwater that can be sustainably pumped from the APEX area. Higher pumping of approximately 2000 AF/yr occurred in 2016 and 2017, without evidence of responses in lowering of regional water levels, although a long-term mild declining trend in regional water levels throughout the LWRFS has been ongoing for approximately 20 years.

Increases in pumping in Garnet Valley should be exercised cautiously, and perhaps in stages or increments. The monitoring network should be expanded to include at least two carbonate aquifer monitoring wells in Hidden Valley, one near SHV-1, which is believed to be completed in alluvium, and one in the southern part of Hidden Valley.

An interesting finding in this hydrogeologic review is the possible subsurface inflow from Las Vegas Valley to southern Garnet Valley. A reconnaissance review of available water level data from wells in northeastern-most Las Vegas Valley and boundary test modeling supports the postulated flow, however no accurate data are available to make a conclusive determination. Two or more monitoring wells are recommended near the boundary of Las Vegas Valley and Garnet Valley from which accurate water level measurements may be made. The wells should be completed in carbonate rocks. To the degree that groundwater inflow from Las Vegas Valley occurs to Garnet Valley, it can likely be developed without impacting the LWRFS. This subsurface inflow may be the primary source of recharge that is supporting existing pumping in the APEX area, along with recharge to that portion of the Las Vegas Range in the basin. Confirmation and more accurate quantification of inflow by establishing gradients and transmissivity is recommended to aid in groundwater resources management in the APEX area.

Leasing senior groundwater rights located in the LWRFS has merit in a couple regards. Senior groundwater rights in Muddy River Springs Area have historically been pumped from alluvium, which appears to capture flows of the Muddy River, thus potentially interfering with senior decreed water rights. Transferring of senior groundwater rights out of this environment and to a distal and down-gradient portion of the LWRFS will help alleviate this potential water right conflict. For the City of North Las Vegas, securing senior groundwater rights will help assure that pumping from the Playa and Kapex wells is not likely to be subject to curtailment, should actions be necessary to regulate groundwater rights of the LWRFS by priority date. A lease of senior water rights and transfer of these water rights to the Playa and Kapex wells can help bridge the time required to complete the Colorado River pipeline throughout APEX. SNWA has ample water rights in Garnet Valley, however, they are junior rights and potentially subject to LWRFS curtailment, should regulation by priority date occur.

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Prediction of the Effects of Changing the Spatial Distribution of Pumping in the Lower White River Flow System

Project #: 117-0524303
July 3, 2019

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APPENDICES

1.0 INTRODUCTION

A regional carbonate-rock aquifer has the potential for being a productive source of additional water in southern Nevada. However, this same regional aquifer is also the source of several large-volume warm springs that discharge on Federal and private lands, and in some cases provide baseflow to streams. The effects of pumping the carbonate-rock aquifer could include the eventual capture of the water that discharges from these springs and thus depletion of their flow. Reduction or cessation of spring discharge on Federal and private lands not only would have an adverse effect on sensitive habitat and species, but also senior water rights associated with stream baseflow provided by some of these springs.

Springs and water-related resource attributes are important features in the Overton Arm area of Lake Mead National Recreation Area (Lake Mead NRA). The springs provide water for vegetation and wildlife habitat and create an environment that many visitors use and enjoy. Many of these springs are fed by regionally- and locally-derived groundwater (Pohlmann et al., 1997), and could be affected by up-gradient groundwater diversions. Springs include Rogers Spring, Blue Point Spring, Corral Spring, and other smaller, unnamed springs. Visitation to Rogers and Blue Point Springs in recent years has been conservatively estimated at 30,000 visitors per year.

The National Park Service (NPS) is entitled to Federal reserved water rights for reserved lands within Lake Mead NRA. The priority dates for these reserved rights are the dates when the lands were reserved. These rights have not been judicially quantified. The NPS also has a State appropriative water right to water from Rogers Spring. The priority date for this water right is February 16, 1937.

Desert bighorn sheep are also dependent upon the springs in the northern part of Lake Mead NRA. The relict Las Vegas Valley leopard frog, *Rana onca*, has been found at Rogers and Blue Point Springs. The relict leopard frog, previously believed extinct, had been petitioned for listing in 2002 as protected under the Endangered Species Act, but the United States Fish and Wildlife Service (USFWS) subsequently determined in 2016 that such a listing is not warranted at this time. There are three endemic springsnail species found in the short springbrook above the flow measurement weir at Blue Point Spring. In 2009, several entities petitioned for the listing of 42 springsnail species in the Great Basin, including the Blue Point pyrg. In 2017, the USFWS decided that listing the Blue Point pyrg is not warranted at this time.

1.1 SETTING

The basins located north of Lake Mead NRA are underlain by a regional groundwater flow system, originally referred to as the White River groundwater flow system (Eakin, 1966), and later as the Colorado River groundwater flow system (Prudic et al., 1995, and Harrill and Prudic, 1998) (Figure 1-1). Groundwater generally flows from north to south in this flow system, which discharges most of its flow at springs near the headwater area for the Muddy River, thus supplying the base flow to the Muddy River (Eakin, 1966; Harrill and Prudic, 1998; and Prudic et al., 1995). Several of the previously mentioned Lake Mead NRA springs are also discharge points for this same regional groundwater flow systems (Harrill et al., 1988 and Prudic et al., 1995).

The White River groundwater flow system contains basin-fill and carbonate-rock aquifers that appear to be hydraulically connected (Prudic et al., 1995). As a result, large-scale development of groundwater in the basin-fill aquifers could induce groundwater to flow from the regional carbonate-rock aquifer to the basin-fill aquifer, lowering the hydraulic head in the regional carbonate-rock aquifer, and eventually causing depletion of the discharge of large regionally sourced springs, such as the Muddy River Springs, and smaller regionally sourced springs such as the previously mentioned Lake Mead NRA springs. Similar concerns would also apply to large-scale development of groundwater directly from the carbonate-rock aquifer, if withdrawals are large enough and occur over a sufficiently long period of time.

Geologic mapping by Page et al. (2005) and later geologic cross-sections developed by Page et al. (2011) indicate that much of the Paleozoic carbonate-rock section is present beneath the Black Mountains Area basin (see cross-sections D-D', E-E', F-F', G-G' and I-I'), extending to the Lake Mead and Rogers Spring fault zones which transect the northern portion of Lake Mead NRA. These Paleozoic rock formations also are present in the upper and lower plates of the Muddy Mountain thrust fault that also transects portions of the Black Mountains Area basin as shown in several of the aforementioned cross-sections (Figure 1-2). Page et al. (2011) state that "the Muddy Mountain thrust in the Muddy Mountains juxtaposes Paleozoic carbonate rocks in the upper plate against Mesozoic and Paleozoic rocks in the lower plate (G–G'); such a relationship suggests that the less permeable Mesozoic rocks below the thrust may act as a groundwater flow barrier, and the thrust has been characterized as a barrier in local groundwater models. Although the lower plate rocks may act as a barrier in localized zones along strike, we think that overprinting of the thrust by Cenozoic faults (Langenheim and others, 2002) provides linkage between rocks in the upper and lower plates, allowing for some groundwater flow across the thrust. This example may apply to other Mesozoic thrust faults in the map area, especially where the thrusts are highly modified by younger Cenozoic extensional faults."

Geochemical modeling (Appendix A) has indicated that the areas around the Muddy River Springs and in Garnet Valley both could be along groundwater flow paths to Rogers Spring and Blue Point Spring (Geochemical Technologies Corporation and Tetra Tech, Inc., 2012). The study determined that while a central flow path through California Wash (and the Moapa River Indian Reservation) is plausible, the more plausible flow path is a southern flow path from Garnet Valley, beneath California Wash and the Black Mountain Area basins to discharge at Rogers Spring and Blue Point Spring. In both cases, the conceptual direction of groundwater flow crosses the Muddy Mountain Thrust Fault and requires that groundwater from the Paleozoic carbonate aquifer pass through Mesozoic clastic sediments and the Tertiary basin-fill evaporite lithologies (Muddy Creek and/or Horse Spring) in the lower thrust plate. Alternatively, groundwater could flow in the lower plate carbonate rocks, and upwards along the Roger Springs Fault, mixing with water discharging from the Mesozoic rocks as it ascends to the surface along the Rogers Spring fault zone (see cross-sections F-F' and G-G', Page et al., 2011). The study indicated that capture zone modeling of Rogers Spring and Blue Point Spring using a recently developed groundwater flow model of this region indicated that the more likely southern flow path is consistent with the geochemical data.

