Case No. 84739

IN THE SUPREME COURT OF THE STATE OF NEVADA

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Elizabeth A. Brown
Clerk of Supreme Court

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

Appellants,

vs.

LINCOLN COUNTY WATER DISTRICT, et al.

<u>JOINT APPENDIX</u>

VOLUME 6 OF 49

SOUTHERN NEVADA WATER AUTHORITY
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June 27, 2013

Jason King, P.E., State Engineer
Nevada Department of Conservation
and Natural Resources
Division of Water Resources
901 South Stewart Street, Suite 2002
Carson City, Nevada 89701

Dear Mr. King:

SUBJECT: SUBMITTAL OF NEVADA STATE ENGINEER ORDERS 1169 AND 1169A STUDY REPORT

The Southern Nevada Water Authority (SNWA) and Las Vegas Valley Water District (LVVWD) hereby submit the subject report to the Nevada State Engineer (NSE) for consideration regarding NSE Orders 1169 and 1169A. As outlined in NSE Order 1169A, the pumping test was deemed complete as of December 31, 2012. Pursuant to Order 1169A, any Order 1169 study participant may file a report with the NSE addressing information obtained during the study/pumping test, impacts of pumping, and availability of water pursuant to pending applications held in abeyance by Order 1169.

SNWA and LVVWD have worked diligently and cooperatively with the NSE, Moapa Valley Water District, Coyote Springs Investments LLC, U.S. Fish and Wildlife Service, and other study participants to ensure the pumping test under Order 1169 met the objectives of the NSE. SNWA and LVVWD have maintained an extensive groundwater and surface-water monitoring network with the first monitoring report submitted to the NSE in 1999. All data associated with Orders 1169 and 1169A collected by SNWA and LVVWD have been submitted to the NSE.

SNWA and LVVWD appreciate your careful consideration of the data collected under the Orders 1169 and 1169A study. If you have any questions regarding this report, please contact Andrew Burns at (702) 862-3772 or Jeffrey Johnson at (702) 862-3748.

Sincerely,

Zane L. Marshall
Director, Water & Environmental Resources

Enclosure

ZLM:JJ:lmv

c: Richard A. Felling, Chief, Hydrology Section, Nevada Division of Water Resources
John Guillory, Supervising Engineer, Division of Water Resources

SE ROA 10091

Doc No. WMP-ED-0001

SOUTHERN NEVADA WATER AUTHORITY

Water & Environmental Resources Department
Water Management and Planning

Nevada State Engineer Order 1169 and 1169A Study Report

June 2013

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Suggested citation: Southern Nevada Water Authority, 2013, Nevada State Engineer Order 1169 and 1169A Study Report: Southern Nevada Water Authority, Las Vegas, Nevada, Doc. No, WMP-ED-0001, x p.

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FIGURES

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TABLES

NUMBER TITLE PAGE

ACRONYMS

CSI	Coyote Springs Investment, LLC
CY	Calendar Year
DRI	Desert Research Institute
ET	Evapotranspiration
ETr	reference Evapotranspiration
HA	hydrographic area
LDS	Church of Latter-day Saints
LVVWD	Las Vegas Valley Water District
MBPI	Moapa Band of Paiute Indians
METRIC	Mapping EvapoTranspiration at high Resolution with Internalized Calibration
MOA	Memorandum of Agreement
MVIC	Muddy Valley Irrigation Company
MVWD	Moapa Valley Water District
NCA	Nevada Cogeneration Associates
NDVI	Normalized Difference Vegetation Index
NDWR	Nevada Division of Water Resources
NPS	National Park Service
NSE	Nevada State Engineer
NVE	NV Energy
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RCA	regional carbonate aquifer
SNWA	Southern Nevada Water Authority
USFWS	U.S. Fish & Wildlife Service
USGS	U.S. Geological Survey
WY	Water Year

ABBREVIATIONS

af	acre-feet
afy	acre-feet per year
amsl	above mean sea level
cfs	cubic feet per second
ft	feet
gpm	gallons per minute

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1.0 INTRODUCTION

This report presents hydrologic data collected during and prior to the two-year pumping test (Test) in Coyote Spring Valley mandated by the Nevada State Engineer (NSE) Order 1169, issued March 8, 2002. The Test was started November 15, 2010, and concluded on December 31, 2012, pursuant to NSE Order 1169A.

1.1 Background

The Las Vegas Valley Water District (LVVWD) filed applications 54055-54059, inclusive, to appropriate groundwater within the Coyote Spring Valley hydrographic area (HA 210) on October 17, 1989 (Table 1). These applications were the subject of a Nevada Division of Water Resources (NDWR) water right hearing in July 2001. Subsequent to the 1989 applications, the Southern Nevada Water Authority (SNWA) acquired existing groundwater rights in Coyote Spring Valley that are also listed in Table 1.

Immediately following the July 2001 hearing on LVVWD's applications, NDWR held a hearing on the Coyote Springs Investment (CSI) applications listed in Table 2, in August 2001.

Table 1
LVVWD Groundwater Permits and Applications[1]

Owner	Application Number	Status	Annual Duty	Hydrographic Basins
SNWA[2]	77291-77306	Permit	9,000 afy	Coyote Spring Valley
GID[3]	70429, 74094	Permit	2,000 afy	Coyote Spring Valley
LVVWD	54055-54059	Application	38 cfs requested	Coyote Spring Valley

[1]As described by Nevada Division of Water Resources Water Rights Database Special Hydrographic Abstract 12/01/2009.
[2]SNWA purchased the water remaining under Permit No. 46777 from CSI. The portion of the water CSI retained has changed to Permit Nos. 70429 and 70430. SNWA Permit Nos. 46777, 49414, 49660-49662 and 49978-49987 have changed to Permit Nos. 77292-77306 The change applications were granted by NDWR on 12/19/2008 for SNWA's point of diversion to MX-5 and CSI-2 and changed the manner of use to Municipal from Industrial.
[3]GID = Clark County Coyote Springs Water Resource General Improvement District

Table 2
CSI Groundwater Permits and Applications in Coyote Spring Valley[1]

Owner	Application Number	Status	Annual Duty	Hydrographic Basins
CSI	70429, 70430, 74094, 74095	Permit	2,600 afy	Coyote Spring Valley
CSI	63272-63276, 63867-63876	Application	150 cfs requested	Coyote Spring Valley

[1]As described by Nevada Division of Water Resources Water Rights Database Special Hydrographic Abstract 12/01/2009.

Following the two hearings, the NSE issued Order 1169 which required a minimum 5-Year Study (Study) in which at least 50 percent of the existing water rights in Coyote Spring Valley, 8,050 afy, be pumped for two years to stress the aquifer and gain additional information on the availability of groundwater resources before additional permits could be issued. The order also held in abeyance the pending Coyote Spring Valley (HA 210) groundwater applications and all other pending applications in Garnet Valley (HA 216), Hidden Valley (HA 217), the Muddy River Springs Area (HA 219), Lower Moapa Valley (HA 220), and the Black Mountains Area (HA 215) until the completion of the Order 1169 Study. Pending applications in California Wash (HA 218) were also held in abeyance until completion of the Order 1169 Study under NSE Ruling 5115.

The Study Participants for Order 1169 include the following entities:

- Las Vegas Valley Water District
- Southern Nevada Water Authority
- Coyote Springs Investment, LLC
- NV Energy (NVE)
- Moapa Valley Water District (MVWD)
- Bureau of Indian Affairs[1]
- U. S. Fish & Wildlife Service (USFWS)[1]
- National Park Service (NPS)[1]
- Moapa Band of Paiute Indians (MBPI)[2]

[1]The State Engineer granted a request by U.S. Department of Interior to allow the Bureau of Indian Affairs, USFWS, and NPS, collectively referred to as the Federal Agencies, to participate in the Study (April 19, 2002).
[2]The NSEvia letter dated April 16, 2010, enabled the MBPI to participate in the Study.

1.2 Report Organization

This report is divided into 5 Sections and 7 Appendices

Section 1.0 presents introductory information regarding the Order 1169 Study and this report.

Section 2.0 describes the objectives of the Order 1169 Study, the study area, and design of the two-year pumping test required by Order 1169.

Section 3.0 describes monitoring efforts and data collected for the Order 1169 Test and related studies.

Section 4.0 presents analyses and results of the Order 1169 Test.

Section 5.0 presents the summary and conclusions.

Appendix A provides a copy of the NSE July 1, 2010, Letter describing the Order 1169 Test monitoring sites

Appendix B describes hydraulic testing of the carbonate-rock aquifer pursuant to Order 1169

Appendix C presents a location map, table, and groundwater hydrographs for wells monitored by SNWA and referenced in this report

Appendix D presents hydrographs depicting flows measured at eight U.S. Geological Survey (USGS) gages on the Muddy River

Appendix E presents a SNWA 2004 report titled: Climate and Barometric Pressure Influences on Pederson Spring Discharge and the Carbonate Aquifer near the Muddy Springs, Southern Nevada

Appendix F presents a SNWA 2007 report titled: Updated Review of Water Level and Discharge Trends at the Muddy Springs, Clark County, Nevada, and Addendum No. 1

Appendix G presents a technical memorandum documenting a DRI evapotranspiration study

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2.0 ORDER 1169 OBJECTIVES, STUDY AREA, AND TEST DESIGN

Aspects of the Order 1169 Study objectives, description of the Study Area, and design of the Test are discussed below.

2.1 Test Objectives

As outlined in Order 1169, the objective of the Test was to enhance the understanding of the regional carbonate-rock aquifer (RCA) in and adjacent to Coyote Spring Valley by pumping existing water rights for a period of time to determine "if pumping of those water rights will have any detrimental impacts on existing water rights or the environment." (NSE Order 1169, 2002). Order 1169 outlines that at least 50 percent of the water rights currently permitted in Coyote Spring Valley, 8,050 afy, be pumped for at least two consecutive years.

The NSE conducted several meetings after issuing Order 1169 to assure the objectives were being met by the parties. During the June 22, 2010, meeting, SNWA and CSI noted that due to slower than anticipated CSI development and possible operational limitations, the minimum volume of 8,050 afy might not be pumped during each year of the Test. Following some discussion, the NSE individually polled the Study Participants and each of them agreed the objectives of Order 1169 could still be met with less than 8,050 afy of groundwater development. The NSE issued a letter dated July 1, 2010, to the Study Participants revising requirements associated with Order 1169 (Appendix A) and stating that the objectives of the Study may still be met with pumping less than 8,050 afy.

2.2 Study Area

The Order 1169 Study area (Study Area) associated with Order 1169 is depicted on Figure 1. It consists of the southern portion of the White River Flow System, and includes the basins held in abeyance under Order 1169.

2.3 Test Design

SNWA developed a working document titled "Hydraulic Testing of the Carbonate-Rock Aquifer Pursuant to Order 1169," which was first presented to the NSE on October 24, 2002. The document was updated several times and the final version dated February 25, 2010, was submitted to the NSE under cover letter dated March 2, 2010, signed by SNWA, MVWD, and CSI (Appendix B). This document outlines the numerous activities and planned development of existing Coyote Spring Valley groundwater rights to meet the objectives of the Test. A summary of the Test design is presented below.

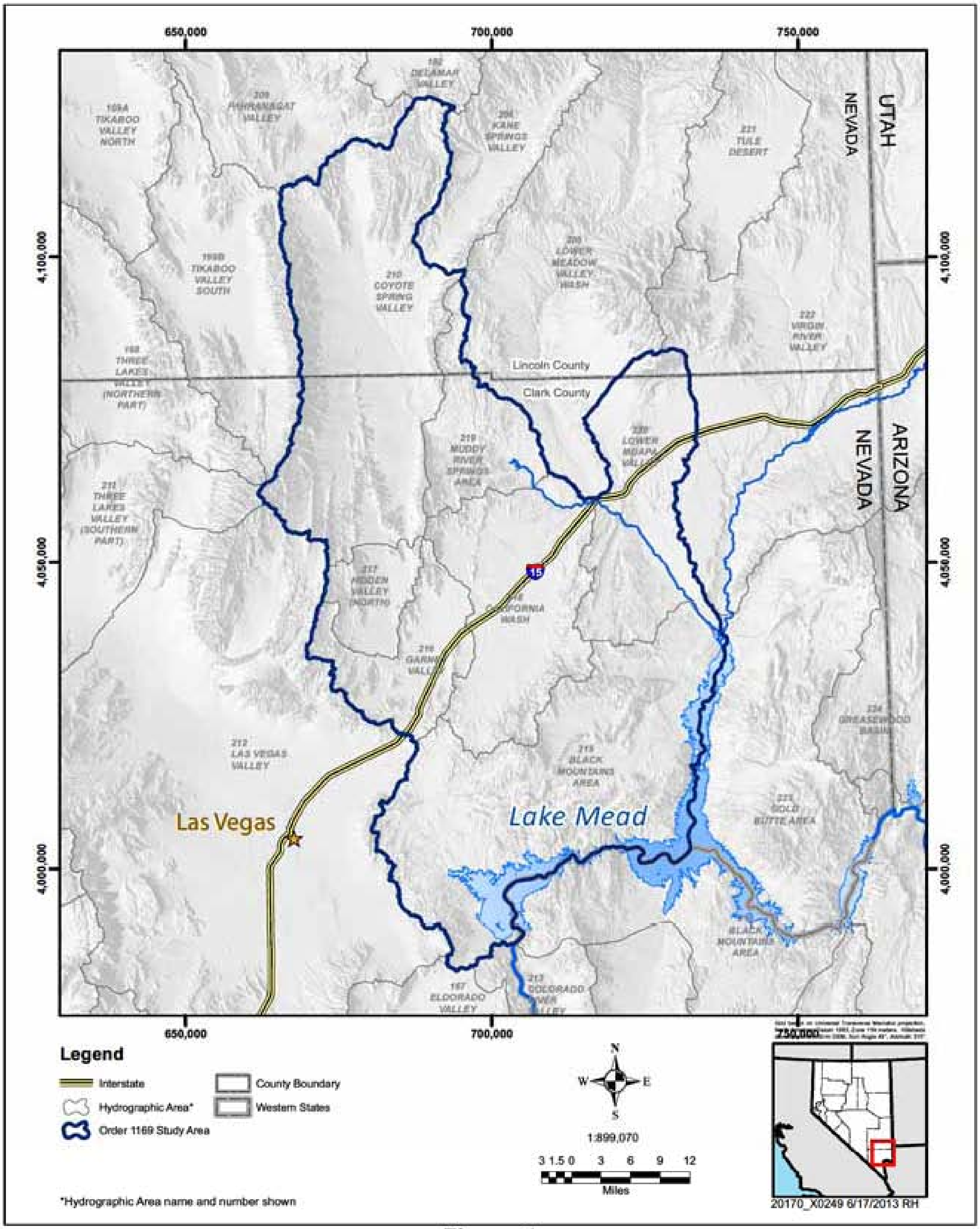

Figure 1
Order 1169 Study Area Map

Groundwater production required to meet the objectives of the Test consisted of SNWA pumping from well MX-5 and CSI pumping from wells CSI-1, CSI-2, CSI-3, and CSI-4.

CSI developed a portion of its groundwater rights in Coyote Spring Valley for golf-course irrigation and construction activities. CSI began use of its existing rights in Coyote Spring Valley in 2005, but not at sufficient quantities to meet the Test objectives. The pumping volume from Coyote Spring Valley was not large enough to meet the objectives of the Test until SNWA brought the MX-5 well on line.

SNWA, in the late 1990s and early 2000s acquired a total of 9,000 afy of existing groundwater rights in Coyote Spring Valley. SNWA, in cooperation with MVWD, constructed a pipeline and associated facilities to convey SNWA's existing 9,000 afy of Coyote Spring Valley groundwater rights to locations where such water could be placed to beneficial use by SNWA and/or MVWD. For the Test, SNWA pumped a portion of its 9,000 afy of groundwater rights in Coyote Spring Valley from well MX-5, treated the water for arsenic at the Moapa Water Treatment Facility (adjacent to well MX-5) and conveyed the water through the newly constructed SNWA pipeline to the MVWD distribution system. MVWD then conveyed the water to Bowman Reservoir where the Muddy Valley Irrigation Company (MVIC) conveyed the water rights from Bowman Reservoir to the Muddy River and Lake Mead. SNWA received Imported Intentionally Created Surplus credits under the Secretary of Interior's *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lakes Powell and Mead* for the water reaching Lake Mead (Figure 2).

SNWA began pumping well MX-5 for the purpose of facility testing in mid-September 2010 for approximately 30 days. During this period groundwater was discharged to Pahranagat Wash and a small amount was discharged to the Muddy River Springs Area adjacent to the MVWD 3-million gallon water tank. Following the completion of facility testing, SNWA delivered water to MVWD periodically for short durations to maintain operational readiness. On November 15, 2010, SNWA, in cooperation with MVWD and MVIC, began delivering groundwater pumped from well MX-5 to Bowman Reservoir located in Lower Moapa Valley, and the Order 1169 Test officially began.

MX-5 pumping was held constant, with the exception of shutdowns due to facility maintenance and operational issues. CSI groundwater development was intermittent and fluctuated seasonally to meet water demands. During the Test, MVWD continued to develop groundwater from its Arrow Canyon #1 and #2 wells located in the Muddy River Springs Area to meet water demands in its service area. The same was true for all other groundwater development in the Study Area. Detailed pumping descriptions by basin are presented in Section 3.0.

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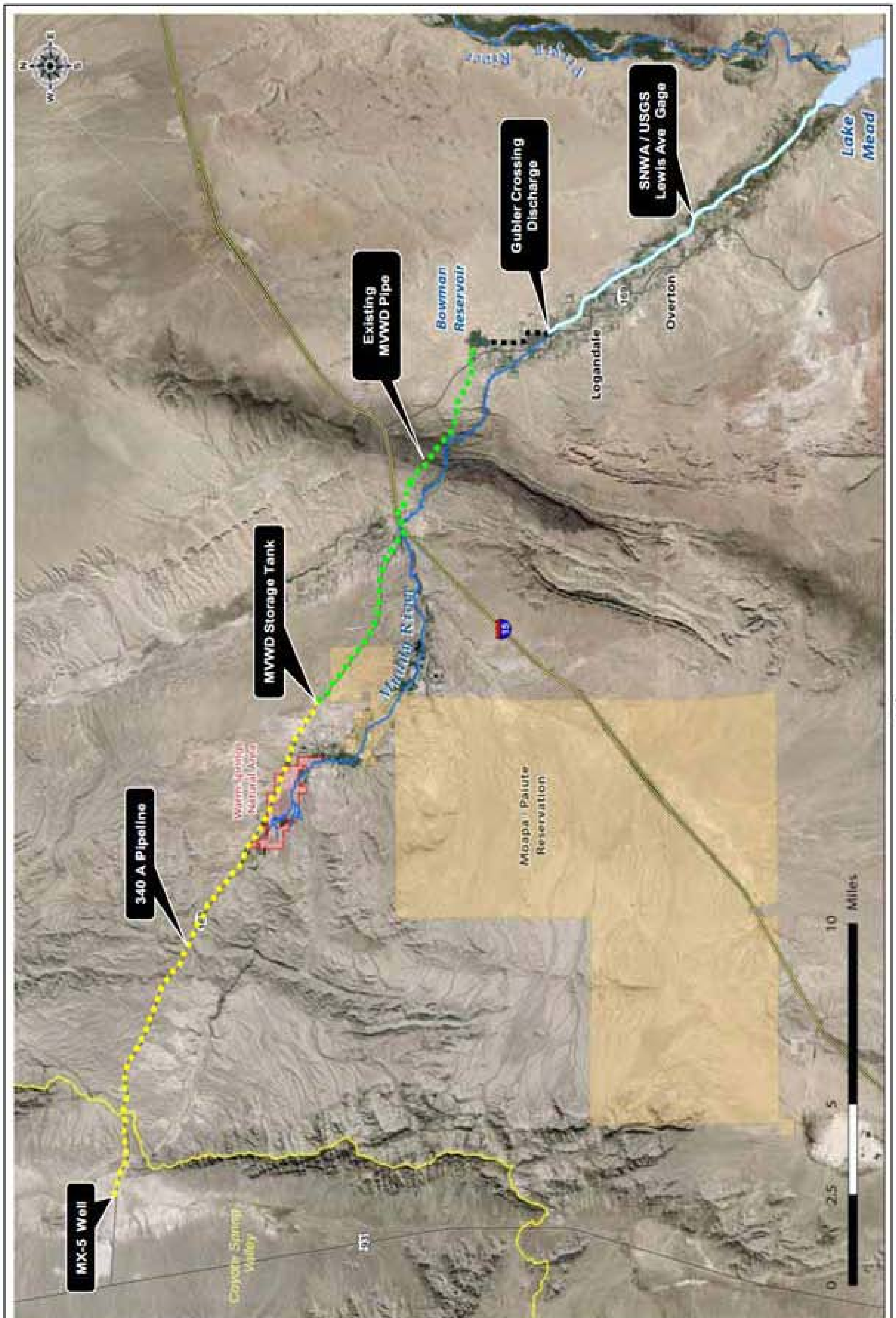

Figure 2
SNWA, MVWD, and MVIC Facilities Used to Convey SNWA Coyote Spring Valley Groundwater Rights from Well MX-5 to Lake Mead for the Creation of Imported Intentionally Created Surplus

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3.0 ORDER 1169 MONITORING AND RELATED STUDIES

The Order 1169 approved monitoring network documents water resource development and its effects, providing a basis for the evaluation and early warning of any unreasonable effects groundwater withdrawals may have on environmental resources and senior water-right holders. Many of the sites monitored for Order 1169 have a long history of data collection and provide a baseline for the evaluation of Order 1169 pumping responses. Types of data collected include discrete and continuous groundwater levels, discrete and continuous spring/stream flows, groundwater production, and surface-water diversions. The sites monitored along with the frequency and agencies responsible are listed in a letter from the NSE dated July 1, 2010 (Appendix A). The locations of the NSE approved groundwater and surface-water monitoring sites are shown on Figure 3.

The data associated with Order 1169 monitoring have been provided to the NSE by the agencies collecting the data and are available on the NSE website: http://water.nv.gov/mapping/order1169/. Spring and stream flow data collected by the USGS are available at website: http://waterdata.usgs.gov/nv/nwis/sw.

3.1 Groundwater Levels

A total of 79 wells completed in alluvial or carbonate aquifers were monitored by the Study Participants. The frequency of well-data collection varied from continuous, to monthly, or quarterly. Groundwater hydrographs for wells monitored by SNWA and wells discussed in this report, representing 40 wells are displayed in Appendix C along with a location map of the selected wells.

3.2 Spring Discharge and Muddy River Streamflow

A total of 10 surface-water gaging sites are included in the monitoring network. Two consist of metered pipes operated by MVWD on the Baldwin and Apcar (aka Jones) spring boxes. The remaining eight gages operated by the USGS and cooperatively funded by SNWA are located in the headwaters of the Muddy River and along the mainstream Muddy River. Appendix D contains flow hydrographs for these gages.

3.3 Water Resource Development

Groundwater withdrawals within the Study Area vary by source and magnitude. A brief basin-by-basin description of groundwater withdrawals and spring and surface-water diversions within the Study Area, as well as within the southern portion of Lower Meadow Valley Wash, are provided in the following sections.

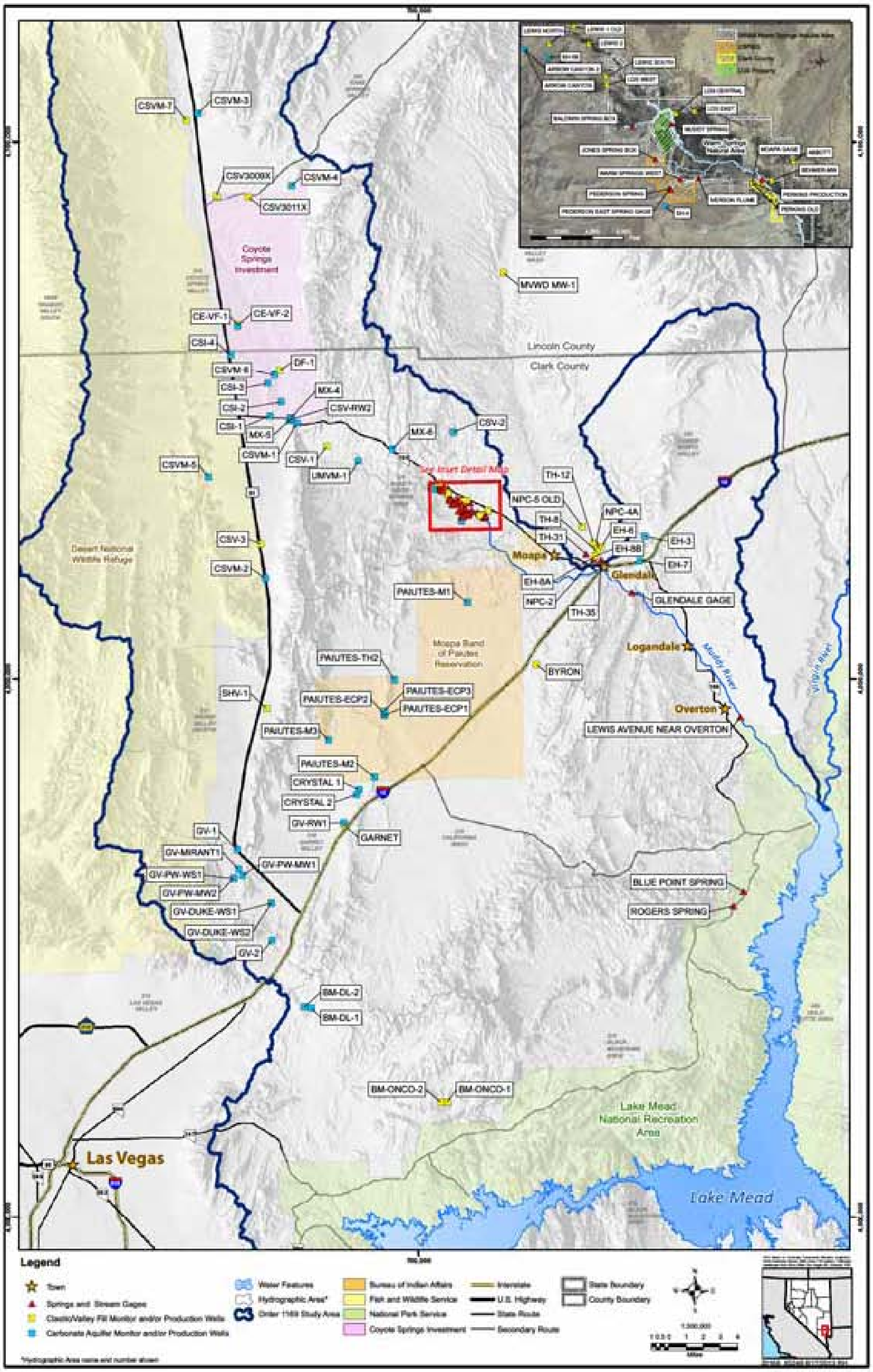

FIGURE 3
Locations of Order 1169 Monitoring Sites

3.3.1 Coyote Spring Valley

NDWR has issued a total of 16,300 afy of groundwater permits in Coyote Spring Valley, of which 200 afy are temporary rights. Historical groundwater withdrawals in Coyote Spring Valley have been limited to the temporary rights in Lincoln County and incidental pumping at MX-5 for testing and monitor-well drilling. Through 2007, SNWA has pumped groundwater under its respective permits only for incidental testing periods to perform hydraulic testing, collect water-quality samples, and well drilling activities. In 2005, CSI began pumping from wells CSI-1 and CSI-2. The volume of water pumped increased through the summer of 2006 and decreased slightly in the fall of 2006. By late 2007, CSI had constructed wells CSI-3 and CSI-4 and began pumping them for water supply. In late 2012, CSI completed installation of permanent pumping equipment in CSI-1 and began installing permanent pumping equipment at CSI-4.

In 2008, SNWA began pumping MX-5 for pipeline construction activities. Construction of the pipeline was completed in early 2009 and the water treatment and pumping facility was substantially completed in November 2010. SNWA began pumping well MX-5 for the purpose of facility testing in mid-September 2010 and the pumping continued for approximately 30 days. Following the completion of facility testing, SNWA delivered water to MVWD periodically for short durations to maintain operational readiness. On November 15, 2010, SNWA, in cooperation with MVWD, began delivering groundwater pumped from well MX-5 to Bowman Reservoir located in Lower Moapa Valley. Since November 2010, the SNWA water treatment facilities and the MX-5 well have experienced shutdowns for maintenance and warranty repairs. Figure 4 and Figure 5 graphically depict CSI's and SNWA's monthly and yearly pumping in Coyote Spring Valley from inception through March 2013. There are no surface-water diversions in the Coyote Spring Valley.

3.3.2 Muddy River Springs Area

In the Muddy River Springs Area, significant groundwater and surface-water development has occurred. Groundwater development of the alluvial aquifer system by NVE has occurred for several decades, primarily north and northwest of the Moapa Valley National Wildlife Refuge in the areas known as Church of Latter-day Saints (LDS) and Lewis well fields, and to a lesser degree at the NVE Perkins and Behmer wells. Additional alluvial pumping by domestic well owners has occurred in the area, but it is generally thought to constitute a relatively small component of the annual pumping in the area. Groundwater development of the RCA by MVWD has occurred since the early 1990s, with increased pumping in the late 1990s in response to water demand in the Logandale and Overton areas. MVWD's primary production wells are the Arrow Canyon wells #1 and #2 northwest of the Moapa Valley National Wildlife Refuge. MVWD also operates well MX-6 to meet peak demands as needed.

MVWD and NVE also own and lease surface-water rights. MVWD diverts from two spring boxes, Baldwin and Jones springs, north of the Moapa Valley National Wildlife Refuge. Under agreements with SNWA, MVWD, CSI, and USFWS, MVWD is foregoing its 1 cubic-foot per second (cfs) diversion from Jones Spring in exchange for a like amount of water from Coyote Spring Valley groundwater developed by SNWA. NVE diverts surface water from the Muddy River directly above the USGS 09416000 Muddy River near Moapa, NV gage (Moapa gage). MVWD and NVE report their groundwater and surface-water diversions in annual monitoring reports to NDWR. Figure 6

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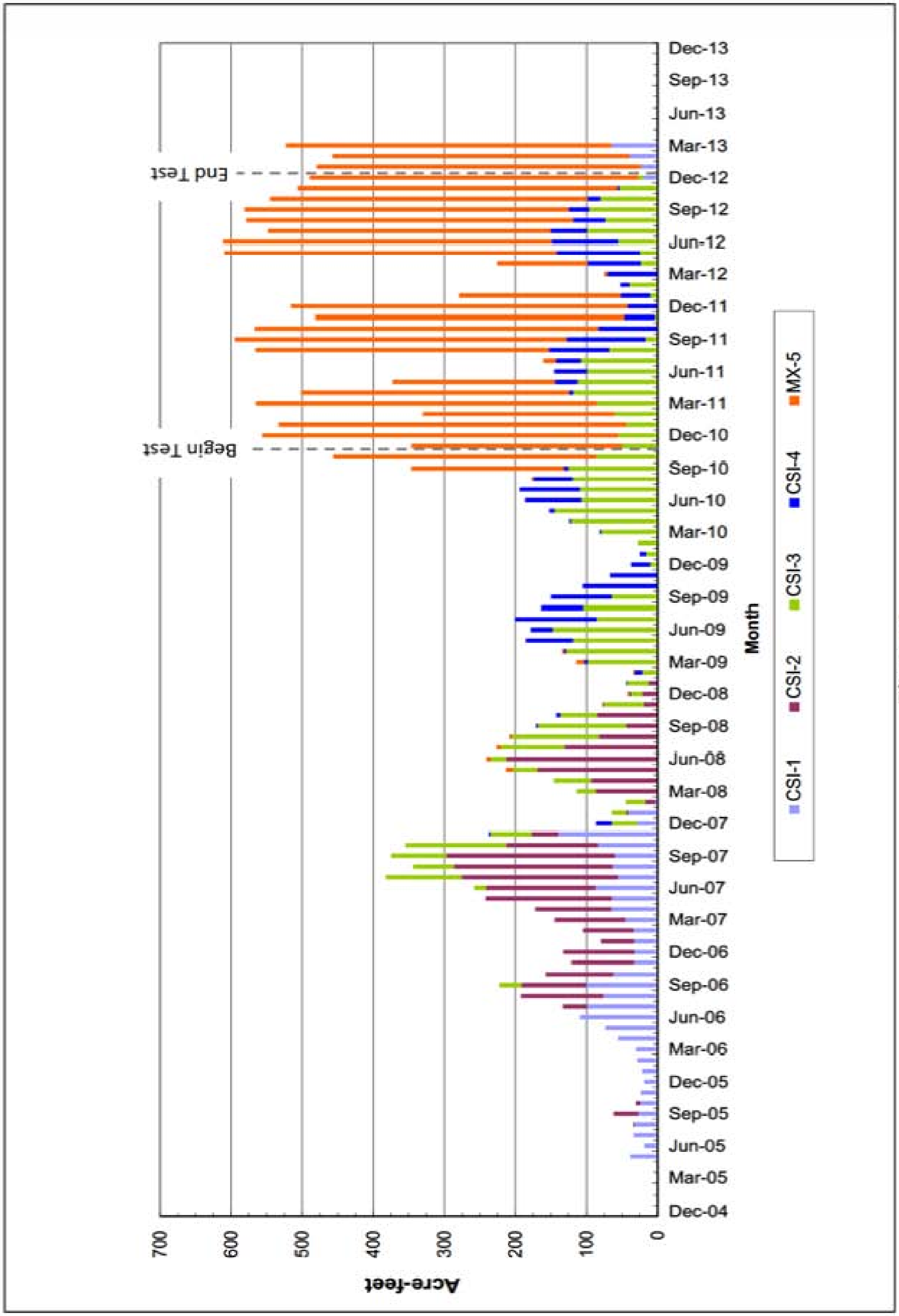

Figure 4
Monthly Groundwater Production for Wells CSI-1, CSI-2, CSI-3, CSI-4, and MX-5 in Coyote Spring Valley

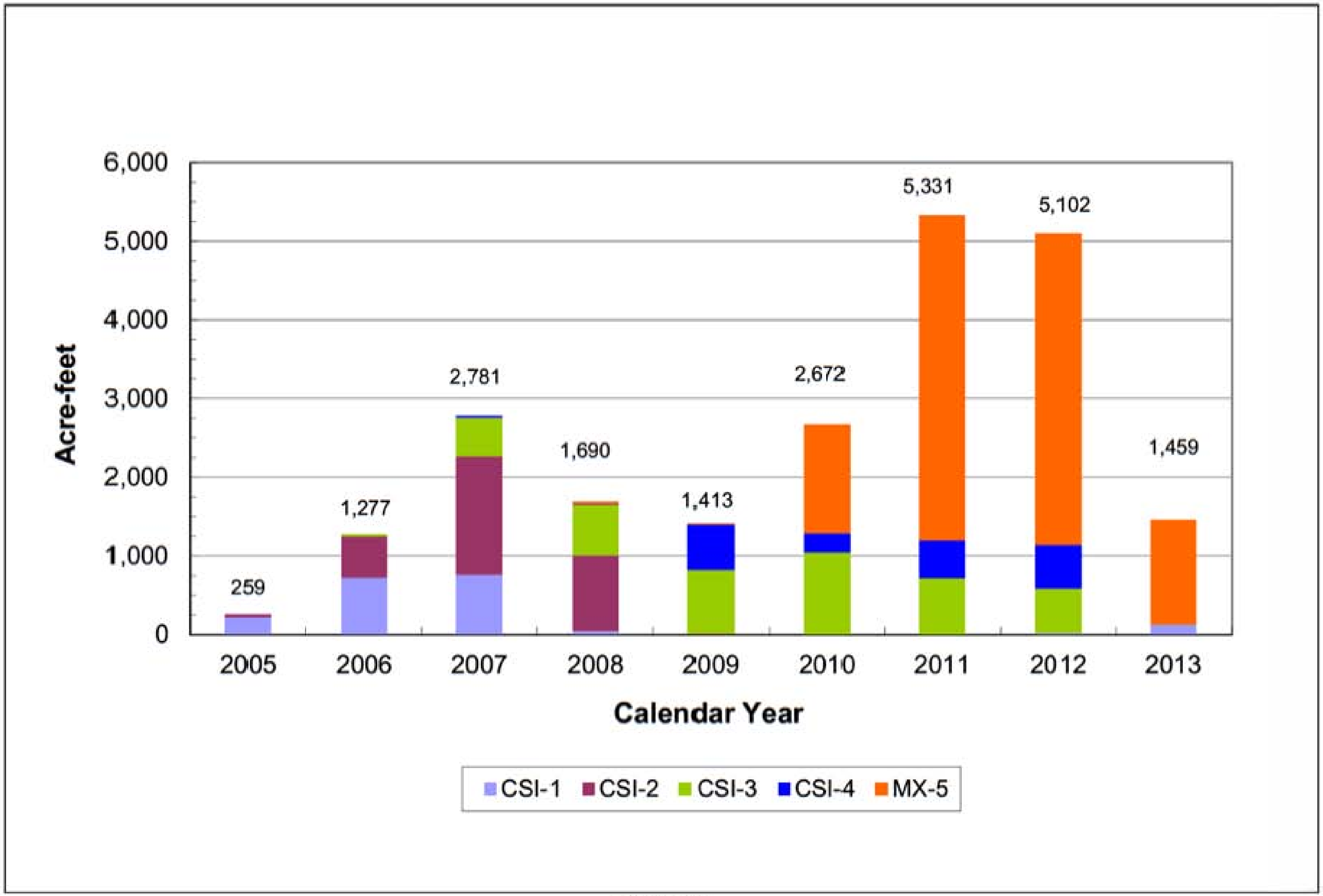

Figure 5
Annual Groundwater Production for Wells CSI-1, CSI-2, CSI-3, CSI-4, and MX-5 in Coyote Spring Valley

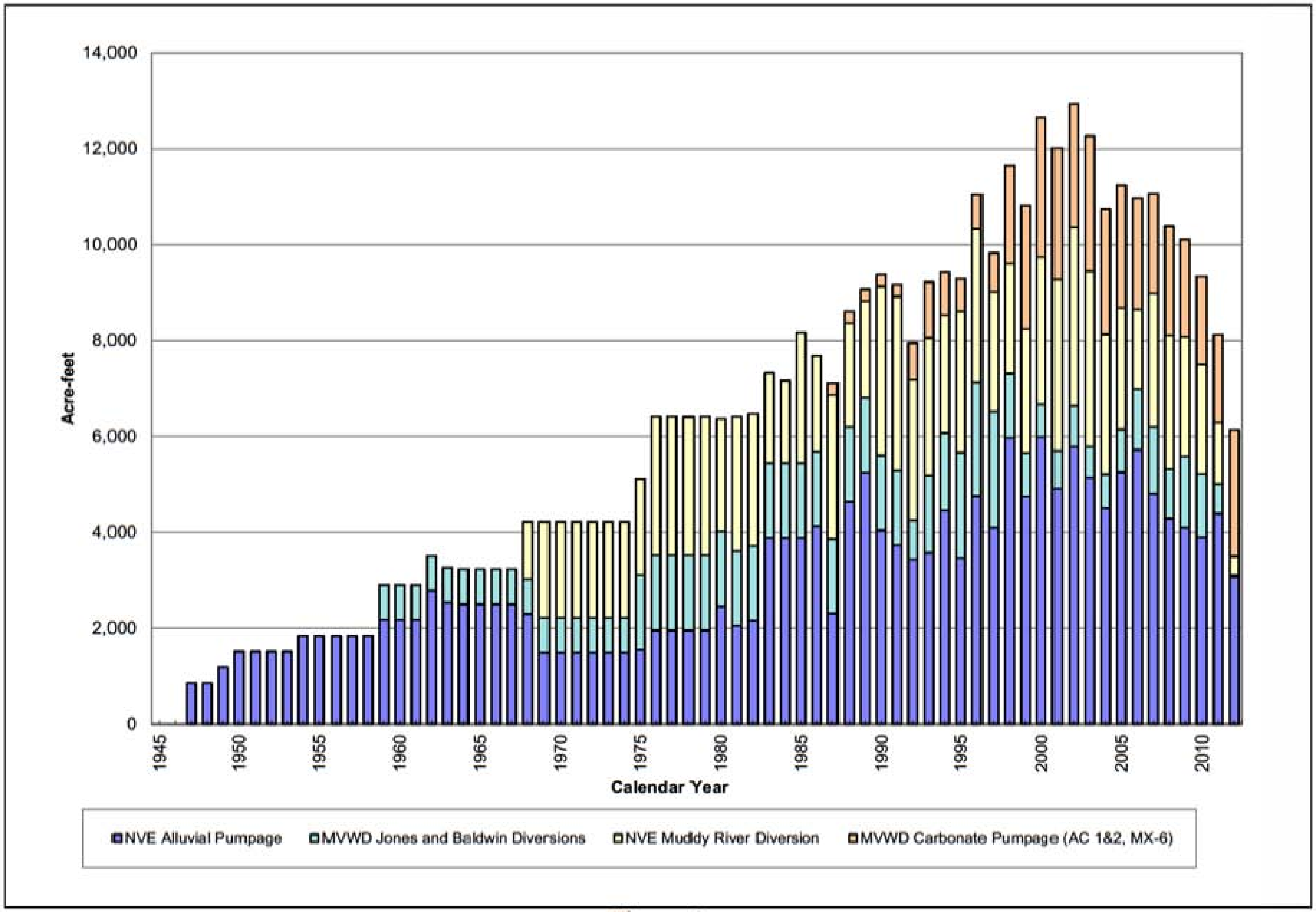

Figure 6
Annual Groundwater Production and Surface Water Diversions by MVWD and NVE in Muddy River Springs Area

presents the alluvial pumping by NVE, the carbonate pumping by MVWD, and the surface-water diversions by MVWD and NVE in the Muddy River Springs Area.

3.3.3 Garnet Valley, Hidden Valley, and Black Mountains Area

LVVWD owns water rights in Garnet and Hidden valleys that were originally granted under Permit Nos. 54073 and 54074 for a combined duty of 2,200 afy. Following the issuance of the 2,200 afy in Garnet and Hidden valleys, LVVWD entered into agreements with electrical power generation companies in Garnet Valley which enabled the power companies to utilize a portion of the LVVWD permitted rights to construct and operate generation facilities. Under the amended agreements, an average of 1,400 afy can be utilized at the Chuck Lenzie, Silverhawk, Harry Allen, and Mirant Power Plants. The power generation companies, in support of their individual operations, have installed production and monitoring wells. LVVWD receive monthly production totals and, recently, daily pumping totals from the four power plants. It is important to note that Calendar Year (CY) 2010 was the first year a portion of these water rights were developed from well RW-1, which is authorized under the permits. Figure 7 and Figure 8 present the monthly and yearly groundwater production of the LVVWD permits in Garnet and Hidden valleys from 2002 (when pumping of the rights began) through March 2013, respectively.

Other water users including Chemical Lime Company and Republic Services of Southern Nevada also develop groundwater in Garnet Valley. No groundwater development has occurred in Hidden Valley. Groundwater development in the Black Mountains Area has occurred to supply mining operations and industrial uses. Figure 9 depicts the total yearly combined groundwater production in Garnet Valley and the Black Mountains Area. Nevada Cogeneration Associates (NCA) pumps the greatest volume in the Black Mountains Area, and the NCA production wells are of primary interest due to their close proximity to Garnet Valley and other development in the area. NCA has withdrawn groundwater in the basin since 1993 and reports their annual groundwater production to NDWR. There are no surface-water diversions in Garnet Valley, Hidden Valley, or Black Mountains Area.

3.3.4 Lower Moapa Valley

Groundwater development in Lower Moapa Valley has occurred principally to supply irrigation and domestic demands. Surface-water development has occurred strictly to meet agricultural demands. The entire flow of the Muddy River has historically been diverted by MVIC at the Well Siding diversion in Logandale. Irrigation water is diverted to the east and west margins of the valley through MVIC ditches. During the winter months, when water is not immediately required for irrigation, the river is diverted to fill Bowman Reservoir which is used to augment summer irrigation demands. SNWA currently owns and leases shares in MVIC equating to approximately 52 percent of the water rights held by MVIC.

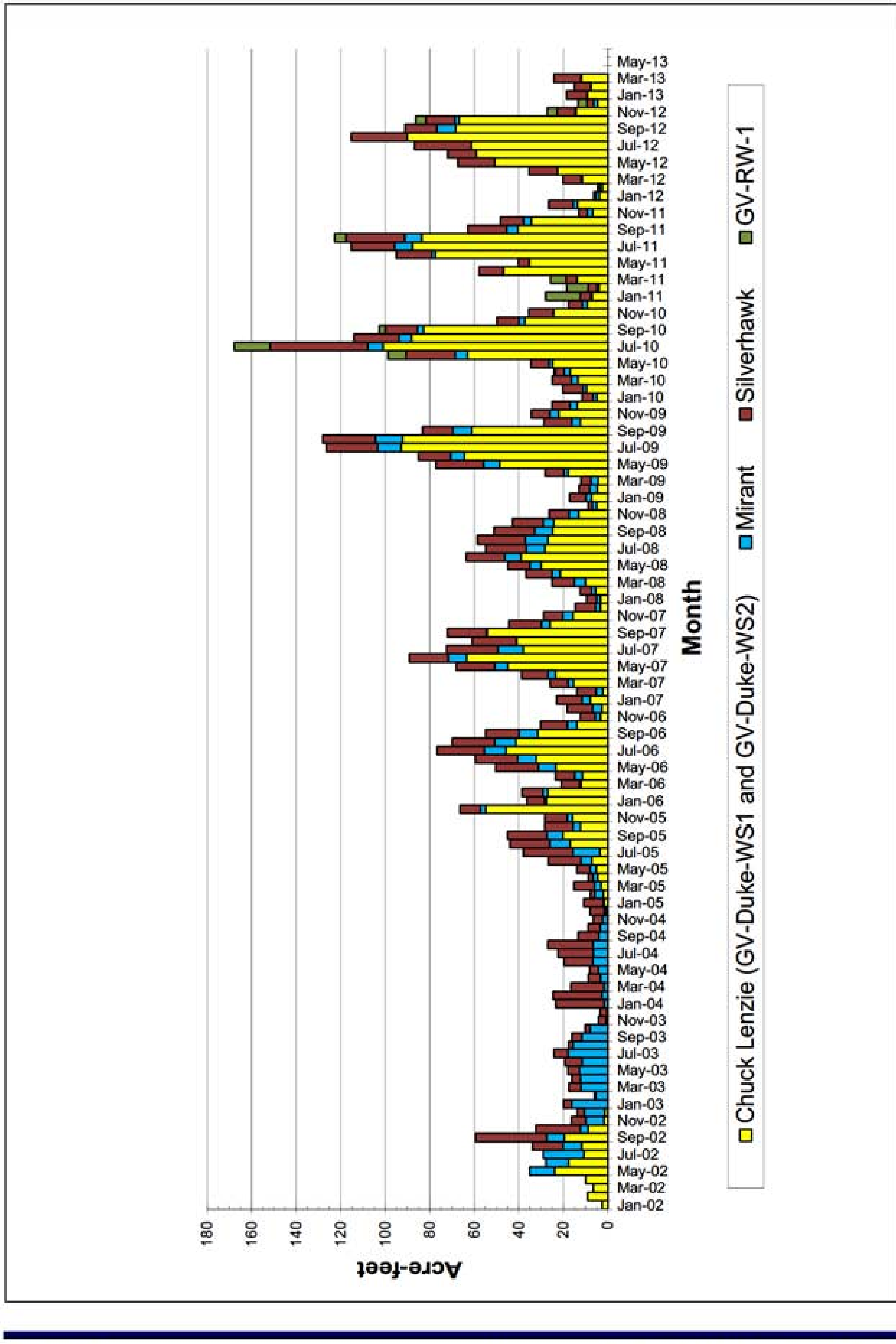

Figure 7
Monthly Groundwater Production by Well under LVVWD Water-Right Permits in Garnet Valley

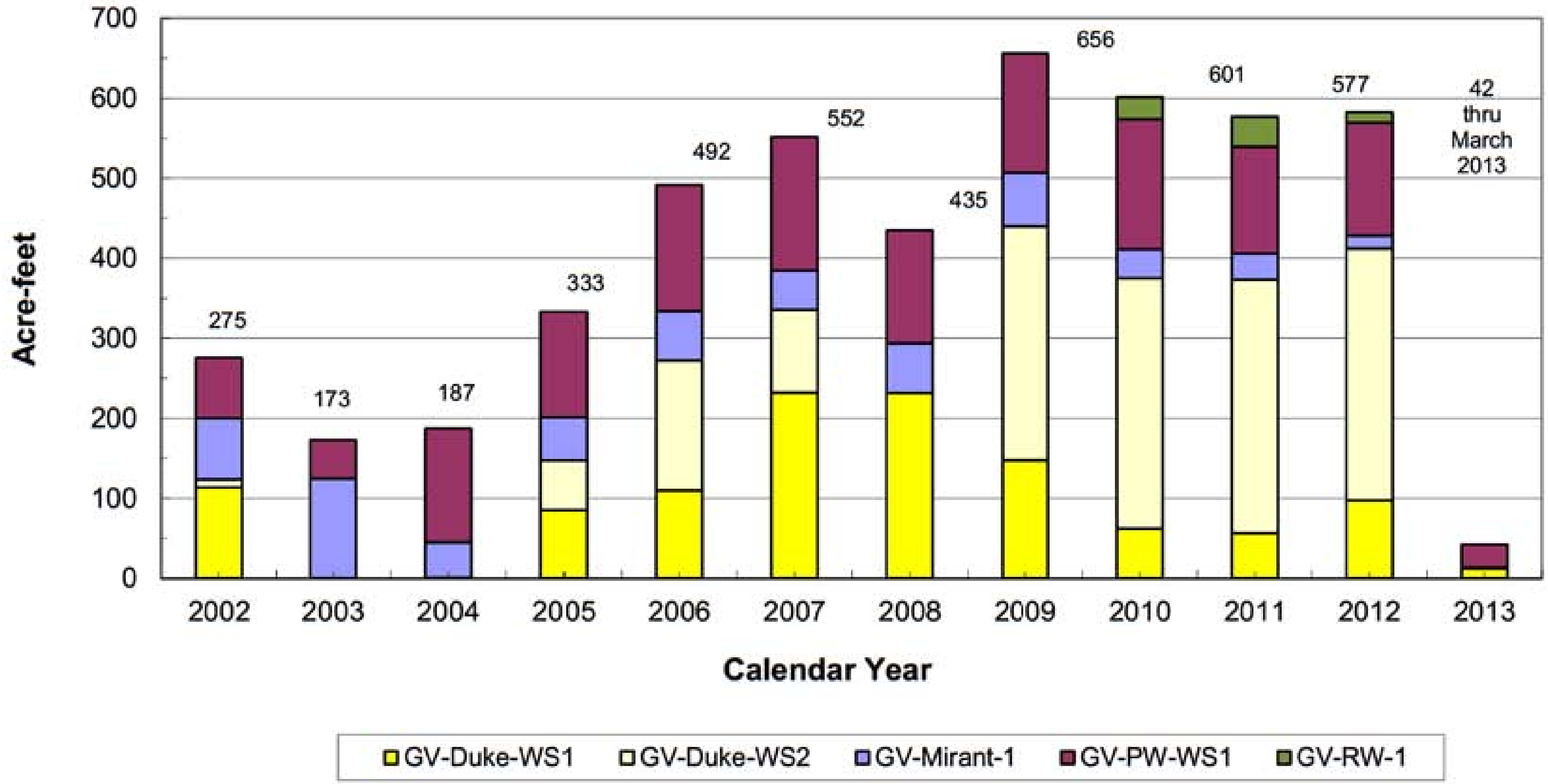

Figure 8
Annual Groundwater Production by Well under LVVWD Water-Right Permits in Garnet Valley

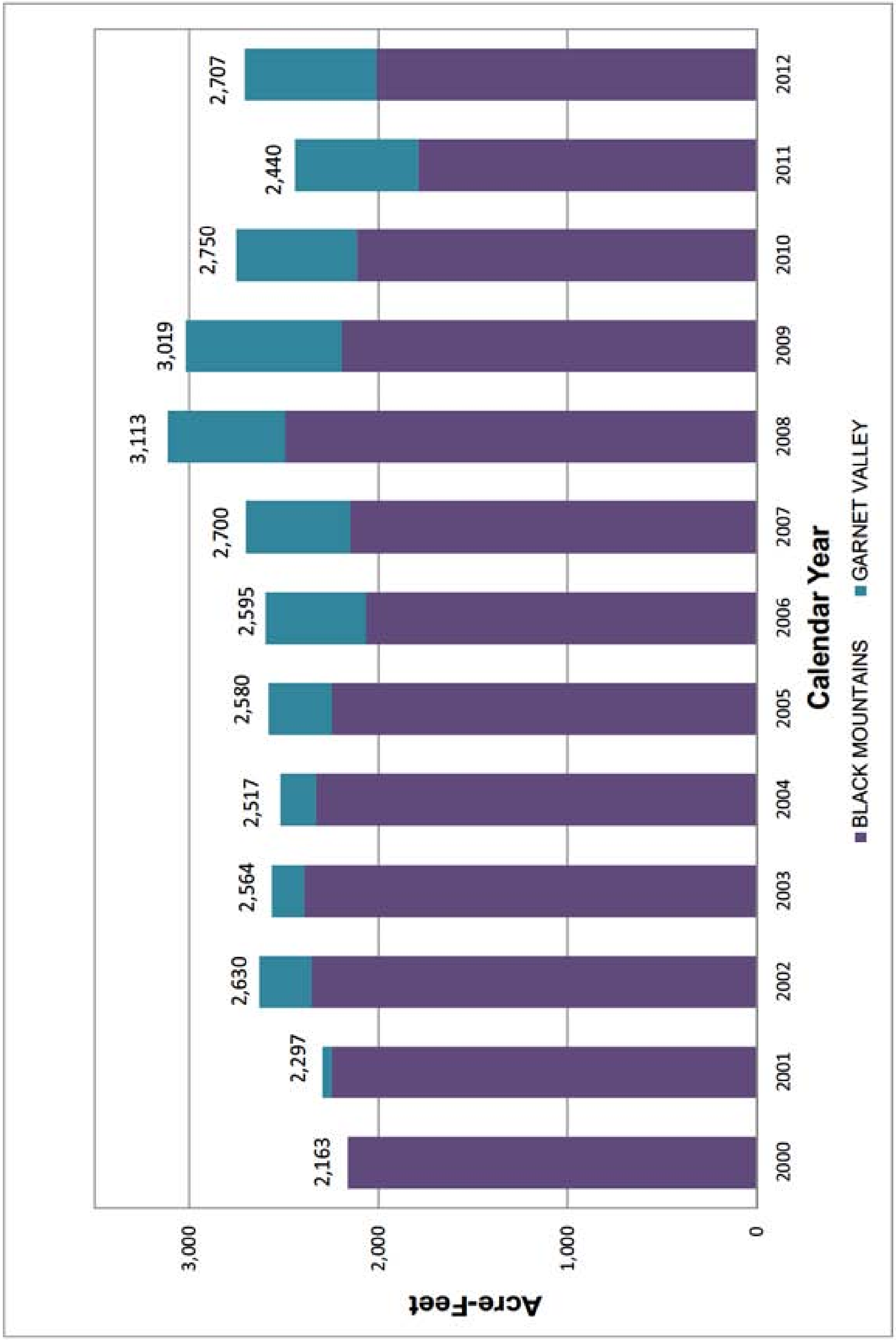

Figure 9
Annual Total Groundwater Production in the Black Mountains Area and Garnet Valley

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3.3.5 California Wash

Groundwater development in California Wash has been very minor and occurred principally to supply industrial, environmental, and domestic use. No appreciable amount of groundwater was pumped in this area during the Test.Surface-water diversions in California Wash were minimal during the Test and occurred below the observation points of interest (i.e., Moapa gage).

3.3.6 Lower Meadow Valley Wash

Lower Meadow Valley Wash was not held in abeyance under Order 1169 and was not included as a hydrographic area within the Study Area of this report. However, the southern portion of the Lower Meadow Valley Wash does contain wells monitored by NVE and NDWR which were included in the Order 1169 monitoring program. Groundwater in the southern portion of Lower Meadow Valley Wash has historically been used for crop irrigation generally within the floodplain of Lower Meadow Valley Wash. NVE has groundwater rights in Lower Meadow Valley Wash and they developed these rights for a brief period in the early 1980s for use at the NVE Reid Gardner Generation Station when Unit #4 became active. However, due to excessive drawdown and poor water quality, NVE greatly reduced pumping in Lower Meadow Valley Wash which has been negligible since 1990.

3.4 Order 1169 Related Studies and Activities

3.4.1 Evapotranspiration

In 2013, SNWA funded the Desert Research Institute (DRI), to perform an evapotranspiration (ET) study on the headwaters of the Muddy River above the Moapa gage. The purpose of this study was to estimate the annual volume of ET discharged from the Muddy River Springs Area from all sources except precipitation. This information will help to evaluate land-management activities and observed increases of flows in the Muddy River at the Moapa gage. The results of this study are discussed in Section 4.5 of this report.

3.4.2 Biological Monitoring

SNWA conducts biological resource monitoring and habitat restoration in accordance with a 2006 Memorandum of Agreement (MOA) and associated Biological Opinion to conserve the endangered Moapa dace during development of its permitted groundwater rights Coyote Spring Valley.

In April 2006, the MOA was entered into by the following five parties: SNWA, USFWS, CSI, MBPI, and MVWD, to conserve and recover the Moapa dace while developing and using permitted water rights. Paragraph N of the MOA states: "the Parties have identified certain conservation measures with the objective of making measurable progress toward the conservation and recovery of the Moapa dace, and have agreed to coordinate the monitoring, management, and mitigation measures…." As of 2013, all efforts associated with the MOA have been or are being implemented.

In addition to the trigger elevations established under the MOA at the USGS 09415920 Warm Springs West near Moapa, NV (Warm Springs West) gage, under which groundwater development by the

Parties would be incrementally curtailed if flows declined to specific levels, the MOA Parties agreed to a series of conservation measures for the Moapa dace. These measures included contributions of roughly $1.275 million for Moapa dace habitat restoration, the development of an ecological model of Moapa dace habitat, installation of fish barriers, and eradication of non-native fish. To date, the Parties have provided the identified funds; completed habitat restoration specified under the MOA with additional restoration ongoing; substantially completed the ecological model; installed one fish barrier with another planned; and efforts to eradicate non-native fish have been implemented and are continuing as needed.

In 2007, SNWA purchased the 1,220-acre parcel formally known as the "Warm Springs Ranch", which was the largest tract of private property along the Muddy River and contains the majority of the historical habitat for the endangered Moapa dace. SNWA renamed the property the Warm Springs Natural Area (WSNA) and is managing it as a natural area for the benefit of native species and for the recovery of the endangered Moapa dace, as described in the WSNA Stewardship Plan dated June 2011. Stream restoration activities on the WSNA began in late 2008 and continued through 2012, resulting in improvements to habitat where the Moapa dace are currently present.

The population count of the Moapa dace is a key indicator of species well-being in the headwaters of the Muddy River. Recent population counts indicate the Moapa dace population began to rise during 2010 and 2011, and nearly doubled in 2012. Thus, the MOA conservation actions have resulted in measurable progress towards conservation and recovery of the Moapa dace, during which groundwater development for beneficial use and to meet the objectives of the Order 1169 Study has occurred. Figure 10 shows the population of the Moapa dace from 1994 to the present.

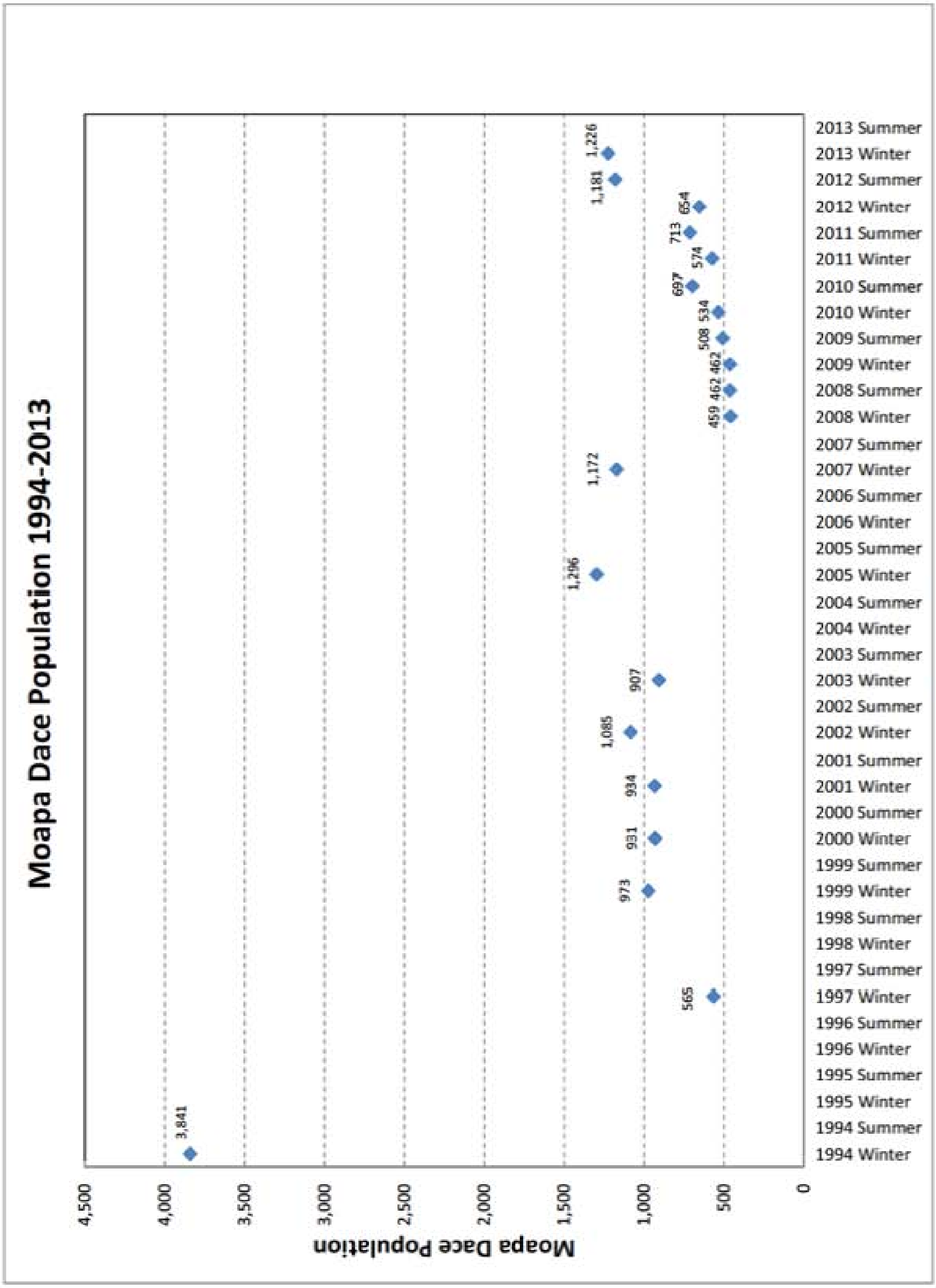

Figure 10
Moapa Dace Population from1994 through Winter (February) 2013

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4.0 RESULTS AND DISCUSSION

Monitoring data collected at the Order 1169 monitoring sites, combined with groundwater production data and meteorological data were evaluated and analyzed to identify important observations, trends and correlations. Selected hydrographs are presented in this section to illustrate key observations and regional and local-scale trends in the data prior to and during the Order 1169 Test.

4.1 Groundwater Observations and Trends

Several analyses have been conducted by SNWA and other Study Participants regarding observed groundwater level and surface-water flow changes prior to the Test. Two key multi-year fluctuations and trends that enhanced the understanding of the RCA in Coyote Spring Valley and nearby basins were the 1997/98 to 2004 decline and the 2005/06 recovery. Figure 11 presents representative hydrographs of groundwater level that portray these regional fluctuations from wells MX-4, CSV-2, GV-1, and Paiutes-M1, located in Coyote Spring Valley, the Muddy River Springs Area, Garnet Valley, and California Wash, respectively. Water level elevation offsets were used in order to display the GV-1 (+8.5 ft) and CSV-2 (+26 ft) on the same hydrograph.

As the hydrographs indicate, a regional carbonate decline in groundwater levels of about 2.5 to 3.0 ft was observed from 1997/98 to 2004 in these basins, followed by a regional groundwater level rise of approximately 1.0 to 1.5 ft in 2005. SNWA examined and compiled reports discussing these fluctuations in 2004 and 2007 and determined the cause of the water level decline/rise was a combination of climatic variation (i.e., drought conditions in the late 1990s and early 2000s followed by a significant wet winter of 2004/05) and to a lesser extent, groundwater production in the Muddy River Springs Area by MVWD (groundwater pumping from the Arrow Canyon wells). The two SNWA reports, which are included in Appendix E and Appendix F, document the significance of climatic variation relative to changes in groundwater levels and spring discharge, and demonstrate that in some instances groundwater fluctuations from climate variation are more significant than fluctuations from groundwater pumping.

Figure 12 depicts hydrographs of groundwater levels measured from wells MX-4, CSV-2, GV-1, and Paiutes-M1, discussed above combined with annual carbonate groundwater pumping, and the deviation from average precipitation for Nevada Climate Division 4, illustrating the correlation between climate variability and groundwater levels. Figure 13 depicts annual carbonate groundwater pumping and the deviation from average precipitation for Nevada Climate Division 4 along with the daily average flows at the Warm Springs West gage, illustrating the correlation between climate variability and surface-water discharge at this gage.

There are also seasonal fluctuations in many of the water level records in the Study Area which follow a sinusoidal pattern with seasonal maximums observed in February to April and seasonal

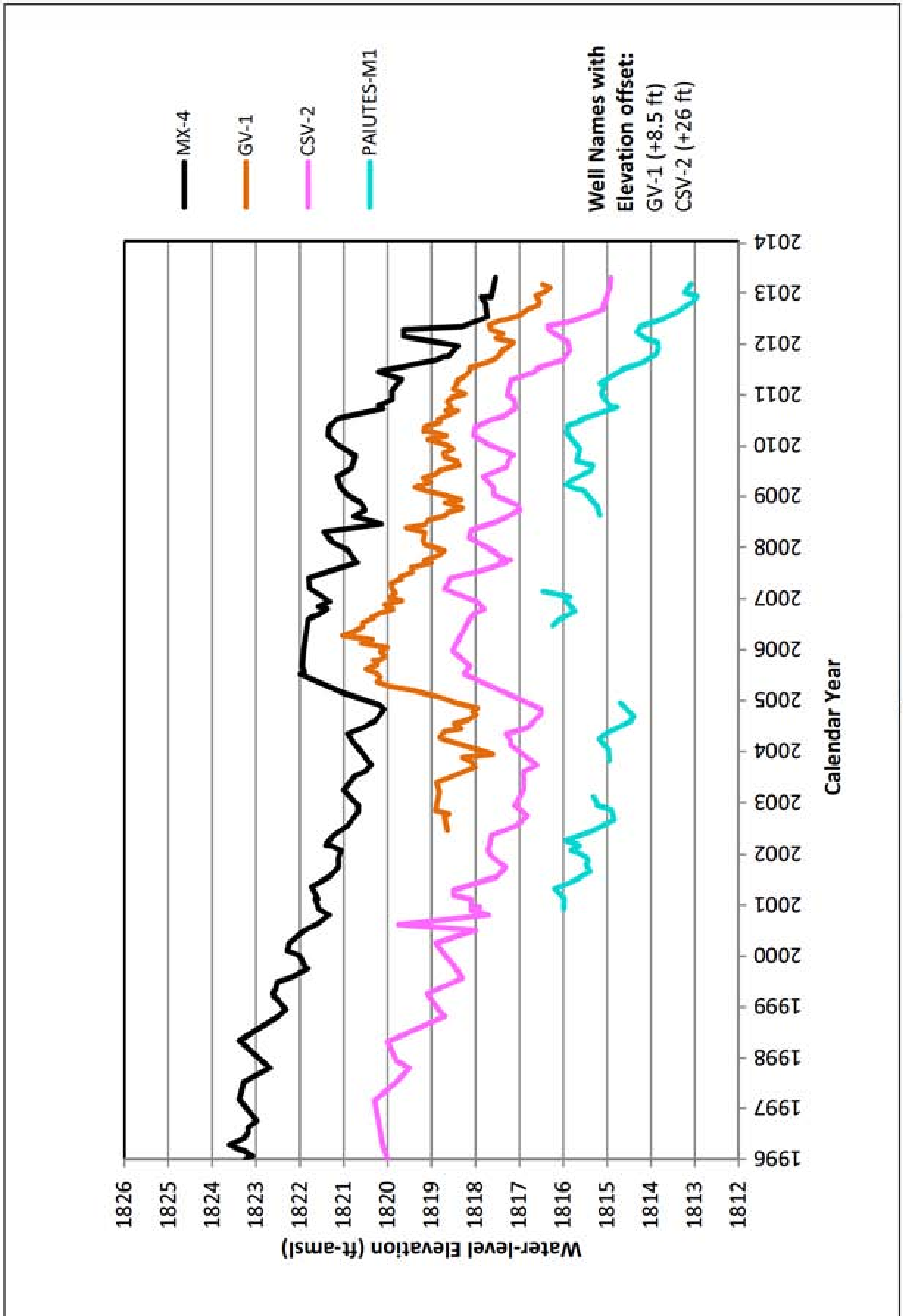

Figure 11
Hydrograph of Groundwater Elevations in Wells MX-4, CSV-2, GV-1, and Paiutes-M1

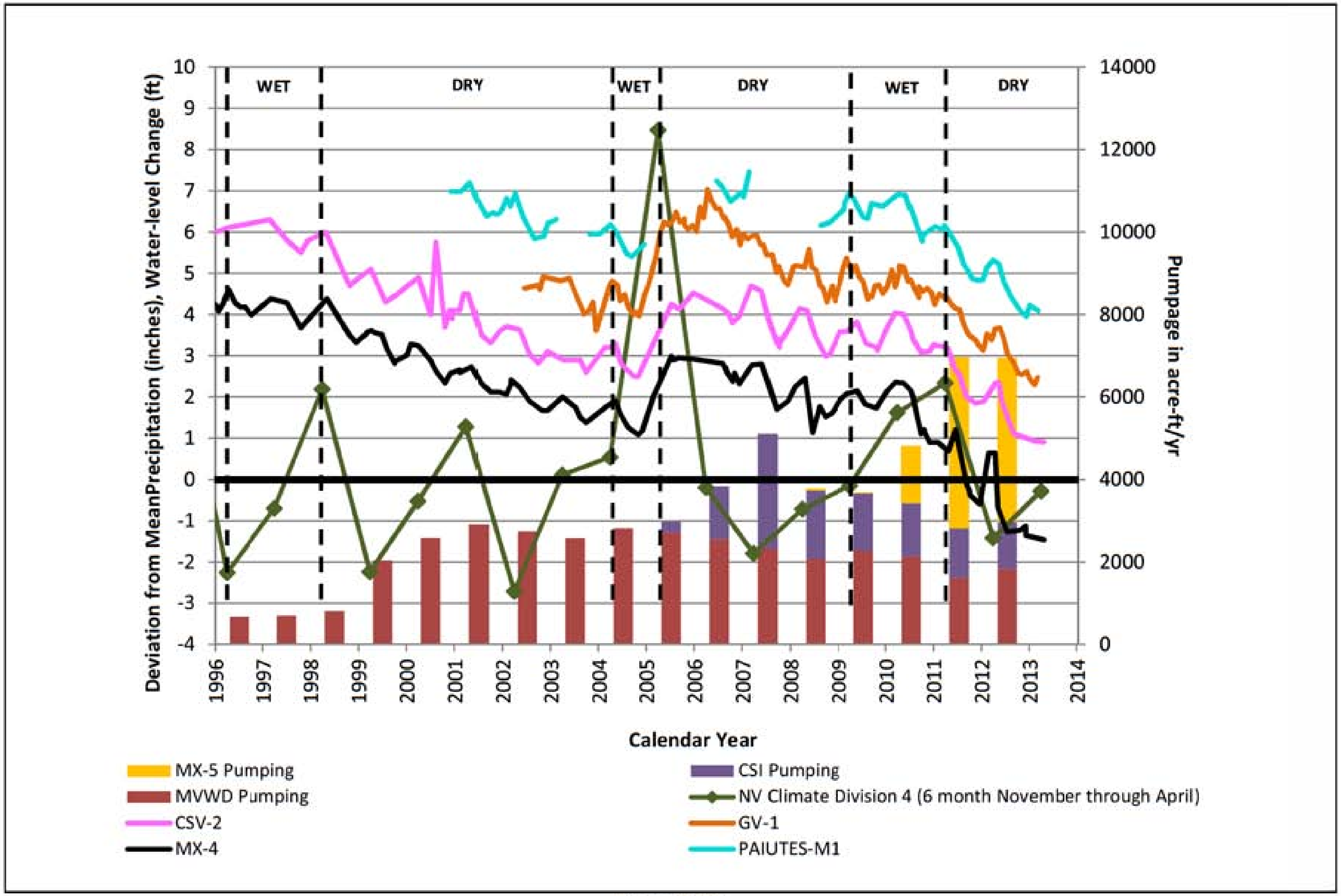

Figure 12
Groundwater Elevations in Wells MX-4, CSV-2, GV-1, and Paiutes-M1; Annual Carbonate Groundwater Pumping in Coyote Spring Valley and Muddy River Springs Area; and the Deviation from Average Precipitation for Nevada Climate Division 4

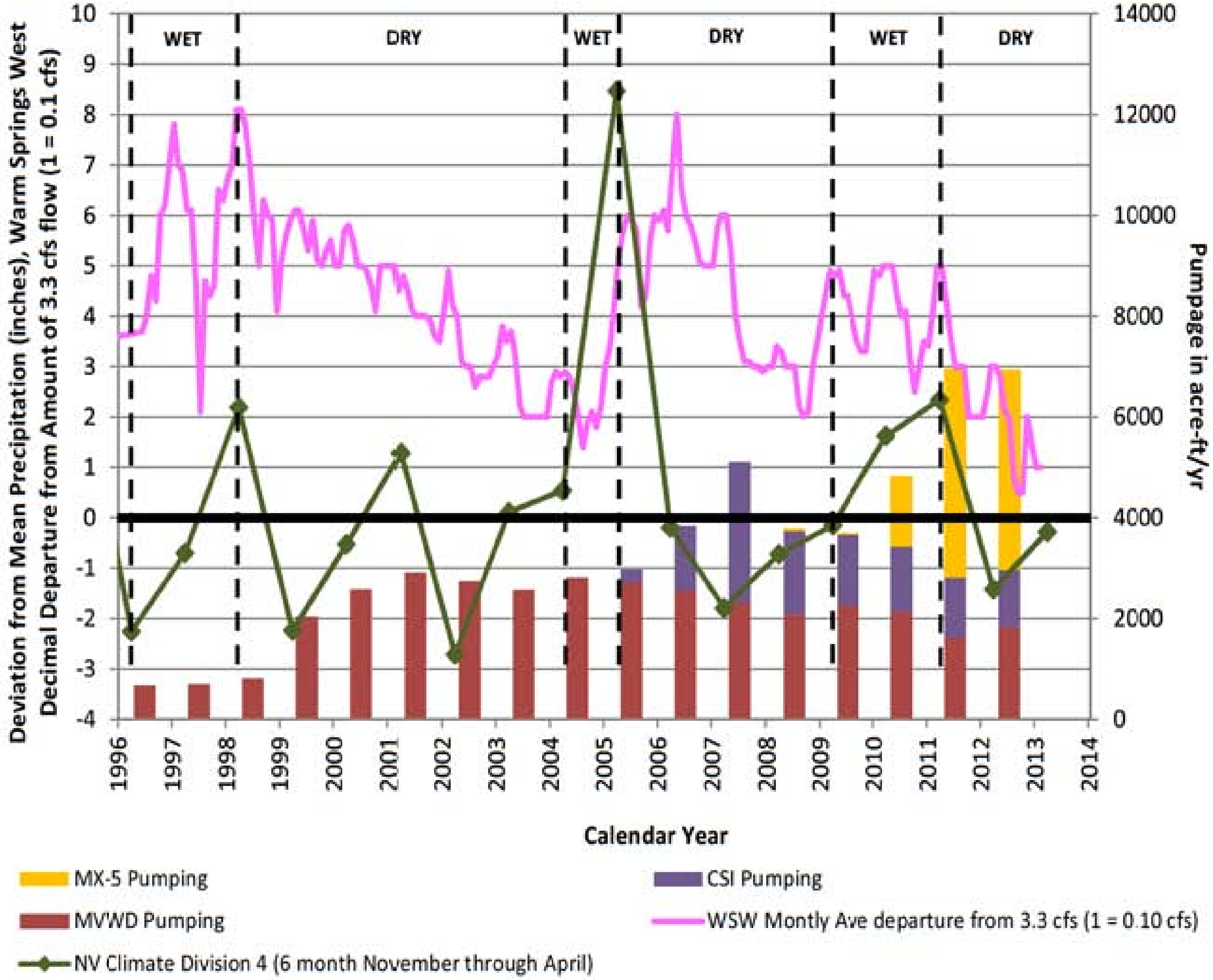

Figure 13
Daily Average Flows at the Warm Springs West Gage; Annual Carbonate Groundwater Pumping in Coyote Spring Valley and the Muddy River Springs Area; and Deviation from Average Precipitation for Nevada Climate Division 4

minimums observed September to November. These highs and lows can also be seen on Figure 11. The seasonal pattern is influenced by a response to barometric pressure, groundwater pumping, and seasonal recharge pulses. The seasonality is likely due to a combination of these factors with the dominant response being the influence of groundwater pumping from the three carbonate pumping centers identified on Figure 14, which are the result of: 1) MVWD pumping of the Arrow Canyon wells, 2) CSI and SNWA pumping in central Coyote Spring Valley, and 3) carbonate pumping in Garnet Valley and the Black Mountains Area.

The installation of additional monitor wells drilled by SNWA in the early 2000s also demonstrated spatial variations in groundwater level elevations within Coyote Spring Valley. Examples of the differences can be observed in wells MX-4, CSVM-6, CSVM-5, CE-VF-2, CSVM-4, and CSVM-3, depicted on Figure 15 with water levels obtained in March 2013.

These water level differences suggest gradations in hydraulic properties in the carbonate aquifer, zones of variable permeability, and possibly impediments to groundwater flow and/or compartmentalization of the aquifer system. A question anticipated to be answered with the Test is whether or not the existence of geologic structures and heterogeneities in the Study Area will affect the propagation of pumping effects to these different areas.

It is also well documented that the groundwater levels in the southern portion of Coyote Spring Valley, Garnet Valley, Hidden Valley, California Wash, and the western portion of the Black Mountains Area, adjacent to the BMDL wells, have groundwater elevations that are very similar (within a few feet of each other). This similarity in water level elevation and trends, suggests an area that is hydraulically interconnected and an area of high transmissivity.

4.2 Order 1169 Test Groundwater Level Trends and Observations

During the Order 1169 Test from November 15, 2010, through December 31, 2012, the pumping rate at well MX-5 ranged from 3,300 to 3,800 gpm and was the single largest stress on the RCA in the Study Area. The drawdown in well MX-5 during pumping was only about 7 ft, equating to a specific capacity of just over 500 gpm/ft. Equipment issues associated with the water treatment facility connected to well MX-5 resulted in periods of non-pumping at well MX-5 during the Test. Figure 16 depicts the duration of the Order 1169 Test, monthly volumes of water pumped from well MX-5 and the CSI wells, and the continuous groundwater levels in well MX-5, providing a distinctive representation of MX-5 pumping. Whether well MX-5 was pumping or not is important to consider when making observations of groundwater level responses. Water levels for the MX-5 well are therefore depicted on all of the hydrographs in Section 4.2, 4.3, and 4.4.

A total of 4,131 afy and 3,961 afy were pumped from the MX-5 well during CY 2011 and 2012, respectively. Combined with CSI pumping from wells CSI-1 through CSI-4, a total of 5,331 afy and 5,102 afy were pumped in Coyote Spring Valley during CY 2011 and 2012, respectively.

The subsequent sections discuss groundwater level observations and trends during the Test in wells near MX-5, referred to as 'proximal' wells; more distal wells within Coyote Spring Valley, referred to as 'distal Coyote Spring Valley' wells; and wells outside of Coyote Spring Valley to the south and east referred to as 'distal' wells.

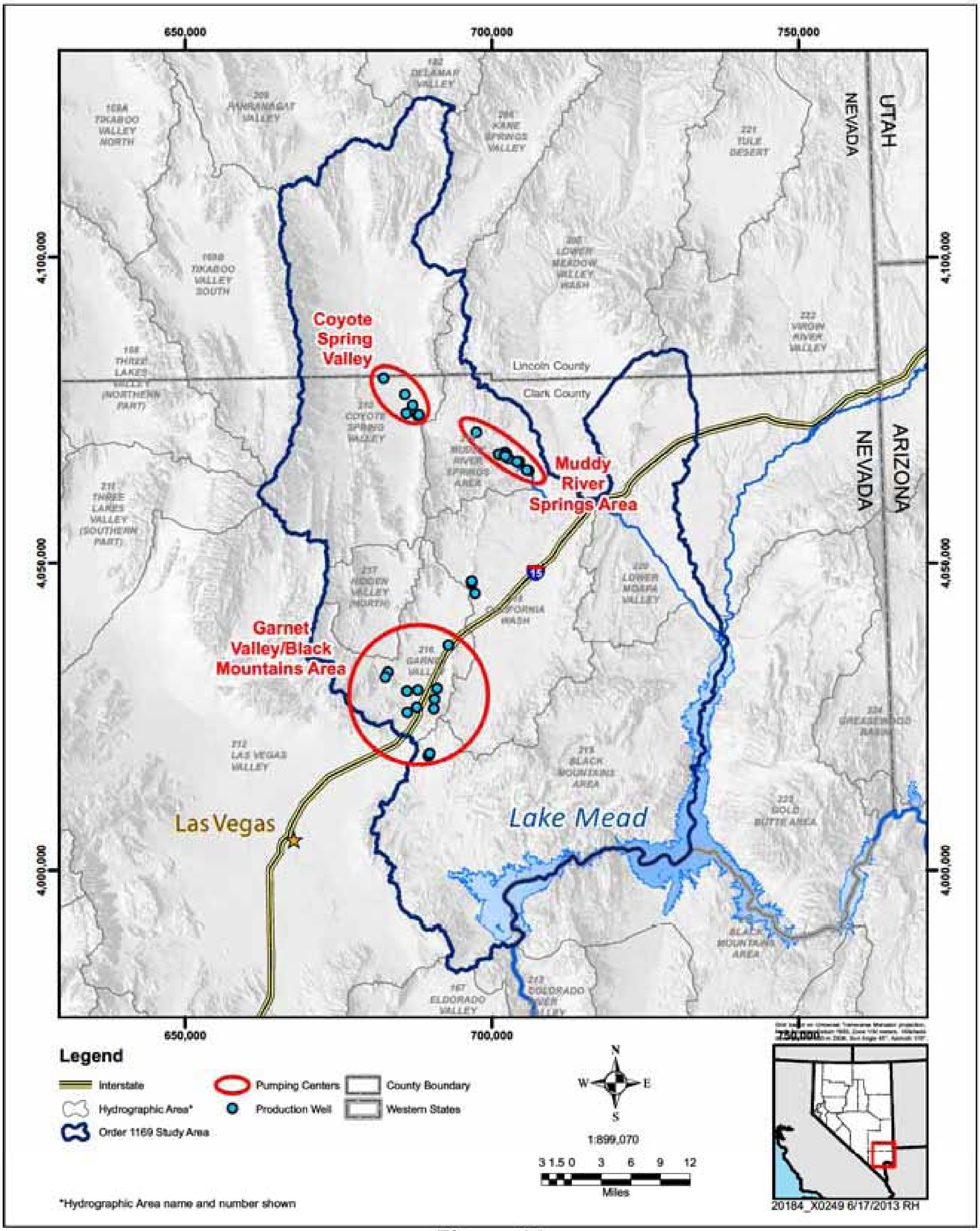

Figure 14
Map of the Three Principal Groundwater Pumping Centers

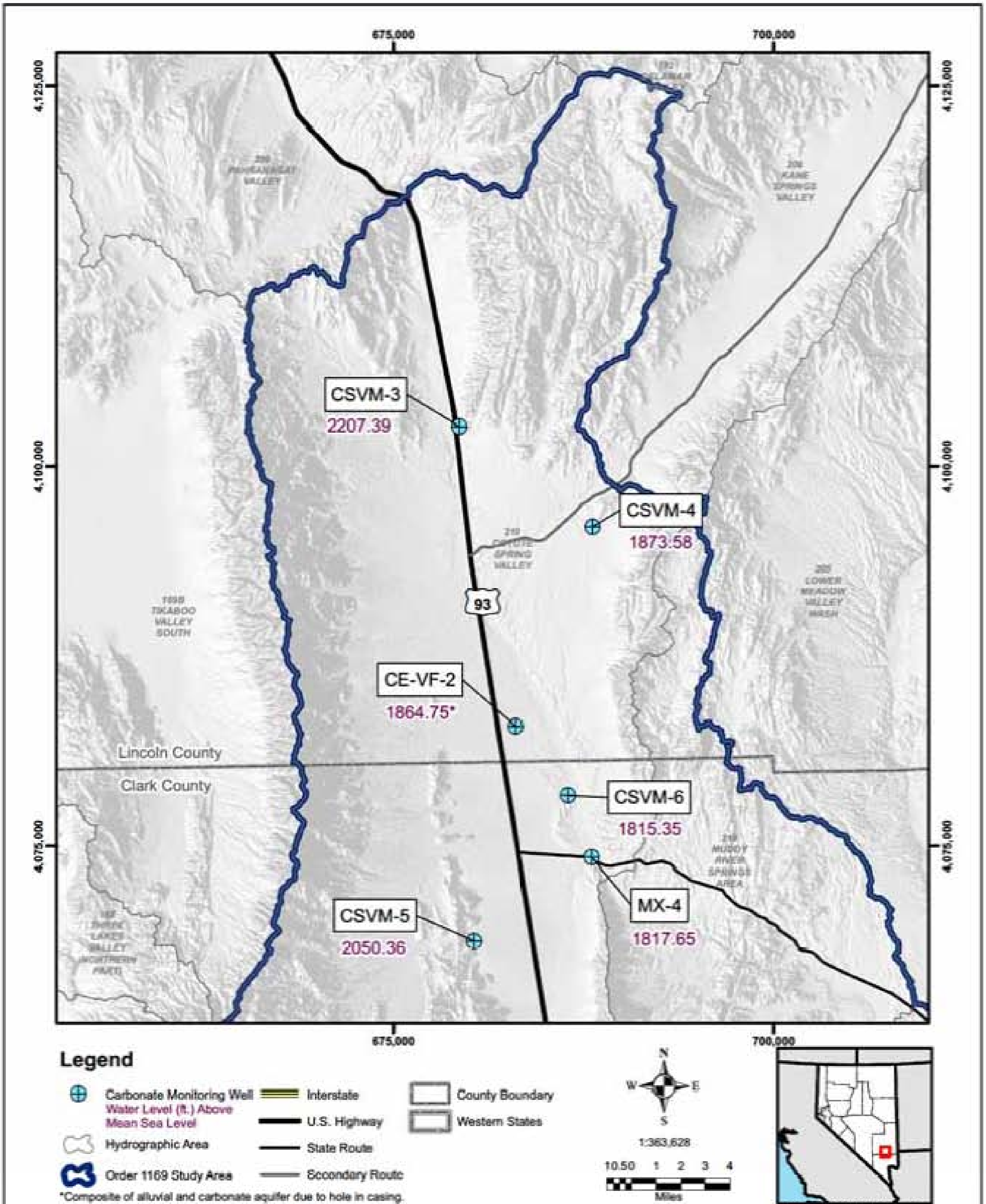

Figure 15
Map Depicting Water-Level Elevations in Wells MX-4, CSVM-6, CE-VF-2, CSVM-5, CSVM-4, and CSVM-3 from March 2013 Water-Level Measurements

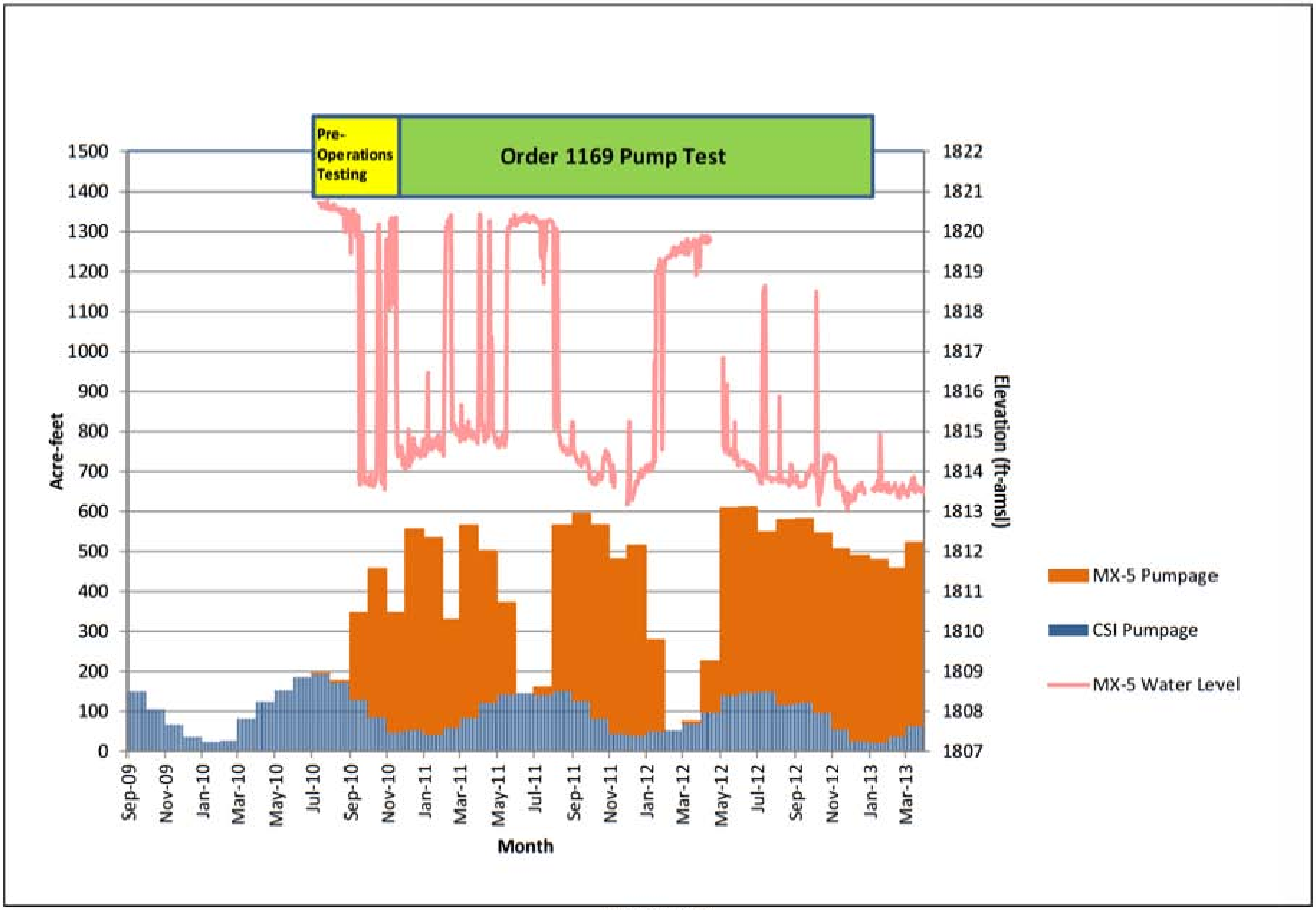

Figure 16
Duration of the Order 1169 Test, Monthly Volumes of Groundwater Production from Coyote Spring Valley, and Continuous MX-5 Water-Levels

4.2.1 Groundwater Level Trends and Observation in Proximal Wells

When the Test officially began on November 15, 2010, the groundwater level responses to well MX-5 pumping in proximal monitor wells CSVM-1 and MX-4 were relatively instantaneous at 0.4 to 0.6 ft. Figure 17 shows the location of these wells relative to MX-5 and Figure 18 shows daily continuous groundwater level data from these wells and well MX-5, all of which are completed in the RCA. All data is final except for USGS data for well MX-4 after September 30, 2012, which is provisional.

From September 2010 to December 2012 water level elevations in these proximal monitoring wells show declines of approximately 2.5 to 3.0 ft due to carbonate pumping of MX-5 and the CSI wells. Comparing the seasonal high groundwater levels from March 2010 to March 2013 demonstrates a groundwater level decline of 3.0 to 3.5 ft. These declines reflect SNWA and CSI carbonate pumping combined with regional climatic stresses.

Figure 18 also demonstrates that the groundwater levels in the proximal monitoring wells recovered almost instantaneously when well MX-5 stops pumping. The longer duration shutdowns in May and June of 2011 and the spring of 2012 depict larger groundwater recovery due to longer duration shutdowns. This demonstrates the ability for the RCA to recover relatively quickly once pumping stresses are removed. When pumping restarted, the slow gradual downward trends in the groundwater levels resume.

4.2.2 Groundwater Level Trends and Observation in Distal Coyote Spring Valley Wells

Figure 19 depicts the location of distal monitor wells in Coyote Spring Valley. Figure 20 shows continuous daily water level elevation data within Coyote Spring Valley from these wells and well MX-5, all of which are completed in the RCA. Water level elevation offsets are used to display the following wells on the same hydrograph: CE-VF-2 (-41 ft), CSVM-3 (-382 ft), CSVM-4 (-60.5 ft), and CSVM-5 (-224 ft). The initial pumping signal from well MX-5 can be inferred beyond barometric fluctuations at monitor wells CE-VF-2 and CSVM-2, at magnitudes less than the proximal wells. From September 2010 to December 2012, the water level elevation at well CSVM-2 shows a decline of roughly 2.5 ft. Also apparent in the groundwater levels at CSVM-2 is the distinct water level rise associated with shutdowns of MX-5. The groundwater level changes at CSVM-2, which is several miles from well MX-5, and are indicative of a confined to semi-confined aquifer system with groundwater level declines extending miles from the well over the duration of the Test.

The September 2010 water level elevation at well CE-VF-2 depicts a less than 1 ft decline to September 2011, which was followed by a water level rise in November 2011. This anomalous 8 ft water level rise in well CE-VF-2, was investigated with a downhole camera, and a hole in the blank casing within the saturated alluvium was discovered in which water was flowing into the well casing. The water level in CE-VF-2 now represents a composite head of the alluvial and carbonate aquifer instead of just the carbonate aquifer.