Both of these flow paths are further supported by recent potentiometric surface mapping of the upper carbonate-rock aquifer in southern Nevada (Wilson, 2019), which indicates a southeast flow direction through these basins toward the NPS' springs. This mapping was part of a larger study involving the drilling, installation and sampling of six monitoring wells completed in the carbonate-rock aquifer system underlying portions of Clark County. Two of these new wells [Buffington Pockets Well (BUFPKTS-01), which may be completed in the Mesozoic rock section below the Muddy Mountain thrust fault, and Rogers Bay Well (RB-01), which is completed near or within the Rogers Spring fault zone], provide important supporting hydrogeologic information on the carbonate rock flow system in California Wash near the Muddy Mountain thrust fault and in the Black Mountains Area near Rogers Springs, respectively. In particular, the water level for BUFPKTS-01, is about 105 feet and 187 feet higher than the water levels in RB-01 and Blue Point Spring, providing sufficient head potential to accommodate groundwater flow through permeable structures or formations within the Mesozoic rock section toward the NPS' springs. Oxygen/deuterium sampling results for BUFPKTS-01 are very similar to the results reported by Geochemical Technologies Corporation and Tetra Tech, Inc. (2012) for the Valley of Fire Well, which is completed in the Mesozoic section nearer to Blue Point Springs. The similarity in stable isotope results for both of these wells supports Geochemical Technologies' earlier suggestion of representing the composition of recharge from more local sources, probably the Muddy Mountains, but may themselves be a mixture of incoming water from the carbonate aquifer plus local recharge from the Muddy Mountains. The close similarity in the analytical results between RB-01, Rogers Spring and Blue Point Spring support the contention that much of their source water is probably originating from depth and ascends to the surface along the Rogers Spring fault zone at various spring discharge sites in the northern portion of Lake Mead NRA. The significant increase in dissolved solids and major ion content at Rogers Spring and Blue Point Spring likely is attributable to evaporite dissolution in the Mesozoic section, in Tertiary volcanic rocks, or in the Tertiary basin-fill sediments (Hershey and Mizell, 1995; Laney and Bales, 1996, from Geochemical Technologies Corporation and Tetra Tech, Inc., 2012).

Based on the information presented above, the NPS is concerned that increases in groundwater withdrawals along this Garnet Valley-California Wash-Black Mountain Area flow path, and possibly the central flow path through California Wash, may cause a decline in discharge from Rogers Spring and Blue Point Springs.

1.2 MANAGEMENT OF GROUNDWATER DEVELOPMENT IN THE LWRFS

The Nevada State Engineer, who regulates water rights within the State of Nevada, traditionally has managed groundwater development in Nevada within individual basins, using the concept of perennial basin yield to determine the amount of groundwater available for appropriation. This approach inherently assumes that groundwater flow is contained within an individual basin, where precipitation recharges the flow system and groundwater discharges from the flow system, primarily by evapotranspiration. As a result, the perennial yield has been defined as the amount of natural discharge that can be reasonably salvaged, without causing long-term depletion of the aquifer, and in no case should it exceed the estimated annual recharge of the basin. Unfortunately, this approach presents difficulties when the groundwater flow system within a basin is actually part of a more extensive regional groundwater flow system that hydraulically interconnects several individual basins.

In 2001, the NPS, the U.S. Bureau of Land Management (BLM), and the USFWS, collectively the Department of Interior (DOI) bureaus, participated in an administrative hearing held by the Nevada State Engineer concerning proposed groundwater development in Coyote Spring Valley, about 40 miles north of Las Vegas Valley. This hearing was one of the earliest examples where the individual basin management approach was challenged by the DOI bureaus' contention that the Coyote Spring Valley basin was part of a hydrologically-connected regional flow system in which the component basins should be managed collectively instead of individually. As part of their preparations for hearing, the DOI bureaus cooperated in the development of a preliminary numerical groundwater flow model, prepared by Tetra Tech, Inc., to simulate regional groundwater flow in the area and to evaluate and demonstrate the potential effects of large-scale groundwater pumping on water levels in the regional aquifer and on nearby spring flows.

Following this hearing, the Nevada State Engineer issued Order 1169 in 2002 holding all pending groundwater applications in Coyote Spring Valley and several surrounding hydrographic areas in abeyance, until further evaluation of the effects of pumping groundwater associated with existing permits was completed. During this abeyance period, the DOI bureaus participated in several scientific investigations with the goal of producing reliable information that would enable Tetra Tech, Inc. to develop refinements to the preliminary numerical model and improve the model's accuracy in predicting the effects of regional groundwater development on nearby Federal water resources. Some of the more notable investigations included gain-loss studies on the Muddy River (Beck and Wilson, 2006) and the Virgin River (Beck and Wilson, 2005), development of a regional geologic map (Page et al., 2005) and associated geologic cross-sections (Page et al., 2011) for the model area, geophysical studies of selected basins in the model area (Scheirer, Page and Miller, 2006), and estimation of evapotranspiration within the model area (DeMeo et al., 2008). Tetra Tech, Inc. completed refinements to the numerical model in 2012 and conducted several simulations to assess the pumping effects from existing water rights and most of the largest water rights applications held in abeyance. This work was documented in a model development report (Tetra Tech, 2012a) and a predictive modeling simulations report (Tetra Tech, 2012b).

During the abeyance period, the Nevada State Engineer required certain water-right holders to conduct a two-year pumping test, in which they were required to pump at least half of their existing water rights in Coyote Spring Valley annually. The purpose of the pumping test was to assess the potential effects on nearby water resources before ruling on the applicants' pending water-right applications in this valley and other surrounding valleys. This pumping test was started in late 2010 and completed in late 2012, at which time the Nevada State Engineer issued a modification to Order 1169 (Order 1169A) that invited any study participant to submit interpretive reports on the results of the pumping test in June 2013. The DOI bureaus submitted an interpretive report that also included additional simulation results generated using the updated predictive numerical model completed by Tetra Tech, Inc. All interpretive reports submitted were considered by the Nevada State Engineer in making their 2014 decisions to deny all pending applications in Coyote Spring Valley and several surrounding valleys. The NPS continues to support the analyses and conclusions presented in the 2013 data interpretation report submitted by the DOI bureaus.

In the years since the Order 1169 pumping test was completed, water level, spring discharge and pumping data continued to be collected in these same basins to monitor the effects of water-level recovery and ongoing groundwater pumping. In 2018, the Nevada State Engineer expressed concern to water-right holders in these basins that water levels and spring discharges affected by the earlier Order 1169 pumping test had not recovered to their pre-pumping conditions, and that higher levels of pumping were likely to adversely affect senior water right holders and an endangered fish (Moapa dace) in the Muddy River Springs Area. This subsequently led the Nevada State Engineer to issue Interim Order 1303 in January 2019, which designated several of the affected basins as a jointly managed administrative unit to be known as the Lower White River Flow System (LWRFS). Interim Order 1303 also seeks to maintain the status quo on groundwater withdrawals in this area, while allowing for the submittal of additional data to inform the Nevada State Engineer on groundwater sustainability, and for progress to continue on the development of a voluntary conjunctive management plan for the LWRFS.

In issuing Interim Order 1303, the Nevada State Engineer ordered that any stakeholder with interests that may be affected by water right development within the LWRFS may file a report by the established deadline, which should address the following matters:

a. The geographic boundary of the hydrologically connected groundwater and surface water systems comprising the LWRFS;

b. The information obtained from the Order 1169 aquifer test and subsequent to the aquifer test, and Muddy River headwater spring flow as it relates to aquifer recovery since the completion of the aquifer test;

c. The long-term annual quantity of groundwater that may be pumped from the LWRFS, including the relationships between the location of pumping on discharge to the Muddy River Springs, and the capture of Muddy River Flow;

d. The effects of movement of water rights between alluvial wells and carbonate wells on deliveries of senior decreed rights to the Muddy River; and

e. Any other matter believed to be relevant to the State Engineer’s analysis.

On behalf of the National Park Service, Tetra Tech, Inc. utilized the updated numerical groundwater flow model developed for the DOI bureaus to qualitatively evaluate some of the matters of interest to the Nevada State Engineer noted in Interim Order 1303. This includes evaluating the spatial relationships between the location of pumping on discharge to the Muddy River Springs and capture of Muddy River flow, the effects of moving water rights between alluvial aquifer wells and carbonate aquifer wells on the deliveries of senior decreed rights on the Muddy River, and the possible expansion of the current geographic boundary of the LWRFS. These are also matters of interest to the NPS, as such movement of water rights within the LWRFS could increase the threat potential to NPS-managed groundwater resources at Lake Mead NRA.

The updated numerical groundwater flow model was used to perform three simulations to qualitatively evaluate the effects of redistributing pumping within and between the alluvial and carbonate aquifers in the LWRFS, and where possible, make recommendations on geographic boundary adjustments to the hydrologically connected groundwater and surface water systems comprising the LWRFS. The three simulations, described in more detail in Section 3, include:

1. Simulation evaluating pumping by priority date,

2. Simulation evaluating the redistribution of increased pumping to the carbonate aquifer, and
3. Simulation evaluating the redistribution of pumping from the alluvial aquifer to the carbonate aquifer.

Each of these simulations limited pumping in the LWRFS to approximately 14,535 acre-feet/year. The results of this study are presented for consideration by the Nevada State Engineer and stakeholders with direct or indirect interests that may be affected by water right development in the LWRFS.

2.0 SUMMARY OF PREVIOUS GROUNDWATER MODELING

As stated in Section 1, Tetra Tech completed an update of their groundwater flow model of the LWRFS in 2012 (Tetra Tech, 2012a). A predictive scenario modeling report followed later that year describing seven scenarios of future pumping within the LWRFS (Tetra Tech, 2012b). After the Order 1169 aquifer testing was completed, a post audit was conducted on the 2012 Tetra Tech Groundwater Flow Model to see how well the 2012 model simulated this aquifer testing (Tetra Tech, 2013). The major conclusions from these three reports and observations of the interpretation of their results are provided below focusing on the five basins of interest.

2.1 2012 GROUNDWATER MODEL CALIBRATION

The 2012 groundwater flow model was completed for all or parts of 13 hydrographic areas within the lower portion of the Colorado River Regional Flow System in southeastern Nevada and parts of Arizona and Utah. Several of these hydrographic areas overlap with those in the Lower White River Flow System. This model simulates the movement of groundwater in an area ranging from the Clover and Delamar Mountains on the north to the Las Vegas Valley Shear Zone and Lake Mead on the south, and from the Sheep Range on the west to the Virgin and Beaver Dam Mountains on the east.

The 2012 model was calibrated based on many different types of information, including measurements of water levels and drawdown, discharge rates for springs, streamflow measurements, reported pumping rates that varied through time, seasonal estimates of ET based on field measurements and satellite mapping of plant communities, and estimates of model boundary fluxes based on regional information. A "pre-production" model was developed to match water levels and water-budget information. Simulated water levels agree well with observed water levels. The correlation between measured and simulated water levels was 0.96. The largest model residuals are in high gradient areas, where model errors can result in large differences, in the Clover Mountains where the volcanic stratigraphy is greatly simplified, and in the Tule Desert where some of the structural complexity may not be incorporated in the geologic model and the model grid is relatively coarse.

The model was also calibrated to the effects of time-varying pumping and seasonal ET during the period October 2008 through December 2011, primarily in the area of the Muddy River Springs, Coyote Spring Valley, and California Wash. This included calibrating the groundwater flow model to data collected during Year 1 of the two-year pumping test required by the Nevada State Engineer under Order 1169. The simulated drawdowns agree reasonably well with the observed drawdowns. In California Wash, the seasonal variation observed in the measurements is not present in the simulated water levels, but the longer-term trends are present.

The simulated discharge rates in the Muddy River Springs area and at Rogers and Blue Point springs agree very well with measured values. The simulated streamflow in the Muddy River near Moapa is less than measured, indicating that more water discharges directly into the stream above the gage than is being simulated, rather than downstream of the gage. In the lower part of Meadow Valley Wash, simulated water levels are higher than observed, causing simulated discharge into the stream over a larger area than it occurs. Similarly, simulated water levels are higher than measured in the lower parts of Beaver Dam Wash, causing simulated flow in the stream over a larger reach than observed. In these areas, the model is likely to underestimate the drawdown that occurs because of the larger area in which buffering of drawdown is simulated to occur. The effects of the drawdown on the Muddy

River Springs and discharge into the Muddy River may occur sooner than would be predicted by the model because of the simulated capture in lower reaches of the Muddy River and in the lowermost reaches of Meadow Valley Wash.

Pertinent observations and comments about the model are provided so that the user of the model is aware of limitations that may affect decisions made related to modeling predictions presented in this report and future reports until the model is re-calibrated:

1. The responses of the groundwater system to pumping are determined primarily by the local geology and the hydrologic properties of the aquifers being pumped. Pumping in the carbonate aquifer in the western part of the model produces widespread drawdown because of the high transmissivity and low storativity of the carbonate aquifer. The model predicts that pumping in the Virgin River basin causes more local (less widespread) drawdown of greater magnitude. Elsewhere, current groundwater development is more limited. In the volcanic rocks in the Clover and Delamar Mountains, the complex stratigraphy of the volcanic rocks will likely limit the extent of drawdown, and the productivity of the rocks will likely be highly variable. The complex stratigraphy is not incorporated in the model. The drawdown is reduced by proximity to large-volume springs, and to perennial reaches of streams. This local effect is caused by the buffering of drawdown caused by capture of water at these locations by pumping.

2. The use of the Well Package to simulate ET (so that seasonal changes in ET rates could be used as a driving function during model calibration) may cause head changes to be exaggerated during the long-term predictions of pumping in areas where ET rates are high and where drawdown from pumping occurs. In nature, as the water table declines, the ET decreases which in turn decreases the drawdown. However, in the simulation the rate of ET will remain constant and produce a greater drawdown. This effect has only been observed in a small reach of Meadow Valley Wash, where it appears that drawdown could be oversimulated by tens of feet over a small area. Effects in other areas do not appear to be significant but are unknown.

Prediction of the effects of groundwater pumping will be more reliable in areas where data are available on the responses to pumping and time-varying ET. The best dataset is from the vicinity of the Muddy River Springs and nearby areas (Coyote Spring Valley and California Wash). Thus, predictions for these areas will be most reliable. An evaluation of the uncertainty in model predictions would be a significant effort, and certainly was outside the scope of this current evaluation. An estimate (based on experience with this model and the sensitivity testing that was performed) of the prediction uncertainty for drawdown in these areas would be in the range of 20 to 30 percent over a period of 20 to 30 years. With increasing distance from the area of the Muddy River Springs, the uncertainty increases. In other areas where pumping is occurring (Garnet Valley and the Virgin River Valley), the simulated drawdowns are reasonable, but cannot be compared with measured drawdowns. Thus, there is more uncertainty of the model results to pumping in these areas.

In summary, this model is a great improvement over previous models of the area, because of the advances in information on the geology and hydrology of the study area, and improvements in modeling codes available. This is also the first model to include the Virgin River Valley and Tule Desert, the lower White River Flow System, and the area of Lower Meadow Valley Wash. It can be used to evaluate cumulative effects of pumping in different areas within the model, and to estimate the magnitude and timing of changes that will occur as a result of use of the groundwater. Predictions made using the model will be approximate but can be used to guide decisions about management of the groundwater resource and to determine whether there will be impacts on sensitive environments and on other users of the water. The uncertainty in the predictions will primarily affect the timing of when impacts become significant, not whether there will be impacts.

2.2 2012 PREDICTIVE MODEL SCENARIOS

Seven different predictive scenarios were evaluated, ranging from a continuation into the future of current pumping rates only, through pumping of all existing rights plus all pending applications filed through 2009. Major findings from these scenarios are presented below. For specific findings on the actual seven scenarios, please refer to Tetra Tech (2012b).

1. The impacts of pumping on spring discharge and stream flow will increase as time passes, and as the rates of pumping increase.
2. The effects of drawdown will cause impacts outside the modeled area, and capture flow from adjoining basins, including those in Utah and Arizona. The magnitude of this impact is not known but could be estimated by linking this model with models of other areas.
3. In some areas, the aquifers may not be able to sustain the projected pumping, regardless of effects elsewhere. In Scenarios 4 through 7, the maximum predicted drawdown exceeded 3,000 feet. The model also lowered the rate of production as water levels were lowered to below the assigned screen intervals of the wells.
4. There is uncertainty in these projections that needs to be evaluated further. A detailed uncertainty analysis is recommended. However, it is unlikely that the general conclusions will be altered substantially, but changes in new equilibrium discharge rates (for lower pumping rates) or rates of depletion would be expected to become better defined through the uncertainty analysis.

2.3 2013 POST AUDIT SUMMARY AND CONCLUSIONS

The Tetra Tech (2012a) model was calibrated using information available through December 2011. The pumping of MX-5, and the related collection of water-level and discharge information during the Order 1169 pumping test, has provided additional information that was used in evaluating the predictions made with the model pertaining to the effects of pumping in Coyote Spring Valley. The pumping dataset for the model was updated with monthly pumping information for 2012, and the model was run with this revised dataset. Results indicate that the model under-simulates the amount (i.e., calculates less effect) of drawdown and reduction of spring discharge than occurred as a result of MX-5 pumping during the Order 1169 pumping test period. The observed drawdown is more widespread, and is of greater magnitude, than simulated by the model during this period. The model simulates that the discharge from springs is not affected to a measurable amount, but the real effects are measurable. Thus, predictions that have been made with the model that evaluate the effects of pumping in Coyote Spring Valley should be considered conservative. More specifically, the actual impacts from pumping would be larger and more widespread than simulated by the model.

In addition, a 15-year period after the end of the Order 1169 pumping test on December 31, 2012 was simulated to determine how quickly water level (and spring discharge) recovery is likely to occur. This evaluation indicates that recovery from the 28-month pumping test will occur over years. In the Muddy River Springs area, it was estimated that recovery will be approximately 70% complete after 15 years. In areas that are "distant" from MX-5, results suggest that drawdown can still be increasing 15 years after pumping of MX-5 stopped. If pumping were to occur for longer than 28 months (the total time of the pumping at MX-5 as part of the Order 1169 test), the rate of recovery can be expected to be slower. In addition, the model predicts that drawdown will continue to increase throughout the LWRFS with pumping of approximately 11,500 acre-feet/year (afy).

The data collected during 2012 and the six years since the completion of the Order 1169 pumping test could be used to improve the calibration of the model to the observed effects of pumping in Coyote Spring Valley and neighboring LWRFS basins. A revised model would be expected to simulate greater and more widespread drawdown than the current model, more impact on spring flow, and shorter recovery times. This additional work was beyond the scope and timeframe for the modeling simulation effort conducted as part of this report.