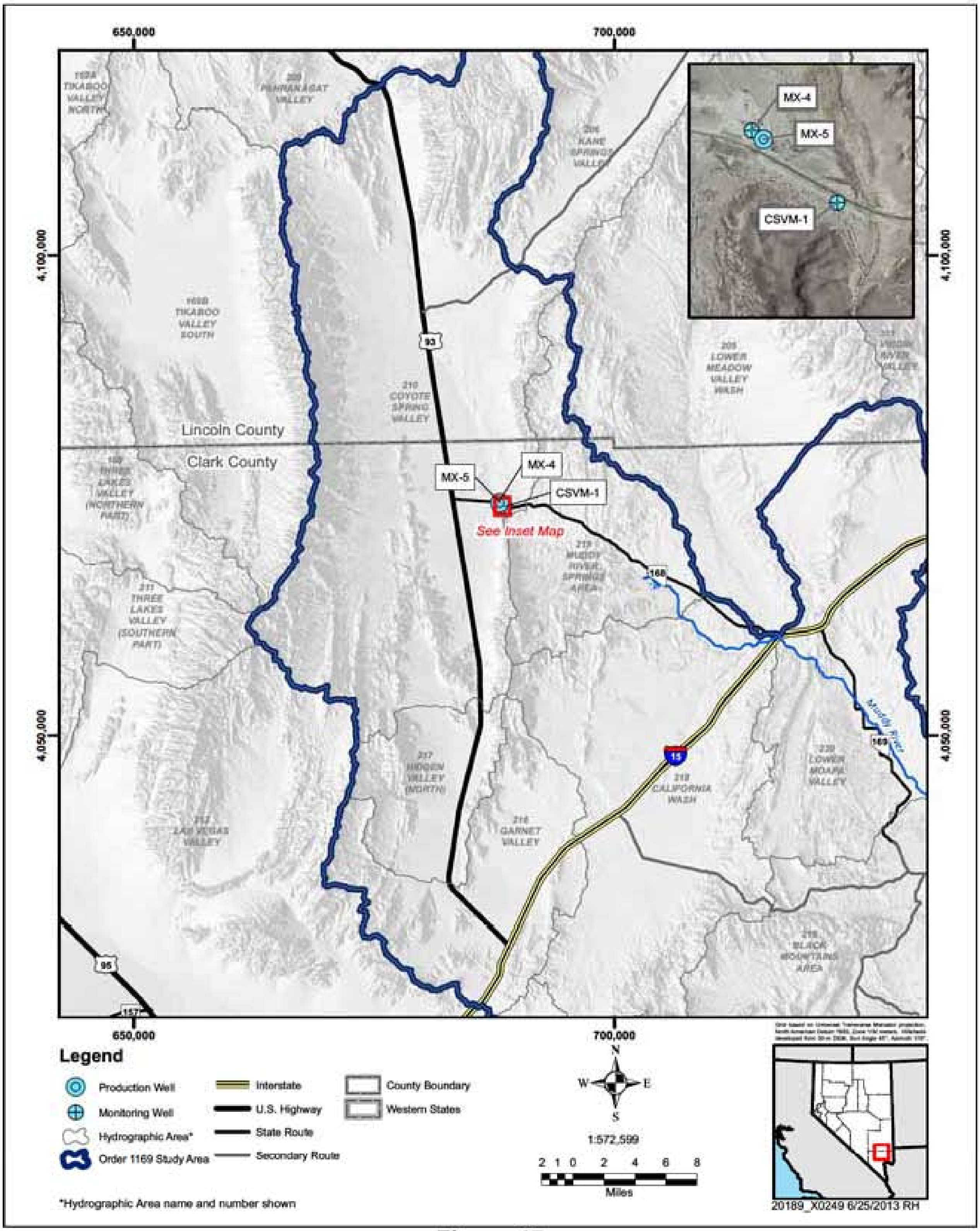

Figure 17
Location Map of Wells Proximal to MX-5

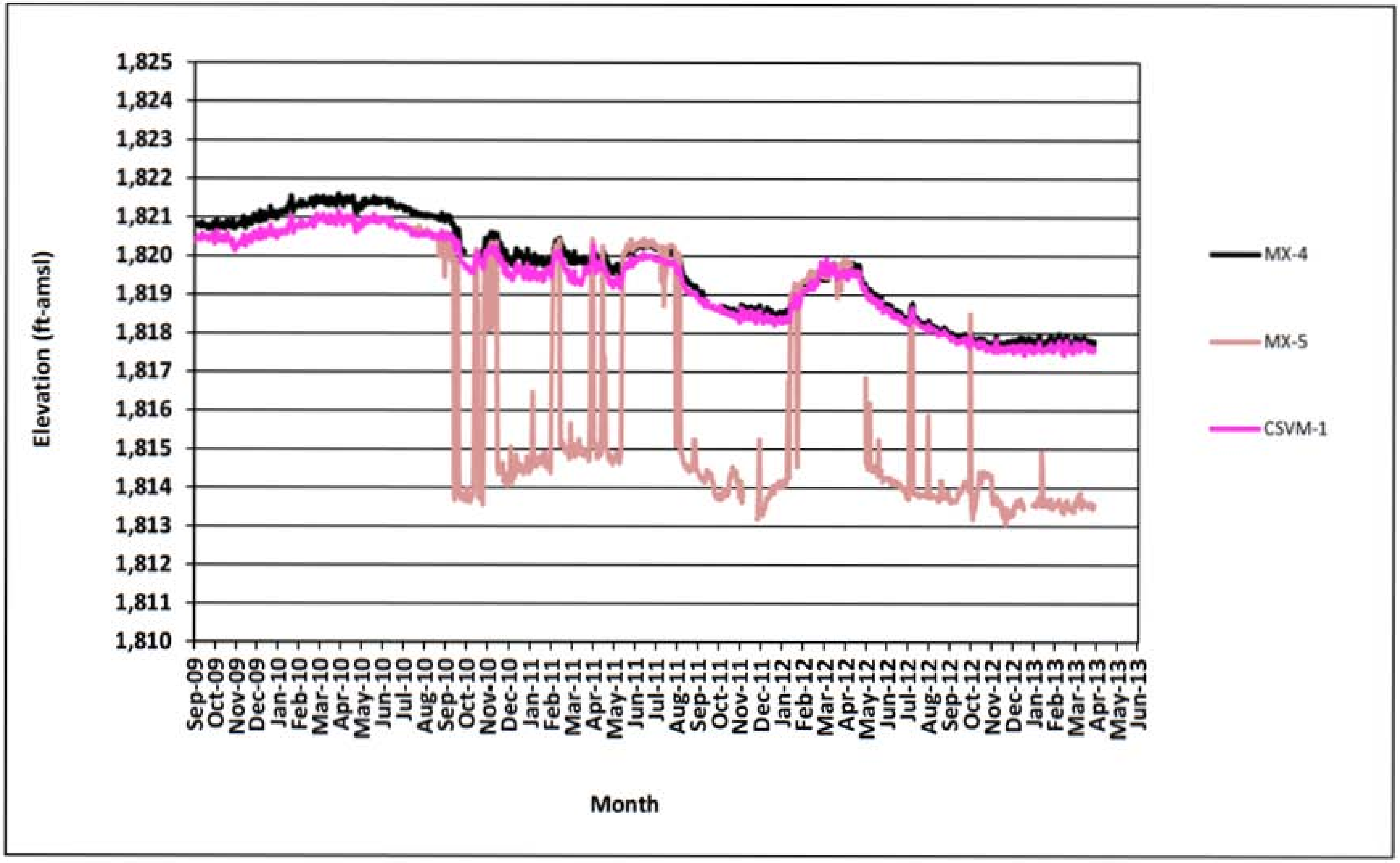

Figure 18
Hydrograph of Daily Continuous Groundwater Levels from MX-5 and Proximal Coyote Spring Valley Monitor Wells CSVM-1 and MX-4

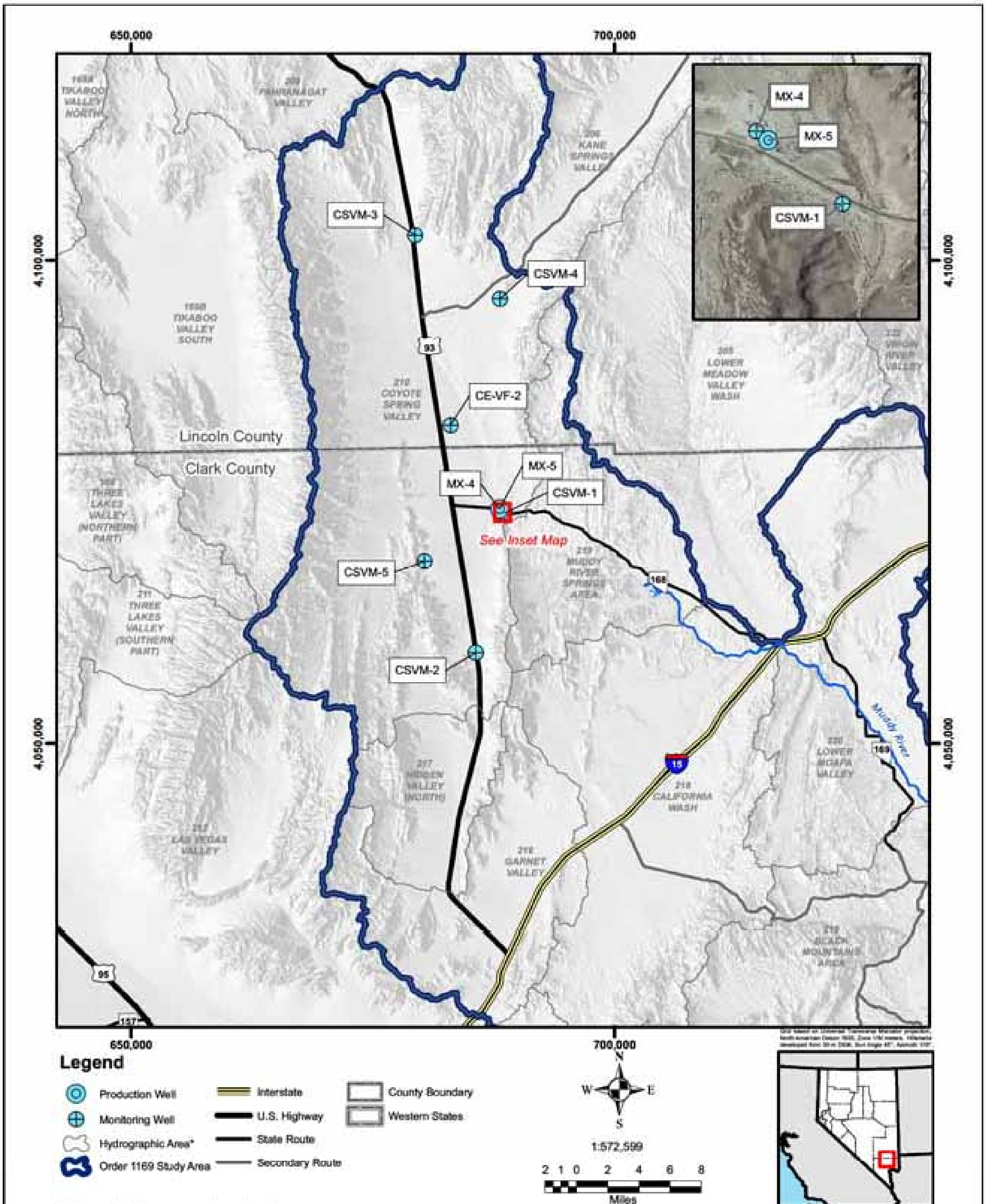

Figure 19
Location Map of Distal Monitor Wells CE-VF-2, CSVM-2, CSVM-3, CSVM-4, and CSVM-5 within Coyote Spring Valley

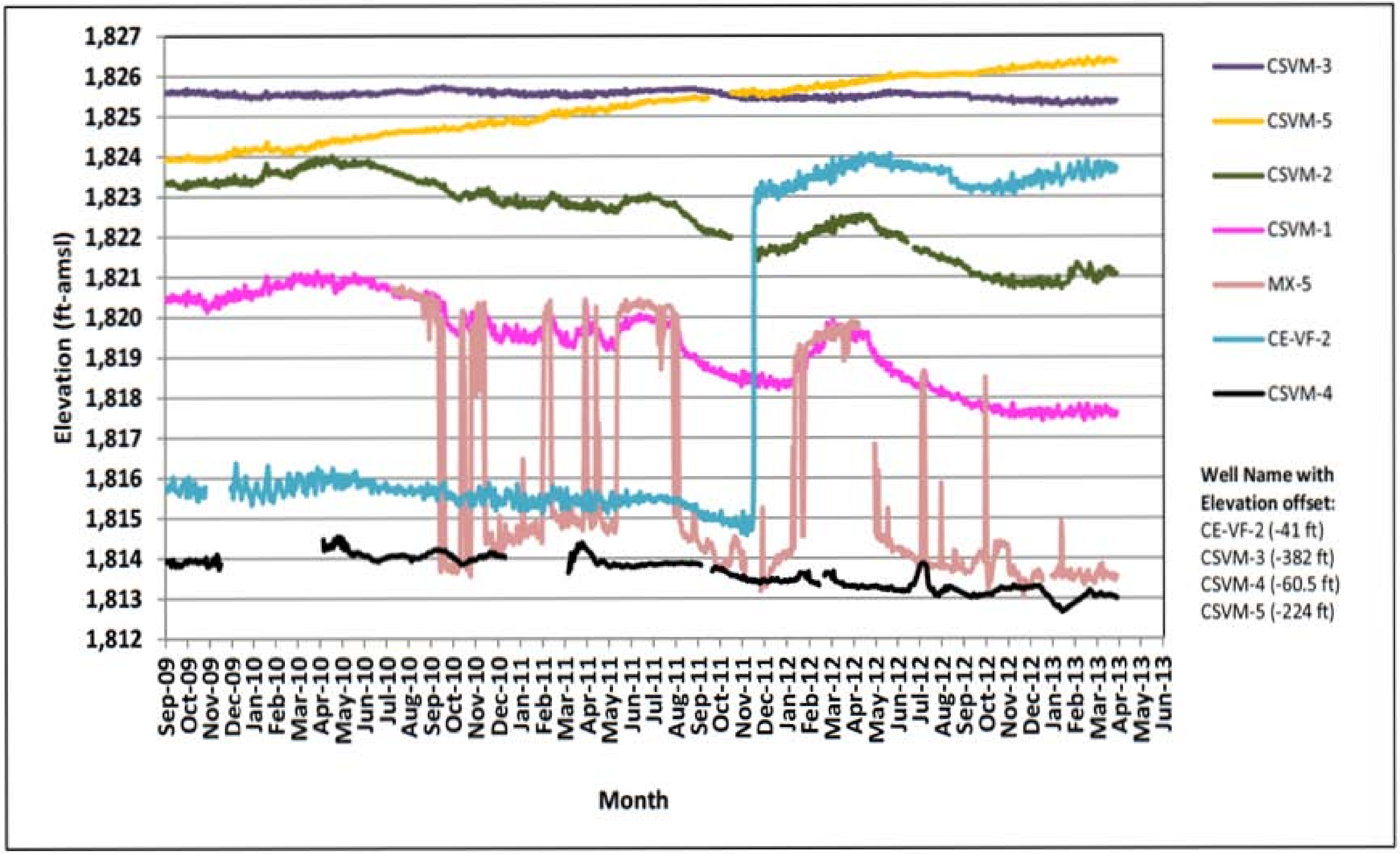

Figure 20
Hydrograph of Daily Continuous Groundwater Levels from MX-5 and Distal Coyote Spring Valley Monitor Wells CE-VF-2, CSVM-2, CSVM-3, CSVM-4, and CSVM-5

Monitor wells CSVM-3 and CSVM-5 do not show any response due to pumping from the MX-5 and CSI 1-4 wells, strongly suggesting the presence of flow barriers between these wells and MX-5 rather than a delayed response (Figure 20). CSVM-4 may be showing a slight response with December 2012 water levels approximately 1 ft lower than September 2010 water levels, but the transducer in CSVM-4 has had a high failure rate due to the high water temperature in the well, so fluctuations of a foot or less should not be used to infer an absolute response.

The seasonal, spring water-level rise observed in the groundwater elevations prior to the Test is apparent in the April 2012 water levels in wells CSVM-1, CSVM-2, and CE-VF-2 and less noticeable in the April 2011 and 2013 water levels. The April 2012 water level rise coincided with a roughly 3-month period of non-pumping at well MX-5. This shutdown resulted in groundwater levels in these distal Coyote Spring Valley monitor wells resuming the seasonal pattern observed prior to the Test, emphasizing the ability for the RCA to recover once pumping stresses are removed.

4.2.3 Groundwater Level Trends and Observation in Distal Wells

Figure 21 and Figure 22 depict the location of distal monitor wells outside of Coyote Spring Valley to the east and south, respectively. Figure 23 shows daily continuous water level elevation data from production well MX-5 and distal monitor wells UMVM-1, Paiutes-M1, EH-4, and CSV-2 to the east of MX-5. USGS daily average data from the USGS NWIS database for CSV-2 are final through September 2012 and provisional thereafter. Well EH-4 data are weekly average water level data from the NDWR Water Rights database prior to September 15, 2010, and daily average water levels from that point forward. An offset was applied to well CSV-2 (+20 ft) to display the groundwater level data on the same hydrograph as the MX-5 well.

The instantaneous pumping signal from well MX-5 is not discernible in these eastern, distal monitoring wells; however, a gradual decline of roughly 2 ft is observed from September 2010 to December 2012, slightly less than the 2.5 ft of decline observed at CSVM-2 located in the southern portion of Coyote Spring Valley. The seasonal rise observed in the spring of 2012 in the proximal monitoring wells is also present in these wells, but to a lesser degree.

Figure 24 shows daily continuous water level elevation data from production well MX-5 and distal monitor wells GV-1, BM-DL-2 (monthly data), and Paiutes-M2 located to the south of Coyote Spring Valley. An offset was applied to well GV-1 (+7 ft) to display the groundwater level data on the same hydrograph as the MX-5 well. The instantaneous pumping signal from well MX-5 is also not discernible in these monitoring wells, and the same gradual decline of roughly 2 ft is observed from September 2010 to December 2012. The seasonal rise observed in the spring of 2012 in the proximal monitoring wells is present, but to a lesser degree. The overall groundwater level trends in the southern distal wells are more muted than the eastern distal wells.

The observations discussed above relating to the four groups of spatially located sets of monitoring wells are the result of not only well MX-5 pumping but the combined pumping from the three pumping centers depicted on Figure 14, as well as, climatic variability. As noted earlier, climatic conditions during the Test were near average or dry, and groundwater development within the two pumping centers outside of Coyote Spring Valley was on-going during the Test. The similarity in

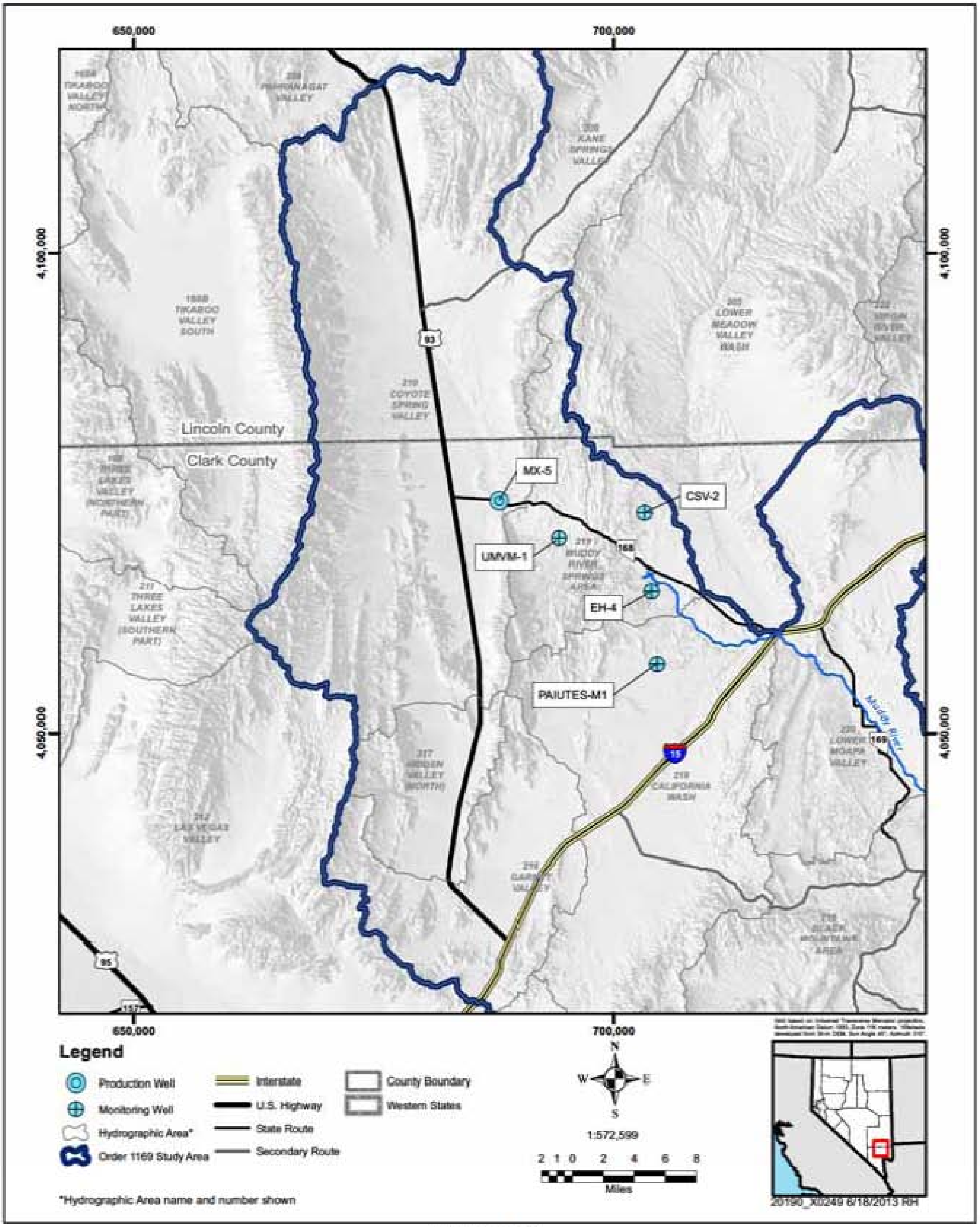

Figure 21
Location Map of Distal Monitoring Wells East of MX-5 in the Muddy River Springs Area and California Wash

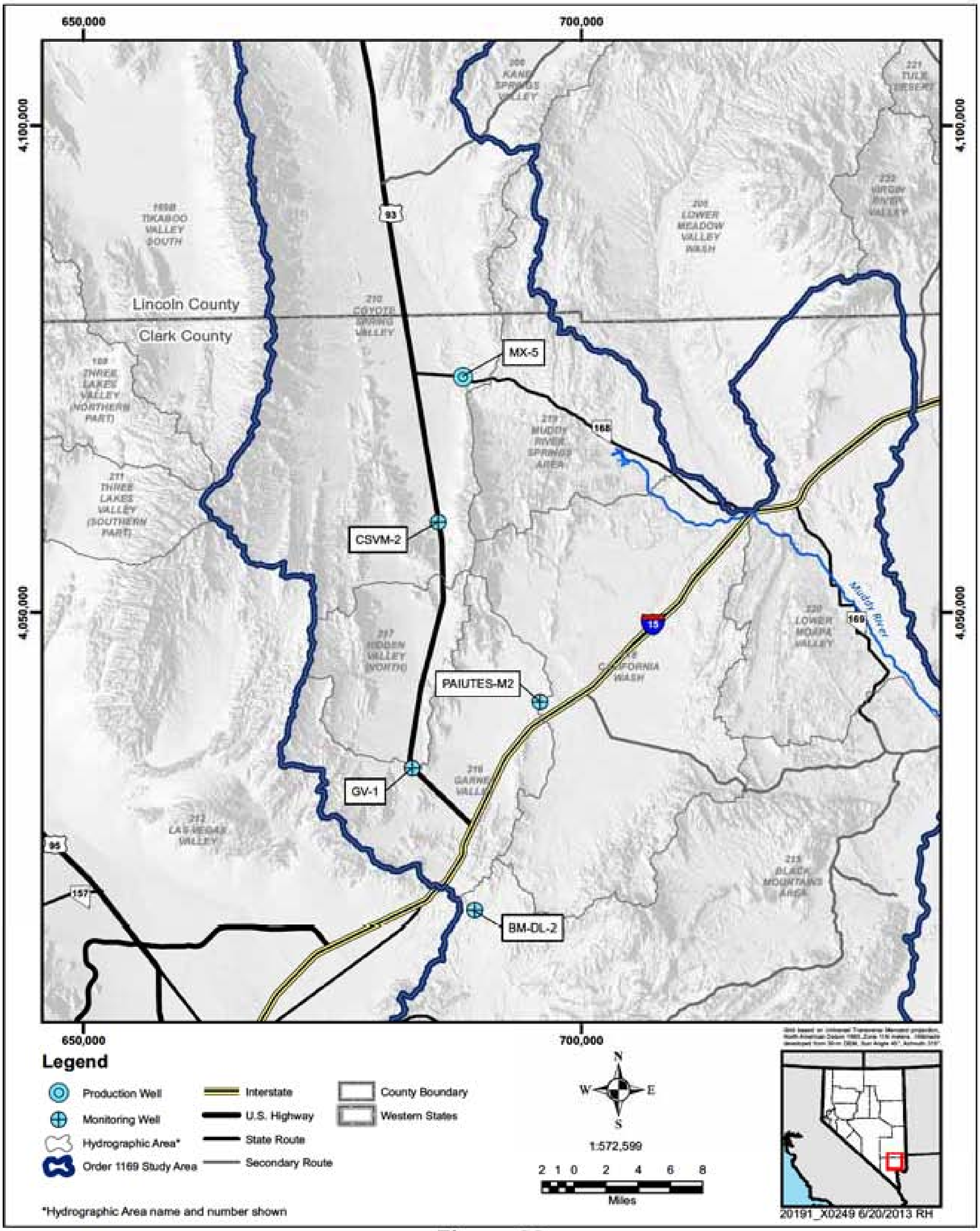

Figure 22
Location Map of Distal Monitoring Wells South of MX-5 in Coyote Spring Valley, California Wash, Garnet Valley, and the Black Mountains Area

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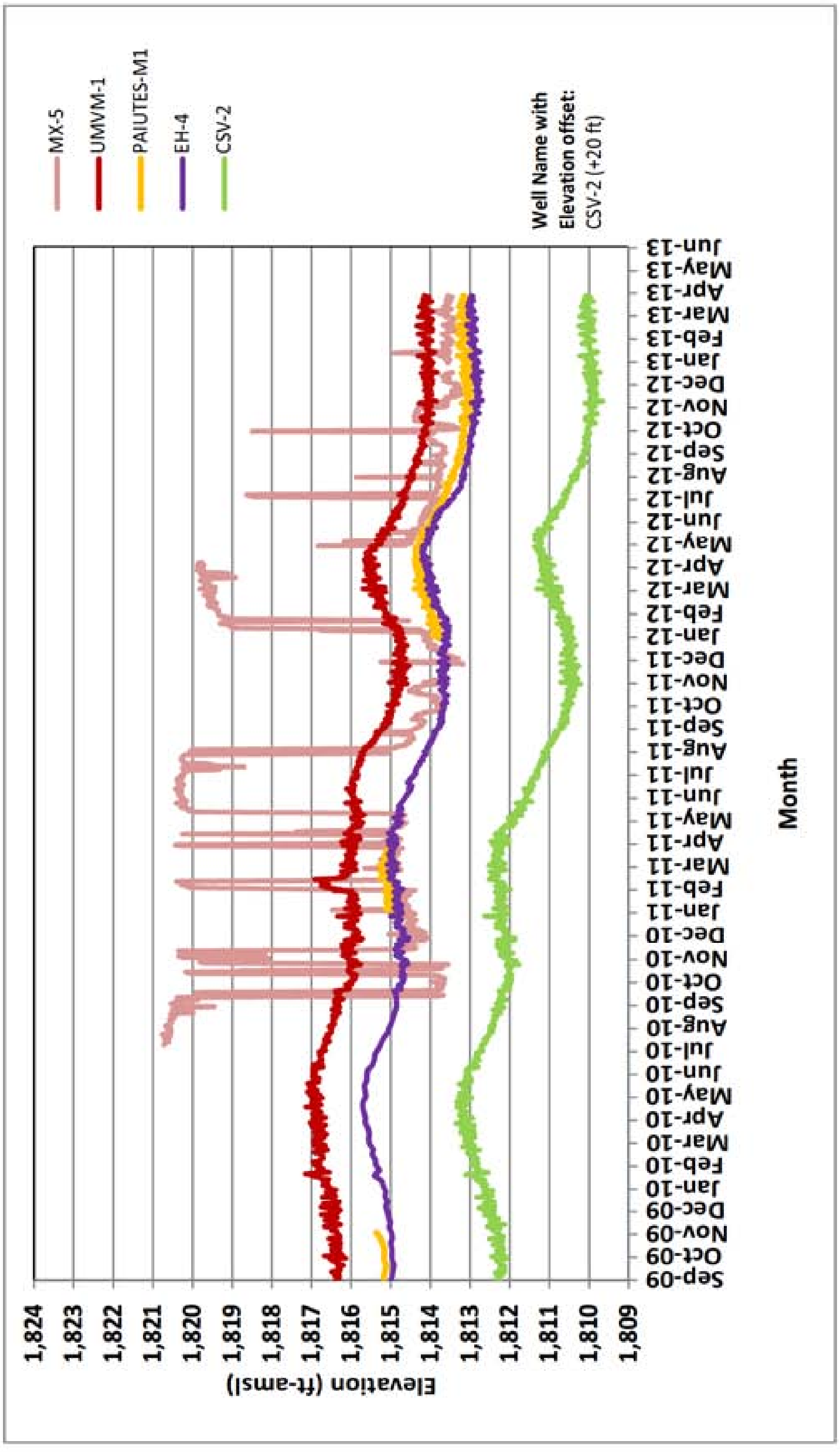

Figure 23
Hydrograph of Daily Continuous Water-level Elevation Data from Well MX-5 and Distal Monitor Wells UMVM-1, PAIUTES-M1, EH-4, and CSV-2 to the East of MX-5

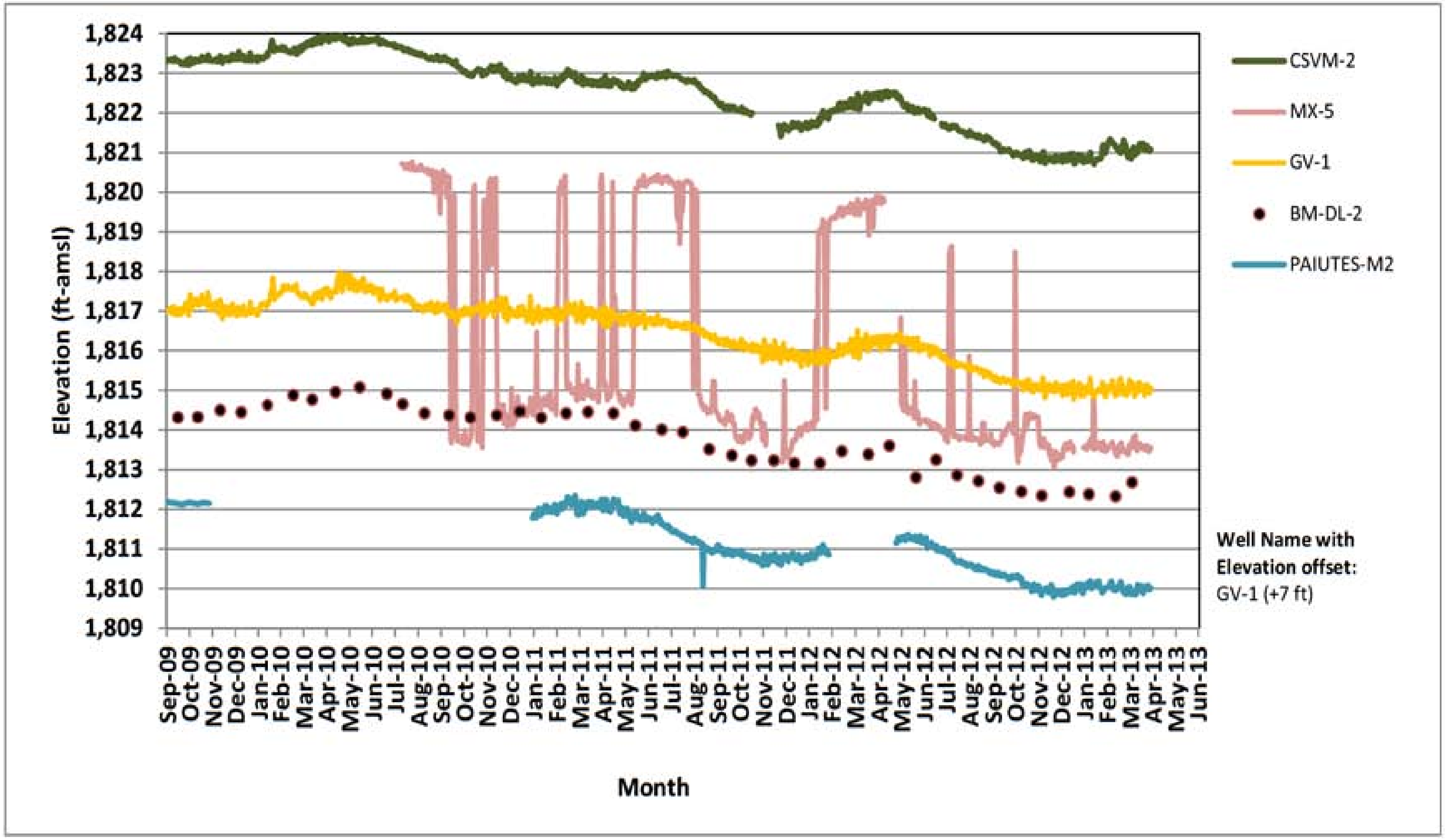

Figure 24
Hydrograph of Daily Continuous Water-level Elevation Data from Well MX-5 and Distal Monitor Wells CSVM-2, PAIUTES-M2, GV-1, and BM-DL-2 to the South of MX-5

magnitude of the groundwater trends during the Test combined with the broad regional water level trends prior to the Test suggest a degree of connection between Garnet Valley, Black Mountains Area, California Wash, Muddy River Springs Area, and Coyote Spring Valley and the influence of overlapping drawdown cones from the three pumping centers.

4.3 Muddy River Springs Discharge Observations and Trends

The Muddy River Springs Area discharges groundwater from the RCA through numerous springs, creating the headwaters of the Muddy River. Eight gages are maintained along the Muddy River and its tributaries (Table 3 and Figure 3) before it enters Lake Mead.

Table 3
Annual Discharge in Acre-Feet Measured at Gaging Stations Operated by the USGS or SNWA on the Muddy River and Tributaries of the Muddy River

USGS Station Number	Gaging Station Name	WY 2004 (afy)	WY 2005 (afy)	WY 2006 (afy)	WY 2007 (afy)	WY 2008 (afy)	WY 2009 (afy)	WY 2010 (afy)	WY 2011 (afy)	WY 2012 (afy)
09415900	Muddy Springs at LDS Farm near Moapa, NV (LDS gage)	5,741	5,778	5,242	4,815	5,321	5,184	5,082	5,240	5,810
09415908	Pederson East Spring near Moapa, NV (Pederson East gage)	139	163	175	155	139	134	189	142	109
09415910	Pederson Spring near Moapa, NV (Pederson gage)	112	174	197	190	168	158	162	141	99
09415920	Warm Springs West near Moapa, NV (Warm Springs West gage)	2,556	2,686	2,824	2,730	2,599	2,680	2,700	2,650	2,550
09415927	Warm Springs Confluence at Iverson Flume near Moapa, NV (Iverson Flume gage)	6,340	6,364	5,691	5,292	5,901	3,200	3,310	3,290	3,260
09416000	Muddy River near Moapa, NV (Moapa gage)	22,010	24,037	24,037	24,037	25,630	25,340	25,847	26,990	27,310
09419000	Muddy River near Glendale, NV (Glendale gage)	23,168	52,273	25,050	24,616	23,385	24,020	26,281	36,940	28,490
09419507	Muddy River at Lewis Avenue at Overton, NV (Lewis gage)	6,342	23,701	10,932	12,091	9,340	14,490	14,625	21,460	20,360

Note: There was significant flooding on the Muddy River in early 2005.

Hydrographs of continuous flows measured at the Pederson, Pederson East, Warm Springs West, LDS, and Iverson Flume gages are provided in Appendix D. These individual springs and Muddy River tributaries are considered part of the Muddy River Springs Complex, whose source is the RCA (Eakin, 1966). As the charts indicate, there is a slight downward trend in the late 1990s and early

2000s followed by an increase in flow from September 2004 to September 2005, similar to observations in groundwater levels during the same time period, as discussed in the previous section.

In October 2008, a restoration channel was constructed downstream of the Warm Springs West gage. Upon completion of the new channel, the water measured by the Warm Springs West gage no longer sheet flows through a grove of palm trees to the Iverson Flume gage. The water now flows under the road and into the new "Lower Pederson" channel to the Apcar Stream, bypassing the Iverson Flume gage.

A fire occurred in the Muddy River Springs Area on July 1, 2010. This rendered several USGS gages inoperable for a period of time in CY 2010 while the USGS initiated repairs.

Figure 25 and Figure 26 depict daily flows measured at the USGS Pederson gages and Warm Springs West gage, respectively, along with monthly carbonate aquifer groundwater pumpage by MVWD, CSI, and SNWA. There appears to be a discernible response to the carbonate pumping, beyond the historical climatic and pumping influence, within the Study Area at the Pederson and Pederson East gages with flows reaching historic lows in December 2012 (based on preliminary USGS data) ranging between 0.06 and 0.09 cfs at Pederson and between 0.10 and 0.13 cfs at Pederson East. Current flows measured at the Warm Springs West gage are slightly above historic lows and there appears to be an attenuated response to carbonate pumping. Flows at the Warm Springs West gage were 3.3 cfs in late September 2012 and remained relatively steady until October 2012 when flows increased to 3.4 cfs through mid-April 2013 before returning to 3.3 cfs. Flow records at the Warm Springs West gage prior to 1996 were influenced by an agricultural diversion above the gage, which is the reason for the increased variability prior to 1996.

Flows at the Iverson Flume and LDS gages have anomalous trends (Appendix D). The Iverson Flume gage has historically been affected by palm tree roots and beaver activity above the gage, influencing the flume rating. The LDS gage has been affected by operations of the swimming pool and irrigation on the LDS property as well as vegetation influencing the gage rating.

Charts depicting Muddy River stream flow at the Moapa and Glendale gages are also provided in Appendix D. As indicated by the charts, a noticeable decrease in the annual flow can be observed at both gages from 1944 to the early 2000s. It is generally understood and accepted that the decrease in surface-water flow is a result of continued surface-water diversions in the Muddy River Springs Area for industrial and municipal purposes associated with the NVE Reid Gardner Generating Station and communities in Lower Moapa Valley, as well as, shallow alluvial pumping by NVE in the Muddy River Springs Area (LVVWD, 2001). A significant increase in flows has also occurred since the early 2000s with flows reaching 40 cfs in December 2012 and 46 cfs in February 2013, despite on-going groundwater development from the RCA. This observation is discussed in subsequent sections.

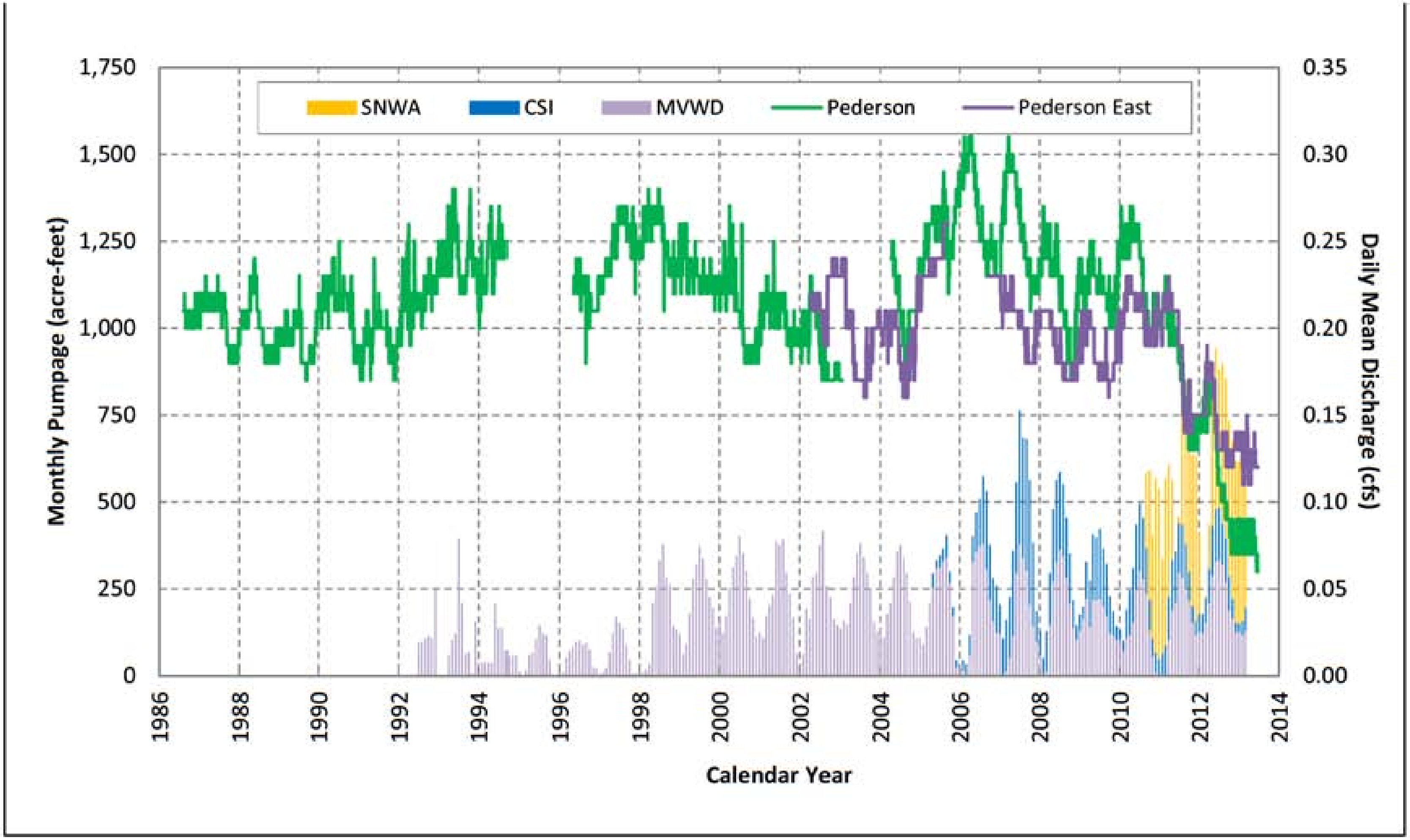

Figure 25
Monthly Well Production for CSI, MVWD, and SNWA in Coyote Spring Valley and the Muddy River Springs Area for Calendar Years 1986 through March 2013 and Daily Flow Data at Pederson and Pederson East Gages

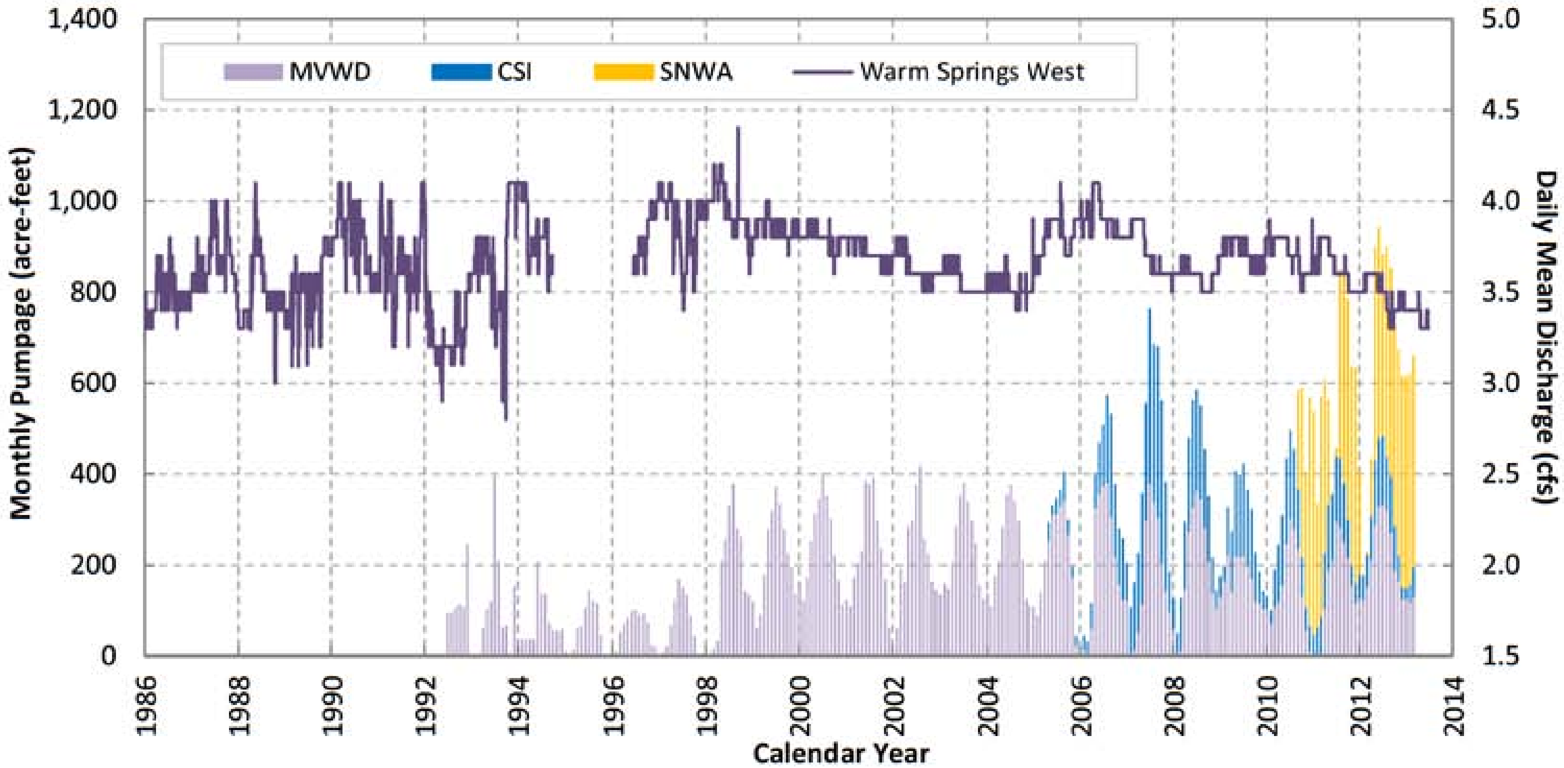

Figure 26
Monthly Well Production for CSI, MVWD, and SNWA in Coyote Spring Valley and the Muddy River Springs Area for Calendar Years 1986 through March 2013 and Daily Flow Data at Warm Springs West Gage

4.4 Muddy River Flow and Trends verses Groundwater Development and Surface-Water Diversions

The Muddy River is formed by springs and gaining stream reaches in the Muddy River Springs Area which coalesce above the Moapa gage. The Moapa gage measures the baseflow of the springs (i.e., Muddy River) less surface-water diversions, ET between the springs and the gage, and also the effects of groundwater withdrawal from the shallow alluvial aquifer in the headwater area of the Muddy River.

Development of groundwater resources adjacent to the upper reaches of the Muddy River began around 1947 when the first well was drilled (NDWR Well Log Database). The wells were initially used for agriculture, then many of the groundwater rights and wells were purchased by NVE and transferred to industrial use at the Reid Gardner Generation Station. Diversions of surface water by NVE upstream of the Moapa gage began in 1968 when NVE leased 1920 decreed Muddy River surface-water rights from MVIC.

A correlation exists between the alluvial groundwater pumping in the Muddy River Springs Area and the decline in stream flow at the Moapa gage. The measured flow at the Moapa gage, excluding flood flows, and the corresponding volume of alluvial groundwater pumping and surface-water diversion are shown on Figure 27. Subtracting historical alluvial groundwater pumping and surface-water diversions from the pre-development stream flow of CY 1946 (prior to groundwater and surface-water development) for each CY from 1947 to 2012 yields a theoretical Muddy River flow line. This theoretical flow closely approximates the actual measured flow at the Moapa gage, demonstrating the decline in gage flow at the Moapa gage is approximately equal to the alluvial groundwater pumping and surface-water diversions.

On Figure 28, carbonate aquifer pumping from MVWD wells (Arrow Canyon 1 & 2), the SNWA MX-5 well, and CSI wells are included in the groundwater development. An additional theoretical flow line was generated by subtracting the surface-water diversions, alluvial pumping, and carbonate aquifer pumping by MVWD, SNWA, and CSI from the pre-development stream flow of CY 1946. The addition of carbonate pumping causes the theoretical flows to deviate significantly from actual Moapa gage flows (excluding floodflows), demonstrating what the flow at the Moapa gage would be if the nearby carbonate pumping were influencing Muddy River flows at the gage. This clearly demonstrates that nearby carbonate pumping is not influencing Muddy River flows at the Moapa gage and is therefore not influencing senior Muddy River surface-water rights.

The correlation between the decline in measured Muddy River flows and alluvial groundwater pumping in the upper reaches of the Muddy River combined with surface-water diversions above the Moapa gage were discussed during the NSE water-right hearings associated with the LVVWD applications in July 2001 and is documented in LVVWD Exhibit 54.

The analysis performed in 2001 and updated here with 12 additional years of data continues to demonstrate and confirm that NVE alluvial groundwater pumping is directly correlated to flow declines in the Muddy River as measured at the Moapa gage on an almost 1:1 basis.

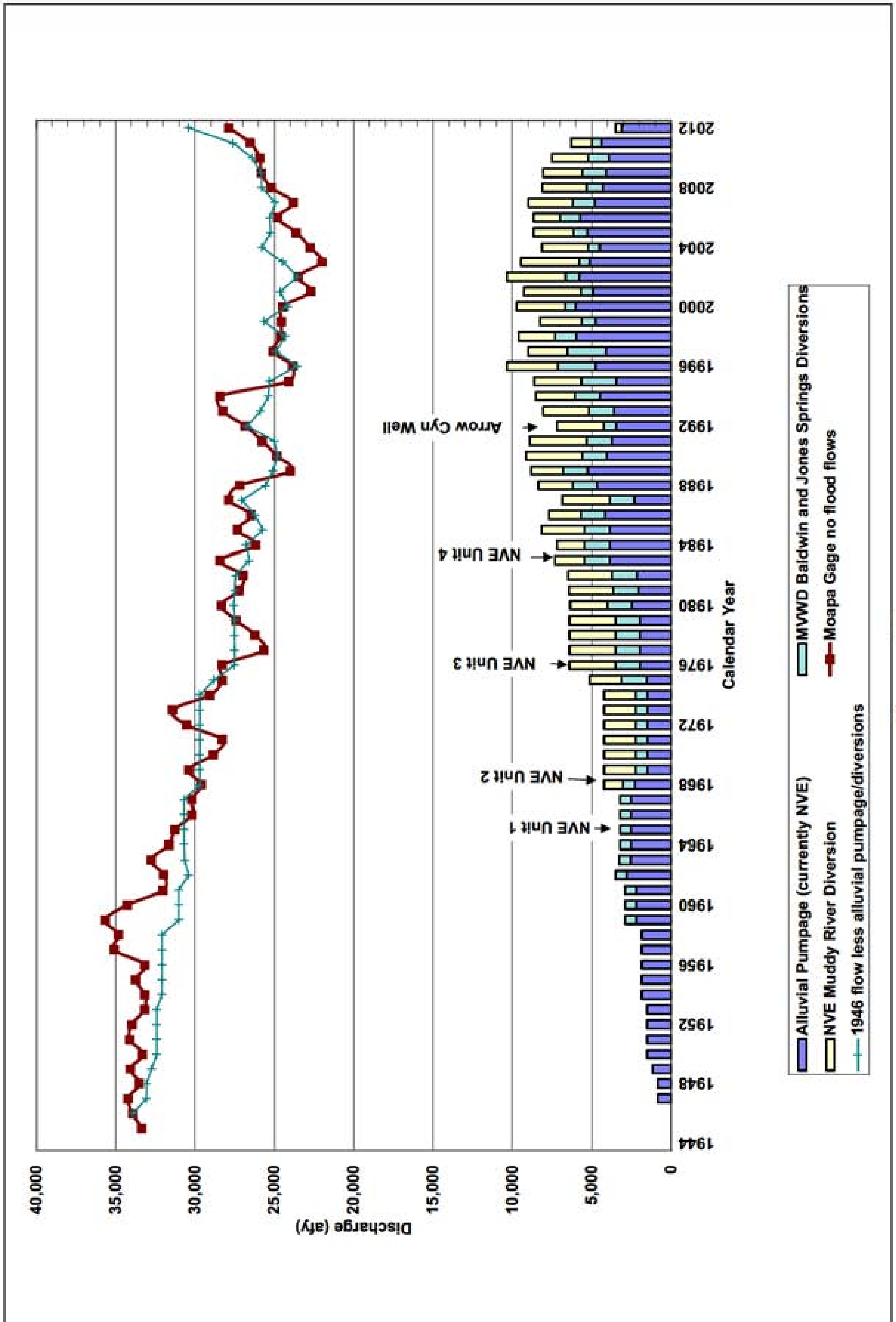

Figure 27
Comparison Between Decline in Flow at the Moapa Gage and Nearby Alluvial Groundwater Pumpage and Surface-Water Diversions

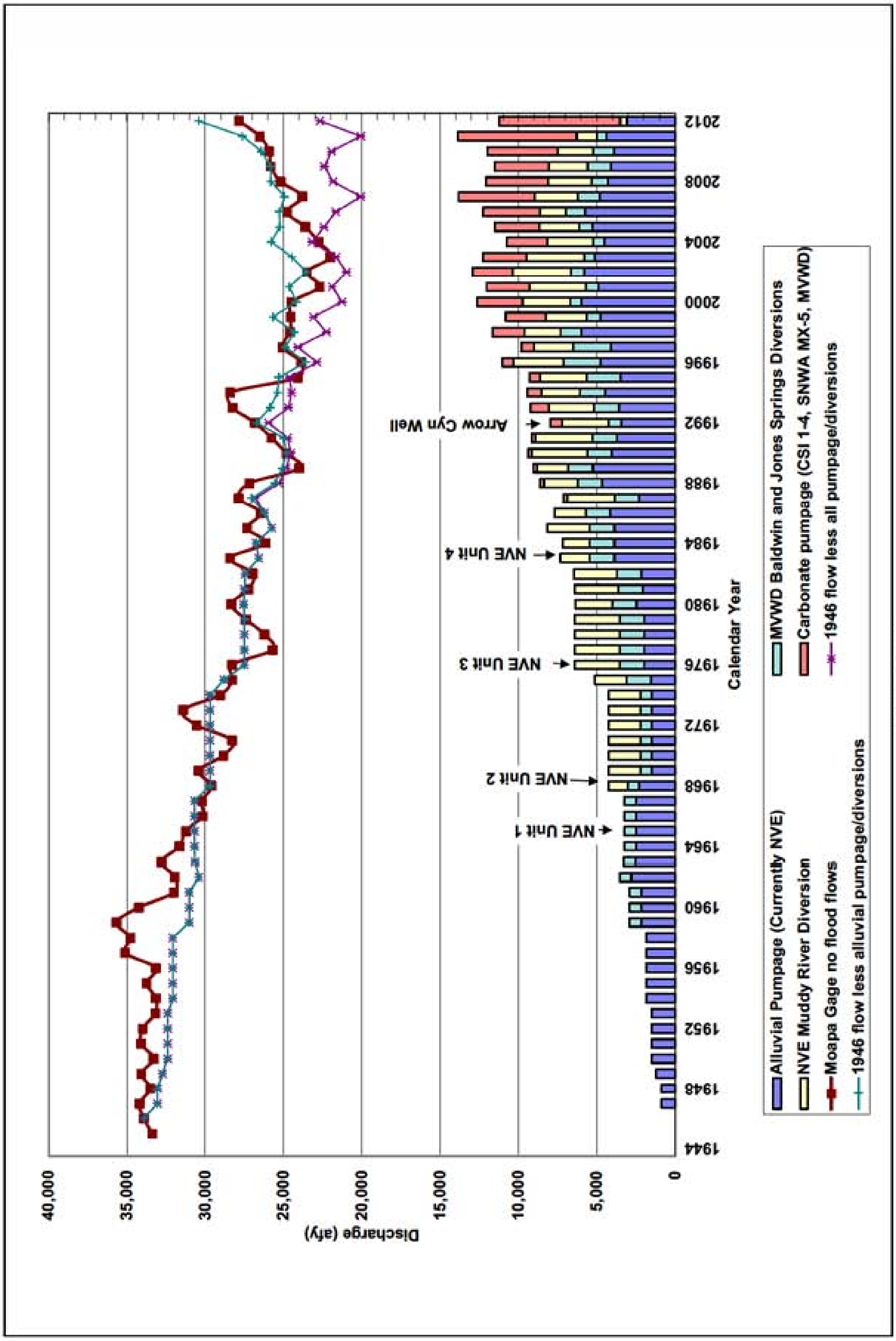

Figure 28
Comparison Between Decline in Flow at the Moapa Gage and Alluvial vs.Carbonate Groundwater Pumpage and Surface-Water Diversions

4.5 Monthly Average Reference ET and ET-Precipitation Trends

The analysis in Section 4.4 above assumes ET within the headwaters of the Muddy River above the Moapa gage remained constant. It has been suggested by some Order 1169 Study Participants that land-use changes in the headwaters have influenced the Moapa gage flows. Some land-use changes in the area have occurred in the last decade principally due to the SNWA acquisition of the WSNA and the corresponding lack of irrigation related to SNWA management of the property as a natural area. To examine the hypothesis that ET has declined in the headwaters of the Muddy River above the Moapa gage, SNWA funded DRI to calculate ET on a monthly time-step in the headwaters of the Muddy River to estimate the annual volume of ET. This section summarizes the study performed by Huntington and Morton (2013), (Appendix G).

The DRI study area delineated on Figure 29 was chosen to encompass the springs, agriculture, and phreatophytes in the headwaters, where most of the change in vegetation has occurred. Major springs in the headwaters, including springs located on the USFWS Moapa Valley Wildlife Refuge, and the SNWA WSNA, are included in the DRI study area. The following subsections provide a summary of the study methods and results.

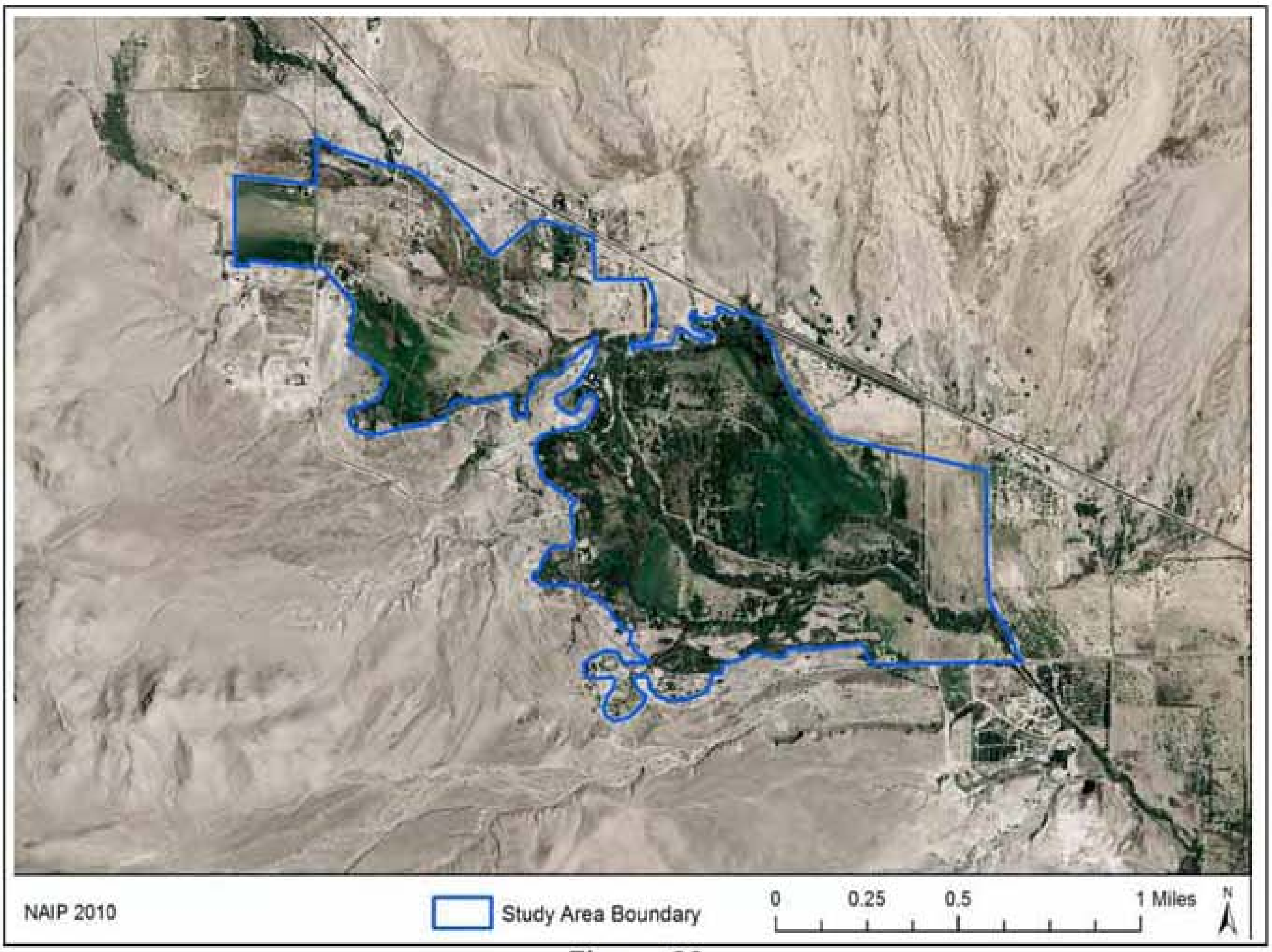

Figure 29
DRI Study Area for METRIC and NDVI-Derived ET Calculations

4.5.1 Methods

Huntington and Morton (2013) calculated ET for several years prior to the Order 1169 Test. The two methods utilized are referred to as Mapping EvapoTranspiration at high Resolution with Internalized Calibration (METRIC) and the Normalized Difference Vegetation Index (NDVI) derived ET method. Two methodologies were used because it takes a large amount of effort and time to perform METRIC for each year so fewer years were processed (CY 2006 to 2012), where the NDVI derived method requires much less time and effort, therefore a longer time span was able to be processed (CY 2001 to 2012).

Both methods used in this analysis utilize Landsat multispectral data. Although Landsat data has a relatively large pixel resolution (30m x 30m) when compared to many aerial photography products, Landsat has many advantages. Landsat has been used to collect multispectral (up to 8 bands plus thermal) imagery since the 1970s; the orbit patterns of the two active Landsat satellites enable data to be collected about twice a month for every location on earth; and the data is free to download. Advances in remote sensing technology and in the field of ET have made it possible to calculate ET utilizing Landsat data.

Monthly Landsat scenes were obtained for the Muddy River Springs Area between CY 2001 and 2012. Landsat scenes captured around July 2010 are notable because they document the headwaters before and after the July 2010 fire that burned a significant portion of the vegetated area above the Moapa gage (Figure 30 and Figure 31, respectively).

METRIC involves processing the Landsat data which is then calibrated to locally collected meteorological data to calculate actual ET on a pixel-by-pixel level. This local meteorological data is used to calculate reference ET (ETr), which is the ET which would occur over a hypothetical crop surface with specified characteristics. This calibration is performed for each available Landsat scene for the period of interest, up to two per month. Actual ET is then interpolated between the Landsat data dates utilizing the local meteorological data to obtain daily ET values. For this study, METRIC was calculated between CY 2006 and 2012.

The NDVI derived ET method utilizes NDVI which is a calculation performed on the red and near infra-red bands of the Landsat data. The result of an NDVI calculation provides a data layer that numerically quantifies the amount of green vegetation in a particular pixel. Previous studies have found a linear relation between NDVI values and the relative fraction ETr, widely known as the crop coefficient. By comparing the NDVI and the relative fraction of reference ET, a linear relationship can be developed and applied to NDVI values to obtain ET for that area. Since NDVI derived ET is less labor intensive to calculate than METRIC, ET was calculated utilizing a locally developed NDVI relative fraction of reference ET regression between CY 2001 and 2012 in order to look at a longer period.

Precipitation was subtracted from the ET results of each method in order to make the results more comparable year to year and to evaluate potential changes independent of precipitation changes. PRISM precipitation data were used for this purpose and correlated well with locally collected precipitation values.

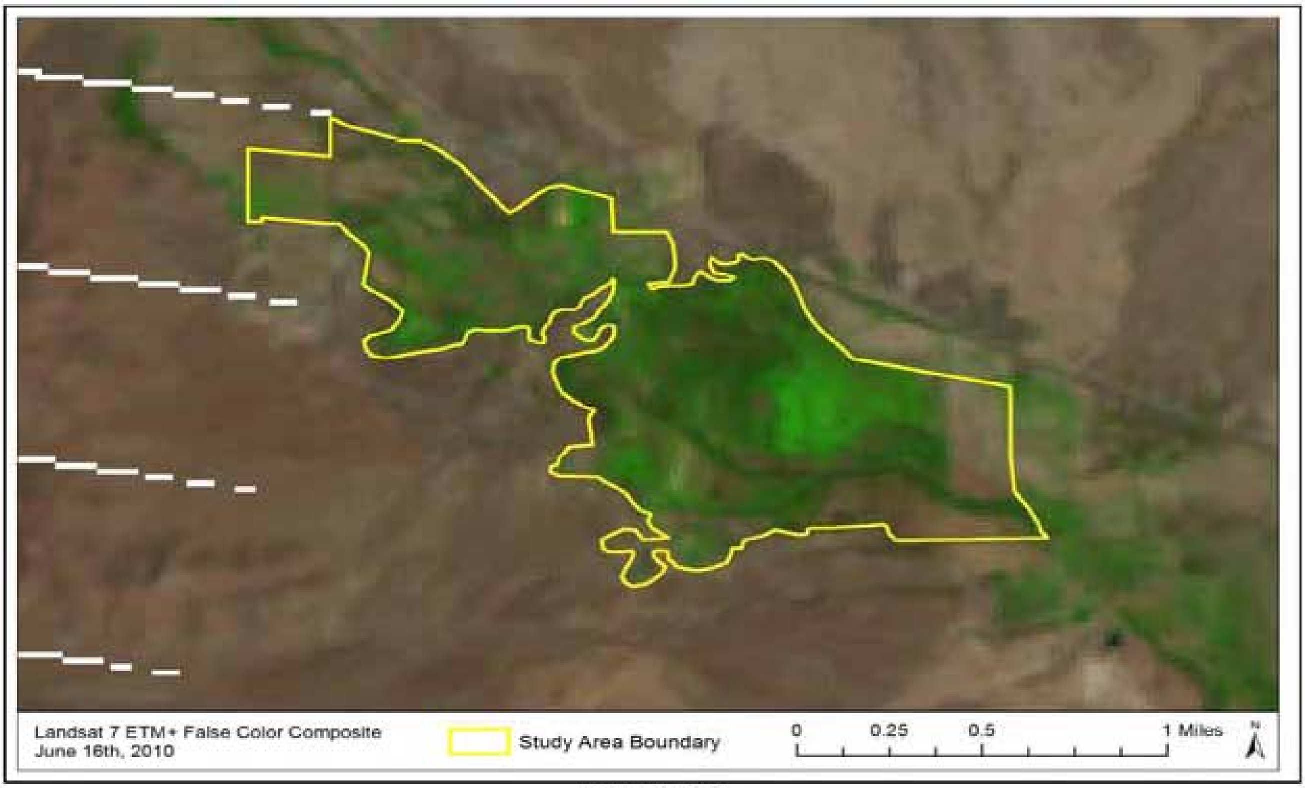

Figure 30
Landsat Image Prior to July 2010 Fire

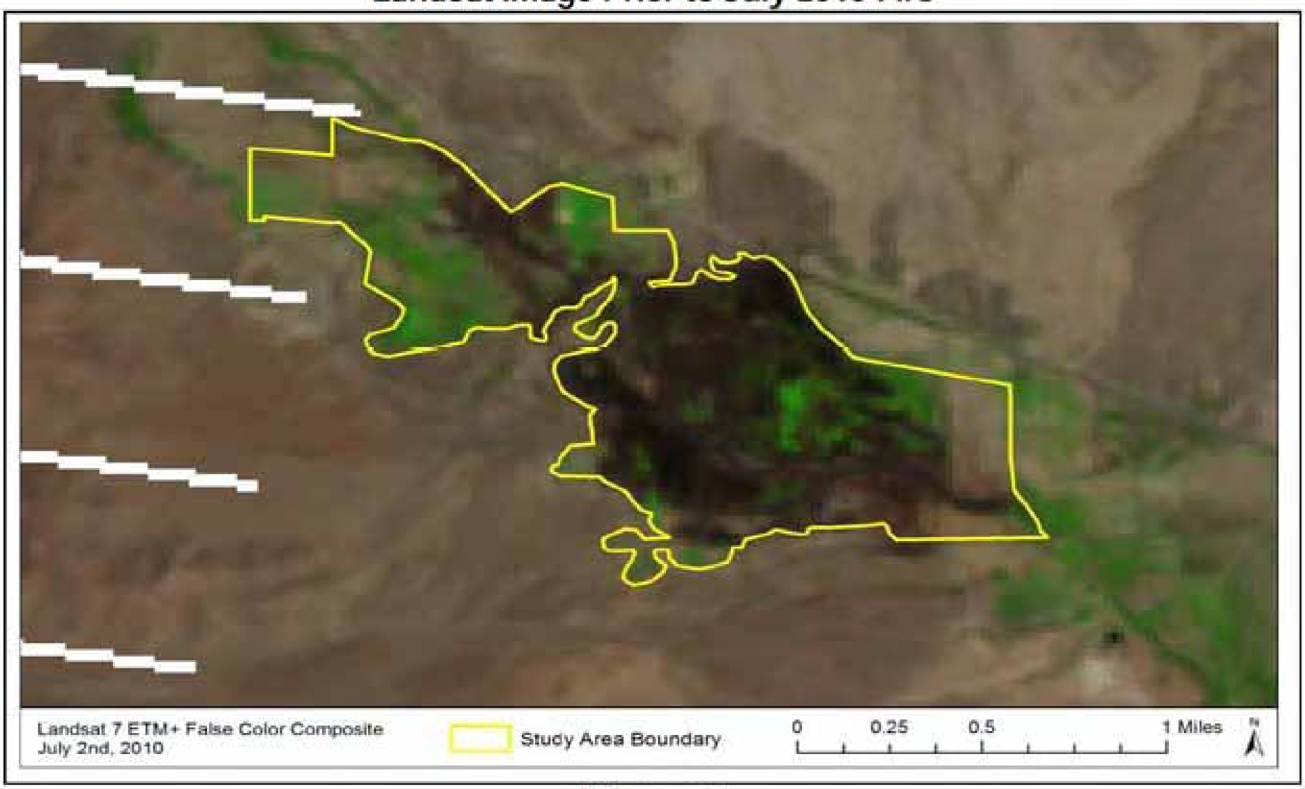

Figure 31
Landsat Image After July 2010 Fire

4.5.2 Results

For the overlapping period of CY 2006 to 2012, the METRIC and NDVI derived ET results were compared. On a seasonal basis the results from both methods correlated well; therefore, to compare ET data over a longer period of time, the NDVI-derived ET results are also used in this report.

Between CY 2001 to 2012 a slight downward trend in ET (Figure 32) is observed in the headwaters based on the NDVI-derived ET results. This slight downward trend is also seen in the 2006 to 2012 METRIC results.

Table 4 shows the annual total ET volumes for the DRI study area. The long-term ET volume decreased between CY 2001 and 2012 about 900 af according to the NDVI-derived ET method, and about 600 af between CY 2006 and 2012 based on METRIC.

Some highs and lows in the record seem to correspond well with observed events that would be expected to have an impact on ET rates in the area. The high point in CY 2005 is due to above normal precipitation that caused greater vegetation density, thereby increasing total ET over the DRI study area for that year. In CY 2010 the ET rate declined, most likely due to the fire in the headwaters. Huntington and Morton (2013) determined the long-term decrease in ET is most likely due to a combination of changes in vegetation and observed decreases in reference ET in the DRI study area.

Based on the Huntington and Morton (2013) study, an overall decrease in ET for the headwaters from 2001 to 2012 likely ranges between 600 and 900 afy. The 600 af estimate is derived from extrapolating the rate of decrease in ET backwards from the CY 2006-2012 METRIC analysis back to CY 2001, and the 900 afy is rounded from the NDVI-derived ET results.

The total change in ET in the headwaters of the Muddy River above the Moapa gage is minor compared to the overall change observed in the flow of the Muddy River at the gage. Thus, the conclusions drawn in the previous section regarding the lack of influence of carbonate pumping on flows in the Muddy River are supported, as is the conclusion that NVE alluvial pumping is capturing water that would have otherwise constituted Muddy River water apportioned under the 1920 Muddy River decree.

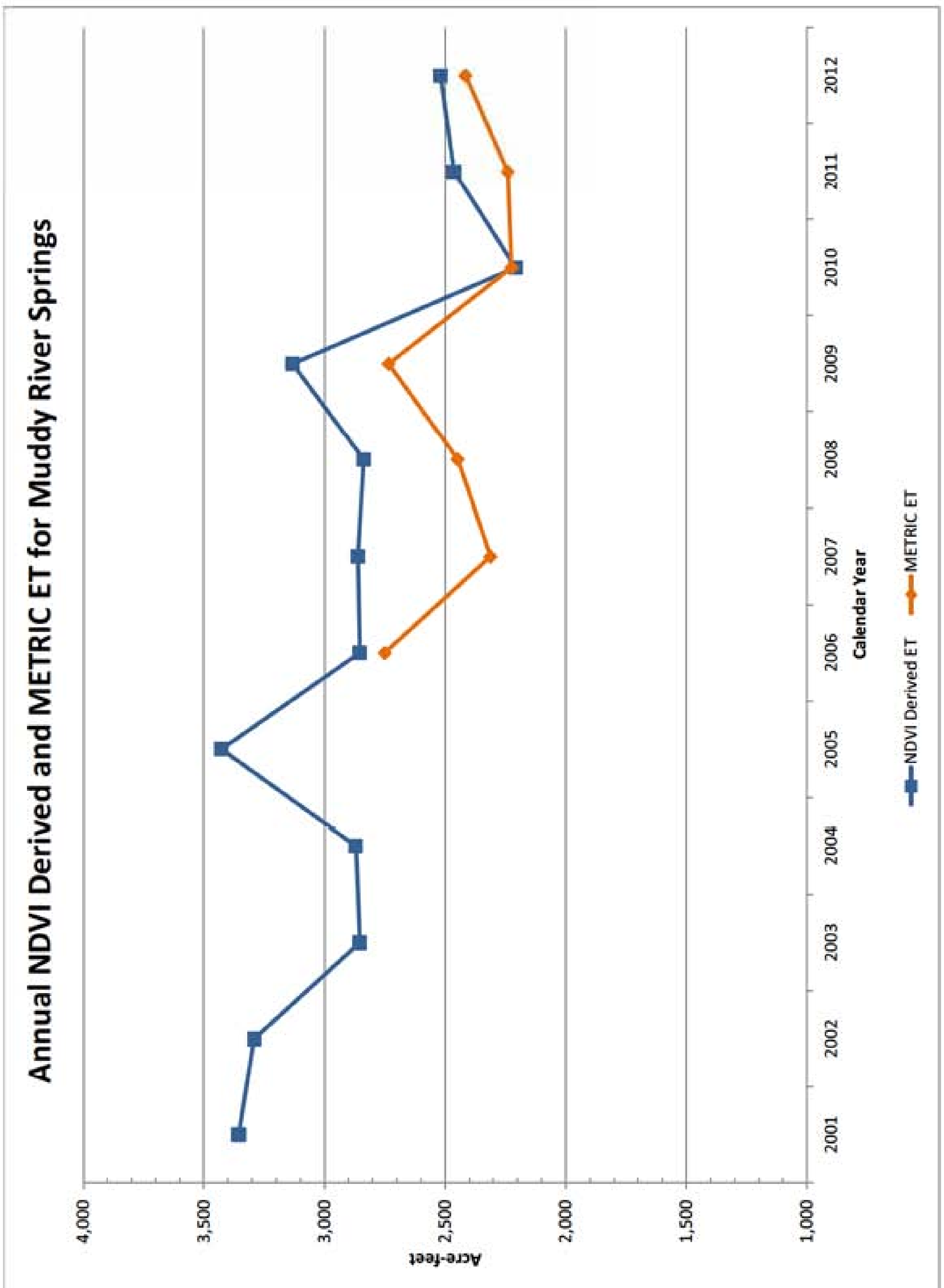

Figure 32
NDVI-Derived ET Rate from DRI Study

Table 4
NDVI Derived ET

Calendar Year	DRI Study Area (acres)	ET_r	NDVI Annual ET Rate (ft)	NDVI Annual ET Volume (afy)	METRIC Annual ET Rate (ft)	METRIC Annual ET Volume (afy)
2001	797	7.51	4.21	3,355		
2002	797	7.85	4.13	3,292		
2003	797	7.56	3.58	2,853		
2004	797	7.51	3.6	2,869		
2005	797	7.06	4.3	3,427		
2006	797	7.24	3.58	2,853	3.45	2,750
2007	797	7.26	3.59	2,861	2.9	2,311
2008	797	7.17	3.56	2,837	3.07	2,447
2009	797	7.32	3.93	3,132	3.43	2,734
2010	797	6.92	2.77	2,208	2.79	2,224
2011	797	6.72	3.09	2,463	2.81	2,240
2012	797	7.09	3.16	2,519	3.03	2,415

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5.0 Summary and Conclusions

After the issuance of Order 1169 in 2002, SNWA and other study participants established an extensive monitoring network in preparation for a two-year pumping test. Preceding the test, water level, spring discharge, and streamflow data were collected and used to characterize the natural variability of the groundwater system and establish baseline hydrologic conditions. Analysis of these data indicates that the groundwater system, particularly the RCA, exhibits widespread and clear responses to changing hydrologic conditions. These responses are observed as groundwater level declines during periods of persistent drought (2000-2004; 2011-present), and groundwater level increases during periods of above normal hydrology (e.g. 2004-2006). Depending on the proximity of observation points to pumping centers in the study area, the effects of groundwater production can also be observed but they are typically minor and are superimposed on the trends associated with the natural variability of the groundwater system.

The NSE and study participants agreed that less than the initially required 8,050 afy of existing Coyote Spring rights could be pumped while still achieving the Test objectives. The Test was started in November 2010 using SNWA well MX-5 and CSI wells CSI-1 through CSI-4. During the Test, well MX-5 was pumped at rates ranging from 3,300 to 3,800 gpm, while the CSI wells were pumped intermittently. A total of 5,331 afy and 5,102 afy were pumped in Coyote Spring Valley during calendar years 2011 and 2012, respectively. Equipment issues with the water treatment facilities associated with the MX-5 well caused pumping to cease for periods during the Test.

Instantaneous responses in groundwater levels near the MX-5 well were observed at small magnitudes. Pumping responses associated with this well are indicative of a confined to semi-confined aquifer system based on groundwater level declines observed miles from the well over the duration of the Test. These declines also corresponded to the persistent drought conditions experienced throughout the study area and regionally during and preceding the Test. Declines ranged from several feet in close proximity to the pumping wells, to two feet or less in the adjacent down-gradient basins. In the northern and western portion of Coyote Spring Valley, no discernible responses to groundwater pumping were observed. The pumping rates associated with the MX-5 well were greater than any single (and in many cases combined) pumping stress imposed to date, and the observed pumping responses were not unexpected.

Maintenance and repair activities of the water treatment facilities adjacent to well MX-5 resulted in several shutdowns of well MX-5 during the Test and allowed for the observation of drawdown recovery of the RCA. Recovery responses to the cessation of pumping from the MX-5 well were small but observable as groundwater levels in monitor wells demonstrated increasing trends. The trends demonstrate the ability for the RCA to recover relatively quickly once pumping stresses are removed. After the recovery periods and the continuation of pumping, slow gradual decreasing trends in the groundwater levels resumed.

Regional water level changes in the carbonate aquifer were the result of pumping from the three pumping centers coupled with changing hydrologic conditions. Seasonal pumping associated with CSI, MVWD, and the power generation stations in Garnet Valley contribute to seasonal declines in groundwater levels which have been observed in the monitor wells. The seasonal pumping signal oscillates between lower groundwater levels in the summer and fall, and higher levels in the winter and spring. Groundwater production by SNWA in Coyote Spring Valley is more consistent throughout the year and therefore does not contribute much to the seasonal oscillation. This oscillation overprints the climatic signal with a similar wavelength and periodicity.

Since the beginning of the Test, groundwater levels near the Coyote Spring production wells and in down-gradient areas have been decreasing as expected. Minor water level declines from the spring of 2010 to the spring of 2013 ranged from about 3.0 ft to 3.5 ft in proximal wells, and from 2.0 ft or less in distal wells. The groundwater level changes resulting from the combined pumping and climatic stresses are apparent in most of the carbonate wells over a broad regional area including Garnet Valley, Black Mountains Area, California Wash, Muddy River Springs Area, and Coyote Spring Valley. This cyclical trend was not observed in carbonate monitor wells CSVM-5 and CSVM-3 to the west and north of the Coyote Spring production wells, respectively.

There was a lack of responses to MX-5 or other RCA pumping in northern (CSVM-3) and western (CSMV-5) portions of Coyote Spring Valley. The lack of responses suggests the presence of boundaries (faults) and/or distributions of contrasting hydraulic conductivity that limit the propagation of pumping effects to the north and west. Discontinuities and steep gradients in RCA potentiometric levels provide additional supporting evidence for these conditions, but due to the lack of responses, the hydraulic properties of these unaffected areas cannot be analyzed with the Test data. As a result, the hydrogeologic understanding of the areas is less certain. However, the presence of boundaries and variations in hydraulic conductivity could potentially allow for the redistribution of pumping to these areas so as to minimize hydrologic impacts to senior water-right holders and environmental resources. It remains unclear if additional resource development beyond existing permitted rights could take place in these locations.

To the east of Coyote Spring Valley, in the Muddy River Springs Area, the observed declines in flow at the Pederson and Pederson East gages were expected as they are the highest elevation springs within the headwaters of the Muddy River. The observed decline at the Pederson gage represented a decrease of roughly 67 gpm, about 0.15 cfs, which is indiscernible at the Moapa Gage. These declines did not result in the lowering of flows at the Warm Springs West gage below established, stipulated triggers, that if reached would have resulted in the reduction of groundwater pumping in Coyote Spring Valley.

A concern associated with Coyote Spring Valley groundwater development is the potential impacts this development may have on senior Muddy River surface water rights. As demonstrated by the analyses of the Muddy River flows at the Moapa gage, surface water flows actually increased prior to and during the Test. This increase is the result of reduced pumping from the alluvial aquifer by NVE. Groundwater development in Coyote Spring Valley did not result in observable effects on Muddy River streamflow.

Analyses of flows at the Moapa gage and ET in the Muddy River Springs Area indicate that the increase in the Muddy River streamflow is principally due to reduced alluvial pumping by NVE and not by pumping in Coyote Spring Valley. The ET analysis indicates changes in vegetation and land use were minor with reductions in ET consumptive uses accounting for less than 900 afy for the period 2001 to 2012. These analyses indicate that the local alluvial pumping is the primary stressor affecting Muddy River streamflows and, thus, the primary threat to senior surface water-right holders on the Muddy River.

Declining groundwater levels observed in monitor wells GV-1 (Garnet Valley) and EH-4b (Muddy River Springs Area) are also observed in the MBPI wells M1, M2, TH2 and ECP1 in California Wash, and well BM-DL-2 in the Black Mountain area. These declines of approximately 2-ft are of the same magnitude as the drawdown in Coyote Spring Valley, suggesting connectivity between Coyote Spring Valley, California Wash, Black Mountain and Garnet Valley, and overlapping cones of depression.

In conclusion, the test results indicate:

- Trends in groundwater levels are driven by both groundwater pumping from the three pumping centers depicted in Figure 14 and changes in hydrologic conditions preceding and during the Test.

- Pumping existing groundwater rights in Coyote Spring Valley did not result in unreasonable lowering of the groundwater table, and when pumping was reduced groundwater levels recovered.

- There is a lack of pumping responses north of the Kane Springs Fault and west of the MX-5 and CSI wells near the eastern front of the Las Vegas Range.

- Declines in spring flow discharge at the highest elevation springs in the Muddy River Spring Area at the Pederson and Pederson East springs were anticipated and the magnitude of decline was minimal relative to the flows at the USGS Warm Springs West near Moapa, NV gage.

- Groundwater development in Coyote Spring Valley did not result in any discernible effects on the flows of the Muddy River at the USGS Muddy River near Moapa, NV gage.

- Local alluvial pumping in the Muddy River Springs Area is the primary stressor affecting Muddy River streamflows and, thus, the primary threat to senior surface-water right holders on the Muddy River.

- Future groundwater production by SNWA will continue to be carefully monitored in accordance with permit conditions and stipulated agreements.

It remains unclear if additional resource development beyond existing permitted rights could take place in Coyote Spring Valley at locations north of the Kane Spring fault in the area near CSMV-3. However, the presence of boundaries and variations in hydraulic conductivity suggest that, at a minimum, these areas may have the potential to be used for redistributing development of existing rights. Whether pending applications in Coyote Spring Valley are approved or denied, in whole or in part, they should be considered in order of priority with all other groundwater applications held in abeyance by Order 1169.

6.0 REFERENCES

Eakin, T.E., 1966, A Regional interbasin ground-water system in the White River area, Southeastern Nevada: Water Resources Research.

Huntington and Morton, 2013, Analysis of Evapotranspiration along the Muddy River and Warm Springs Natural Area, Desert Research Institute Technical Memo Prepared for Southern Nevada Water Authority.

Las Vegas Valley Water District, 2001, Water Resources and Ground-Water Modeling in the White River and Meadow Valley Flow Systems, Clark, Lincoln, Nye and White Pine Counties, submitted as evidence in State Engineer hearing of LVVWD ground-water applications 54055 through 54059.

Office of the State Engineer of the State of Nevada, 2002, Order 1169

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Appendix A

Nevada State Engineer July 1, 2010, Letter

SE ROA 10167

JIM GIBBONS
Governor

STATE OF NEVADA

LEO DROZDOFF
Acting Director

JASON KING, P.E.
State Engineer

DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES

DIVISION OF WATER RESOURCES

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JUL 2010 RECEIVED SNWA RESOURCES

July 01, 2010

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Seattle, Washington 98121

Darren Doboda, Chairperson
Moapa Band of Paiutes
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Moapa, Nevada 89025

Re: Applications 54055-54059, 63272-63276, 63867-63876, 54076; Order No. 1169

Study Participants:

This letter is intended as follow-up to the meeting held June 22, 2010, and to address outstanding issues and reporting requirements related to State Engineer's Order No. 1169, in particular the critical pumping test portion of the Order. Order No. 1169, which was signed on March 8, 2002, holds in abeyance all pending carbonate-rock aquifer system groundwater applications and new filings to appropriate water in Coyote Spring Valley (Basin 210), Black Mountains Area (Basin 215), Garnet Valley (Basin 216), Hidden Valley (Basin 217), Muddy River Springs aka as Upper Moapa Valley (Basin 219), and Lower Moapa Valley (Basin 220) until further information is obtained by stressing the aquifer by the pumping of those water right permits already issued in Coyote Spring Valley. Application 54076 in California Wash was also held in abeyance until the test was completed.

The entities initially required to participate in the study included: Las Vegas Valley Water District (LVVWD), Southern Nevada Water Authority (SNWA), Coyote Springs Investment, LLC, Nevada Power Company, and the Moapa Valley Water District (MVWD). The Moapa Band of Paiutes recently requested and was granted status as a participant.

The Order calls for a minimum five-year hydrological study during which at least 50% of the existing water rights in Coyote Spring Valley must be pumped for at least two consecutive years. The permitted groundwater rights of the study participants in Coyote Spring Valley total

16,100 acre-feet annually (afa); therefore, the amount that must be pumped each year for two consecutive years is 8,050 afa. The water may be pumped from any of the currently permitted points of diversion of the participants. Pumped water must be put to beneficial use within Coyote Spring Valley or exported from the hydrographic basins subject of Order No. 1169.

A hydrologic report, prepared by Mifflin and Associates, Inc. (MAI) and forwarded to this office by the Moapa Band of Paiutes, presented information supporting a conclusion that pumping from Coyote Spring Valley would reduce Muddy River spring flows at a 1:1 rate just nine months after pumping occurs. In its report and in a presentation at the June 22, 2010 meeting, MAI concluded:

- The pumping that has occurred to date in Coyote Spring Valley has produced results that effectively satisfy the objectives of Order No. 1169.
- Pumping in Coyote Spring Valley in 2007 was coincident with, and possibly responsible for, a 60% decrease in the Moapa dace population.
- Flows in the Warm Springs area would not be adequately protected by the Memorandum of Understanding agreed to by the U.S. Fish and Wildlife Service (USFWS), the SNWA, the MVWD, and the Moapa Band of Paiutes.

MAI recommended that the pumping test not proceed until the cause of the dace population decline is better known, minimum flows for their habitat are established, and a pumping test designed to protect those minimum flows is developed. However, comments by the USFWS did not concur with the MAI view that the low flows during that period of time were responsible for the decrease in dace population, and the USFWS recommended that the pumping test take place as outlined in Order No. 1169. At the end of the meeting, it was decided that the pumping test should be carried out to the extent possible. Modifications to the test, reporting and subsequent studies are outlined below.

Section 7 of the Order requires the study participants to file a report within 180 days of the end of the fifth year detailing the results of the study. Section 8 requires that at the end of the study period, LVVWD/SNWA are to update Exhibit 54 from the July 2001 hearing to show the State Engineer the effects, if any, of production of water under Applications 54055 - 54059. The State Engineer was to then make a determination if he had sufficient information to proceed with ruling on those additional applications in Coyote Spring Valley for which hearings had already been conducted, and other pending applications in these basins.

For various reasons, eight years have passed since the State Engineer issued Order No. 1169, and the pumping requirements of the Order have not yet begun. SNWA's present plan is to pump only the MX-5 well and pipe that water to Lower Moapa Valley, where it will be allowed to flow into Lake Mead for the benefit of SNWA. However, maximum pumping rates from MX-5, even when combined with Coyote Springs Investment, LLC's ongoing pumping, may not meet the 8,050 afa minimum pumping requirement of the Order. As established in the Order, final reports and the update to Exhibit 54 are only required after completion of the pumping test. However, decisions regarding future appropriations in the basins subject to Order No. 1169 cannot be deferred indefinitely. Therefore, in accordance with NRS 533.368, 533.375 and 534.110, and regardless of whether the 8,050 afa minimum requirement is met or not, the study participants shall comply with the reporting requirements of Sections 7 and 8 from Order No. 1169. SNWA shall submit a report detailing the results of the first two years of the pumping. The two-year time period will start when pumping and water export from well MX-5 commences. The report shall be due 180 days after completion of two years of pumping from well MX-5, in other words, the report is due to be filed with the State Engineer $2^1/_2$ years after initiation of the MX-5 pumping and export of water. In addition, SNWA shall submit model simulation results using the SNWA Pipeline EIS groundwater flow model, or a suitable alternative, showing the predicted effects of pumping both existing water rights and current applications in Lower Meadow Valley Wash (Basin 205), Kane Springs Valley (Basin 206), Coyote Spring Valley (Basin 210), Black Mountains Area (Basin 215), Garnet Valley (Basin 216), Hidden Valley (Basin 217), California Wash (Basin 218), Muddy River Springs aka as Upper Moapa Valley (Basin 219), and Lower Moapa Valley (Basin 220). The modeling report shall clearly tabulate and illustrate the modeled effects of the various pumping rates on the monitored groundwater levels, spring flow, and Muddy River flow.

In Section 6 of the Order, the State Engineer ordered the Las Vegas Valley Water District, Southern Nevada Water Authority, Coyote Springs Investment, LLC, Nevada Power Company, Moapa Valley Water District, Dry Lake Water Company, LLC, Republic Environmental Technologies, Inc., Chemical Lime Co., Nevada Cogeneration Associates, or their successors, who presently hold water rights authorized for appropriation from the carbonate-rock aquifer, to provide the other parties to the study and the State Engineer with data on a quarterly basis as to the rate at which water was diverted under the specific water right permits issued, total acre-feet diverted per month, and monthly water level measurements. Multiple parties have expressed a need for daily pumpage data from major producers. Therefore, each of the entities identified in Order No. 1169 Section 3 - the Las Vegas Valley Water District, Southern Nevada Water Authority, Coyote Springs Investment, LLC, Nevada Power Company, the Moapa Valley Water District and the Moapa Band of Paiutes, shall report pumpage on a daily basis for any wells that pump more than ten (10) acre feet in a given month. Those wells without automated monitoring and data recording systems (SCADA) systems must record and report when the wells are in operation on a daily basis, so that when combined with monthly total pumpage it will be possible to ascertain with reasonable accuracy the daily pumpage amounts from the well. Production wells and their required monitoring frequency are shown in the attachment.

The pumping test is expected to begin in August or September of this year. Therefore, all parties are hereby notified that all monitoring activities as outlined in this letter must be in place no later than August 1, 2010.

All reporting shall occur on a quarterly basis. Reports are due to the State Engineer's office within 30 days of the end of each calendar quarter. Water levels and pumpage data are to be submitted to the State Engineer's office in electronic format. Monitoring data will be available to the parties and public to view or download from the Division of Water Resources website http://water.nv.gov/. If you have questions concerning test procedures or reporting, please contact Rick Felling at (775) 684-2866 or rfelling@water.nv.gov.

Sincerely,

P.E.