3.0 DEVELOPMENT OF CURRENT PREDICTIVE SCENARIOS

3.1 GROUNDWATER WITHDRAWAL TRENDS IN LWRFS BASINS (2007 – 2017)

Table 3-1 presents the estimated annual withdrawals for each LWRFS basin from 2007 through 2017, as reported by the Nevada State Engineer in Appendix B of Interim Order 1303. Figure 3-1 presents a graphical representation of this annual withdrawal data for each basin. Additional summary statistics are included in Table 3-1, as estimated by the NPS. These statistics include summaries of estimated annual amounts of alluvial aquifer versus carbonate aquifer withdrawals, and the annual withdrawals grouped by the northern basins [Coyote Spring Valley and the Muddy River Springs Area (MRSA)] versus the southern basins (Garnet Valley, California Wash and Black Mountains Area). Figure 3-2 and Figure 3-3 present graphical representations of the additional summary statistics for each basin. This information was important in understanding the spatial and temporal trends of groundwater withdrawals over the last decade and helped to inform our development of the predictive scenarios described in the next section.

Annual pumping in the LWRFS basins has averaged about 11,900 acre-feet/year (afy) from 2007-2017 (Table 3-1). During this same period, approximately 34% (4,000 afy) of the average annual pumping occurred in the alluvial aquifer, most of it in the Muddy River Springs Area, and 66% (7,900 afy) occurred in the carbonate aquifer. Additionally, about 73% (8,700 afy) of the pumping during this period occurred in the northern basins and about 27% (3,200 afy) occurred in the southern basins. By individual basin, the estimated average annual withdrawals in descending order includes: Muddy River Springs Area – 5,800 afy (49%), Coyote Spring Valley – 2,900 afy (25%), Garnet Valley – 1,600 afy (13%), Black Mountains Area – 1,500 afy (12%), and California Wash – 100 afy (1%).

Examination of this same withdrawal data over shorter periods of time within this period of record indicates that greater amounts and percentages of withdrawals have been shifting from the alluvial aquifer to the carbonate aquifer and from the northern basins to the southern basins. In the years prior to the Order 1169 pumping test (2007-2010), annual withdrawals in the LWRFS basins averaged about 12,000 afy. During this same period, approximately 41% (4,900 afy) of the average annual pumping occurred in the alluvial aquifer and 59% (7,100 afy) occurred in the carbonate aquifer. During the Order 1169 pumping test period (2011-2012), average annual withdrawals in the LWRFS basins increased to about 14,535 afy, with approximately 29% (4,300 afy) of the average annual pumping occurring in the alluvial aquifer and 71% (10,300 afy) occurring in the carbonate aquifer. In the two years following the pumping test (2013-2014), average annual withdrawals generally returned to pre-test levels, averaging about 12,600 afy, along with similar pre-test percentages and amounts of annual pumping occurring in the alluvial aquifer (41% or 5,100 afy) and carbonate aquifer (59% or 7,500 afy).

In the last three years of record (2015-2017), the annual withdrawals in the LWRFS basins decreased substantially to about 9,400 afy, with approximately 18% (1,700 afy) of the average annual pumping occurring in the alluvial aquifer and 82% (7,600 afy) occurring in the carbonate aquifer. This drop in groundwater withdrawals is primarily due to reduced alluvial aquifer pumping by NV Energy in the Muddy River Springs Area, as the Reid Gardner power plant was decommissioned and the need for this water diminished. This decrease is reflected in the estimated alluvial aquifer pumping information for the Muddy River Springs Area contained in Appendix B of Interim Order 1303, in which NV Energy's average annual pumping from the alluvial aquifer was about 4,150 afy from 2007-2014, and dropped to about 900 afy from 2015-2017.

In the years prior to the Order 1169 pumping test (2007-2010), approximately 76% (9,100 afy) of the average annual pumping occurred in the northern basins and 24% (2,900 afy) occurred in the southern basins. During the Order 1169 pumping test period (2011-2012), average annual pumping in the northern basins increased slightly to about 80% (11,600 afy), while average annual pumping in the southern basins decreased slightly to 20% (2,900 afy) of the total pumping in the LWRFS basins. In the two years following the pumping test (2013-2014), average annual pumping generally returned to pre-test levels, with similar pre-test percentages and amounts of annual pumping occurring in the northern basins (75% or 9,400 afy) and southern basins (25% or 3,200 afy).

In the last three years of record (2015-2017), the average annual pumping in the northern basins noticeably decreased to about 61% (5,800 afy), while average annual pumping in the southern basins increased to 39% (3,600 afy) of the total pumping in the LWRFS basins. Again, this drop in groundwater withdrawals in the northern basins is primarily due to reduced alluvial pumping by NV Energy in the Muddy River Springs Area. Prior to this period, average annual pumping in the northern basins was about 9,800 afy, and decreased to about 5,700 afy, which represents about a 41% reduction by comparison. The noticeable percentage increase in groundwater withdrawals in the southern basins is mainly the result of this pumping making up a larger percentage of the whole during this 3-year period, as pumping in the northern basins decreased. It should be noted that average annual pumping in the southern basins has been slowly rising in recent years from an average of about 2,900 afy (2007-2012) to about 3,400 afy (2013-2017), which represents about an 18% increase by comparison.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Average
Coyote Spring V. (210)	3,147	2,000	1,792	2,923	5,606	5,516	3,407	2,258	2,064	1,722	1,961	2,945
Black Mtns Area (215)	1,585	1,591	1,137	1,561	1,398	1,556	1,585	1,429	1,448	1,434	1,507	1,476
Garnet V. (216)	1,412	1,552	1,427	1,373	1,427	1,351	1,484	1,568	1,520	2,181	1,981	1,571
California Wash (218)	27	27	21	26	33	28	66	241	460	252	88	115
MRSA (219)	7,076	6,811	6,379	6,167	6,302	5,852	6,712	6,520	3,898	4,048	3,553	5,756
TOTAL	**13,247**	**11,981**	**10,756**	**12,050**	**14,766**	**14,303**	**13,254**	**12,016**	**9,390**	**9,637**	**9,090**	**11,863**
Alluvial Aquifer	5,361	4,877	4,722	4,764	4,892	3,627	4,629	5,691	2,070	1,856	1,288	3,980
	40%	41%	44%	40%	33%	25%	35%	47%	22%	19%	14%	34%
Carbonate Aquifer	7,886	7,104	6,034	7,286	9,874	10,676	8,625	6,325	7,320	7,781	7,802	7,883
	60%	59%	56%	60%	67%	75%	65%	53%	78%	81%	86%	66%
Basins 210 + 219	10,223	8,811	8,171	9,090	11,908	11,368	10,119	8,778	5,962	5,770	5,514	8,701
	77%	74%	76%	75%	81%	79%	76%	73%	63%	60%	61%	73%
Basins 215 + 216 + 218	3,024	3,170	2,585	2,960	2,858	2,935	3,135	3,238	3,428	3,867	3,576	3,161
	23%	26%	24%	25%	19%	21%	24%	27%	37%	40%	39%	27%

Table 3-1. Summaries of estimated annual withdrawals (acre-feet/year) from LWRFS basins and aquifers, 2007-2017.
[Sources: NDWR Interim Order 1303 (App. B) & NDWR pumping inventories for LWRFS basins and aquifers

3.2 CURRENT PREDICTIVE SCENARIOS EVALUATED

The updated numerical groundwater flow model was originally calibrated to data collected during Year 1 of the two-year pumping test required by the Nevada State Engineer under Order 1169. Subsequent simulations indicated the model conservatively under-predicted the effects of pumping observed during the Order 1169 pumping test (See Section 2 for further discussion). The NPS has requested additional model simulations to qualitatively assess the spatial relationships between the location and redistribution of withdrawals within and between the alluvial and carbonate aquifers in the LWRFS, and the accompanying effects on the groundwater resources in the Muddy River Springs headwater area and Lake Mead NRA.

The updated groundwater flow model was used to conduct a set of three (3) simulations, which allows for the qualitative evaluation of the potential effects of redistributing pumping within and between the alluvial and carbonate aquifers in the LWRFS. In all 3 simulations, the total groundwater withdrawals in the LWRFS basins was maintained at or near the average annual withdrawals achieved during the Order 1169 pumping test (approximately 14,535 afy), so that the effects of progressively moving greater volumes of withdrawals further from the Muddy River Springs Area can be assessed under the same level of pumping stress within the LWRFS. This pumping level was chosen for this set of simulations because pumping impacts to the Muddy River Springs headwater area were observed not only during the Order 1169 pumping test, but also in pumping Simulation #1, which was reported in the earlier modeling simulation work conducted in 2012 (Tetra Tech, 2012b). Under Scenario #1, the pumping level simulated in the LWRFS basins was approximately 14,470 afy, which represented the average pumping conditions occurring in the 2009-2011 time frame, the latter part of which the Order 1169 pumping test had started. By extension, Scenario #1 modeled the estimated long-term pumping impacts in the LWRFS associated with withdrawals estimated to have occurred during the Order 1169 pump test period. Given that similar pumping impacts were observed on the ground and in the groundwater flow model results under similar aquifer stress conditions, this provides confidence in using the groundwater flow model as a tool to qualitatively evaluate whether or not similar pumping impacts may occur under similar aquifer stress conditions, but different spatial pumping arrangements for the 3 simulations modeled as part of this report.

Simulation #1

In the first simulation, a scenario of pumping by "priority date" in the LWRFS was evaluated. Table 3-2 and Figure 3-4 presents the annual withdrawals simulated in each LWRFS basin for the three withdrawal scenarios evaluated in this report. In the first scenario, nearly all of the senior water rights are concentrated in the northern basins. Under this scenario, approximately 96% (13,926 afy) of the simulated annual withdrawals occurs in the northern basins and the remaining 4% (609 afy) of withdrawals occurs in the southern basins. However, withdrawals are distributed between the alluvial and carbonate aquifers in relatively equivalent amounts of about 6,904 afy (47%) and 7,631 afy (53%), respectively (see Table 3-2 and Figures 3-5 and 3-6).

This first simulation serves as a baseline from which to qualitatively evaluate the effects on the Muddy River Springs headwater area resulting from redistributing withdrawals to other basins within the LWRFS, which were evaluated in the two subsequent modeling simulations. This first simulation also may help to inform the State Engineer and stakeholders on the potential pumping effects that might result if stakeholders are unable to voluntarily develop a conjunctive management plan and the State Engineer is forced to "manage by priority date."

	Simulation #1	Simulation #2	Simulation #3
Coyote Spring Valley (210)	6,440	1,934	1,730
Black Mountains Area (215)	0	1,374	1,638
Garnet Valley (216)	519	2,103	4,234
California Wash (218)	90	2,362	3,316
Muddy River Springs Area (219)	7,486	6,761	3,616
TOTAL	14,535	14,534	14,534
Alluvial Aquifer	6,904	2,234	1,376
	47%	15%	9%
Carbonate Aquifer	7,631	12,300	13,158
	53%	85%	91%
Basins 210 + 219	13,926	8,695	5,346
	96%	60%	37%
Basins 215 + 216 + 218	609	5,840	9,188
	4%	40%	63%

Table 3-2. Summaries of simulated annual withdrawals (acre-feet/year) from LWRFS basins and aquifers.

Simulation #2

In the second simulation, the model simulated a scenario in which the existing water rights associated with all active 2017 pumping sites in the LWRFS were apportioned equally (approximately 82.5% of each annual duty) to reach the same level of total annual pumping achieved during the Order 1169 pumping test. Under this scenario, approximately 60% (8,695 afy) of the withdrawals occurs in the northern basins and the remaining 40% (5,840 afy) of the withdrawals occurs in the southern basins. Approximately 15% (2,234 afy) of the pumping occurs in the alluvial aquifer and 85% (12,300 afy) occurs in the carbonate aquifer under the second simulation (see Table 3-2 and Figures 3-5 and 3-6). These percentages are nearly identical to those estimated for the actual 2017 pumping total reported in the LWRFS by the Nevada State Engineer.

Pumping locations in 2017 are more widely distributed throughout the LWRFS compared to the concentration of pumping that occurs under the first simulation. As a result, this second simulation should provide a convenient way to qualitatively evaluate the effects of redistributing larger portions of the alluvial and/or carbonate withdrawals to other areas within the LWRFS, when compared to the effects predicted for the first simulation. This simulation also should help to provide similar qualitative information on the potential effects of redistributing increased amounts of pumping closer to the groundwater resources of concern managed by the NPS.

Simulation #3

In the third simulation, the apportioned pumping occurring at the 2017 pumping sites in the LWRFS under the second simulation was modified to accommodate the redistribution of pumping from alluvial aquifer sites in the northern basins to carbonate aquifer sites in the southern basins. Under this modified scenario, water rights associated with 2 sets of pending change applications submitted by NV Energy (Application Nos. 87735, 87736, 87738 and 88181 for a total combined duty of 1,800 afy) and the Moapa Band of Paiute Indians (Application Nos. 86738 and 86739 for a total combined duty of 500 afy) are redistributed from alluvial aquifer pumping sites in the Muddy River Springs headwater area to carbonate aquifer pumping sites in Garnet Valley and California Wash, respectively. While the actual NV Energy change applications seek to move a portion of an unused junior carbonate aquifer water right in Coyote Spring Valley to existing carbonate aquifer pumping sites in Garnet Valley, this simulation instead chose to examine a possible alternative scenario where a similar amount of senior alluvial water rights owned and used by NV Energy in the Muddy River Springs headwater area is moved to the same existing carbonate aquifer pumping sites in Garnet Valley. Under this third simulation, it is assumed that all water rights held by NV Energy at alluvial aquifer pumping sites in the Muddy River Springs headwater area are not pumped, as NV Energy would have no need for this water in this area. In the case of the Moapa Band of Paiute Indians, their change application actually involves moving senior alluvial aquifer water rights recently acquired from NV Energy from the Muddy River Springs headwater area to existing carbonate aquifer pumping sites on the Moapa River Indian Reservation. Under the third simulation, these senior alluvial rights were pumped in full, while the remainder of the Moapa Band of Paiutes carbonate aquifer water rights were prorated accordingly with other water rights in the southern basins.

Under the third simulation, the existing water rights associated with all 2017 pumping sites in Coyote Spring Valley and the Muddy River Springs Area were used in equal proportions (approximately 74% of each annual duty) to help make up the difference in achieving the same level of total pumping (14,535 afy) tested in the first two simulations. The one exception was pumping of Moapa Valley Water District (MVWD) water rights, which were held at their reported 2017 total pumping level (2,823 afy). This one exception allowed for an intermediate pumping level (compared to the first two simulations) to be evaluated for the MVWD as part of the three simulations performed. Similarly, the existing water rights associated with the remaining 2017 pumping sites in Garnet Valley, California Wash and the northwest corner of the Black Mountains Area were used in equal proportions (approximately 98% of each annual duty), but at a higher level than those in the northern basins. The proration of pumping in these southern basins was higher in order to further accommodate increased levels of pumping in the southern basins, while the overall level of total pumping within the LWRFS remained consistent with the first two simulations. The one exception in the southern basins involved the NV Energy carbonate aquifer pumping site in Garnet Valley, where only the changed amount of 1,800 afy was simulated.

Under this modified scenario, approximately 37% (5,346 afy) of the pumping occurs in the northern basins and the remaining 63% (9,188 afy) of pumping occurs in the southern basins. Approximately 9% (1,376 afy) of the pumping occurs in the alluvial aquifer and 91% (13,158 afy) occurs in the carbonate aquifer under the third simulation (see Table 3-2 and Figures 3-5 and 3-6).

The third simulation should serve to qualitatively evaluate the potential effects of redistributing greater amounts of alluvial pumping away from the Muddy River Springs headwater area and to the carbonate aquifer, when compared to the effects predicted for the first two simulations. This simulation also should help to provide similar qualitative information on the potential effects of redistributing greater amounts of pumping closer to the groundwater resources of concern managed by the NPS.

In addition to the groundwater pumping simulated in the LWRFS basins, groundwater pumping was also simulated in Kane Springs Valley in all three simulation runs to qualitatively evaluate potential pumping interactions with groundwater withdrawals occurring in Coyote Spring Valley and the Muddy River Springs Area. Such interactions could indicate that Kane Springs Valley may be hydrologically connected to Coyote Springs Valley, and therefore may need to be considered for inclusion in the LWRFS. To date, groundwater rights have been permitted, but not used, in the amount of 1,000 afy in Kane Springs Valley. Pumping in Kane Springs Valley was simulated at four proposed points of diversion associated with these existing water rights.

Groundwater pumping was also simulated in the Tule Desert basin and the Virgin River Valley basin to qualitatively evaluate if there could be drawdown interference effects between these two pumping centers and the pumping simulated in the LWRFS. The amount of permitted groundwater simulated in all three scenarios for the Tule Desert basin and the Virgin River Valley basin was 9,340 afy and 12,272 afy, respectively. This approach of simulating the permitted water rights in neighboring basins beyond the current boundary of the LWRFS is consistent with pumping Scenario #2 reported in the earlier modeling simulation work conducted in 2012 (Tetra Tech, 2012b).

4.0 PREDICTION SIMULATIONS

4.1 MODEL SETUP

For the predictions of the effects of the three pumping scenarios, some model datasets described in Tetra Tech (2012b) were modified to represent changes in hydrogeologic conditions since the release of the 2012 groundwater model or improve model performance, while others remained unchanged.

Initial conditions of hydraulic head for the predictive scenarios were calculated by the model at the end of a long-term historic simulation representing December 31, 2017. The existing pumping records used to generate the 2012 model predictive scenarios' initial conditions represented actual groundwater withdrawal through 2011. Recent pumping records published by the Nevada State Engineer's Office (NSEO) were used to update most of the pumping rates through calendar year 2017.

When available, monthly pumping rates were used from 2012 through 2017. Otherwise, annual rates were distributed evenly across the year for which they were reported to NSEO. An exception was made for pumping wells in the Virgin River Valley, for which we applied the wells' average annual pumping rate between 2009 and 2011 through the end of the long-term historic simulation in 2017.

The long-term historic simulation used a combination of monthly and yearly stress periods with single time-steps within each. Model simulations for predictive scenarios used a single stress period of 500 years, split into one hundred 5-year time steps.

No changes were made to the material properties of the 2012 model.