Jason King, P.E.
State Engineer

JK/ml
Attachment
c: Rick Felling - Email
Susan Joseph Taylor - Email
Kelvin Hickenbottom - Email
John Guillory - Email

Order No. 1169 Monitoring Sites

Groundwater Level Monitoring:

Basin_no	Name	Alias1	WellType	Hydrogeologic Unit	Agency	WL Measurement Frequency	UTM_X	UTM_Y
205	MVWD MW-1		Monitor	Valley Fill	MVWD	Monthly	707906	4087860
205	EH-6		Monitor	Valley Fill	NPC (NVEnergy)	Quarterly	717058	4062265
205	EH-8A		Monitor	Muddy Creek	NPC (NVEnergy)	Quarterly	716453	4061395
205	EH-8B		Monitor	Valley Fill	NPC (NVEnergy)	Quarterly	716453	4061395
205	NPC-4A		Monitor	Muddy Creek	NPC (NVEnergy)	Quarterly	716557	4062678
205	NPC-5 OLD		Monitor	Valley Fill	NPC (NVEnergy)	Quarterly	715288	4064185
205	TH-12		Monitor	Valley Fill	NPC (NVEnergy)	Quarterly	716322	4062680
205	TH-31		Monitor	Muddy Creek	NPC (NVEnergy)	Quarterly	715626	4061638
205	TH-35		Monitor	Muddy Creek	NPC (NVEnergy)	Quarterly	717055	4061095
205	TH-8		Monitor	Valley Fill	NPC (NVEnergy)	Quarterly	716648	4061854
205	NPC-2		Monitor	Valley Fill	NPC (NVEnergy)	Quarterly	716321	4061107
210	CSI-1		Production	Carbonate	CSI/SNWA	Continuous	686043	4074459
210	CSI-2		Production	Carbonate	CSI/SNWA	Continuous	687083	4075781
210	CSI-3		Production	Carbonate	CSI/SNWA	Monthly/Cont.	685813	4077531
210	CSI-4		Production	Carbonate	CSI/SNWA	Monthly/Cont.	682366	4080185
210	CSV-RW2	RW-2	Production	Carbonate	NPC (NVEnergy)	Continuous	687862	4074082
210	CE-VF-1	365232114554401	Monitor	Valley Fill	SNWA	Monthly	683025	4083038
210	CE-VF-2	365227114554401	Monitor	Carbonate	SNWA	Continuous	683007	4082892
210	CSV-3	364127114553001	Monitor	Valley Fill	SNWA	Monthly	685222	4062583
210	CSV3009X		Monitor	Valley Fill	SNWA	Continuous	681075	4094993
210	CSV3011X		Monitor	Valley Fill	SNWA	Continuous	684065	4094870
210	CSVM-1	PAHRANAGAT WASH	Monitor	Carbonate	SNWA	Continuous	688602	4073793
210	CSVM-2	SOUTH PASS	Monitor	Carbonate	SNWA	Continuous	685625	4059370
210	CSVM-3	NORTH PASS	Monitor	Carbonate	SNWA	Continuous	679319	4102600
210	CSVM-4	STINGRAY RIDGE	Monitor	Carbonate	SNWA	Continuous	688086	4095971
210	CSVM-5	MORMON WELL ROAD	Monitor	Carbonate	SNWA	Continuous	680295	4068774
210	CSVM-6	DUTCHFLAT 2	Monitor	Carbonate	SNWA	Continuous	686453	4078333

Order No. 1169 Monitoring Sites

Groundwater Level Monitoring:

Basin_no	Name	Alias1	WellType	Hydrogeologic Unit	Agency	WL Measurement Frequency	UTM_X	UTM_Y
210	CSVM-7	Williams Well	Monitor	Valley Fill	SNWA	Monthly	678234	4101968
210	DF-1	DUTCHFLAT	Monitor	Valley Fill	SNWA	Monthly	686980	4078687
210	MX-5	CE-DT-5	Production	Carbonate	SNWA	Continuous	688084	4074219
210	MX-4	CE-DT-4	Monitor	Carbonate	SNWA/USGS	Continuous	688003	4074277
215	EBM-3		Monitor	Carbonate	Nevada Cogen.	Monthly	689605	4018529
215	BM-DL-1	BM-1	Monitor	Carbonate	SNWA	Monthly	689926	4019493
215	BM-DL-2	BM-2	Monitor	Carbonate	SNWA	Monthly	689270	4019591
215	BM-ONCO-1		Monitor	Clastic Rock	SNWA	Quarterly	702650	4010748
215	BM-ONCO-2		Monitor	Clastic Rock	SNWA	Quarterly	702054	4010722
216	CRYSTAL 1		Grounding	Carbonate	NPC (NVEnergy)	Continuous	694389	4039716
216	CRYSTAL 2		Grounding	Carbonate	NPC (NVEnergy)	Continuous	694146	4039284
216	GV-RW1	RW-1	Production	Carbonate	NPC (NVEnergy)	Quarterly	692928	4036645
216	WELL #1	RS-1	Production	Clastic Rock	Republic Env. Tech.	Monthly	690790	4028841
216	GARNET		Monitor	Valley Fill	SNWA	Monthly	693046	4036387
216	GV-1		Monitor	Carbonate	SNWA	Continuous	682983	4034143
216	GV-2		Monitor	Carbonate	SNWA	Monthly	686226	4025690
216	GV-DUKE-WS1		Production	Carbonate	SNWA	Monthly	686197	4029178
216	GV-MIRANT1		Production	Carbonate	SNWA	Monthly	683115	4032318
216	GV-PW-MW1	PINNACLE WEST MW-1	Monitor	Carbonate	SNWA	Continuous	683460	4031730
216	GV-PW-MW2	PINNACLE WEST MW-2	Monitor	Carbonate	SNWA	Monthly	682652	4031488
216	GV-PW-WS1	PINNACLE WEST WS-1	Production	Carbonate	SNWA	Monthly	682654	4031460
216	GV-DUKE-WS2		Production	Carbonate	SNWA/NPC (NVEnergy)	Monthly	686185	4029177
217	SHV-1	HIDDEN	Monitor	Valley Fill	SNWA/USGS	Continuous	685751	4047256
218	PAIUTES-ECP1	ECP-1	Monitor	Carbonate	MBPI	Continuous	696729	4046590
218	PAIUTES-ECP2	ECP-2	Monitor	Carbonate	MBPI	Quarterly	696723	4046742
218	PAIUTES-ECP3	ECP-3	Monitor	Carbonate	MBPI	Quarterly	696714	4046984
218	PAIUTES-M1	M-1	Monitor	Carbonate	MBPI	Continuous	704517	4057109

Order No. 1169 Monitoring Sites

Groundwater Level Monitoring:

Basin_no	Name	Alias1	WellType	Hydrogeologic Unit	Agency	WL Measurement Frequency	UTM_X	UTM_Y
218	PAIUTES-M2	M-2	Monitor	Carbonate	MBPI	Continuous	695836	4040876
218	PAIUTES-M3	M-3	Monitor	Carbonate	MBPI	Continuous	691536	4044302
218	PAIUTES-TH2	TH-2	Monitor	Carbonate	MBPI	Continuous	697684	4049916
218	BYRON		Production	Carbonate	SNWA	Monthly	710994	4051282
219	ARROW_CANYON		Production	Carbonate	MVWD	Continuous	701104	4067755
219	ARROW CANYON 2		Production	Carbonate	MVWD	Continuous	701103	4067768
219	MX-6	CE-DT-6	Production	Carbonate	MVWD	Monthly	697482	4071381
219	ABBOTT	UM7	Monitor	Valley Fill	NPC (NVEnergy)	Monthly	706443	4065657
219	BEHMER-MW		Monitor	Valley Fill	NPC (NVEnergy)	Monthly	706031	4065280
219	EH-4		Monitor	Carbonate	NPC (NVEnergy)	Continuous	703929	4064736
219	EH-5B		Monitor	Carbonate	NPC (NVEnergy)	Continuous	701569	4067619
219	LDS CENTRAL	UM49	Production	Valley Fill	NPC (NVEnergy)	Monthly	704114	4066544
219	LDS EAST	UM50	Production	Valley Fill	NPC (NVEnergy)	Monthly	704479	4066594
219	LDS WEST	UM18	Production	Valley Fill	NPC (NVEnergy)	Monthly	702746	4067083
219	LEWIS 1 OLD	UM55	Monitor	Valley Fill	NPC (NVEnergy)	Monthly	702077	4068229
219	LEWIS 2	UM74	Production	Valley Fill	NPC (NVEnergy)	Continuous	702339	4067921
219	LEWIS NORTH	UM45	Monitor	Valley Fill	NPC (NVEnergy)	Continuous	701589	4067872
219	LEWIS SOUTH	UM43	Monitor	Valley Fill	NPC (NVEnergy)	Continuous	702737	4067266
219	PERKINS OLD	UM15	Monitor	Valley Fill	NPC (NVEnergy)	Continuous	705637	4065223
219	PERKINS PRODUCTION		Production	Valley Fill	NPC (NVEnergy)	Monthly	705693	4065206
219	CSV-1	364601114514301	Monitor	Valley Fill	SNWA	Monthly	691378	4071630
219	UMVM-1	DEADMAN WASH	Monitor	Carbonate	SNWA	Continuous	694305	4070248
219	CSV-2	364650114432001	Monitor	Carbonate	SNWA/USGS/NV Energy	Continuous	703217	4072967
220	EH-3		Monitor	Carbonate	NPC (NVEnergy)	Continuous	721085	4063300
220	EH-7		Monitor	Carbonate	NPC (NVEnergy)	Continuous	720660	4060990

Order No. 1169 Monitoring Sites

Spring and Stream Flow Monitoring:

Basin_no	Name	Alias1	TYPE	Hydrogeologic Unit	Agency	Production/Flow Data Frequency	Will Monitor for duration of Order 1169 Test	UTM_X	UTM_Y
215	BLUE POINT SPRING		Spring	Stream Gage	NPS	Continuous	Yes	730353	4030271
215	ROGERS SPRING		Spring	Stream Gage	NPS	Continuous	Yes	729420	4028891
219	BALDWIN SPRING BOX		Spring	Flow Meter	MVWD	Continuous	Yes	703257	4066270
219	JONES SPRING BOX		Spring	Flow Meter	MVWD	Continuous	Yes	703714	4065661
219	PEDERSON EAST SPRING GAGE	PLAYBOY POOL GAGE	Spring	Flume	SNWA/USGS	Continuous	Yes	704034	4065063
219	PEDERSON SPRING GAGE		Spring	Weir	SNWA/USGS	Continuous	Yes	704008	4065089
219	WARM SPRINGS WEST GAGE		Spring	Flume	SNWA/USGS	Continuous	Yes	704211	4065272
219	IVERSON FLUME		Stream	Flume	SNWA/USGS	Continuous	Yes	704570	4065296
219	MUDDY SPRING GAGE		Spring	Flume	SNWA/USGS	Continuous	Yes	704016	4066348
219	MOAPA GAGE		Stream	Stream Gage	USGS	Continuous	Federally Funded	705823	4065350
220	LEWIS AVENUE NEAR OVERTON GAGE		Stream	Stream Gage	SNWA/USGS	Continuous	Yes	730091	4046454
220	GLENDALE GAGE		Stream	Stream Gage	USGS	Continuous	Federally Funded	719897	4058057

Order No. 1169 Monitoring Sites

Groundwater Pumpage:

Basin_no	Name	Alias1	Agency	Hydrogeologic Unit	Production / Flow Data Fequency	Permit	UTM_X	UTM_Y
210	CSI-1		CSI/SNWA	Carbonate	Daily	70430	686043	4074459
210	CSI-2		CSI/SNWA	Carbonate	Daily	70429	687083	4075781
210	CSI-3		CSI/SNWA	Carbonate	Daily	74094	685813	4077531
210	CSI-4		CSI/SNWA	Carbonate	Daily	74095	682366	4080185
210	CSV-RW2	RW-2	NPC (NV Energy)	Carbonate	Daily	77164	687862	4074082
210	MX-5	CE-DT-5	SNWA	Carbonate	Daily	77292	688084	4074219
215	EBP-2		Nevada Cogen.	Carbonate	Monthly	55269	689628	4018599
215	EGV-3		Nevada Cogen.	Carbonate	Monthly	58031	689858	4018999
215	EBM-4		Nevada Cogen.	Carbonate	Monthly	58032	689784	4018826
216	OLD		Chemical Lime Co.	Valley Fill	Monthly	63261	687941	4029333
216	NEW		Chemical Lime Co.	Carbonate	Monthly	64880	687748	4026563
216	GV-2	Central Well	Dry Lake Water Co.	Carbonate	Monthly	66784	686226	4025690
216	GV-RW1	RW-1	NPC (NV Energy)	Carbonate	Daily	74399	692928	4036645
216	WELL #2		Republic Env. Tech.	Carbonate	Monthly	67716	690674	4027890
216	WELL #5		Republic Env. Tech.	Carbonate	Monthly	67715	691053	4029626
216	WELL #6		Republic Env. Tech.	Carbonate	Monthly	67718	690552	4026318
216	GV-DUKE-WS1		SNWA	Carbonate	Daily	73149	686197	4029178
216	GV-MIRANT1		SNWA	Carbonate	Daily	68822	683115	4032318
216	GV-PW-WS1	PINNACLE WEST WS-1	SNWA	Carbonate	Daily	72798	682654	4031460
216	GV-DUKE-WS2		SNWA/NPC NV Energy	Carbonate	Daily	73150	686185	4029177
218	TH-1		MBPI	Carbonate	Daily	76643	697233	4044981
218	PAIUTES-ECP-1	South	MBPI	Carbonate	Daily	70257	696729	4046590
218	PAIUTES-ECP-2	Middle	MBPI	Carbonate	Daily	70259	696723	4046742

Order No. 1169 Monitoring Sites

Groundwater Pumpage:

Basin_no	Name	Alias1	Agency	Hydrogeologic Unit	Production / Flow Data Fequency	Permit	UTM_X	UTM_Y
218	PAIUTES-ECP-3	North	MBPI	Carbonate	Daily	70258	696729	4046590
219	MX-6	CE-DT-6	MVWD	Carbonate	Daily	46932	697482	4071381
219	ARROW_CANYON		MVWD	Carbonate	Daily	52520	701104	4067755
219	ARROW CANYON 2		MVWD	Carbonate	Daily	66043	701103	4067768
219	BEHMER	UM14	NPC (NV Energy)	Valley Fill	Daily	29296	706031	4065080
219	LDS CENTRAL	UM49	NPC (NV Energy)	Valley Fill	Daily	50732	704114	4066544
219	LDS EAST	UM50	NPC (NV Energy)	Valley Fill	Daily	50723	704479	4066594
219	LDS WEST	UM18	NPC (NV Energy)	Valley Fill	Daily	50724	702746	4067083
219	LEWIS 1		NPC (NV Energy)	Valley Fill	Daily	24186	702182	4068043
219	LEWIS 2	UM74	NPC (NV Energy)	Valley Fill	Daily	24186	702339	4067921
219	LEWIS 3		NPC (NV Energy)	Valley Fill	Daily	22633	701956	4068021
219	LEWIS 4		NPC (NV Energy)	Valley Fill	Daily	22636	702028	4067620
219	LEWIS 5		NPC (NV Energy)	Valley Fill	Daily	22632	702196	4067485
219	PERKINS PRODUCTION		NPC (NV Energy)	Valley Fill	Daily	50272	705693	4065206

Note: If pumping from a given well is les than 10 acre feet per month, daily pumpage reporting is not required.

SE ROA 10179

Appendix B

Hydraulic Testing of the Carbonate-Rock Aquifer Pursuant to Order 1169

SE ROA 10181

SOUTHERN NEVADA WATER AUTHORITY
100 City Parkway, Suite 700 • Las Vegas, NV 89106
MAILING ADDRESS: P.O. Box 99956 • Las Vegas, NV 89193-9956
(702) 862-3400 • snwa.com

March 2, 2010

Tracy Taylor, P.E. State Engineer
Nevada Department of Conservation and Natural Resources
Division of Water Resources
901 South Stewart Street
Carson City, Nevada 89701

SUBJECT: STATE ENGINEER ORDER 1169 STUDY

Dear Mr. Taylor:

Please find enclosed an updated version of the document entitled: "*Hydraulic Testing of the Carbonate-Rock Aquifer Pursuant to Order 1169*" dated February 25, 2010, which updates the previous version dated November 28, 2008. This document provides a current description of the Southern Nevada Water Authority's (SNWA), Las Vegas Valley Water District's, Coyote Spring Investment LLC's (CSI), and Moapa Valley Water District's (collectively referred to as Principal Entities) on-going and planned activities to perform and successfully complete the objectives of the aquifer test required by the Order 1169 study.

The SNWA plans to begin pumping the MX-5 well in June or July 2010 and convey the water to the Muddy River and Lake Mead for the creation of Colorado River Intentionally Created Surplus credits. These credits can then be utilized by SNWA to meet existing and future water demands. This pumpage combined with groundwater development by CSI is anticipated to meet the 2-year pumping requirement outlined in Order 1169. The State Engineer, during the December 9, 2008, meeting regarding Order 1169, suggested the Study Participants meet immediately prior to the start of SNWA's pumping. If a meeting is desired the Principal Entities can meet to discuss the enclosed document at your convenience. If you have any questions, please contact Jeff Johnson at (702) 862-3748.

Sincerely,

William E. Rinne

William E. Rinne, Director
Surface Water Resources Department

with concurrence by:

Brad Huza, General Manager Moapa Valley Water District	Carl Savely, General Counsel Coyote Spring Investments LLC

WR:JJ:lmv

Enclosure

c: Janet Bair, Assistant Field Supervisor, U.S. Fish and Wildlife Service
Richard Berley, Attorney at Law, Ziontz, Chestnut, Varnell, Berley and Slonim
Sue Braumiller, Groundwater Hydrologist, Nevada Fish and Wildlife Office
Kay Brothers, Deputy General Manager, SNWA Engineering/Operations
Robert Coache, Deputy State Engineer, Nevada Department of Conservation and Natural Resources, Division of Water Resources
John Entsminger, Deputy General Counsel, SNWA
Peter Fahmy, Attorney at Law, Regional Solicitors Office, U.S. Department of the Interior
Richard Felling, Chief, Hydrology Section, Nevada Department of Conservation and Natural Resources, Division of Water Resources
Brad Huza, General Manager, Moapa Valley Water District
Jason King, P.E., Deputy State Engineer, Nevada Department of Conservation and Natural Resources, Division of Water Resources
Cynthia Martinez, Complex Manager, Desert National Wildlife Refuge Complex, U.S. Fish and Wildlife Service
Tim Mayer, Hydraulic Engineer, U.S. Fish and Wildlife Service, Water Resources Branch
Janet Monaco, SNWA Division Manager, Muddy and Virgin Rivers Division
Stephen Palmer, Attorney at Law, Office of the Solicitor, U.S. Department of the Interior
Sarah Peterson, Hydrologist, U.S. Department of the Interior, Bureau of Land Management
Colleen Rice, Associate General Counsel, NVEnery
Carl D. Savely, Esquire, Wingfield Nevada Group
Paul Taggart, Esquire, Taggart and Taggart, Ltd.
William Van Liew, P.E., Hydrologist, U.S. Department of the Interior, National Park Service, Water Resources Division
Robert Williams, Supervisor, U.S. Fish and Wildlife Service, Nevada Fish and Wildlife Office

Hydraulic Testing of the Carbonate-Rock Aquifer Pursuant to Order 1169 February 25, 2010[1]

1.0 Introduction and Requirements of Nevada State Engineer Order 1169

The Nevada State Engineer issued Order 1169 on March 8, 2002 regarding groundwater applications filed by the Las Vegas Valley Water District and Coyote Spring Investment, LLC to develop groundwater from Coyote Spring Valley (Basin 210). The Order required a minimum 5-Year Study (Study) to provide data and information on the effects of pumping existing water rights permitted from the carbonate-rock aquifer in Coyote Spring Valley.

A key element of the Study is the development of a minimum of fifty (50) percent of the permanent, permitted rights in Coyote Spring Valley [16,100 acre-feet per year (afy)] for at least two (2) consecutive years during the study. Fifty (50) percent of the existing permanent permitted rights equates to 8,050 afy, or approximately 5,000 gallons per minute (gpm), if pumped continuously for a year.

Upon completion of the Study, the Southern Nevada Water Authority (SNWA) will update Exhibit 54 from the July 2001 hearings by incorporating new data, the results of the aquifer test and associated pumping effects, and then submit the updated version of the exhibit to the State Engineer for consideration of the Las Vegas Valley Water District's (LVVWD) applications.

At a minimum, the Study Participants include the following entities:

Las Vegas Valley Water District (LVVWD)
Southern Nevada Water Authority (SNWA)
Coyote Springs Investment, LLC (CSI)
NVEnergy (NVE)
Moapa Valley Water District (MVWD)
Federal Bureaus[2]
Moapa Band of Paiutes (Paiutes)[3]

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[1] This document has been previously distributed as *Conceptualization of Hydraulic Testing of the Carbonate-Rock Aquifer Pursuant to Order 1169* dated March 4, 2005; and *Conceptualization and Long-Term Monitoring of the Carbonate-Rock Aquifer* dated May 8, 2003. The name was changed to avoid confusion between this document and the SNWA monitoring plan as well as to reflect progress on the Order 1169 Study.

[2] The State Engineer granted a request by U.S. Department of Interior to allow the Bureau of Indian Affairs, U. S. Fish & Wildlife Service (FWS), and National Park Service (NPS) (collectively referred to as the federal bureaus) to participate in the study (April 19, 2002).

[3] The State Engineer via letter dated 11-25-2009 enabled the Moapa Band of Paiutes to participate in the Order 1169 Study.

Although almost 8 years have passed since Order 1169 was issued, the Study has yet to be completed because groundwater development in Coyote Spring Valley has been less than 8,050 afy. Therefore, the completion of the Study depends on groundwater development in Coyote Spring Valley sufficient to meet Order 1169.

The SNWA plans to begin pumping the MX-5 well located in Coyote Spring Valley in June or July 2010 and convey the groundwater to the Muddy River and Lake Mead for the creation of Colorado River Intentionally Created Surplus credits, as allowed for in the Secretary of Interior's *Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead*, dated December 2007. These credits can then be utilized by SNWA to meet existing and future water demands. This pumpage combined with groundwater development by CSI is anticipated to meet the Study's pumping requirement.

The Sections below outline completed and on-going activities which fulfill the Order 1169 Study. Many of these tasks are noted with the boxes below to indicate their level of completion.

☐ - **Task 0% Complete** ■ - **Task 100% Complete**

2.0 Monitoring Baseline Conditions (fully implemented in mid 2004; refined in Feb 2009 at State Engineer's request)

Continue existing monitoring programs established by MVWD, FWS, NPS, NVE, and SNWA to collect water level, water-quality/chemistry, spring discharge, and precipitation data from selected sites as outlined by each entities existing, State Engineer required, monitoring plans. (It is important to note that the monitoring frequency is determined by the entity conducting the monitoring in support of their monitoring plans.) At the request of the State Engineer, on December 9, 2008, the Study Participants summarized the monitoring activities that will be conducted during the 2-year pumping test. This monitoring was summarized in a letter from SNWA to the State Engineer dated February 27, 2009. This letter, the attached list of monitoring activities, and location map are included as Appendix 1.

2.1 Coyote Spring and Upper Moapa Valley

■
- Drill and complete monitor wells CSVM-1, CSVM-2, CSVM-3, CSVM-4, CSVM-5, CSVM-6, and UMVM-1 in the carbonate-rock aquifer and well CSVM-7 in the alluvial aquifer per LVVWD Contract No. W0101.
STATUS: COMPLETED – SUMMER 2003

■
- Equip monitor wells CSVM-1, CSVM-2, CSVM-3, CSVM-4, CSVM-5, CSVM-6, and UMVM-1 with pressure transducers for continuous monitoring of water level changes. Equip UMVM-1 wellsite with a barometric pressure transducer.

STATUS: COMPLETED – FALL 2003; on-going data collection

- Equip carbonate monitor well CE-VF-2 with a pressure transducer for continuous monitoring of water level changes.
  STATUS: COMPLETED; SNWA Installation 12/18/02; on-going data collection

- Collect baseline water chemistry and isotopic samples from selected wells to further characterize the groundwater in the area. Water chemistry and isotopic samples were collected from new monitor wells CSVM-1, CSVM-2, CSVM-4, CSVM-5, CSVM-6, and UMVM-1 after their completion, and well MX-5 during implementation of the drilling program. Water chemistry and isotopic samples were also collected from wells CSVM-1, CSVM-2, CSVM-3, CSVM-4, CSVM-5, CSVM-6, CSVM-7, and CSV-1 by URS Corporation in the winter of 2005/2006. A report entitled "Final Groundwater Sampling Report Coyote Spring Valley, Nevada" was issued March 15, 2006.
  STATUS: SAMPLING COMPLETED SUMMER 2003 AND WINTER 05/06.

- Drill and complete monitor wells CSV3009M and CSV3011M on the northern end of CSI's property, within and just north of the Kane Springs fault zone in November 2008 and December 2008, respectively. The two wells were drilled to a diameter of 14.75-inches and cased with 8-inch I.D. steel pipe to depths of 1,580 feet (ft) below land surface (bls) (well CSV3009M) and 1,557 ft bls (well CSV3011M). Both wells were completed in alluvium and document intermediate groundwater elevations between wells MX-5 and CSVM-3.

- Fund USGS to install and monitor two additional surface water gages: PEDERSON EAST SPRING GAGE (installed May 2002) and IVERSON FLUME (installed October 2001). Table 2-1 lists selected surface water monitoring sites.
  STATUS: COMPLETED – FALL 2002 – SNWA continues to fund these two gages as well as three additional gages in the Muddy River Springs Area

Table 2-1 -- Surface Water Monitoring Sites (continuous monitoring)

Spring Discharge Sites	**Stream Flow**
PEDERSON SPRING (09415910) [/1]	MUDDY RIVER NEAR MOAPA (09416000) [/2]
PEDERSON EAST SPRING [/1]	MUDDY RIVER NEAR GLENDALE (09419000) [/2]
WARM SPRING WEST (09415920) [/1]	MUDDY RIVER AT LEWIS AVENUE AT OVERTON (09419507) [/1]
IVERSON FLUME [/1]	
MUDDY SPRING (09415900) [/1]	
BALDWIN SPRING [/3]	
JONES SPRING [/3]	

[/1] Funded co-operatively by SNWA and USGS; [/2] Funded by USGS; [/3] Funded and operated by MVWD.

- Install flowmeters to measure bypass flows at Baldwin and Jones Springs.
  STATUS: COMPLETED 2002; MVWD Installation; on-going data collection

2.2 <u>Black Mountains Area and Garnet Valley</u>

- Equip carbonate wells BM-DL-2, GV-1, GV-2, and GV-PW-MW1 in Garnet Valley and Black Mountains Area with pressure transducers for continuous monitoring of water level changes to augment existing data collection in the southern portion of the regional flow system.
  STATUS: SNWA INSTALLATION; COMPLETED – NOV/ DEC 2002; on-going data collection

3.0 Pipeline Design, Environmental Compliance, and Construction

The SNWA, in cooperation with MVWD, has constructed a pipeline and associated facilities to convey SNWA's existing 9,000 afy of Coyote Spring Valley groundwater rights in an efficient and practical manner to locations where such water can be placed to beneficial use by SNWA and/or MVWD and/or the Muddy Valley Irrigation Company (MVIC). Initially SNWA will develop approximately 6,500 afy of its owned 9,000 afy of groundwater rights in Coyote Spring Valley from well MX-5. Water from well MX-5 will be treated to reduce arsenic concentrations to meet drinking water standards at the Moapa Water Treatment Facility (adjacent to well MX-5) and pumped through the new pipeline to MVWD's distribution system, which will convey the water to Bowman Reservoir. MVIC will then convey the water from Bowman Reservoir to the Muddy River which will convey them to Lake Mead, where SNWA anticipates receiving Intentionally Created Surplus credits for the water under the Secretary of Interior's *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lakes Powell and Mead*.

3.1 <u>Design</u>

- The pipeline and associated facilities, including a forebay, pump station, power facilities, approximately 15 miles of 24-inch pipeline from the MX -5 wellsite to the MVWD storage reservoir, and a regulating tank at the top of the incline between the MX-5 well and the MVWD storage reservoir to convey a minimum of 9,000 afy has been constructed.
  STATUS: COMPLETE

3.2 <u>Environmental Compliance</u>

- An Environmental Assessment was completed in association with obtaining the permits and right-of-way grants for the pipeline and associated facilities. The lead federal agency for the environmental compliance was the Bureau of Land Management.
- In April 2006, SNWA entered into a Memorandum of Agreement (MOA) with FWS, CSI, the Tribe, and MVWD, which establishes a plan for monitoring, management, and mitigation that permits groundwater

development in Coyote Spring Valley and California Wash groundwater basins, while simultaneously working to protect and recover the Moapa dace. The MOA is also the subject of a Programmatic Biological Opinion that covers a total of 16,100 afy of groundwater development. The 16,100 afy total includes 9,000 afy by SNWA in Coyote Spring Valley; 4,600 afy by CSI in Coyote Spring Valley; and 2,500 afy by the Tribe in California Wash. The basic terms of the agreement are:

- Curtailing use of MVWD's Jones Spring water right (1 cubic-foot per second) as a pass through flow to allow for augmentation of habitat
- Trigger flow levels at the Warm Springs West gage which reduce the volume of groundwater development by the signatories to ensure protection of Moapa dace
- Dedication of 10% of CSI's existing rights to Moapa dace recovery
- Establish a Recovery Implementation Program
- Establish a Hydrologic Review Team

3.3 Construction

- SNWA and MVWD anticipate all facilities will be operational in June or July 2010.

4.0 Aquifer-Test Design and Constraints

4.1 General Test Design

The aquifer test will begin after the pipeline and associated facilities have been completed and tested, and the necessary monitoring equipment has been installed.

- The aquifer test will consist of SNWA's pumping of well MX-5 as well as CSI's well production, and/or the Coyote Springs Water Resources District, which will own and operate the municipal water supply for the Coyote Spring development once constructed – the operator of which will be the LVVWD. As feasible, pumping rates from well MX-5 will be held constant. It is important to note that SNWA was granted change applications by the Nevada State Engineer on all of its existing Coyote Spring Valley groundwater rights to develop the rights from well MX-5 and potentially well CSI-2 for municipal use within SNWA's service area.

- CSI and the Coyote Springs Water Resources District, over the duration of the 2 years of hydraulic pumping, will continue to develop their rights sufficient to meet the needs of the community in Coyote Spring Valley.

- The anticipated start of pumping well MX-5 for the conveyance of water (not just equipment testing) is anticipated to begin in June or July 2010. Intermediate shutdowns can and may take place to evaluate recovery and pumpage effects and/or to perform facility maintenance.

- The MVWD's Arrow Canyon Wells I and 2 will operate prior to, and during the test, along with its other resources, based on the demands from MVWD. Since SNWA is pursuing credit for the pumped Coyote Spring Valley groundwater entering Lake Mead, MVWD must utilize its own resources on an annual basis to meet its customer demands.

- Operation of NVE's Lewis well field will be coordinated to optimize data collection so additional understanding of the relationships related to the alluvial/carbonate-rock interface and the local springs can be achieved.

- Listed in Table 4-1 and 4-2 are the anticipated annual productions totals and production rates of the pumping wells. The well locations are depicted on Figure 1. Actual pumping rates and volumes will be monitored on a continuing basis during the test by MVWD, CSI, and SNWA.

- To the extent possible, data collected during the aquifer test will be uploaded to the Central Data Repository (CDR) after they have been reviewed for completeness and accuracy and have been qualified.

Table 4-1 – Anticipated Annual Production of Pumping Wells

	2009	2010	2011	2012
Coyote Spring Valley (Basin 210)				
MX-5	0 afy	3,250 afy	6,500 afy	6,500 afy
CSI 1,2,3,4[1]	1000-2,000 afy	1,550-2,000 afy	1,550-2,000 afy	1,550 - 4,140 afy
Upper Moapa Valley (Basin 219)				
Arrow Canyon 1 Arrow Canyon 2	Variable – Based on Estimated Demand	Variable – Based on Estimated Demand	Variable – Based on Estimated Demand	Variable – Based on Estimated Demand

Table 4-2 – Anticipated Production Rates of Pumping Wells and Current Status

Coyote Spring Valley (Basin 210)	**Anticipated Range of Production Rates**
CSI-2	2,200 – 4,000 gpm (not permanently equipped)
MX-5	4,000 – 4,300 gpm (being equipped)
CSI-1	1,200 – 1,400 gpm (not permanently equipped)
CSI-3	2,200 - 4,000 gpm (not permanently equipped)
CSI-4	2,200 - 4,000 gpm (not permanently equipped)
Upper Moapa Valley (Basin 219)	**Anticipated Production Rate**
ARROW CANYON / ARROW CANYON 2	Variable – Based on Estimated Demand

4.2 <u>Water Chemistry Sampling</u>

- During aquifer testing, groundwater samples will be collected semi-annually from the pumping wells and analyzed for major ions, trace elements, and stable isotopes. Subsequent long-term water chemistry sampling will be conducted as determined under existing agreements.

- The SNWA, in consultation with the federal bureaus per the SNWA/federal bureau Stipulation, will identify two surface water sites in the Muddy Springs Area from which water chemistry samples will be collected semi-annually for analysis of major ion concentrations.
STATUS: ON-GOING – 1ST QUARTER 2006

4.3 <u>Recovery Monitoring</u>

The SNWA anticipates continuing the development of its groundwater rights following the 2-year pumping test. Recovery monitoring will be coordinated with planned shut-downs for facility maintenance.

5.0 Additional Studies / Supporting Work

5.1 <u>Compilation of Regional Geology Map</u>

Cooperatively funded by the federal bureaus and SNWA ($60K federal, $60K SNWA) to undertake geologic mapping of the carbonate-rock terrain within the expanded SNWA model area and the Virgin River Valley. The map is published as Nevada Bureau of Mines and Geology Map 150 "Geological Map of Southeastern Nevada, Southwestern Utah, and Northwestern Arizona, an area covering the Colorado, White River and the Death Valley Regional Groundwater Flow Systems;" scale 1:250,000; W.R. Page, G.L. Dixon, P.D. Rowley, and D.W. Brickey.
STATUS: COMPLETE

5.2 <u>Groundwater Flow Model (on-going)</u>

The SNWA's most recent groundwater flow model which covers the southern extent of the White River Flow System will be enhanced by incorporating new hydrologic and geologic data acquired as a result of drilling new monitor wells by incorporating aquifer test data acquired from the test.
STATUS: ON-GOING – Groundwater modeling efforts will incorporate additional data as warranted

5.3 <u>Elevation Survey</u>

The SNWA completed a first round of professional-grade elevation surveys to determine the coordinates and elevations of groundwater and surface water sites (42 wells, 5 surface water sites) in June 2002. The final report was published in May 2003 and includes survey results and photographs of each surveyed site. A second set of surveys was completed in December 2003.

The final report for these additional wells was published in March 2005 as an appendix to the annual monitoring report. In 2004, SNWA funded the USGS to produce a report on spring pool elevations in the Warm Springs area. This report is published as USGS Open File Report 2006-1311. The initial SNWA report will be updated to include additional sites as necessary.
STATUS: ONGOING

5.4 Common Data Repository (CDR) / Internet Application (on-going)
In cooperation with CSI, MVWD, NVE, and the federal bureaus, SNWA has developed and is administering an internet-based CDR that allows cooperators access to data from groundwater and surface sites related monitoring activities by SNWA in the Coyote Spring Valley and nearby basins. SNWA posts and uploads cooperator data when it is provided.
STATUS: ON-GOING

APPENDIX 1

Monitoring Locations for Order 1169 Study

SE ROA 10192

SOUTHERN NEVADA WATER AUTHORITY
100 City Parkway, Suite 700 • Las Vegas, NV 89106
MAILING ADDRESS: P.O. Box 99956 • Las Vegas, NV 89193-9956
(702) 862-3400 • snwa.com

February 27, 2009

Tracy Taylor, P.E. State Engineer
Nevada Department of Conservation and Natural Resources
Division of Water Resources
901 South Stewart Street
Carson City, Nevada 89701

Dear Mr. Taylor:

SUBJECT: MONITORING LOCATIONS FOR ORDER 1169 STUDY

During the meeting on December 9, 2008, regarding the Order 1169 Study, a request was made to summarize the monitoring activities the Study Participants would conduct during the 2-year pumping test. To meet this objective, the Southern Nevada Water Authority (SNWA) routed a table to the Moapa Valley Water District, Moapa Band of Paiutes, Coyote Spring Investments LLC, NVEnergy, U.S. Fish and Wildlife Service, National Park Service and Bureau of Land Management to establish a list of monitoring locations. The enclosed table and corresponding map summarize the monitoring activities the various Study Participants plan to conduct during the 2-year pumping test. The vast majority of the monitoring summarized is currently being conducted. It is anticipated monitoring activities will be reviewed periodically by the Study Participants to ensure optimal data collection for Order 1169. Any updates will be provided to your office.

In December 2008, SNWA anticipated that groundwater pumping at rates sufficient to meet the requirements of Order 1169 would begin in early 2010. Based on recent construction schedules, SNWA pumping is currently anticipated to begin mid-2010. As requested, SNWA will keep the State Engineer's Office appraised of the schedule in order to facilitate a meeting of the Study Participants prior to the start of pumping.

If you have any questions, please contact me at (702)-862-3748 or Sean Collier at (702) 691-5375.

Sincerely,

Jeffrey Johnson, SNWA Division Manager
Water Management and Accounting Division

JJ:lmv

Enclosures (2)

[redacted]

c: Richard Berley, Attorney at Law, Ziontz, Chestnut, Varnell, Berley and Slonim, w/o map
Robert Boyd, Hydrologist, U.S. Department of the Interior, Bureau of Land Management, w/o map
Kay Brothers, Deputy General Manager, SNWA Engineering/Operations, w/o map
Robert Coache, Deputy State Engineer, Nevada Department of Conservation and Natural Resources, Division of Water Resources, w/o map
John Entsminger, Deputy General Counsel, SNWA, w/o map
Peter Fahmy, Attorney at Law, Regional Solicitors Office, U.S. Department of the Interior, w/o map
Richard A. Felling, Chief, Hydrology Section, Nevada Department of Conservation and Natural Resource, Division of Water Resources, w/o map
Brad Huza, General Manager, Moapa Valley Water District, w/o map
Jason King, P.E., Deputy State Engineer, Nevada Department of Conservation and Natural Resources, Division of Water Resources, w/o map
Janet Bair, Assistant Field Supervisor, U.S. Fish and Wildlife Service, w/o map
Cynthia Martinez, Project Leader, U.S. Fish and Wildlife Service, w/o map
Tim Mayer, Hydraulic Engineer, U.S. Fish and Wildlife Service, Water Resources Branch, w/o map
Janet Monaco, SNWA Division Manager, Water Resources, w/o map
Stephen Palmer, Attorney at Law, Office of the Solicitor, U.S. Department of the Interior, w/o map
William Rinne, Director, SNWA Surface Water Resources, w/o map
Carl D. Savely, Esquire, Lionel Sawyer & Collins, w/o map
Paul Taggart, Esq., Taggart and Taggart LTD, w/o map
William Van Liew, P.E., Hydrologist, U.S. Department of the Interior, National Park Service, Water Resources Division, w/o map
Colleen Rice, Associate General Counsel, NVEnergy, w/o map
Robert Williams, Supervisor, U.S. Fish and Wildlife Service, Nevada Fish and Wildlife Office, w/o map

*The map referenced is available on the Common Data Repository at: www.snwawatershed.org/portal

Sites to be Monitored for Duration of Order 1169 Test

Basin_no	Name_2	Alias1	Alias2	TYPE	WellType	Hydrogeologic Unit	AGENCY	WL MEASUREMENT FREQUENCY	PRODUCTION/ FLOW DATA FREQUENCY	Will Monitor for duration of Order 1169 Test	Remarks	UTM_X	UTM_Y
Groundwater Monitoring:													
205	EH-6			Well	Monitor	Valley Fill	NPC (NVEnergy)	Quarterly		Yes		717057.8229	4062264.5310
205	EH-8A			Well	Monitor	Muddy Creek	NPC (NVEnergy)	Quarterly		Yes		716453.3065	4061395.1542
205	EH-8B			Well	Monitor	Valley Fill	NPC (NVEnergy)	Quarterly		Yes		716453.3065	4061395.1542
205	NPC-4A			Well	Monitor	Muddy Creek	NPC (NVEnergy)	Quarterly		Yes		716556.8208	4062677.9450
205	NPC-5 OLD			Well	Monitor	Valley Fill	NPC (NVEnergy)	Quarterly		Yes		715287.9974	4064184.9106
205	TH-12			Well	Monitor	Valley Fill	NPC (NVEnergy)	Quarterly		Yes		716321.9487	4062679.6988
205	TH-31			Well	Monitor	Muddy Creek	NPC (NVEnergy)	Quarterly		Yes		715626.1443	4061638.2906
205	TH-35			Well	Monitor	Muddy Creek	NPC (NVEnergy)	Quarterly		Yes		717055.2998	4061094.5021
205	TH-8			Well	Monitor	Valley Fill	NPC (NVEnergy)	Quarterly		Yes		716648.3044	4061853.9518
205	NPC-2			Well	Monitor	?	NPC (NVEnergy)	Quarterly		Yes			
205	MVWD MW-1			Well	Monitor	Valley Fill	MVWD	Monthly		Yes		707905.9648	4087859.8533
210	CE-VF-1	365232114554401		Well	Monitor	Valley Fill	SNWA	Monthly		Yes		683024.8034	4083038.0123
210	CE-VF-2	365227114554401		Well	Monitor	Carbonate	SNWA	Continuous		Yes		683007.1006	4082892.1451
210	CSI-1			Well	Production	Carbonate	CSI/SNWA	Continuous	Monthly	Yes		686043.0700	4074459.1500
210	CSI-2			Well	Production	Carbonate	CSI/SNWA	Continuous	Monthly	Yes		687082.7320	4075780.6200
210	CSI-3			Well	Production	Carbonate	CSI/SNWA	Monthly/Cont.	Monthly	Yes	Note: If pumping well will be monitored continuously.	685812.6700	4077531.2580
210	CSI-4			Well	Production	Carbonate	CSI/SNWA	Monthly/Cont.	Monthly	Yes	Note: If pumping well will be monitored continuously.	682366.2050	4080185.3230
210	CSV-3	364127114553001		Well	Monitor	Valley Fill	SNWA	Monthly		Yes		685222.1942	4062583.2919
210	CSV3009X			Well	Monitor	Valley Fill	SNWA	Continuous		Yes		681075.0000	4094993.0000
210	CSV3011X			Well	Monitor	Valley Fill	SNWA	Continuous		Yes		684064.7000	4094870.3000
210	CSVM-1	PAHRANAGAT WASH		Well	Monitor	Carbonate	SNWA	Continuous		Yes		688602.2770	4073793.3540
210	CSVM-2	SOUTH PASS		Well	Monitor	Carbonate	SNWA	Continuous		Yes		685625.4370	4059369.5370
210	CSVM-3	NORTH PASS		Well	Monitor	Carbonate	SNWA	Continuous		Yes		679319.3470	4102599.9570
210	CSVM-4	STINGRAY RIDGE		Well	Monitor	Carbonate	SNWA	Continuous		Yes		688086.4380	4095970.6500
210	CSVM-5	MORMON WELL ROAD		Well	Monitor	Carbonate	SNWA	Continuous		Yes		680294.9530	4068773.9840
210	CSVM-6	DUTCHFLAT 2		Well	Monitor	Carbonate	SNWA	Continuous		Yes		686453.2940	4078333.4380
210	CSVM-7	Williams Well		Well	Monitor	Valley Fill	SNWA	Monthly		Yes		678233.5900	4101967.9910
210	CSV-RW2	RW-2		Well	Production	Carbonate	NPC (NVEnergy)	Continuous	Monthly	Yes		687862.2530	4074082.0729
210	DF-1	DUTCHFLAT		Well	Monitor	Valley Fill	SNWA	Monthly		Yes		686980.1582	4078687.0038
210	MX-4	CE-DT-4	364743114533101	Well	Monitor	Carbonate	SNWA/USGS	Continuous		Yes		688003.1665	4074276.9210
210	MX-5	CE-DT-5	364741114532801	Well	Production	Carbonate	SNWA	Continuous	Monthly	Yes	Currently being measured monthly but will monitor continuously when pumping begins	688083.9970	4074219.3463
215	BM-DL-1	BM-1		Well	Monitor	Carbonate	SNWA	Monthly		Yes		689926.2070	4019493.1184
215	BM-DL-2	BM-2		Well	Monitor	Carbonate	SNWA	Monthly		Yes		689269.5155	4019590.9889
215	BM-ONCO-1			Well	Monitor	Clastic Rock	SNWA	Quarterly		Yes		702650.3982	4010747.9511
215	BM-ONCO-2			Well	Monitor	Clastic Rock	SNWA	Quarterly		Yes		702054.4574	4010721.8062
216	CRYSTAL 1			Well	Grounding	Carbonate	NPC (NVEnergy)	Continuous		Yes		694389.0847	4039716.0433
216	CRYSTAL 2			Well	Grounding	Carbonate	NPC (NVEnergy)	Continuous		Yes		694146.3344	4039284.3054
216	GARNET			Well	Monitor	Valley Fill	SNWA	Monthly		Yes		693046.3435	4036386.5712
216	GV-1			Well	Monitor	Carbonate	SNWA	Continuous		Yes		682983.4186	4034143.0740
216	GV-2			Well	Monitor	Carbonate	SNWA	Monthly		Yes		686226.4918	4025689.6305
216	GV-DUKE-WS1			Well	Production	Carbonate	SNWA	Monthly	Monthly	Yes		686197.4219	4029177.5794
216	GV-DUKE-WS2			Well	Production	Carbonate	SNWA/NPC (NVEnergy)	Monthly	Monthly	Yes		686184.9635	4029177.3115
216	GV-MIRANT1			Well	Production	Carbonate	SNWA	Monthly	Monthly	Yes		683114.6056	4032318.4501
216	GV-PW-MW1	PINNACLE WEST MW-1		Well	Monitor	Carbonate	SNWA	Continuous		Yes		683459.9629	4031729.8159
216	GV-PW-MW2	PINNACLE WEST MW-2		Well	Monitor	Carbonate	SNWA	Monthly		Yes		682652.4113	4031488.4375
216	GV-PW-WS1	PINNACLE WEST WS-1		Well	Production	Carbonate	SNWA	Monthly	Monthly	Yes		682653.9380	4031460.4453
216	GV-RW1	RW-1		Well	Production	Carbonate	NPC (NVEnergy)	Quarterly	Monthly	Yes		692927.7177	4036645.4218
217	SHV-1	HIDDEN	363308114553001	Well	Monitor	Valley Fill	SNWA/USGS	Continuous		Yes		685751.0096	4047255.7560

Sites to be Monitored for Duration of Order 1169 Test

Basin_no	Name_2	Alias1	Alias2	TYPE	WellType	Hydrogeologic Unit	AGENCY	WL MEASUREMENT FREQUENCY	PRODUCTION/ FLOW DATA FREQUENCY	Will Monitor for duration of Order 1169 Test	Remarks	UTM_X	UTM_Y
218	BYRON			Well	Production	Carbonate	SNWA	Monthly	Monthly		Still working on site access, so we cannot commit the well at this time	710993.8680	4051282.3340
218	PAIUTES-ECP1	ECP-1		Well	Monitor	Carbonate	MBPI	Continuous		Yes		696729.1466	4046589.8060
218	PAIUTES-ECP2	ECP-2		Well	Monitor	Carbonate	MBPI	Quarterly		Yes		696722.9510	4046742.1576
218	PAIUTES-ECP3	ECP-3		Well	Monitor	Carbonate	MBPI	Quarterly		Yes		696713.6181	4046984.3662
218	PAIUTES-M1	M-1		Well	Monitor	Carbonate	MBPI	Continuous		Yes		704517.1287	4057109.1423
218	PAIUTES-M2	M-2		Well	Monitor	Carbonate	MBPI	Continuous		Yes		695835.8998	4040875.9507
218	PAIUTES-M3	M-3		Well	Monitor	Carbonate	MBPI	Continuous		Yes		691535.8506	4044301.6038
218	PAIUTES-TH2	TH-2		Well	Monitor	Carbonate	MBPI	Continuous		Yes		697684.0744	4049916.2106
219	ABBOTT	UM7		Well	Monitor	Valley Fill	NPC (NVEnergy)	Monthly		Yes		706442.8946	4065656.5879
219	ARROW_CANYON			Well	Production	Carbonate	MVWD	Continuous	Continuous	Yes		701103.7690	4067755.2460
219	ARROW CANYON 2			Well	Production	Carbonate	MVWD	Continuous	Continuous	Yes		701103.3700	4067768.3000
219	BEHMER-MW			Well	Monitor	Valley Fill	NPC (NVEnergy)	Monthly		Yes		706030.6983	4065280.1818
219	CSV-1	364601114514301		Well	Monitor	Valley Fill	SNWA	Monthly		Yes		691377.9927	4071630.4100
219	CSV-2	364650114432001		Well	Monitor	Carbonate	SNWA/USGS/NV Energy	Continuous		Yes	NVEnergy includes data obtained from the USGS website for this well on a monthly basis....so technically we don't but we report data.	703217.0806	4072966.7777
219	EH-4			Well	Monitor	Carbonate	NPC (NVEnergy)	Continuous		Yes		703929.2650	4064736.4078
219	EH-5B			Well	Monitor	Carbonate	NPC (NVEnergy)	Continuous		Yes		701568.7861	4067619.1347
219	LDS CENTRAL	UM49		Well	Production	Valley Fill	NPC (NVEnergy)	Monthly	Monthly	Yes		704113.9580	4066543.6361
219	LDS EAST	UM50		Well	Production	Valley Fill	NPC (NVEnergy)	Monthly	Monthly	Yes		704478.9759	4066594.2407
219	LDS WEST	UM18		Well	Production	Valley Fill	NPC (NVEnergy)	Monthly	Monthly	Yes		702746.2777	4067083.3415
219	LEWIS 1 CLD	UM55		Well	Monitor	Valley Fill	NPC (NVEnergy)	Monthly		Yes		702076.8581	4068229.1435
219	LEWIS 2	UM74		Well	Production	Valley Fill	NPC (NVEnergy)	Continuous	Monthly	Yes		702339.3990	4067921.3381
219	LEWIS NORTH	UM45		Well	Monitor	Valley Fill	NPC (NVEnergy)	Continuous		Yes		701588.5926	4067871.6716
219	LEWIS SOUTH	UM43		Well	Monitor	Valley Fill	NPC (NVEnergy)	Continuous		Yes		702737.1327	4067265.8985
219	MX-6	CE-DT-6	364604114471301	Well	Production	Carbonate	MVWD	Monthly	Continous	Yes		697482.4475	4071381.1641
219	PERKINS OLD	UM15		Well	Monitor	Valley Fill	NPC (NVEnergy)	Continuous		Yes		705637.2978	4065223.3801
219	PERKINS PRODUCTION			Well	Production	Valley Fill	NPC (NVEnergy)	Monthly	Monthly	Yes		705692.9601	4065206.0659
219	UMVM-1	DEADMAN WASH		Well	Monitor	Carbonate	SNWA	Continuous		Yes		694304.6450	4070247.5450
220	EH-3			Well	Monitor	Carbonate	NPC (NVEnergy)	Continuous		Yes		721085.0000	4063300.0000
220	EH-7			Well	Monitor	Carbonate	NPC (NVEnergy)	Continuous		Yes		720660.0000	4060990.0000

Sites to be Monitored for Duration of Order 1169 Test

Basin_no	Name_2	Alias1	Alias 2	TYPE	WellType	Hydrogeologic Unit	AGENCY	WL MEASUREMENT FREQUENCY	PRODUCTION/ FLOW DATA FREQUENCY	Will Monitor for duration of Order 1169 Test	Remarks	UTM_X	UTM_Y
Surface Water Monitoring:													
219	BALDWIN SPRING BOX			Spring		Flow Meter	MVWD	Continuous	Continuous	Yes		703257.3243	4066270.2745
219	JONES SPRING BOX			Spring		Flow Meter	MVWD	Continuous	Continuous	Yes		703713.6616	4065660.8144
219	PEDERSCN EAST SPRING GAGE	PLAYBOY POOL GAGE		Spring		Flume	SNWA/USGS	Continuous	Continuous	Yes		704034.2489	4065063.0421
219	PEDERSCN SPRING GAGE			Spring		Weir	SNWA/USGS	Continuous	Continuous	Yes		704008.0508	4065088.5140
219	WARM SPRINGS WEST GAGE			Spring		Flume	SNWA/USGS	Continuous	Continuous	Yes		704210.7611	4065272.2446
219	IVERSON FLUME			Stream		Flume	SNWA/USGS	Continuous	Continuous	Yes		704569.9449	4065295.8619
219	MUDDY SPRING GAGE			Spring		Flume	SNWA/USGS	Continuous	Continuous	Yes		704018.1277	4066347.6635
219	MOAPA GAGE			Stream		Stream Gage	USGS	Continuous	Continuous	Federally Funded		705823.3289	4065349.9049
220	GLENDALE GAGE			Stream		Stream Gage	USGS	Continuous	Continuous	Federally Funded		719696.9331	4058057.4259
220	LEWIS AVENUE NEAR OVERTON GAGE			Stream		Stream Gage	SNWA/USGS	Continuous	Continuous	Yes		730091.3558	4046453.5134
215	BLUE POINT SPRING			Spring		Stream Gage	NPS	Continuous	Continuous	Yes		730352.7311	4030270.7397
215	ROGERS SPRING			Spring		Stream Gage	NPS	Continuous	Continuous	Yes		729419.7449	4028891.3629

SNWA MONITORING SITES

Basin_no	Name_2	Alias1	Alias2	TYPE	WellType	AGENCY	WL Measurment FREQUENCY	Production / Flow Data FREQUENCY	Will Monitor for duration of Order 1169 Test	Remarks	UTM_X	UTM_Y
206	KMW-1			Well	Monitor	Vidler	Monthly			SNWA is cooperatively monitoring this well w/ Vidler but cannot commit to its monitoring.		
210	CE-VF-1	365232114554401		Well	Monitor	SNWA	Monthly		Yes		683024.8034	4083038.0123
210	CE-VF-2	365227114554401		Well	Monitor	SNWA	Continuous		Yes		683007.1006	4082892.1451
210	CSI-1			Well	Production	CSI/SNWA	Continuous	Monthly	Yes		686043.0700	4074459.1500
210	CSI-2			Well	Production	CSI/SNWA	Continuous	Monthly	Yes		687082.7320	4075780.6200
210	CSI-3			Well	Production	CSI/SNWA	Monthly/Cont.	Monthly	Yes	Note: If pumping, well will be monitored continuously.	685812.6700	4077531.2580
210	CSI-4			Well	Production	CSI/SNWA	Monthly/Cont.	Monthly	Yes	Note: If pumping, well will be monitored continuously.	682366.2050	4080185.3230
210	CSV-3	364127114553001		Well	Monitor	SNWA	Monthly		Yes		685222.1942	4062583.2919
210	CSV3009X			Well	Monitor	SNWA	Continuous		Yes	Well drilled in late 2008 by SNWA; name will change	681075.0000	4094993.0000
210	CSV3011X			Well	Monitor	SNWA	Continuous		Yes	Well drilled in late 2008 by SNWA; name will change	684064.7000	4094870.3000
210	CSVM-1	PAHRANAGAT WASH		Well	Monitor	SNWA	Continuous		Yes		688602.2770	4073793.3540
210	CSVM-2	SOUTH PASS		Well	Monitor	SNWA	Continuous		Yes		685625.4370	4059369.5370
210	CSVM-3	NORTH PASS		Well	Monitor	SNWA	Continuous		Yes		679319.3470	4102599.9570
210	CSVM-4	STINGRAY RIDGE		Well	Monitor	SNWA	Continuous		Yes		688086.4380	4095970.6500
210	CSVM-5	MORMON WELL ROAD		Well	Monitor	SNWA	Continuous		Yes		680294.9530	4068773.9840
210	CSVM-6	DUTCHFLAT 2		Well	Monitor	SNWA	Continuous		Yes		686453.2940	4078333.4380
210	CSVM-7	Williams Well		Well	Monitor	SNWA	Monthly		Yes		678233.5900	4101967.9910
210	DF-1	DUTCHFLAT		Well	Monitor	SNWA	Monthly		Yes		686980.1582	4078687.0038
210	MX-4	CE-DT-4	364743114533101	Well	Monitor	SNWA/USGS	Continuous		Yes		688003.1665	4074276.9210
210	MX-5	CE-DT-5	364741114532801	Well	Production	SNWA	Continuous	Monthly	Yes	Currently being measured monthly but will monitor continuously when pumping begins	688083.9970	4074219.3463
215	BM-DL-1	BM-1		Well	Monitor	SNWA	Monthly		Yes		689926.2070	4019493.1184
215	BM-DL-2	BM-2		Well	Monitor	SNWA	Monthly		Yes		689269.5155	4019590.9889
215	BM-ONCO-1			Well	Monitor	SNWA	Quarterly		Yes		702650.3982	4010747.9511
215	BM-ONCO-2			Well	Monitor	SNWA	Quarterly		Yes		702054.4574	4010721.8062
216	GARNET			Well	Monitor	SNWA	Monthly		Yes		693046.3435	4036386.5712
216	GV-1			Well	Monitor	SNWA	Continuous		Yes		682983.4186	4034143.0740
216	GV-2			Well	Monitor	SNWA	Monthly		Yes		686226.4918	4025689.6305
216	GV-DUKE-WS1			Well	Production	SNWA	Monthly	Monthly	Yes		686197.4219	4029177.5794
216	GV-DUKE-WS2			Well	Production	SNWA	Monthly	Monthly	Yes		686184.9635	4029177.3115
216	GV-MIRANT1			Well	Production	SNWA	Monthly	Monthly	Yes		683114.6056	4032318.4501
216	GV-PW-MW1	PINNACLE WEST MW-1		Well	Monitor	SNWA	Continuous		Yes		683459.9629	4031729.8159
216	GV-PW-MW2	PINNACLE WEST MW-2		Well	Monitor	SNWA	Monthly		Yes		682652.4113	4031488.4375
216	GV-PW-WS1	PINNACLE WEST WS-1		Well	Production	SNWA	Monthly	Monthly	Yes		682653.9380	4031460.4453
217	HV-1			Well	Monitor	SNWA	No Access		No	Well has concrete plug in surface casing	684198.0000	4035619.0000
217	SHV-1	HIDDEN	363308114553001	Well	Monitor	SNWA/USGS	Continuous		Yes		685751.0096	4047255.7560
218	BYRON			Well	Production	SNWA	Monthly	Monthly		Will measure but we are still working on site access, so we cannot commit the well at this time	710993.8680	4051282.3340
219	CSV-1	364601114514301		Well	Monitor	SNWA	Monthly		Yes		691377.9927	4071630.4100
219	CSV-2	364650114432001		Well	Monitor	SNWA/USGS	Continuous		Yes		703217.0806	4072966.7777
219	UMVM-1	DEADMAN WASH		Well	Monitor	SNWA	Continuous		Yes		694304.6450	4070247.5450
219	PEDERSON EAST SPRING GAGE	PLAYBOY POOL GAGE		Spring		SNWA/USGS	Continuous	Continuous	Yes		704034.2489	4065063.0421
219	PEDERSON SPRING GAGE			Spring		SNWA/USGS	Continuous	Continuous	Yes		704008.0508	4065088.5140
219	WARM SPRINGS WEST GAGE			Spring		SNWA/USGS	Continuous	Continuous	Yes		704210.7611	4065272.2446
219	IVERSON FLUME			Stream		SNWA/USGS	Continuous	Continuous	Yes		704569.9449	4065295.8619
219	MUDDY SPRING GAGE			Spring		SNWA/USGS	Continuous	Continuous	Yes		704018.1277	4066347.6635
219	MOAPA GAGE			Stream		USGS	Continuous	Continuous	Federally Funded		705823.3289	4065349.9049
220	GLENDALE GAGE			Stream		USGS	Continuous	Continuous	Federally Funded		719896.9331	4058057.4259
220	LEWIS AVENUE NEAR OVERTON GAGE			Stream		SNWA/USGS	Continuous	Continuous	Yes		730091.3558	4046453.5134

NVENERGY MONITORING SITES

Basin_no	Name_2	Alias1	Alias2	TYPE	WellType	AGENCY	WL Measurment FREQUENCY	Production / Flow Data FREQUENCY	Will Monitor for duration of Order 1169 Test	Remarks	UTM_X	UTM_Y
205	EH-6			Well	Monitor	NPC (NV Energy)	Quarterly		Yes		717057.8229	4062264.5310
205	EH-8A			Well	Monitor	NPC (NV Energy)	Quarterly		Yes		716453.3065	4061395.1542
205	EH-8B			Well	Monitor	NPC (NV Energy)	Quarterly		Yes		716453.3065	4061395.1542
205	NPC-4A			Well	Monitor	NPC (NV Energy)	Quarterly		Yes		716556.8208	4062677.9450
205	NPC-5 OLD			Well	Monitor	NPC (NV Energy)	Quarterly		Yes		715287.9974	4064184.9106
205	TH-12			Well	Monitor	NPC (NV Energy)	Quarterly		Yes		716321.9487	4062679.6988
205	TH-31			Well	Monitor	NPC (NV Energy)	Quarterly		Yes		715626.1443	4061638.2906
205	TH-35			Well	Monitor	NPC (NV Energy)	Quarterly		Yes		717055.2998	4061094.5021
205	TH-8			Well	Monitor	NPC (NV Energy)	Quarterly		Yes		716648.3044	4061853.9518
205	NPC-2			Well	Monitor	NPC (NV Energy)	Quarterly		Yes			
210	CSV-RW2	RW-2		Well	Production	NPC (NV Energy)	Continuous	Monthly	Yes		687862.2530	4074082.0729
216	CRYSTAL 1			Well	Grounding	NPC (NV Energy)	Continuous		Yes		694389.0647	4039716.0433
216	CRYSTAL 2			Well	Grounding	NPC (NV Energy)	Continuous		Yes		694146.3344	4039284.3054
216	CRYSTAL 1			Well	Grounding	NPC (NV Energy)	Continuous		Yes		694389.0647	4039716.0433
216	CRYSTAL 2			Well	Grounding	NPC (NV Energy)	Continuous		Yes		694146.3344	4039284.3054
216	GV-DUKE-WS2			Well	Production	SNWA/NPC NV Energy	Monthly	Monthly	Yes		686184.9635	4029177.3115
216	GV-RW1	RW-1		Well	Production	NPC (NV Energy)	Quarterly	Monthly	Yes		692927.7177	4036645.4218
218	EH-2			Well	Monitor	NPC (NV Energy)			No	NV Energy no longer monitors this well.	709964.8800	4057216.3300
219	ABBOTT	UM7		Well	Monitor	NPC (NV Energy)	Monthly		Yes		706442.8946	4065656.5879
219	BEHMER	UM14		Well	Production	NPC (NV Energy)		Monthly	No	This is a production well with no access for water level readings...we do track production but rely on the adjacent monitor well for water levels.	706030.7400	4065080.0000
219	BEHMER-MW			Well	Monitor	NPC (NV Energy)	Monthly		Yes		706030.6983	4065280.1818
219	CSV-2		3.6465E+14	Well	Monitor	SNWA/USGS/NV Energy	Continuous		Yes	NV Energy includes data obtained from the USGS website for this well on a monthly basis....so technically we don't but we report data.	703217.0806	4072966.7777
219	EH-4			Well	Monitor	NPC (NV Energy)	Continuous		Yes		703929.2650	4064736.4078
219	EH-5B			Well	Monitor	NPC (NV Energy)	Continuous		Yes		701568.7861	4067619.1347
219	LDS CENTRAL	UM49		Well	Production	NPC (NV Energy)	Monthly	Monthly	Yes		704113.9580	4066543.6361
219	LDS EAST	UM50		Well	Production	NPC (NV Energy)	Monthly	Monthly	Yes		704478.9759	4066594.2407
219	LDS WEST	UM18		Well	Production	NPC (NV Energy)	Monthly	Monthly	Yes		702746.2777	4067083.3415
219	LEWIS 1			Well	Production	NPC (NV Energy)		Monthly	No	NV Energy no longer monitors this well.	702182.2580	4068043.3550
219	LEWIS 1 OLD	UM55		Well	Monitor	NPC (NV Energy)	Monthly		Yes		702076.8581	4068229.1435
219	LEWIS 2	UM74		Well	Production	NPC (NV Energy)	Continuous	Monthly	Yes		702339.3990	4067921.3381
219	LEWIS 3			Well	Production	NPC (NV Energy)		Monthly	No	NV Energy no longer monitors this well.	701956.1519	4068021.3525
219	LEWIS 3A			Well	Monitor	NPC (NV Energy)			No	NV Energy no longer monitors this well.	701971.5334	4067983.1004
219	LEWIS 4			Well	Production	NPC (NV Energy)		Monthly	No	NV Energy no longer monitors this well.	702027.6971	4067619.5254
219	LEWIS 5			Well	Production	NPC (NV Energy)		Monthly	No	NV Energy no longer monitors this well.	702196.4390	4067485.2928
219	LEWIS FARM			Well	Monitor	NPC (NV Energy)			No	NV Energy no longer monitors this well.	701949.5290	4067860.8500
219	LEWIS NORTH	UM45		Well	Monitor	NPC (NV Energy)	Continuous		Yes		701588.5926	4067871.6716
219	LEWIS SOUTH	UM43		Well	Monitor	NPC (NV Energy)	Continuous		Yes		702737.1327	4067265.8985
219	PERKINS OLD	UM15		Well	Monitor	NPC (NV Energy)	Continuous		Yes		705637.2978	4065223.3801
219	PERKINS PRODUCTION			Well	Production	NPC (NV Energy)	Monthly	Monthly	Yes		705692.9601	4065206.0659
220	EH-3			Well	Monitor	NPC (NV Energy)	Continuous		Yes		721085	4063300
220	EH-7			Well	Monitor	NPC (NV Energy)	Continuous		Yes			4060990

MVWD MONITORING SITES

Basin_no	Name_2	Alias1	Alias2	TYPE	WellType	AGENCY	WL Measurment FREQUENCY	Production / Flow Data FREQUENCY	Will Monitor for duration of Order 1169 Test	Remarks	UTM_X	UTM_Y
219	MX-6	CE-DT-6	3.64604E+14	Well	Production	MVWD	Monthly	Monthly	Yes		697482.4475	4071381.1641
219	JONES SPRING BOX			Spring		MVWD	Continuous	Continuous	Yes		703713.6616	4065660.8144
219	ARROW_CANYON			Well	Production	MVWD	Continuous	Continuous	Yes		701103.7690	4067755.2460
219	ARROW CANYON 2			Well	Production	MVWD	Continuous	Continuous	Yes		701103.3700	4067768.3000
219	BALDWIN SPRING BOX			Spring		MVWD	Continuous	Continuous	Yes		703257.3243	4066270.2745
205	MVWD MW-1			Well	Monitoring	MVWD	Monthly		Yes			
210	SAWMILL CANYON 4K			Precip		MVWD	Monthly			Tom Buquo indicated the requirement to	676695.7258	4066470.7082
210	SAWMILL CANYON 5K			Precip		MVWD	Monthly			monitor the sawmill canyon sites sunsetted	673375.9947	4063039.6739
210	SAWMILL CANYON 6K			Precip		MVWD	Monthly			in 2006. MVWD has discontinued monitor	668992.7488	4062144.8245
210	SAWMILL CANYON 7K			Precip		MVWD	Bi-Annual			If deemed necessary, these sites can be	665590.1781	4060826.5746
210	SAWMILL CANYON 8K			Precip		MVWD	Bi-Annual			added back into the schedule	663088.9837	4061164.5837

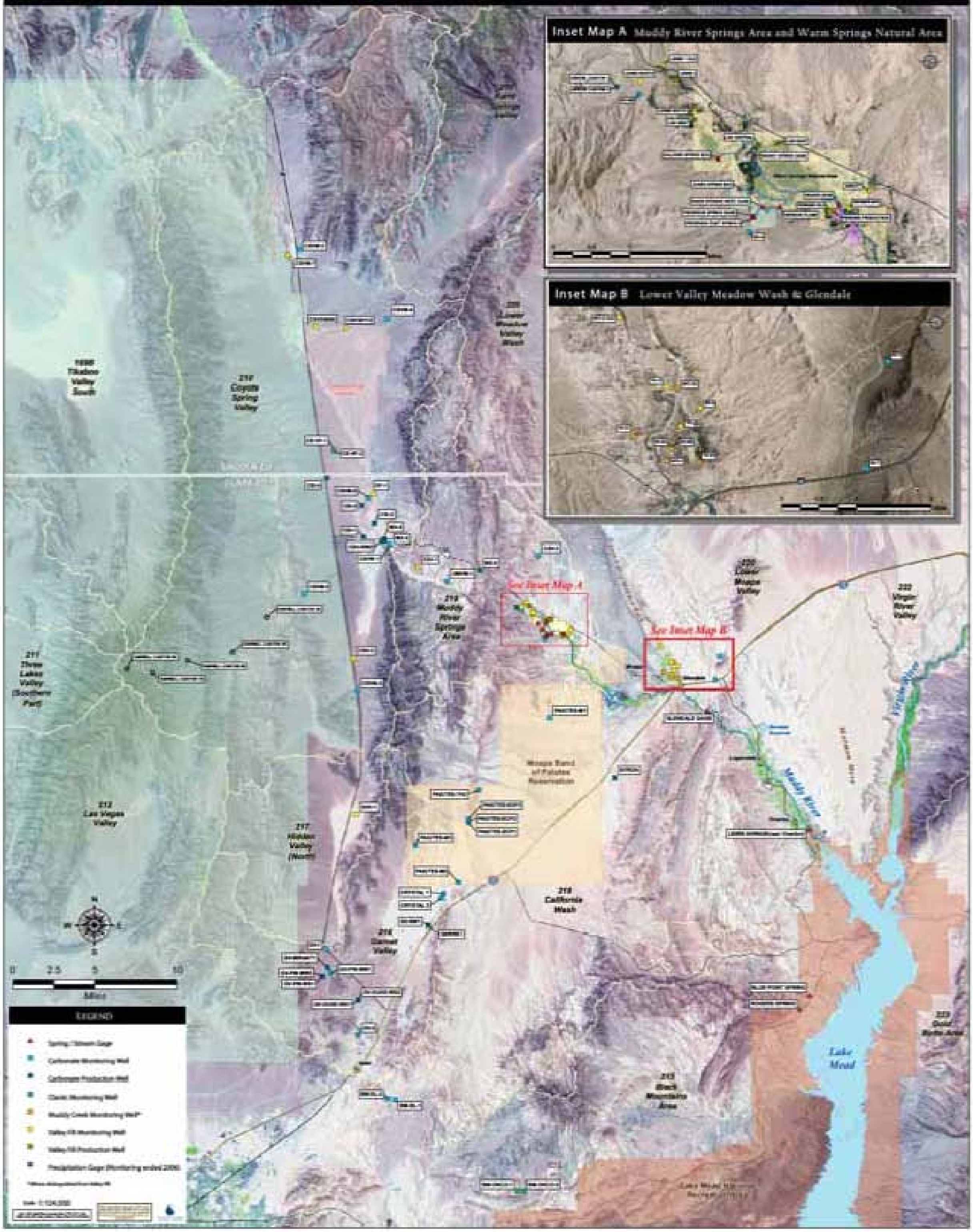
MBPI MONITORING SITES

Basin_no	Name_2	Alias1	Alias2	TYPE	WellType	AGENCY	WL Measurment FREQUENCY	Production / Flow Data FREQUENCY	Will Monitor for duration of Order 1169 Test	Remarks	UTM_X	UTM_Y
218	PAIUTES-ECP1	ECP-1		Well	Monitor	MBPI	Continuous		Yes		696729.1466	4046589.8060
218	PAIUTES-ECP2	ECP-2		Well	Monitor	MBPI	Quarterly		Yes		696722.9510	4046742.1576
218	PAIUTES-ECP3	ECP-3		Well	Monitor	MBPI	Quarterly		Yes		696713.6181	4046984.3662
218	PAIUTES-M1	M-1		Well	Monitor	MBPI	Continuous		Yes		704517.1287	4057109.1423
218	PAIUTES-M2	M-2		Well	Monitor	MBPI	Continuous		Yes		695835.8998	4040875.9507
218	PAIUTES-M3	M-3		Well	Monitor	MBPI	Continuous		Yes		691535.8506	4044301.6038
218	PAIUTES-TH2	TH-2		Well	Monitor	MBPI	Continuous		Yes		697684.0744	4049916.2106

NPS MONITORING SITES

Basin_no	Name_2	Alias1	Alias2	TYPE	WellType	AGENCY	WL Measurment FREQUENCY	Production / Flow Data FREQUENCY	Will Monitor for duration of Order 1169 Test	Remarks	UTM_X	UTM_Y
215	BLUE POINT SPRING			Spring	Stream Gage	NPS	Continuous	Continuous	Yes		730352.7311	4030270.7397
215	ROGERS SPRING			Spring	Stream Gage	NPS	Continuous	Continuous	Yes		729419.7449	4028891.3629

ORDER 1169 MONITORING SITES



Appendix C

Water Level Hydrographs for Wells

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C.1.0 WATER LEVEL HYDROGRAPHS FOR WELLS

Appendix C contains a location map of wells monitored by SNWA wells and additional wells discussed in this Report (Figure C-1). A list of the wells is provided in Table C-1. Hydrographs for the wells with discrete and continuous water level measurements are depicted on Figure C-2 through Figure C-63.

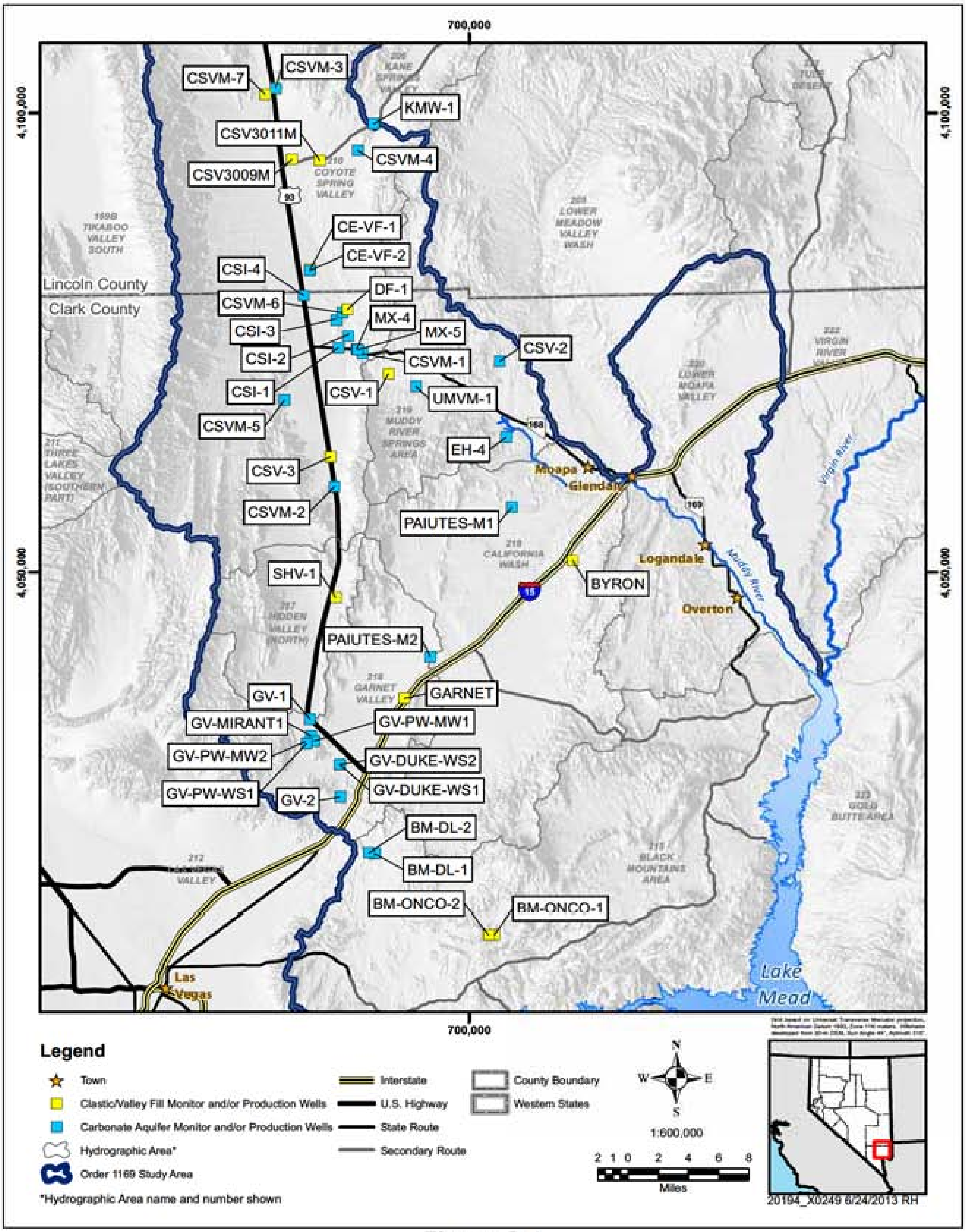

Figure C-1
Location of Wells Included in Appendix C

Table C-1
Groundwater Sites Monitored by SNWA and Monitoring Frequency during CY 2012
(Page 1 of 2)

Hydrographic Basin	Site Name	Well Type[1]	Well Completion	Monitoring Frequency[2]
Black Mountains Area	BM-DL-1[3, 8]	M	Carbonate	Monthly
Black Mountains Area	BM-DL-2[3,4]	M	Carbonate	Monthly
Black Mountains Area	BM-ONCO-1	M	Clastic	Quarterly
Black Mountains Area	BM-ONCO-2	M	Clastic	Quarterly
California Wash	Byron	M	Clastic	Monthly
California Wash	PAIUTES-M1	M	Carbonate	Continuous/Monthly
California Wash	PAIUTES-M2	M	Carbonate	Continuous/Monthly
Coyote Spring Valley	CE-VF-1	M	Alluvial	Monthly
Coyote Spring Valley	CE-VF-2	M	Carbonate	Continuous/Monthly
Coyote Spring Valley	CSI-1[6]	P	Carbonate	Monthly
Coyote Spring Valley	CSI-2	P	Carbonate	Continuous/Monthly
Coyote Spring Valley	CSI-3	P	Carbonate	Continuous/Monthly
Coyote Spring Valley	CSI-4	P	Carbonate	Monthly
Coyote Spring Valley	CSV-3	M	Alluvial	Monthly
Coyote Spring Valley	CSV3009M[7]	M	Alluvial	Continuous/Monthly
Coyote Spring Valley	CSV3011M[7]	M	Alluvial	Continuous/Monthly
Coyote Spring Valley	CSVM-1	M	Carbonate	Continuous/Monthly
Coyote Spring Valley	CSVM-2	M	Carbonate	Continuous/Monthly
Coyote Spring Valley	CSVM-3	M	Carbonate	Continuous/Monthly
Coyote Spring Valley	CSVM-4	M	Carbonate	Continuous/Monthly
Coyote Spring Valley	CSVM-5	M	Carbonate	Continuous/Monthly
Coyote Spring Valley	CSVM-6	M	Carbonate	Continuous/Monthly
Coyote Spring Valley	CSVM-7	M	Volcanic	Monthly
Coyote Spring Valley	DF-1	M	Alluvial	Monthly
Coyote Spring Valley	MX-4[2,5]	M	Carbonate	Continuous/Monthly
Coyote Spring Valley	MX-5	P	Carbonate	Continuous/Monthly
Garnet Valley	GARNET	M	Alluvial	Monthly
Garnet Valley	GV-1	M	Carbonate	Continuous/Monthly
Garnet Valley	GV-2[3,4]	M	Carbonate	Monthly
Garnet Valley	GV-DUKE-WS1	P	Carbonate	Monthly
Garnet Valley	GV-DUKE-WS2	P	Carbonate	Monthly
Garnet Valley	GV-MIRANT1	P	Carbonate	Monthly
Garnet Valley	GV-PW-MW1	M	Carbonate	Continuous/Monthly
Garnet Valley	GV-PW-MW2	M	Carbonate	Monthly

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Table C-1
Groundwater Sites Monitored by SNWA and Monitoring Frequency during CY 2012
(Page 2 of 2)

Hydrographic Basin	Site Name	Well Type[1]	Well Completion	Monitoring Frequency[2]
Garnet Valley	GV-PW-WS1	P	Carbonate	Monthly
Hidden Valley	SHV-1[2, 5]	M	Alluvial	Continuous/Monthly
Kane Springs Valley	KMW-1	M	Carbonate	Monthly
Muddy River Springs Area	CSV-1	M	Alluvial	Monthly
Muddy River Springs Area	CSV-2[2,5]	M	Carbonate	Continuous/Monthly
Muddy River Springs Area	EH-4	M	Carbonate	Continuous/Monthly
Muddy River Springs Area	UMVM-1	M	Carbonate	Continuous/Monthly

[1]Well Type: M = Monitoring Well, P = Production Well
[2]CSV-2, MX-4, and SHV-1 were monitored by SNWA/USGS through joint funding agreements.
[3]Pump with pump string installed in well on November 1, 2008.
[4]Transducer removed from well on November 1, 2008, transducer not redeployed.
[5]Continuously monitored by the USGS.
[6]Upon completion of CSI-1 equipping, water level access was limited and is being evaluated for additional modification.
[7]New monitoring wells completed in late 2008. Continuous/monthly monitoring began in early 2009.
[8]Well access port blocked; unable to get depth to water measurement after November 17, 2011.