Most boundary conditions were unchanged from the previous predictive scenario model simulations. For the long-term historic simulation, the constant-head boundaries representing Lake Mead were updated to represent changes in lake stage between 2011 and 2017. For the predictive scenarios, the lake stage was set to an elevation of approximately 1,133 feet above mean sea level, the lake stage used for the previous predictive modeling runs, to be consistently conservative. Additionally, some pumping wells were added to the long-term historic simulation, to account for pumping at new locations since 2011 reported to the NSEO. Predictive scenario pumping rates are summarized in Table 4-1, and shown in full in Appendix B.

4.2 PREDICTION RESULTS

The results of the model predictions are presented through a series of the maps showing simulated drawdown at specific times, and graphs of simulated spring discharge and streamflow versus time at select locations. The scales for both map and graphical figures are kept constant across time and scenarios to allow the reader to more easily compare the differences in simulation results.

Information is provided on both drawdown and discharge because of the relationship between the two. For example, when drawdown occurs beneath a stream that is hydraulically-connected with the groundwater system, the drawdown will reduce groundwater discharge to a gaining stream or increase losses from a losing stream. In this case, pumping causing drawdown is capturing water from the stream. Similarly, when a portion of the water being pumped from a well is being captured from a stream, drawdown is reduced. The amount of drawdown is buffered by stream-water capture. Similar effects occur between groundwater and groundwater-fed streams and springs. If the stream or spring is dry or poorly connected to the groundwater system, however, this capture and buffering will not occur. In this way, drawdown maps and stream and spring discharge plots can provide information on whether a stream or spring is flowing and able to buffer drawdown. In the following drawdown maps, streams or springs that appear to be affecting drawdown are likely to be flowing. Streams or springs not affecting drawdown are likely either dry or poorly connected to the groundwater system.

Each of the three scenarios simulate 500 years of pumping, beginning on January 1, 2018. Each of the three simulations also simulate the pumping of approximately 14,535 afy from the LWRFS basin. Pumping was also simulated in Kane Springs Valley, Virgin River Valley, and Tule Desert at rates equal to their full permitted annual duty and kept constant across all three simulations. While alluvial aquifer pumping generally is moved away from the Muddy River Springs Area in Simulations 2 and 3, an exception is noted for a well owned by NV Energy located in California Wash near the Muddy River Springs Area. This well is pumping from the alluvial aquifer in close proximity to the Muddy River and its pumping rate was increased in Simulations 2 and 3 due to the methodology applied to increase pumping in the southern basins, which includes California Wash. As a result, the alluvial pumping associated with this well is likely contributing to the simulated reduction of streamflow in the river. Relative magnitude and distribution of pumping across the three scenarios is shown in Figures 4-1 through 4-3. Table 4-1 presents the withdrawal amounts for several of the larger water right holders in the LWRFS basins that were modeled in the three simulations. Appendix B presents a similar summary of the withdrawal amounts for all water-right holders that were modeled in the three scenarios.

Water Right Holder Pumping Basin	2017 Withdrawals (ac-ft)	Simulation #1 Withdrawals (afy)	Simulation #2 Withdrawals (afy)	Simulation #3 Withdrawals (afy)
Coyote Springs Investment				
Coyote Spring Valley	1,399	4,140	1,650	1,477
SNWA				
Coyote Spring Valley		1,957		
Garnet Valley	1,048		1,433	1,709
Moapa Valley Water District				
California Wash		90		
Muddy River Springs Area	2,823	1,000	5,079	2,823
Moapa Band of Paiutes				
California Wash	43		2,063	2,960
Muddy River Springs Area		500		
NV Energy				
California Wash	29		299	356
Garnet Valley	75	75	62	1,800
Muddy River Springs Area	296	3,160	795	
LDS Church				
Muddy River Springs Area	240	2,329	655	586
Nevada Cogeneration Associates				
Black Mountains Area	1,507		1,374	1,638

Table 4-1. Summary of the largest simulated annual withdrawals for selected water-right holders in the LWRFS basins and aquifers.

4.3 DRAWDOWN MAPS

Simulated drawdown for model layer 1 is shown on Figures 4-4 through 4-12 for simulated times of 10, 100, and 200 years for Simulations 1 through 3. An inset has been added to these figures to show a close-up of drawdown around the Muddy River Springs Area. Model layer 1 represents the water table, and drawdown in deeper layers will differ from that simulated for layer 1, depending on the depth of pumping and geology. In addition, simulated streams are located in layer 1, and their effect on the drawdown is greatest in layer 1. The model-predicted drawdown is calculated based on the simulated water levels at the end of the long-term historic simulation (December 2017). It should be noted that annual pumping within the LWRFS basin at the end of the long-term simulation was approximately 9,500 afy, substantially less than the pumping rate assigned for the three scenarios (14,535 afy).

4.3.1 Results at 10 years

To reiterate, withdrawals in Simulation 1 were modeled on a "priority date" basis, resulting in the vast majority of the pumping (96%) occurring in the northern basins and with pumping being distributed between the alluvial aquifer and the carbonate aquifer in roughly equivalent proportions (47% and 53%, respectively). Under this scenario, the largest withdrawals involved pumping of alluvial-aquifer rights held by NV Energy and the LDS Church in the Muddy River Springs Area, and pumping of carbonate-aquifer rights held by Coyote Springs Investment (CSI) and Southern Nevada Water Authority (SNWA) in Coyote Spring Valley and MVWD in the Muddy River Springs Area (Table 4-1 and Appendix B).

The simulated drawdown for Simulation 1 after 10 years is between 2 and 20 feet in the immediate vicinity of Muddy River Springs Area (Figure 4-4). In the carbonate aquifer beneath Coyote Spring Valley, Hidden Valley (North), Garnet Valley, California Wash, and the rest of Muddy River Springs Area, drawdown is widespread and ranges from 1 to 5 feet, with larger drawdown occurring near the CSI and MX-5 wells. In Kane Springs Valley, drawdown from the three southernmost wells, pumping from the carbonate aquifer, have coalesced with the drawdown in the LWRFS basin. The northernmost well in Kane Springs Valley is pumping from the less hydraulically conductive volcanic aquifer and has induced a larger drawdown of over 20 feet that extends over a more restricted area. Drawdown induced by pumping in Kane Springs Valley and Muddy River Springs Area is also observed in Lower Meadow Valley Wash.

In Simulation 2, withdrawals for existing water rights associated with active 2017 pumping sites in the LWRFS were apportioned equally (approximately 82.5% of each annual duty) resulting in about 60% and 40% of the pumping occurring in the northern basins and southern basins, respectively, and with pumping being distributed between the alluvial aquifer and the carbonate aquifer in amounts of 15% and 85%, respectively. Under this scenario, the largest withdrawals involved pumping of carbonate aquifer rights held by MVWD in the Muddy River Springs Area, the Moapa Band of Paiute Indians in California Wash and CSI in Coyote Spring Valley, and pumping of alluvial aquifer rights held by NV Energy and the LDS Church in the Muddy River Springs Area (Table 4-1 and Appendix B).

The simulated drawdown for Simulation 2 at 10 years shows smaller magnitude and less extensive drawdown in the Muddy River Springs area compared to Simulation 1 (Figure 4-5). Maximum drawdown is reduced to below 10 feet, and the area of drawdown exceeding 2 feet has been substantially reduced. Drawdown in the carbonate aquifer beneath Coyote Spring Valley and surrounding basins has expanded to the south and has reached the southern model boundary (Las Vegas Valley Shear Zone), and the area of increased drawdown of 2 to 5 feet has shifted to the Moapa Band of Paiute Indians' wells in California Wash. Drawdown in Kane Springs Valley carbonate aquifer has been isolated from the area of drawdown in Coyote Springs Valley, but the relative extent and magnitude has remained the same.

In Simulation 3, existing water rights in the northern basins were used in lower proportions (about 74% of each annual duty) while existing water rights in the southern basins were used in higher proportions (about 98%), compared to Simulation 2. Additionally, this scenario also simulated the transference of alluvial-aquifer rights held

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by NV Energy and the Moapa Band of Paiute Indians in the northern basins to carbonate aquifer pumping sites in the southern basins, thus resulting in about 37% and 63% of the pumping occurring in the northern basins and southern basins, respectively, and with pumping being distributed between the alluvial aquifer and the carbonate aquifer in amounts of 9% and 91%, respectively. Under this scenario, the largest withdrawals involved pumping in the carbonate aquifer by the Moapa Band of Paiute Indians in California Wash, MVWD in the Muddy River Springs Area, NV Energy and SNWA in Garnet Valley and CSI in Coyote Spring Valley. Pumping of alluvial aquifer rights by several entities on the order of a few hundred acre-feet/year occurred mostly in the Muddy River Springs Area (Table 4-1 and Appendix B).

The simulated drawdown for Simulation 3 shows an even less extensive area of drawdown in the Muddy River Springs Area, but still shows an area of drawdown exceeding 5 feet, centered on the LDS East well (Figure 4-6). Drawdown in the carbonate aquifer beneath Coyote Spring Valley and surrounding basins is now mostly concentrated in Hidden Valley, Garnet Valley, and California Wash, and shows drawdown exceeding 2 feet over an area much larger than either Scenario 1 or 2. The pattern of drawdown in Kane Springs is very similar to what is seen in Simulation 2.

Patterns of drawdown in the Virgin River Valley and Tule Desert remain the same across all three scenarios, which is expected because pumping rates remain the same. Less permeable aquifer units in both basins result in larger drawdown cones over relatively restricted areas compared to drawdown seen in the LWRFS carbonate aquifer to the west and southwest. Changes in Lake Mead stage between the historic and predictive simulation causes drawdown to be calculated at some model cells adjacent to the lake that are not associated with pumping.

4.3.2 Results at 100 years

The simulated drawdown for Simulation 1 after 100 years shows an increase in drawdown in the Muddy River Springs Area, with the magnitude of drawdown increasing to over 5 feet for most of the inset area and the area of drawdown exceeding 10 feet expanding to the west to include the Lewis and Arrow Canyon wells (Figure 4-7). Drawdown in the carbonate aquifer beneath Coyote Spring Valley and surrounding basins has expanded and now extends over most or all of Coyote Spring Valley, Hidden Valley (North), California Wash, Garnet Valley, and northeastern Las Vegas Valley, with drawdown between 5 and 20 feet. Drawdown in the Kane Springs Valley carbonate and volcanic aquifers has coalesced with both drawdown in the LWRFS and Tule Desert, in the Lower Meadow Valley Wash area.

Simulated drawdown for Simulation 2 is very similar to Simulation 1, with some exceptions (Figure 4-8). Drawdown in the Muddy River Springs Area is limited to less than 10 feet. However, the area of drawdown exceeding 5 feet has expanded south to the model boundary in Las Vegas Valley, Garnet Valley, California Wash, and the eastern edge of the Black Mountains Area.

Simulated drawdown for Simulation 3 after 100 years is again similar to that of Simulation 1 (Figure 4-9). The area of drawdown exceeding 5 feet has been further reduced compared to Simulation 2, and drawdown is visibly buffered by the Muddy River. Drawdown has exceeded 10 feet in California Wash, Garnet Valley, Hidden Valley (North), northeastern Las Vegas Valley, and a small portion of the Black Mountains Area.

Drawdown in the Virgin River Valley and Tule Desert have exceeded 100 feet and 200 feet, respectively, and coalesced. Flow in the Virgin River continues to buffer drawdown, preventing drawdown from expanding into Utah, and almost entirely separating drawdown cones in Nevada.

4.3.3 Results at 200 years

Simulated drawdown in Simulation 1 follows a similar pattern as simulated drawdown after 100 years (Figure 4-10). Drawdown exceeding 10 feet in the Muddy River Springs Area has expanded and the buffering of drawdown by the Muddy River is less impactful. Drawdown in the northern portion of the LWRFS carbonate aquifer, southern Kane Springs Valley, and southwestern Lower Meadow Valley Wash has exceeded 10 feet.

Simulated drawdown in Simulation 2 after 200 years closely resembles Simulation 1 (Figure 4-11). Drawdown exceeding 10 feet is less extensive than in Simulation 1 after the same amount of time, and the Muddy River is more effective at buffering drawdown. Drawdown increases to above 10 feet in the carbonate aquifer below the southern portion of the LWRFS and extends to the Las Vegas Valley shear zone.

Drawdown for Simulation 3 after 200 years varies only a small amount from Simulation 2 (Figure 4-12). There is a small reduction in the area of drawdown exceeding 10 feet in the Muddy River Springs Area and southwestern Lower Meadow Valley Wash, while the area and magnitude of drawdown increases slightly in northeastern Las Vegas Valley and the Black Mountains Area.

4.4 FLOW HYDROGRAPHS

Hydrographs of simulated spring discharge and stream flow for the three simulations are presented below. Locations of the flow measurements within the model are shown in Figure 4-13.

4.4.1 Muddy River Springs Area Flow Comparison

Changes in spring discharge at the Muddy River Springs Area are shown in Figure 4-14. Spring discharge is relatively consistent through all three simulations. After ten years, Simulation 3 shows the highest discharge rate for all springs, followed by Simulation 2, then Simulation 1, each with marginally lower rates. Between 200 and 300 years, discharge for Simulation 2 decreases to below the discharge rate for both Simulations 1and 3. The relative amounts of discharge then remain the same for the reminder of the simulation, with Simulation 3 having the highest discharge and Simulation 2 the lowest. Across all springs, Muddy Spring shows the largest difference in discharge between the three scenarios, while the Cardy-Lamb and Pederson springs show the smallest differences. Pederson Spring is predicted to dry up at approximately 250 years, but because the model underpredicted drawdown by several fold in this area, the spring would likely become dry many years sooner.

The primary effect on moving the locations of pumping to the southern basins is a slight increase in flow rate, causing a delay of 10 to 25 years for flow from Muddy Spring to match the Simulation 1 rates for the other simulations. Delays are shorter for the other springs.

4.4.2 Streamflow Comparison

Simulated streamflow along Muddy River are shown in Figures 4-15 through 4-18. Figure 4-15 shows all simulated streamflow for all locations at the same scale for Simulation 1. Figures 4-16 through 4-18 show streamflow at select areas for all three scenarios.

Simulated streamflow at the upper confluence of the Muddy River is approximately 5 cubic feet per second (cfs) at the beginning of all simulations and decreases to about 3 cfs after 500 years. Simulation 3 shows the highest discharge throughout the simulation with Simulation 2 showing a just slightly lower value, and Simulation 1 the lowest.

Simulated streamflow at Muddy River near Moapa is approximately 25 cfs at the beginning of the simulation and decreases to approximately 17 cfs after 500 years. Scenario 3 has the highest flow rate, followed by Scenario 2. Scenario 2 and 3 flow about 1.1 cfs and 1.5 cfs higher than Scenario 1, respectively, at the beginning of the simulation, with the differences reducing over time.

Streamflow for the Muddy River above Overton, near Glendale, and near Bowman Reservoir all show similar flow rates throughout the simulation. Flow rates range from 61 to 63 cfs at the beginning of the simulation and decrease to 45 to 46 cfs after 500 years. Simulation 3 shows the highest discharge among the three scenarios throughout the simulation, with the difference in flow rates across scenarios decreasing with time. The large increase in streamflow between Moapa and Glendale is caused by displacement along the Muddy Mountain Thrust Fault, placing lower permeability Mesozoic rocks against the carbonate aquifer (Figure 1-2), damming up the water and raising water levels on the upgradient side of the fault.

Simulated streamflow for the Muddy River at Lake Mead decreases from about 53 cfs down to 38 cfs over 500 years of simulation. Again, Simulation 3 shows a higher discharge than Simulation 1 or 2, with a decrease in the differences between them over time. The changes in rate of streamflow decline during the first forty years of simulation is largely caused by the difference in lake stage between the historical and predictive simulations.

Moving the locations of pumping to the southern basins is predicted to result in higher surface-water flow rates but not enough to prevent the decline of streamflow. The time required for the flow rate to reach a certain value (e.g., 60 cfs) is increased at the different downstream locations (for example, near Glendale and Bowman Reservoir) is increased by 25 to 40 years for Simulation 2, and 35 to 60 years for Simulation 3. Moving pumping will not prevent impacts to surface-water rights, but does delay the impact.

4.4.3 Rogers and Blue Point Springs Comparison

Simulated discharge from the Rogers and Blue Point Springs are shown in Figure 4-18. Discharge from the springs is highest at the beginning of the simulations, about 2.25 cfs. Discharge from the springs is reduced by the smallest amount in Simulation 1, down to 2.1 cfs. Simulation 2 and 3, in which greater amounts of pumping were moved from the northern to southern basins, simulated a slightly lower discharge of about 2.0 cfs after 500 years.

5.0 DISCUSSION

5.1 SIGNIFICANT OBSERVATIONS FROM THE PREDICTIVE RUNS FOR THE THREE SCENARIOS

Predicted decline in spring and stream discharge - The predictive runs assume a constant pumping rate of about 14,535 afy. This rate is consistent with the average annual pumping that occurred during the Order 1169 test, and is greater than the rate in 2017 (approximately 9,300 afy) that was used to develop the starting conditions for the predictive simulations. As a result, the increase in pumping in the predictive runs causes an increase in the rate of decline in discharge at the Muddy River Springs Area that decreases over several decades. Pumping at the lower historical rates caused smaller declines in simulated discharge. Because the model under-simulated the effects of the Order 1169 pumping, it should not be used to predict the magnitude of the change in discharge for future pumping without additional calibration. However, it can be used to predict the direction of change, and to compare the effects of pumping from different areas. The model suggests that re-establishing hydrologic equilibrium with a LWRFS pumping rate of 14,535 afy will require centuries (longer than 500 years in the simulations), and that discharge rates will continue to decrease for centuries.

Temporal and spatial changes in drawdown – The spatial distribution of drawdown is affected by the locations of pumping at early time, but less so for longer time. During the first several decades, there are very apparent differences between the maps of predicted drawdown for the three scenarios. Shifting of pumping to the southern basins (Simulations 2 and 3) causes drawdown in the northern basins to decrease initially. However, with continued pumping, the differences between the maps decrease significantly as the drawdown extends over long distances from the pumping wells. A strategy of moving pumping away from the MRSA to protect the springs and streamflow will be beneficial for a relatively short period of time (decades) but is unlikely to be a long-term solution, because of the continuity of the carbonate aquifer and its hydraulic properties.