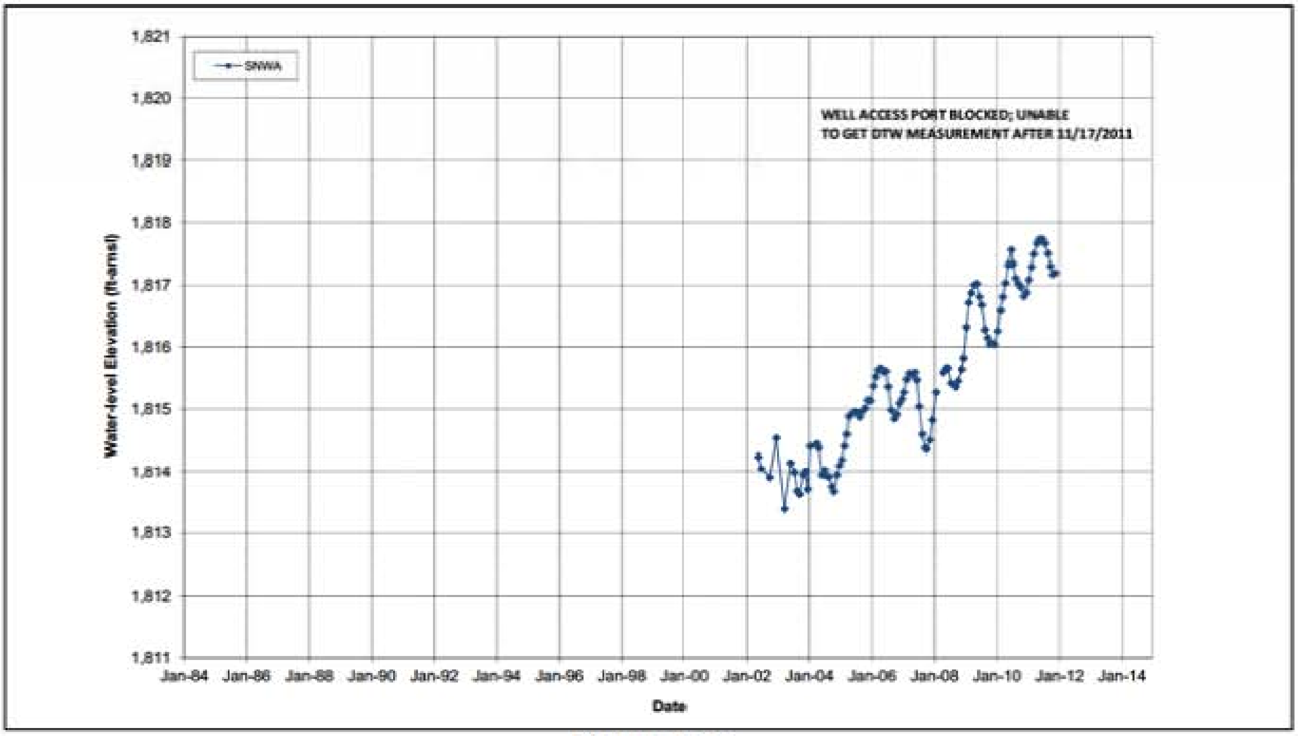

Figure C-2
BM-DL-1 (Carbonate - Basin 215: Black Mountains Area)

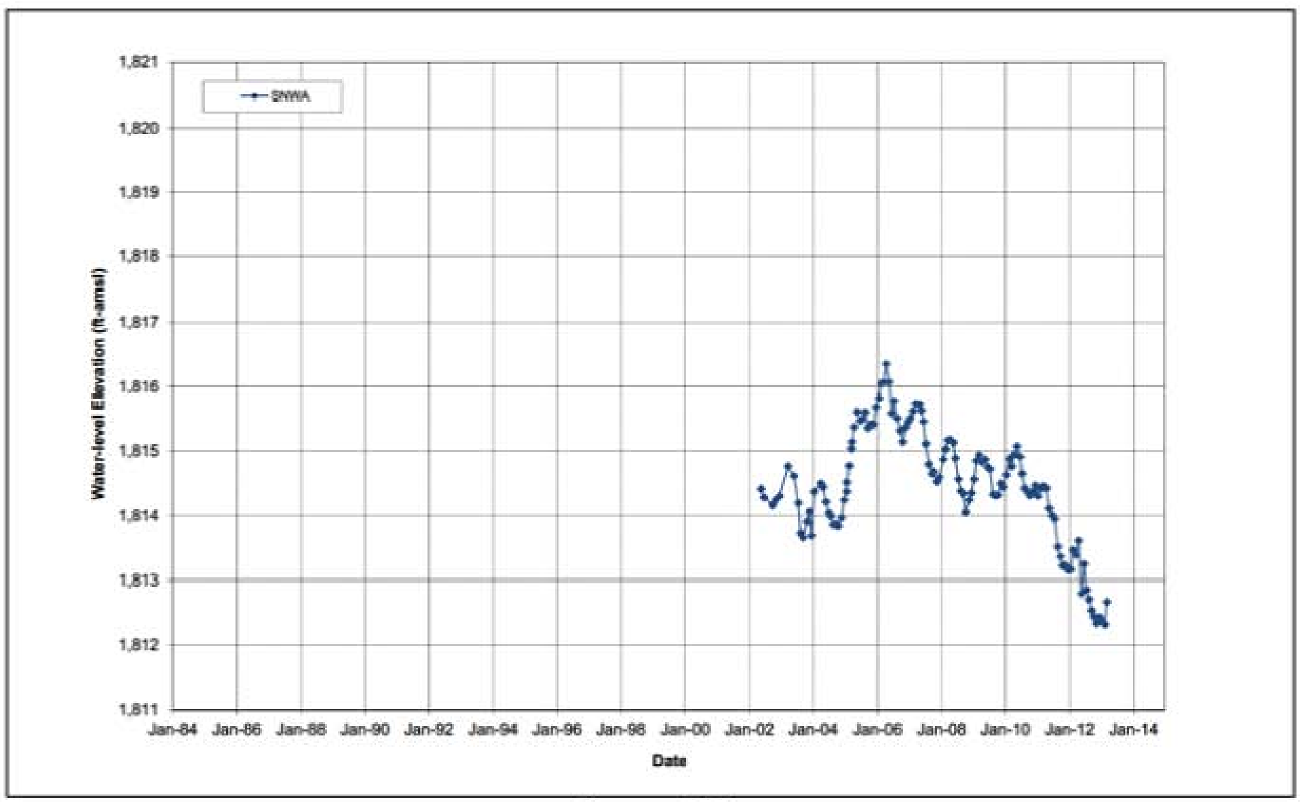

Figure C-3
BM-DL-2 (Carbonate - Basin 215: Black Mountains Area)

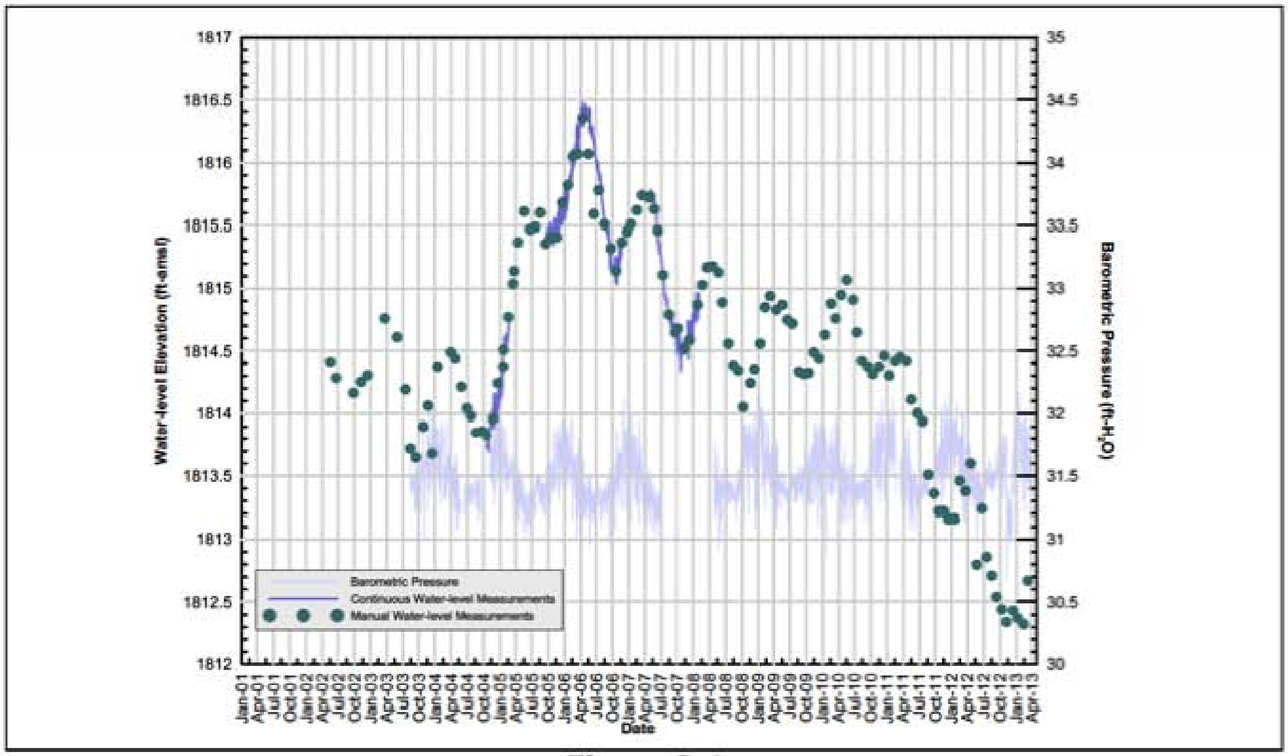

Figure C-4
BM-DL-2 (Carbonate - Basin 215: Black Mountains Area)

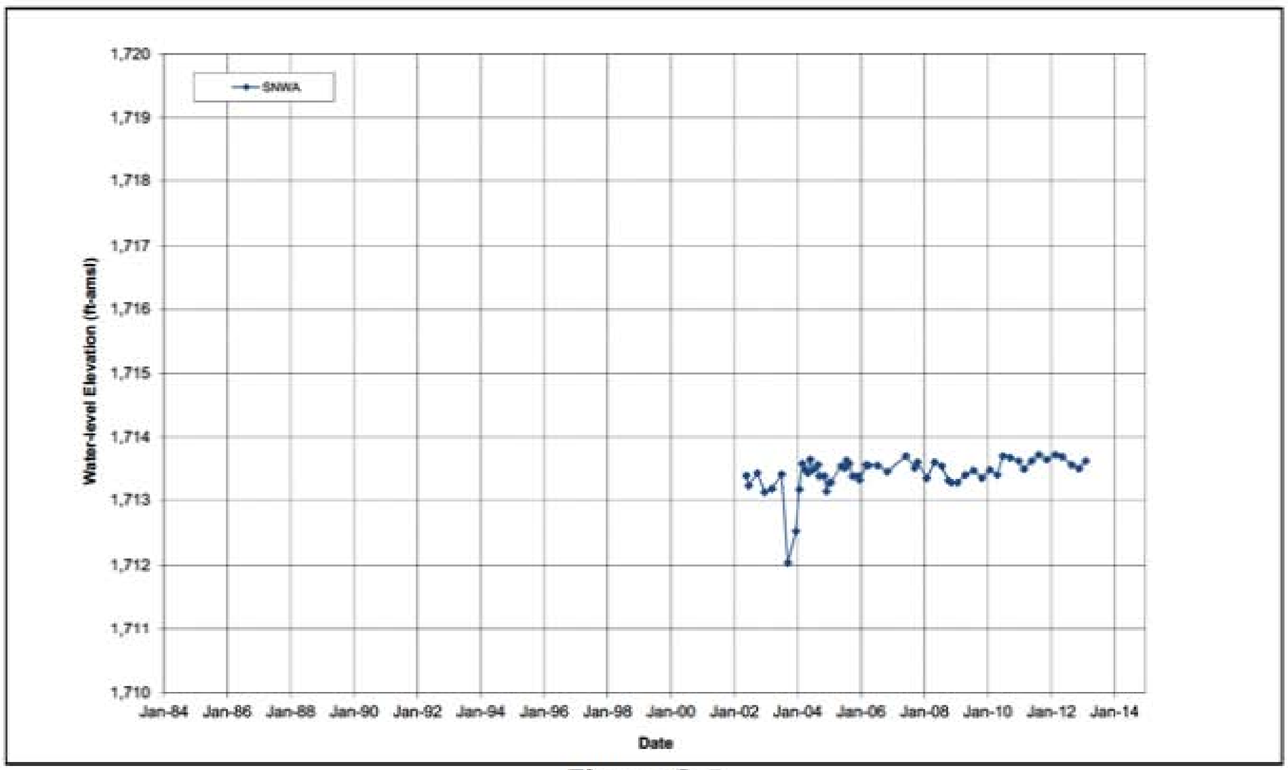

Figure C-5
BM-ONCO-1 (Clastic - Basin 215: Black Mountains Area)

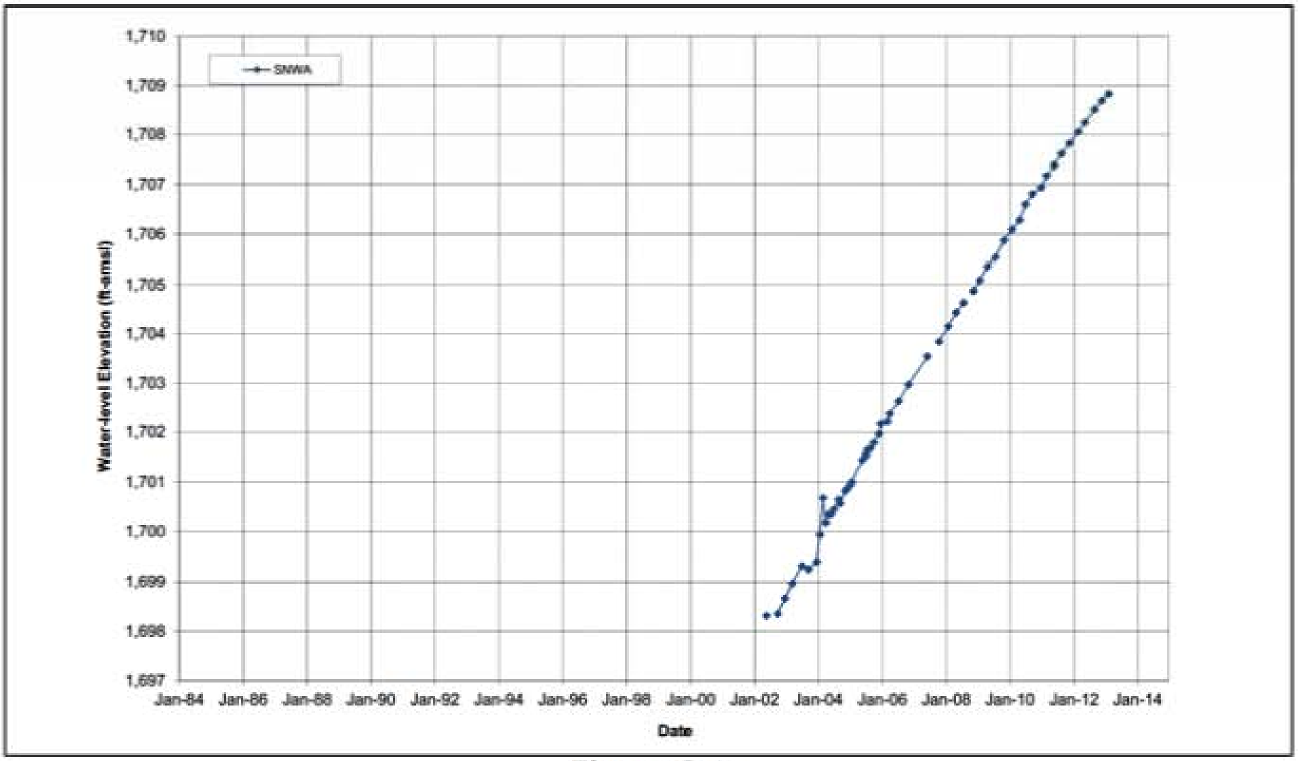

Figure C-6
BM-ONCO-2 (Clastic - Basin 215: Black Mountains Area)

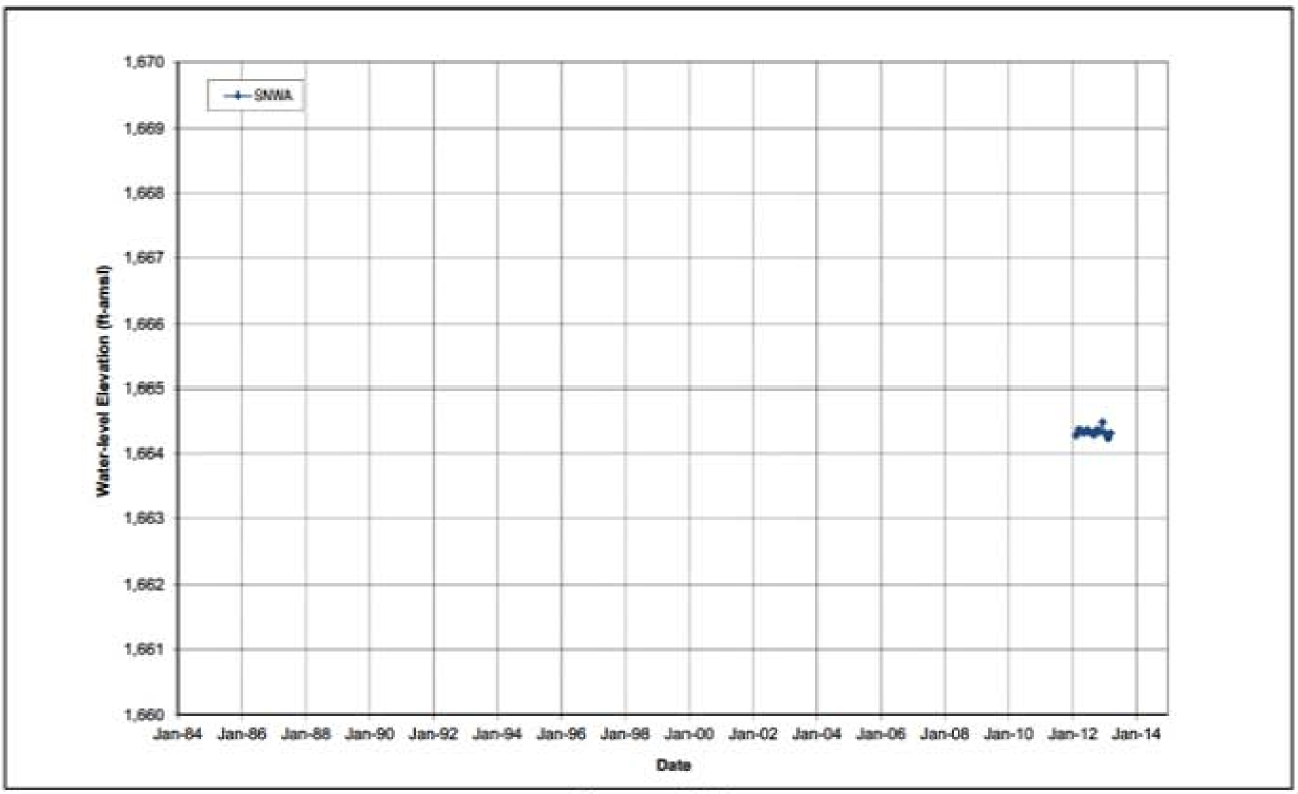

Figure C-7
BYRON (Clastic - Basin 218: California Wash)

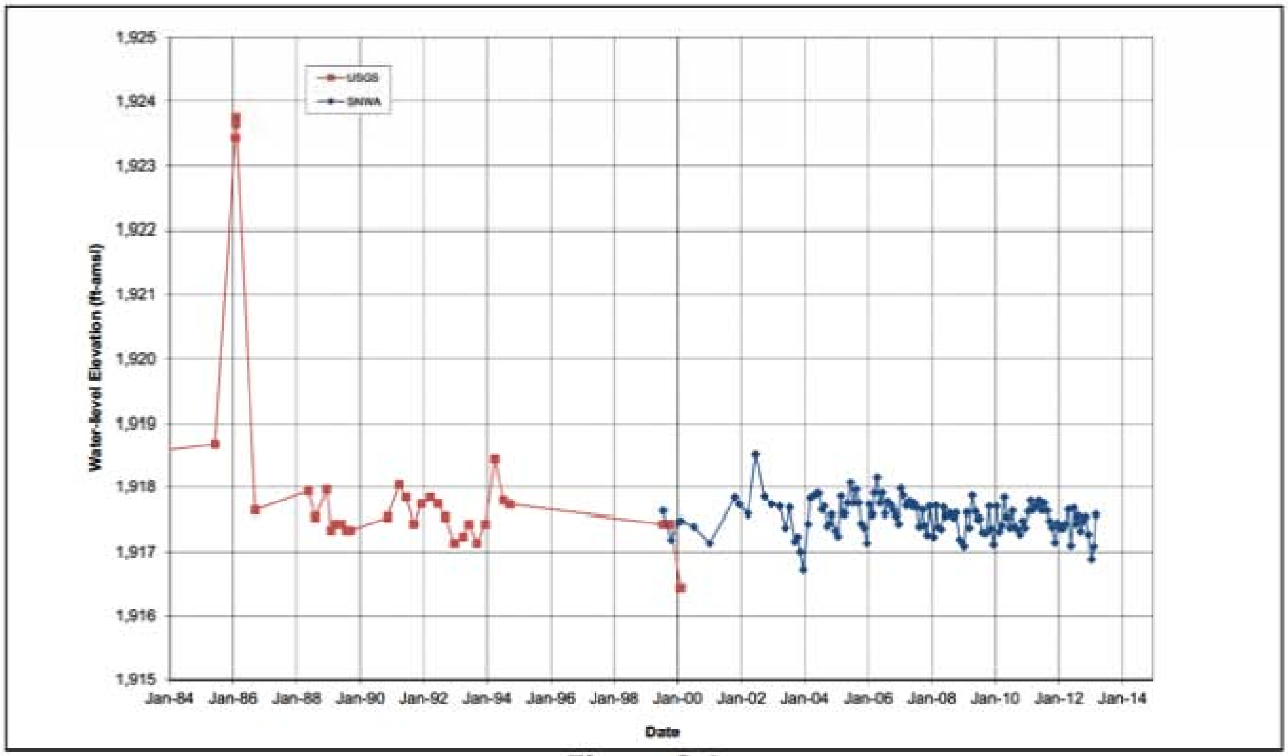

Figure C-8
CE-VF-1 (Alluvial - Basin 210: Coyote Spring Valley)

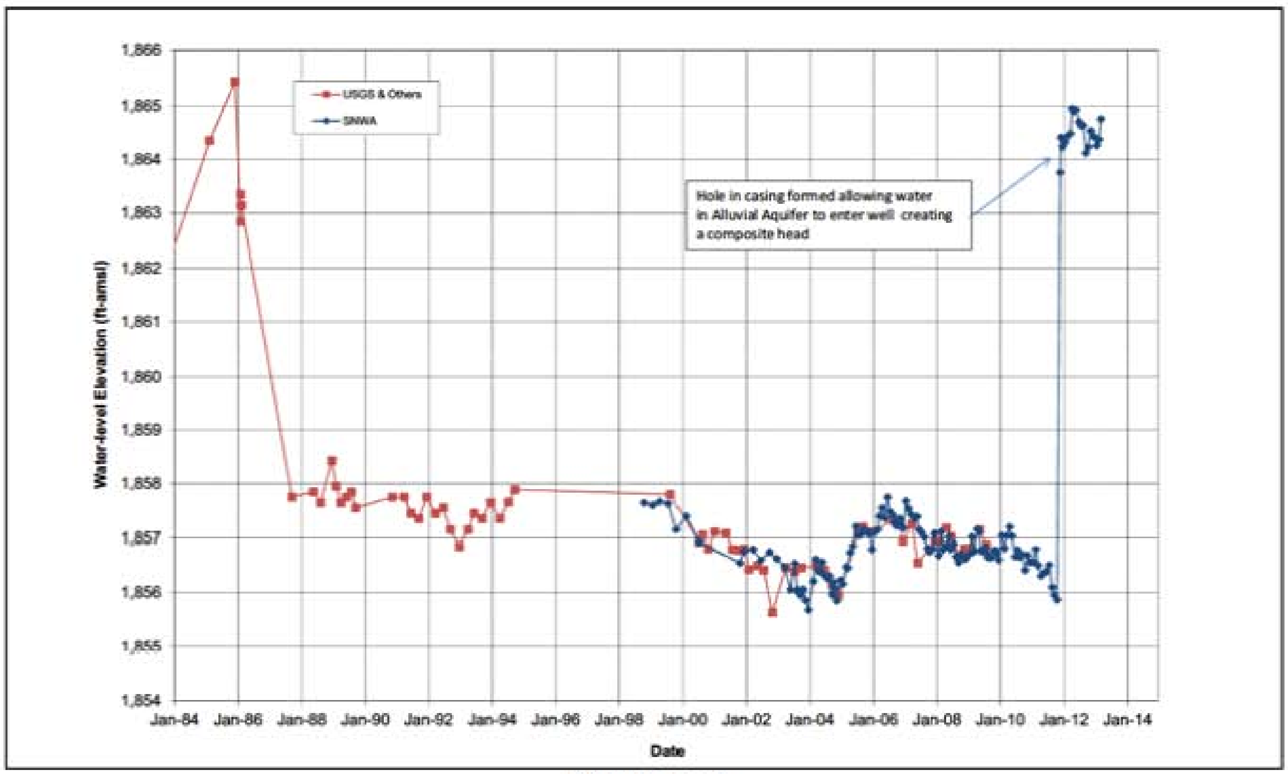

Figure C-9
CE-VF-2 (Carbonate - Basin 210: Coyote Spring Valley)

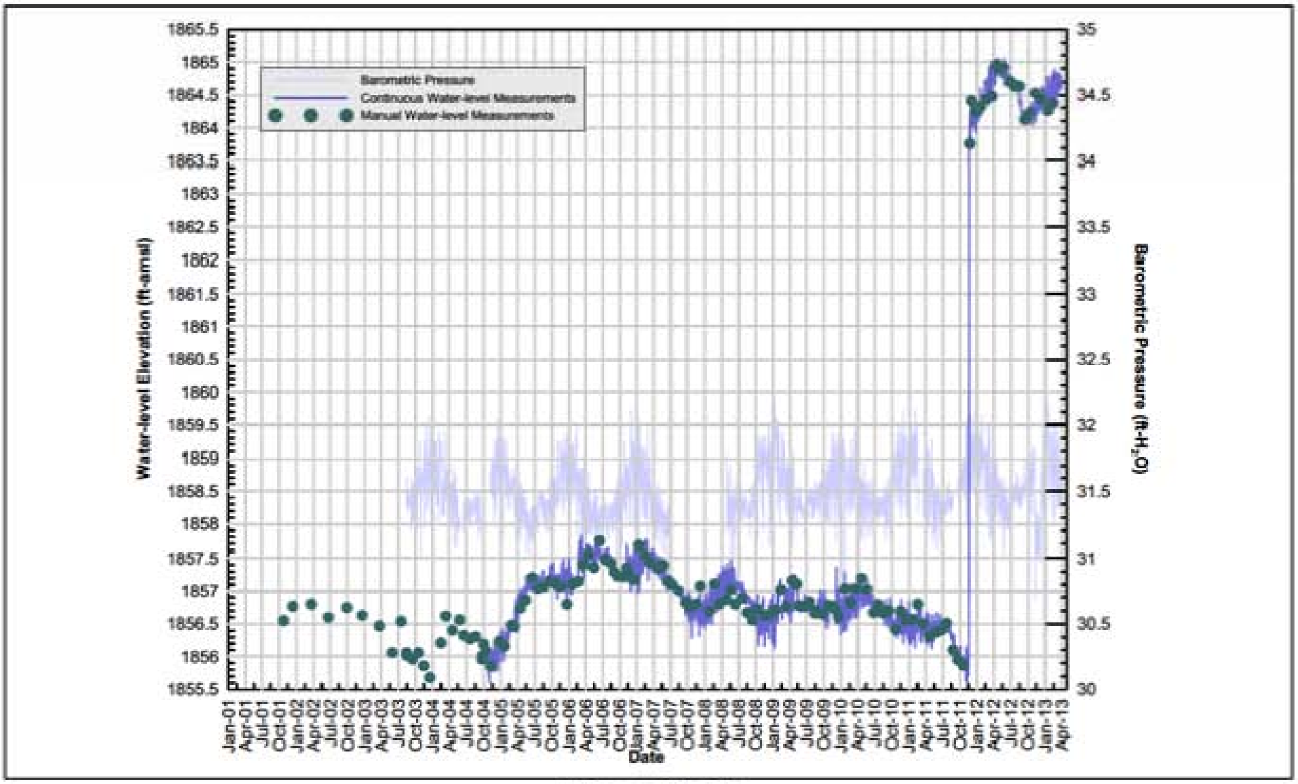

Figure C-10
CE-VF-2 (Carbonate - Basin 210: Coyote Spring Valley)

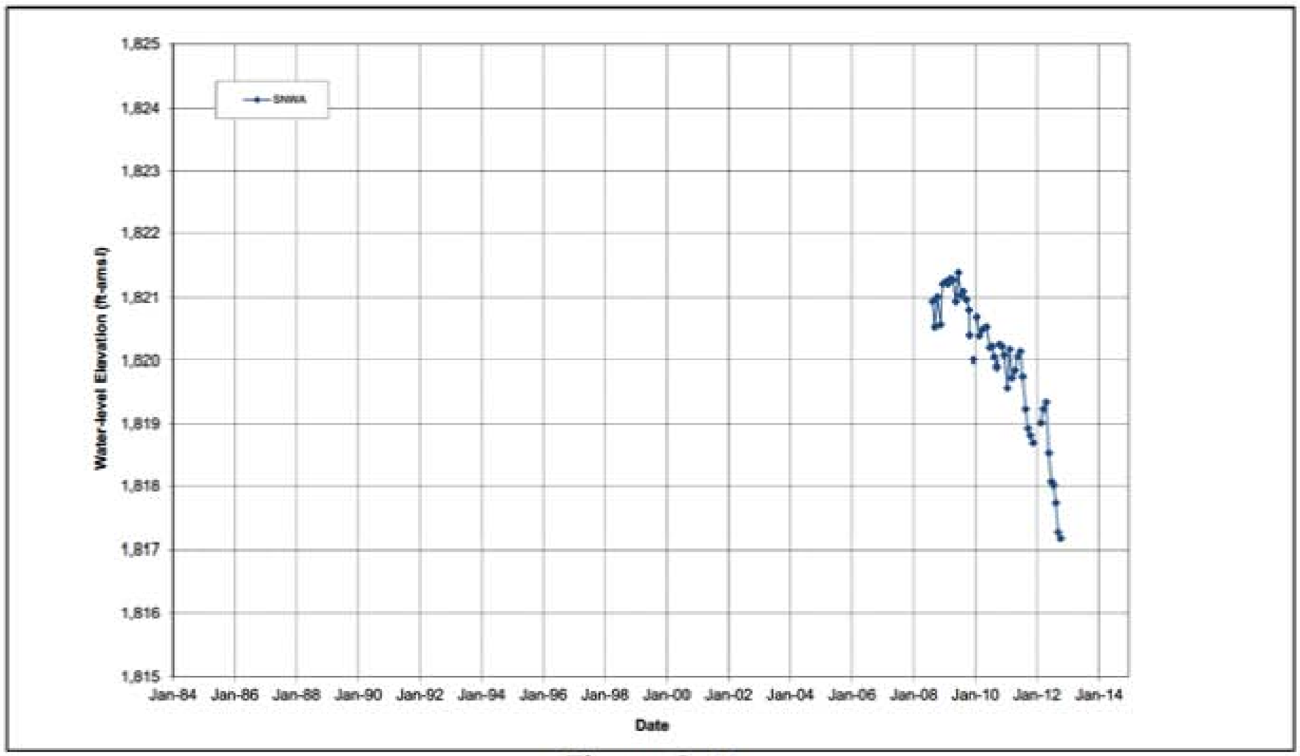

Figure C-11
CSI-1 (Carbonate - Basin 210: Coyote Spring Valley)

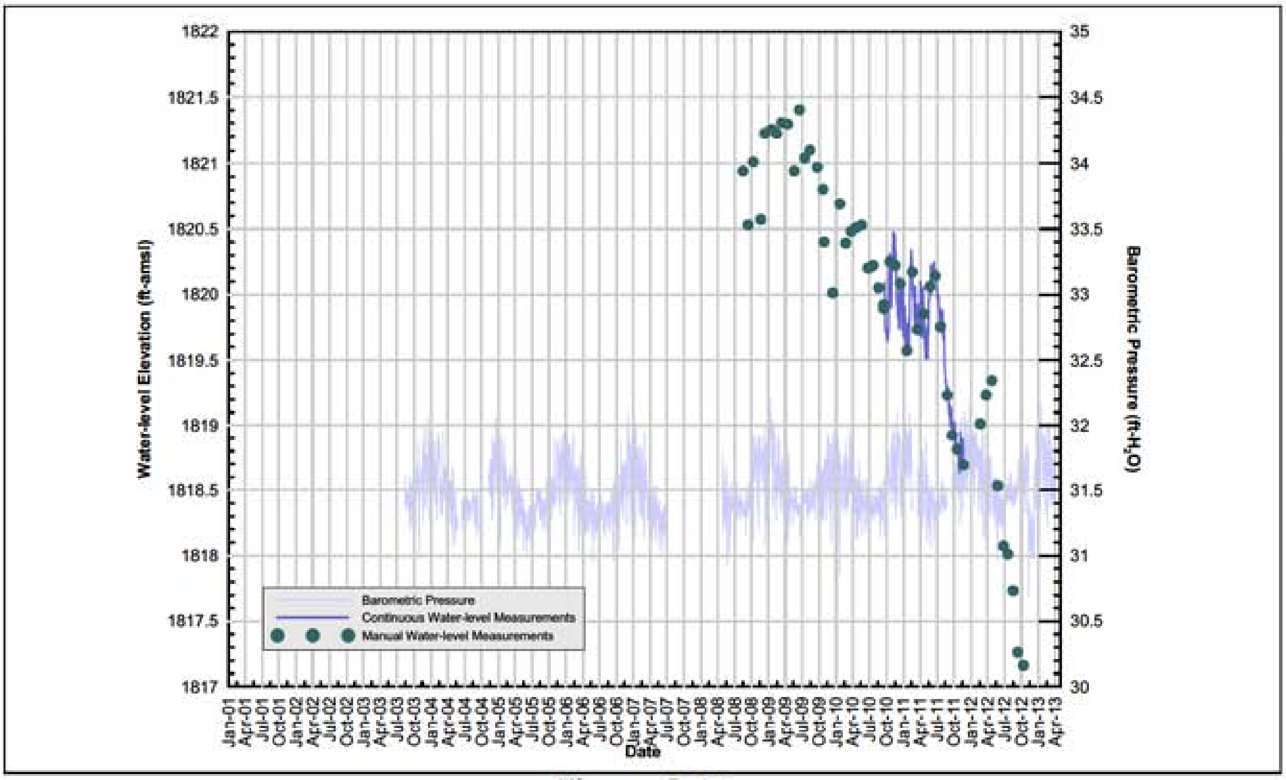

Figure C-12
CSI-1 (Carbonate - Basin 210: Coyote Spring Valley)

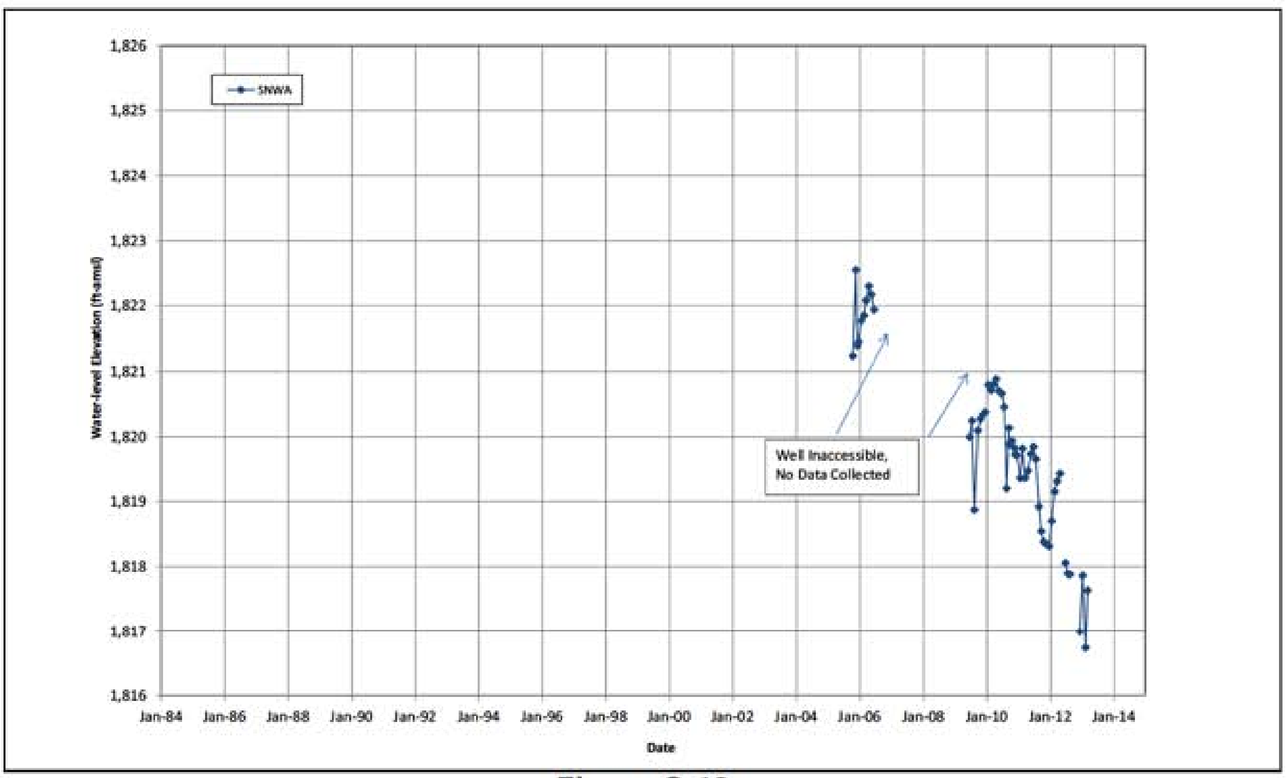

Figure C-13
CSI-2 (Carbonate - Basin 210: Coyote Spring Valley)

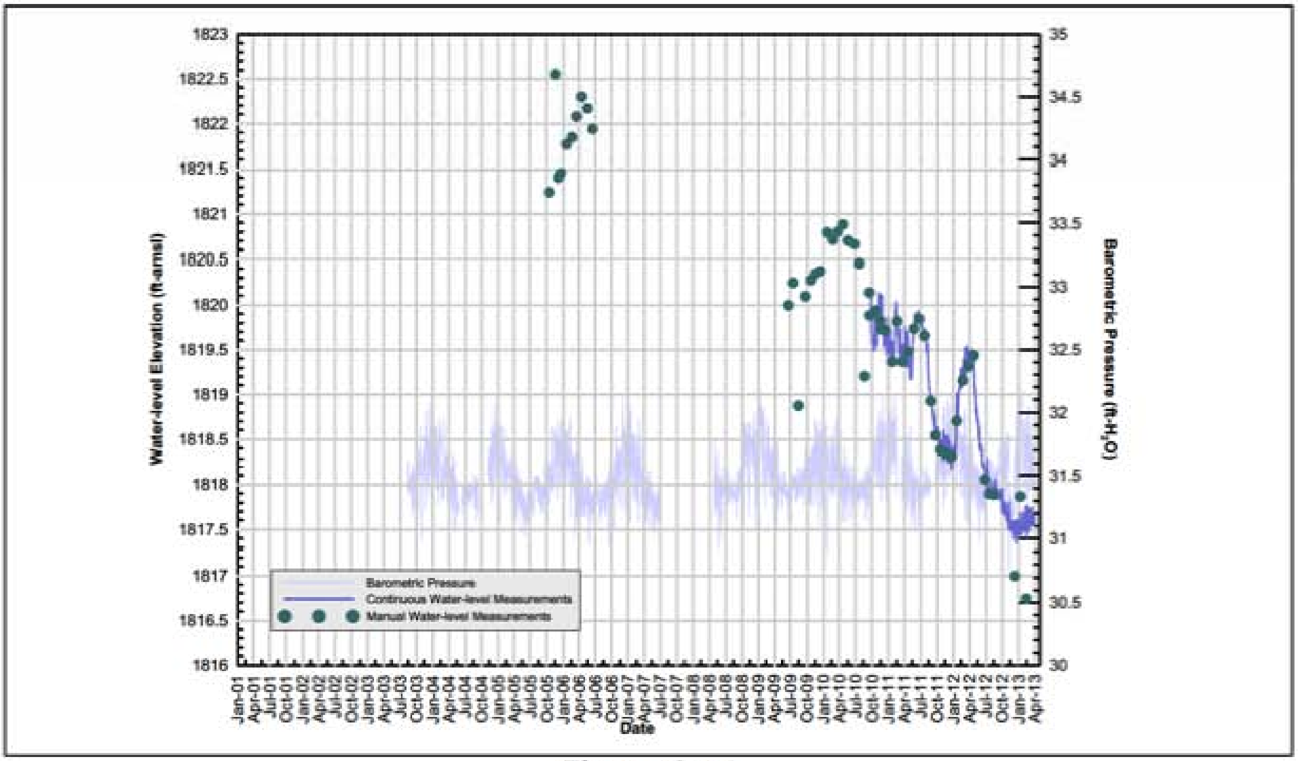

Figure C-14
CSI-2 (Carbonate - Basin 210: Coyote Spring Valley)

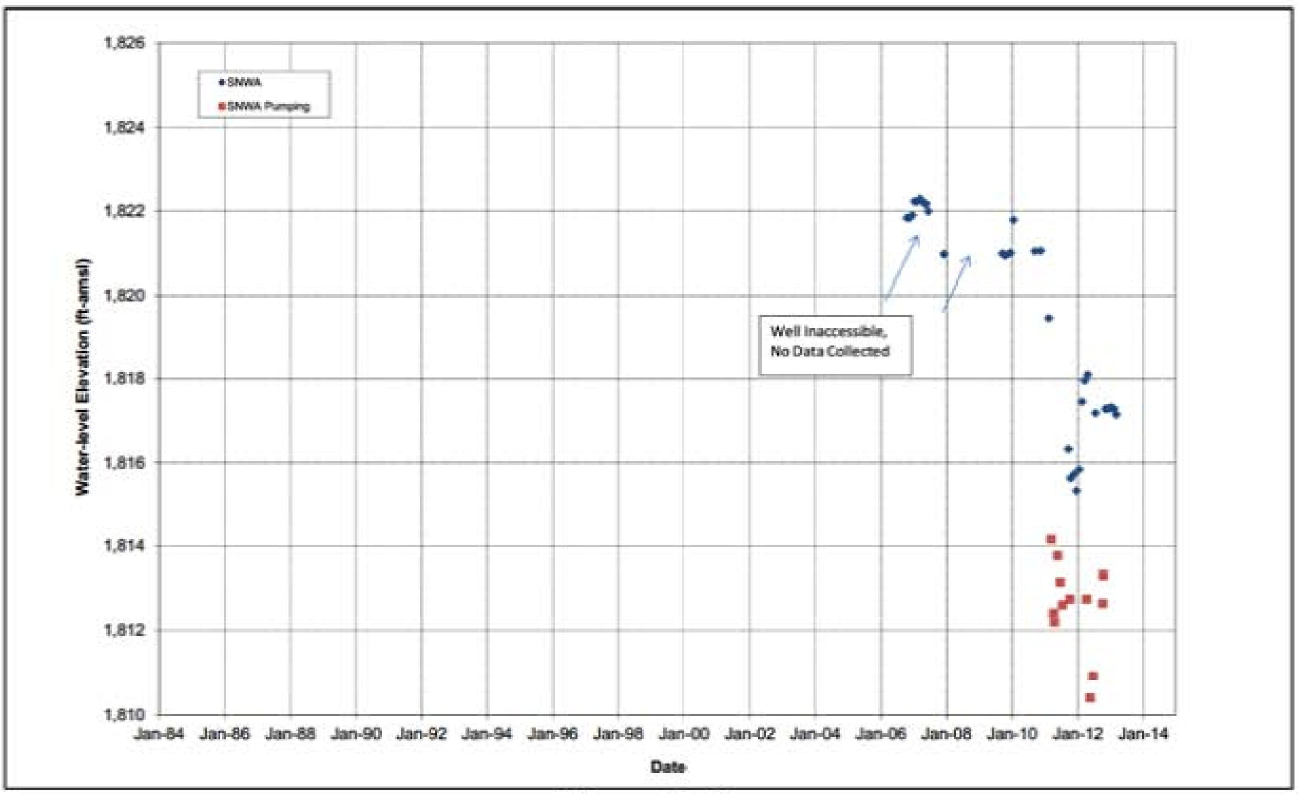

Figure C-15
CSI-3 (Carbonate - Basin 210: Coyote Spring Valley)

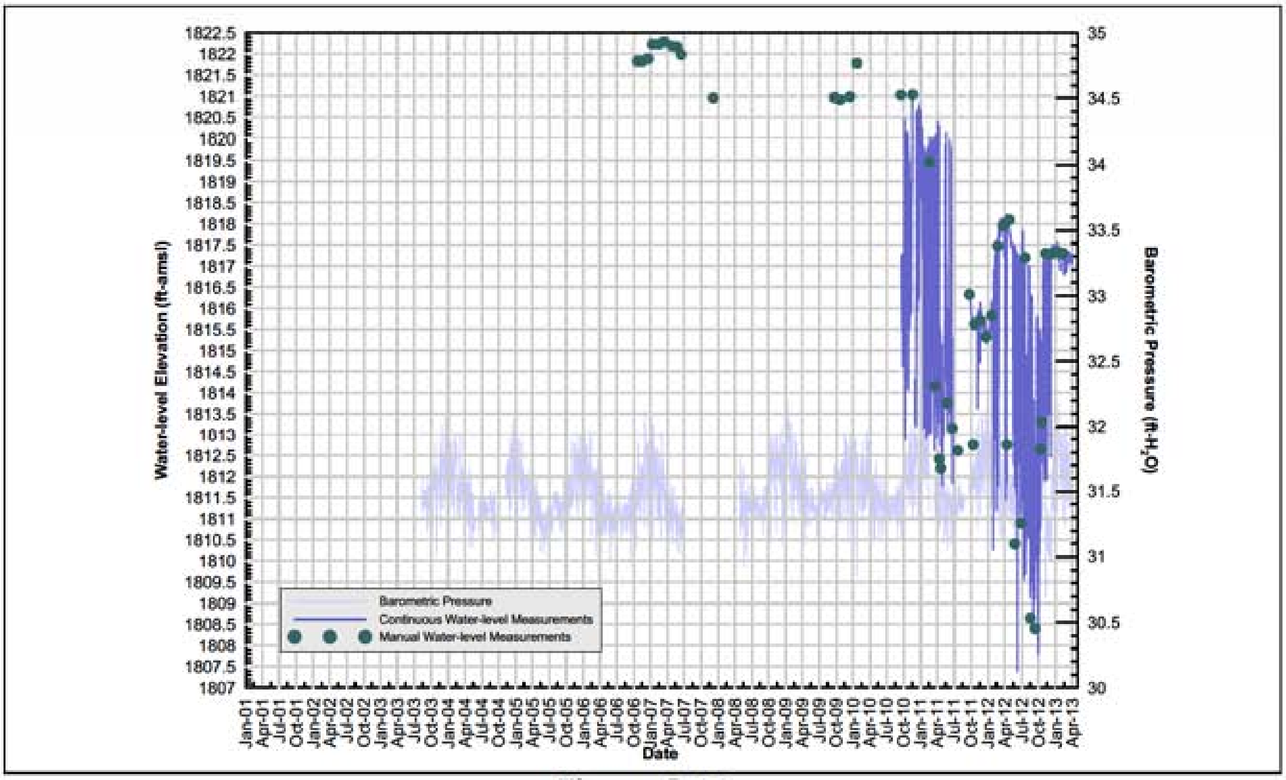

Figure C-16
CSI-3 (Carbonate - Basin 210: Coyote Spring Valley)

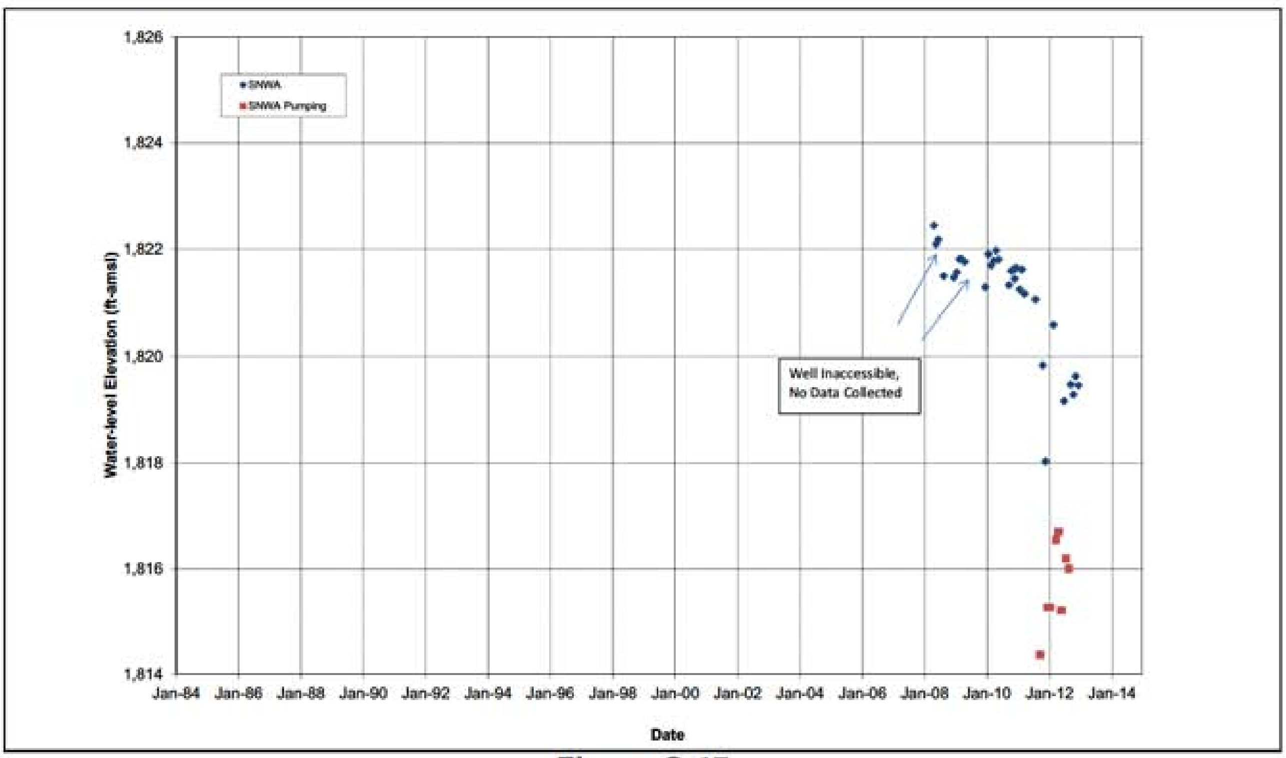

Figure C-17
CSI-4 (Carbonate - Basin 210: Coyote Spring Valley)

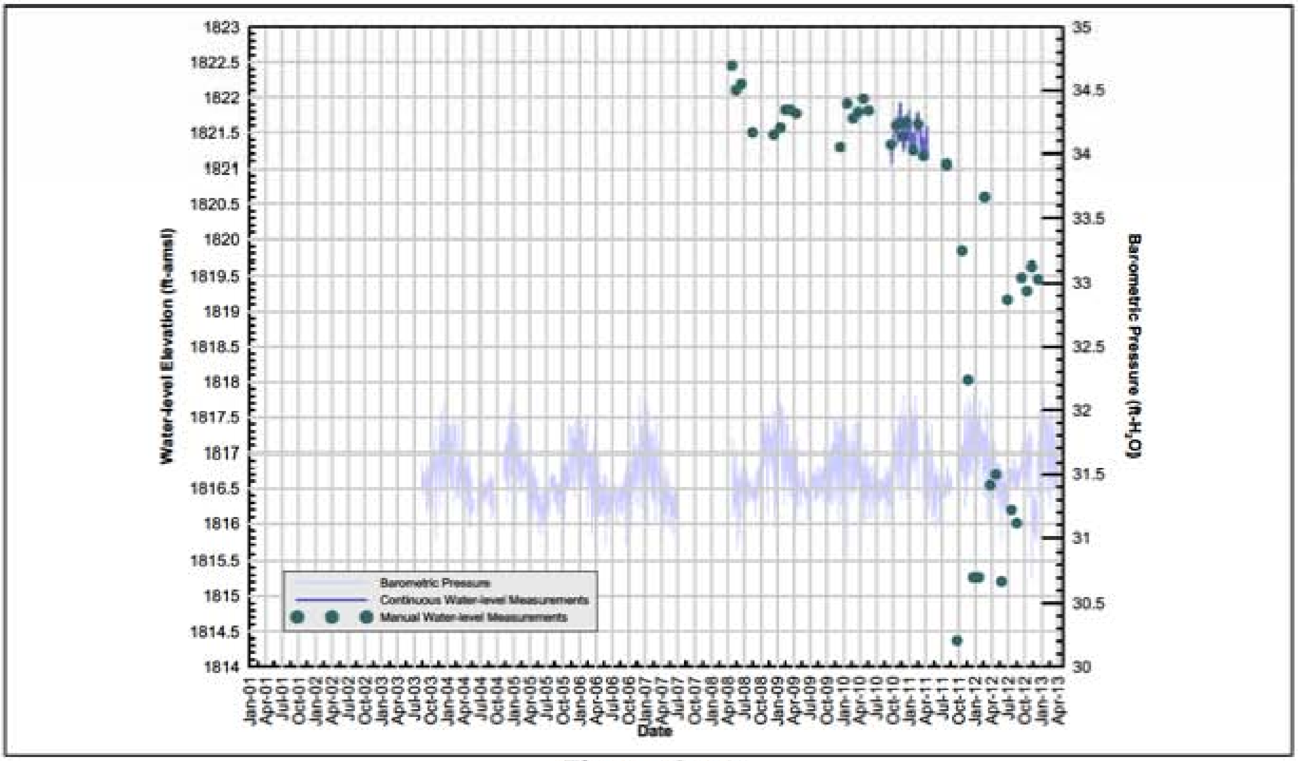

Figure C-18
CSI-4 (Carbonate - Basin 210: Coyote Spring Valley)

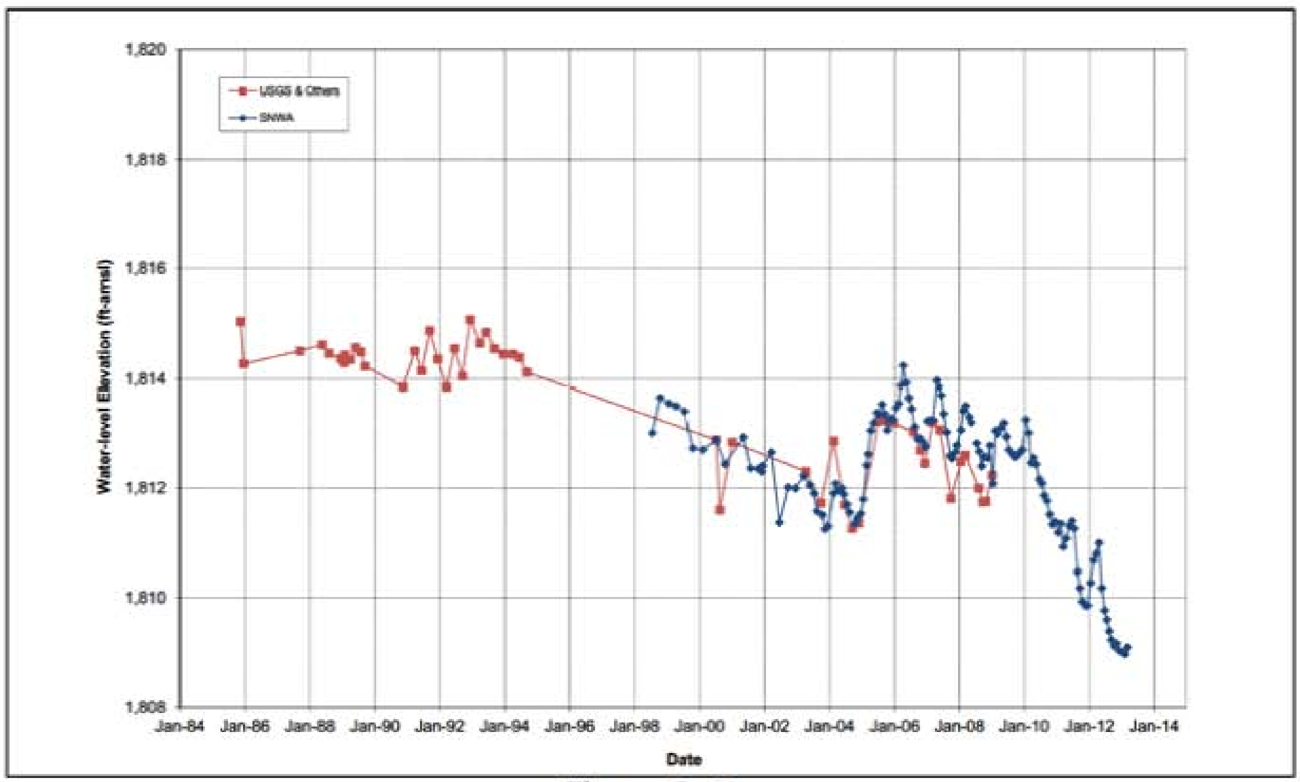

Figure C-19
CSV-1 (Alluvial - Basin 219: Muddy River Springs Area)

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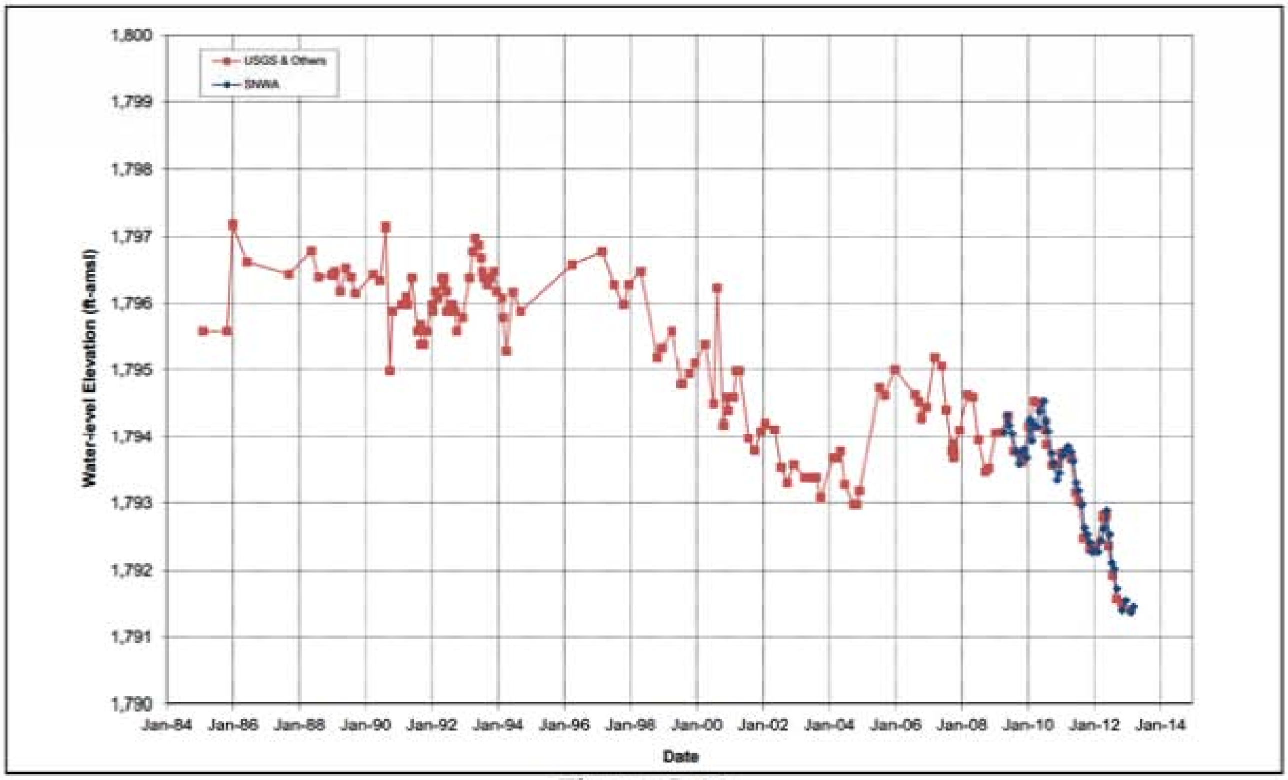

Figure C-20
CSV-2 (Carbonate - Basin 219: Muddy River Springs Area)

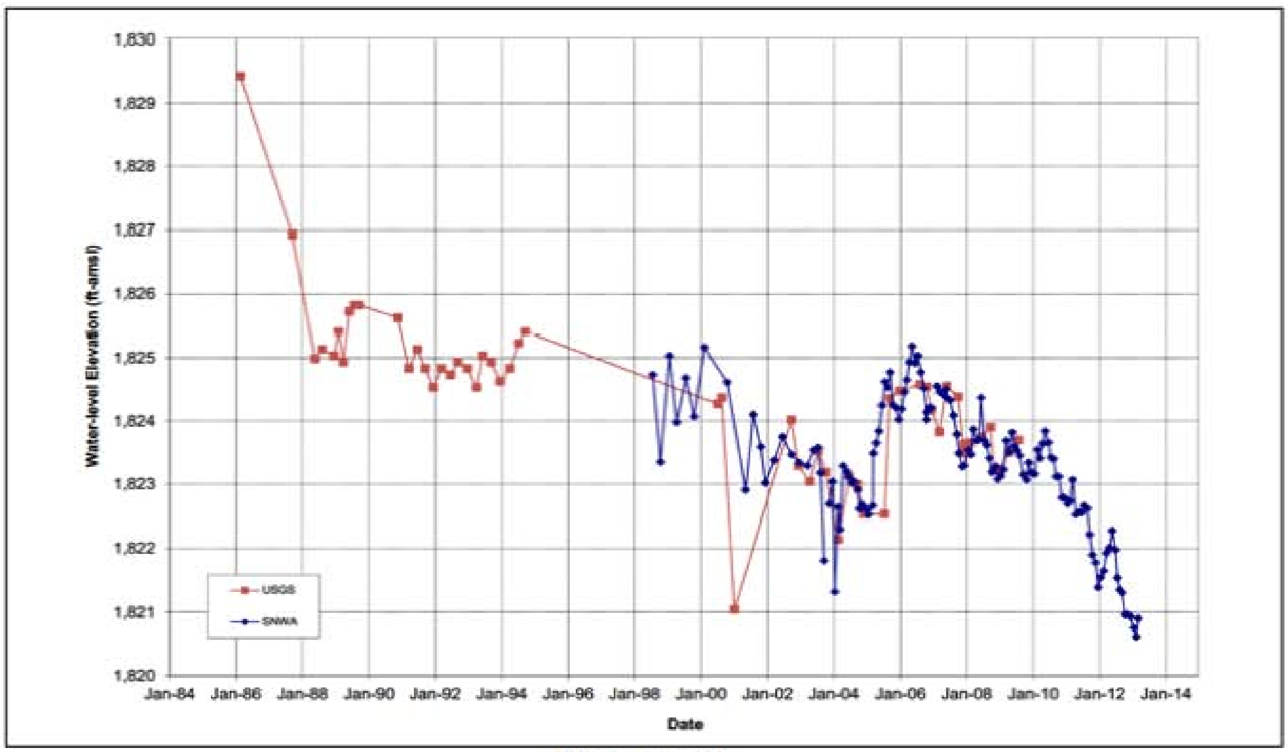

Figure C-21
CSV-3 (Alluvial - Basin 210: Coyote Spring Valley)

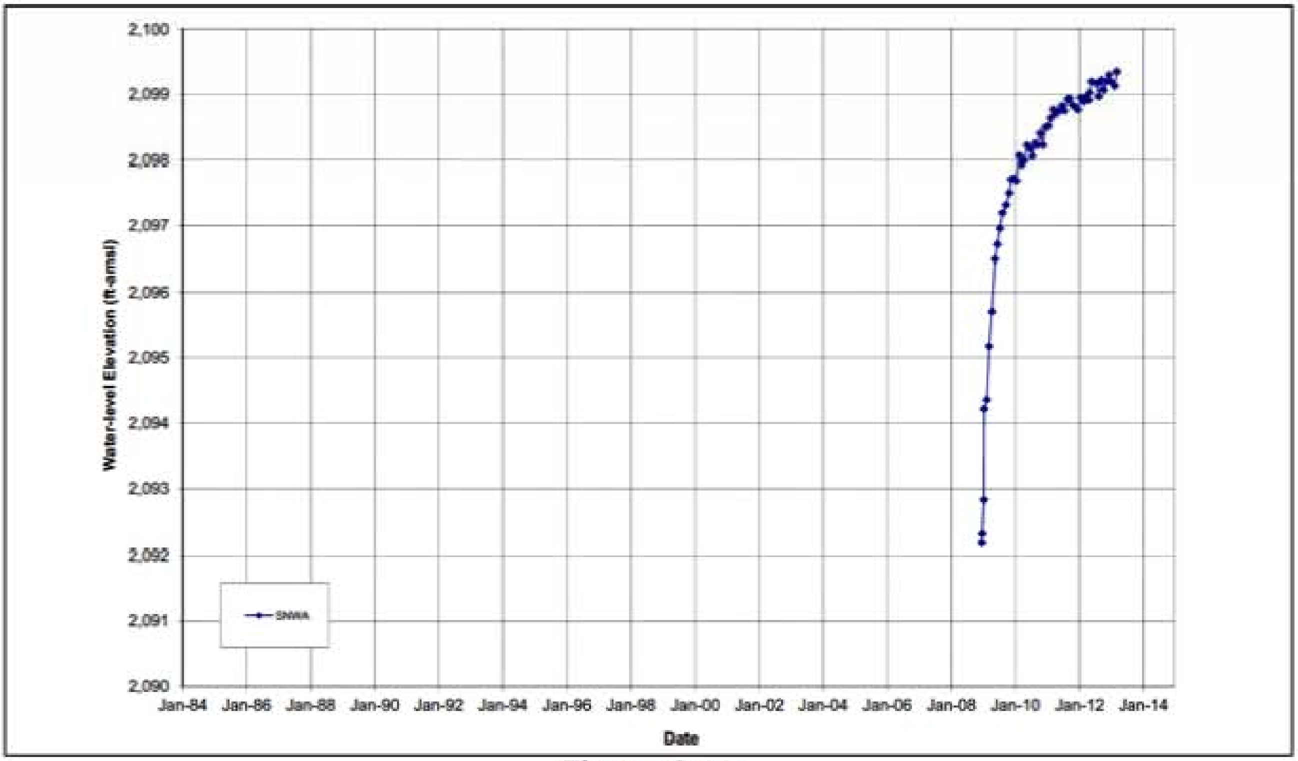

Figure C-22
CSV3009M (Alluvial - Basin 210: Coyote Spring Valley)

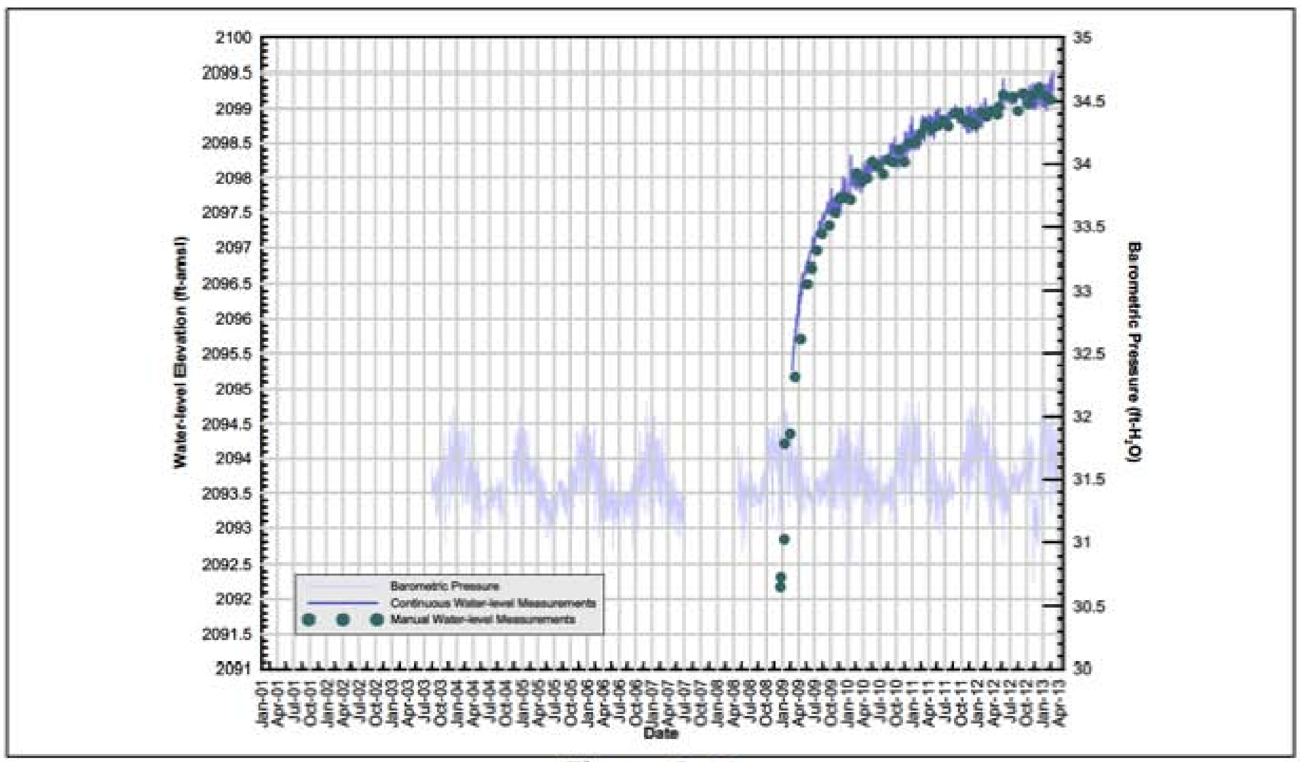

Figure C-23
CSV3009M (Alluvial - Basin 210: Coyote Spring Valley)

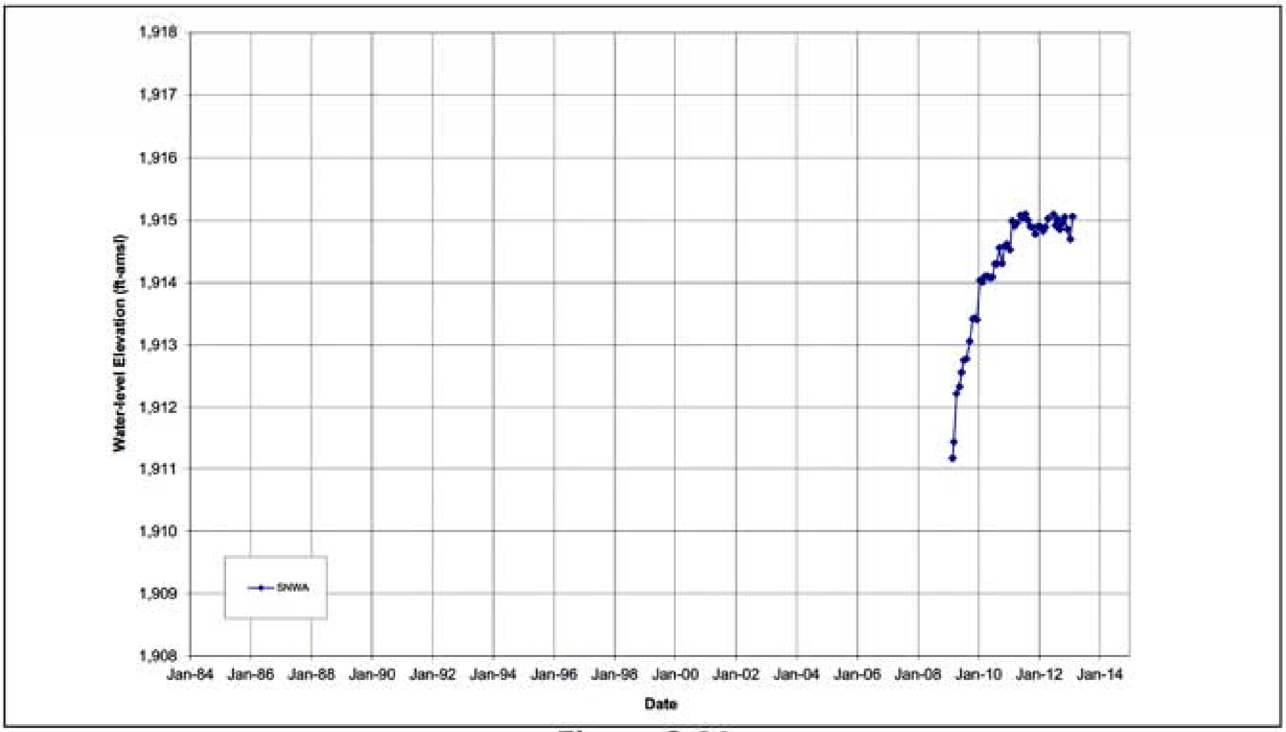

Figure C-24
CSV3011M (Alluvial - Basin 210: Coyote Spring Valley)

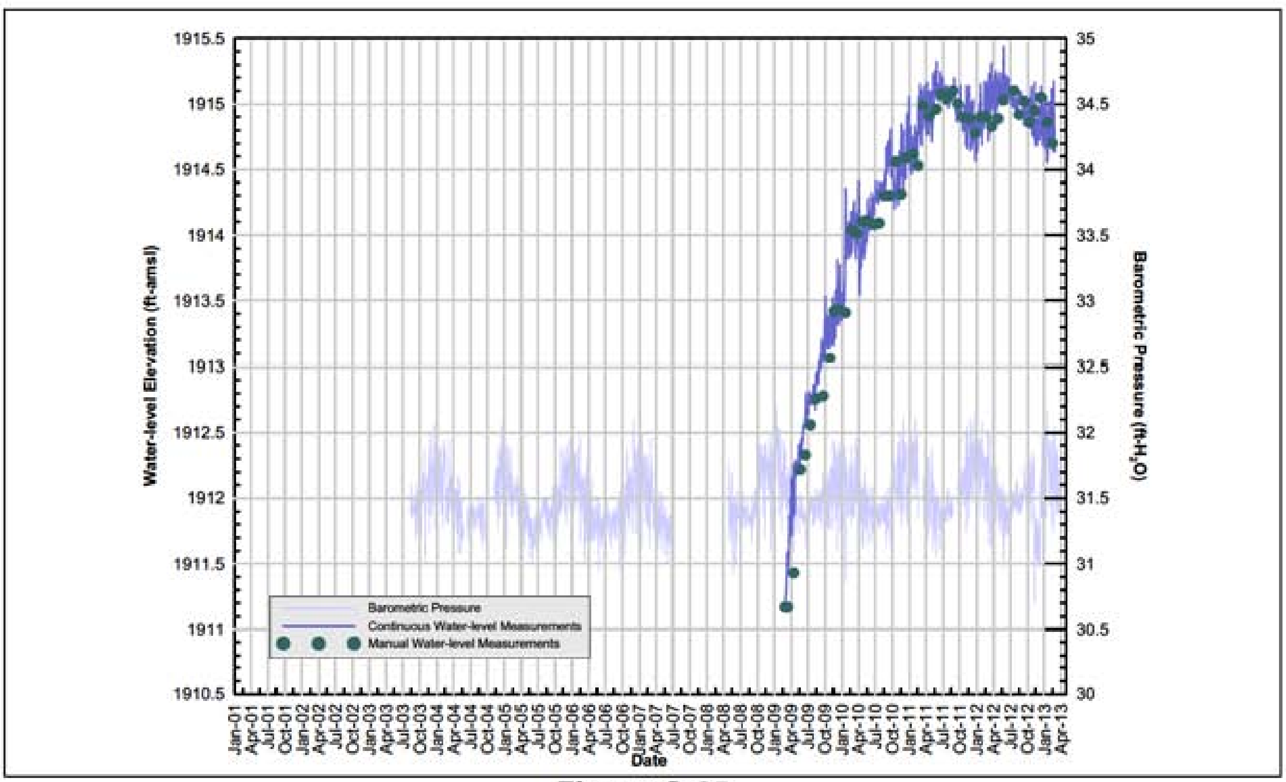

Figure C-25
CSV3011M (Alluvial - Basin 210: Coyote Spring Valley)

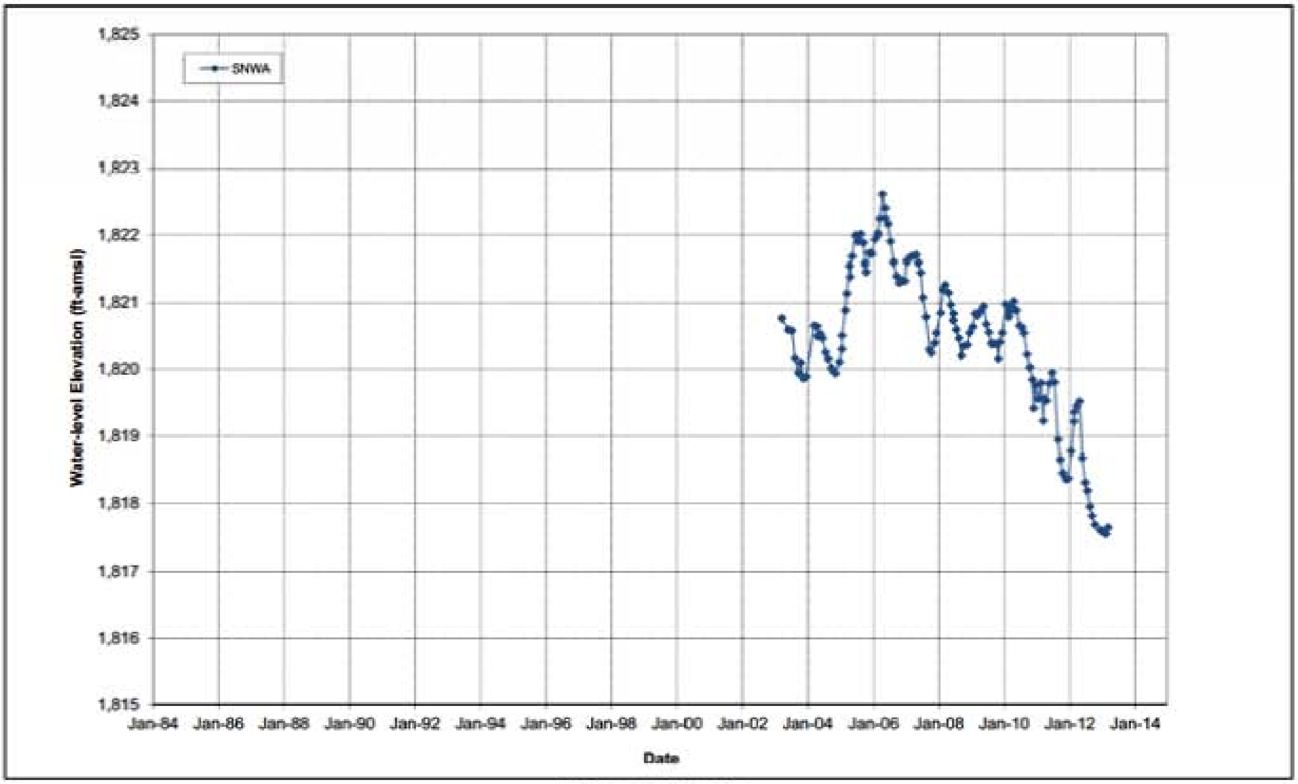

Figure C-26
CSVM-1 (Carbonate - Basin 210: Coyote Spring Valley)

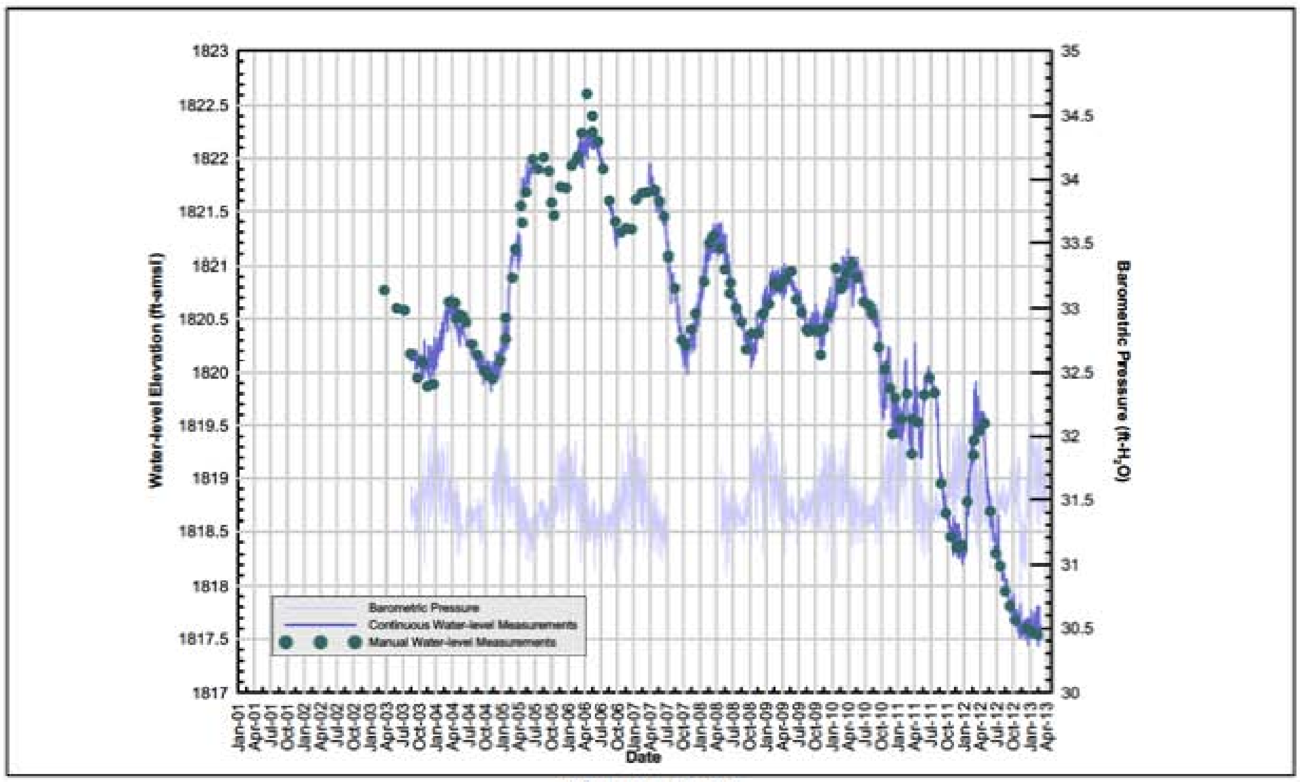

Figure C-27
CSVM-1 (Carbonate - Basin 210: Coyote Spring Valley)

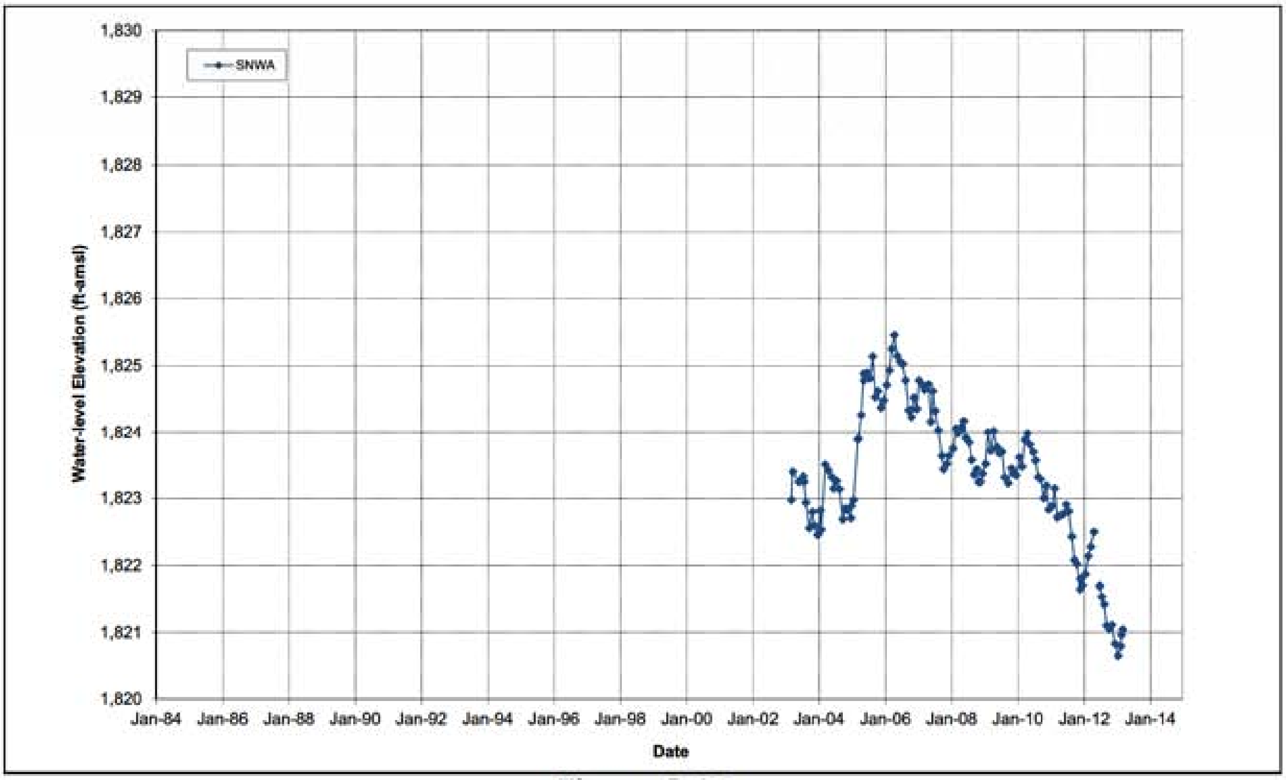

Figure C-28
CSVM-2 (Carbonate - Basin 210: Coyote Spring Valley)

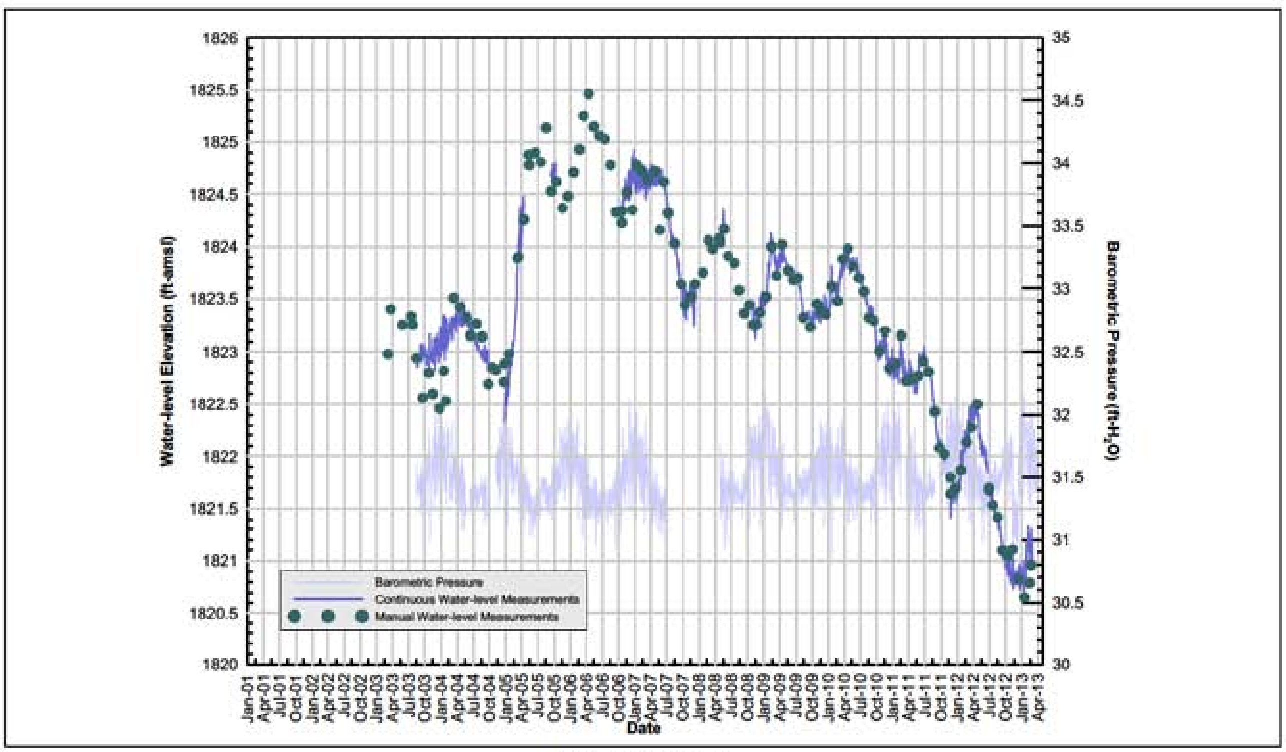

Figure C-29
CSVM-2 (Carbonate - Basin 210: Coyote Spring Valley)

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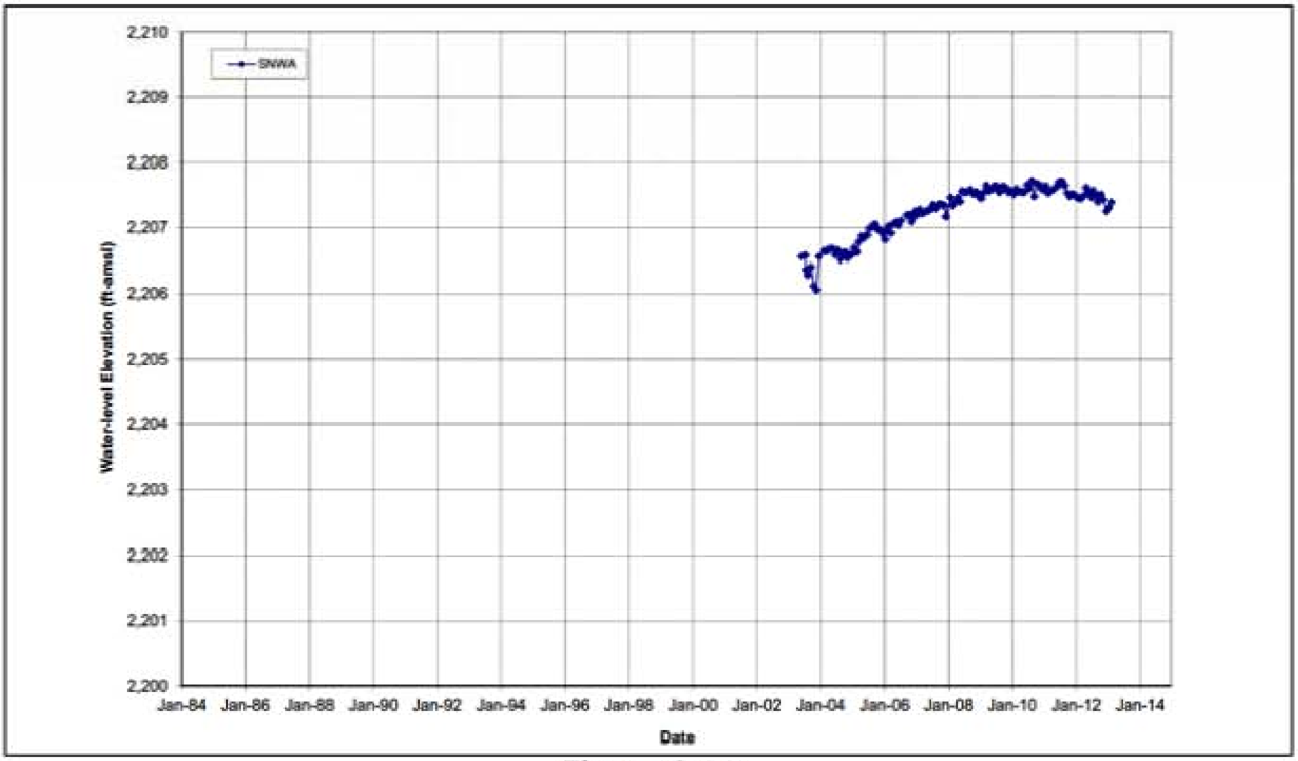

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CSVM-3 (Carbonate - Basin 210: Coyote Spring Valley)

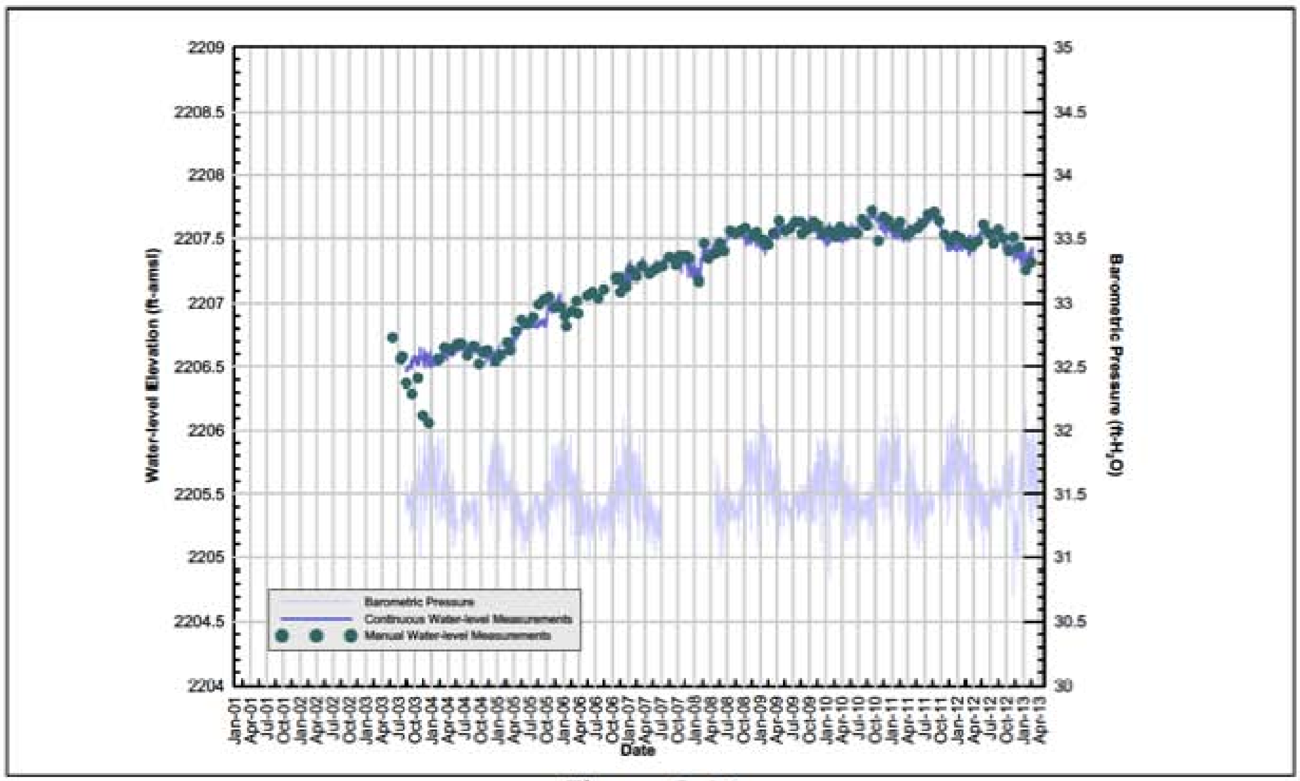


Figure C-31
CSVM-3 (Carbonate - Basin 210: Coyote Spring Valley)

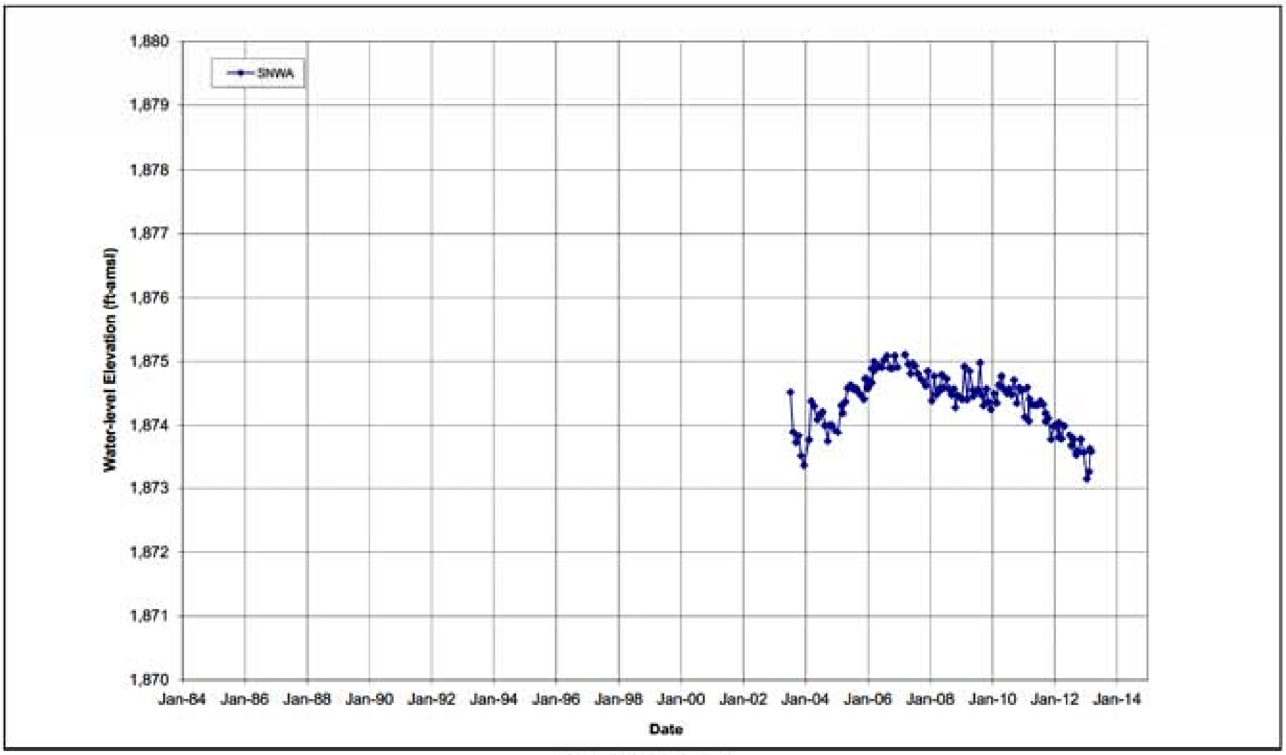
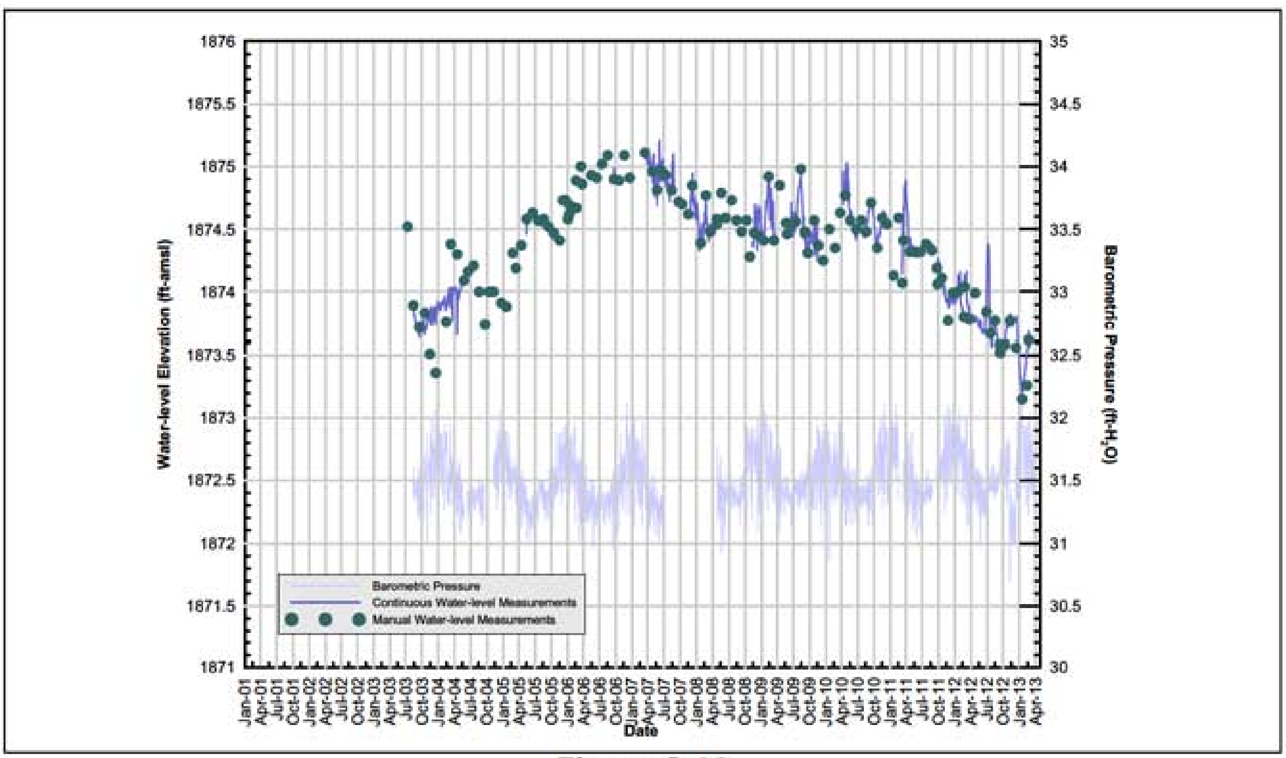


Figure C-32
CSVM-4 (Carbonate - Basin 210: Coyote Spring Valley)



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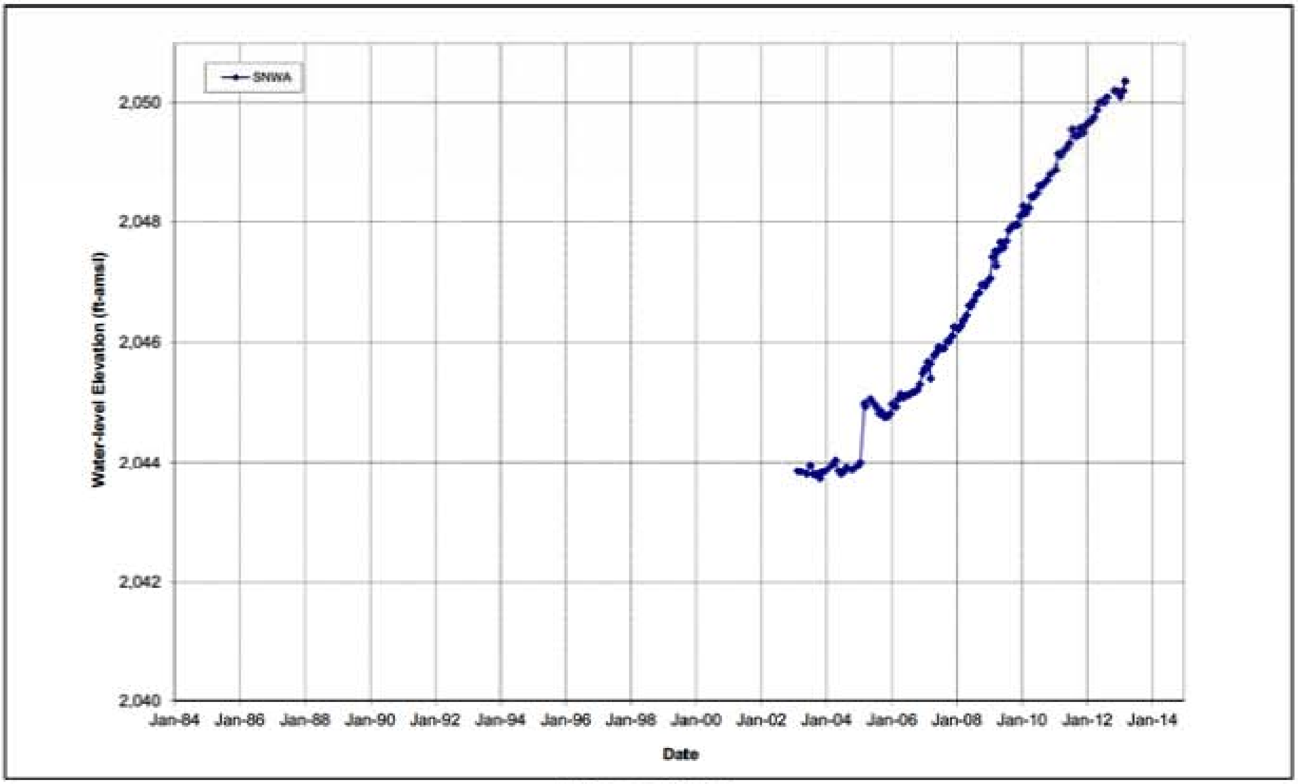

Figure C-34
CSVM-5 (Carbonate - Basin 210: Coyote Spring Valley)

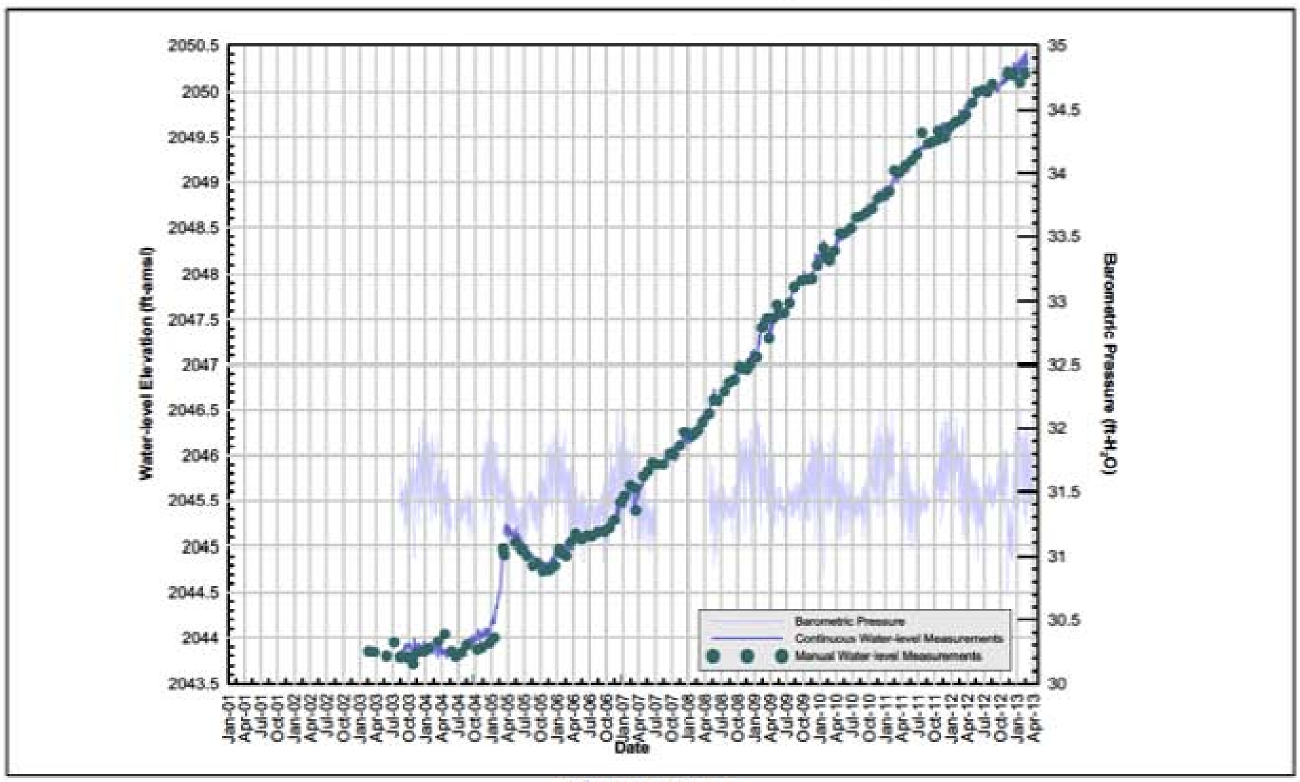

Figure C-35
CSVM-5 (Carbonate - Basin 210: Coyote Spring Valley)