Limited effect of changing pumping from northern to southern basins on discharge rates – With the total pumping rate from the LWRFS held constant in all 3 simulations, changing the locations of pumping cause small changes in the predicted impacts on discharge rates at early time. Because the drawdown effects extend over large areas (as demonstrated by the Order 1169 test), as pumping continues the differences between the scenarios diminish. In

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other words, moving pumping away from the MRSA and Coyote Spring Valley will provide small benefits to protecting spring flows in the MRSA and stream flows in the Muddy River for several decades. As pumping continues over time, these benefits will diminish as drawdown expands and captures spring and river discharge. The similarity in the results from all three simulations reaffirms the DOI Agencies' 2013 conclusion that due to the high degree of hydrologic connectivity throughout the LWRFS basins, carbonate pumping anywhere within the connected basins (even under different spatial pumping configurations) will affect groundwater levels throughout these basins and eventually capture the major forms of natural discharge in the area – spring/stream discharge and evapotranspiration present within the connected basins.

Because the model underpredicted the drawdown and reduction in discharge caused by the Order 1169 pumping, it should not be used in its current state to determine what the safe yield of the LWRFS aquifer is. In addition, it has not been calibrated to data on the effects of pumping in the southern basins because of the limited data available at the time it was calibrated. Recalibration of the model using data collected since 2011 is recommended to improve the accuracy of predictions.

We emphasize again that simulation of the recovery from ceasing MX-5 pumping at the end of the Order 1169 test indicated that recovery in locations distant from the pumping well occurs slowly, consistent with the observed water-level data. Thus, we support the approach of phased development of the aquifer, in which limited pumping is performed, accompanied by monitoring of water levels and discharge rates both near and distant from the productions well(s). If wells are drilled in the southern basins, pumping should be limited initially and data collected on pumping rates and water level changes. Use of recording pressure transducers is highly recommended so that barometric pressure and earth-tide effects can be measured and removed.

While the model predicts that discharge from Rogers and Blue Point Springs will be decreased a small amount by moving larger volumes of pumping from the northern basins to the southern basins, we emphasize that there is a paucity of information on the effects of pumping in the southern part of the flow system on these springs. Continued monitoring of spring discharge and aquifer water levels is essential.

5.2 NSEO REQUESTED INPUT

Three different predictive scenarios were simulated to qualitatively evaluate the potential effects of redistributing pumping within and between the alluvial and carbonate aquifers in the LWRFS. These three simulations, described in more detail in Section 3, include:

1. Simulation evaluating pumping by priority date,
2. Simulation evaluating the redistribution of increased pumping to the carbonate aquifer, and
3. Simulation evaluating the redistribution of pumping from the alluvial aquifer to the carbonate aquifer.

Major findings from the groundwater modeling simulations as they relate to matters of interest to the State Engineer defined in the Interim Order 1303, are discussed below.

5.2.1 Geographic Boundary of LWRFS

Interim Order 1303 requested analysis to assist in addressing the geographic boundary of the groundwater / surface water system comprising the LWRFS. Results from Simulations 1, 2, and 3 clearly show that under the same aquifer stress (pumping) levels but different pumping configurations, the potential impacts from future pumping are migrating into or out of the existing boundaries of the five basins in Interim Order 1303. The adjacent basins of interest include Black Mountains, Kane Springs Valley, and Las Vegas Valley. Each of these three basins are discussed below.

5.2.1.1 Black Mountains Area (HA 215)

Drawdown has the potential to extend into the Black Mountain Area basin further than just the northwestern corner. The drawdown maps presented previously show drawdown only at the water table (layer 1 in the model). The carbonate aquifer extends continuously in the subsurface further to the east, beneath the Muddy Mountain thrust sheet exposed at the surface, until it is truncated by the Rogers Spring fault (Page and others, 2011). Rogers and Blue Point Springs, which discharge carbonate-rock sourced water, are located along the Rogers Spring fault. Drawdown occurs in the model within this deeper carbonate layer in all three simulations.

These springs were simulated as discharging from all layers present at their locations, including the Mesozoic section and the underlying deep carbonate aquifer. The simulated discharge declines a small amount in all three scenarios, with the greatest decline in Simulations 2 and 3 when greater amounts of pumping in the carbonate aquifer are moved closer to these springs. Given that other lines of hydrogeologic evidence also strongly support a pathway for groundwater flow to Rogers and Blue Point Springs in this area (see Section 1.1), we would recommend including all of the Black Mountains Area basin within the final boundary of the LWRFS. The effects of pumping on these springs should be considered when permitting and management decisions are made. A phased approach for development and monitoring is recommended for wells in the southern part of the LWRFS.

5.2.1.2 Kane Springs Valley (HA 206)

The three pumping simulations assumed that 1,000 afy was pumped from 4 wells situated along Kane Springs Valley. The three southwestern wells were assumed to be completed in the carbonate aquifer, and the northeastern-most well was assumed to be completed in volcanic rocks based on available geologic mapping of the valley. In Simulation 1, the drawdown cones of the three carbonate wells are predicted to coalesce with the drawdown caused by pumping from the wells in Coyote Spring Valley. In Simulations 2 and 3, in which the pumping from the Coyote Spring Valley wells was reduced, the drawdown in both valleys had not coalesced by 10 years, but had coalesced by 100 years. Thus, the model predicts that the carbonate aquifers in Kane Springs Valley and Coyote Spring Valley are connected. Observations of water levels in wells CSVM-4 and KMW-1 show drawdown caused by the pumping in MX-5 during the Order 1169 test, showing that pumping effects are transmitted into this area in a few months. Based on this evidence, we would recommend including all of Kane Springs Valley within the final boundary of the LWRFS.

5.2.1.3 Las Vegas Valley (HA 212)

The Las Vegas Valley Shear Zone is considered to be the down-gradient end of the LWRFS. While there is a gradient across the shear zone indicating that there may be groundwater flowing from the LWRFS into the rest of Las Vegas Valley, the amount of flow is believed to be very low. The model simulates that boundary flow to be 0 afy, using a no-flow boundary condition, based on estimates developed by USGS hydrologists Jim Harrill and Doug Bedinger. Thus, the model does not simulate a change in the flow rate as a result of drawdown along the boundary. In reality, there is likely to be a small, but probably insignificant, decrease in the flux into Las Vegas Valley across the shear zone. Thus, it is appropriate to manage Las Vegas Valley groundwater separately from the LWRFS.

5.2.2 Aquifer Recovery Since Order 1169 Test

The predictive modeling discussed here did not provide additional insight into aquifer recovery. Refer to section 2.3 for conclusions of the Order 1169 post-audit modeling.

5.2.3 Sustainable Quantity of Groundwater Pumping and Relationship of Pumping Location on Spring and River Flow

As indicated previously, the model under-simulated the amount of drawdown that occurred during the Order 1169 test. Flow measurements indicated significant changes in the discharge of Pederson Spring (to about one-third of the pre-test flow rate). The model indicates that pumping at approximately 14,535 afy under several different pumping configurations continues to cause declines in discharge in the MRSA area for more than 500 years, so that it is very likely that continuation of the Order 1169 test would have caused Pederson Spring and maybe other Muddy River springs to dry up over time. Thus, the annual, sustainable quantity of groundwater available is less than 14,500 afy. Recall that the post-audit of the model involved a simulation of the system to evaluate recovery times, in which the LWRFS was pumped at approximately 11,500 afy. Besides showing that drawdown can continue to increase for years in areas distant from the pumping well, there was a general decline in water levels that was not associated with the Order 1169 test caused by the simulated pumping at this rate.

The simulations indicate that there would be short-term benefit on the flows of the Muddy River Springs and the Muddy River from moving greater amounts of alluvial and/or carbonate withdrawals from the northern basins into the southern basins, but that after several decades, the drawdown caused by the southern pumping will affect the springs in the MRSA and the surface flow in the Muddy River to the same degree as if the pumping locations were not changed. Moving pumping to the south and from the alluvial aquifer delays impacts by a few decades, but does not avoid impacts. The similarity in the results from all three simulations reaffirms the DOI Agencies' 2013 conclusion that due to the high degree of hydrologic connectivity throughout the LWRFS basins, carbonate pumping anywhere within the connected basins (even under different spatial pumping configurations) will affect groundwater levels throughout these basins and eventually capture the major forms of natural discharge in the area – spring/stream discharge and evapotranspiration present within the connected basins.

5.2.4 Effects of Replacing Alluvial Well Pumping with Carbonate Well Pumping on Delivery of Decreed Rights on the Muddy River

It would seem that decreasing the pumping from the alluvium along the Muddy River would reduce the capture of the surface flow by this alluvial groundwater pumping, and as a result, would provide more surface water to meet the delivery of decreed rights on the Muddy River. The simulations indicate that this is true in early years, but not enough to fully offset the reduction in surface flow that is predicted in later years. Changing the location of the wells delays, but does not prevent, the impact. Recall that the alluvial groundwater is primarily derived from the underlying carbonate aquifer in the area north and west of Glendale. Increased pumping of the carbonate aquifer, as a result of moving alluvial aquifer pumping to the carbonate aquifer, reduces the discharge of groundwater from the carbonate aquifer into the overlying alluvial aquifer over time as drawdown effects expand throughout the LWRFS.

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