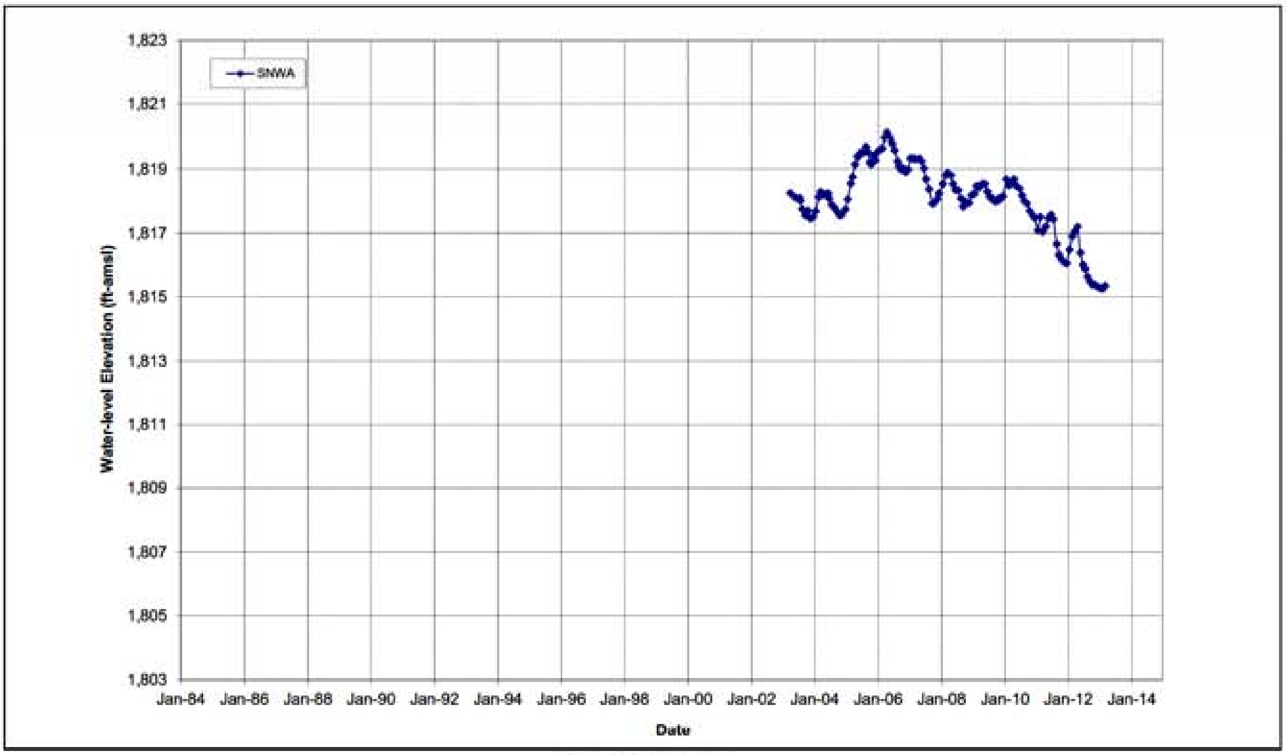

Figure C-36
CSVM-6 (Carbonate - Basin 210: Coyote Spring Valley)

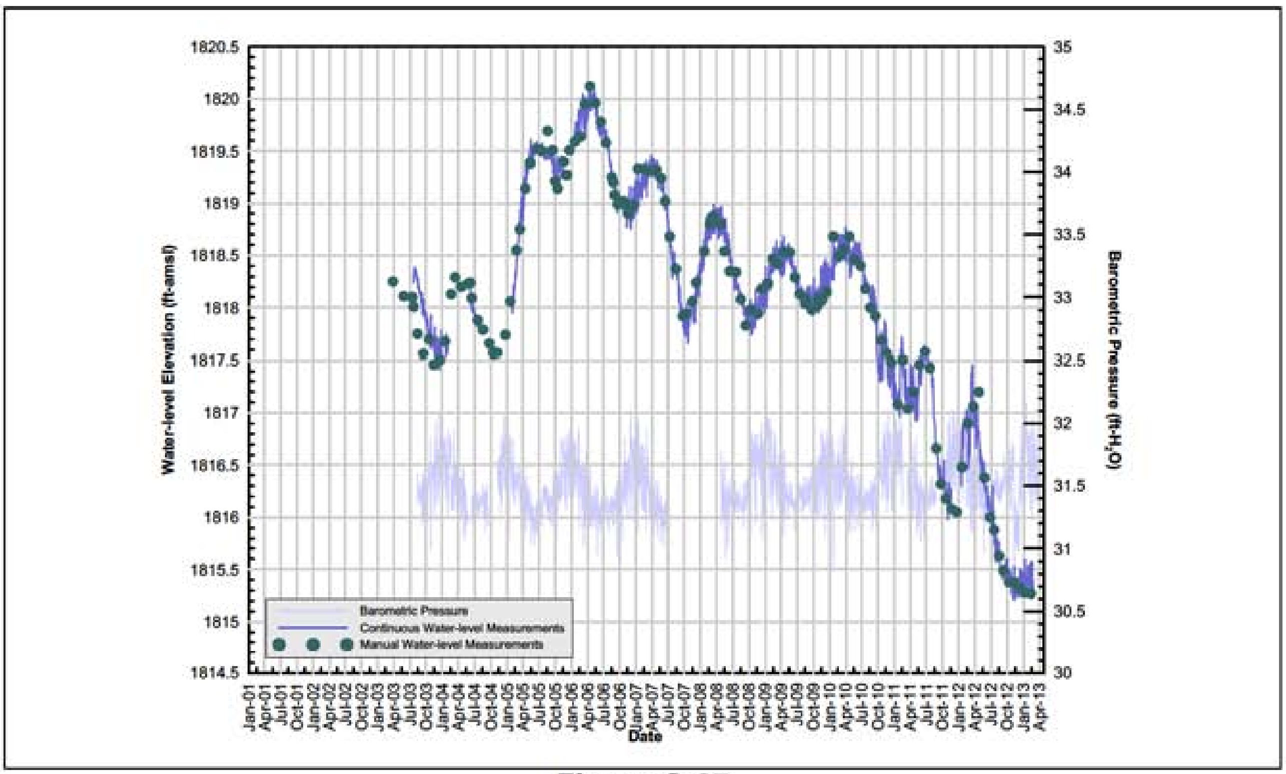

Figure C-37
CSVM-6 (Carbonate - Basin 210: Coyote Spring Valley)

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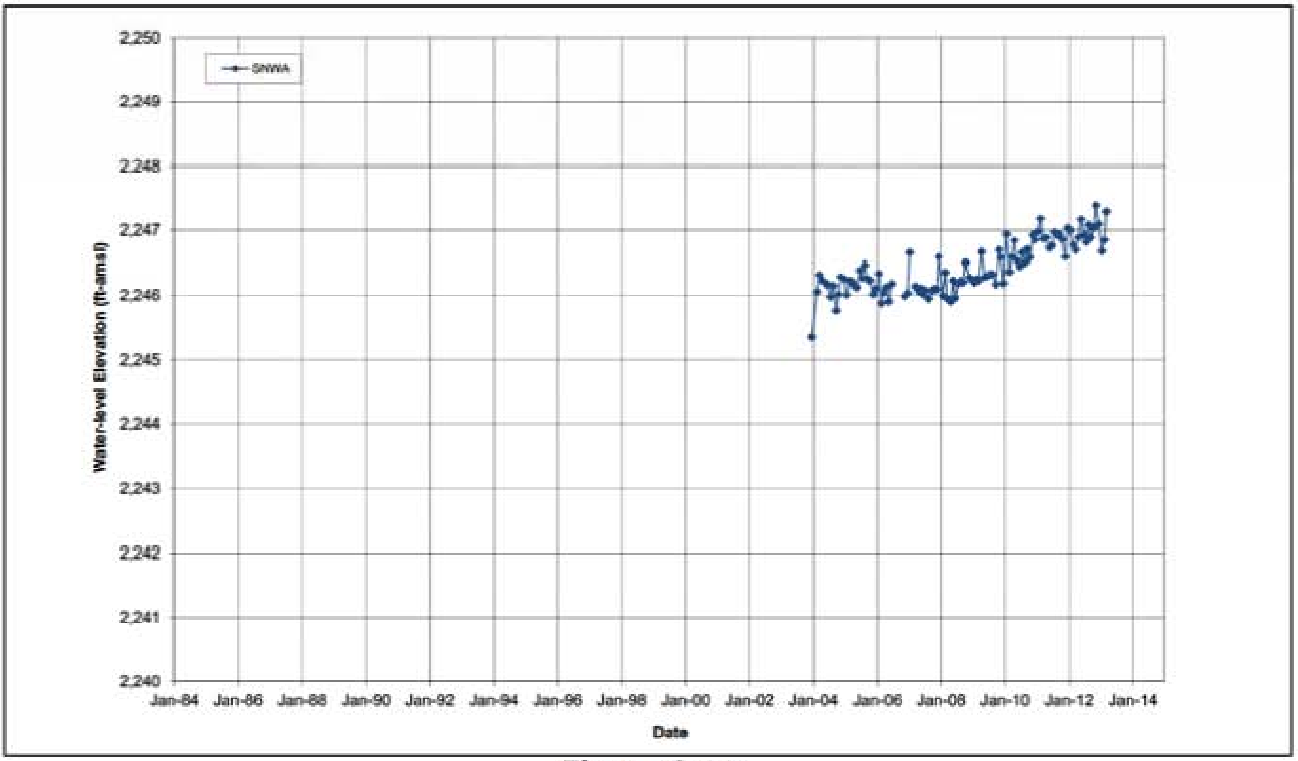

Figure C-38
CSVM-7 (Alluvial/Volcanic - Basin 210: Coyote Spring Valley)

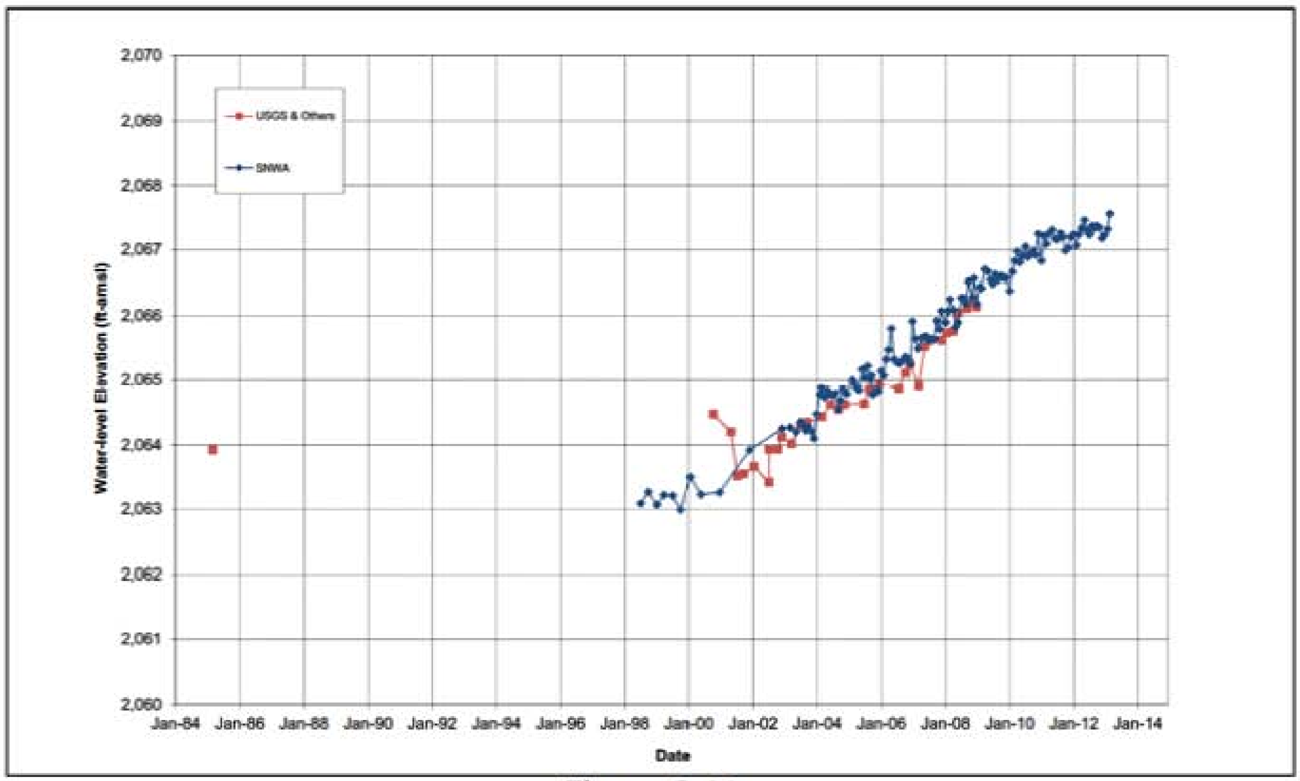

Figure C-39
DF-1 (Alluvial - Basin 210: Coyote Spring Valley)

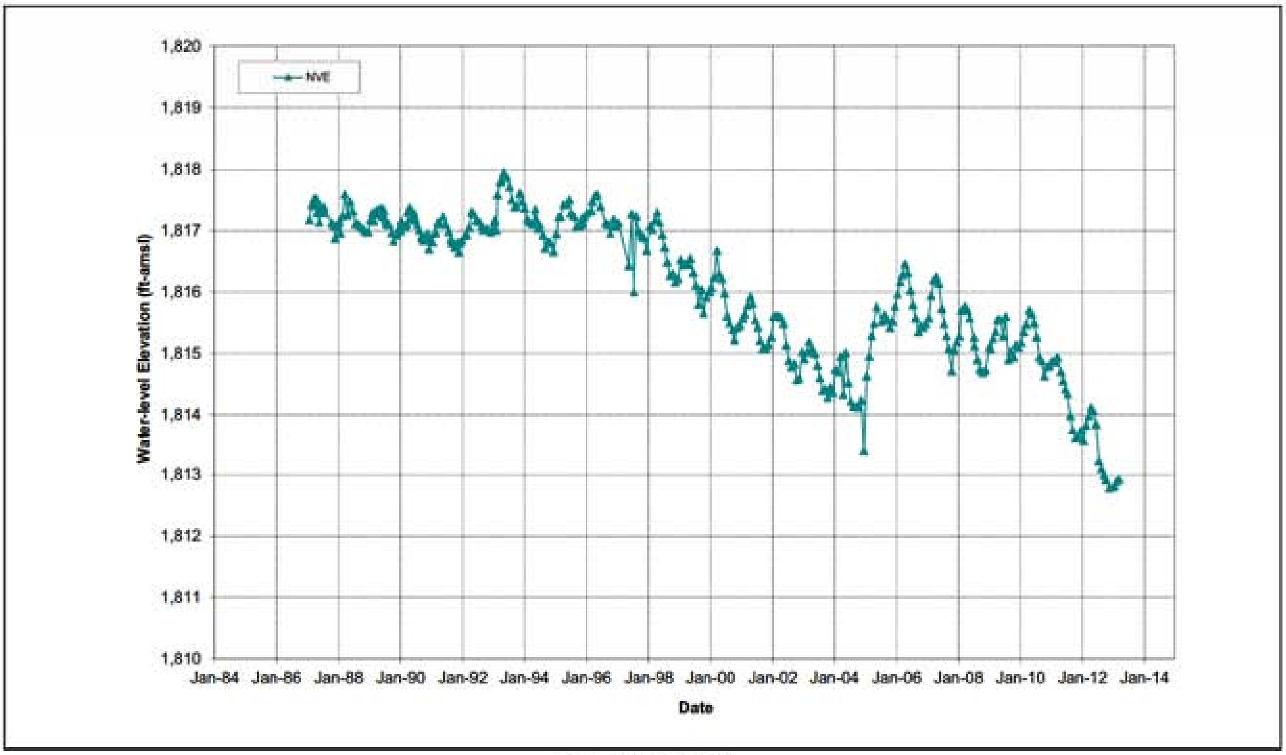

Figure C-40
EH-4 (Carbonate - Basin 219: Muddy River Springs Area)

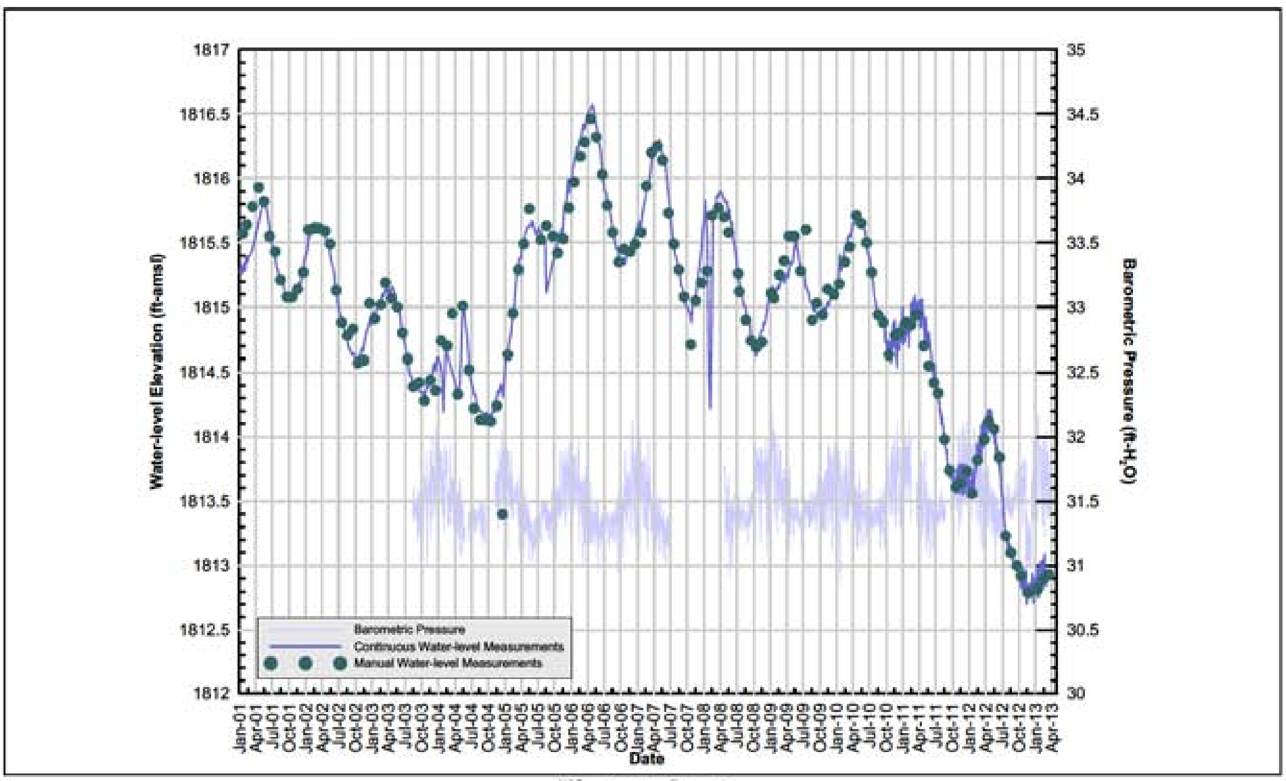

Figure C-41
EH-4 (Carbonate - Basin 219: Muddy River Springs Area)

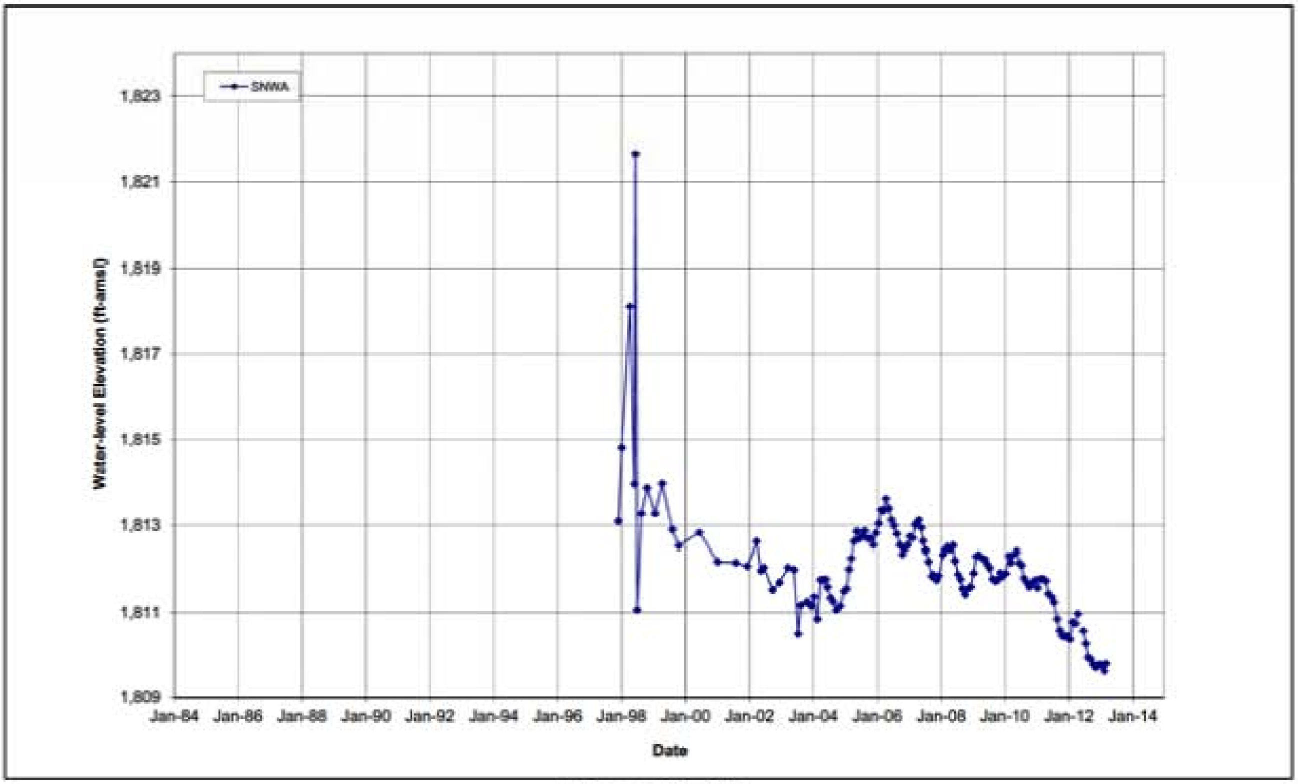

Figure C-42
GARNET (Alluvial - Basin 216: Garnet Valley)

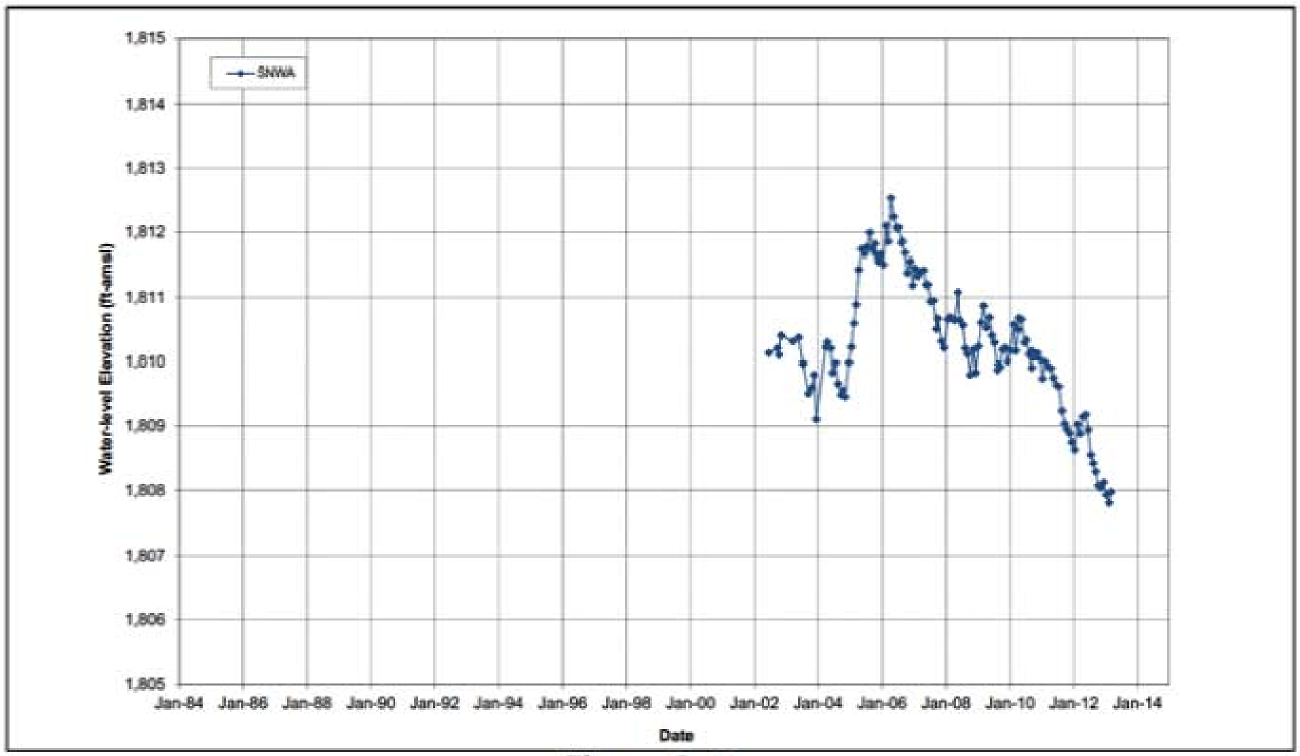

Figure C-43
GV-1 (Carbonate - Basin 216: Garnet Valley)

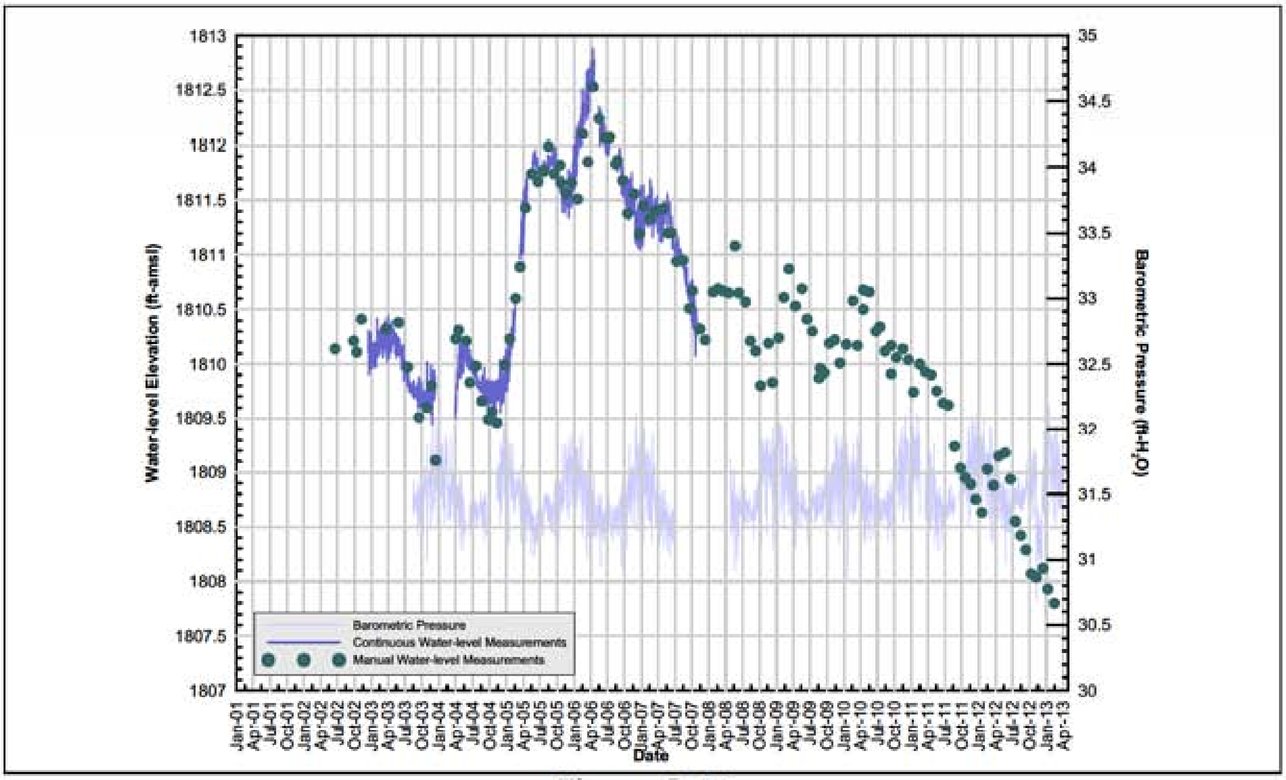

Figure C-44
GV-1 (Carbonate - Basin 216: Garnet Valley)

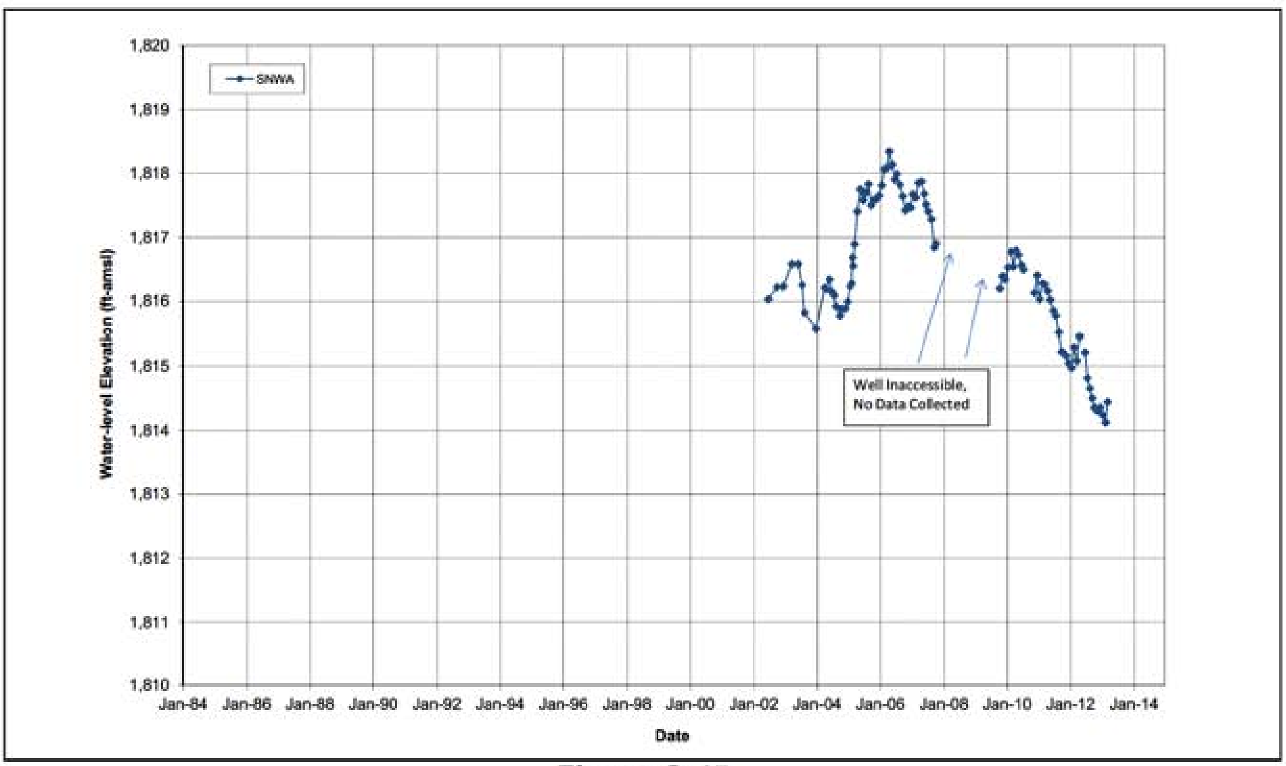

Figure C-45
GV-2 (Carbonate - Basin 216: Garnet Valley)

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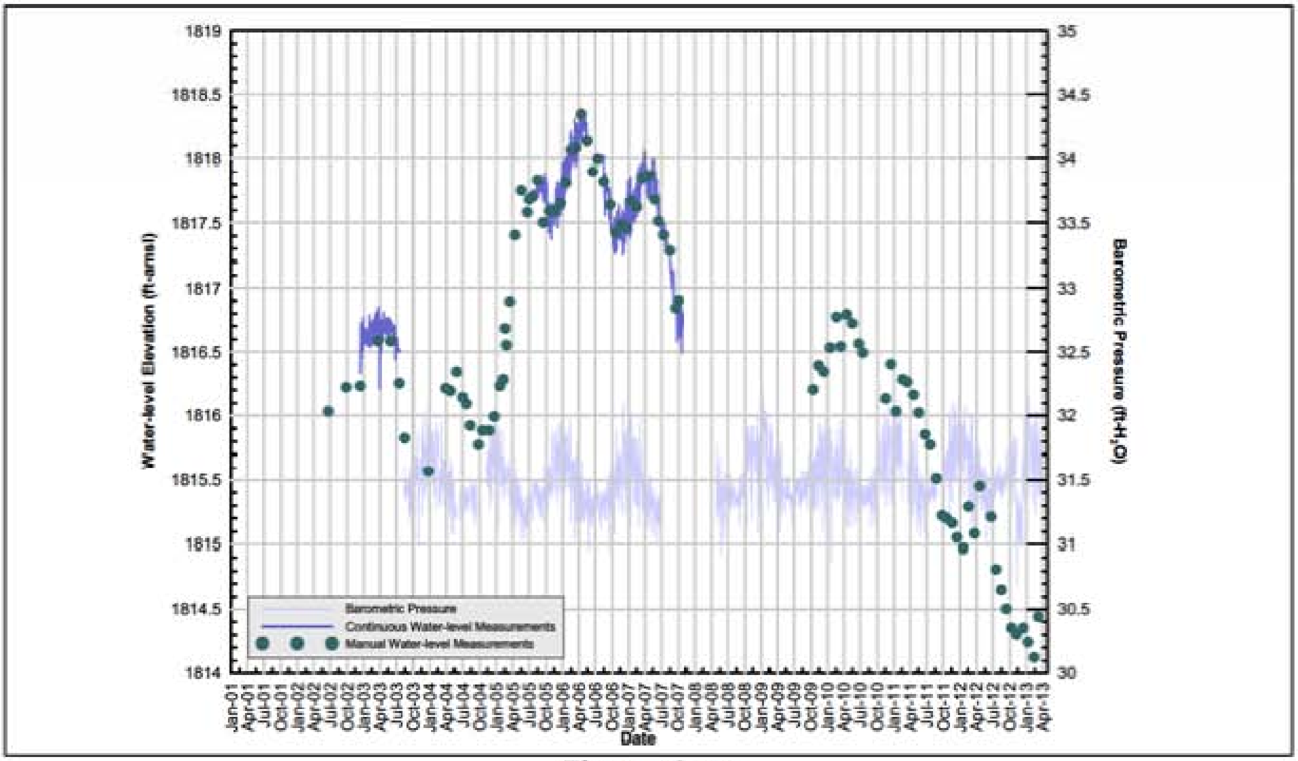

Figure C-46
GV-2 (Carbonate - Basin 216: Garnet Valley)

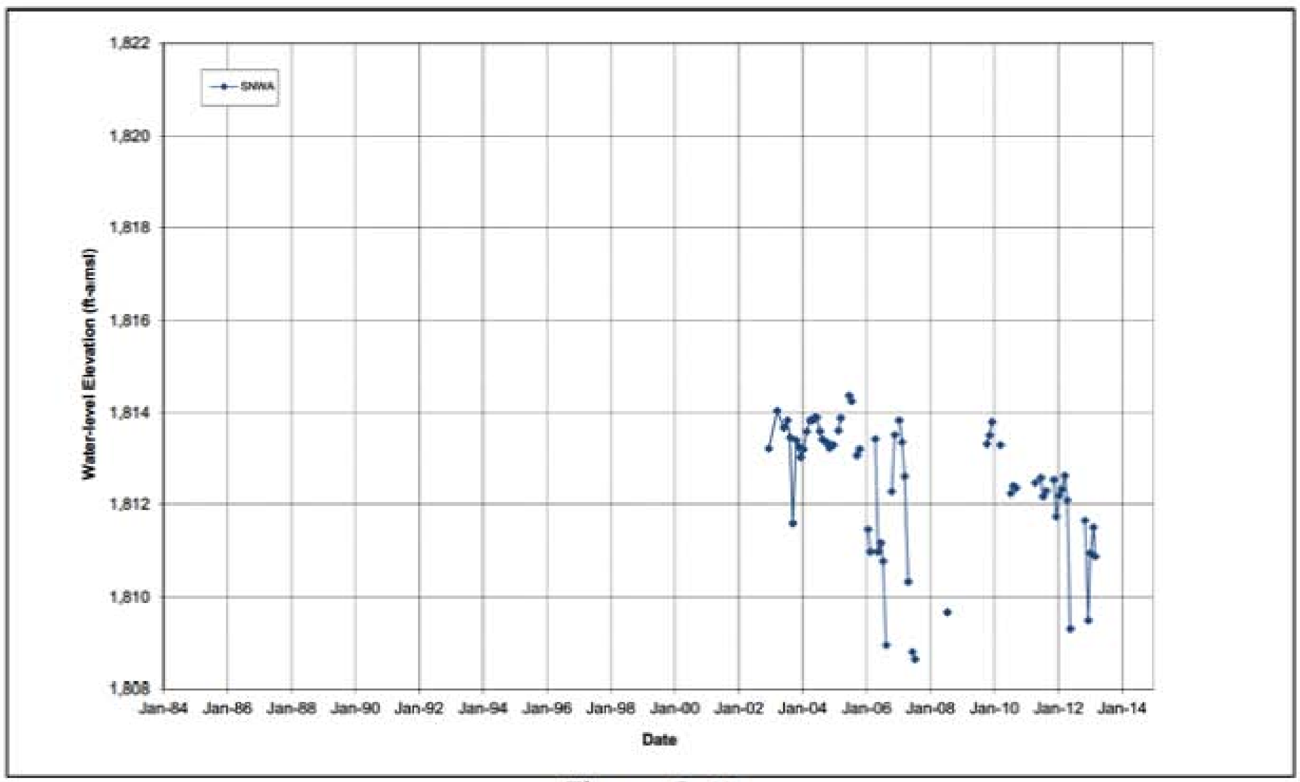

Figure C-47
GV-DUKE-WS1 (Carbonate - Basin 216: Garnet Valley)

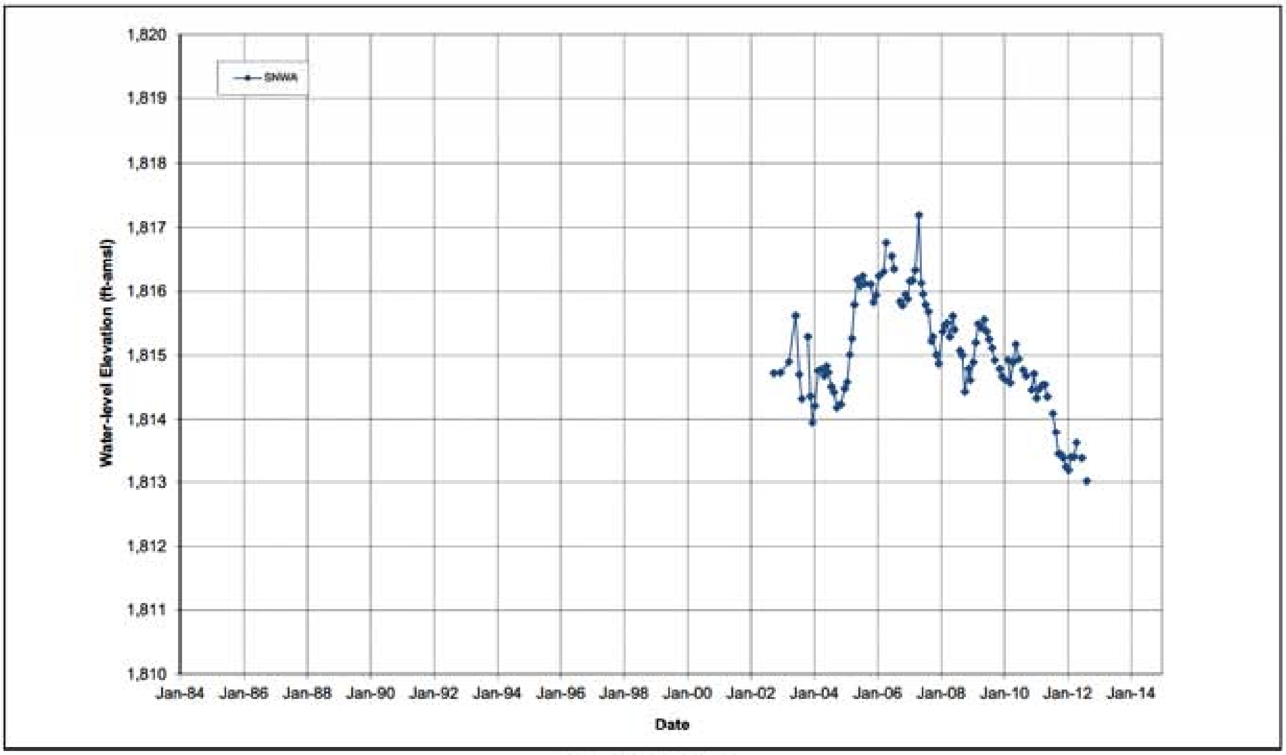

Figure C-48
GV-DUKE-WS2 (Carbonate - Basin 216: Garnet Valley)

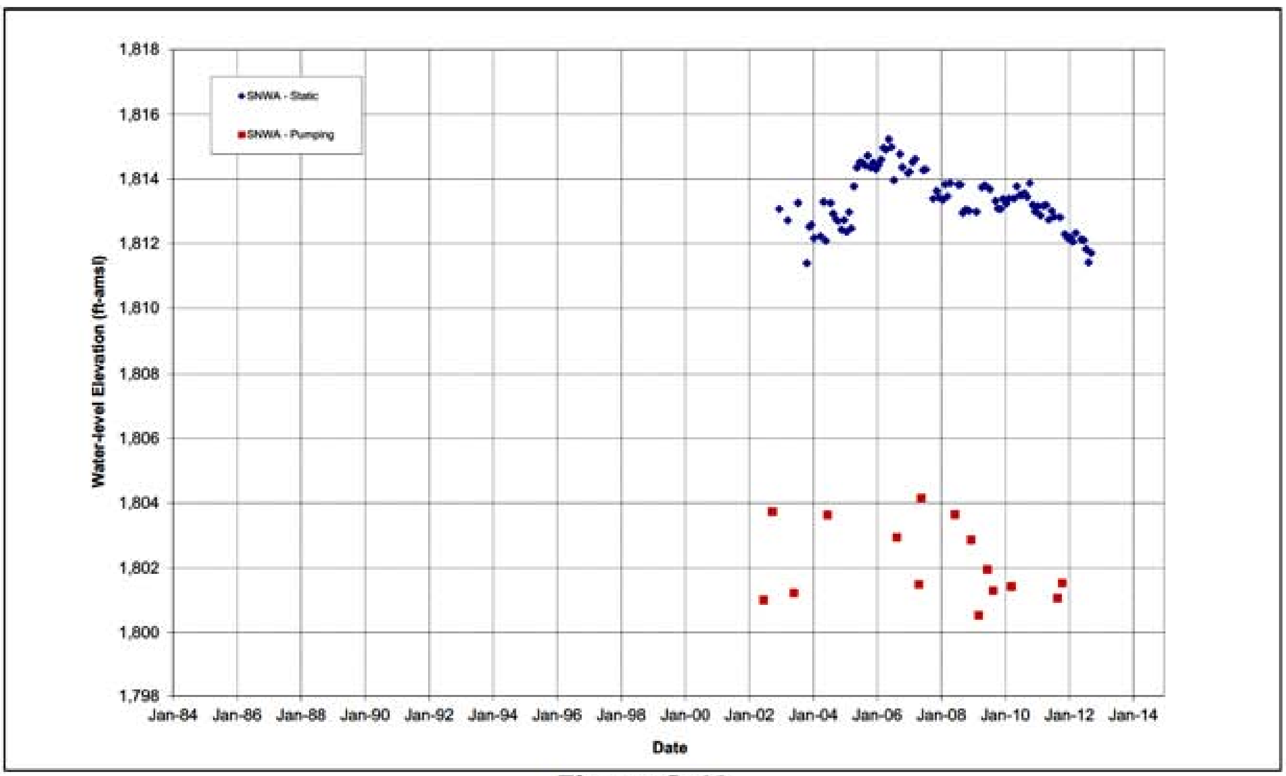

Figure C-49
GV-MIRANT1 (Carbonate - Basin 216: Garnet Valley)

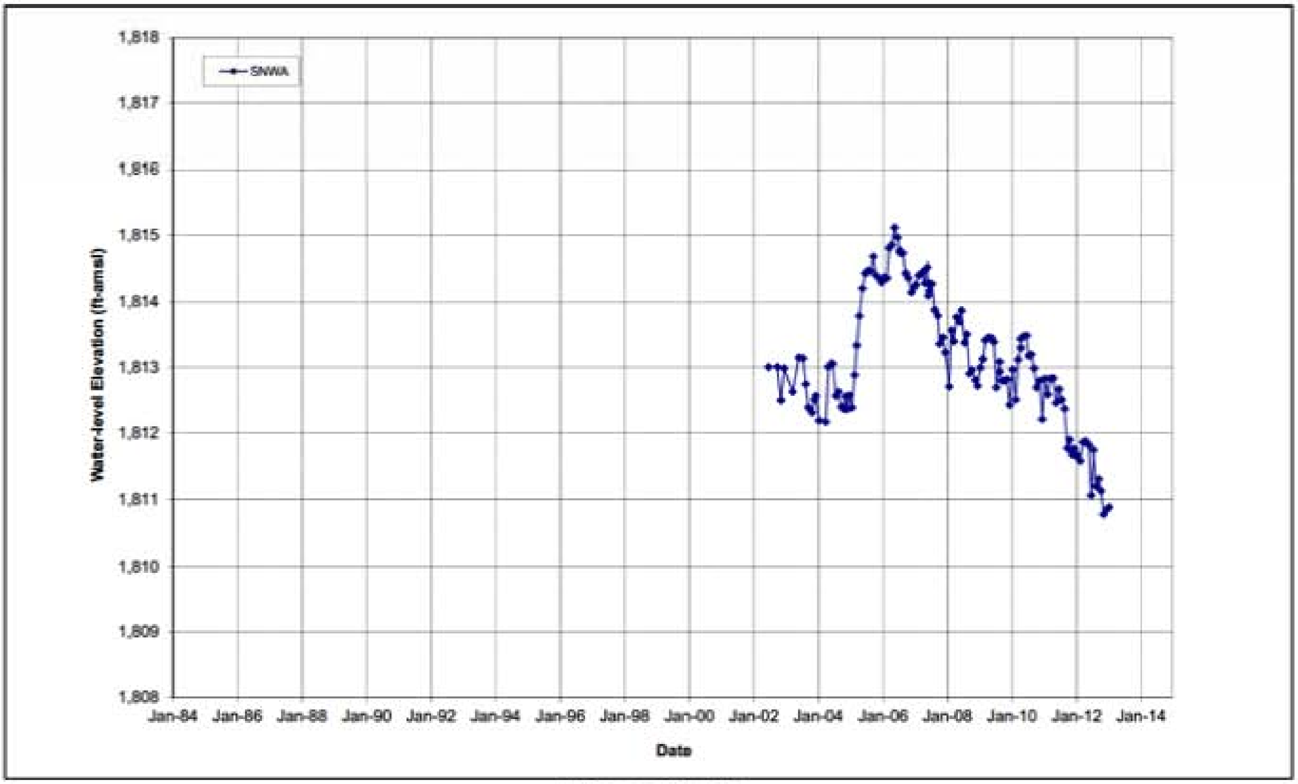

Figure C-50
GV-PW-MW1 (Carbonate - Basin 216: Garnet Valley)

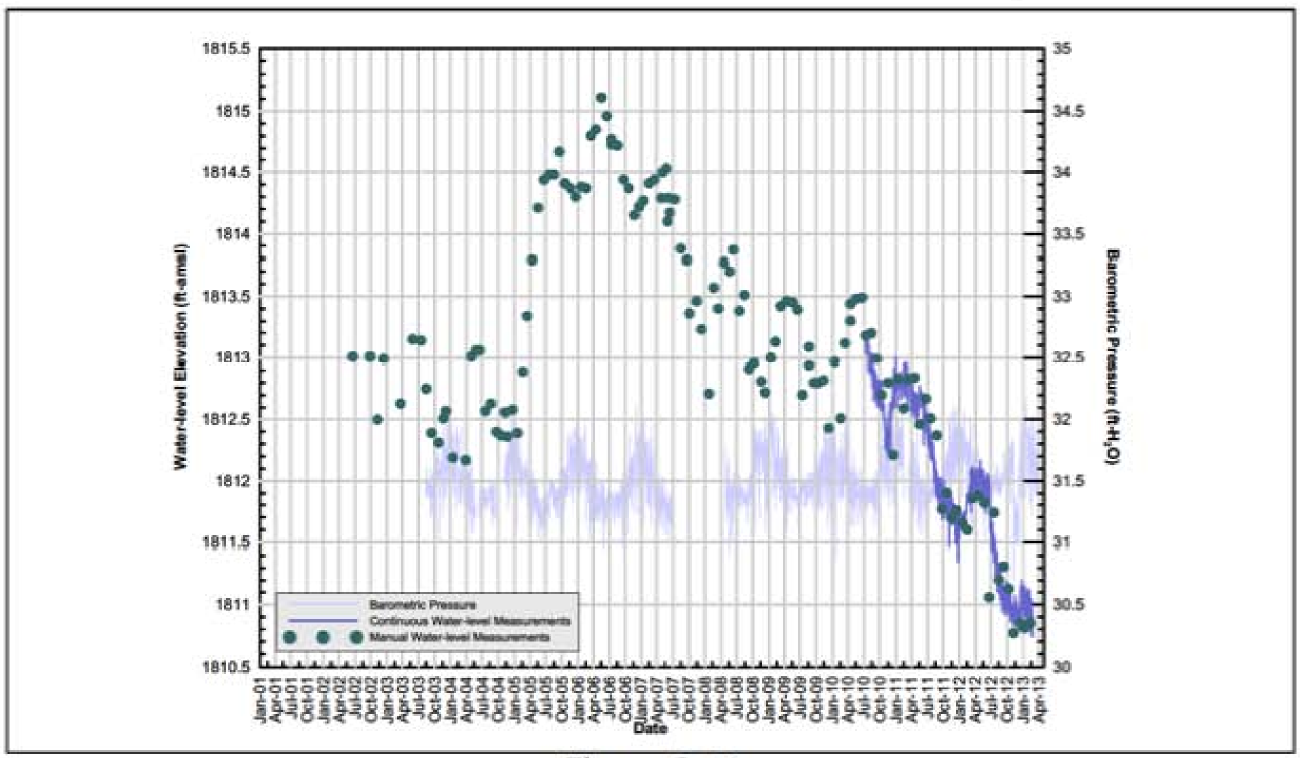

Figure C-51
GV-PW-MW1 (Carbonate - Basin 216: Garnet Valley)

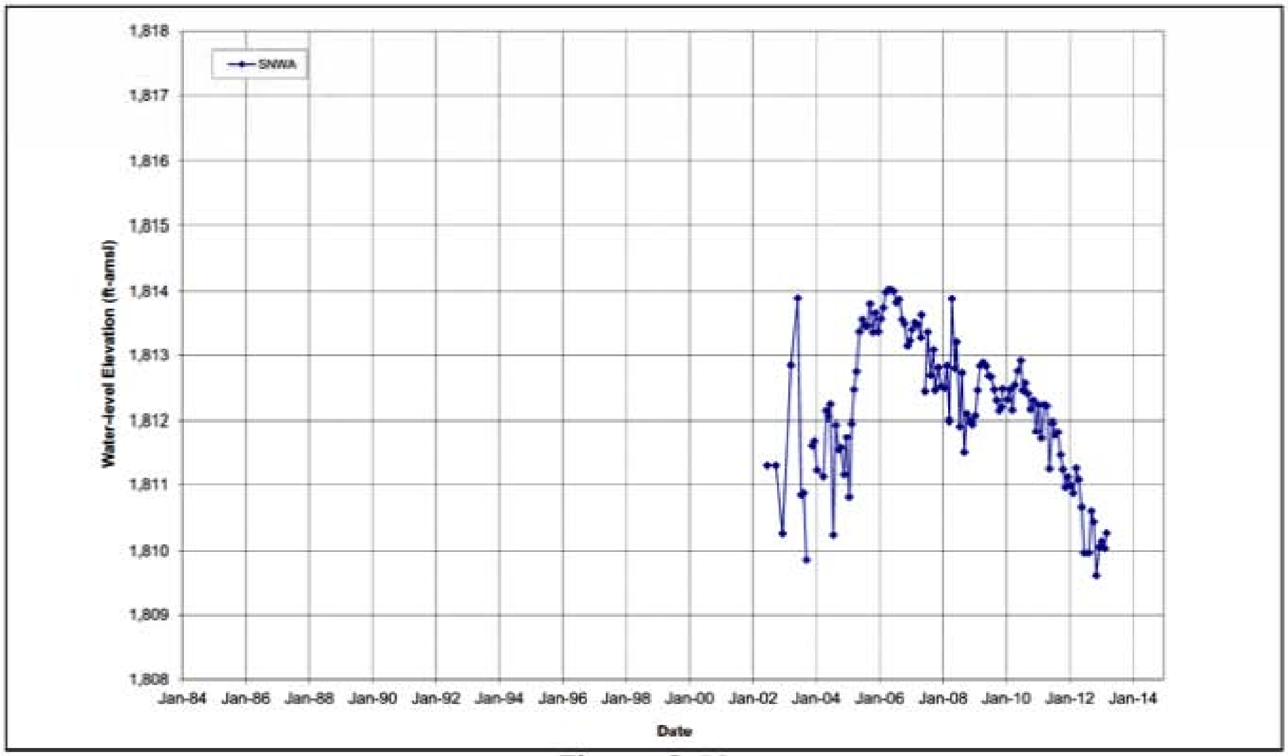

Figure C-52
GV-PW-MW2 (Carbonate - Basin 216: Garnet Valley)

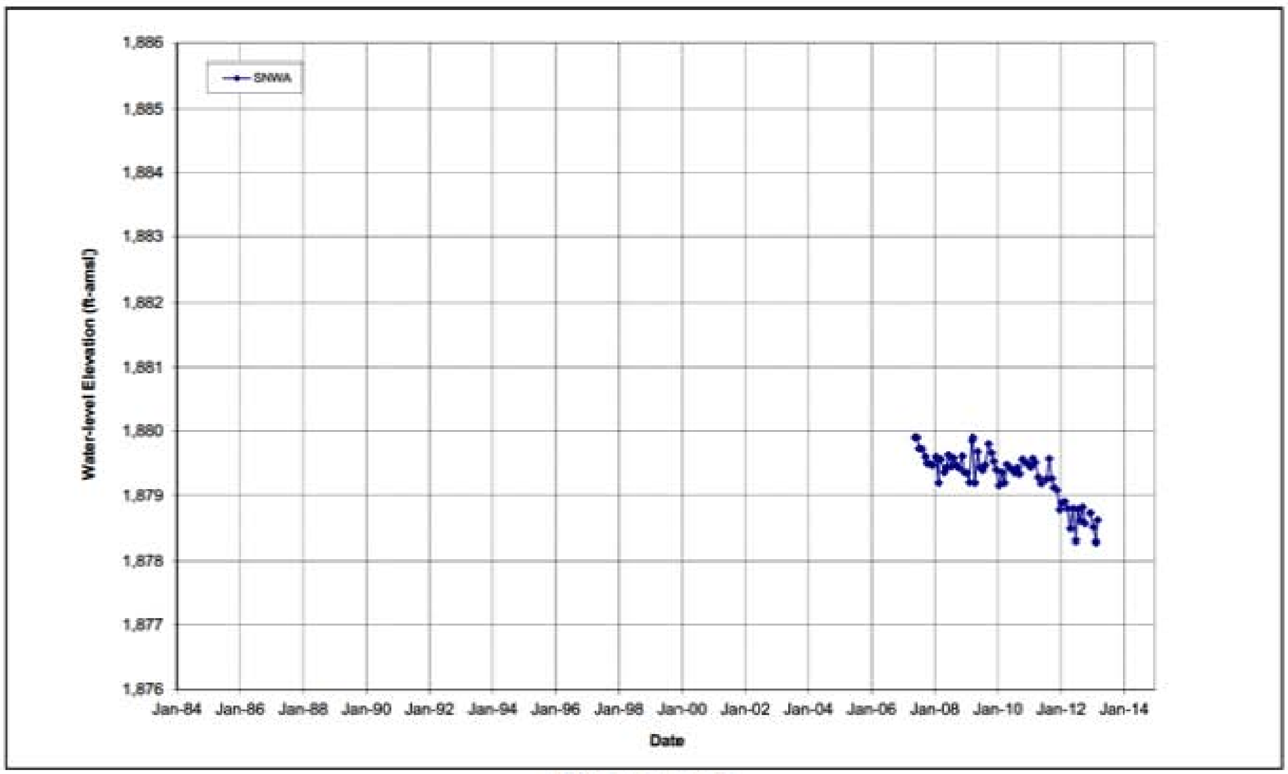

Figure C-53
KSM-1 (Carbonate - Basin 206: Kane Springs Valley)

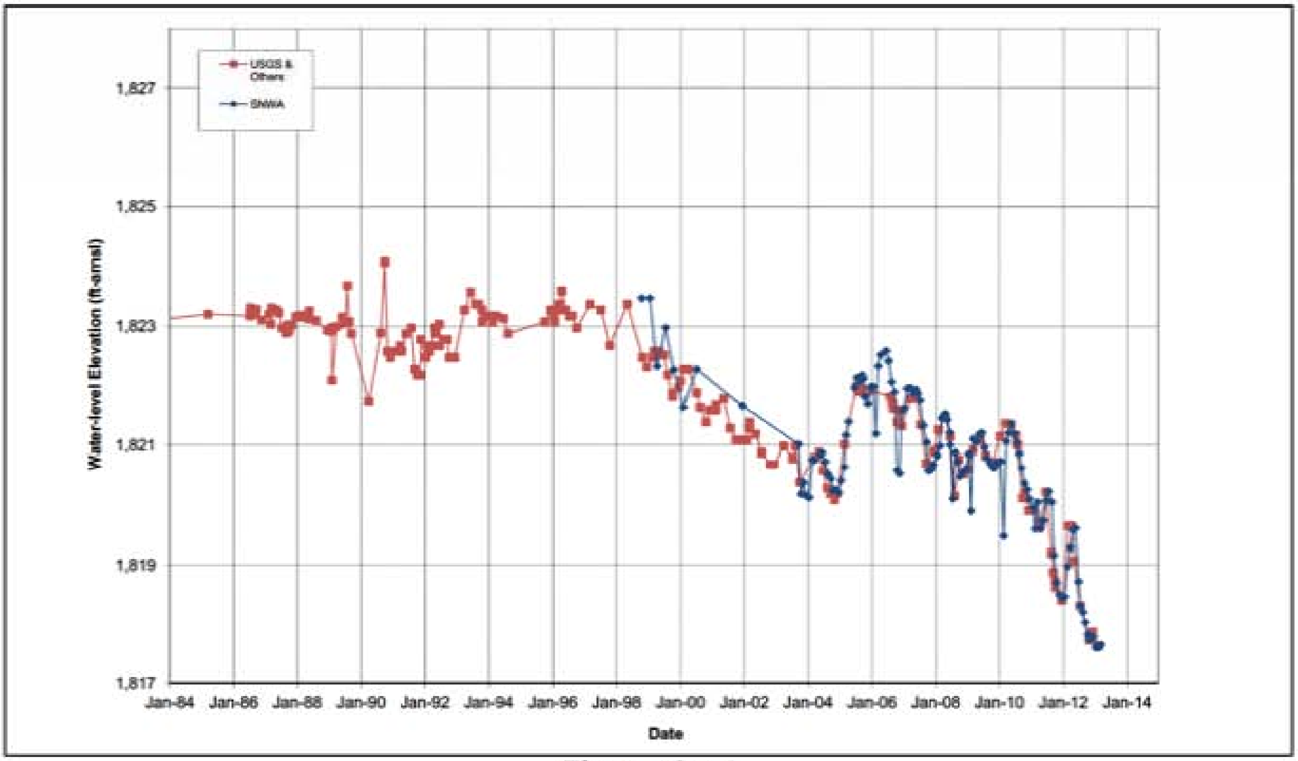

Figure C-54
MX-4 (Carbonate - Basin 210: Coyote Spring Valley)

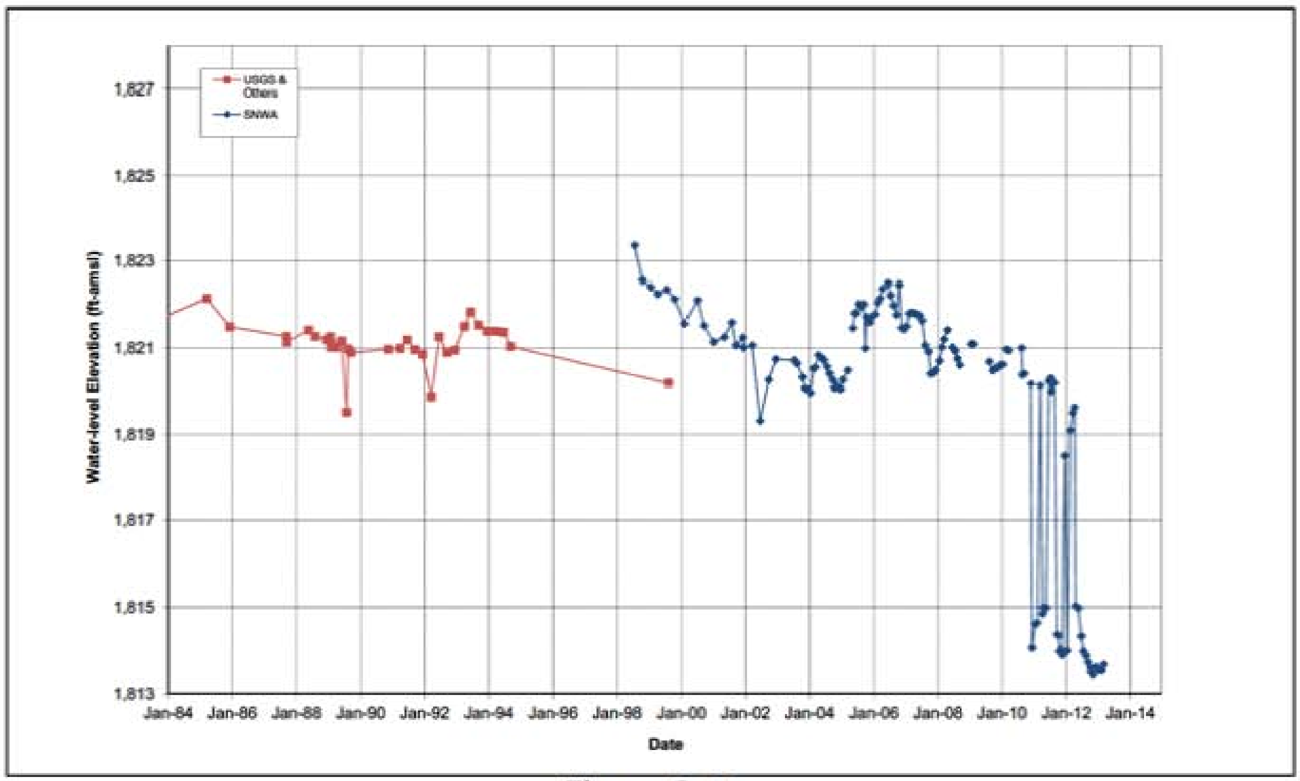

Figure C-55
MX-5 (Carbonate - Basin 210: Coyote Spring Valley)

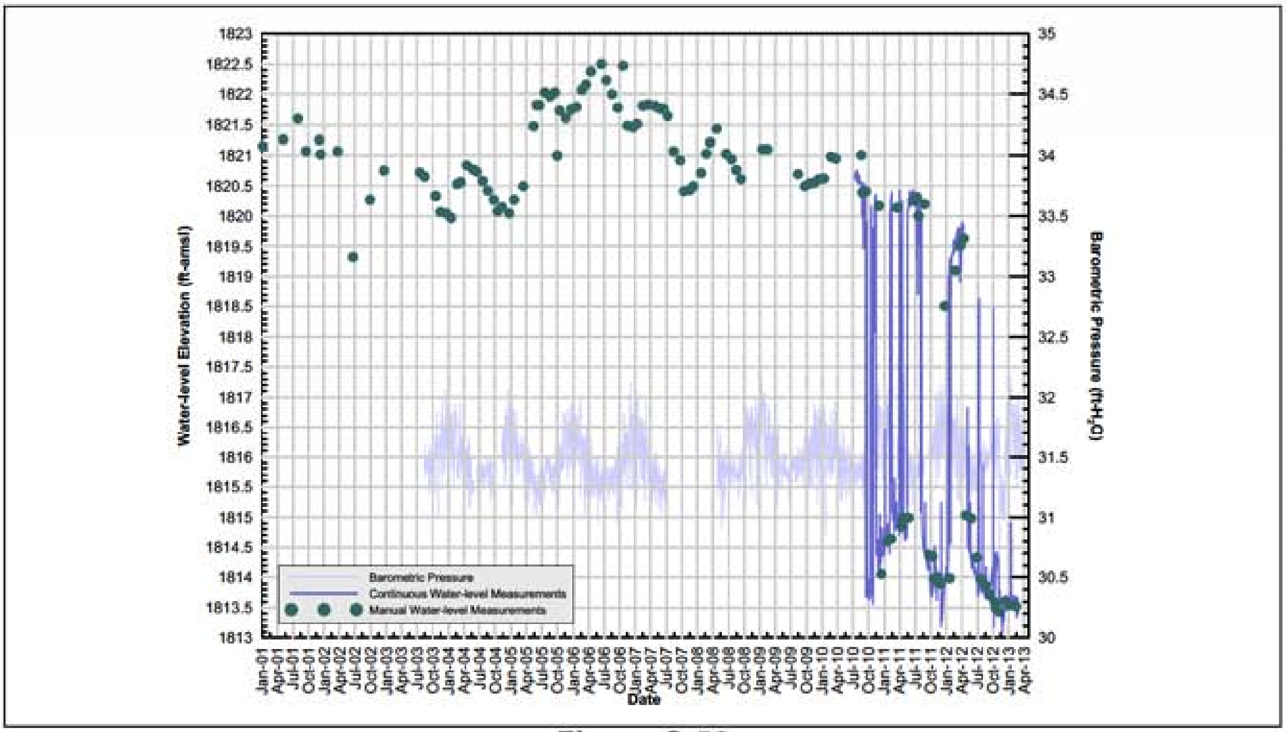

Figure C-56
MX-5 (Carbonate - Basin 210: Coyote Spring Valley)

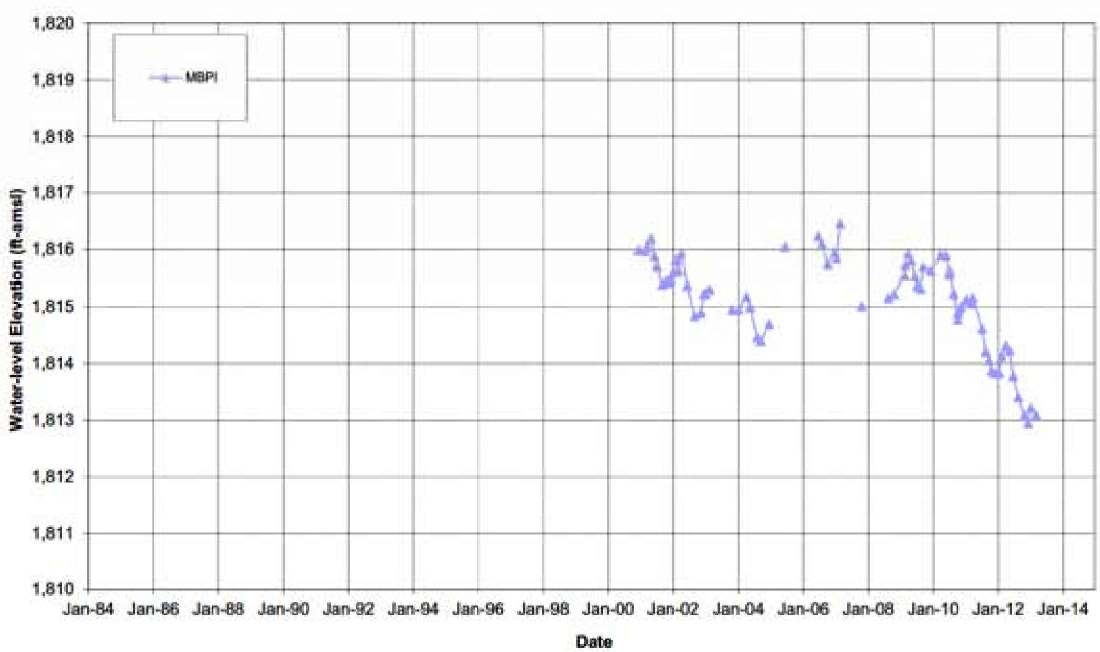

Figure C-57
PAIUTES-M1 (Carbonate - Basin 218: California Wash)

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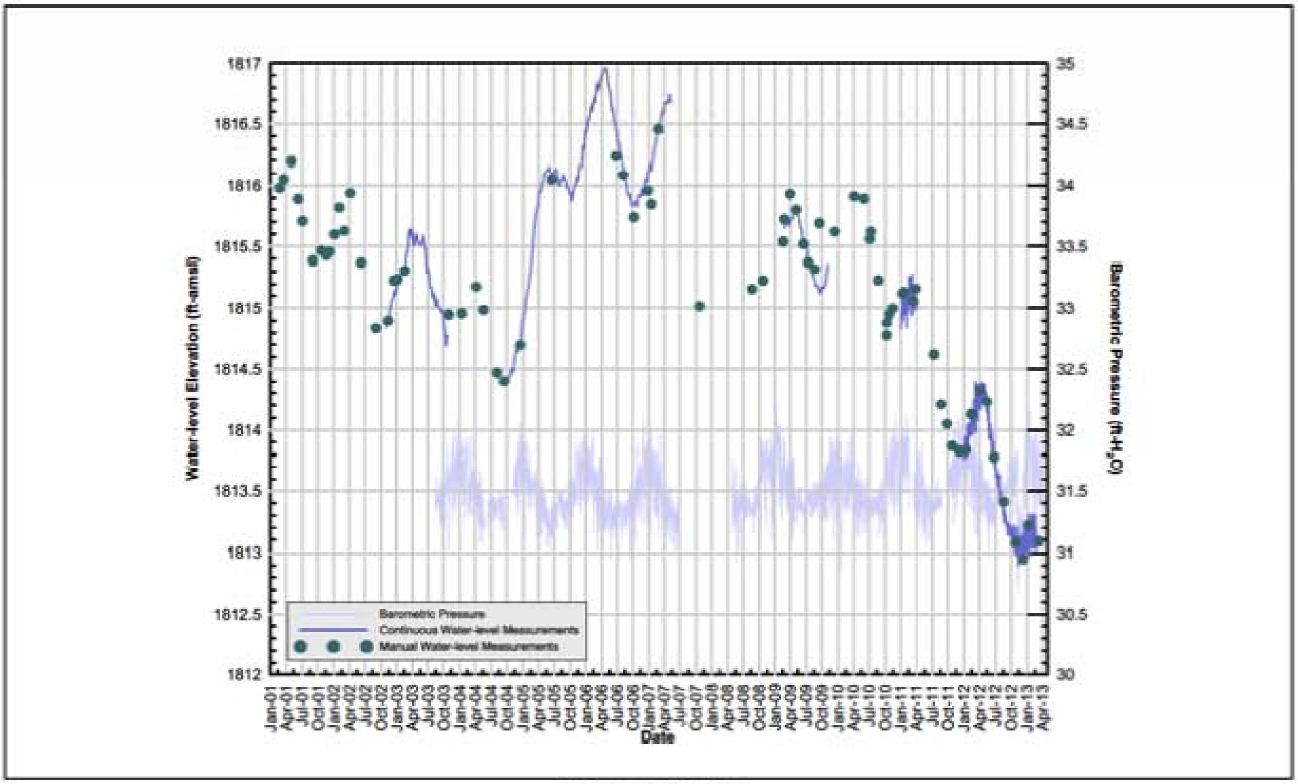

Figure C-58
PAIUTES-M1 (Carbonate - Basin 218: California Wash)

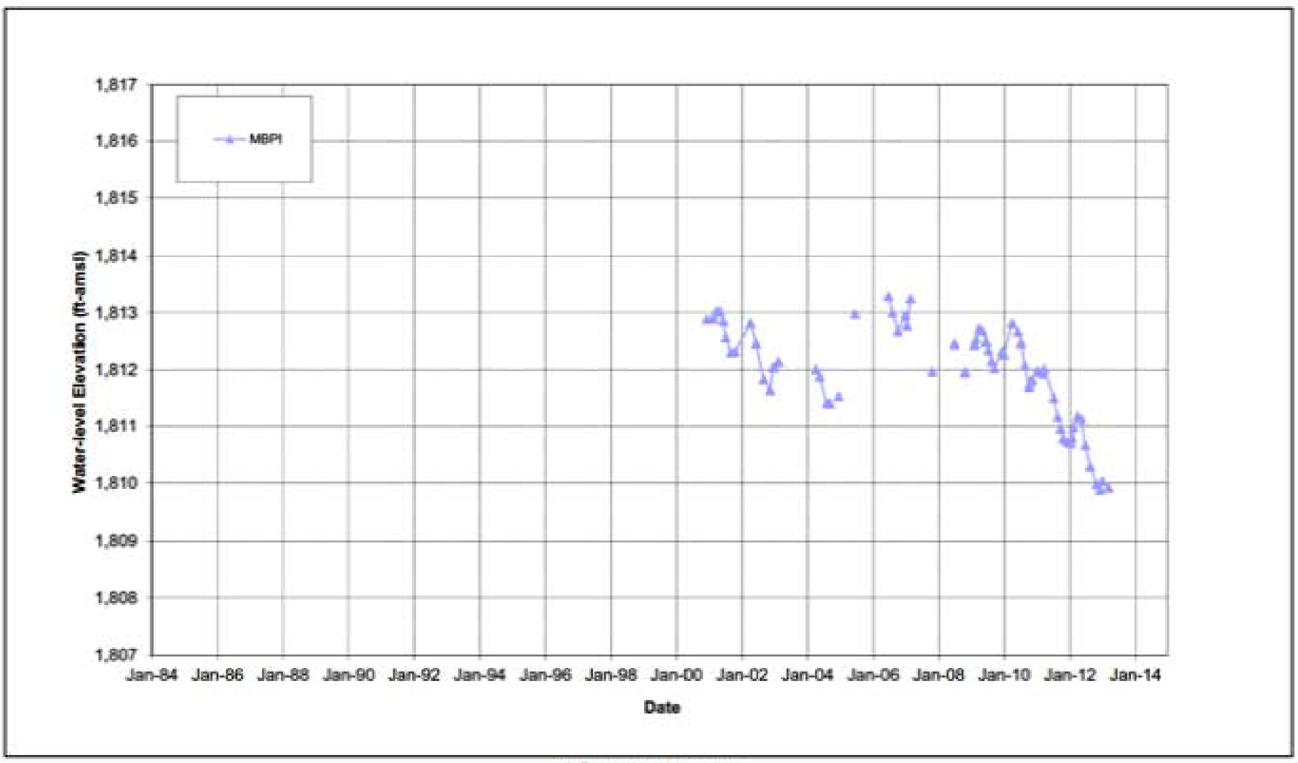

Figure C-59
PAIUTES-M2 (Carbonate - Basin 218: California Wash)

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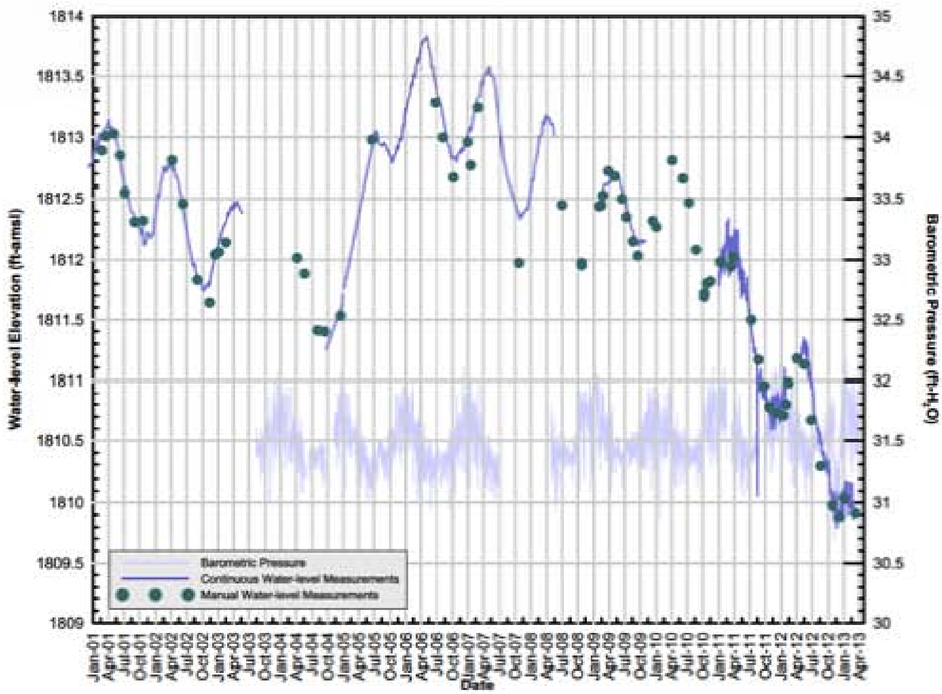

Figure C-60
PAIUTES-M2 (Carbonate - Basin 218: California Wash)

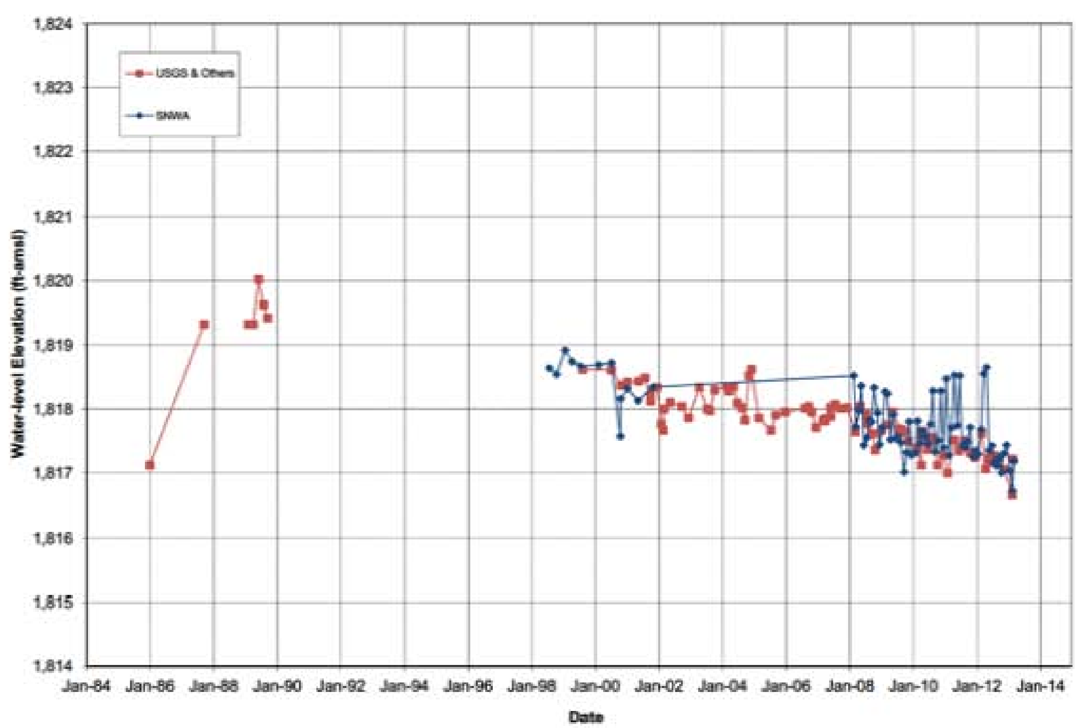

Figure C-61
SHV-1 (Carbonate - Basin 217: Hidden Valley)

SE ROA 10239

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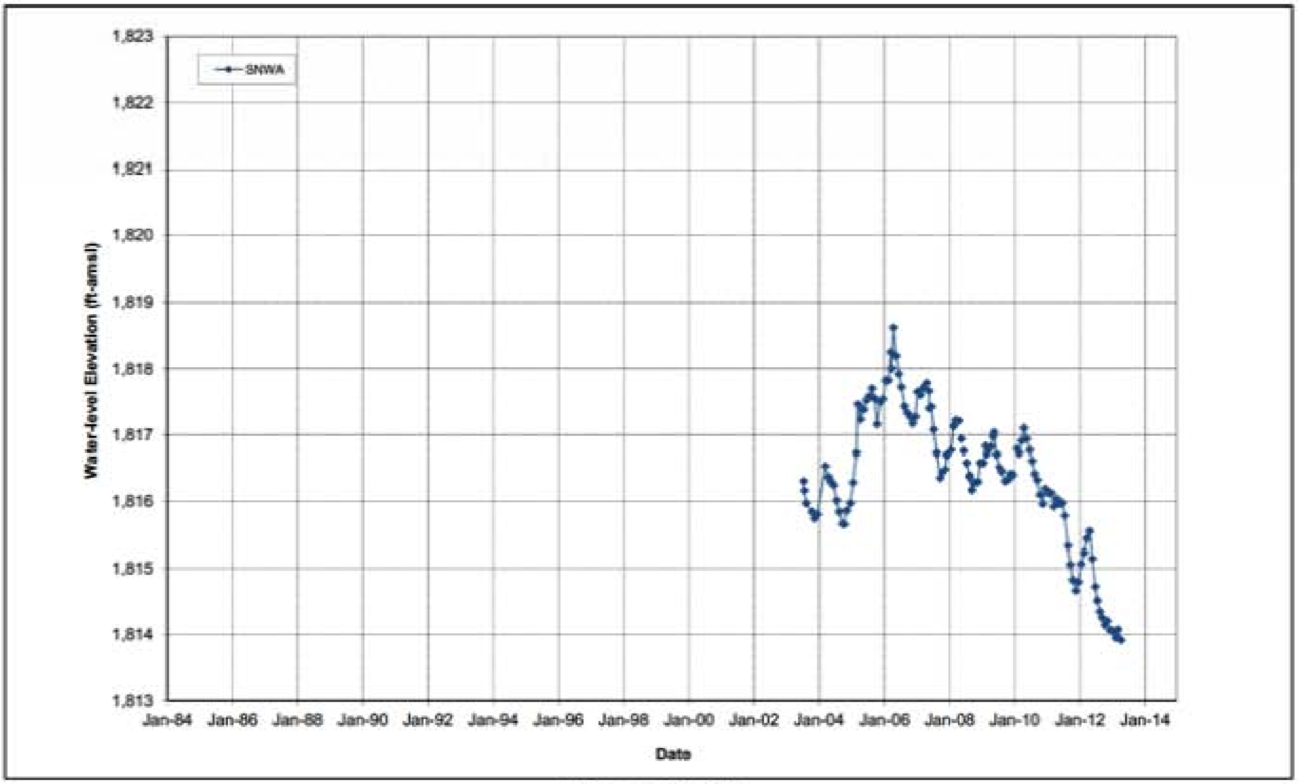

Figure C-62
UMVM-1 (Carbonate - Basin 219: Muddy River Springs Area)

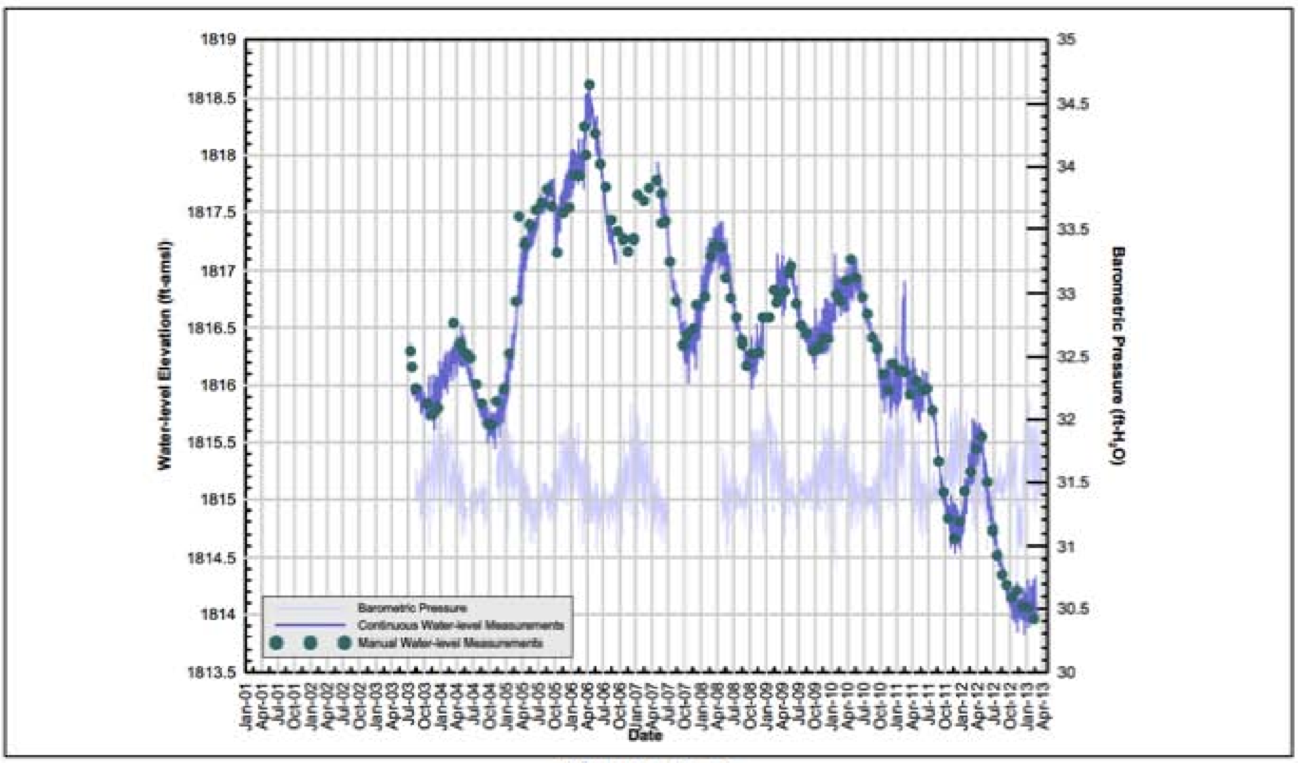

Figure C-63
UMVM-1 (Carbonate - Basin 219: Muddy River Springs Area)

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Appendix D

Discharge Records for Streams and Springs

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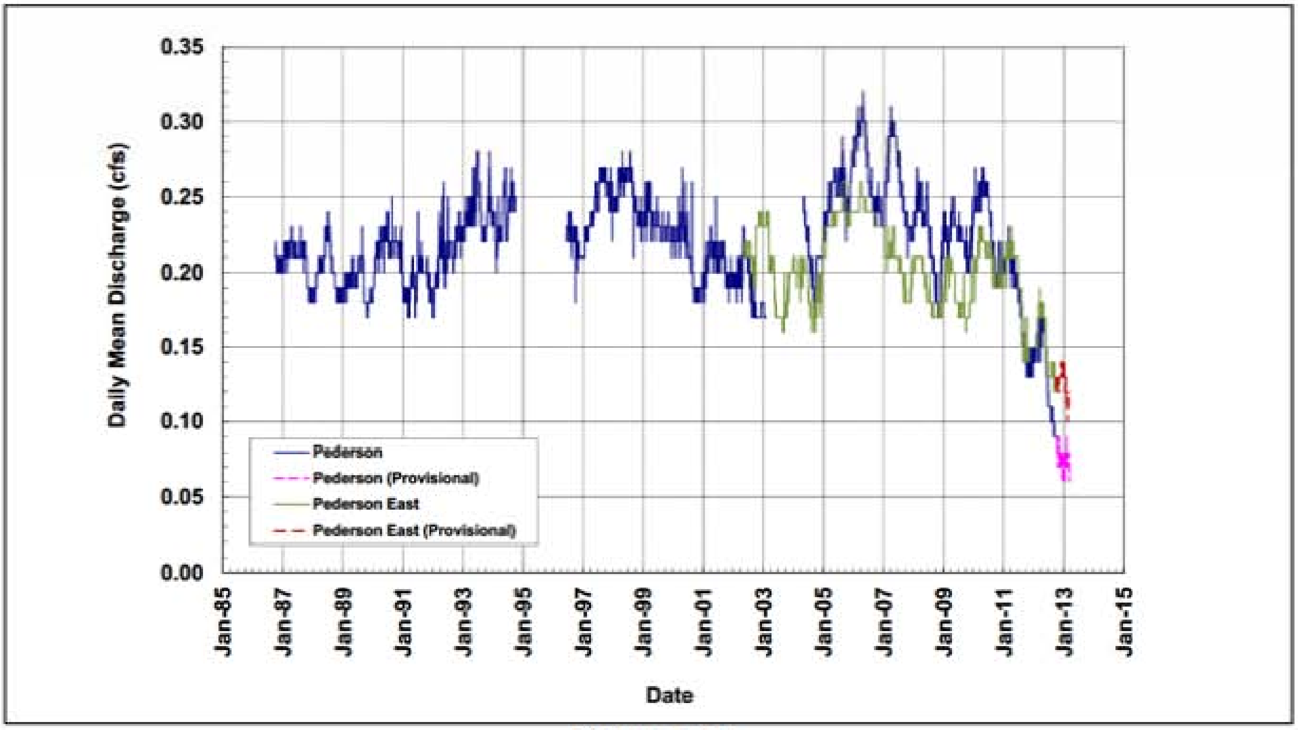

Figure D-1
Pederson and Pederson East Gages
Daily Average Flow for Period-of-Record

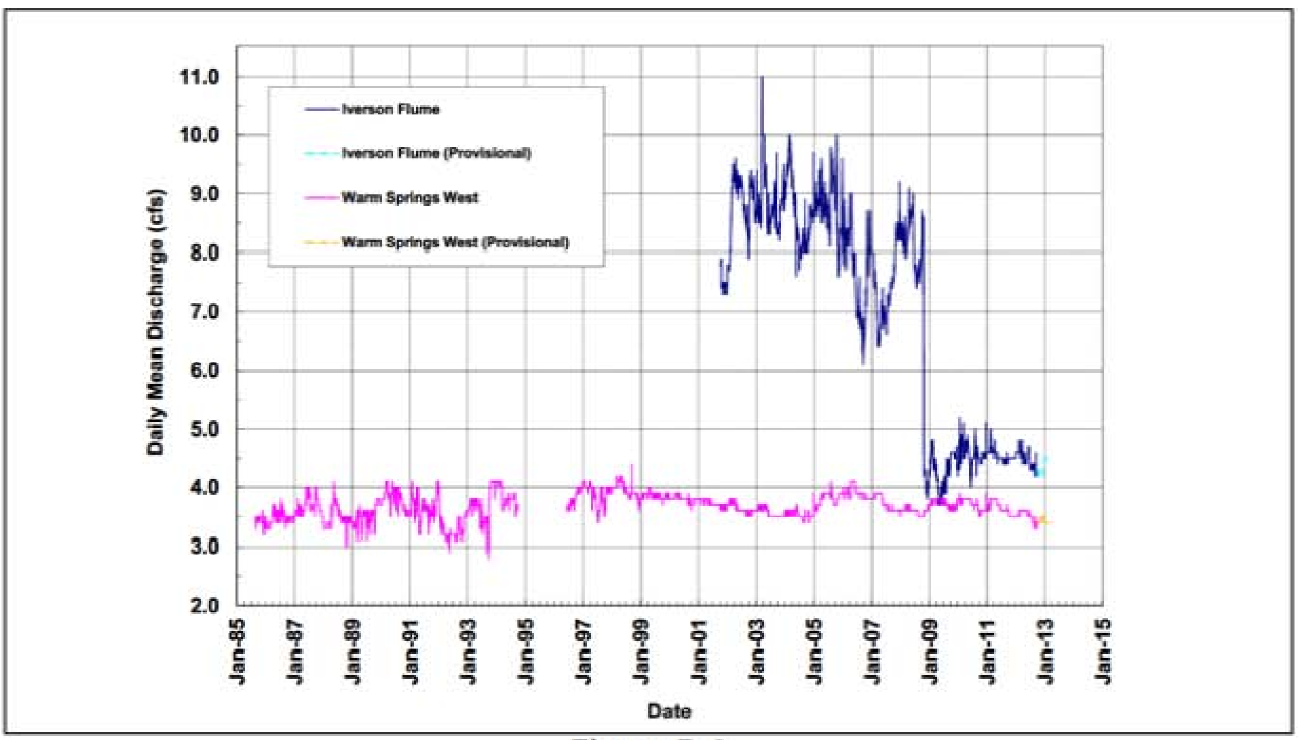

Figure D-2
Warm Springs West and Iverson Flume Gages
Daily Average Flow for Period-of-Record

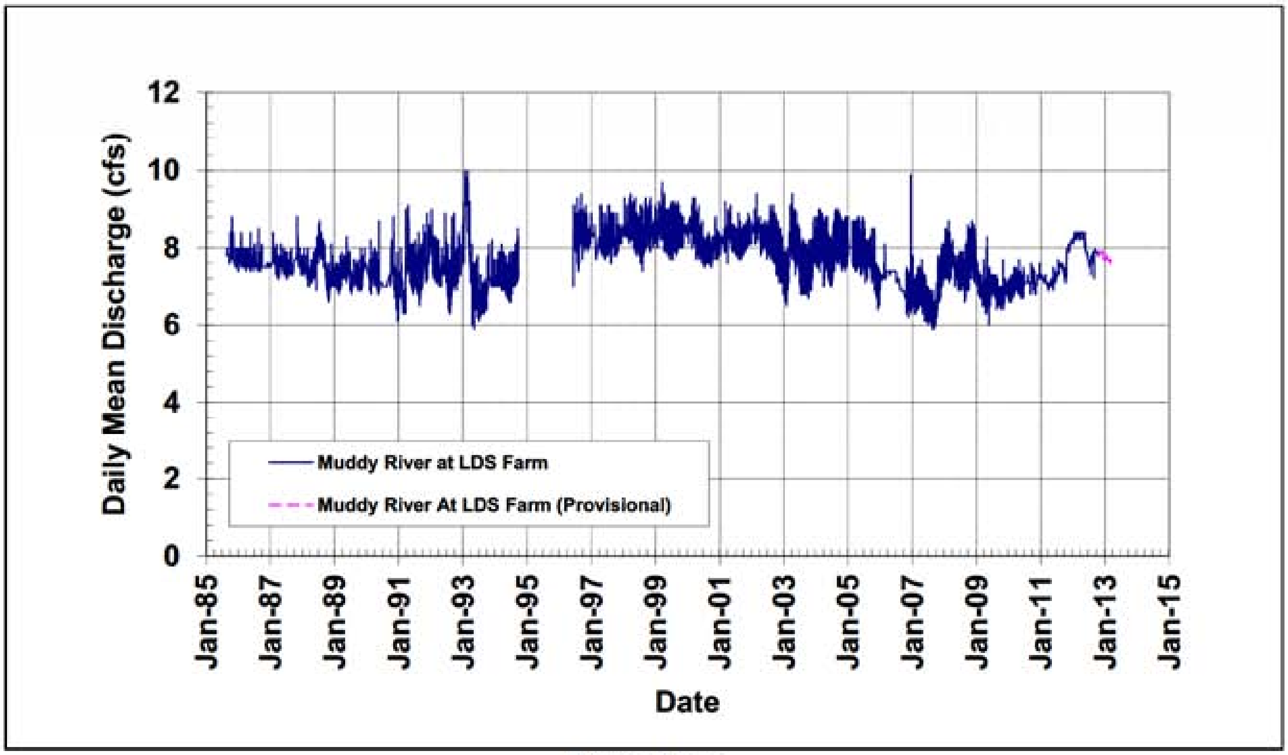

Figure D-3
LDS Gage Daily Average Flow for Period-of-Record

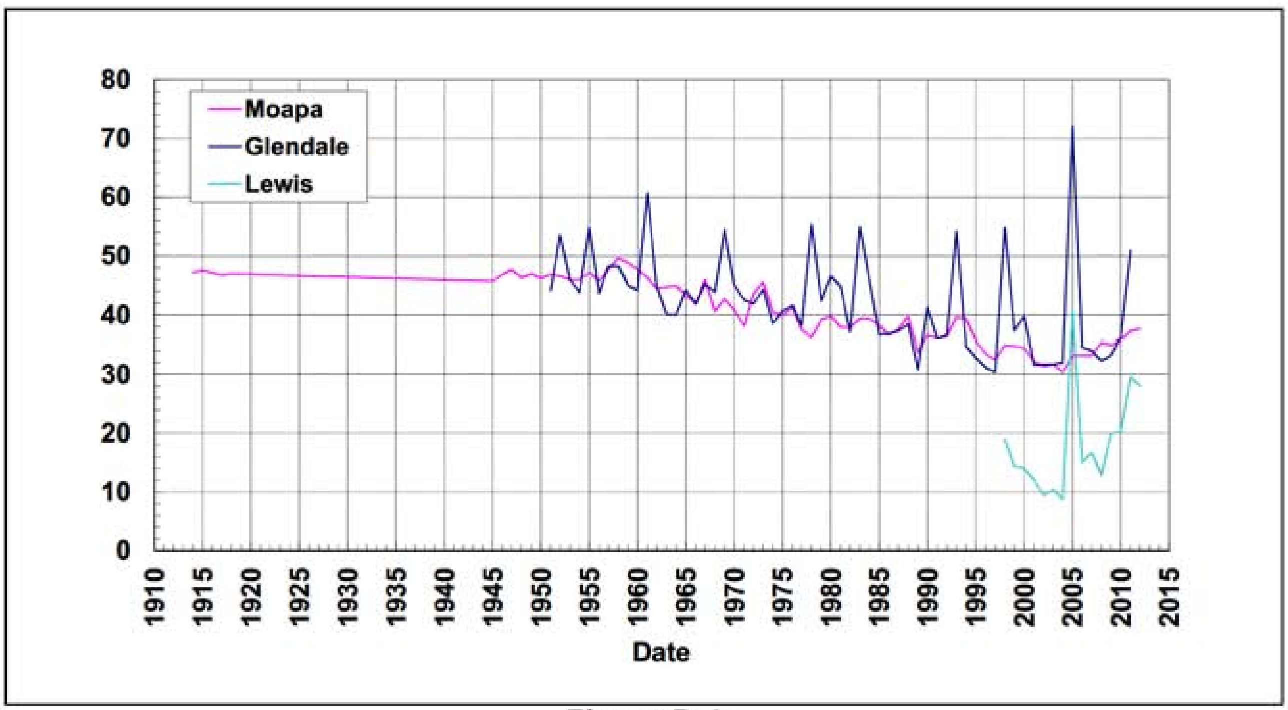

Figure D-4
Moapa, Glendale, and Lewis Gages
Yearly Average Flow for Period-of-Record

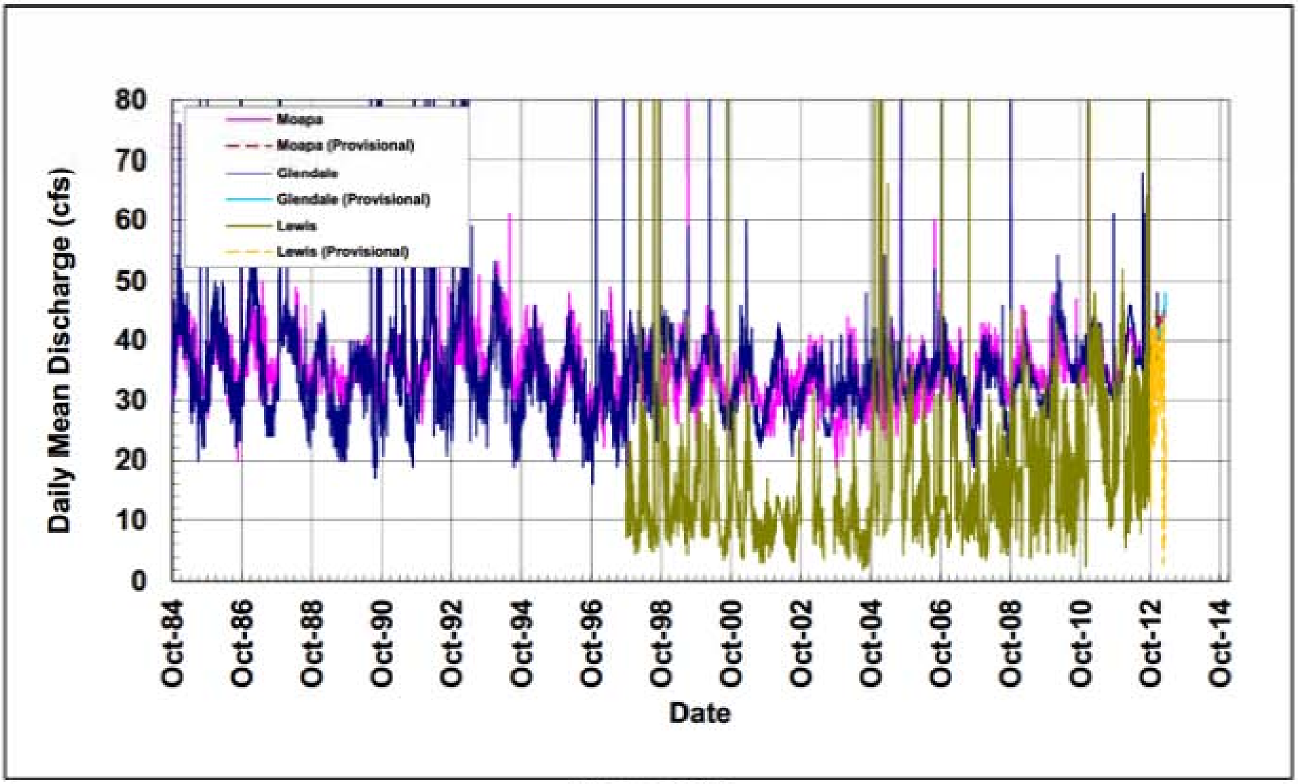

Figure D-5
Moapa, Glendale, and Lewis Gages
Daily Average Flow for Water Years 1984-2012

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Appendix E

Southern Nevada Water Authority 2004 Water Level and Climate Variation Report

SE ROA 10249

Journal of the Nevada Water Resources Association

Fall 2004

A publication of the Nevada Water Resources Association, providing hydrologic information to the people of Nevada

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Nevada Water Resources Association

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Climate and Barometric Pressure Influences on Pederson Spring Discharge and the Carbonate Aquifer near the Muddy Springs, Southern Nevada

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ABSTRACT

The Muddy Springs, including Pederson Spring, derive flow from a regional carbonate aquifer in central-southern Nevada. Annual potentiometric water level fluctuations near Muddy Springs range from 0.6 to 1.2 feet, which are attributed predominantly to barometric pressure responses. Computed barometric efficiencies are 0.42 to 0.67 at well MX-4 situated 9 miles west of Muddy Springs, 0.60 at well UMVM-1 situated 5 miles west, 0.50 at well EH-5B located near the southwestern edge of the springs, and decreasing to 0.25 at well EH-4 located 2 miles east of EH-5B and ¼-mile south of Pederson Spring. Pederson Spring barometric efficiency is calculated at 0.065 cfs per foot of barometric pressure change. Since 1998, declining water levels in nearby observation wells and spring discharges are observed, being generally coincident with both a pronounced dry trend in central-southern Nevada and increased production from a nearby municipal well completed in the carbonate aquifer. Declining trends appear to have commenced in 1998, one year prior to the 5-year dry climate trend which began in 1999. These declining trends appear to be more pronounced than preceding climate influences since the mid-1980s, supporting the hypothesis of pumping influences. These observations are less evident in Pederson Spring discharge, as the declining discharge began in 1999, supporting the hypothesis of climate dominated influences on spring discharge, and suggesting a hydraulic discontinuity between the pumping well and spring. Several other lines of evidence suggest that hydraulic discontinuities exist between the up-gradient carbonate wells and Pederson Spring, including: 1.) fault structures cross cutting the region of the springs, 2.) differences in barometric efficiencies up-gradient and down-gradient of fault structures, and 3.) deviations in degrees of interpreted drawdown effects at well EH-5b, and between well EH-4 and Pederson Spring.

INTRODUCTION

The Southern Nevada Water Authority (SNWA) has implemented a monitoring program to improve the scientific understanding of the regional carbonate aquifer in the vicinity of Coyote Spring Valley and the Muddy Springs. Implemented over the past 4 years are an improved data collection and archiving system, construction of 8 monitoring wells in Coyote Spring Valley and down-gradient towards the Muddy Springs, and commencement of expanded water level and barometric pressure data collection. Ongoing work includes support of reconstruction of the Pederson Spring weir, and construction of a pipeline and pumping facilities to support a 2-year aquifer pumping test at Well MX-5 situated in east-central Coyote Spring, 9 miles up-gradient of the Muddy Springs.

A subtle declining trend in regional water levels and spring discharges over the past 5 to 6 years has caused some concern and debate. Uncertainty presently exists in interpretations of the causes of the observed trends. Some of the complexities and uncertainties of the system have included undefined climatic responses, barometric pressure responses, pumping responses, uncertain hydraulic connections between the springs and the underlying carbonate aquifer, spring flow measurement inaccuracies, a limited period of time of baseline data, and a limited amount of regional hydrogeologic data regarding the carbonate aquifer system. The response of the hydrologic system in the Muddy Springs area is undoubtedly a function of some combination of the above variables; however, data to support conclusive statements on the magnitudes and effects are lacking. The interpretations presented herein have the objective of advancing the understanding of the hydrologic system, but should be considered preliminary, as data collection and evaluations are on going.

HYDROGEOLOGIC OVERVIEW

The Muddy Springs are comprised of numerous individual springs and spring groups (complexes) spread over a two square mile area located approximately 5 miles west of the town of Moapa in Clark County, Nevada (Figure 1). Approximately 36,000 acre-feet per year (afy) of ground water has historically discharged from the springs (Eakin, 1964; and Eakin, 1966). The source of water for the springs is presently understood to be derived from a regional carbonate rock flow system. This is based on spring water chemistry and the anomalously large magnitude of discharge at Muddy Springs in relation to the small watershed in which the springs reside. Paleozoic carbonate rocks host a complicated flow system that links many hydrographic basins in Central and Southern Nevada. The regional geology is complex with a long geologic history of tectonic activity associated with the formation of the Basin and Range Province. That portion of the flow system contributory to the Muddy Springs is interpreted to be primarily derived from recharge on mountain ranges along the White River Flow System (WRFS), extending approximately 200 to 300 miles to the north (Eakin, 1966), and perhaps from the Meadow Valley Flow System immediately east of the WRFS (Thomas and others, 2001; LVVWD, 2001) (Figure 1).

Figure 1 – Location Map: Muddy River Springs Area, White River Flow System and Meadow Valley Flow System.

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The potentiometric gradient in the carbonate aquifer near the Muddy Springs is shallow, with water levels only varying about 20 feet in altitude within a 10-mile distance from the springs (Figure 2). Aquifer transmissivities in the vicinity of Muddy Spring are high, with interpretations in the range of 200,000 gallons per day per foot (gpd/ft) (Eakin, 1966 for the White River Flow System) to 1,870,000 gpd/ft, or greater, at well MX-5 (Ertec Western, 1981), enabling a large flux of ground water even under low hydraulic gradients.

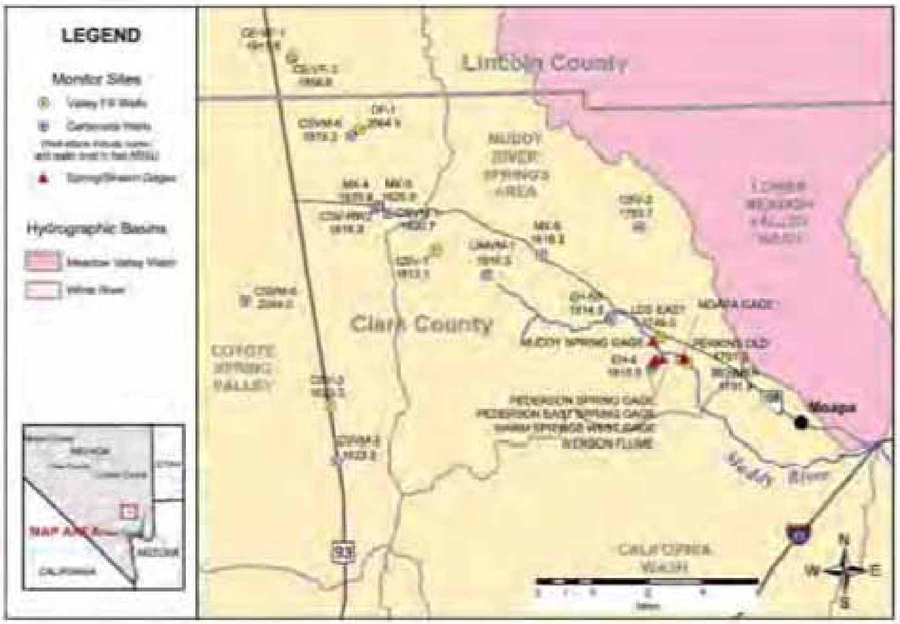

Figure 2 — Wells and springs in Coyote Spring Valley and Muddy Springs Area with potentiometric water surface elevations noted.

Local Geology

The Muddy Springs area has been previously mapped by Longwell and others (1965) and further refined by Schmidt and others (1996), and Donovan and others (2004). Figure 3 is a detail of Donovan and others (2004) preliminary geologic map of the Muddy Springs area.

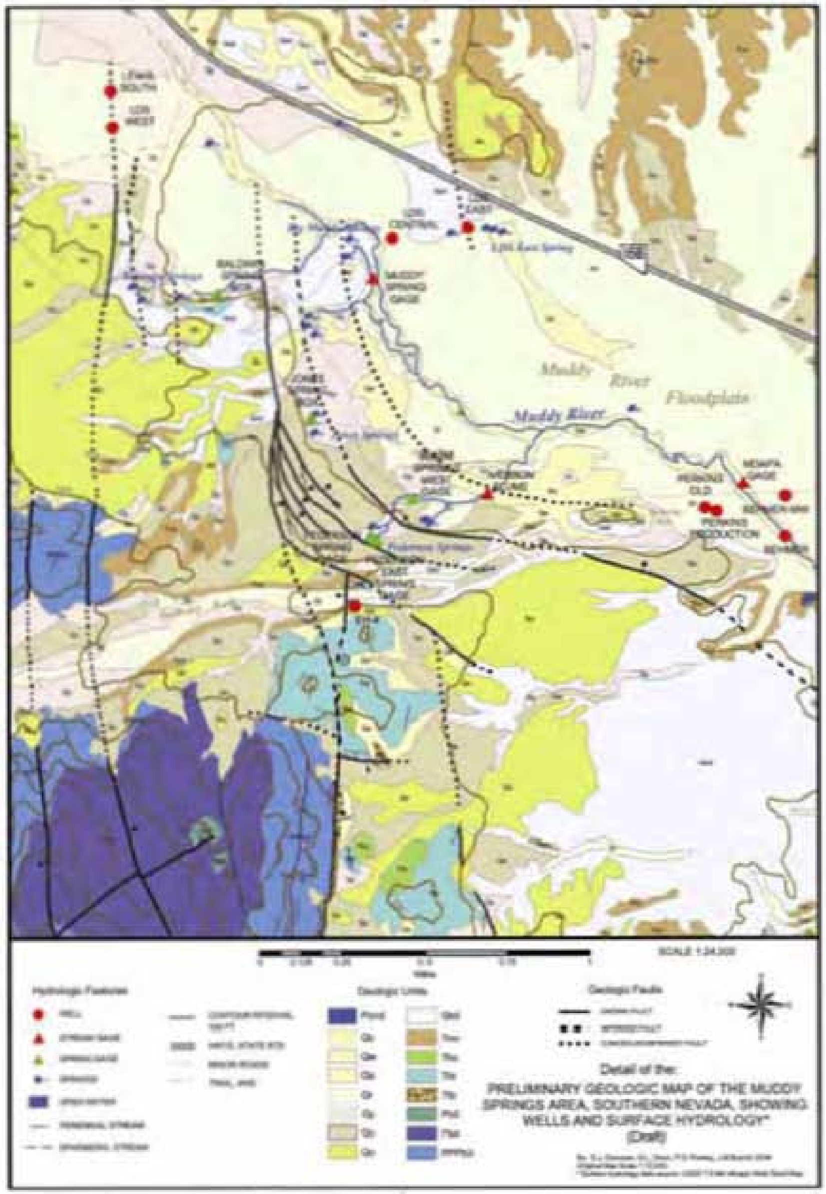

Figure 3 — Geologic Map of the Muddy Springs area.

The Muddy Springs are situated at base of the eastern flank of the Arrow Canyon Range, which is comprised of folded and faulted Paleozoic carbonate rocks. Spring discharge occurs through recent alluvium deposited along the ensized valley floor – flood plain of the Muddy River, and through underlying semi-consolidated alluvial deposits of the Muddy Creek Formation. Mesozoic age compressional features (primarily folds) are common local structural features in the bedrock. Unnamed north-south faults are common in the nearby bedrock. Tertiary and Quaternary normal faults associated with the Basin and Range Province are also common.

Of specific interest to recent mapping was a review of whether the Muddy Springs area was associated with a fault zone, as is common for large springs in the valley lowlands within the Basin and Range Province. The Clark County geologic map (1:250,000 scale, Longwell and others, 1965) does not indicate a major fault structure in this area or in the adjacent part of the Arrow Canyon Range, however, the scale of this regional mapping is such that many faults of significance may not be incorporated. By contrast however, regional correlations by the LVVWD (2001), the detailed bedrock mapping of the Schmidt and others (1996), and adjacent USGS maps, show this area to be structurally deformed with a strong north-south structural orientation caused by Mesozoic compressional features and Tertiary and Quaternary normal faulting.

Geology mapping Donovan and others (2004) has identified an important north-south normal fault, located directly west of the Pederson Spring complex (Figure 3), which is a continuation of the normal faults in adjacent Paleozoic bedrock to the southwest of the springs as previously mapped by Schmidt and others (1996). Several other associated minor subparallel faults have been mapped to the east and within the Pederson Spring complex. Other minor faults have mapped with an orientation of about N60°W, which is subparallel with Muddy River. Features such as offset and tilted beds, slickensides, and linear landscape features were used to identify the structures. At various stages in the geologic history of these faults, they have acted as conduits to spring discharge as is indicated by water discharge features such as tufa, mamillary calcite, cementation zones, and dissolution cavities along the trace of and immediately down gradient of the faults.

Also of interest, is the character and distribution of the Quaternary (mid-Pleistocene) paleo-spring deposits (Qsd) shown on Figure 3. The Qsd deposits are similar to the younger (Pleistocene-Holocene) paleo-spring deposits, common in southern Nevada (Quade and others, 1995) but lacks the distinctive organic horizons "black mats" and gastropod shells, and generally have a better developed caliche cap. The older (Miocene) Muddy Creek Formation is more monotonous texturally and is easily differentiated from the Qsd where it is red in color.

The stratigraphic units used on Figure 3 were generalized from previous published mapping and are described in Table 1.

Table 1 – Description of stratigraphic units.

CODE	UNIT DESCRIPTION
Qc	Quaternary – Active channel deposits of the Muddy River.
Qw	Quaternary – (Holocene) Active spring-fed wetlands.
Qa	Quaternary – alluvium. Unit is similar to Schmidt and others (1996) "slope wash and talus deposits" "Qs".
Qr	Quaternary – flood plain of Muddy River. Surface is reworked by agricultural development.
Qy	Quaternary – (Holocene – Pleistocene transition) young paleo-spring deposits Similar to those found near other active spring areas in southern Nevada (Corn Creek, Tule Springs, Mound Spring).
Qu	Quaternary – undivided Quaternary deposits. Deposits are primarily coarse grained and are either older or contemporary with the younger paleo-spring deposits.
Qo	Quaternary – Distinctive older coarse-grained terrace deposits that are darker (better developed desert varnish) with a well-developed caliche cap.
Qsd	Quaternary – (Mid Pleistocene) Older paleo-spring deposits, usually very light in color fine-grained, and strongly calcareous. The bulk of the deposit is located in a north-south trending graben on the east side of map
Tmr	Tertiary – (late Miocene) Muddy Creek Formation, red and green fine-grained sediment
Thc	Tertiary – (early to mid Miocene) Horse Spring Formation (conglomerate facies)
Thl	Tertiary – (early to mid Miocene) Horse Spring Formation (limestone facies)
Tfb	Fault breccia, assumed to be Tertiary
Pb5	Permian – Bird Spring Formation, red slope forming member
Pb4	Permian – Bird Spring Formation, medium gray, fine-grained, massive to thick bedded limestone
PPPb3	Pennsylvanian and Permian – Bird Spring Formation, medium gray to yellow, fine-grained, dolomitic and silty limestone

Regional Water Level Trends

Over the past 5 years, potentiometric water levels in carbonate aquifer wells near the Muddy Springs have declined approximately 1.5 to 2.5 feet (Figure 4). Possible causes of the water level fluctuations and trends in the flow system are: 1.) precipitation and climatic cycles, 2.) pumping from the carbonate aquifer, 3.) pumping from the shallow alluvial aquifer at the Muddy Springs, 4.) alterations to the environment such as spring restoration, 5.) degradation of measurement devices/conditions, and 6.) regional earth crust stress changes associated with earthquakes. Fenelon and Moreo (2002), Bright and others (2001), Harrill and Bedinger (2000), and Avon and Durbin (1994), and many others, have evaluated water level trends and controlling mechanisms in the southern Nevada flow systems, including the regional carbonate aquifer. Buqo (2004) presented a hypothesis of potentiometric water level changes near the terminus of the WRFS being in part due to response to Lake Mead water level fluctuations.

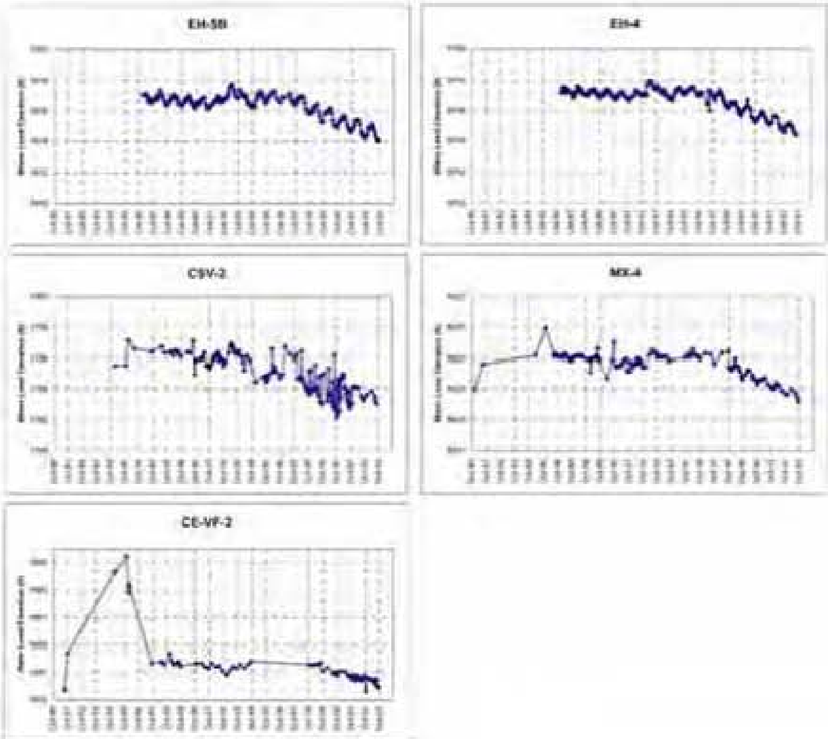

Figure 4 — Carbonate aquifer water level hydrographs, Coyote Spring Valley and Muddy Springs Area. Water level data reported by USGS, SNWA, Nevada Power Company, and MVWD.

Pederson Spring

Pederson Spring is one of many springs within the Muddy Springs complex and is situated on the Moapa Valley National Wildlife Refuge. While Pederson Spring discharges a small fraction of spring flow derived from the refuge (approximately 4% of an average 6.2 cubic feet per second (cfs)), it is the highest altitude spring on the refuge and therefore believed to be the most sensitive to potential impacts from pumping from the carbonate aquifer. The Moapa dace, a federally listed endangered species, resides in the spring and streams emanating from the refuge.

Discharge measured at Pederson Spring and the down-gradient Warm Springs West gage have also had a declining trend since 1999 (Figures 5). Discharge measurements have been made at Pederson Spring by the US Geological Survey (USGS) since October 1986, and the monthly average flows typically range from 0.18 to 0.26 cfs.

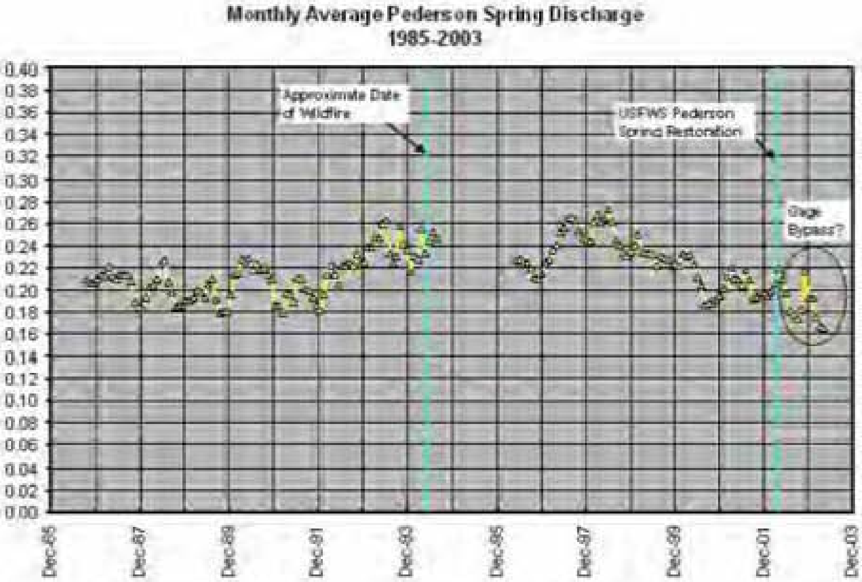

Figure 5 — Pederson Spring Monthly Average Discharge Rates through December 2003. Data source: USGS.

The reliability of Pederson Spring discharge measurements between the time periods of April 2002 to April 2004, as a cumulative measure of spring discharge, is considered by the authors to be low. A progressive leak around the Pederson Spring weir plate is reported by the USGS to have become pronounced in early 2003 (USGS, 2003). Further exasperating the quality of spring discharge measurements have been dramatic changes to the Pederson Spring environment as a result of ongoing restoration work at the refuge, which began in April 2002. While the Pederson Spring pool and weir remained intact during these activities, many palm trees were removed from the vicinity of the spring to within approximately 5 to 10 feet of the pool (Figure 6). Approximately 100 to 150 feet to the east of the pool, five new discharging springs were created at a location where one developed spring formerly existed (Figure 6). The interconnection between springs in the complex is poorly understood, and physical alterations to the spring complex have introduced greater uncertainty as to the accuracy of total spring discharge interpretations. Because of the failing condition of the weir, the USGS in collaboration with SNWA and the U.S. Fish and Wildlife Service (USFWS) replaced the weir structure in late April, 2004 in concert with USFWS spring restoration efforts.

Figure 6 — Upper Pederson Spring Complex (left side), July 2003. Note creation of five new flowing springs (right side) in place of former Playboy Pool site, with removal of palm trees (approximately 60) up to the edge of Peterson Spring Pool.

Pumping from the Arrow Canyon Well

Moapa Valley Water District (MVWD) provides water service in the Moapa area, and relies upon both springs and two wells completed in the carbonate aquifer in the vicinity of the Muddy Springs. MVWD's Arrow Canyon well is located approximately ½-mile southwest of the Muddy Springs area, and 2 miles west of the Moapa Valley National Wildlife Refuge (Figure 2). In 1998, MVWD's pumping from the carbonate aquifer increased from around 750 afy (1991 to 1997) to approximately 2,500 afy (1998 to 2003) due to water demands and changes in operational pumping strategies (Figure 7).

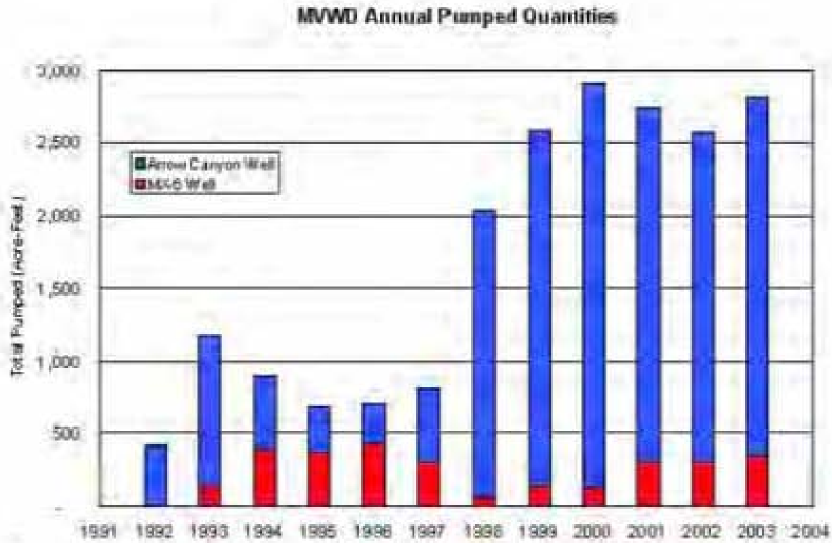

Figure 7 — Annual Total and Seasonal Pumping from MVWD Arrow Canyon and MX-6 Wells. Data source: MVWD.

REGIONAL CLIMATE

White River Flow System Climate Trends

Wet and dry climate trends are commonly reflected, although to varying degrees, in natural hydrologic systems. Annual variability in recharge is dependant on climatic variables, particularly high-altitude winter precipitation quantities in the semi-arid mountainous environments found in Central and South Nevada (Winograd and others, 1998). Recharge variation subsequently may produce potentiometric water level fluctuations throughout a flow system, which is a pressure response phenomenon in the confined carbonate aquifer.

Long-term climate trends have been evaluated using cumulative departure from mean precipitation and the Palmer Drought Severity Index as published by the National Climate Data Center (2003). The Palmer Index includes additional variables of temperature and soil moisture deficit. It is interpreted similarly to the cumulative departure from mean precipitation curve, with zero being a normal year, positive numbers being wet climate cycles, and negative numbers being drought cycles with minus 3 representing a "severe" drought condition (Palmer, 1965) (Figure 8).

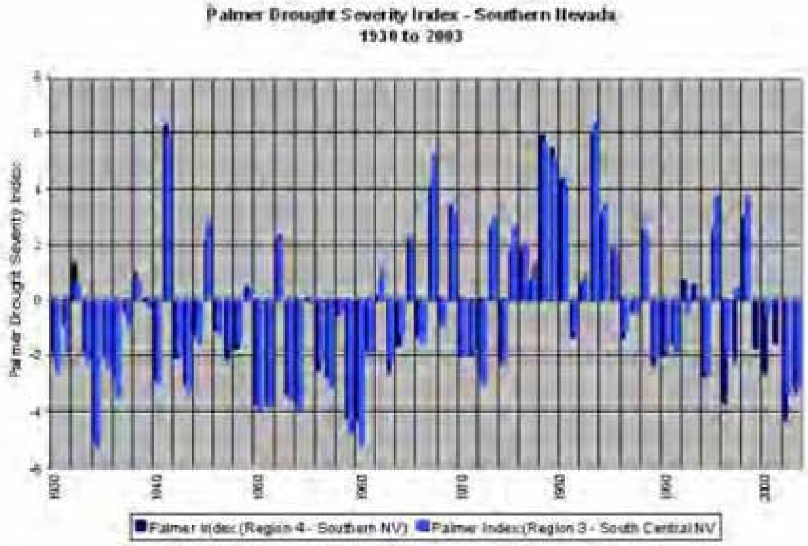

Figure 8 — Palmer Index Bar Plot. Data source: National Climate Data Center, 2003.

An index precipitation dataset has been constructed (1931 through 2003) to represent precipitation falling over the regional flow system contributory to Muddy Springs (Figure 9). An index precipitation dataset has several advantages over use of data from a single station, particularly for interpretations of large regional flow systems. Potential errors related to occurrences of localized precipitation events near a station, climatic variability over distances of tens to several hundred miles, and inherent data collection errors are all reduced over dependence of data from a single station.

Annual precipitation records, as published by the Western Regional Climate Center (WRCC, 2003), for Pahranagat Wildlife Refuge, Sunnyside, Lund, and the Desert Game Range were used for construction of the index precipitation dataset (Table 2), applying weighted averaging based on proportions of recharge to the regional flow system defined by Thomas and others (2001) (Table 3). Additionally, WRCC (2003) precipitation records at Caliente and Las Vegas stations were utilized to reconstruct incomplete Pahranagat records (1998 to 2003) using an averaging technique presented by Dunne and Leopold (1978), and to synthesize records back to a common beginning date of 1931 using relationships defined by linear regression. Cumulative departure from mean index precipitation versus individual station data are presented in Figure 10. Trends observed in the index precipitation data are comparable with individual stations throughout the region, and also compare favorably with limited high altitude and winter only datasets, and are felt to be an adequate representation of the regional climate of the WRFS.

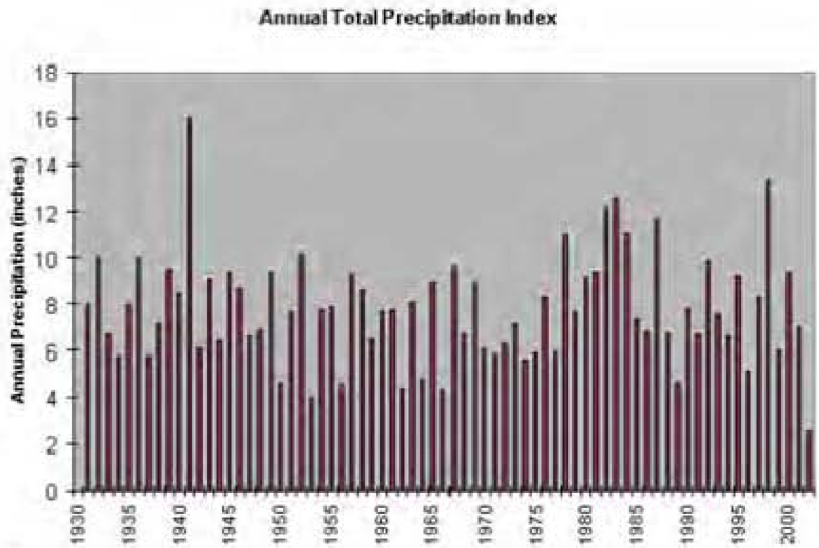

Figure 9 — WRFS Regional Precipitation Index based on records from Las Vegas, Desert Game Range, Pahranagat, Sunnyside, Lund, and Caliente stations. Individual station data source: Western Region Climate Center (WRCC).

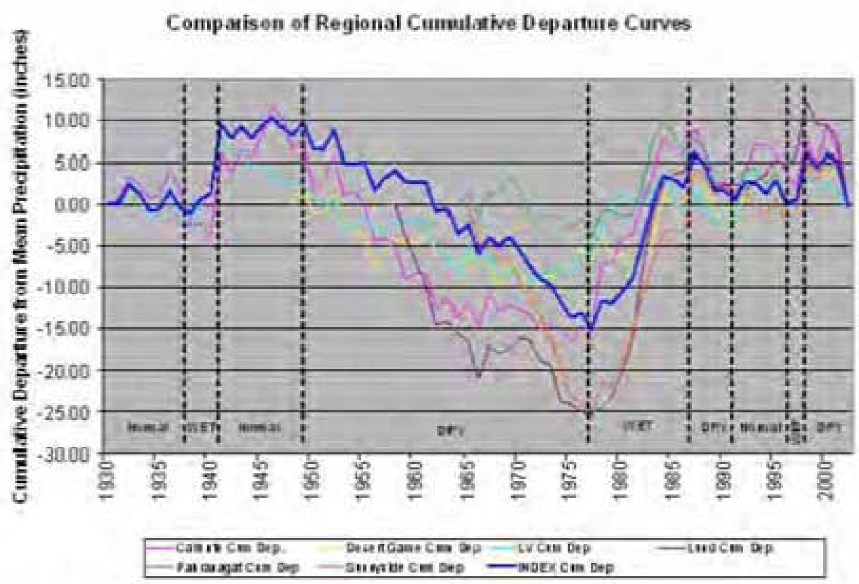

Figure 10 — Cumulative Departure from Mean Precipitation, Comparison for Regional Precipitation Stations. Precipitation data source: WRCC

Table 2 – Summary of regional long-term precipitation records.

Station Name	NWS* ID Number	Period of Record (continuous annual records)	Long-Term Mean Precipitation (inches)
Lund	264745	1958 - present	10.44
Sunnyside	267908	1966 - present	9.50
Caliente	261358	1931 - present	8.77
Pahranagat	265880	1965 - 1997	6.53
Desert Game Range (Corn Creek)	262243	1949 - present	4.31
Las Vegas Airport	264436	1937 - present	4.15

*NWS – National Weather Service

Table 3 – Summary of development of regional index precipitation from Thomas and others (2001) White River Flow System recharge interpretations.

Hydrographic Area	Recharge to Regional Flow System (afy)	Percent Total Contribution	Regional Precipitation Trend Represented By Station:
White River Valley, Long and Jakes	8,000*	14.8	Lund
Pahroc, Cave, Garden, Coal	19,000*	35.2	Sunnyside
Pahranagat, Dry, Delamar, Kane Springs	23,000**	42.6	Pahranagat (Reconstructed Dataset)
Coyote Spring Valley	4,000	7.4	Desert Game Range
TOTAL	54,000	100.0	

* Assumes approximately 55 percent of regional inflow (LVVWD, 2001) to Pahranagat Valley is consumed by evapotranspiration in Pahranagat Valley, with 45 percent comprising regional outflow reflected in Muddy Springs.

** Assumes approximately 1,000 afy regional recharge derived in Pahranagat Valley, with most local recharge consumed by evapotranspiration within the valley.

Climate and Potentiometric Water Level Trend Comparisons

Subtle responses to climate variability appear to be reflected in the potentiometric water levels for wells near the Muddy Springs, as depicted for wells MX-4 and EH-5b (Figures 11 and 12), with a general mimic of climate indices and water levels (wet years producing an upward index trend with corresponding gradual rise in water levels, and visa versa for dry years). However, based on approximately 20-years of water level records, the declining trend in the past 5 to 6 years appears to be more pronounced than past climate responses. The more pronounced declining trend since 1998 could be interpreted as a result of pumping drawdown from the Arrow Canyon well, as a dominate factor superimposed over lesser effects of dry climate. This interpretation, however, is subject to great uncertainty due to the pronounced nature of the current dry climate cycle. A factor that supports the pumping drawdown interpretation is the observation that 1998 was a wetter than average year, however, the declining potentiometric water level trend appeared to have commenced in 1998. Timing of precipitation in 1998 and preceding climatic conditions and resultant soil moisture deficit could easily have dampened the effects of above average moisture for the year. Continued monitoring into the next wet climate cycle will aid in differentiation of the magnitude of these probable pumping versus climate contributory variables.

Figure 11 — MX-4 Water Level Elevation versus Regional Climate Trend

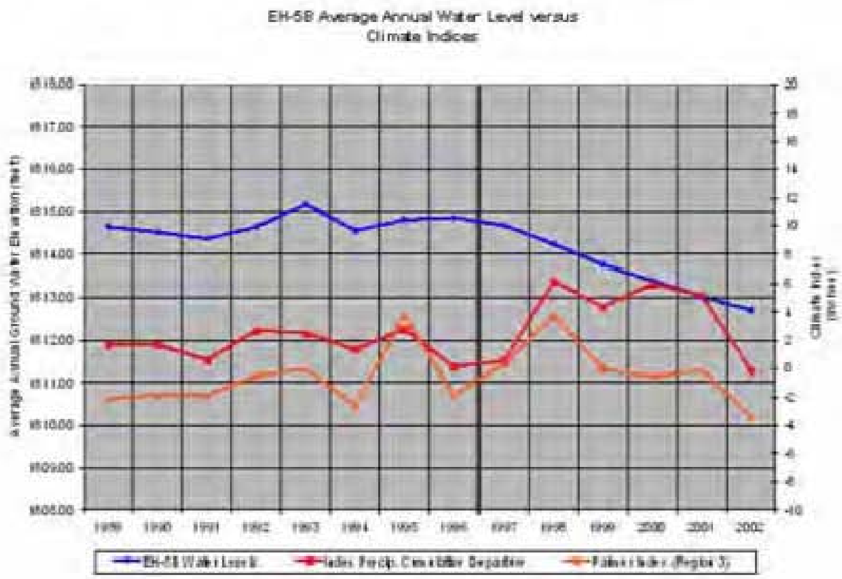

Figure 12 — EH-5B Water Level Elevation versus Regional Climate Trend.

INTERPRETED EFFECTS OF REGIONAL PUMPING

Assuming that a majority of the observed water level decline since 1998 is a result of pumping from the Arrow Canyon well (Table 3), a distinct distance-drawdown relationship can be derived (Figure 13). Except for observation well EH-5B, which is the closest well to Arrow Canyon, the interpreted distance-drawdown relationship agrees with Theis drawdown theory (Table 4). A computed carbonate aquifer transmissivity of approximately 630,000 gallons per day per foot (gpd/ft) and a storage coefficient of 0.0007, is derived from the distance-drawdown plot using the Jacob-Cooper straight line method (Driscol, 1986). While this transmissivity is high, it is in general agreement with carbonate aquifer test data from wells in the region (Belcher and others, 2001).

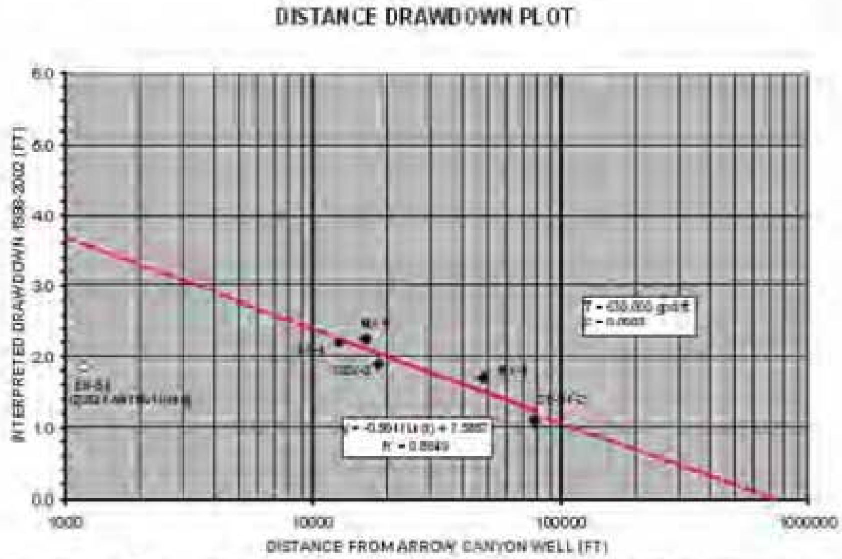

Figure 13 — Distance Drawdown Interpretation for Carbonate Aquifer Wells in the Vicinity of the Arrow Canyon Well.

It is important to note that the distance-drawdown relationship presented in Figure 13 is highly dependent on the interpretation of drawdown in well CE-VF-2, located approximately 14.7 miles from the Arrow Canyon well. Without this single data point, the amount of water level decline amongst the five remaining observation wells is practically uniform (Figure 14), supporting the hypothesis of a regional lowering of potentiometric water levels instead of a distance-drawdown effect.

Table 4 – Comparison of Interpreted Distance-Drawdown from Arrow Canyon Well with Theis.

Well	Distance from Arrow Canyon (ft)	Drawdown Interpreted from Hydrograph (1998 to 2002)	Theis Predicted Drawdown, (T=630,000 gpd/ft, S=0.0007)	Percent Difference
EH-5B	1,148	1.95	3.62	46.2
EH-4	12,714	2.2	2.27	2.9
MX-6	16,360	2.25	2.12	-6.0
CSV-2	18,393	1.9	2.06	7.6
MX-4	48,125	1.7	1.52	-12.2
CE-VF-2	77,572	1.1	1.25	11.7

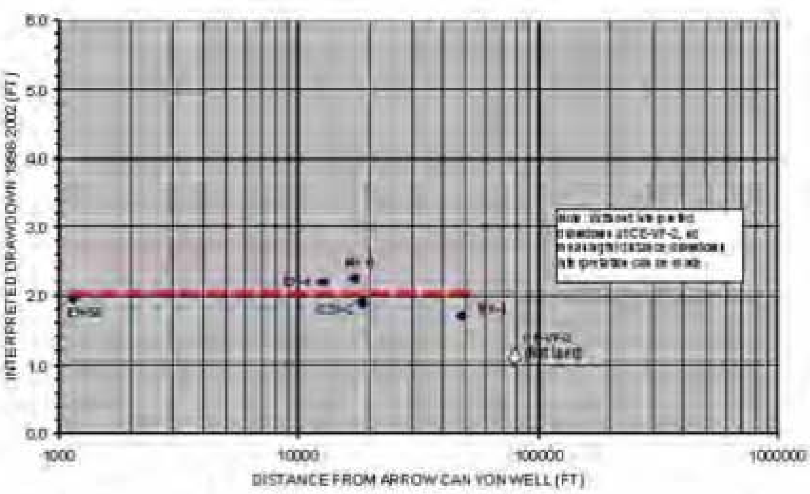

Figure 14 — Alternative Interpretation of Distance Drawdown Data if Well EH-5B is Included andWell CE-VF-2 is Removed from Consideration.

PEDERSON SPRING DISCHARGE TRENDS

Pederson Spring typically produces a monthly average flow of approximately 0.18 to 0.26 cfs. From one perspective, it can be noted that even after 5 years of a declining trend in discharge, flows are still within historic rates (Figure 5). This observation in itself supports an interpretation that climate is the dominant factor contributing to the presently declining trend. A comparison of climate indices and spring discharge shows spring discharge response that can be visually correlated to climate (Figure 15).

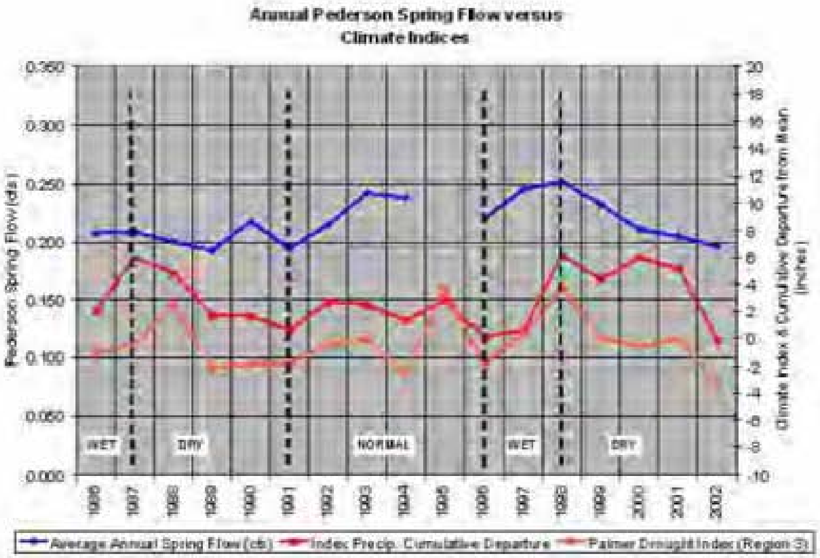

Figure 15 — Comparison of Pederson Spring Flows with Regional Climate Trends. Data source for spring discharge: USGS.

Moapa Valley Water District's pumping of the Arrow Canyon well increased by about 300 percent from 1997 to 1998 (Figure 7) due to changes in operation pumping strategies. During that same time, Pederson Spring and down-gradient Warm Springs West discharges were observed to have remained at the highest mean annual discharge (or annual volume) on record. Given the confined nature of the carbonate aquifer, relatively immediate and clear responses would have been expected but were not observed, suggesting a lack of direct hydraulic connection between the Arrow Canyon well and Pederson Spring. However, interpretations of regional water level trends tend to support pumping drawdown influences to the carbonate aquifer, and time-lagged pumping drawdown effects may still be intertwined in a declining trend that is a combination of climate and pumping affects. Continued monitoring of discharges and water levels into the next wet climate cycle will aid in differentiation of the possible pumping affects versus natural climate affects to the springs.

Applicability of Darcy's Law in Spring Flow Regimes

Some interpretations of Pederson Spring discharge and response to aquifer potentiometric water level change have applied the well-known Darcy's Law for fluid flow through porous medium, assuming a direct relationship between head and discharge. This assumption may be overly simplistic to represent the complexities of the spring system. Upward flow from the carbonate aquifer may be visualized as upward flow through a network of calcium carbonate cemented pathways or conduits. Upward velocities through these pathways may be high enough to create a turbulent flow regime, invalidating application of Darcy's Law, which assumes laminar flow and a Reynolds number below a critical range of 1 to 10 (Deming, 2002). Future interpretations of responses of spring discharge to potentiometric water level fluctuations need to take this into consideration.

BAROMETRIC PRESSURE RESPONSES

Aquifer Responses of Barometric Pressure Fluctuations

Barometric pressure will fluctuate throughout any given day in response to weather, but also exhibits an annual cycle in southern Nevada (Figure 16). High barometric pressures cause reduced potentiometric water levels in wells, which is a measurable phenomenon in confined aquifer systems, but is less noticeable in unconfined aquifers. Barometric efficiency is a unit-less (ft/ft) coefficient that defines the relationship between atmospheric pressure change and potentiometric water level change, with atmospheric pressure being expressed as equivalent height of water rather than more common units of millibars or inches of mercury. In confined aquifers, barometric efficiencies typically range from 0.2 to 0.7 (Todd, 1980).

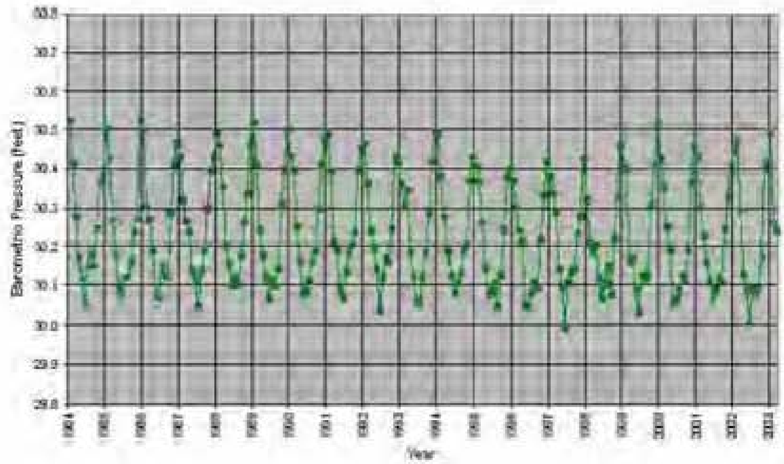

Figure 16 — Monthly Average Barometric Pressure recorded at Las Vegas McCarran Airport. Data Source: National Climate Data Center.

Barometric pressure is documented as measurably affecting potentiometric heads in the carbonate aquifer in southern and central Nevada. Bright and others (2001) documented barometric pressure responses of maximum amplitude of approximately 1.0 feet in well WW-5a at Frenchman Flat. Fenelon and Moreo (2002) calculated barometric efficiencies of 0.48 for Tracer Well 3 in Amargosa Desert, and 1.0 for well JF-3 in Jackass Flats. Kilroy (1992), Harrill and Bedinger (2000), and Fenelon and Moreo (2002) calculated the barometric efficiency of Devils Hole be in the range of 0.31 to 0.40.

Barometric pressure responses in monitoring wells completed in the carbonate aquifer in the vicinity of Muddy Springs appear to range from approximately 0.6 up to 1.2 feet annually (wells MX-4, CSV-4, EH-4, EH-5B, and CE-VF-2, time period mid- to late 1980s to present), without consideration of earth tide influences caused by gravitational attraction of the sun and moon.

Earth tide effects are observed in the vicinity of the Nevada Test Site and Devils Hole to have similar or lesser magnitudes as compared to barometric responses (Harrill and Bedinger, 2000; and Fenelon and Moreo, 2002), creating background noise in the datasets. Effects of earth tides have not been removed from barometric efficiency calculations presented herein. Because the period of frequency of earth tides is in cycles of semi-daily, daily, and cumulative 2-week cycles, and because the length of records evaluated in this study ranged from 1 month to 1 year, earth tide "noise" in the datasets is not expected to significantly affect the barometric efficiency interpretations. However, earth tide fluctuations are believed to account for a large portion of observed data scatter, resulting in lower than optimum correlation coefficients.

Barometric efficiency for well MX-4 was initially defined as approximately 0.67 using daily average data from January 1991 through December 1995 (Figure 17). This computational method utilized barometric pressure data measured in Las Vegas, as no site specific data was being collected at the time, and relies upon the occurrence of annual cycles of barometric pressure and larger scale day to day fluctuations. Annual plots of average daily barometric pressure versus average daily potentiometric water level were analyzed by linear regression, the slope of the regression line defining the barometric efficiency. Correlation coefficients were low and did not exceed 0.58, with apparent shifts in water levels observed in the 1991 and 1993 datasets, accounting for the lowest correlation coefficients. However, the slope of the barometric pressure versus potentiometric water level relationship was visually apparent for all years as best exhibited for 1992 (Figure 18), with annually derived barometric efficiency values falling within plus or minus 37 percent of the 5-year average.

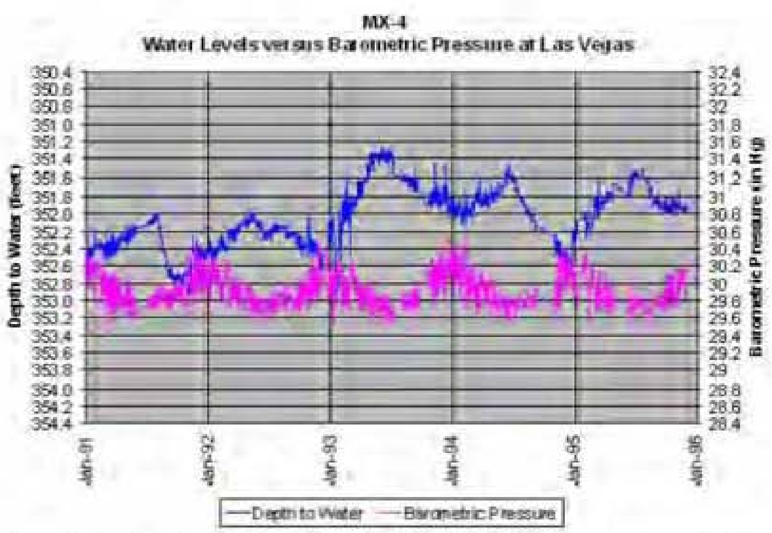

Figure 17 — Depth to water at monitoring well MX-4 versus barometric pressure at Las Vegas. Data sources: Barometric pressure from the National Climate Data Center, MX-4 water levels from USGS.

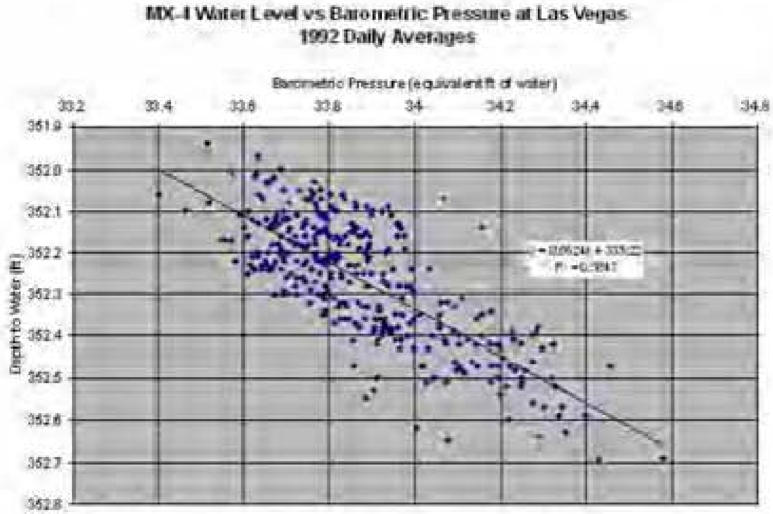

Figure 18 — Average Daily Barometric Pressure at Las Vegas versus Average Daily Water Level at Well MX-4. Data sources: Barometric pressure from the National Climate Data Center, MX-4 water levels from USGS.

Since August 2003, barometric-pressure data have been locally collected by SNWA on 15-minute intervals at monitoring well UMVM-1, allowing for more rigorous barometric efficiency computations. The barometric efficiency at well UMVM-1 is calculated as 0.60 (Figure 19). Preliminary barometric efficiencies for MX-4, EH-4, and EH-5b are calculated at 0.42, 0.25 and 0.50, respectively (Table 5, and Figure 20). The barometric efficiency for MX-4 is noticeably lower at 0.42 than calculated using 1991 to 1995 average daily data, and further data collection and analysis is needed to refine the estimates, thus all reported values are considered preliminary.

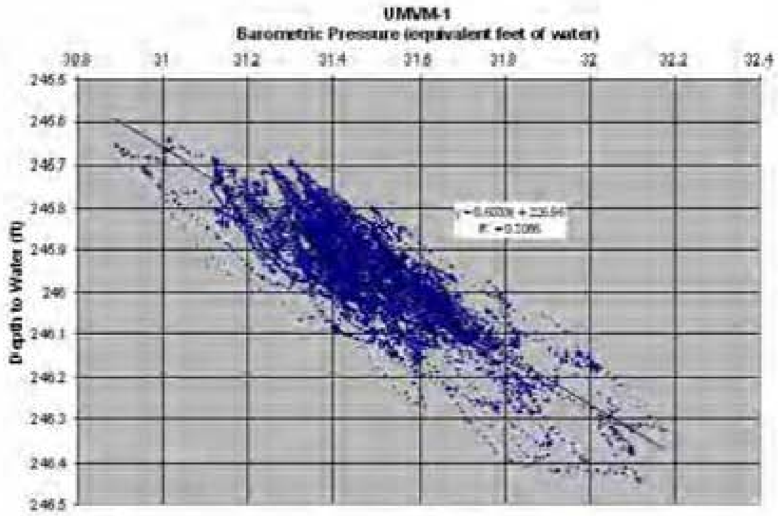

Figure 19 — Barometric Pressure vs. Water Levels recorded at monitoring Well UMVM-1 (15-minute data from August 13, 2003 to December 17, 2003), unadjusted for earth tide effects.

Table 5 – Summary of Barometric Efficiency Calculations using UMVM-1 Barometric Pressure Data, August to December 2003.

Site	Location of Barometric Pressure Data	Time Period	Time Interval	Barometric Efficiency	R^2
UMVM-1	UMVM-1	Aug. 13 to Dec. 17, 2003	15-minute	0.60	0.71
MX-4	UMVM-1	September 2003	Hourly	0.42	0.61
EH-5b	UMVM-1	September 2003	Hourly	0.50	0.58
EH-4	UMVM-1	September 2003	Hourly	0.25	0.59

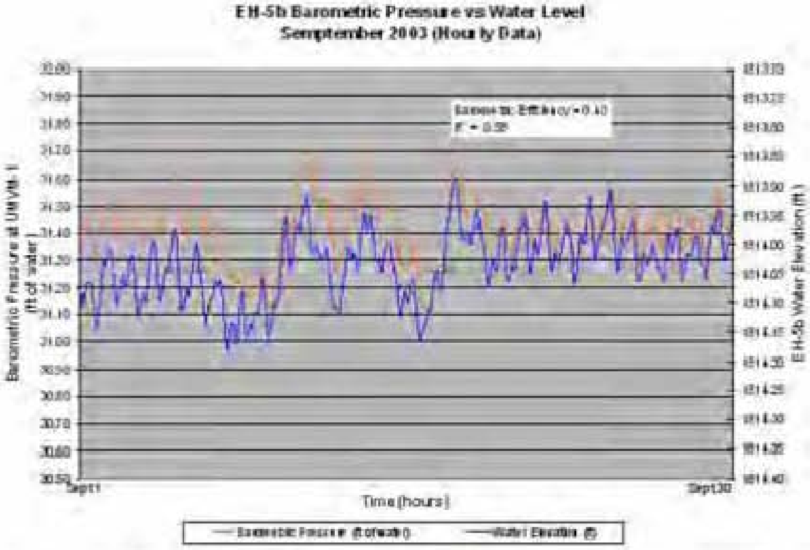

Figure 20. — Barometric Pressure at UMVM-1 versus Potentiometric Water Level at Well EH-5b for Hourly September 2003 Dataset.

Pederson Spring Discharge Responses to Barometric Pressure Fluctuations

Assuming Pederson Spring responds similarly to a piezometer tapping the confined carbonate aquifer and the discharge response to barometric pressure change is significant enough to be measured, a spring discharge barometric efficiency may be defined. At Pederson Spring, a visual correspondence between seasonal barometric pressure change (Las Vegas data) and spring discharge appears present in the time period of 1987 to 1990, prior to significant local pumping from the carbonate aquifer (Figure 21). A preliminary barometric efficiency of 0.04 cfs/ft has been derived using average weekly and average monthly datasets, which relies predominantly upon the longer-term annual cycle in local barometric pressure. With the recent repair of the Pederson Spring weir and on-going barometric pressure data collection at well UMVM-1, continued examination of the apparent discharge response to barometric pressure fluctuation will be possible.

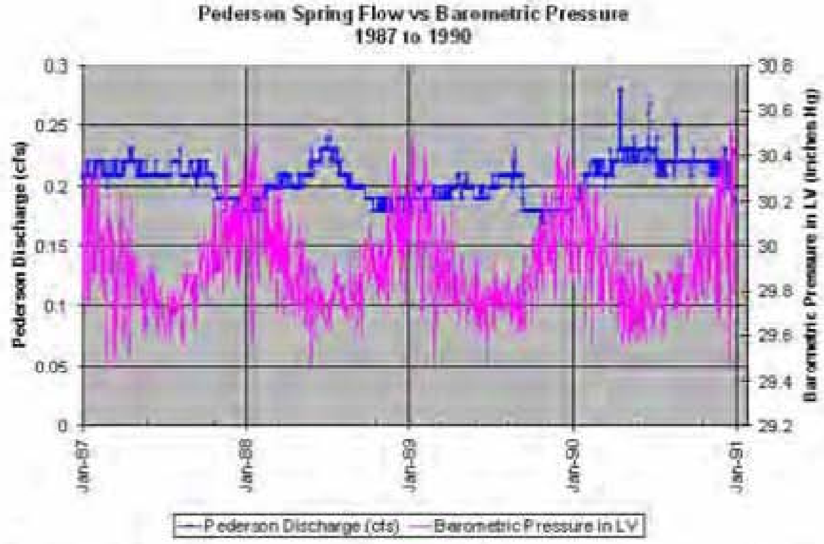

Figure 21 — Pederson Spring Discharge versus Daily Average Barometric Pressure Recorded in Las Vegas. Data sources: barometric pressure from the National Climate Data Center, Pederson Spring discharge from USGS.

The preliminary barometric efficiencies in the carbonate aquifer up-gradient of the Muddy Springs and at Pederson Spring can be combined to define a Pederson Spring discharge response function to potentiometric water level change in the carbonate aquifer, as follows:

(1) $\Delta H_{aquifer} = BE_{aquifer} \times \Delta H_{pressure\text{-}H2O}$
(2) $\Delta Q_{Pederson} = BE_{spring} \times \Delta H_{pressure\text{-}H2O}$

Combining equation 1 and 2 with the common variable of $\Delta H_{pressure\text{-}H2O}$ yields:

(3) $\Delta Q_{Pederson} = (BE_{spring}/BE_{aquifer}) \times \Delta H_{aquifer}$

where,

- $\Delta H_{aquifer}$ is the differential potentiometric head change (feet) caused by barometric pressure fluctuation;
- $\Delta H_{pressure\text{-}H2O}$ is the barometric pressure expressed in equivalent height (feet) of water;
- $\Delta Q_{Pederson}$ is the differential discharge change (cfs) caused by barometric pressure fluctuation;
- $BE_{aquifer}$ is the barometric efficiency of the carbonate aquifer, and
- BE_{spring} is the barometric efficiency of Pederson Spring.

Applying a unit value for $\Delta H_{aquifer}$ of 1, BE_{spring} of 0.04 cfs/ft, and $BE_{aquifer}$ of 0.50 (as defined at EH-5B, and as a general average for the carbonate aquifer up-gradient of the Muddy Springs), one foot of potentiometric head change in the carbonate aquifer equals approximately 0.08 cfs of discharge change in Pederson Spring.

From the derived spring response function, the observed discharge decline in Pederson Spring from 1999 to early 2003 (prior to significant weir leakage) of approximately 0.06 cfs (see Figure 5) is estimated to reflect a 0.75 feet potentiometric head decline in the portion of the carbonate aquifer feeding the spring. This is significantly less than the observed potentiometric head decline in well EH-4, which is approximately 2.0 feet during the same time period, indicating a disconnection between aquifer water levels and spring flows. Faulting between the springs and EH-4 (Figure 3) may be creating a hydraulic discontinuity between these two locations within the aquifer. It should also be noted that well EH-4 may be completed in younger carbonate rocks of the Horse Springs Formation rather than Paleozoic carbonate rocks which hosts the regional flow system (Figure 3).

SUMMARY

Regional climate in White River Flow System and Muddy Springs has exhibited dry conditions from 1999 through 2004. Climate appears to have a degree of effect on the local carbonate aquifer, however, declining water level trends began in 1998, one year prior to the dry climate cycle, and appear to be more dramatic than previous responses to climate, based on the limited period of record from the mid-1980s to present. Pumping from the carbonate aquifer at the Arrow Canyon well is believed to be responsible for a portion of the declining trend in potentiometric water levels, with distance-drawdown interpretations generally consistent with Theis theory. However, distance-drawdown interpretations are uncertain due to a strong dependence on the interpretation of drawdown at a single well (CE-VF-2) located 14.7 miles from the Arrow Canyon well.

Several discordances support the presence of hydraulic discontinuities within the carbonate aquifer in the vicinity of the Muddy Springs. Pederson Spring discharge did not commence a declining trend until 1999, an observation which is more consistent with response to a dry climate cycle. Secondly, the magnitude of spring discharge response does not appear consistent with the magnitude of potentiometric water level decline measured in nearby well EH-4. The predicted potentiometric decline at Pederson Spring is approximately 0.8 feet from 1999 to early 2003 as derived using preliminary barometric pressure response relationships, versus 2.0 feet of potentiometric water level decline observed in nearby well EH-4. Other discordances include a less than expected potentiometric drawdown response in well EH-5b due to Arrow Canyon well pumping, based on Theis drawdown theory, and a barometric efficiency reduction from approximately 0.5 up-gradient of the springs to 0.25 adjacent to Pederson Spring at well EH-4.

North-south trending faults are mapped crossing the Muddy Springs in the vicinity of Pederson Spring and well EH-4. Also, well EH-4 is suspected to be completed in the Horse Springs Formation, a much younger fresh water carbonate rock formation, rather than the Paleozoic carbonate rocks that constitute the regional carbonate aquifer, although drawdown responses in EH-4 appear in line with carbonate aquifer wells up-gradient of the Muddy Springs. Hydraulic connections between formations in the vicinity are unclear, and faulting appears to form conduits for discharge of deeper carbonate aquifer water, but may constitute hydraulic barriers to lateral spread of pumping drawdown effects.

Interpretations of climate versus pumping responses in the local carbonate aquifer will gain confidence with continued water level and spring discharge monitoring, and with the undertaking of the planned long-term carbonate aquifer test at well MX-5. The recent replacement of the Pederson Spring weir along with the addition of carbonate aquifer monitoring wells and collection of local barometric pressure data will aid in future interpretations and refinement of the preliminary barometric efficiencies and Pederson Spring discharge responses.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of Judy Brandt, GIS Specialist and Colby Temple, Hydrologist Intern, both with SNWA, for their assistance with data collection and graphics.

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Appendix F

Southern Nevada Water Authority 2007 Water Level and Climate Variation Report plus Addendum

SE ROA 10281

Updated Review of Water Level and Discharge Trends at the Muddy Springs, Clark County, Nevada

Prepared by:

Southern Nevada Water Authority
and
Dwight L. Smith, Interflow Hydrology

Executive Summary

Previous analyses on hydrologic and meteorological data for the Muddy Springs region were performed for the purpose of interpreting historical fluctuations in water level of wells and discharge of springs in the region (SNWA, 2004). The analysis concluded that factors such as: climate, carbonate pumping by Moapa Valley Water District (MVWD), and seasonal barometric pressure cycles were all contributing to the variations in water levels and spring discharge. In addition, data had indicated recent steady declines in spring discharge from the Pederson Spring were occurring; however, these declines were believed to be partially (if not the full result of) the product of a leaky weir structure as a result of construction activities occurring in and around the spring orifice, and the resultant loss of quantifiable flow.

In the 6 years prior to the 2004 analyses, the entire Southern and Central Nevada region was in a period of prolonged drought. Data indicated a regional decline in carbonate aquifer water levels during this period, leading to the conclusion that climate may have a significant role in regional aquifer water levels.

Soon after publication of these results and conclusions by Smith and others (2004), the period of prolonged drought was interrupted by a very wet 2005 water year. After the conclusion of the 2005 water year, data indicated that water levels increased regionally. These observations further reinforced the significant role climate may have on water levels.

An index precipitation was created using long-term data from six precipitation stations around the basins of the White River Flow System. To define historical wet and dry climate trends, the cumulative departure from mean was calculated using the index precipitation values. A comparison of the index precipitation versus National Climate Data Center (NCDC) Standard Precipitation Indices (SPI) for zones covering the White River Flow System, along with high altitude precipitation data from the nearby Sheep Range was made to examine how the index precipitation from the White River Flow System compares with these other climate indices. Additional examination to develop the best possible climate index to correlate with natural variability in water levels in and spring discharges from the flow system should be undertaken in concert with Order 1169.

Hydrographs of historical water level measurements from carbonate and alluvial aquifers around the Muddy Springs region, which included the recent 2005 water year levels were compared. The comparisons demonstrated an overall rise in carbonate aquifer water levels in response to the wet 2005 water year. Wells completed in alluvial sediments did not demonstrate clear climatic responses, probably due to the fact that these alluvial aquifers are not as directly connected to the regional flow system as the carbonate aquifers. Although these water levels fluctuations are readily apparent, a comparison of carbonate aquifer water level fluctuation with the index-precipitation cumulative departure indicates that although climate is a prominent variable, it is not the sole variable.

To further analyze for statistically significant trends in the carbonate wells across the Muddy Springs region a Mann-Kendall trend test was performed. The analysis entails a rank-based test for monotonic correlation between two variables; in this case water level

(y) versus time (x). Results of the Mann-Kendall analysis suggest statistically significant declining water trends are present in many of the carbonate wells.

Replacement of the weir structure of Pederson Spring in the summer of 2004 warranted revisiting the spring flow discharge data. Immediately after the replacement of the weir structure, discharge measurements returned to within the historic range of the record. By applying the Mann-Kendall trend test to both the Pederson and Warm Springs discharge measurements, no statistically significant trend in a fluctuation of spring discharges beyond historic ranges is statistically likely.

To further assess the influence of climate fluctuation at Warm Springs West a bivariate model was prepared. The two variables in the model that are used to adequately explain the majority of spring discharge variance are climate and pumping from the carbonate aquifer from MVWD Arrow Canyon wells 1 and 2, and the MX-6 well. Results from the bivariate model suggest that long-term variations in regional precipitation may account for about 73 percent of the variance in spring discharge, while 10 percent of the variance may be from pumping at Arrow Canyon and MX-6. The remaining of 17 percent residual is not explained by the model.

Background

In 2004, SNWA published interpretations of water levels and spring discharges fluctuations observed in the Muddy Springs region, and in particular Pederson Spring at the Moapa Wildlife Refuge (Smith and others, 2004). Key interpretations were presented as follows:

- Climate plays a role in long-term water level and spring discharge trends,
- Pumping by Moapa Valley Water District (Arrow Canyon well) may also be contributing to observed long-term trends,
- Weir bypass and environmental changes in the Moapa Valley National Wildlife Refuge could be affecting spring discharge records,
- Cyclical seasonal variations in water levels and spring discharges are in part explained by seasonal barometric pressure cycles, and
- Uncertainty regarding principal influences over trends could be reduced once the existing long-term drought had been broken.
- The pumping planned to meet requirements of Order 1169 will enhance our understanding, and provide critical data to understand carbonate aquifer pumping responses and surface water – ground water interactions.

Water year (WY) 2005 was wetter than normal and interrupted a pronounced drought in southern and central Nevada. Las Vegas received approximately 74 percent above the long-term mean precipitation for calendar year 2005, and Lund in central-eastern Nevada received 21 percent above the mean (WRCC, 2007). On a water-year (WY) basis (October 2004 through September 2005), these percentages are even greater. The drought period extended from WY 1998 to 2004 and was believed to be at least partly responsible for declining water levels and spring discharges. Commencement of nearby pumping from the carbonate aquifer by the Moapa Valley Water District (MVWD) at the

Arrow Canyon well coincided with the period of drought, thus, differentiation between climatic influence and possible pumping drawdown was problematic. During 2005, water levels and spring discharges were observed to rise, coincident with the wet year, allowing further examination and definition of climate response relationships. This technical memorandum reviews data collected from 2004 through 2006, and provides updated observations and interpretations.

Review of Climate Trends

Long-term climate trends were previously reviewed by SNWA (Smith and others, 2004) using an index precipitation constructed using data from six stations with complete annual long-term precipitation records (Table 1). The six stations are geography situated from Las Vegas to the White River Valley (Figure 1), and generally represent the extent of the White River Flow System, as defined by Eakin (1966). These precipitation stations are located on the valley floors, and it is assumed that similar precipitation trends occur in the higher altitude watersheds (recharge areas), although the amount of precipitation at higher altitudes is typically greater and more varied.

Table 1 – Summary of Regional Long-Term Precipitation Records

Station Name	NWS ID Number	Period of Record (complete annual records)	Unadjusted Long-Term Mean Precipitation (inches)
Lund	264745	1958 - present	10.25
Sunnyside	267908	1966 - present	9.41
Caliente	261358	1931 - present	9.13
Pahranagat	265880	1965 - present	6.33
Desert Game Range (Corn Creek)	262243	1949 - present	4.55
Las Vegas WSO Airport	264436	1937 - present	4.25

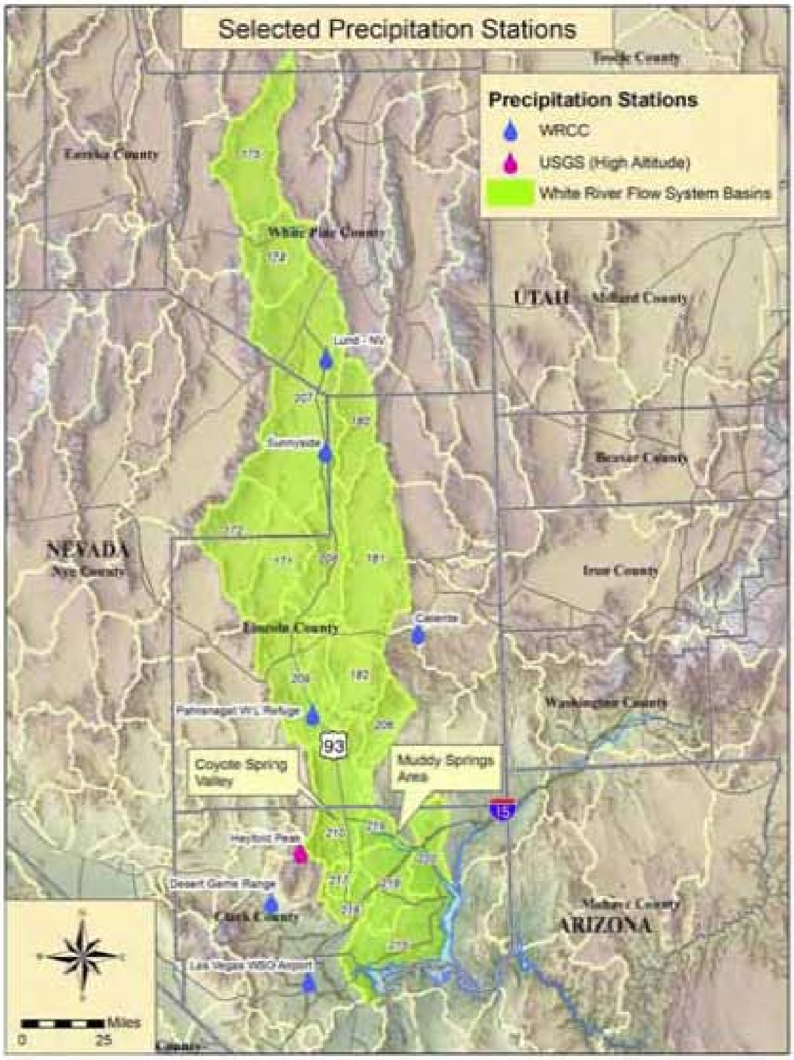

Figure 1 - Precipitation Stations Used in Calculating Index Precipitation

Construction of the index precipitation values required a degree of data synthesis to generate complete records back to 1931, and also to account for incomplete records, particularly at the Pahranagat station. The consistency of data for the Pahranagat station is poor for 1998 through 2003 and 2006, with measurement data missing for many periods ranging from several days to several weeks. These incomplete records have been reconstructed using an interpolation technique described by Dunne and Leopold (1978, p. 40-41) in conjunction with annual precipitation records from Caliente, Sunnyside, Desert Game Range (Corn Creek), and the Las Vegas Airport stations (see Table 2 and Figure 2). This technique was also used to create an estimate of annual precipitation record from 1937 to 1964 (Figure 2). Regression relationships with the Caliente station were also used to construct precipitation values for years between 1931 and the beginning of the period of record for other stations. This allowed a common starting date of 1931 for all stations used in preparation of the index.

Table 2 - Reconstruction of 1998 to 2002 annual precipitation records for Pahranagat Station (265880), Precipitation Values in Inches

Year	Reported (with significant missing data)	Dunne and Leopold (1978) Estimate using Four Regional Stations**
1998	7.71	11.63
1999	3.97	5.21
2000	3.31	7.38
2001	0.5	5.70
2002	0.69	1.93
2003	4.78	6.25
2004	8.21*	NA
2005	9.86*	NA
2006	3.73	5.03

* Data relatively complete
** Sunnyside, Caliente, Desert Game Range, Las Vegas WSO Airport

The index precipitation is weighted based on interpretations of recharge geographically distributed in the White River Flow System, as presented by Thomas and others (2001) and LVVWD (2001) (Table 3).

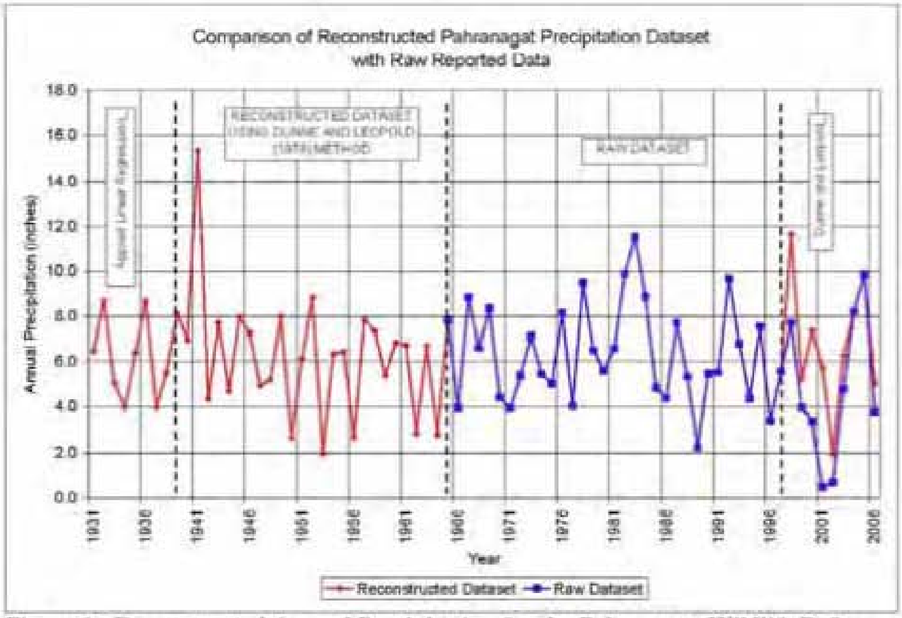

Figure 2 - Reconstructed Annual Precipitation for the Pahranagat Wildlife Refuge Station

Table 3 - Summary of Development of Regional Precipitation Index from SNWA (2001) and Thomas, and others (2001) White River Flow system Recharge Interpretations

Hydrographic Area	Recharge to Regional Flow System (AF/yr)	Percent Total Contribution	Regional Precipitation Trend Represented By Station
Region A – White River Valley, Long and Jakes	8,000*	14.8	Lund
Region B – Pahroc, Cave, Garden, Coal	19,000*	35.2	Sunnyside
Region C – Pahranagat, Dry, Delamar, Kane Springs	23,000**	42.6	Pahranagat (Reconstructed Dataset)
Region D – Coyote Spring Valley	4,000	7.4	Desert Game Range (Corn Creek)
TOTAL	54,000	100.0	

* Assumes approximately 55 percent of regional inflow (SNWA, 2001) to Pahranagat Valley is lost to ET in Pahranagat Valley, with 45 percent comprising regional outflow reflected in Muddy Springs.
** Assumes approximately 1,000 AF/yr regional recharge derived in Pahranagat Valley, with most local recharge consumed by ET within the valley.

Cumulative departure from mean precipitation is a frequently used graphical technique for illustrating and defining dry and wet climatic trends. For each year of precipitation record, the long-term mean precipitation is subtracted from the annual total, and the annual difference from the mean is cumulatively added. An upward sloping line indicates a wetter than average climatic period and a down-ward sloping line indicates a drier than average period (Figure 3). In many hydrology systems, it is common for long-term fluctuations of ground water levels and spring flows to correlate well with a cumulative departure from mean precipitation curve. In regional or deep flow systems, a lagged response of water levels or spring flow can occur as affects of precipitation fluxes propagate through the hydrologic system.

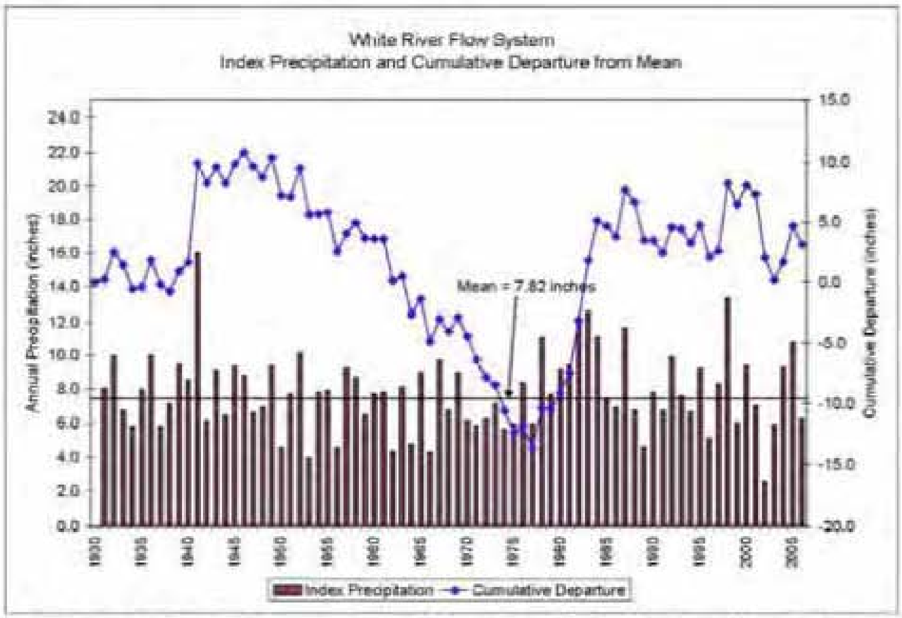

Figure 3 - Cumulative Departure from Mean Precipitation of the White River Flow System Index Precipitation

Historic precipitation indices (Standard Precipitation Indices) are published for four zones covering Nevada by the National Climate Data Center (NCDC). Zone 4 represents southern-most Nevada and Zone 3 covers south-central Nevada. These zones span east-west over the entire width of the state. A comparison of precipitation indices with the high altitude data at the Hayford Peak station in the Sheep Range is presented as Figure 4.

Since some north-south orientation to the carbonate aquifer flow system is interpreted due to the isotopically light water (derived from northern source areas) and the prevailing north-south geologic structural orientation of the Basin and Range Province, the flow-system specific index precipitation relationship is thought to more accurately represent precipitation falling on the recharge areas for the White River Flow System and the Muddy Springs. However, there is uncertainty in the flow system, the geographic distribution of recharge, and weighting of magnitudes of precipitation derived from recharge with the flow system.

It should also be noted that "localized" recharge, while not the dominate source of recharge to the flow system, could have disproportionate influences on water level fluctuations and spring flow discharges. For example, precipitation falling on the Sheep Range, while perhaps only contributing a small percent of the total flow system recharge, could be a dominant variable in controlling Coyote Springs Valley and Muddy Springs water level fluctuations.

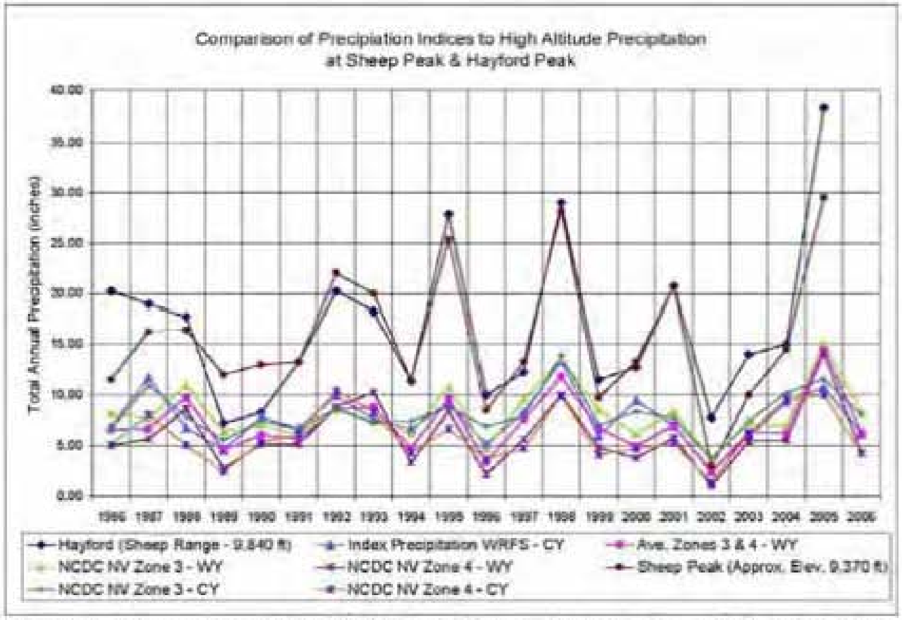

Figure 4 – Comparison of the USGS Sheep Range high-altitude precipitation station data with regional precipitation indices (WY = water year, CY = calendar year)

Review of Ground Water Fluctuations

Comparison of Hydrographs

Hydrographs of historic water level measurements are presented in Figures 6 through 20. Geographic locations of these wells are depicted in Figure 5. The hydrographs are grouped by aquifer type (carbonate-rock and alluvial) and hydrographic basin. Data presented in the hydrographs reflects data collected through September 2006 by the Nevada Power Company (NPC), and through November 2006 by SNWA. Some water level datasets have pumping water level measurements incorporated, such as well MX-6, pumped by the Moapa Valley Water District. Other pumped wells include those utilized by NPC (LDS East, LDS West and LDS Central). In these cases, apparent pumping water level measurements were removed from the hydrograph in order to observe static water level trends. Graphical interpretations are discussed below.

Clear responses to above average precipitation in water year 2005 are observed in many wells throughout the region. In Coyote Spring Valley, water levels in carbonate-rock wells CSVM-1, CSVM-2, CSVM-6, MX-4 and MX-5 (Figure 6) show a marked increase in response to the wetter period. However, water level responses in CSVM-3 (Figure 7) were gradual and CSVM-7 (Figure 8) showed little response to the wet year. Similar observations of discordances can be observed in other basins in the region. Several explanations are possible. The wells showing dampened response to climate may be completed in compartmentalized parts of the carbonate aquifer that are not well connected with the regional flow system. Alternatively, the geographic location and altitude of the wells may result in dampened climate responses. For example, the ground water gradient at wells CSVM-3 and CSVM-7 is steeper from a regional perspective than the gradients of wells closer to the valley floor. If the lower down gradient portion of the flow system is envisioned to respond like a reservoir, the dam being the Muddy Creek Formation down-gradient of the Muddy Springs and the reservoir being the lower portion of the high tranmissivity portion for of the carbonate-rock aquifer, the terminus "reservoir" may show more dramatic responses to wet and dry climate variations versus the higher gradient areas.

Wells completed in alluvium in Coyote Spring Valley (Figures 9-11) demonstrate differing responses to climate. Two of three wells, DF-1, and CSV-3, show a climactic response and the remaining well CS-VF-1, does not show a perceptible response. Differences in response could be related to the depth and extent of the basin fill aquifer(s) penetrated by the wells, hydraulic communication between aquifer(s) and the well, and the well's proximity to recharge areas such as Pahranagat Wash, or other variables.

Static water levels in carbonate-rock aquifer monitoring wells in the Upper Moapa Valley (Figure 12) show similar response to water levels observed at lower altitude wells in Coyote Spring Valley. Alluvial monitoring wells in the vicinity of the Muddy Springs show no perceptible responses to the 2005 wet water year (Figure 13), however, the alluvial well completed up-gradient of the Muddy Springs (CSV-1) shows a mild response to climate, and responses in the shallow alluvium may be masked by alluvial pumping.

Wells in Garnet Valley (Figure 15) show similar magnitude water level responses to climate with the exception of one well (GV Duke-WS1) where static water level data may have incorporated pumping.

Further down-gradient, water levels in the lower Meadow Valley Wash (Figure 17) have differing responses than observed in Coyote Spring Valley and the Muddy Springs area. Water levels trends show no clear correlation with climate, with the exception of the carbonate-rock aquifer well EH-7 (Figure 18).

In the Black Mountains area, carbonate monitoring wells (Figure 19) show similar response to climate as observed in Coyote Spring Valley and the Muddy Springs area, however, the wells completed in clastic rocks (Figure 20)show no clear response to climate variation.

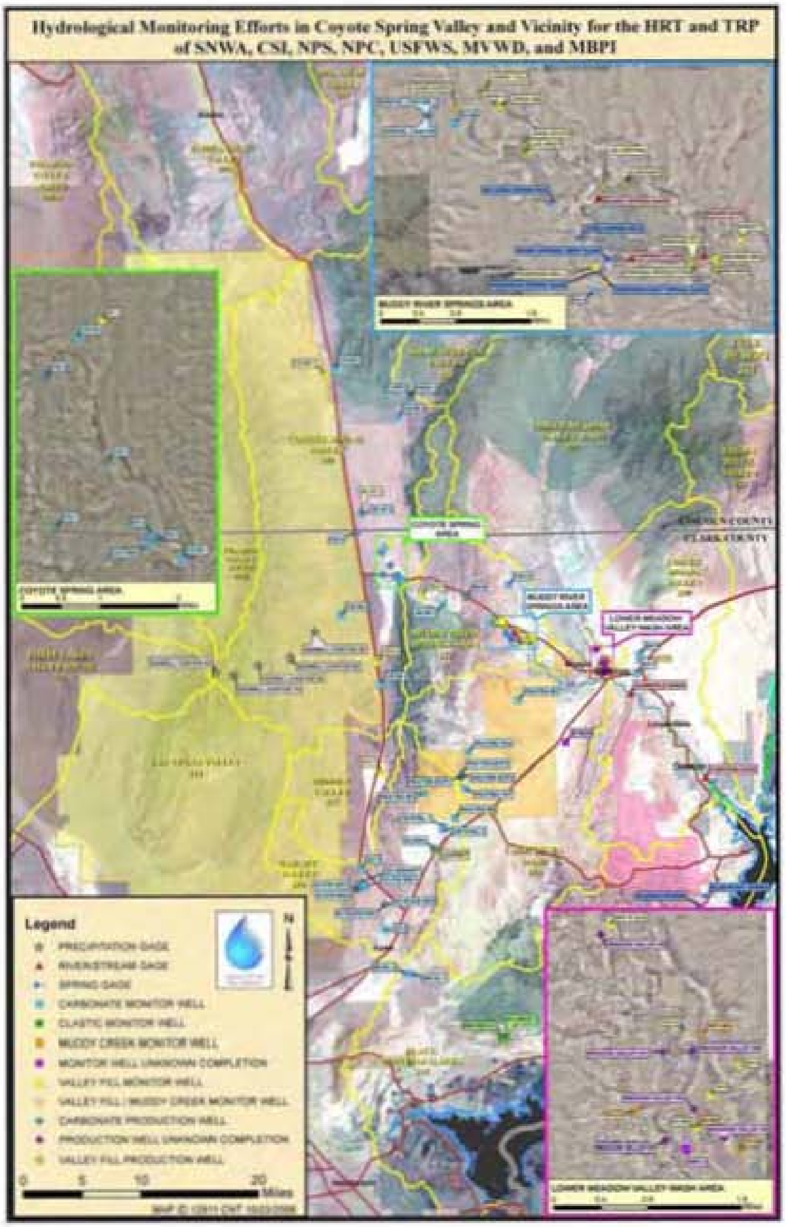

Figure 5 – Locations of wells discussed in this report

Figure 6 – Comparison of carbonate well hydrographs in Coyote Spring Valley

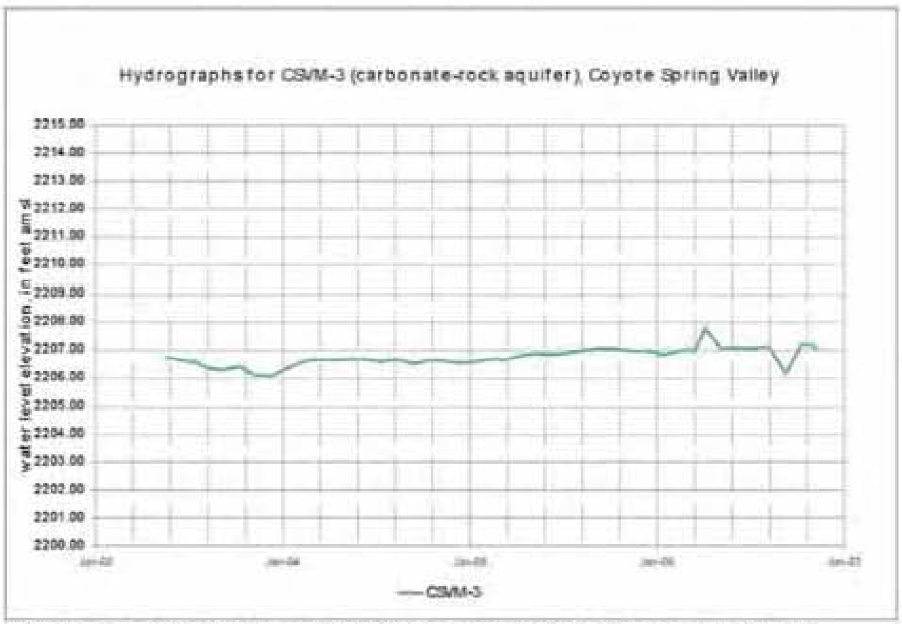

Figure 7 – Hydrograph for carbonate well CSVM-3 in Coyote Spring Valley

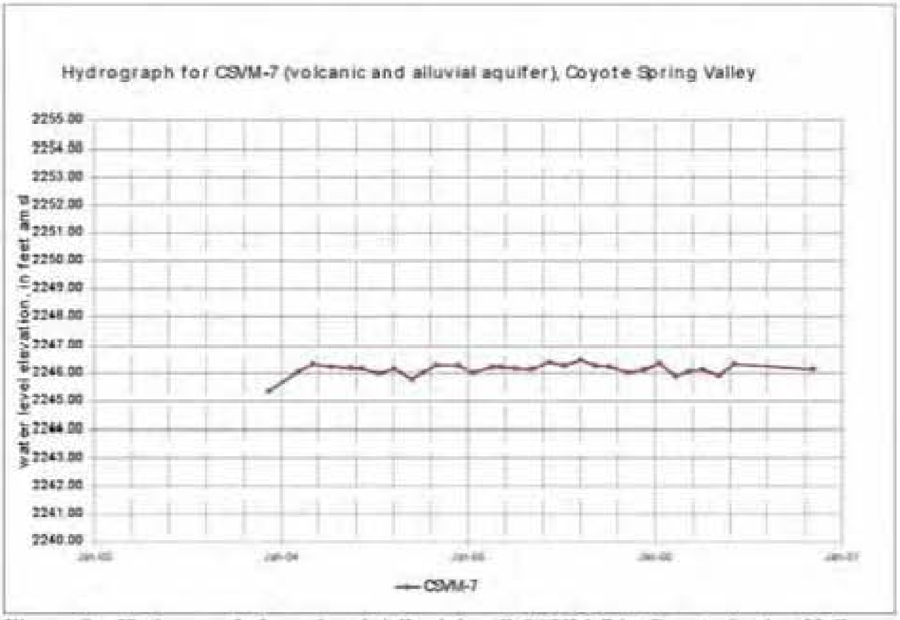

Figure 8 – Hydrograph for volcanic/alluvial well CSVM-7 in Coyote Spring Valley

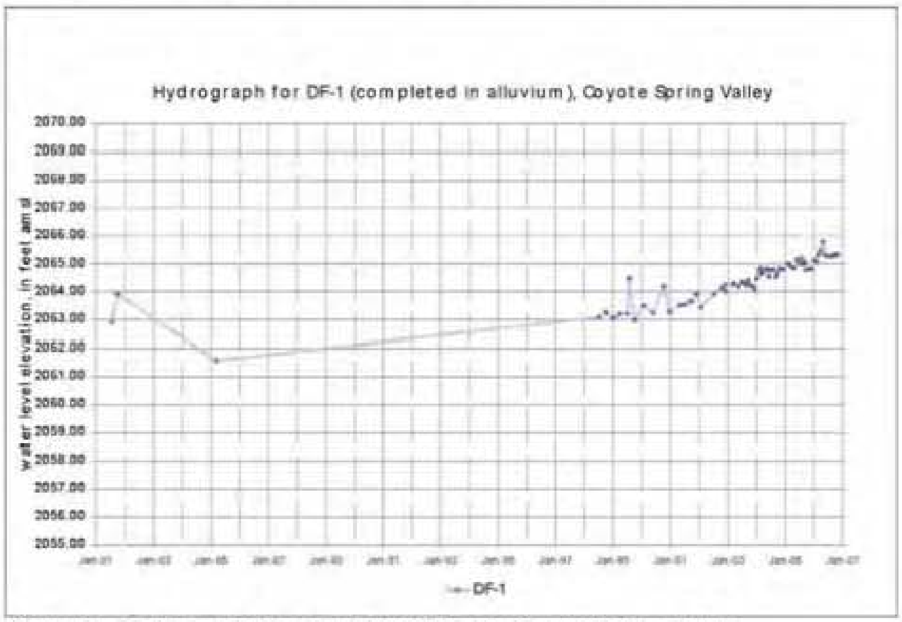

Figure 9 – Hydrograph for alluvial well DF-1 in Coyote Spring Valley

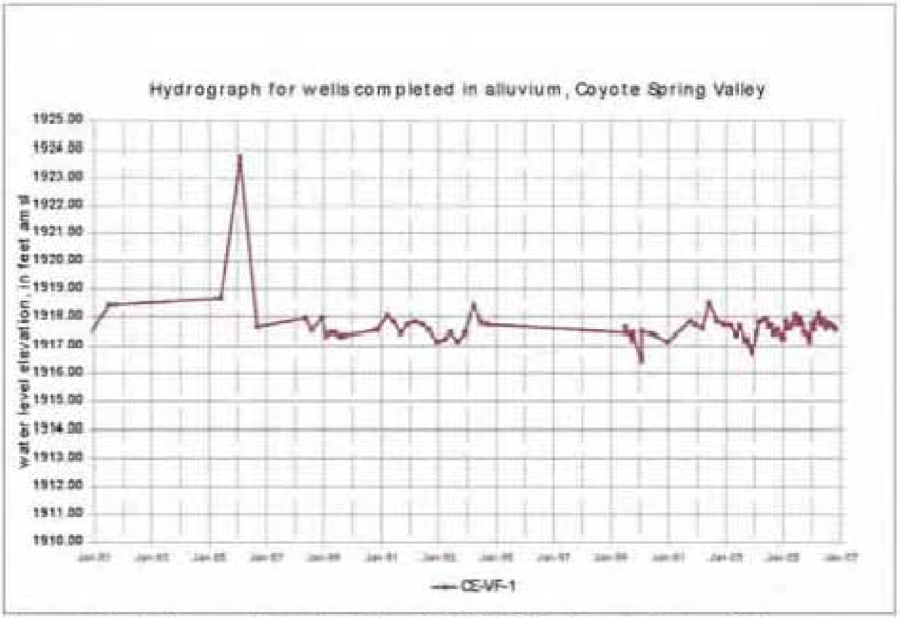

Figure 10 – Hydrograph for alluvial well CE-VF-1 in Coyote Spring Valley

Figure 11 – Hydrograph for alluvial well CSV-3 in Coyote Spring Valley

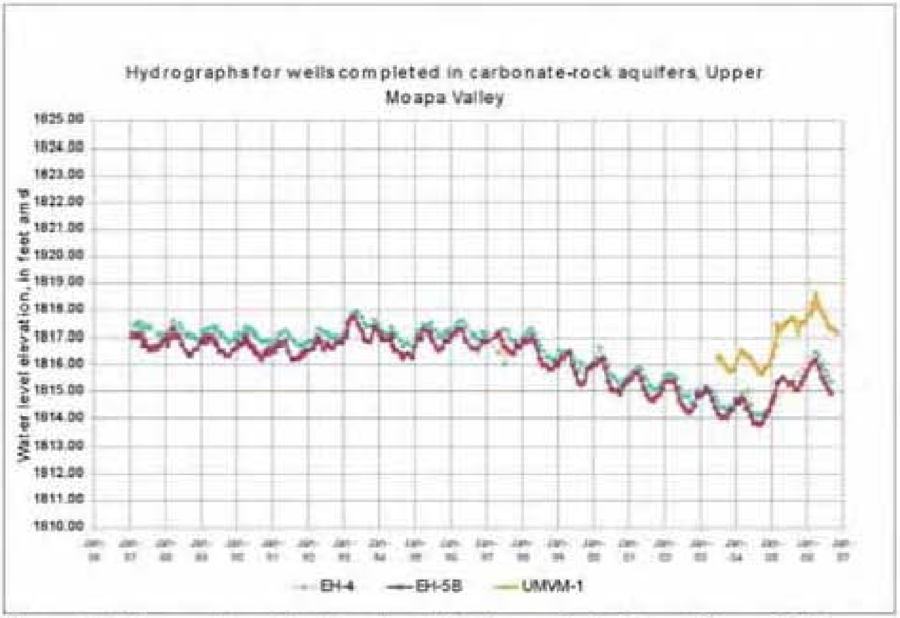

Figure 12 – Comparison of carbonate well hydrographs in Upper Moapa Valley

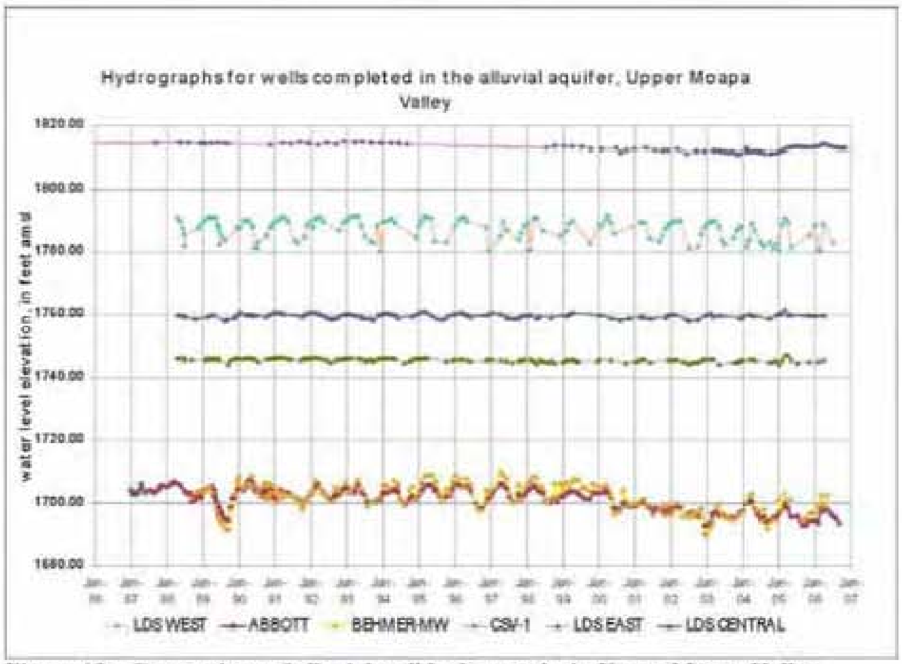

Figure 13 – Comparison of alluvial well hydrographs in Upper Moapa Valley

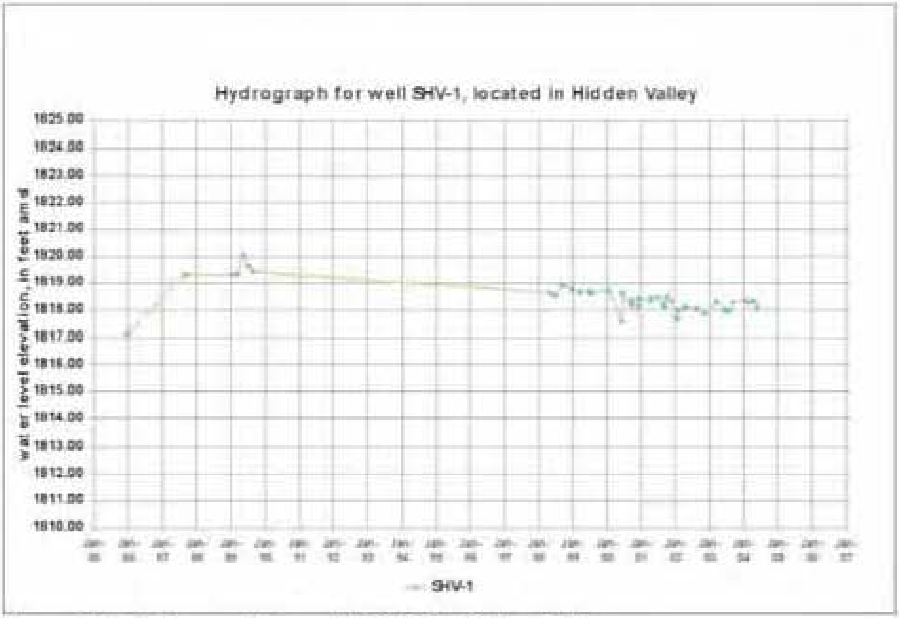

Figure 14 – Hydrograph for well SHV-1 in Hidden Valley

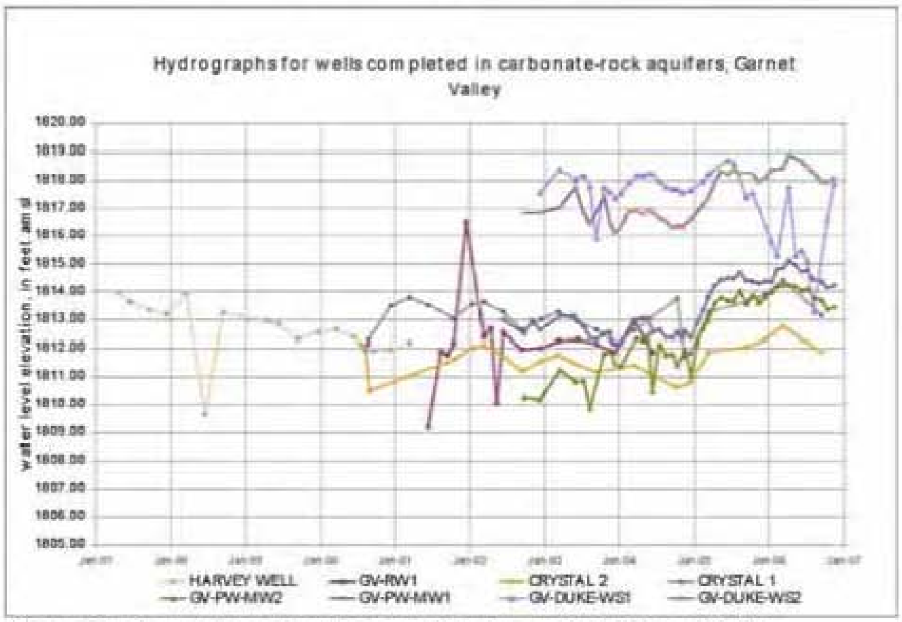

Figure 15 – Comparison of carbonate well hydrographs in Garnet Valley

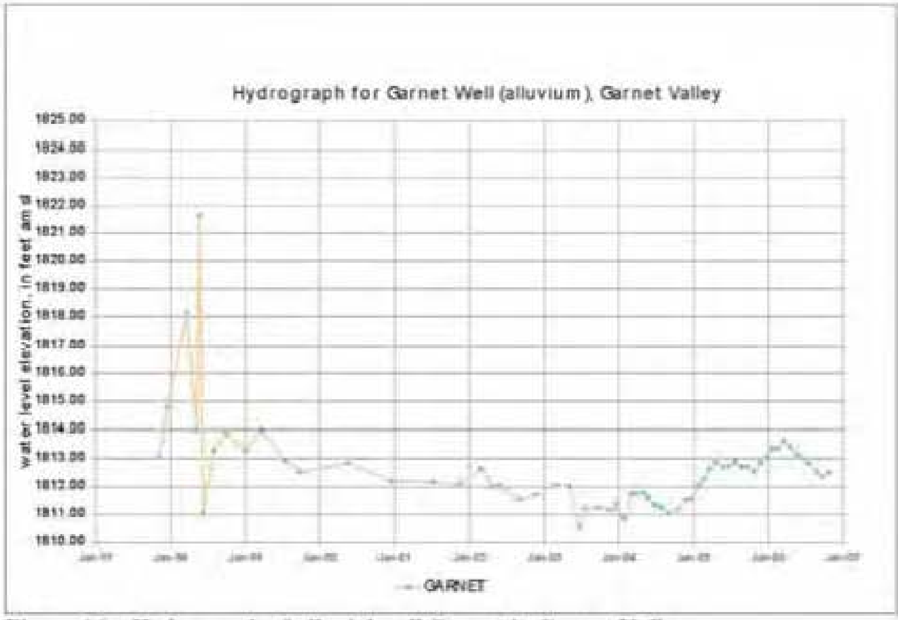

Figure 16 – Hydrograph of alluvial well Garnet in Garnet Valley

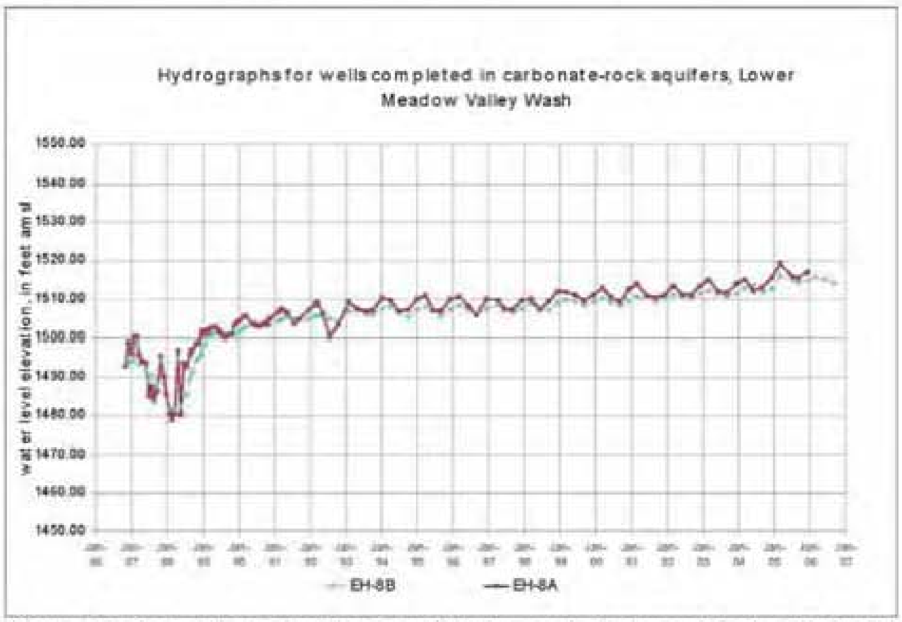

Figure 17 – Comparison of carbonate well hydrographs in Lower Meadow Valley Wash

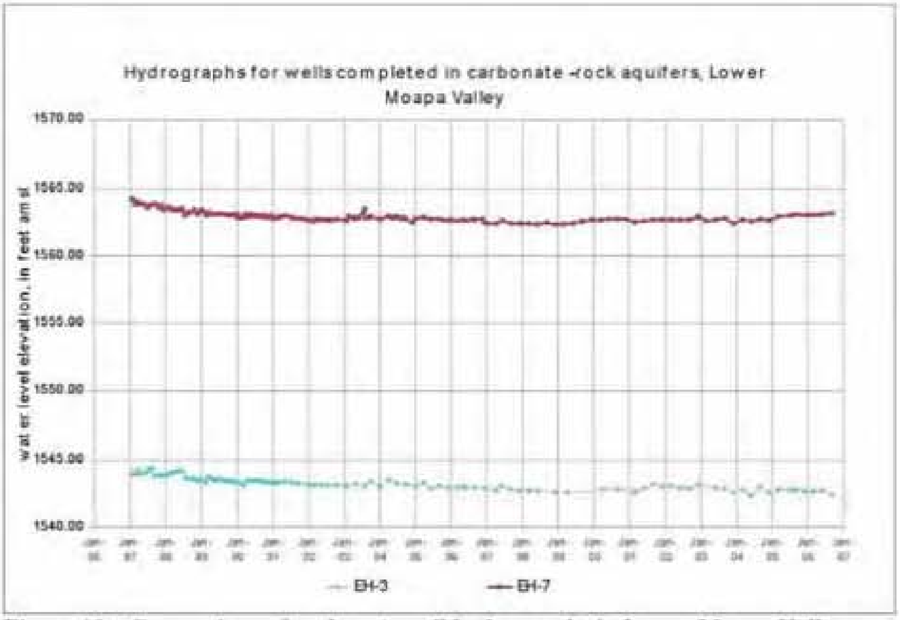

Figure 18 – Comparison of carbonate well hydrographs in Lower Moapa Valley

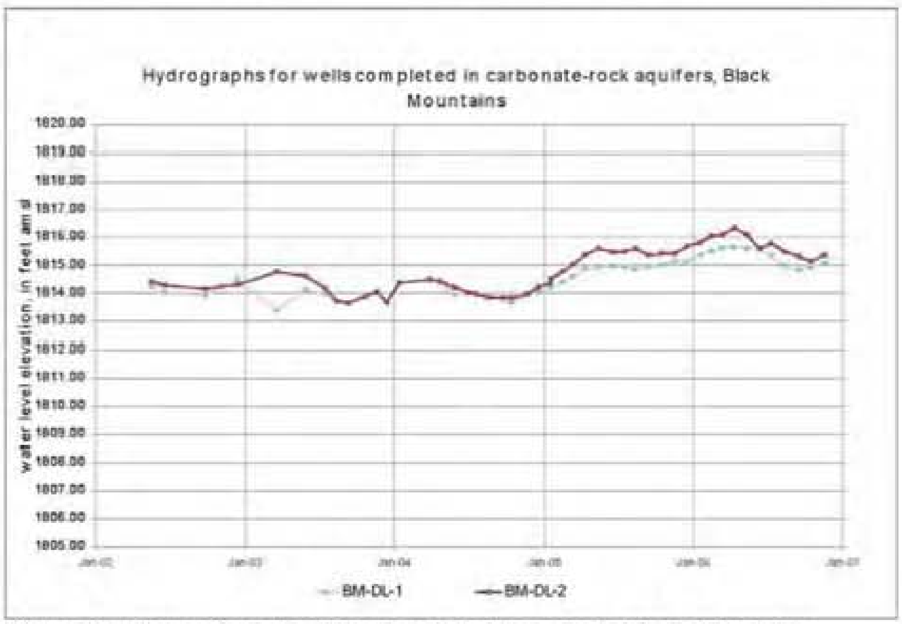

Figure 19 – Comparison of carbonate well hydrographs in Black Mountains

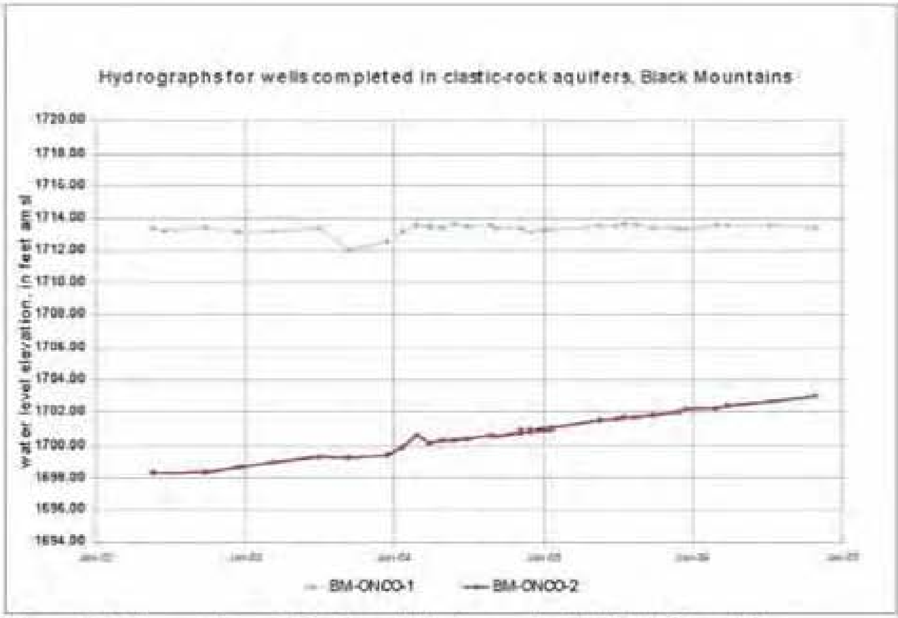

Figure 20 – Comparison of clastic-rock hydrographs for Black Mountains

Comparison of Precipitation Index and Water Level Fluctuation

Graphical comparison of the water level fluctuations in the carbonate-rock aquifer with the index precipitation cumulative departure curve (Figures 21 and 22) show similar trends, but appear statistically weak. These visual observations of hydrograph responses corresponding with long-term wet and dry cycles suggests that climate is a prominent variable but is not the sole variable responsible for water level trends.

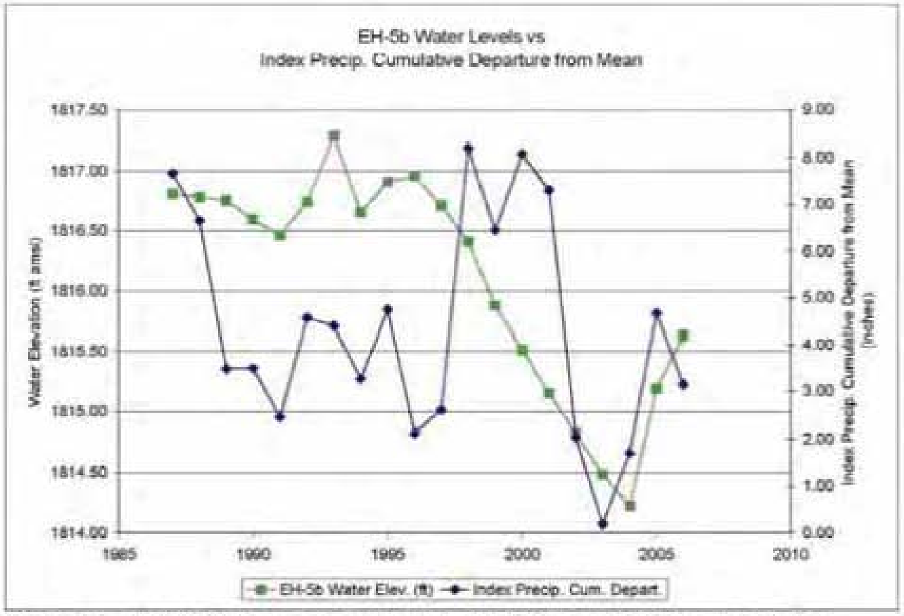

Figure 21 – EH-5b hydrograph compared with index precipitation cumulative departure from mean

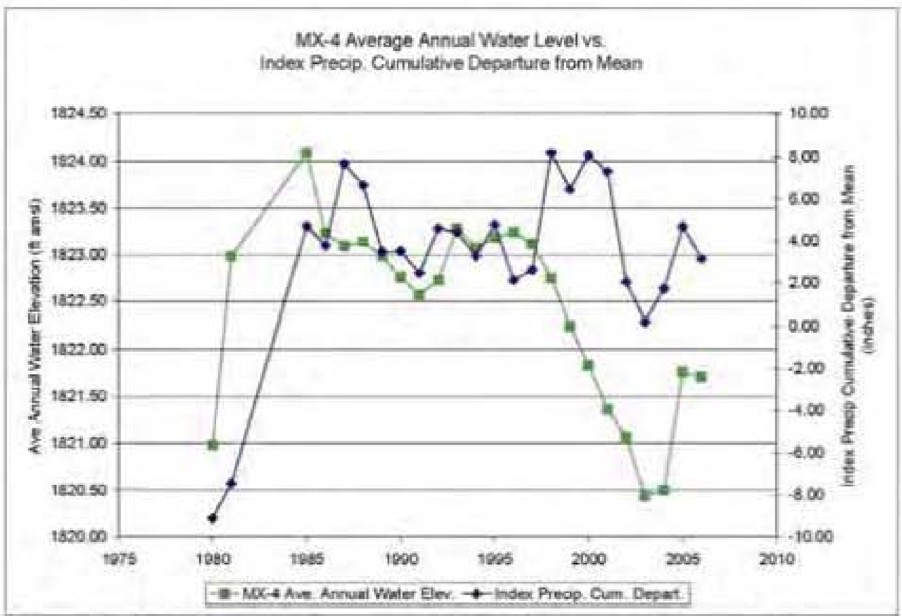

Figure 22 – MX-4 hydrograph compared with index precipitation cumulative departure from mean

Statistical Analysis

A Mann-Kendall test (Helsel and Hirsch, 2002) was applied to some of the monitoring well datasets to understand if a water level trend of statistical significance is present. Data sets selected for statistical analysis have a minimum of 10 years of record. Average annual water levels were used to remove the effects of seasonal variations.

Criteria used to define a trend of statistical significance are similar to that applied by Fenelon and Moreo (2002) for the Yucca Mountain region. Specifically, to identify a statistically significant trend, the following conditions were required:

- Mann-Kendall statistic (S) is significantly different from zero (assumed greater than 1.0)
- Kendall's tau (t) correlation coefficient is greater than 0.2,
- p-value for confidence level is less than 0.01 (99 percent confidence interval),
- Maximum change in water level is greater than 1.0 feet for a rolling 5-year average (note: Fenelon and Moreo used 0.2 ft for LOWESS smoothed data).

If these conditions have been met, then the trend is described as a statistically significant monotonic trend.

Mann-Kendall testing suggests that statistically significant declining water level trends are present in some of the carbonate-rock aquifer monitoring wells in the Muddy Springs region (Table 4). Statistically significant downward trends are also present in some alluvial wells in the Muddy Springs region. However, trend directions and the strength of trends are not uniform throughout the region, as can also be noted in visual review of the hydrographs.

Table 4 - Summary of Mann-Kendall trend test for historic water levels in selected wells in the region of Muddy Springs

Site name	Basin	Aquifer type	Period of record	Number of observations	Level of significance (p)	Kendall τ	Mann-Kendall S	Maximum change – rolling 5 yr average (ft)	Statistically significant trend
MX-4	Coyote Spring	Carbonate	1980 - 2006	196	0.0025	-0.449	-3.026	2.25	Down
CE-VF-1	Coyote Spring	Alluvial	1980 - 2006	88	0.310	-0.170	-1.015	1.4	None
DF-1	Coyote Spring	Alluvial	1981 - 2006	72	0.0003	0.636	3.659	1.6	Up
CSV-3	Coyote Spring	Alluvial	1985 - 2006	97	0.00005	-0.684	-4.061	3.2	Down
EH-5b	Upper Moapa	Carbonate	1987 - 2006	274	0.0002	-0.611	-3.699	2.1	Down
EH-4	Upper Moapa	Carbonate	1987 - 2006	249	0.00005	-0.661	-4.093	2.1	Down
Abbott	Upper Moapa	Alluvial	1986 - 2006	290	0.00007	-0.629	-3.986	7.0	Down
CSV-1	Upper Moapa	Alluvial	1985 - 2006	93	0.0001	-0.673	-3.901	2.2	Down
SHV-1	Hidden	Alluvial?	1989 - 2004	41	0.013	-0.714	-2.74	0.5	None
Crystal - 2	Garnet	Carbonate	1989 – 2004*	24	0.013	0.333	-2.474	0.5	None
Garnet	Garnet	Alluvial	1997 - 2006	62	0.060	-0.956	-1.878	1.0	None
EH-8A	Lower Meadow	Carbonate	1986 - 2005	112	7.7E-09	0.937	5.775	17	Up

* 8 years of record (less than 10 year criteria)
Note: Values in red fail respective statistical significance test (see text)

Review of Spring Discharge

The weir at Pederson Spring was replaced in the summer of 2004 by the USGS (Figure 23). An instantaneous increase in spring discharge was recorded (Figure 24), indicating that the older weir had not been measuring the full spring discharge. It is unclear if any bypass flow was occurring prior to USFWS restoration; however, the abrupt decrease in spring discharge observed in 2003 appears to have been leakage related. The US Geologic Survey (USGS) has removed this suspect data from the published discharge dataset for Pederson Spring (Figure 25).

After Pederson Spring weir replacement, spring discharge measurements returned to within the historic range of discharge recorded for the site (Figure 24), and an upward trend is observed during water year 2005, coincident with a wet climate period.

Figure 23 - Replacement Weir at Pederson Spring

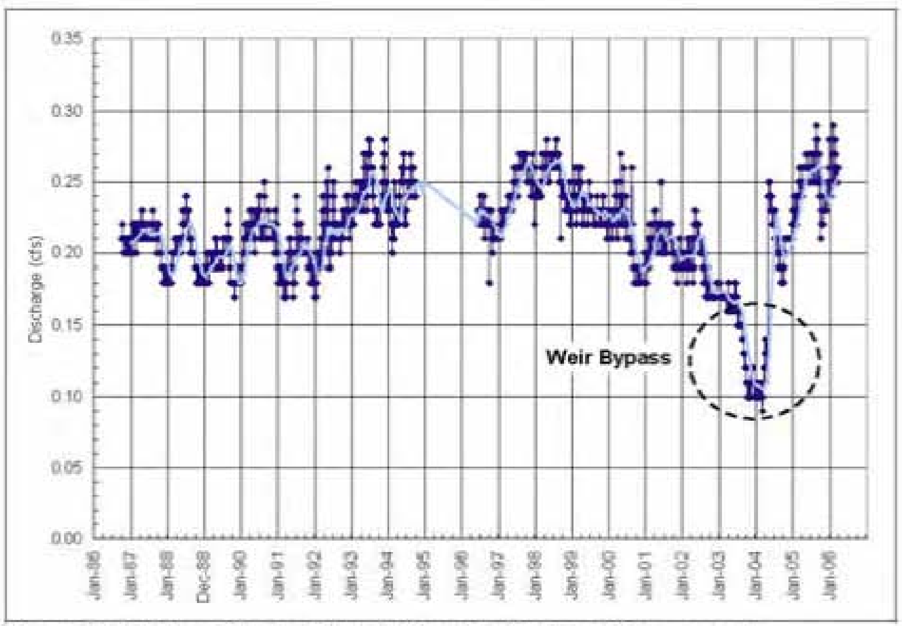

Figure 24 - Pederson Spring Historic Monthly Discharge Measurements

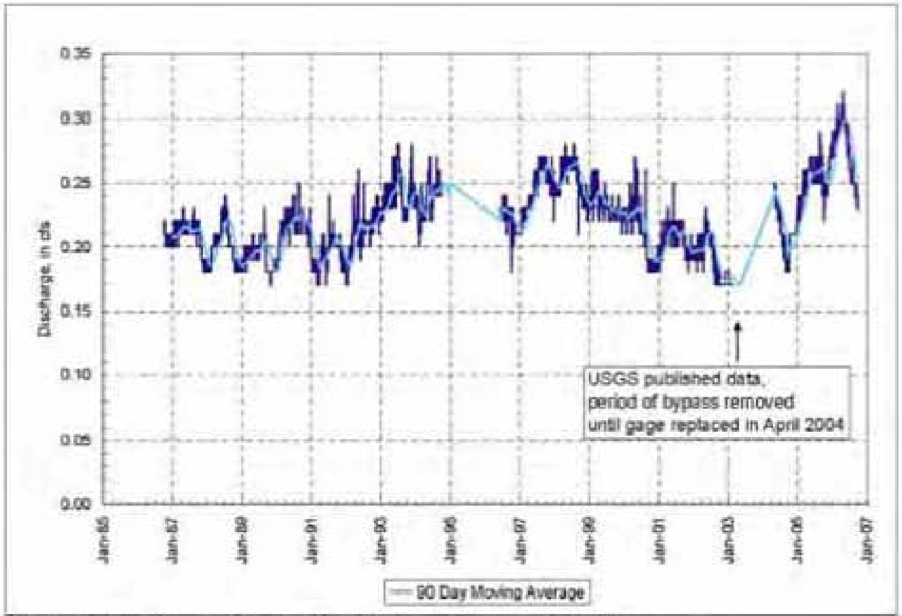

Figure 25 - Pederson Spring Discharge – Leakage Data Removed

From a graphical perspective, once the period of record affected by weir leakage has been removed from consideration, there does not appear to be any significant downward or upward trend in the long-term discharge records at Pederson Spring.

Further review of the Pederson Spring discharge trend was made using the Mann-Kendall test (Helsel and Hirsch, 2002). Discharge was converted to mean annual rates to remove seasonal fluctuations. The criteria for defining a statistically significant trend are the same as applied to water level trends, except that differential water levels of the period of record are replaced with the criteria of at least a maximum-minimum discharge differential (rolling 3-year average) of 5 percent of long-term mean discharge. Data from 2003 and 2004 at Pederson Spring were excluded due to incomplete discharge measurements (weir leakage). No discharge records are available for 1995. Partial records are available for 1994 and 1996, of which the averages for the available period of record were utilized as the annual mean. The Mann-Kendall test suggests no statistically significant trend of increasing or decreasing discharge at Pederson Spring (Table 5).

Discharge data from Warm Springs West indicate similar trends as observed at Pederson Spring, with discharges recovering to higher levels during water year 2005 (Figure 26). Discharge measurements prior to 1995 (1986 to 1994) are uncertain in accuracy due to unaccounted diversions, limiting comparisons of long-term trends. A Mann-Kendall test for the completed period of record (1987 to 2006) and the time period of 1996 to 2006 both suggest no statistically significant trend (Table 5).

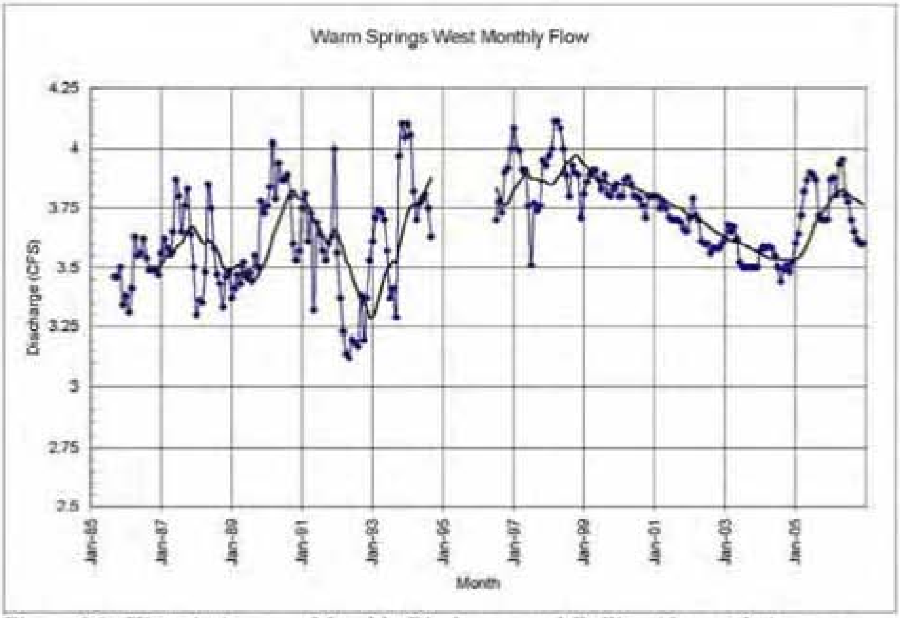

Figure 26 - Historic Average Monthly Discharge, and Rolling 12-month Average Discharge at Warm Springs West

Table 5 - Summary of Mann-Kendall trend test for historic discharge from Pederson and Warm Springs West

Site name	Period of record	Number of Observations*	Level of significance (p)	Kendall's τ	Mann-Kendall S	Average annual discharge for period of record (cfs)	Maximum change – rolling 3 year average (cfs)	Statistically significant trend
Pederson Spring	1986 – 2006 (2003 and 2004 removed)	18	0.063	0.126	+1.86	0.22	0.04	None
Warm Springs West	1987 - 2006	21	0.091	0.314	+1.69	3.67	.34	None
Warm Springs West	1996 - 2006	11	0.024	-0.527	-2.26	3.75	0.31	None

* Number of annual average discharge values derived from continuous discharge records.
Note: Values in red fail respective statistical significance test (see text).

The observation that spring discharges may not have fluctuated beyond historic ranges, as previously noted by Smith and others (2004), continues to be valid. Interpretations of variables affecting subtle trends within the natural range of variability for spring discharge have considerable uncertainty. While subtle declining trends in the regional carbonate aquifer water levels near the Muddy Springs can be more clearly defined, the connection between regional water levels and spring discharge may be more complicated than a simple direct connection, particularly when considering local mapped faults (Smith and others, 2004) and interpretations of complex regional geologic structure and stratigraphy (Page and others, 2005).

Interpretation of Climate and Potential Pumping Influences on Spring Discharge

A relatively simplistic bivariate model has been prepared to make preliminary assessments of the weight of climate fluctuations in explaining discharge variance at Warm Springs West. The bivariate model assumes only two variables adequately explain the majority of spring discharge variance; being climate and pumping from the carbonate aquifer at the MVWD Arrow Canyon wells No. 1 and 2 and the MX-6 well.

The basic equation is as follows:

$$Q = Q_{y-1} + (C_{precip} \times \text{DEV } P_{mean}) - (C_{pump} \times \text{Pumping}) \qquad \text{Eqn 1}$$

where,

- Q = Simulated mean annual discharge at Warm Springs West (cfs)
- Q_{y-1} = Previous year simulated mean annual discharge at Warm Springs West (cfs)
- C_{precip} = Precipitation coefficient
- DEV P_{mean} = Deviation of annual total precipitation (inches) from long-term mean annual precipitation for (index)
- C_{pump} = Pumping coefficient

Pumping = total annual pumped volume from Arrow Canyon No. 1 and 2 plus MX-6 (af/yr)

The bivariate model does not describe the nature of the climate variable. For example, it does not make any inferences as to whether local or regional precipitation is dominant, or if other potentially climate dependant variables (such as Lake Mead water levels) are incorporated in the climate function. Additionally, it does not exclude other pumping wells, such as NPC pumping from the alluvium near the Muddy Springs, as a potential variable. Pumping from the Arrow Canyon wells has been incorporated as a variable since it has a water source in the carbonate-rock aquifer and is the nearest carbonate-rock aquifer pumping of significance.

Weighting coefficients for the climate and pumping functions were achieved using trial and error methods, with iterations repeated until the modeled results produced reasonable fits with observed data. The bivariate "model" reproduces historic mean annual spring discharges reasonably well (Figure 27), and the unadjusted statistical correlation coefficient (r^2) is 83 percent (Figure 28). The "calibrated" weighting coefficients for the model equate to approximately 75 percent for the climate variable and 25 percent for the pumping variable. Approximately 17 percent of Warm Springs discharge fluctuation is not explained by the bivariate model.

A better statistical fit was achieved using the average annual precipitation reported for NCDC Nevada Zones 3 and 4 versus the index precipitation derived for the White River Flow System. Further evaluation of precipitation variables is warranted, including review of high altitude data from the Sheep Range, and other combinations of indices. Identification of the statistically strongest climate index to relate to climate induced discharge variance will decrease the unexplained Warm Springs West discharge variability (presently 17 percent), and increase the climate function weighting (presently 75 percent) in the bivariate model.

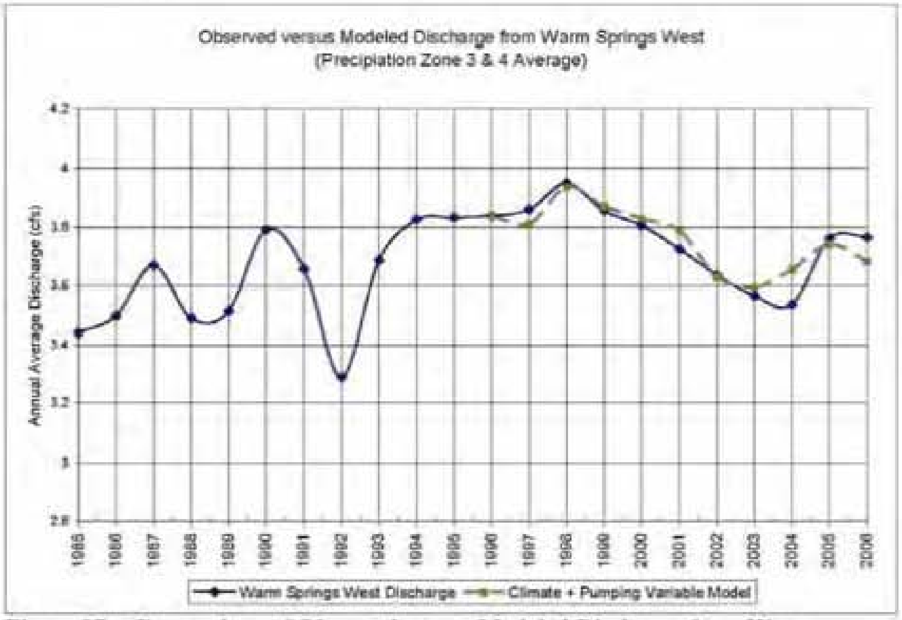

Figure 27 - Comparison of Observed versus Modeled Discharge from Warm Springs West

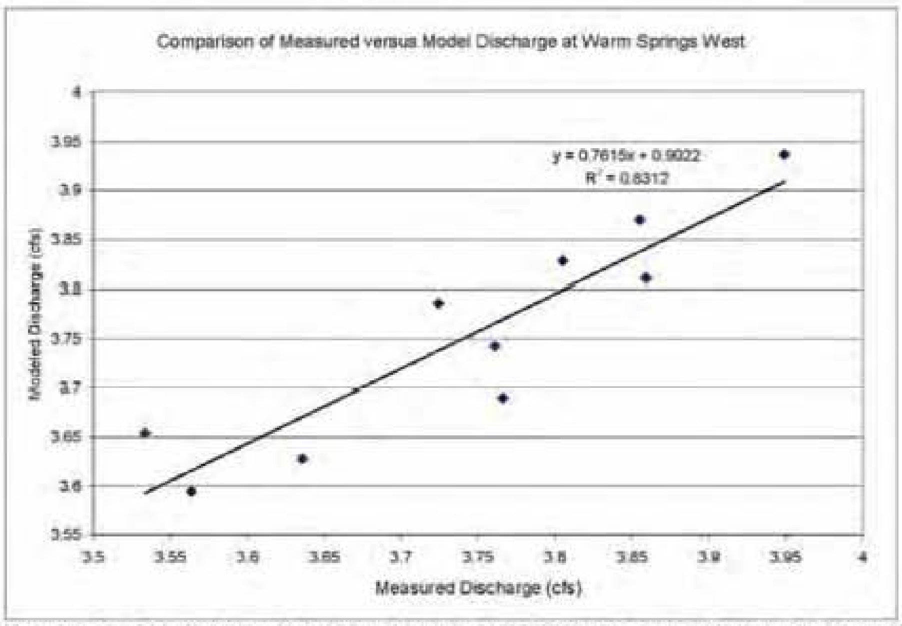

Figure 28 – Comparison of Measured versus Modeled Discharge at Warm Springs West

Conclusions

- All lines of evidence indicate climate trends are reflected in water level and spring discharge trends.
- Climate appears to account for about 75% of the explained variability observed in historical Warm Springs West discharge.
- Specific aspects of climate that are associated with water level and spring discharge variability may require additional data collection and further assessment. Review of "local" high altitude precipitation trends in the Sheep Range is one example of additional review that could be undertaken.
- The bivariate relationship using climate and Arrow Canyon pumping appears to address much of the spring discharge variability at Warm Springs West. A multivariate analysis might be used to further study the system. All postulated variables with potential to influence water levels and spring discharges could be examined, including:
  - High altitude precipitation in the Sheep Range,
  - Seasonal barometric pressure fluctuations,
  - Seasonal pumping fluctuations,
  - Index Precipitation for White River Flow System,
  - Water level fluctuations of Lake Mead
  - Alluvial aquifer pumping near the springs
- The assumption of significant aquifer connection between the Coyote Spring Valley carbonate aquifer and the Muddy Springs needs to be adequately evaluated. Water level data suggest a declining trend in many carbonate aquifer wells, however, the trend of spring discharges at Pederson Spring and Warm Springs West remains unclear. Statistically, no significant decreasing trend has been observed at the springs to positively correlate with aquifer water level trends.
- Coyote Spring Valley monitoring well data suggest some degree of compartmentalization, and/or differing hydraulic connections, within the carbonate-rock aquifer when viewed on a basin-wide scale. Aquifer testing and long-term pumping stresses will be needed to define hydraulic connections and disconnections.
- **Lacking a clear understanding of the connections within the carbonate aquifer, the aquifer test mandated by Order 1169 is critically needed to advance the understanding of the flow system.**

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Addendum No. 1

Updated Review of Water Level and Discharge Trends at the Muddy Springs, Clark County, Nevada

Statistical Review of Climate Indices for Predicting Discharge at Warm Springs West

The bivariate relationship describing discharge at Warm Springs West was investigated in the recent Updated Review of Water Level and Discharge Trends at the Muddy Springs, Clark County, Nevada (SNWA, 2007). A reasonable fit to discharge was achieved through trial-and-error calibration of the climate and Arrow Canyon well pumping coefficients. This initial bivariate model predicted 83 percent of the discharge variance, and approximately 75% of the explained variance could be attributed to the climate variable.

In order to further investigate the climate-discharge relationship, a more sophisticated calibration and climate input analysis was performed, with the objective of testing different climate indices to identify the best index for association with Warm Springs West discharge. Data from regional precipitation indices (NCDC Zones 3 & 4), a precipitation index (PI) developed for the White River Flow System by SNWA, data from several regional climate stations, and the USGS high-altitude Hayford Peak station in the Sheep Range were analyzed as climate input datasets.

The software program PEST Model-Independent Parameter Estimation, by Watermark Numerical Computing (2002) was utilized to find the best fit coefficients for the bivariate model for each climate input dataset. PEST iterations were run to determine the statistically optimum coefficients for the bivariate equation, based on minimization of the residuals between the observed Warm Springs West annual flows and model predicted flows. Figures 1 through 3 illustrate the results of the parameter estimation process.

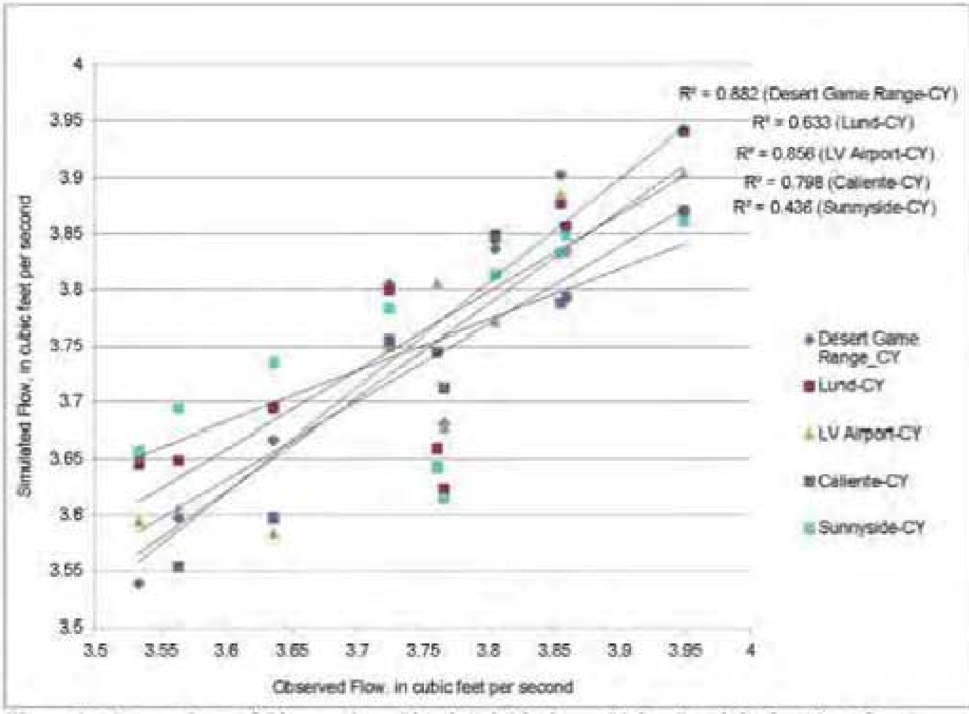

Figure 1 - Comparison of Observed vs. Simulated Discharge Using Precipitation Data from Individual Stations – Calendar Year

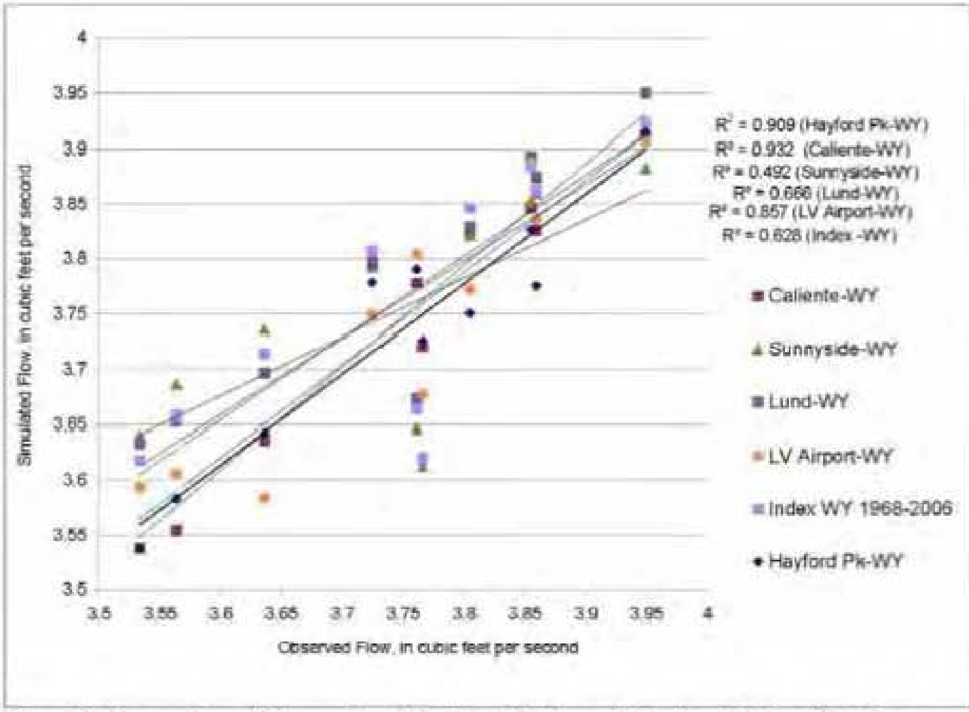

Figure 2 - Comparison of Observed vs. Simulated Discharge Using Precipitation Data from Individual Stations & White River Flow System PI – Water Year

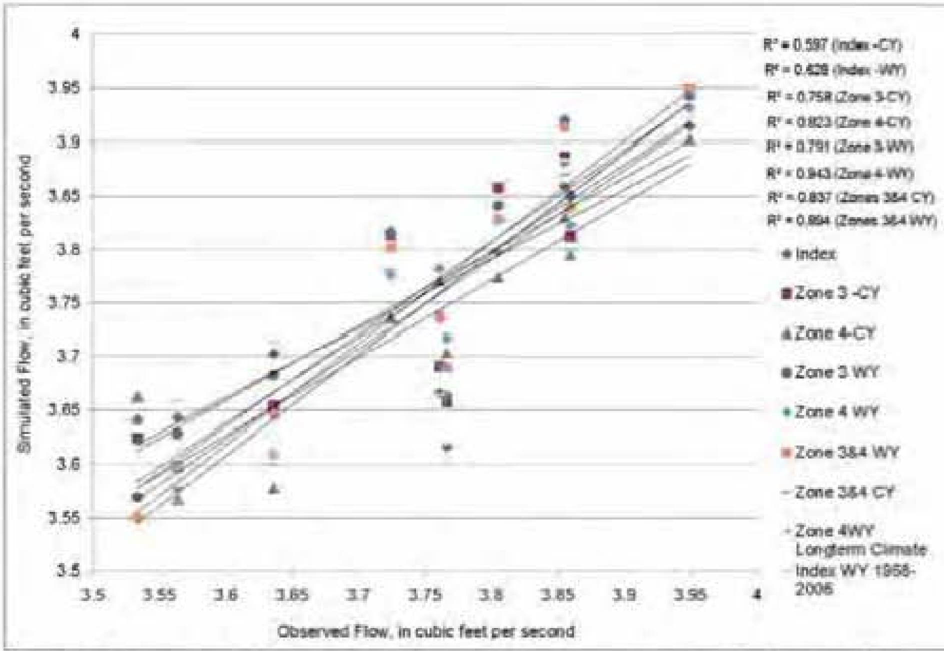

Figure 3 - Comparison of Observed vs. Simulated Discharge Using Precipitation Data from Indices – Water Year & Calendar Year

Table 1 presents optimized coefficients for the climate and pumping variables, as produced from PEST optimization. The results indicate that water year climate data from the Desert Game Range, Zone 4, the high-altitude Sheep Range station, and Caliente produce the best results in the bivariate model for simulation of spring discharges from Warm Springs West, as evidenced by comparison of the regression coefficient (R^2). Figure 4 illustrates the predictive strength of the bivariate model using these four climate input datasets.

The regression relationships produced from the optimization process indicate that average annual precipitation data, computed in the time frame of water years (WY), generally creates a better match to observed calendar year (CY) discharge from Warm Springs West. This observation suggests that a 3 month lag in discharge response to climate variables is statistically better that an immediate response.

In addition, the bivariate model coefficients produced by the optimization process provide a relative weight factor to variations in discharge caused by climate and pumping influences. The results of the analyses indicate that climate has a greater effect on spring discharge for climate inputs producing the highest R^2 value.

Also of note, PEST sensitivity parameters indicate that the pumping variable coefficient has greater sensitivity than the climate coefficient variable.

Table 1 - Summary of PEST Bivariate Model Coefficient Calibation for Multiple Precipitation Stations and Indices

Station	R^2	Bivariate Coefficients		Climate Contribution Factor**	Pumping Contribution Factor*
		A *(Dev Precip)**	*B* *(Pumping)**		
Calendar Year					
White River PI	0.597	0.0168	0.0109	60.6%	39.4%
Caliente	0.798	0.0198	0.0095	67.6%	32.4%
Desert Game Range	0.882	0.0288	0.0176	62.1%	37.9%
Lund	0.633	0.0166	0.0085	66.2%	33.8%
LV Airport	0.856	0.0411	0.0150	73.3%	26.7%
Sunnyside	0.436	0.0042	0.0096	30.5%	69.5%
Zone 3	0.758	0.0287	0.0075	79.3%	20.7%
Zone 3&4	0.837	0.0345	0.0063	84.6%	15.4%
Zone 4	0.823	0.0309	0.0056	84.6%	15.4%
Water Year					
White River PI	0.628	0.0146	0.0080	64.6%	35.4%
Caliente	0.932	0.0212	0.0091	70.0%	30.0%
Desert Game Range	0.974	0.0240	0.0139	63.4%	36.6%
Lund	0.666	0.0144	0.0109	56.9%	43.1%
LV Airport	0.857	0.0411	0.0163	71.6%	28.4%
Sunnyside	0.492	0.0057	0.0103	35.7%	64.3%
Zone 3	0.791	0.0221	0.0073	75.1%	24.9%
Zone 3&4	0.894	0.0280	0.0062	81.9%	18.1%
Zone 4	0.943	0.0307	0.0050	85.9%	14.1%
Hayford Peak – WY	0.909	0.0128	0.0093	57.8%	42.2%

* Precipitation deviation from average in inches per year; Pumping input in units of 1,000 af/yr.
** Contribution factors based on proportions of sum of the bivariate coefficients, with input variables in equal orders of magnitude (see footnote above)

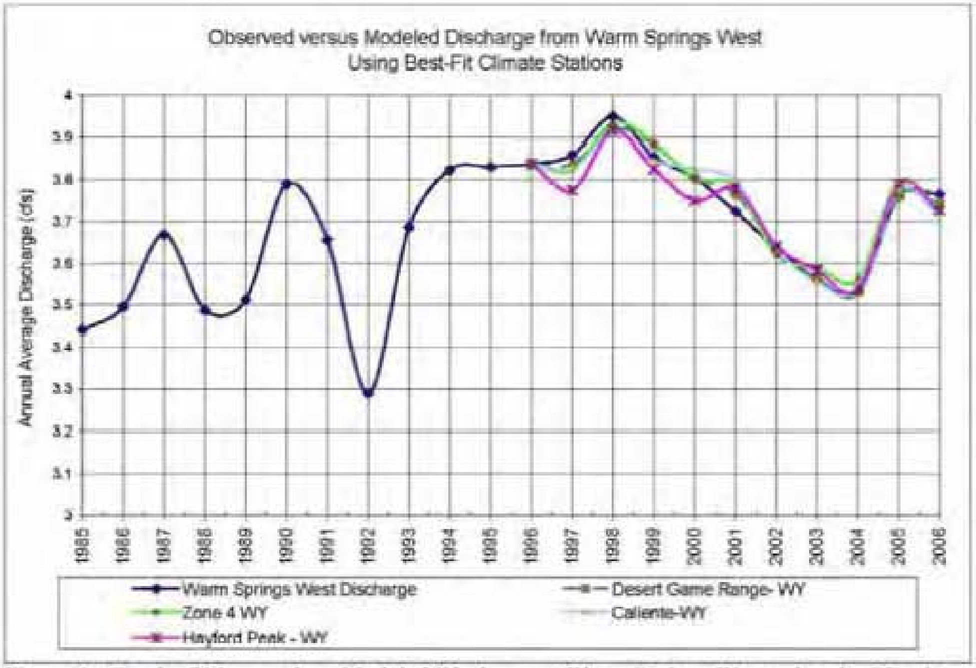

Figure 4 - Graph of Measured vs. Modeled Discharge at Warm Springs West using the Bivariate Climate and Arrow Canyon Pumping Model, for Climate Inputs Producing R^2 Values over 90%

In summary, the preliminary review of different climate indicators for the bivariate model to simulate Warm Springs West discharge indicates that the Desert Game Range annual average precipitation on a water-year basis provides the statistically best climate input dataset. Using the Desert Game Range precipitation data as the climate variable input, 97% of the variability in Warm Springs West Discharge is explained, with approximately 63% of the discharge explained by the climate variable and 37% explained by the Arrow Canyon pumping variable. NCDC Zone 4 precipitation, the Hayford Peak high-altitude station in the Sheep Range, and Caliente also provide good results in the bivariate model, with R^2 values over 90%. However, the climate versus pumping ratios are noticeably different for each climate input, with the climate influence ranging from 58% for the Hayford Peak input to 86% for the Zone 4 input. Climate remains the dominate influence in all statistically strong predictive relationships.

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Appendix G

DRI Evapotranspiration Report (Huntington and Morton, 2013)

SE ROA 10319

Technical Memo

To: Jeff Johnson and Sean Collier, Southern Nevada Water Authority
From: Justin Huntington, Charles Morton, Matt Bromley, Ryan Liebert, Desert Research Institute
Date: June 4, 2013
Re: Analysis of Evapotranspiration for the Muddy River Springs Area

Purpose and Scope

This technical memo provides estimates of evapotranspiration (*ET*) for the Muddy River Springs area from 2001-2012. This work is part of a larger effort toward mapping historical *ET* along the Muddy River and Muddy River Springs (Figure 1) utilizing surface energy balance and vegetation indices from 2001-2012. The Muddy River Springs focused study area (Figure 2) primarily consists of pasture grass, mesquite trees, cotton woods, palm trees, and several species of vines (DeMeo et al., 2008). Previous studies have estimated *ET* in the Muddy River Springs area using a water budget approach (Eakin 1964; 1966), and more recently with *ET* station measurements and remote sensing (DeMeo et al., 2008). This study builds on previous work, and attempts to identify trends in *ET* over the study period of 2001-2012 to identify potential impact on *ET* due to land management and vegetation changes.

Surface Energy Balance and Vegetation Index Approaches

Surface energy balance estimates are made in this study using the Mapping EvapoTranspiration at high Resolution with Internalized Calibration, METRIC, model (Allen et al., 2007). METRIC relies Landsat imagery and locally collected meteorological data to calculate actual *ET*. METRIC recently has been applied by state and federal agencies to estimate ET from rainfed and irrigated vegetation in Nevada, New Mexico, Oregon, Wyoming, Montana, Nebraska, and Colorado (Hendrickx, 2010; Kjaersagaard and Allen, 2010; Sullivan et al., 2011; Snyder et al., 2012). This study also applies a vegetation index reference ET fraction approach to estimate actual *ET* in the Muddy River Springs area similar to Allen et al. (2011), Tasumi and Allen (2007), and Singh and Irmak (2009).

Methods

Estimating actual *ET* required numerous weather data and image processing steps that are briefly described below. Landsat 5 Thematic Mapper (TM) and 7 Enhanced Thematic Mapper Plus (ETM+) images were acquired for the study period of 2001-2012 from the U.S. Geological Survey (USGS) Global Visualization web page (http://glovis.usgs.gov/) totaling 323

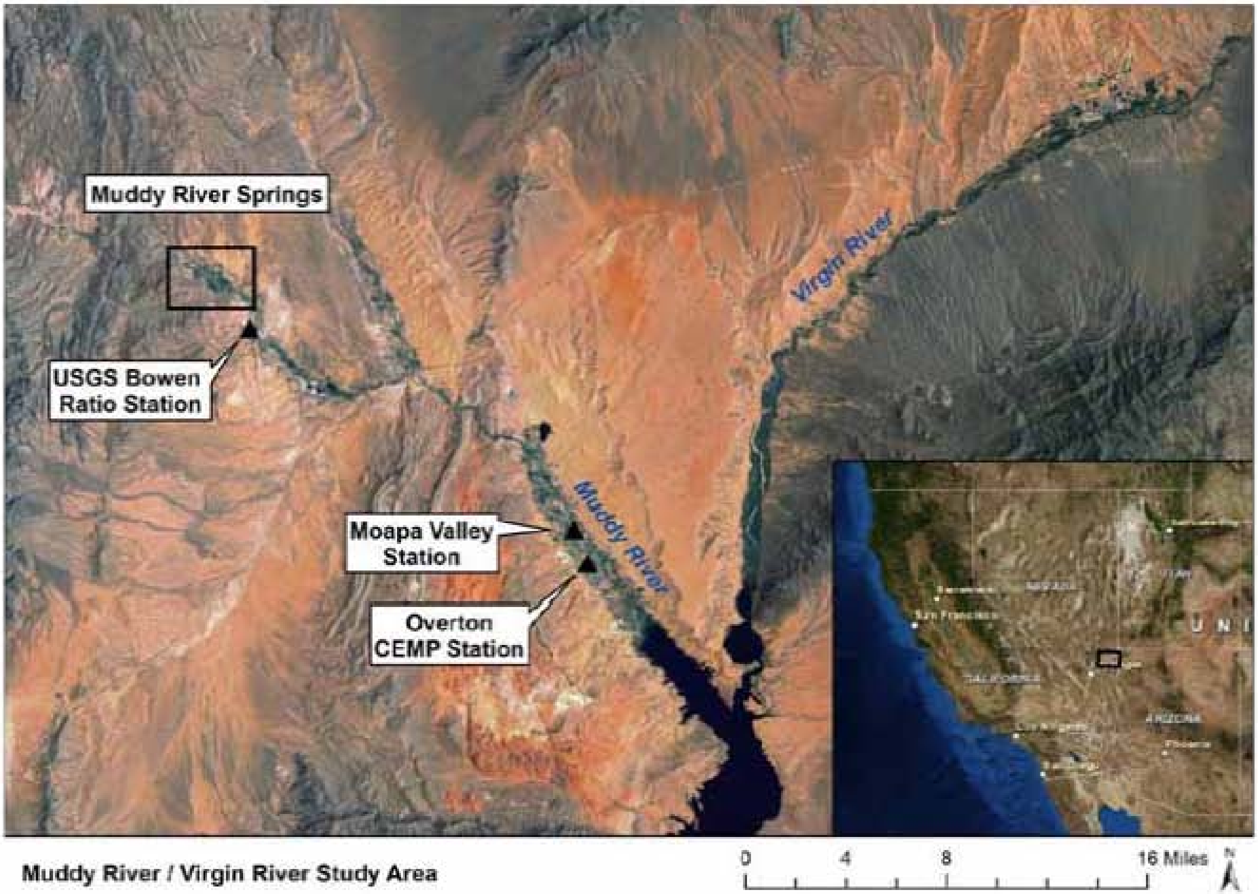

Figure 1. General study area with highlighted Muddy River Springs area.

images (Table A1). Landsat data processing was handled using Python scripts, many of which are described in Morton (2013). General processing steps include performing radiometric and atmospheric corrections using the Landsat Ecosystem Disturbance and Adaptive Processing System (LEDAPS) (Masek et al., 2006) to compute at surface reflectance, with following computations of the Normalized Difference Vegetation Index (NDVI), surface temperature, albedo, and various energy balance components following Allen et al. (2007) and Morton et al. (2013). The land surface energy balance is simulated by METRIC as

$$LE = R_n - H - G$$

where LE is latent heat flux (W/m^2), R_n is net radiation (W/m^2), H is sensible heat flux (W/m^2), and G is ground heat flux in (W/m^2). The reader is referred to Allen et al. (2007) and Morton et al. (2013) for detail on METRIC and how each component of the energy balance is computed from Landsat data. Once LE is computed for each pixel, the equivalent amount of instantaneous ET (mm/hr) is computed by dividing by the latent heat of vaporization (λ). Instantaneous ET at the time of the Landsat image is estimated over the day as

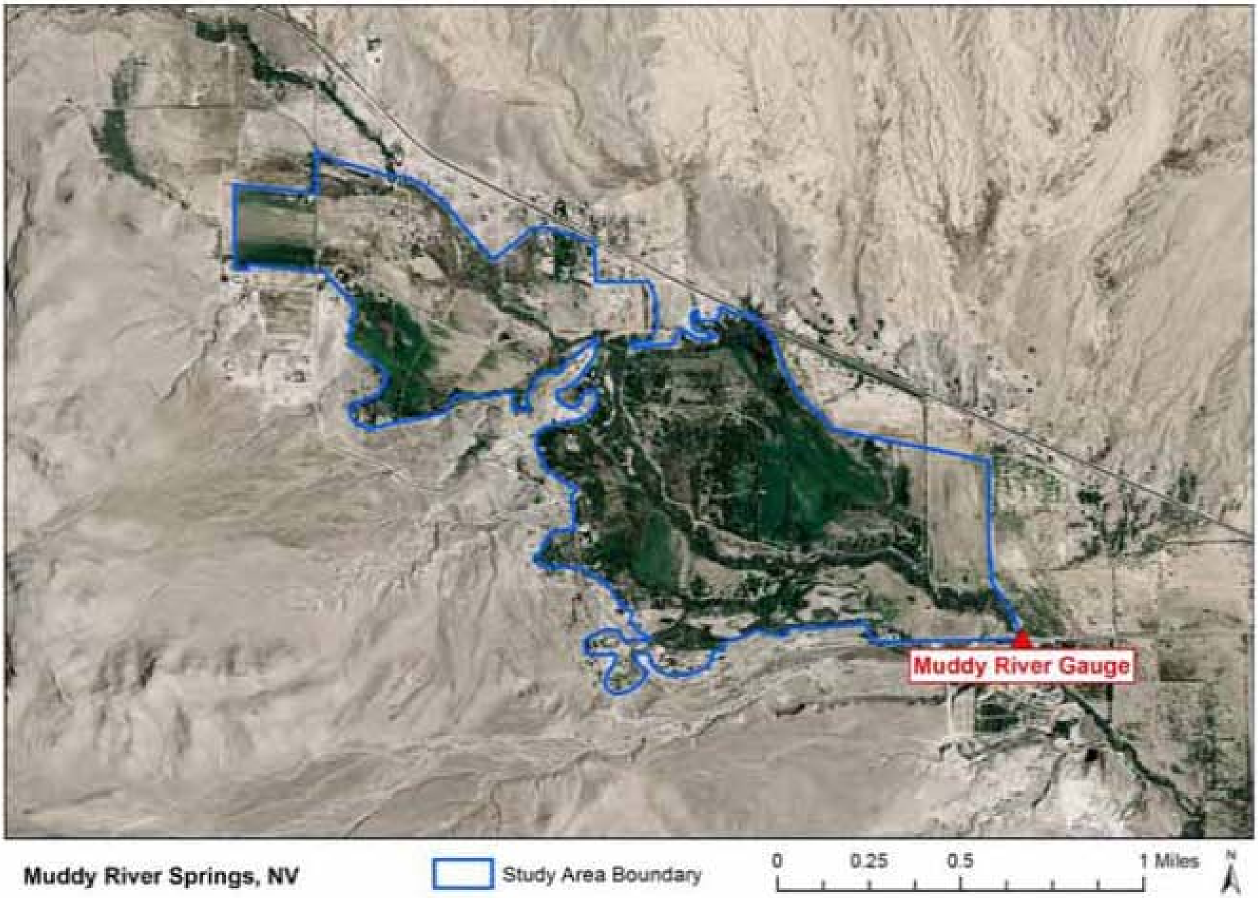

Figure 2. Warm Springs (Muddy River Springs) study area for estimating ET from 2001-2012.

$$ET_{24} = (ET_{inst} / ET_r) * ET_{r24}$$

where the ratio of ET_{inst} (mm/hr) to ET_r (mm/hr) is the reference ET fraction (ET_rF) measured at the satellite overpass time and ET_{r24} is the cumulative ET_r for the day (mm/day). Seasonal total *ET* is estimated by linearly interpolating the daily ET_rF per pixel in between Landsat images, and multiplying daily ET_rF pixel values by the ET_{r24} for respective days. The reference *ET* fraction is commonly referred to as the crop coefficient. In this method, the computation and application of ET_rF simulates vegetation growth stages and phenology changes, roughness of the vegetation surface to account for turbulent effects, and vegetation geometry. Simply put, the effects of weather are incorporated into ET_r, whereas the effects that distinguish vegetated and bare surfaces from the reference surface are integrated into the ET_rF (Allen et al., 1998). There are many physiological and physical variables that determine *ET*, and the ET_r*ET_rF method incorporates the majority of these variables (Bos et al., 2008).

The vegetation index reference *ET* fraction approach is similar to the METRIC surface energy balance approach for estimating *ET* through time, but ET_rF is derived from the NDVI instead of an instantaneous surface energy balance. The reason for applying both approaches is due to the fact that it currently requires a relatively large amount of time and effort to process METRIC for multiple years, whereas it requires significantly less time and effort to compute

NDVI. Heilman et al. (1982) proposed a linear relationship between a vegetation index and fraction of reference ET, and has been supported by various other studies (Choudhury et al., 1994; Tasumi et al., 2005; Tasumi and Allen, 2007; Singh and Irmak, 2009; Calera-Belmonte et al., 2005). If no local calibration data exists, Allen et al. (2011) suggests that ET_rF can be generally estimated as

$$ET_rF = 1.25 * \text{NDVI}$$

where ET_rF is the relative fraction of the alfalfa reference ET. NDVI is defined as

$$\text{NDVI} = (\rho_{\text{NIR}} - \rho_{\text{Red}}) / (\rho_{\text{NIR}} + \rho_{\text{Red}})$$

where ρ is the at-surface reflectance, *NIR* is near infrared waveband from 0.76 to 0.90 μm, *Red* is the visible waveband from 0.63 to 0.69 μm. The relationship suggested by Allen et al. (2011) was modified in this work to more accurately represent the conditions specific to the study area using METRIC derived ET_rF and NDVI for all pixels in the Muddy River Springs study area (Figure 2). Seasonal average slopes between ET_rF and NDVI for 2006-2012 were found to vary between 1.21 and 1.37, with an average of 1.30, and intercepts ranging from 0.02 to 0.1, with an average of 0.06, and R^2 values ranging from 0.66 to 0.80, with an average of 0.74. Figure 3 illustrates an example of the correlation between ET_rF and NDVI for 2006. The fairly large scatter exists due to the fact that NDVI is not capable of detecting evaporation from wet soil due to irrigation, where METRIC is able to detect soil evaporation using the Landsat derived surface temperature, which results in high ET_rF and low NDVI. Additionally, NDVI is not able to detect acute vegetation stress due to water limitations, whereas the use of surface temperature in METRIC detects this acute water stress, which results in relatively high NDVI and low ET_rF due to low predicted evaporation by METRIC. While the use of NDVI does have limitations, for the sake of simplicity and providing the ability to estimate changes in *ET* for years before 2006 over the Muddy River Springs area, the equation

$$ET_rF = 1.30 * \text{NDVI} + 0.06$$

was applied in this work over the Muddy River Springs area to all cloud free Landsat 5 TM and 7 ETM+ images from 2001-2012 period (Table A1). A typical annual time series of spatially averaged NDVI from 2006 is illustrated for the Muddy River Springs study area in Figure 4, where greenup and senescence periods are clearly evident. Once NDVI is transformed into ET_rF at each pixel, ET_rF is linearly interpolated per pixel in between Landsat image dates, and then multiplied by the ET_r, ET_rF, to estimate *ET*.

Reference ET (ET_r) Estimates

Hourly weather data of solar radiation, air temperature, dewpoint temperature, and windspeed collected at SNWA's Moapa agricultural weather station and DRI's Overton Community Environmental Monitoring Program (CEMP) weather station (Figure 1) were downloaded and quality assured and controlled (QAQCed) according to Allen et al. (1996).

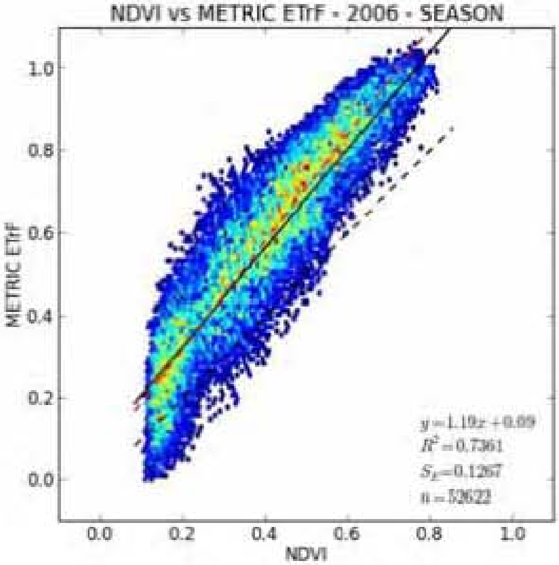

Figure 3. Scatter plot of ET_rF and NDVI for the 2006 growing season (February-November). Colors of the scatter plot represent point density where red is high density, and blue is low density. The red hatched line is the average regression line used to compute ET_rF from NDVI in this study, and the black hatched line is the 1:1 line.

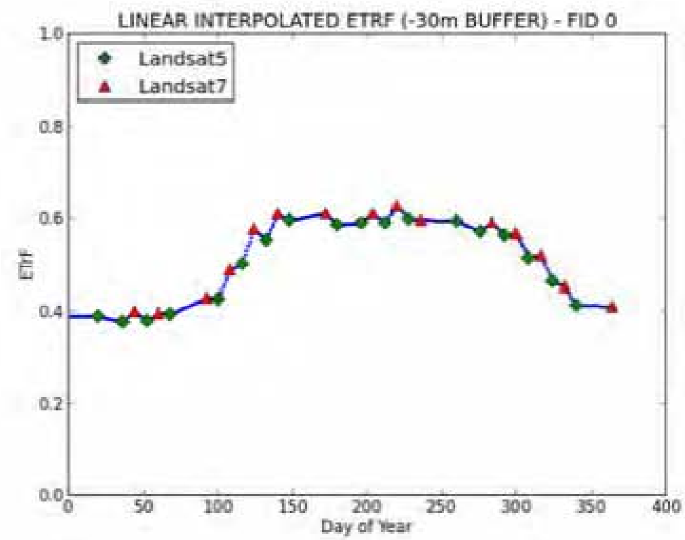

Figure 4. Time series of NDVI derived ET_rF for 2006 spatially averaged over the Muddy River Springs area shown in Figure 2. Interpolation of ET_rF in between Landsat image dates occurs on a pixel by pixel basis; however, this figure shows interpolation ET_rF averaged over the study area simply for illustrative purposes.

Overton CEMP weather data was analyzed from 2001-2012, and SNWA Moapa weather data was analyzed from 2010-2012, the available period of record for Moapa. Following adjustment procedures outlined in Allen et al. (1998) and Allen et al. (2011a), reported windspeed measured at respective measurement heights were logarithmically transformed to 2m height equivalent windspeed estimates, as required for input into the ASCE standardized reference ET equation. Windspeed measurement heights are 2.3m and 6m (7.5ft and 20ft) at the Moapa and Overton stations, respectively. Many years of solar radiation (R_s) measurements required some level of correction to better match clear sky solar radiation curves (R_{so}). Such needed corrections are common due to pyronometer sensor calibration drift (Allen, 1996). Figure 5 illustrates raw and corrected R_s from the Overton CEMP station. In this case it is evident that sensor calibration is in error due to the fact that measured R_s over a day never reaches the theoretical R_s that would occur for a clear sky day (R_{so}). Overton CEMP hourly solar radiation data was found to be corrupt from 2011 and 2012 and the data were not salvageable. Therefore, Moapa QAQCed hourly R_s was used to fill Overton CEMP hourly R_s for years 2011 and 2012. After QAQC was completed, ET_r was computed for both stations utilizing the standardized reference ET equation (ASCE-EWRI, 2005) for an alfalfa reference surface using the Ref-ET program (Allen, 2011).

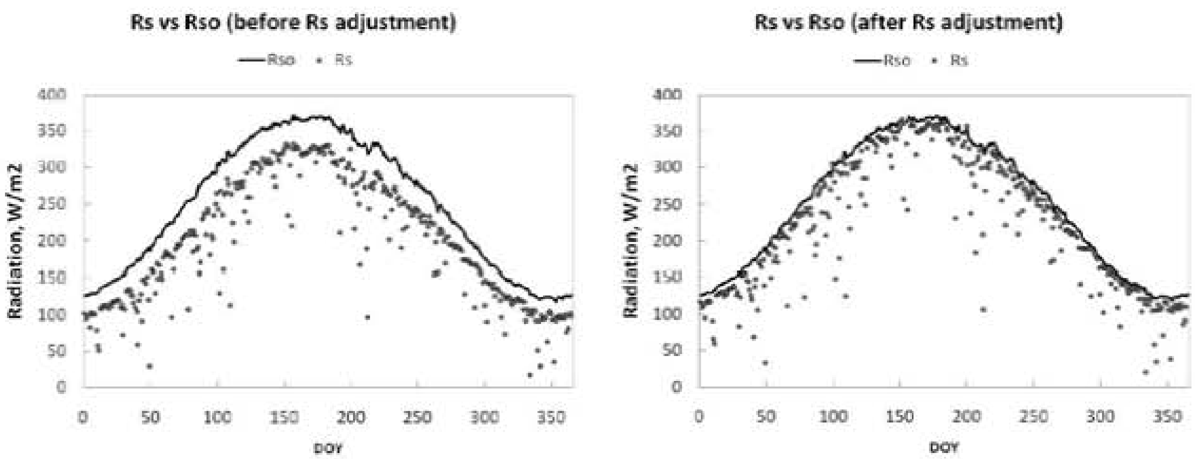

Figure 5. Overton CEMP 2007 measured solar radiation (R_s) (left), and corrected solar radiation to the theoretical clear sky solar radiation (R_{so}) (right) following recommendations of Allen (1996). Solar radiation corrections are typically needed due to pyronometer calibration drift, as is evident in this figure.

Because the desired study period was from 2001-2012 and Moapa weather data was only available from 2010-2012, a comparative analysis between Overton and Moapa computed ET_r was completed to potentially develop ET_r adjustment factors for Overton computed ET_r to simulate Moapa ET_r from 2001-2010. Figures 6 and 7 illustrate monthly ET_r computed from Overton and Moapa weather data for 2010-2012. It is evident that ET_r is nearly the same for most months, even though the Overton CEMP station is not located in an optimal reference environment that reflects the climate of agricultural and active *ET* conditions. As previously discussed, 2011 and 2012 Moapa R_s was substituted for Overton R_s, however, from inspection of Figure 6 it is evident that 2011 Moapa ET_r is lower than Overton ET_r during mid-summer months. After investigating the potential cause of this difference, it was found that, raw, pre-QAQCed hourly windspeed for the Moapa station was often zero at night and during some hours of the day. In comparing windspeed between Moapa and Overton for 2010 and 2012, it was found that Overton 2m equivalent windspeed was typically lower than Moapa, except for this mid-summer period of 2011, where Moapa was lower than Overton. Due to the consistency of Overton having lower 2m equivalent windspeed in all months except for these three mid-summer months, and the fact that there were many reported zero values, it was assumed that the Moapa measured windspeed was in error for this period.

Due to the nearly identical computed ET_r between Overton and Moapa, Overton computed ET_r was utilized in this work to estimate *ET* using METRIC and NDVI-ET_rF approaches from 2001-2009, and 2011, while Moapa computed ET_r was used to estimate *ET* for 2010 and 2012. Growing season (February-November) and annual ET_r from 2001-2012 is illustrated in Figure 8 where it is evident that ET_r has generally decreased from 2001. This is significant, because any decreasing trends in ET_r will cause decreasing trends in *ET*. This result was cause for concern due to possible sensor drift and or data quality, therefore, an analysis was conducted to investigate if any trends were present in driving ET_r weather variables of solar radiation, temperature, dewpoint, and windspeed. While the analysis showed slight decreasing trends in annual averages, a more focused analysis was conducted for warm season months of May-September, since most of the annual *ET* occurs during these months. Results of the warm season trend analysis indicate that warm season average daily maximum and minimum temperatures, windspeed, and solar radiation all have decreasing trends from 2001-2012, while warm season average daily minimum temperature minus dewpoint temperature (i.e. dewpoint depression) is rising during this same period, indicating drying conditions (Appendix Figures A1-A5).

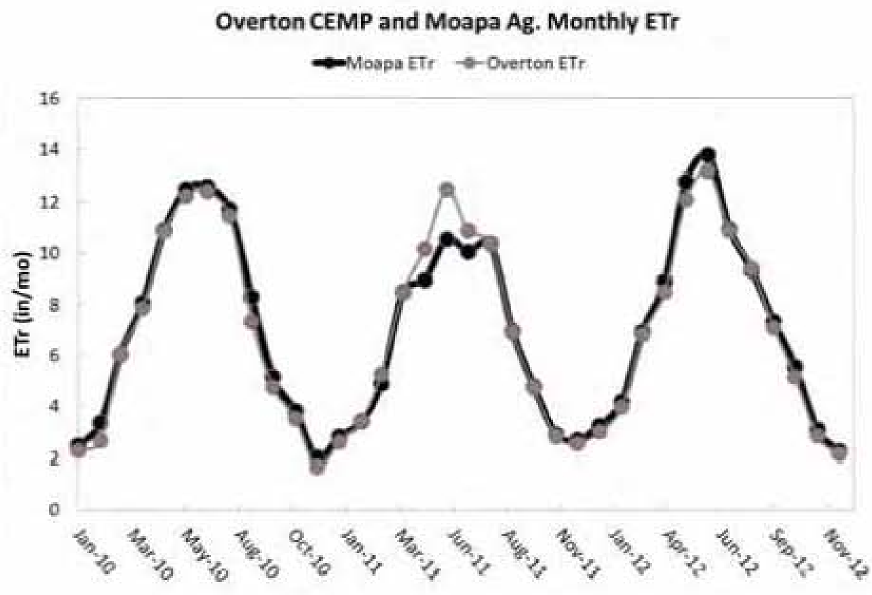

Figure 6. Monthly time series comparison of ET_r from Overton CEMP and Moapa agricultural weather stations

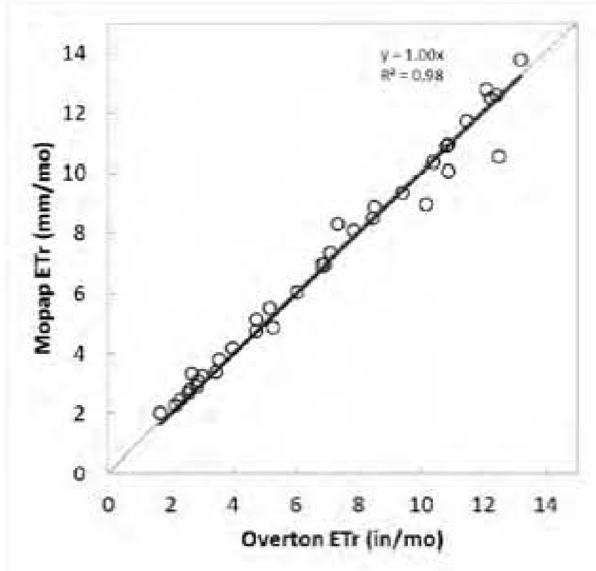

Figure 7. Scatter plot comparison of monthly ET_r from Overton CEMP and Moapa agricultural weather stations.

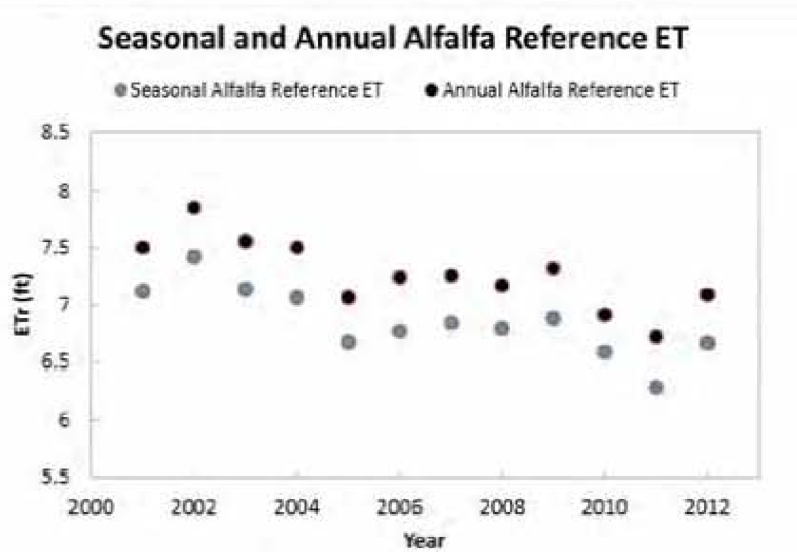

Figure 8. Seasonal (February – November) and annual ET_r from 2001-2012. As illustrated, ET_r has generally decreased over the study period of 2001-2012.

To confirm that these trends are real and not an artifact of possible weather station sensor drift, weather data from the closest weather station measuring temperature and windspeed was acquired and analyzed over the same period for warm season months of May-September. Results indicate very similar trends, where warm season average daily maximum and minimum temperatures and windspeed exhibit decreasing trends from 2001-2012, and warm season average daily minimum temperature minus dewpoint temperature is rising during the same period (Appendix Figures A6-A9). The comparative weather variable trend analysis between Overton and Nellis weather stations suggests that the trend in Overton computed ET_r from 2001-2012 is likely real and not artificial, and thus thought to be valid.

Evapotranspiration Estimates

Annual and seasonal *ET* from the Muddy River Springs study area was estimated using METRIC and the NDVI approaches, as previously described, by utilizing all available and cloud free images during each year from 2001-2012 (listed in Table A1). Mechanically, for both approaches, ET_rF is estimated for each image date and linearly interpolated, per pixel, in between image dates, and then multiplied by the respective daily reference *ET* (ET_r), to estimate the daily *ET*. Graphically, Figure 4 illustrates interpolation of ET_rF in between image dates for the Muddy River Springs area. Figure 9 illustrates respective ET_r, and the product of Figure 4 and Figure 9 for respective days results in estimated daily *ET* for 2006, shown in Figure 9. The use of ET_r to estimate *ET* in between image dates is critical for properly accounting for daily variations in atmospheric water demand (i.e., solar radiation, windspeed, temperature, humidity), and resulting impacts on *ET*. The translation of the daily variability in ET_r to *ET* can be seen in Figure 9, a process that would be missing, and in error, if *ET* were to be simply interpolated in between image dates (shown as green triangles on right panel of Figure 9).

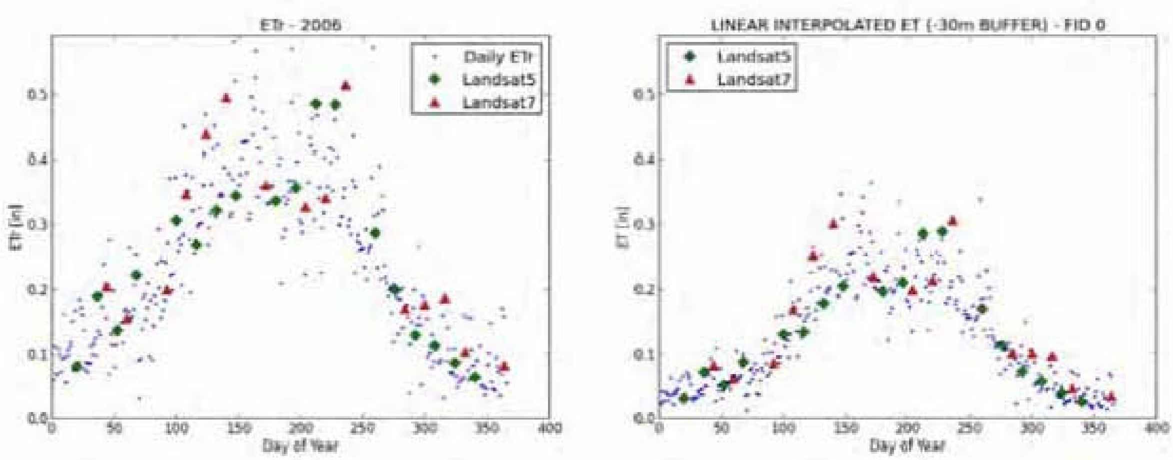

Figure 9. Daily reference *ET*, ET_r, (left) is multiplied by daily interpolated ET_rF (shown in Figure 4) to estimate daily *ET* for 2006 (right).

Seasonal (February-November) and annual *ET* totals were estimated utilizing METRIC from 2006-2012 and NDVI from 2001-2012, and results are shown in Figure 10 and Figure 11. A slight decrease in METRIC estimated *ET* is noticeable, however, this is largely due to the decrease in ET_r over this period, as the ratio of METRIC *ET* to ET_r (ET_rF) is fairly stable, as shown in Figure 12. The trend in NDVI estimated *ET* from 2001-2012 is more pronounced. The ratio of NDVI estimated *ET* to ET_r (ET_rF) is also fairly stable for 2006-2012, but decreases over the entire study period of 2001-2012 (Figure 13). Because *ET* is a function of precipitation (*PPT*), and *PPT* is highly variable from year to year, normalizing *ET* by removing the influence of *PPT* is needed for trend analysis. To accomplish this, annual *PPT* was subtracted from seasonal and annual METRIC and NDVI estimated *ET*. Monthly and annual *PPT* totals for the Muddy River Springs area were estimated from 2001-2011 using 800m spatial resolution PRISM data (Daly et al., 1994) for a single pixel within the study area to remove potential elevation biases from spatial averaging multiple pixels that fell outside the study area. A comparison between measured *PPT* at the Overton COOP station and estimated PRISM *PPT* for a single pixel at the Overton COOP station location is shown in Figure 14, where the correspondence between COOP measured and PRISM estimated *PPT* is good, although this was expected since the PRISM process uses the COOP station as a control point. Missing *PPT* in the Overton COOP precipitation record was filled with *PPT* from the Overton CEMP station, which totaled 424 days from 2001-2007. A comparison was also made between the Overton COOP *PPT* and Muddy River Springs area PRISM 800m *PPT* (Figure 15). Because 800m PRISM *PPT* was not available for 2012, and effectively no bias exists between Overton COOP *PPT* and 800m PRISM *PPT* for the Muddy River Springs area, Overton COOP monthly *PPT* was used for the Muddy River Springs area for 2012.

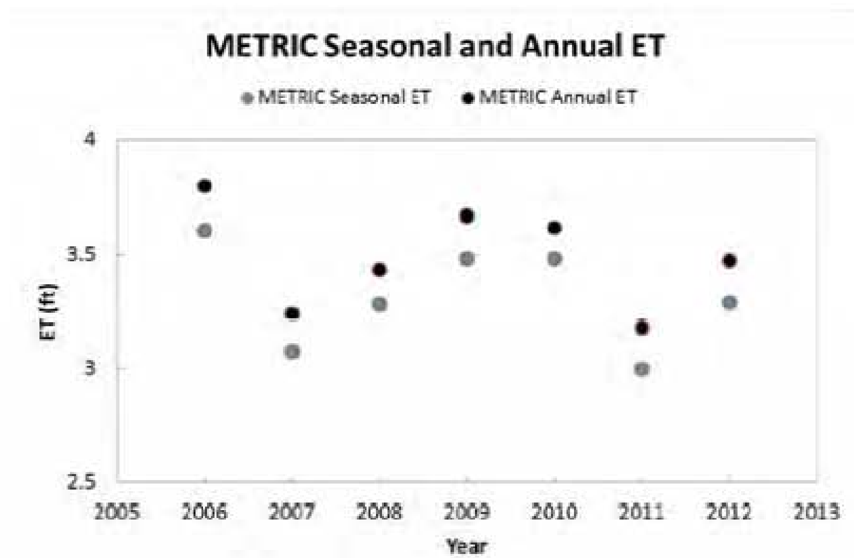

Figure 10. Seasonal and annual METRIC derived *ET* from 2006-2012. Seasonal totals are for the growing season, estimated to be February-November.

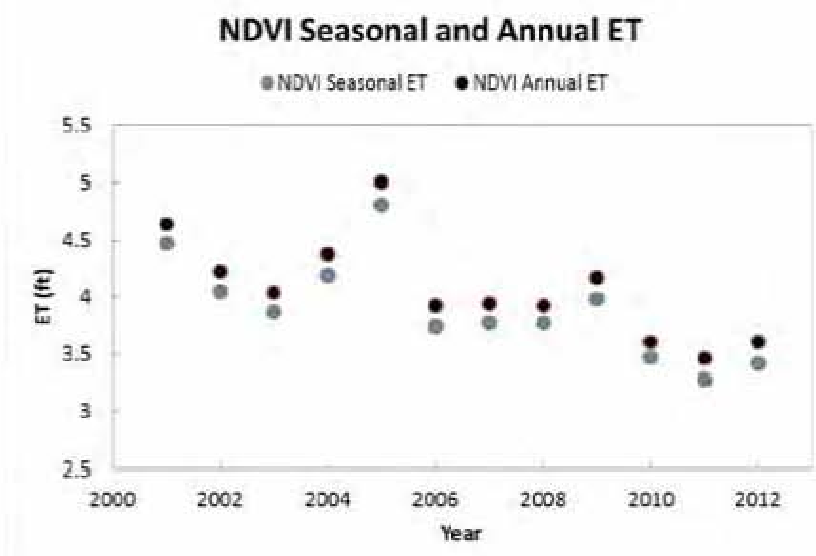

Figure 11. Seasonal and annual NDVI derived *ET* from 2001-2012. Seasonal totals are for the growing season, estimated to be February-November.

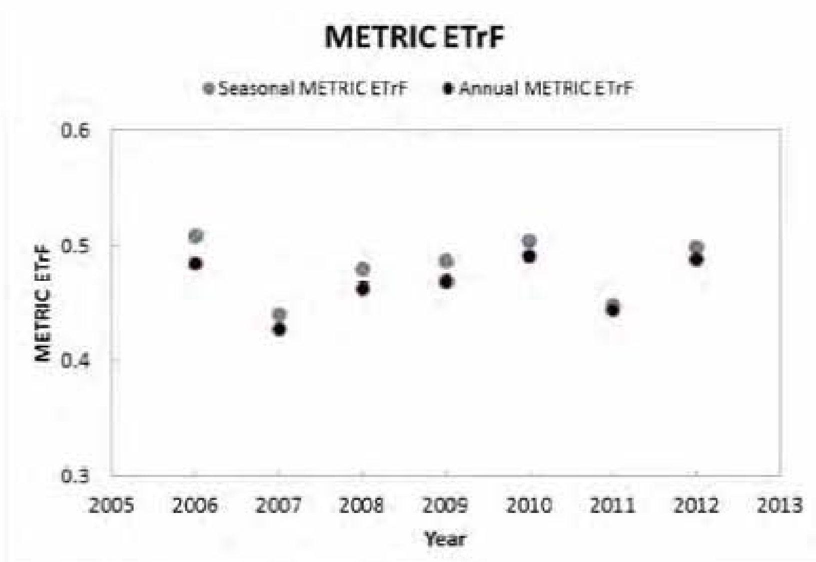

Figure 12. Seasonal and annual METRIC derived ET_rF from 2006-2012.

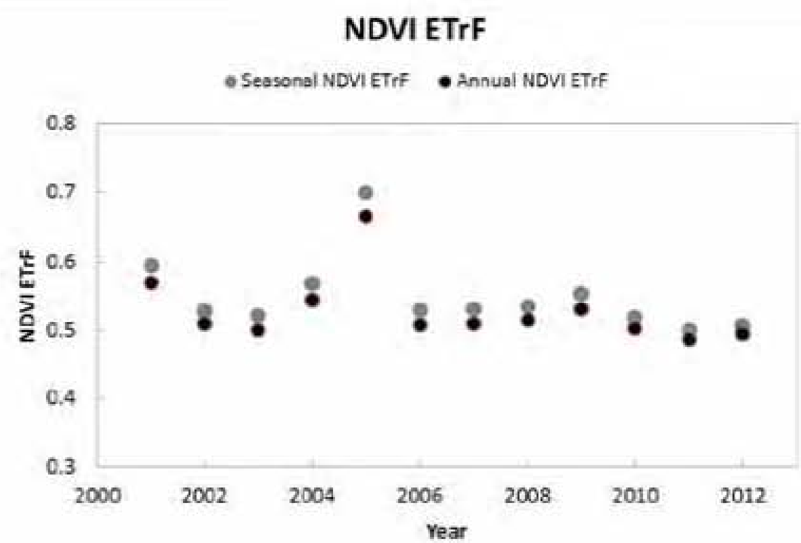

Figure 13. Seasonal and annual NDVI derived ET_rF from 2001-2012.

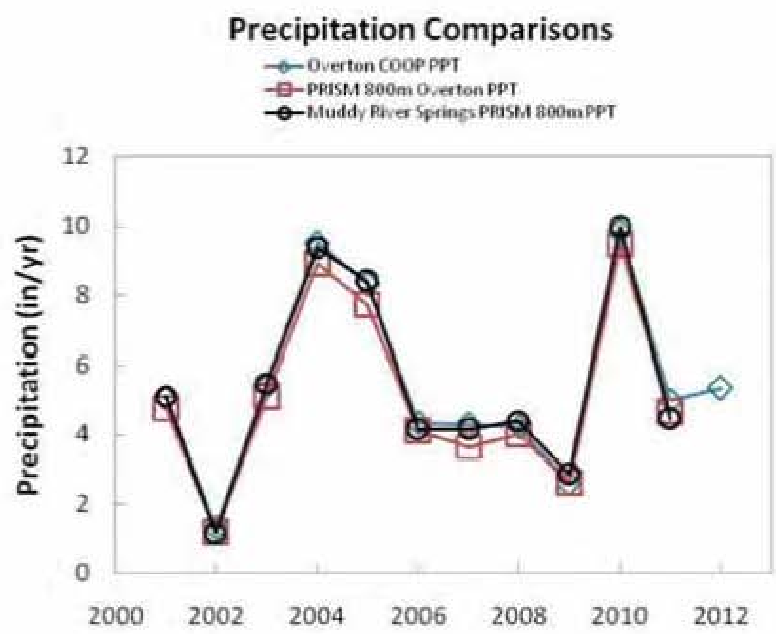

Figure 14. Comparison of Overton COOP *PPT*, 800m PRISM *PPT* for the Overton COOP location, and 800m PRISM *PPT* for the Muddy River Springs area. PRISM *PPT* at the 800m spatial resolution was not available for 2012, therefore, Overton COOP data was used due to the low bias between Overton COOP and Muddy River Springs PRISM *PPT* (Figure 15, right).

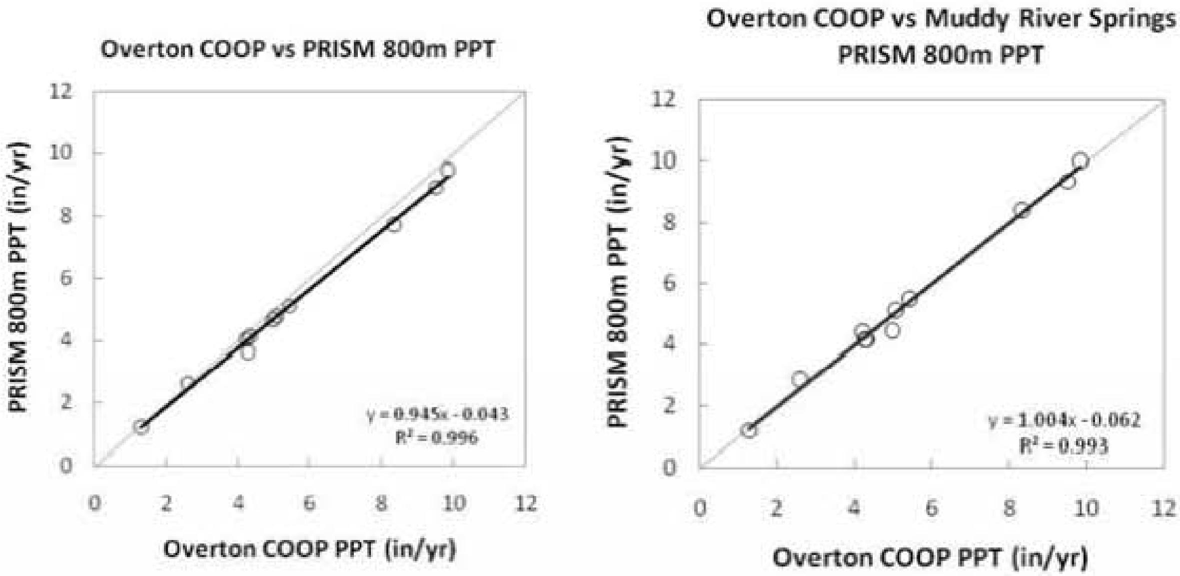

Figure 15. Overton COOP *PPT* vs. 800m PRISM *PPT* for the Overton COOP location (left), and Overton COOP *PPT* vs. 800m PRISM *PPT* for the Muddy River Springs area (right). PRISM *PPT* at the 800m spatial resolution was not available for 2012, therefore, Overton COOP data was used due to the low bias between Overton COOP and Muddy River Springs PRISM PPT.

Utilizing PRISM and COOP *PPT* estimates, seasonal and annual METRIC and NDVI estimated *ET-PPT* was computed (Figures 16 and 17). As previously mentioned, reduced *ET* over the study period is largely due to the decline in ET_r from 2001-2012, and this impact is also evident in the estimated *ET-PPT*. Both METRIC and NDVI estimated ET_rF of *ET-PPT* slightly decline over the 2006-2012 and 2001-2012 periods by 0.07 and 0.10, respectively, indicating that *ET* has declined independent of ET_r and *PPT* due to changes in vegetation and or water management in the study area (Tables A7 and A10). METRIC and NDVI annual estimated ET and ET_rF for 2006-2012 are illustrated in Figures 18 and 19, where it is evident that NDVI estimated *ET* is slightly higher than METRIC estimated *ET* (Figures 20-22). This is due to the fact that bare soil evaporation, potential vegetation stress, and changing surface conditions causes the relationship between NDVI and ET_rF for the Muddy River Springs area to be different from year to year, therefore no average regression will perform well over all years. Average annual METRIC estimated *ET* and *ET-PPT* for 2006-2012 is 3.5 ft/yr and 3.1 ft/yr, respectively. Average annual NDVI estimated *ET* and *ET-PPT* for 2006-2012 is 3.8 ft/yr and 3.4 ft/yr, respectively. For the period of 2006-2012, annual bias between NDVI and METRIC estimated *ET* and ET_rF ranges from 0 to 0.7 ft/yr, and 0.01 to 0.08, respectively, and the average annual bias is 0.32 ft/yr and 0.04, respectively (Figure 23).

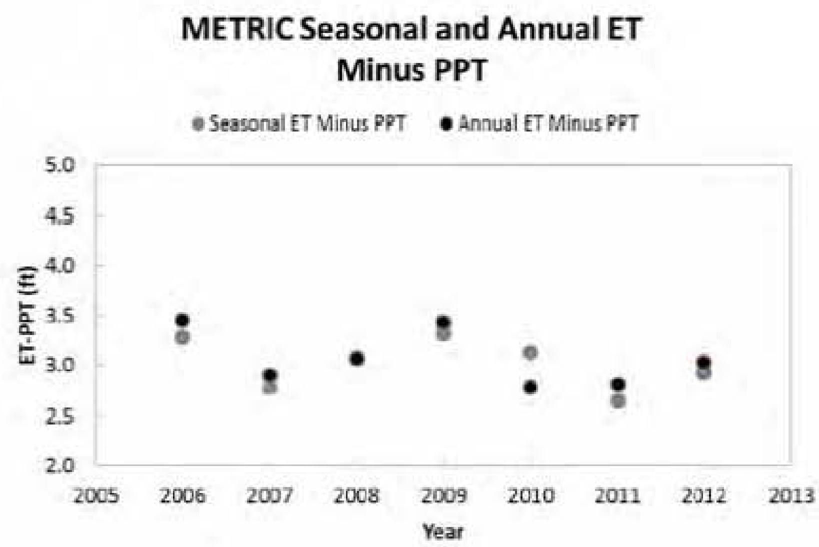

Figure 16. Seasonal and annual METRIC derived *ET-PPT* from 2006-2012.

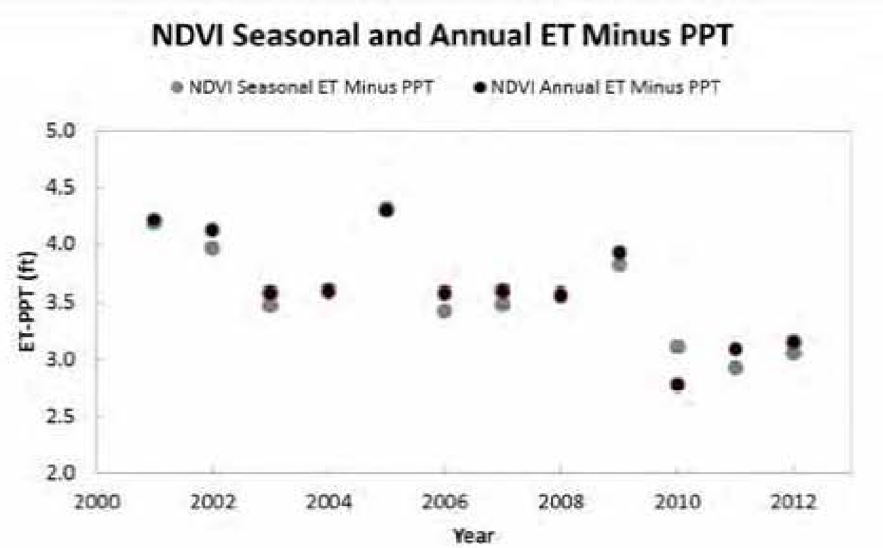

Figure 17. Seasonal and annual NDVI derived *ET-PPT* from 2001-2012.

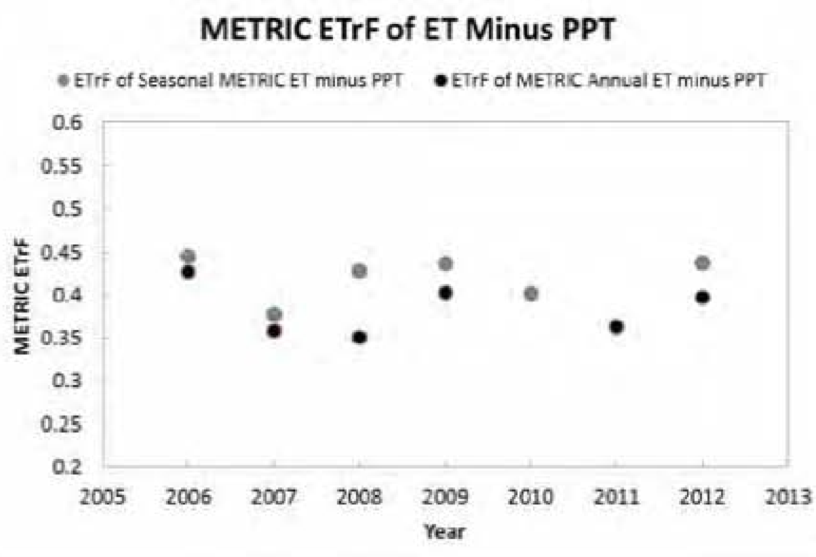

Figure 18. Seasonal and annual METRIC derived ET_rF from 2006-2012.

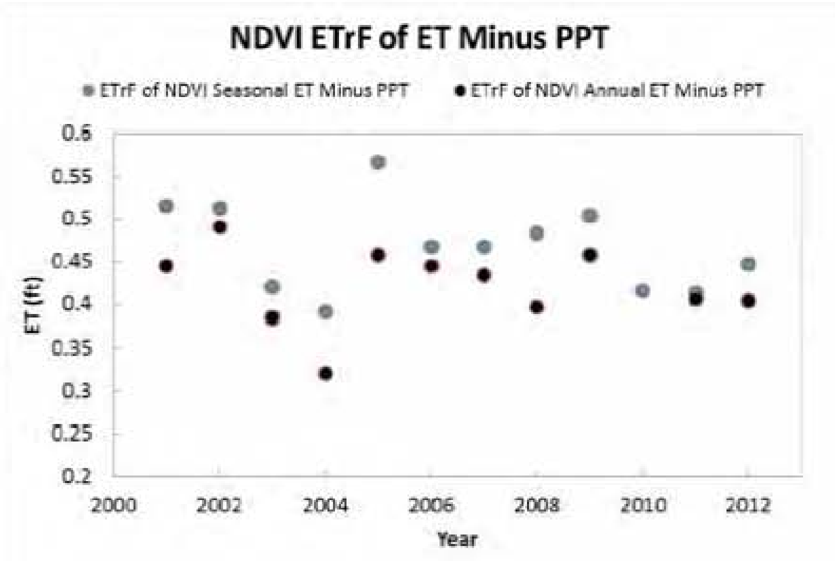

Figure 19. Seasonal and annual NDVI derived ET_rF from 2001-2012.

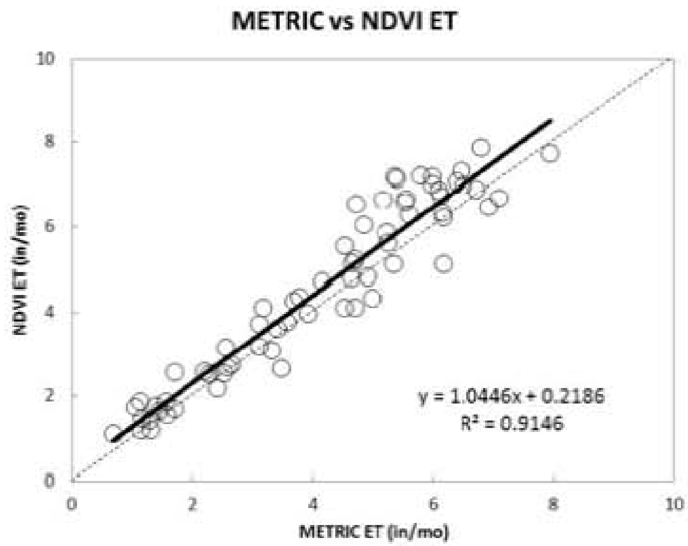

Figure 20. METRIC and NDVI estimated monthly *ET* from 2006-2012.

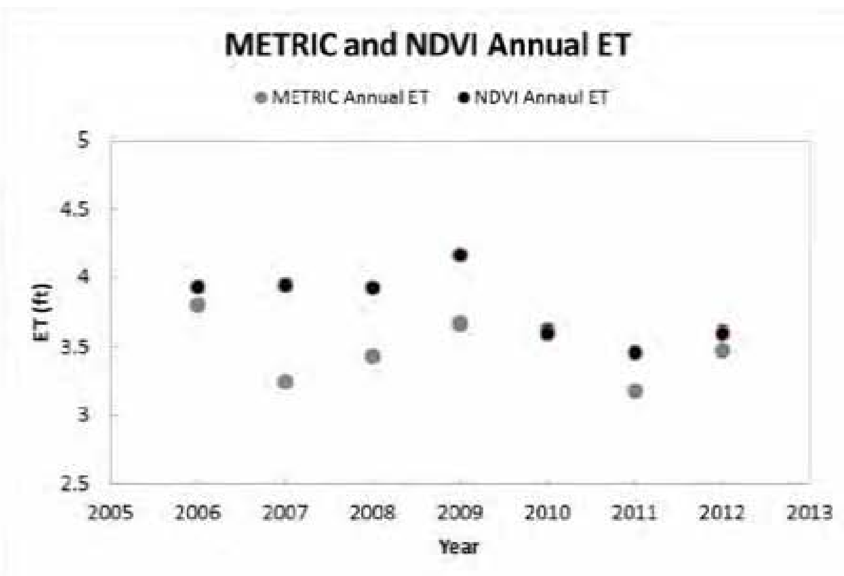

Figure 21. METRIC and NDVI estimated annual *ET* from 2006-2012.

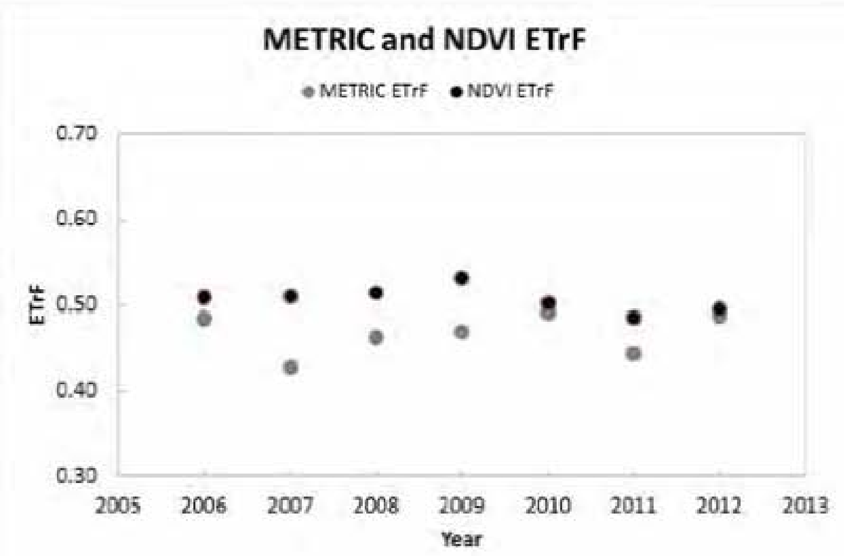

Figure 22. METRIC and NDVI estimated annual *ETrF* from 2006-2012.

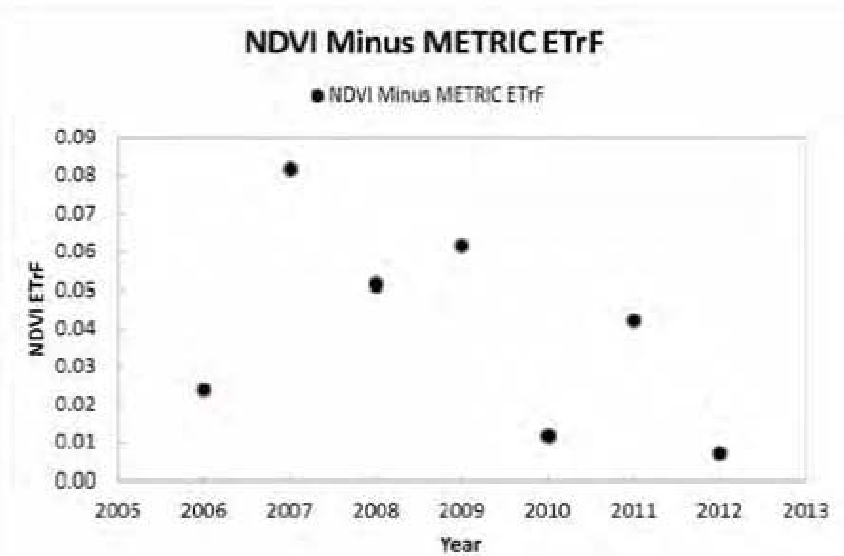

Figure 23. NDVI minus METRIC estimated annual *ETrF* from 2006-2012.

Considering that METRIC estimated *ET* relies on a surface energy balance based on surface temperature, and NDVI strictly relies on optical reflectance and a simple linear index, and the fact that the average annual bias between NDVI and METRIC ET_rF is only 0.04, the comparison between NDVI and METRIC estimated *ET* is thought to be fairly good. As previously mentioned, the use of NDVI does have weaknesses, especially in detecting bare soil evaporation, however, due to the fact that bare soil evaporation is thought to be a fairly small component of *ET* in the Muddy River Springs area due to irrigation practices and moderate vegetation cover. For this reason, the use of NDVI for estimating *ET* is considered to be fairly robust in this work.

Evapotranspiration Reductions

Average METRIC and NDVI estimated annual *ET-PPT* reductions for the Muddy River Springs area for the period of 2006-2012 range from -0.062 ft/yr to -0.11 ft/yr, respectively, with total reductions of METRIC and NDVI annual *ET-PPT* over the 2006-2012 period being -0.43ft and -0.77ft, respectively. Average NDVI estimated annual *ET-PPT* decline for the Muddy River Springs area over the period of 2001-2012 is estimated to be -0.095 ft/yr, with a total reduction in annual *ET-PPT* of -1.14 ft (Tables A6 and A9). For the period 2006-2012, METRIC and NDVI estimated annual *ET-PPT* volume reductions over the 797 acre Muddy River Springs study area are estimated to be -344 ac-ft and -613 ac-ft, respectively. For the period 2001-2012, the NDVI estimated annual *ET-PPT* volume reduction over the 797 acre study area is estimated to be -910 ac-ft. These results along with monthly, seasonal, and annual results of METRIC *ET*, ET_r, PRISM *PPT*, NDVI *ET*, METRIC *ET-PPT*, NDVI *ET-PPT*, METRIC ET_rF, and NDVI ET_rF are listed in Appendix Tables A2-A10. Differences in reductions between METRIC and NDVI from 2006-2012 are due to differences in the computed slopes in ET-PPT during this period. METRIC estimates of *ET* and *ET-PPT* are noticeably lower than NDVI estimates of *ET* and *ET-PPT* for 2007-2009, a period of relatively low precipitation, potentially causing water limited stress conditions that NDVI is not sensitive to. To support this argument METRIC seems to compare well with NDVI estimated *ET* and *ET-PPT* during years of relatively higher precipitation. Also, calibration of METRIC during 2007-2009 could possibly be abnormally low, however, it is thought that calibration during these years are relatively robust and consistent.

Comparison to Previous ET Work

For comparison purposes, METRIC and NDVI derived *ET* was compared to a recent study by DeMeo et al. (2008), who estimated *ET* in the Muddy River Springs area using the Bowen Ratio Energy Balance (BREB) approach from July 2003-October 2006. The Bowen ratio station location is shown in Figure 24, and is surrounded by a dense grove of 10 to 15 ft tall mesquite trees (DeMeo et al., 2008) (Figure 25). DeMeo et al. (2008) reports the average annual *ET* to be 3.6 ft/yr from summing 2003-2006 daily average *ET* estimates from the Muddy River Bowen station. No monthly totals were reported. To compare METRIC *ET* and NDVI *ET* to the Muddy River station estimated *ET* for respective years, 20 minute *ET* data was acquired from the USGS and summed into daily and monthly totals. METRIC and NDVI *ET* estimates were extracted from a 75m buffer around the USGS Muddy River station (Figure 24). Previous work has shown that roughly 80% of the turbulent fluxes measured at many Nevada ET stations with surrounding riparian and shrubland vegetation originates within a 30 to 100m radius of the *ET* station, with the lower range being associated with taller riparian vegetation (Moreo et al., 2007; Allander et al., 2009).

Monthly METRIC and NDVI *ET* estimates were compared to Bowen ratio station *ET* estimates from 2003-2006 (Figures 25 and 26). Results suggest that METRIC and NDVI over predict *ET* at the low *ET* range, but is fairly accurate at the moderate to high *ET* range. The comparisons are considered favorable given that a large part of the annual *ET* in the study area is derived from high *ET* months.

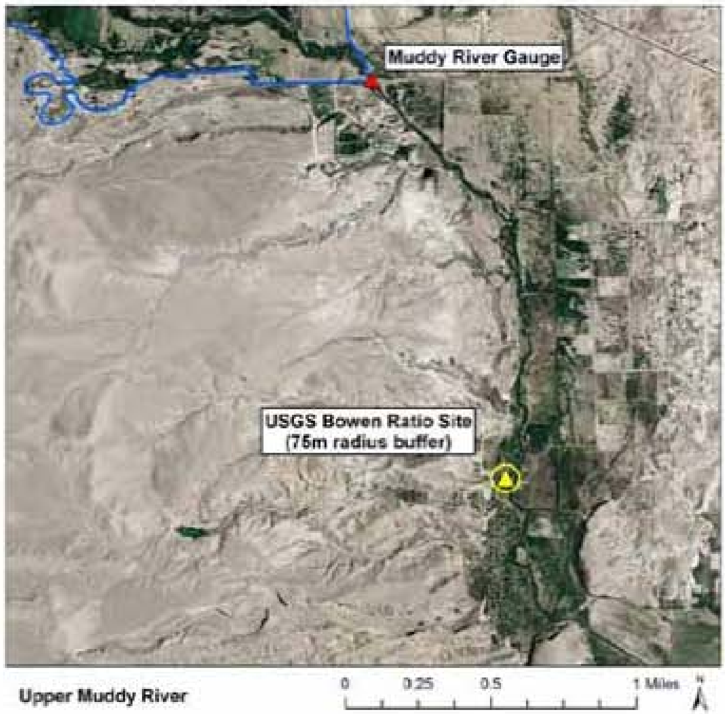

Figure 24. USGS Bowen Ratio Energy Balance station to compare METRIC and NDVI ET estimates to for 2003-2006.

Figure 25. USGS Bowen Ratio Energy Balance station located in the Muddy River area. Modified figure from DeMeo et al. (2008).

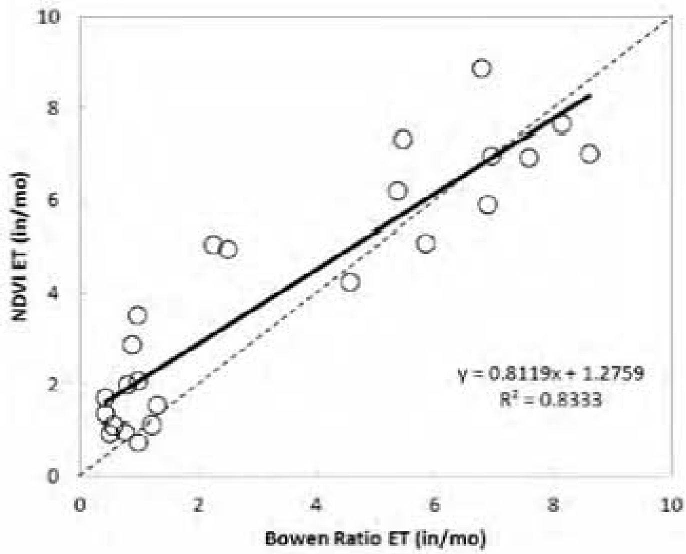

Figure 25. Bowen Ratio Energy Balance estimated monthly ET and NDVI estimated monthly ET from 2003-2006 (with several months of missing data).

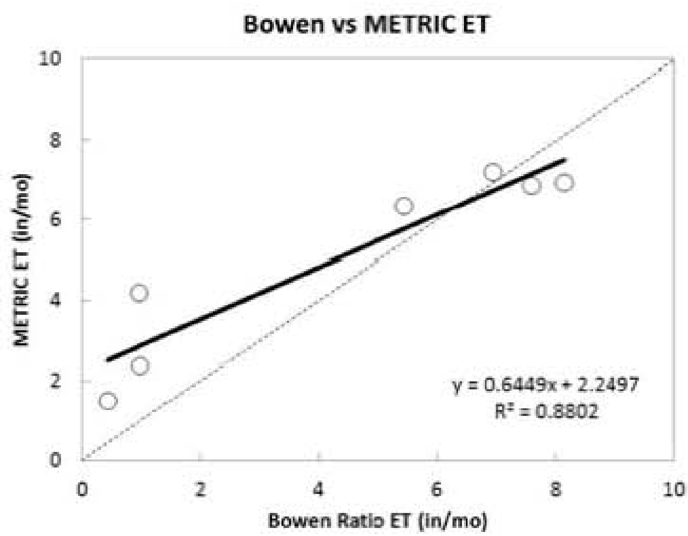

Figure 26. Bowen Ratio Energy Balance estimated monthly ET and METRIC estimated monthly ET from February-August of 2006 (only data available for METRIC comparison).

While the DeMeo et al. (2008) study from 2003-2006 estimated the average *ET* to be 3.6 ft/yr, there were over 271 missing days, many of which were in the spring and summer of 2004 and 2005. As previously indicated, annual *ET* totals reported by DeMeo et al. (2008) were computed by summing period of record daily average *ET* rates (i.e., 365 daily average values). Using daily averages from multiple years is a general approach for gap filling daily *ET* data, and in this case for computing an average annual *ET* rate, however, such averaging and filling approaches do not consider *ET* variability caused by precipitation. For example, a large portion of summer 2005, which was exceptionally wet in the preceding months, was filled with daily average summer values from 2004 and 2006, which were preceded by relatively wet and dry periods, respectively (Figure 14, Table A5). The impact of this type of summation is likely causing a biased low average annual *ET* estimate in this case. As a result of missing data, an accurate comparison of METRIC and NDVI estimated annual *ET* is not possible. For reporting purposes, Bowen station NDVI estimated *ET* ranged from 5.6 ft/yr to 3.9 ft/yr for 2005 and 2006, respectively, with an average annual estimate of 4.3 ft/yr from 2003 -2006. For purposes of making a more respective cumulative *ET* comparison, a comparison was made between the Bowen station, METRIC, and NDVI *ET* over the longest continuous record at the Bowen *ET* station from February-August 2006. Results indicate that Bowen station, METRIC, and NDVI estimated *ET* over this period is 30.5 in, 35.4 in, and 36.2 in, respectively (Figure 27).

Comparing to previous work of DeMeo et al. (2008) revealed that METRIC and NDVI estimated *ET* is likely biased high during low *ET* periods. This bias could be due to inaccuracies of METRIC during the cool season caused by small differences in METRIC surface temperatures at extreme ET conditions (i.e., hot and cold pixel temperature values at dry and well irrigated conditions are nearly the same). Additionally, NDVI bias during the cool period likely exists due to the presence of background NDVI from bare soil and vegetation during fall and winter senescence and dormancy periods, along with inaccuracies in the statistical model between NDVI and ET_rF. In general, the comparison between Bowen station *ET* and METRIC and NDVI estimated *ET* is considered fairly robust given that *ET* estimates generally fall within the uncertainty of Bowen station *ET* estimates, which is likely around 10-15% (Allander et al., 2009). It is difficult to judge the quality of these Bowen ratio *ET* data given that there is extremely limited description on Bowen ratio station instrumentation, and station setup and deployment, such as reporting the make and model of net radiometer and ground heat flux plates, number of soil heat flux plates used, discussion on methods for computing soil heat storage and soil heat flux, filtering of erroneous Bowen ratio values, QAQC of net radiation and ground heat flux, soil moisture measurements, etc., all of which are critical aspects for *ET* measurement reporting (Allen et al., 2011b).

Summary

This study evaluated over 300 Landsat TM and ETM+ images to assess potential changes in *ET* over the Muddy River Springs area from 2001-2012. Results suggest that *ET* has declined from 2001-2012 independent of *PPT* changes. Changes in *ET* are primarily due to to changes in ET_r, and to a lesser extent, due to changes in ET_rF. Reduction of annual *ET-PPT* ranges between -600 to -900 ac-ft. The -600 ac-ft rounded value is derived from the METRIC estimated *ET-PPT* rate of change of -0.062 ft/yr over the period of 2006-2012, and applied to the 12 year period of 2001-2012 (Table A6). The -900 ac-ft rounded value is derived from the NDVI estimated *ET-PPT* rate of change of -0.095 ft/yr over the period of 2001-2012, and is applied to the 12 year period of 2001-2012 (Table A9). Comparisons between METRIC and NDVI, and Bowen ratio station estimated *ET* in the Muddy River Springs area from 2003-2006 are favorable and are generally within the uncertainty of Bowen station *ET* estimates.

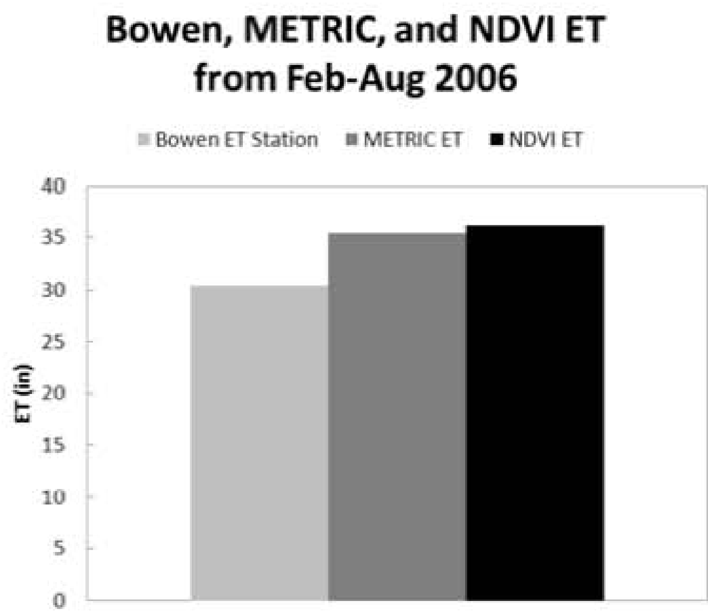

Figure 27. Comparison of total estimated ET from Feb-Aug. 2006 between the Bowen station METRIC, and NDVI. The Feb-Aug. 2006 period was the longest continuous data record for the Bowen station.

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Appendix

Table A1. Listing of Landsat scenes and ET and precipitation results using METIC, NDVI, and EVI methods. Landsat 5 (TM), Landsat ETM, and Landsat ETM SLC off were all used for NDVI and METRIC ET estimates. Landsat ETM SLC off did not impact the quality of ET estimates in the Muddy River Springs area, as SLC gaps were not present in the study area due to the Muddy River Springs area being located in the center of Landsat ETM scenes.

Count	SCENE_ID	DATE	YEAR	DOY	SENSOR	NDVI ET	METRIC ET
1	LT50390352001006XXX02	1/6/2001	2001	6	LANDSAT_TM	x	
2	LE70390352001014EDC00	1/14/2001	2001	14	LANDSAT_ETM	x	
3	LE70390352001030EDC00	1/30/2001	2001	30	LANDSAT_ETM	x	
4	LE70390352001046EDC00	2/15/2001	2001	46	LANDSAT_ETM	x	
5	LT50390352001054XXX02	2/23/2001	2001	54	LANDSAT_TM	x	
6	LE70390352001062EDC01	3/3/2001	2001	62	LANDSAT_ETM	x	
7	LE70390352001078EDC00	3/19/2001	2001	78	LANDSAT_ETM	x	
8	LT50390352001102XXX02	4/12/2001	2001	102	LANDSAT_TM	x	
9	LT50390352001118XXX02	4/28/2001	2001	118	LANDSAT_TM	x	
10	LE70390352001126EDC00	5/6/2001	2001	126	LANDSAT_ETM	x	
11	LT50390352001134AAA02	5/14/2001	2001	134	LANDSAT_TM	x	
12	LE70390352001142EDC00	5/22/2001	2001	142	LANDSAT_ETM	x	
13	LT50390352001150AAA02	5/30/2001	2001	150	LANDSAT_TM	x	
14	LE70390352001158EDC00	6/7/2001	2001	158	LANDSAT_ETM	x	
15	LT50390352001166XXX02	6/15/2001	2001	166	LANDSAT_TM	x	
16	LE70390352001174EDC00	6/23/2001	2001	174	LANDSAT_ETM	x	
17	LT50390352001182LGS03	7/1/2001	2001	182	LANDSAT_TM	x	
18	LE70390352001190EDC00	7/9/2001	2001	190	LANDSAT_ETM	x	
19	LT50390352001214LGS01	8/2/2001	2001	214	LANDSAT_TM	x	
20	LE70390352001222EDC00	8/10/2001	2001	222	LANDSAT_ETM	x	
21	LT50390352001230LGS01	8/18/2001	2001	230	LANDSAT_TM	x	
22	LE70390352001238EDC00	8/26/2001	2001	238	LANDSAT_ETM	x	
23	LT50390352001246LGS01	9/3/2001	2001	246	LANDSAT_TM	x	
24	LT50390352001262LGS01	9/19/2001	2001	262	LANDSAT_TM	x	
25	LE70390352001270EDC00	9/27/2001	2001	270	LANDSAT_ETM	x	
26	LE70390352001286EDC00	10/13/2001	2001	286	LANDSAT_ETM	x	
27	LT50390352001310LGS01	11/6/2001	2001	310	LANDSAT_TM	x	
28	LE70390352001318EDC00	11/14/2001	2001	318	LANDSAT_ETM	x	
29	LT50390352001342LGS01	12/8/2001	2001	342	LANDSAT_TM	x	
30	LE70390352001350EDC00	12/16/2001	2001	350	LANDSAT_ETM	x	
31	LT50390352001358LGS01	12/24/2001	2001	358	LANDSAT_TM	x	

32	LE70390352002017EDC00	1/17/2002	2002	17	LANDSAT_ETM	x	
33	LE70390352002033EDC00	2/2/2002	2002	33	LANDSAT_ETM	x	
34	LT50390352002041EDC01	2/10/2002	2002	41	LANDSAT_TM	x	
35	LT50390352002057LGS01	2/26/2002	2002	57	LANDSAT_TM	x	
36	LE70390352002081EDC00	3/22/2002	2002	81	LANDSAT_ETM	x	
37	LT50390352002089LGS01	3/30/2002	2002	89	LANDSAT_TM	x	
38	LE70390352002097EDC00	4/7/2002	2002	97	LANDSAT_ETM	x	
39	LT50390352002105LGS01	4/15/2002	2002	105	LANDSAT_TM	x	
40	LT50390352002121LGS03	5/1/2002	2002	121	LANDSAT_TM	x	
41	LE70390352002129EDC00	5/9/2002	2002	129	LANDSAT_ETM	x	
42	LT50390352002137LGS01	5/17/2002	2002	137	LANDSAT_TM	x	
43	LE70390352002145EDC01	5/25/2002	2002	145	LANDSAT_ETM	x	
44	LE70390352002161EDC00	6/10/2002	2002	161	LANDSAT_ETM	x	
45	LT50390352002169LGS03	6/18/2002	2002	169	LANDSAT_TM	x	
46	LE70390352002177EDC00	6/26/2002	2002	177	LANDSAT_ETM	x	
47	LT50390352002185EDC02	7/4/2002	2002	185	LANDSAT_TM	x	
48	LE70390352002193EDC00	7/12/2002	2002	193	LANDSAT_ETM	x	
49	LT50390352002201LGS01	7/20/2002	2002	201	LANDSAT_TM	x	
50	LE70390352002209EDC00	7/28/2002	2002	209	LANDSAT_ETM	x	
51	LE70390352002225EDC00	8/13/2002	2002	225	LANDSAT_ETM	x	
52	LT50390352002233LGS01	8/21/2002	2002	233	LANDSAT_TM	x	
53	LE70390352002241EDC00	8/29/2002	2002	241	LANDSAT_ETM	x	
54	LE70390352002257EDC00	9/14/2002	2002	257	LANDSAT_ETM	x	
55	LT50390352002265LGS01	9/22/2002	2002	265	LANDSAT_TM	x	
56	LE70390352002273EDC00	9/30/2002	2002	273	LANDSAT_ETM	x	
57	LT50390352002281LGS01	10/8/2002	2002	281	LANDSAT_TM	x	
58	LE70390352002289EDC00	10/16/2002	2002	289	LANDSAT_ETM	x	
59	LT50390352002297LGS01	10/24/2002	2002	297	LANDSAT_TM	x	
60	LE70390352002305EDC00	11/1/2002	2002	305	LANDSAT_ETM	x	
61	LE70390352002337EDC00	12/3/2002	2002	337	LANDSAT_ETM	x	
62	LE70390352002353EDC00	12/19/2002	2002	353	LANDSAT_ETM	x	
63	LT50390352002361LGS01	12/27/2002	2002	361	LANDSAT_TM	x	
64	LE70390352003020EDC00	1/20/2003	2003	20	LANDSAT_ETM	x	
65	LT50390352003028LGS01	1/28/2003	2003	28	LANDSAT_TM	x	
66	LE70390352003052EDC01	2/21/2003	2003	52	LANDSAT_ETM	x	
67	LE70390352003068EDC00	3/9/2003	2003	68	LANDSAT_ETM	x	
68	LT50390352003092LGS01	4/2/2003	2003	92	LANDSAT_TM	x	
69	LE70390352003100EDC00	4/10/2003	2003	100	LANDSAT_ETM	x	
70	LE70390352003116EDC00	4/26/2003	2003	116	LANDSAT_ETM	x	
71	LT50390352003124LGS01	5/4/2003	2003	124	LANDSAT_TM	x	
72	LT50390352003140LGS01	5/20/2003	2003	140	LANDSAT_TM	x	

73	LE70390352003148EDC00	5/28/2003	2003	148	LANDSAT_ETM	x	
74	LT50390352003156LGS01	6/5/2003	2003	156	LANDSAT_TM	x	
75	LT50390352003172EDC03	6/21/2003	2003	172	LANDSAT_TM	x	
76	LT50390352003188PAC02	7/7/2003	2003	188	LANDSAT_TM	x	
77	LE70390352003212EDC02	7/31/2003	2003	212	LANDSAT_ETM_SLC_OFF	x	
78	LT50390352003220PAC04	8/8/2003	2003	220	LANDSAT_TM	x	
79	LE70390352003244EDC01	9/1/2003	2003	244	LANDSAT_ETM_SLC_OFF	x	
80	LT50390352003252PAC02	9/9/2003	2003	252	LANDSAT_TM	x	
81	LE70390352003260EDC02	9/17/2003	2003	260	LANDSAT_ETM_SLC_OFF	x	
82	LE70390352003276EDC02	10/3/2003	2003	276	LANDSAT_ETM_SLC_OFF	x	
83	LT50390352003284LGS01	10/11/2003	2003	284	LANDSAT_TM	x	
84	LE70390352003308EDC01	11/4/2003	2003	308	LANDSAT_ETM_SLC_OFF	x	
85	LT50390352003348PAC02	12/14/2003	2003	348	LANDSAT_TM	x	
86	LE70390352003356EDC01	12/22/2003	2003	356	LANDSAT_ETM_SLC_OFF	x	
87	LT50390352004015PAC02	1/15/2004	2004	15	LANDSAT_TM	x	
88	LE70390352004023EDC01	1/23/2004	2004	23	LANDSAT_ETM_SLC_OFF	x	
89	LE70390352004039EDC01	2/8/2004	2004	39	LANDSAT_ETM_SLC_OFF	x	
90	LT50390352004063PAC02	3/3/2004	2004	63	LANDSAT_TM	x	
91	LE70390352004071EDC02	3/11/2004	2004	71	LANDSAT_ETM_SLC_OFF	x	
92	LT50390352004079PAC02	3/19/2004	2004	79	LANDSAT_TM	x	
93	LE70390352004087EDC02	3/27/2004	2004	87	LANDSAT_ETM_SLC_OFF	x	
94	LE70390352004103EDC02	4/12/2004	2004	103	LANDSAT_ETM_SLC_OFF	x	
95	LE70390352004119EDC03	4/28/2004	2004	119	LANDSAT_ETM_SLC_OFF	x	
96	LE70390352004135EDC01	5/14/2004	2004	135	LANDSAT_ETM_SLC_OFF	x	
97	LT50390352004143PAC02	5/22/2004	2004	143	LANDSAT_TM	x	
98	LE70390352004151EDC01	5/30/2004	2004	151	LANDSAT_ETM_SLC_OFF	x	
99	LT50390352004159PAC02	6/7/2004	2004	159	LANDSAT_TM	x	
100	LE70390352004167EDC01	6/15/2004	2004	167	LANDSAT_ETM_SLC_OFF	x	
101	LT50390352004175PAC02	6/23/2004	2004	175	LANDSAT_TM	x	
102	LT50390352004191PAC01	7/9/2004	2004	191	LANDSAT_TM	x	
103	LT50390352004207PAC02	7/25/2004	2004	207	LANDSAT_TM	x	
104	LT50390352004223PAC01	8/10/2004	2004	223	LANDSAT_TM	x	
105	LT50390352004239PAC01	8/26/2004	2004	239	LANDSAT_TM	x	
106	LE70390352004247EDC02	9/3/2004	2004	247	LANDSAT_ETM_SLC_OFF	x	
107	LE70390352004263EDC02	9/19/2004	2004	263	LANDSAT_ETM_SLC_OFF	x	
108	LT50390352004271EDC00	9/27/2004	2004	271	LANDSAT_TM	x	
109	LT50390352004287PAC01	10/13/2004	2004	287	LANDSAT_TM	x	
110	LT50390352004303PAC01	10/29/2004	2004	303	LANDSAT_TM	x	
111	LT50390352004319PAC01	11/14/2004	2004	319	LANDSAT_TM	x	
112	LT50390352004351PAC01	12/16/2004	2004	351	LANDSAT_TM	x	
113	LE70390352004359EDC00	12/24/2004	2004	359	LANDSAT_ETM_SLC_OFF	x	

114	LT50390352005017PAC01	1/17/2005	2005	17	LANDSAT_TM	x	
115	LT50390352005033PAC01	2/2/2005	2005	33	LANDSAT_TM	x	
116	LT50390352005065PAC01	3/6/2005	2005	65	LANDSAT_TM	x	
117	LE70390352005089EDC00	3/30/2005	2005	89	LANDSAT_ETM_SLC_OFF	x	
118	LE70390352005105EDC00	4/15/2005	2005	105	LANDSAT_ETM_SLC_OFF	x	
119	LT50390352005129PAC01	5/9/2005	2005	129	LANDSAT_TM	x	
120	LE70390352005137EDC00	5/17/2005	2005	137	LANDSAT_ETM_SLC_OFF	x	
121	LT50390352005145EDC00	5/25/2005	2005	145	LANDSAT_TM	x	
122	LE70390352005153EDC00	6/2/2005	2005	153	LANDSAT_ETM_SLC_OFF	x	
123	LT50390352005161PAC01	6/10/2005	2005	161	LANDSAT_TM	x	
124	LE70390352005169EDC00	6/18/2005	2005	169	LANDSAT_ETM_SLC_OFF	x	
125	LT50390352005177PAC01	6/26/2005	2005	177	LANDSAT_TM	x	
126	LT50390352005193PAC01	7/12/2005	2005	193	LANDSAT_TM	x	
127	LT50390352005209PAC01	7/28/2005	2005	209	LANDSAT_TM	x	
128	LT50390352005225PAC01	8/13/2005	2005	225	LANDSAT_TM	x	
129	LE70390352005233EDC00	8/21/2005	2005	233	LANDSAT_ETM_SLC_OFF	x	
130	LT50390352005241PAC01	8/29/2005	2005	241	LANDSAT_TM	x	
131	LE70390352005249EDC00	9/6/2005	2005	249	LANDSAT_ETM_SLC_OFF	x	
132	LT50390352005257PAC01	9/14/2005	2005	257	LANDSAT_TM	x	
133	LE70390352005265EDC00	9/22/2005	2005	265	LANDSAT_ETM_SLC_OFF	x	
134	LT50390352005273PAC01	9/30/2005	2005	273	LANDSAT_TM	x	
135	LT50390352005289PAC01	10/16/2005	2005	289	LANDSAT_TM	x	
136	LE70390352005297EDC00	10/24/2005	2005	297	LANDSAT_ETM_SLC_OFF	x	
137	LT50390352005321PAC01	11/17/2005	2005	321	LANDSAT_TM	x	
138	LE70390352005345EDC00	12/11/2005	2005	345	LANDSAT_ETM_SLC_OFF	x	
139	LT50390352006020EDC00	1/20/2006	2006	20	LANDSAT_TM	x	
140	LT50390352006036PAC01	2/5/2006	2006	36	LANDSAT_TM	x	x
141	LE70390352006044EDC00	2/13/2006	2006	44	LANDSAT_ETM_SLC_OFF	x	
142	LT50390352006052PAC01	2/21/2006	2006	52	LANDSAT_TM	x	
143	LE70390352006060EDC00	3/1/2006	2006	60	LANDSAT_ETM_SLC_OFF	x	
144	LT50390352006068PAC01	3/9/2006	2006	68	LANDSAT_TM	x	x
145	LE70390352006092EDC00	4/2/2006	2006	92	LANDSAT_ETM_SLC_OFF	x	
146	LT50390352006100PAC01	4/10/2006	2006	100	LANDSAT_TM	x	x
147	LT50390352006116PAC01	4/26/2006	2006	116	LANDSAT_TM	x	x
148	LE70390352006124EDC00	5/4/2006	2006	124	LANDSAT_ETM_SLC_OFF	x	
149	LT50390352006132PAC01	5/12/2006	2006	132	LANDSAT_TM	x	x
150	LE70390352006140EDC00	5/20/2006	2006	140	LANDSAT_ETM_SLC_OFF	x	
151	LT50390352006148PAC01	5/28/2006	2006	148	LANDSAT_TM	x	x
152	LE70390352006156EDC00	6/5/2006	2006	156	LANDSAT_ETM_SLC_OFF	x	
153	LE70390352006172EDC00	6/21/2006	2006	172	LANDSAT_ETM_SLC_OFF	x	
154	LT50390352006180PAC01	6/29/2006	2006	180	LANDSAT_TM	x	x

155	LT50390352006196PAC01	7/15/2006	2006	196	LANDSAT_TM	x	x
156	LE70390352006204EDC00	7/23/2006	2006	204	LANDSAT_ETM_SLC_OFF	x	
157	LT50390352006212PAC02	7/31/2006	2006	212	LANDSAT_TM	x	x
158	LE70390352006220EDC00	8/8/2006	2006	220	LANDSAT_ETM_SLC_OFF	x	
159	LT50390352006228PAC01	8/16/2006	2006	228	LANDSAT_TM	x	x
160	LE70390352006236EDC00	8/24/2006	2006	236	LANDSAT_ETM_SLC_OFF	x	
161	LT50390352006260PAC01	9/17/2006	2006	260	LANDSAT_TM	x	x
162	LT50390352006276PAC01	10/3/2006	2006	276	LANDSAT_TM	x	x
163	LE70390352006284EDC00	10/11/2006	2006	284	LANDSAT_ETM_SLC_OFF	x	
164	LT50390352006292PAC01	10/19/2006	2006	292	LANDSAT_TM	x	x
165	LE70390352006300EDC00	10/27/2006	2006	300	LANDSAT_ETM_SLC_OFF	x	
166	LT50390352006308PAC01	11/4/2006	2006	308	LANDSAT_TM	x	x
167	LE70390352006316EDC00	11/12/2006	2006	316	LANDSAT_ETM_SLC_OFF	x	
168	LT50390352006324PAC01	11/20/2006	2006	324	LANDSAT_TM	x	x
169	LE70390352006332EDC00	11/28/2006	2006	332	LANDSAT_ETM_SLC_OFF	x	
170	LT50390352006340PAC01	12/6/2006	2006	340	LANDSAT_TM	x	x
171	LE70390352006364EDC00	12/30/2006	2006	364	LANDSAT_ETM_SLC_OFF	x	
172	LT50390352007007PAC01	1/7/2007	2007	7	LANDSAT_TM	x	
173	LE70390352007015EDC00	1/15/2007	2007	15	LANDSAT_ETM_SLC_OFF	x	
174	LT50390352007023PAC01	1/23/2007	2007	23	LANDSAT_TM	x	
175	LE70390352007047EDC00	2/16/2007	2007	47	LANDSAT_ETM_SLC_OFF	x	x
176	LT50390352007055PAC01	2/24/2007	2007	55	LANDSAT_TM	x	x
177	LE70390352007063EDC00	3/4/2007	2007	63	LANDSAT_ETM_SLC_OFF	x	
178	LT50390352007071PAC01	3/12/2007	2007	71	LANDSAT_TM	x	
179	LT50390352007103PAC01	4/13/2007	2007	103	LANDSAT_TM	x	
180	LE70390352007111EDC00	4/21/2007	2007	111	LANDSAT_ETM_SLC_OFF	x	
181	LT50390352007119PAC01	4/29/2007	2007	119	LANDSAT_TM	x	x
182	LE70390352007127EDC00	5/7/2007	2007	127	LANDSAT_ETM_SLC_OFF	x	x
183	LT50390352007135PAC01	5/15/2007	2007	135	LANDSAT_TM	x	x
184	LE70390352007143EDC00	5/23/2007	2007	143	LANDSAT_ETM_SLC_OFF	x	x
185	LT50390352007151PAC01	5/31/2007	2007	151	LANDSAT_TM	x	x
186	LE70390352007159EDC00	6/8/2007	2007	159	LANDSAT_ETM_SLC_OFF	x	x
187	LT50390352007167PAC01	6/16/2007	2007	167	LANDSAT_TM	x	x
188	LE70390352007175EDC00	6/24/2007	2007	175	LANDSAT_ETM_SLC_OFF	x	x
189	LT50390352007183PAC01	7/2/2007	2007	183	LANDSAT_TM	x	x
190	LE70390352007191EDC00	7/10/2007	2007	191	LANDSAT_ETM_SLC_OFF	x	
191	LT50390352007199PAC01	7/18/2007	2007	199	LANDSAT_TM	x	x
192	LT50390352007215PAC01	8/3/2007	2007	215	LANDSAT_TM	x	x
193	LE70390352007223EDC00	8/11/2007	2007	223	LANDSAT_ETM_SLC_OFF	x	x
194	LT50390352007247PAC01	9/4/2007	2007	247	LANDSAT_TM	x	x
195	LE70390352007255EDC00	9/12/2007	2007	255	LANDSAT_ETM_SLC_OFF	x	x

196	LE70390352007287EDC00	10/14/2007	2007	287	LANDSAT_ETM_SLC_OFF	x	x
197	LE70390352007303EDC00	10/30/2007	2007	303	LANDSAT_ETM_SLC_OFF	x	x
198	LE70390352007319EDC00	11/15/2007	2007	319	LANDSAT_ETM_SLC_OFF	x	x
199	LE70390352007351EDC00	12/17/2007	2007	351	LANDSAT_ETM_SLC_OFF	x	
200	LE70390352008018EDC00	1/18/2008	2008	18	LANDSAT_ETM_SLC_OFF	x	
201	LT50390352008026EDC00	1/26/2008	2008	26	LANDSAT_TM	x	
202	LT50390352008042EDC00	2/11/2008	2008	42	LANDSAT_TM	x	
203	LT50390352008058PAC01	2/27/2008	2008	58	LANDSAT_TM	x	
204	LE70390352008066EDC00	3/6/2008	2008	66	LANDSAT_ETM_SLC_OFF	x	x
205	LT50390352008074PAC01	3/14/2008	2008	74	LANDSAT_TM	x	
206	LE70390352008082EDC00	3/22/2008	2008	82	LANDSAT_ETM_SLC_OFF	x	x
207	LE70390352008098EDC00	4/7/2008	2008	98	LANDSAT_ETM_SLC_OFF	x	x
208	LT50390352008106PAC01	4/15/2008	2008	106	LANDSAT_TM	x	
209	LE70390352008114EDC00	4/23/2008	2008	114	LANDSAT_ETM_SLC_OFF	x	x
210	LT50390352008122PAC01	5/1/2008	2008	122	LANDSAT_TM	x	x
211	LE70390352008130EDC00	5/9/2008	2008	130	LANDSAT_ETM_SLC_OFF	x	x
212	LT50390352008138PAC01	5/17/2008	2008	138	LANDSAT_TM	x	x
213	LT50390352008154PAC01	6/2/2008	2008	154	LANDSAT_TM	x	x
214	LE70390352008162EDC00	6/10/2008	2008	162	LANDSAT_ETM_SLC_OFF	x	
215	LT50390352008170PAC01	6/18/2008	2008	170	LANDSAT_TM	x	x
216	LE70390352008178EDC00	6/26/2008	2008	178	LANDSAT_ETM_SLC_OFF	x	x
217	LT50390352008234PAC01	8/21/2008	2008	234	LANDSAT_TM	x	x
218	LE70390352008242EDC00	8/29/2008	2008	242	LANDSAT_ETM_SLC_OFF	x	x
219	LT50390352008250PAC01	9/6/2008	2008	250	LANDSAT_TM	x	x
220	LE70390352008258EDC00	9/14/2008	2008	258	LANDSAT_ETM_SLC_OFF	x	x
221	LT50390352008266PAC01	9/22/2008	2008	266	LANDSAT_TM	x	x
222	LE70390352008274EDC00	9/30/2008	2008	274	LANDSAT_ETM_SLC_OFF	x	x
223	LT50390352008282PAC01	10/8/2008	2008	282	LANDSAT_TM	x	x
224	LE70390352008290EDC00	10/16/2008	2008	290	LANDSAT_ETM_SLC_OFF	x	x
225	LT50390352008298PAC01	10/24/2008	2008	298	LANDSAT_TM	x	x
226	LE70390352008322EDC00	11/17/2008	2008	322	LANDSAT_ETM_SLC_OFF	x	x
227	LE70390352008338EDC00	12/3/2008	2008	338	LANDSAT_ETM_SLC_OFF	x	
228	LE70390352009004EDC00	1/4/2009	2009	4	LANDSAT_ETM_SLC_OFF	x	
229	LT50390352009012PAC01	1/12/2009	2009	12	LANDSAT_TM	x	
230	LE70390352009020EDC00	1/20/2009	2009	20	LANDSAT_ETM_SLC_OFF	x	
231	LT50390352009092PAC01	4/2/2009	2009	92	LANDSAT_TM	x	x
232	LT50390352009108PAC01	4/18/2009	2009	108	LANDSAT_TM	x	x
233	LE70390352009116EDC00	4/26/2009	2009	116	LANDSAT_ETM_SLC_OFF	x	x
234	LE70390352009132EDC02	5/12/2009	2009	132	LANDSAT_ETM_SLC_OFF	x	x
235	LT50390352009140PAC01	5/20/2009	2009	140	LANDSAT_TM	x	x
236	LE70390352009148EDC00	5/28/2009	2009	148	LANDSAT_ETM_SLC_OFF	x	x

237	LT50390352009172PAC01	6/21/2009	2009	172	LANDSAT_TM	x	x
238	LE70390352009180EDC00	6/29/2009	2009	180	LANDSAT_ETM_SLC_OFF	x	x
239	LT50390352009188PAC01	7/7/2009	2009	188	LANDSAT_TM	x	x
240	LE70390352009196EDC00	7/15/2009	2009	196	LANDSAT_ETM_SLC_OFF	x	x
241	LE70390352009212EDC00	7/31/2009	2009	212	LANDSAT_ETM_SLC_OFF	x	x
242	LT50390352009220PAC01	8/8/2009	2009	220	LANDSAT_TM	x	x
243	LE70390352009228EDC00	8/16/2009	2009	228	LANDSAT_ETM_SLC_OFF	x	x
244	LT50390352009236PAC01	8/24/2009	2009	236	LANDSAT_TM	x	x
245	LT50390352009252PAC01	9/9/2009	2009	252	LANDSAT_TM	x	x
246	LE70390352009260EDC00	9/17/2009	2009	260	LANDSAT_ETM_SLC_OFF	x	x
247	LT50390352009268PAC01	9/25/2009	2009	268	LANDSAT_TM	x	x
248	LT50390352009284PAC01	10/11/2009	2009	284	LANDSAT_TM	x	x
249	LE70390352009292EDC00	10/19/2009	2009	292	LANDSAT_ETM_SLC_OFF	x	x
250	LE70390352009308EDC00	11/4/2009	2009	308	LANDSAT_ETM_SLC_OFF	x	x
251	LE70390352009324EDC00	11/20/2009	2009	324	LANDSAT_ETM_SLC_OFF	x	x
252	LT50390352009332PAC01	11/28/2009	2009	332	LANDSAT_TM	x	x
253	LE70390352009340EDC00	12/6/2009	2009	340	LANDSAT_ETM_SLC_OFF	x	
254	LT50390352009348PAC01	12/14/2009	2009	348	LANDSAT_TM	x	
255	LT50390352010015PAC01	1/15/2010	2010	15	LANDSAT_TM	x	
256	LT50390352010031PAC01	1/31/2010	2010	31	LANDSAT_TM	x	
257	LT50390352010047PAC01	2/16/2010	2010	47	LANDSAT_TM	x	x
258	LE70390352010071EDC00	3/12/2010	2010	71	LANDSAT_ETM_SLC_OFF	x	
259	LT50390352010079PAC01	3/20/2010	2010	79	LANDSAT_TM	x	
260	LE70390352010087EDC00	3/28/2010	2010	87	LANDSAT_ETM_SLC_OFF	x	x
261	LE70390352010103EDC00	4/13/2010	2010	103	LANDSAT_ETM_SLC_OFF	x	x
262	LT50390352010111PAC01	4/21/2010	2010	111	LANDSAT_TM	x	
263	LT50390352010127PAC01	5/7/2010	2010	127	LANDSAT_TM	x	x
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267	LE70390352010167EDC00	6/16/2010	2010	167	LANDSAT_ETM_SLC_OFF	x	x
268	LT50390352010175EDC00	6/24/2010	2010	175	LANDSAT_TM	x	x
269	LE70390352010183EDC00	7/2/2010	2010	183	LANDSAT_ETM_SLC_OFF	x	
270	LE70390352010199EDC00	7/18/2010	2010	199	LANDSAT_ETM_SLC_OFF	x	x
271	LE70390352010215EDC00	8/3/2010	2010	215	LANDSAT_ETM_SLC_OFF	x	x
272	LT50390352010223EDC00	8/11/2010	2010	223	LANDSAT_TM	x	x
273	LE70390352010231EDC00	8/19/2010	2010	231	LANDSAT_ETM_SLC_OFF	x	x
274	LT50390352010239EDC00	8/27/2010	2010	239	LANDSAT_TM	x	x
275	LE70390352010247EDC00	9/4/2010	2010	247	LANDSAT_ETM_SLC_OFF	x	x
276	LE70390352010263EDC00	9/20/2010	2010	263	LANDSAT_ETM_SLC_OFF	x	x
277	LT50390352010271EDC00	9/28/2010	2010	271	LANDSAT_TM	x	x

278	LE70390352010279EDC00	10/6/2010	2010	279	LANDSAT_ETM_SLC_OFF	x	
279	LT50390352010287EDC00	10/14/2010	2010	287	LANDSAT_TM	x	x
280	LE70390352010311EDC00	11/7/2010	2010	311	LANDSAT_ETM_SLC_OFF	x	x
281	LT50390352010319PAC01	11/15/2010	2010	319	LANDSAT_TM	x	x
282	LE70390352010327EDC00	11/23/2010	2010	327	LANDSAT_ETM_SLC_OFF	x	
283	LT50390352010335EDC00	12/1/2010	2010	335	LANDSAT_TM	x	x
284	LE70390352011042EDC00	2/11/2011	2011	42	LANDSAT_ETM_SLC_OFF	x	x
285	LT50390352011082PAC01	3/23/2011	2011	82	LANDSAT_TM	x	x
286	LE70390352011090EDC00	3/31/2011	2011	90	LANDSAT_ETM_SLC_OFF	x	x
287	LE70390352011106EDC00	4/16/2011	2011	106	LANDSAT_ETM_SLC_OFF	x	x
288	LT50390352011114PAC01	4/24/2011	2011	114	LANDSAT_TM	x	x
289	LT50390352011146PAC01	5/26/2011	2011	146	LANDSAT_TM	x	x
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291	LT50390352011162PAC01	6/11/2011	2011	162	LANDSAT_TM	x	x
292	LE70390352011170EDC00	6/19/2011	2011	170	LANDSAT_ETM_SLC_OFF	x	x
293	LT50390352011178PAC01	6/27/2011	2011	178	LANDSAT_TM	x	x
294	LT50390352011194PAC01	7/13/2011	2011	194	LANDSAT_TM	x	x
295	LE70390352011202EDC00	7/21/2011	2011	202	LANDSAT_ETM_SLC_OFF	x	x
296	LT50390352011210PAC01	7/29/2011	2011	210	LANDSAT_TM	x	x
297	LE70390352011218EDC00	8/6/2011	2011	218	LANDSAT_ETM_SLC_OFF	x	x
298	LT50390352011226PAC01	8/14/2011	2011	226	LANDSAT_TM	x	x
299	LE70390352011234EDC00	8/22/2011	2011	234	LANDSAT_ETM_SLC_OFF	x	x
300	LT50390352011242PAC01	8/30/2011	2011	242	LANDSAT_TM	x	x
301	LE70390352011250EDC00	9/7/2011	2011	250	LANDSAT_ETM_SLC_OFF	x	x
302	LT50390352011258PAC01	9/15/2011	2011	258	LANDSAT_TM	x	x
303	LE70390352011266EDC00	9/23/2011	2011	266	LANDSAT_ETM_SLC_OFF	x	x
304	LE70390352011298EDC00	10/25/2011	2011	298	LANDSAT_ETM_SLC_OFF	x	x
305	LT50390352011306PAC01	11/2/2011	2011	306	LANDSAT_TM	x	x
306	LE70390352011330EDC00	11/26/2011	2011	330	LANDSAT_ETM_SLC_OFF	x	x
307	LE70390352012013EDC00	1/13/2012	2012	13	LANDSAT_ETM_SLC_OFF	x	
308	LE70390352012029EDC00	1/29/2012	2012	29	LANDSAT_ETM_SLC_OFF	x	
309	LE70390352012061EDC00	3/1/2012	2012	61	LANDSAT_ETM_SLC_OFF	x	x
310	LE70390352012093EDC00	4/2/2012	2012	93	LANDSAT_ETM_SLC_OFF	x	x
311	LE70390352012109EDC04	4/18/2012	2012	109	LANDSAT_ETM_SLC_OFF	x	x
312	LE70390352012125EDC00	5/4/2012	2012	125	LANDSAT_ETM_SLC_OFF	x	x
313	LE70390352012141EDC00	5/20/2012	2012	141	LANDSAT_ETM_SLC_OFF	x	x
314	LE70390352012157EDC00	6/5/2012	2012	157	LANDSAT_ETM_SLC_OFF	x	x
315	LE70390352012173EDC00	6/21/2012	2012	173	LANDSAT_ETM_SLC_OFF	x	x
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317	LE70390352012205EDC00	7/23/2012	2012	205	LANDSAT_ETM_SLC_OFF	x	
318	LE70390352012221EDC00	8/8/2012	2012	221	LANDSAT_ETM_SLC_OFF	x	x

319	LE70390352012237EDC00	8/24/2012	2012	237	LANDSAT_ETM_SLC_OFF	x	x
320	LE70390352012269EDC00	9/25/2012	2012	269	LANDSAT_ETM_SLC_OFF	x	x
321	LE70390352012301EDC00	10/27/2012	2012	301	LANDSAT_ETM_SLC_OFF	x	x
322	LE70390352012317EDC00	11/12/2012	2012	317	LANDSAT_ETM_SLC_OFF	x	x
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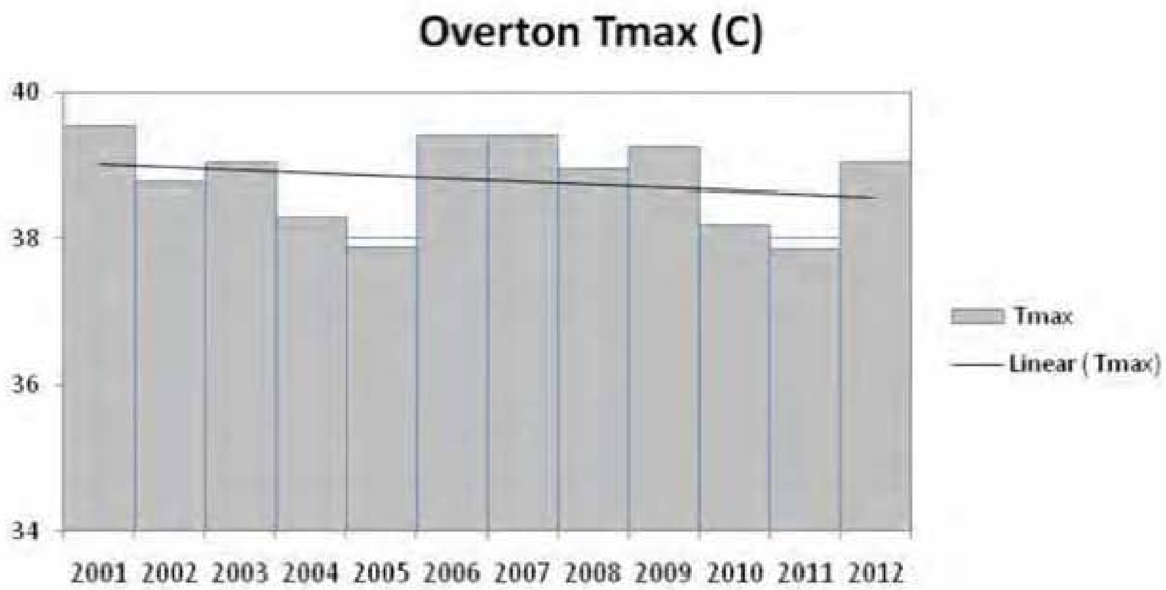

Figure A1. Overton CEMP warm season (May-September) average daily maximum temperature (Tmax).

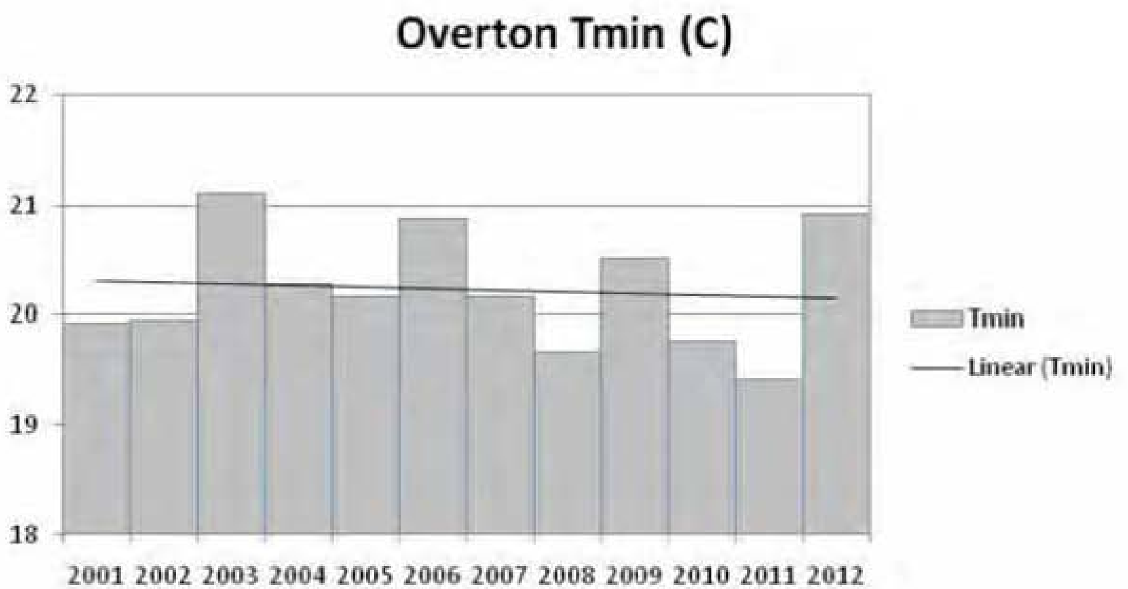

Figure A2. Overton CEMP warm season (May-September) average daily minimum temperature (Tmin).

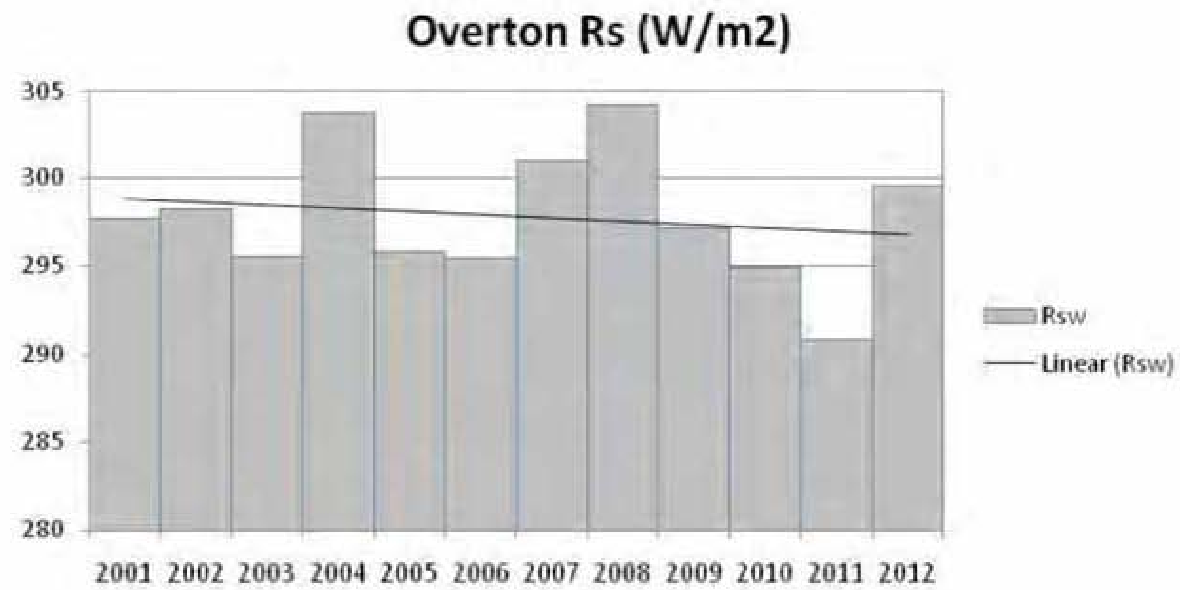

Figure A3. Overton CEMP warm season (May-September) average daily solar radiation (Rs).

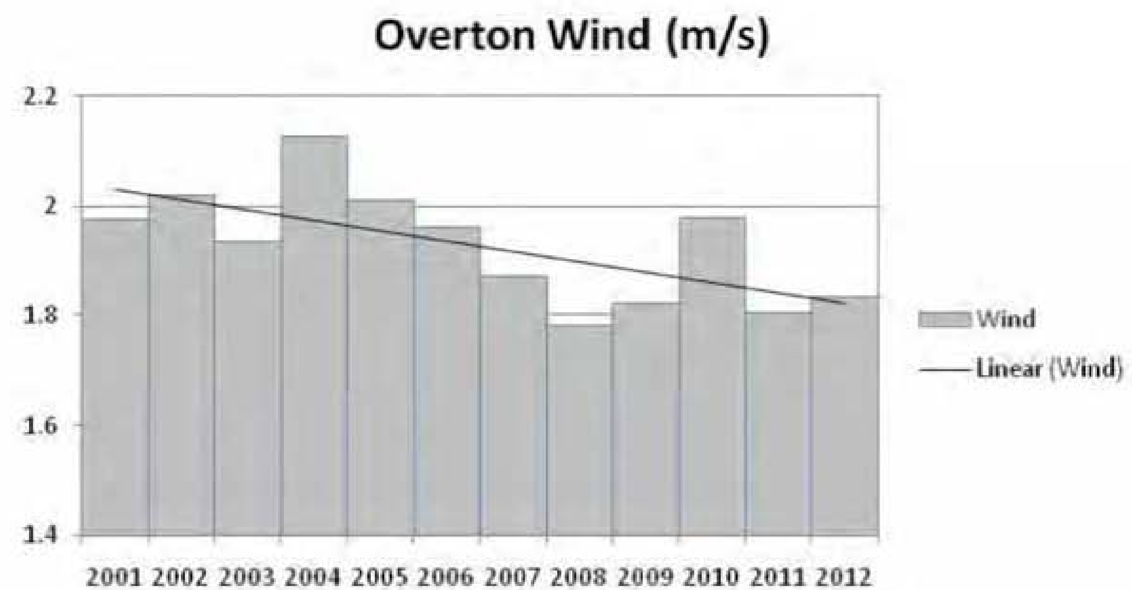

Figure A4. Overton CEMP warm season (May-September) average daily 6m height windspeed.

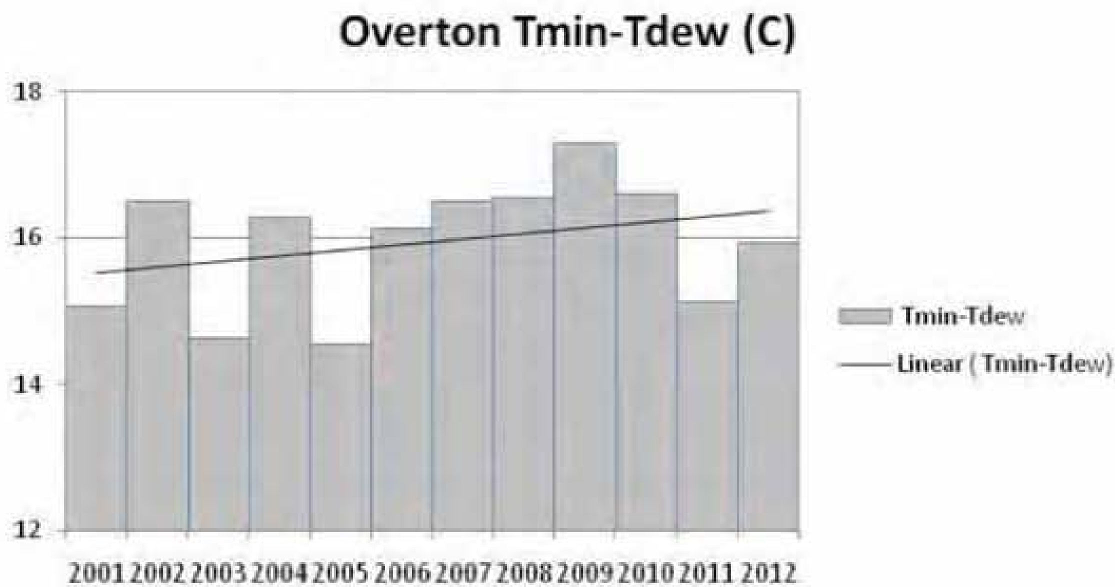

Figure A5. Overton CEMP warm season (May-September) average daily minimum temperature minus dewpoint temperature (i.e. dewpoint depression).

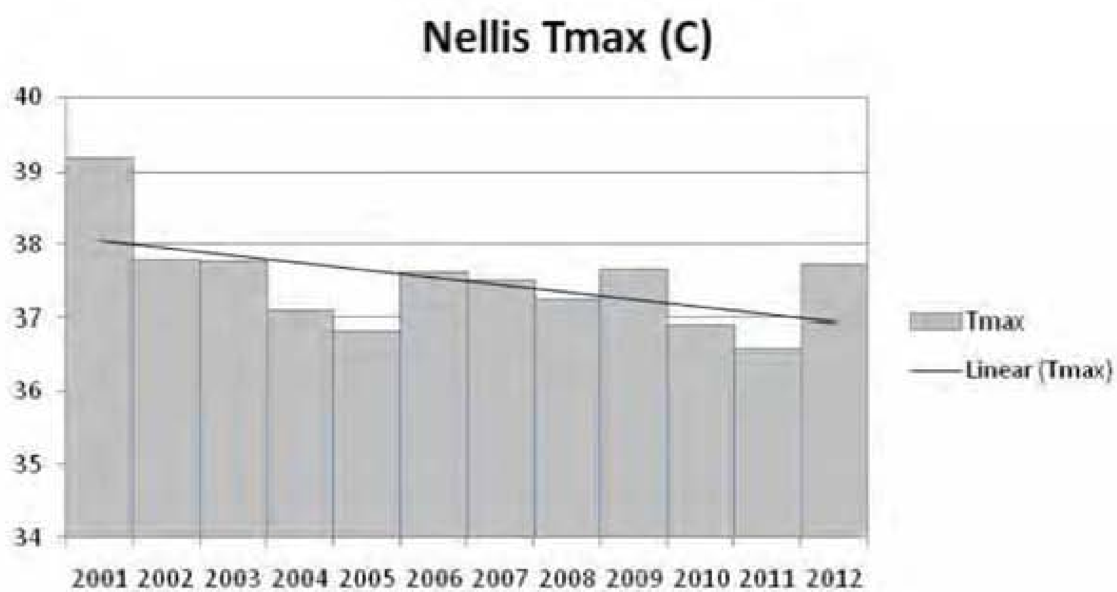

Figure A6. Nellis AFB warm season (May-September) average daily maximum temperature (Tmax).

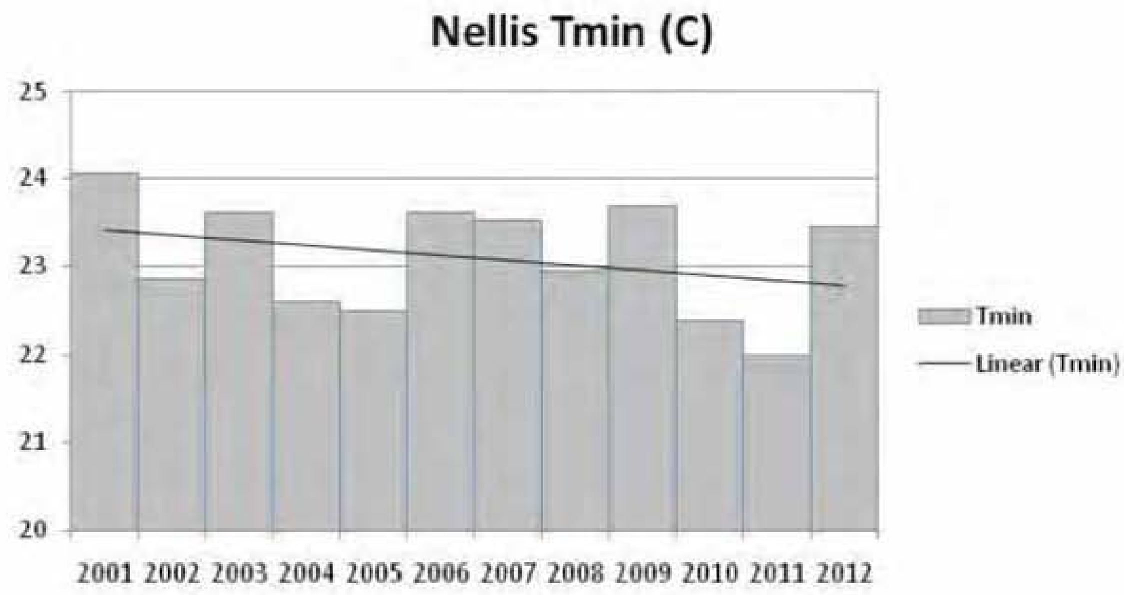

Figure A7. Nellis AFB warm season (May-September) average daily minimum temperature (Tmin).

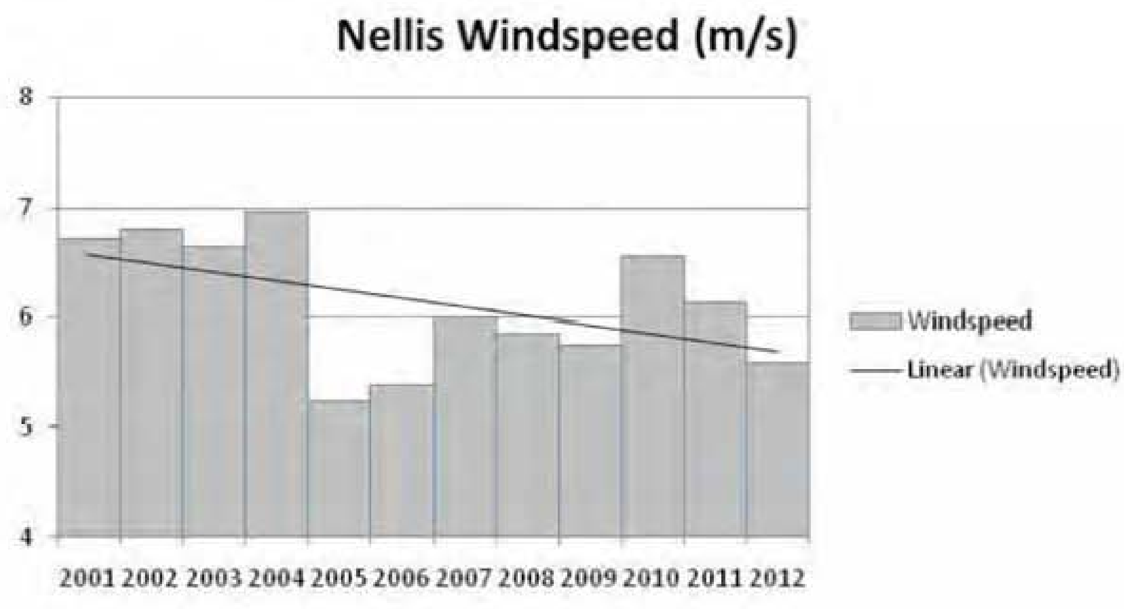

Figure A8. Nellis AFB warm season (May-September) average daily 10m height windspeed.

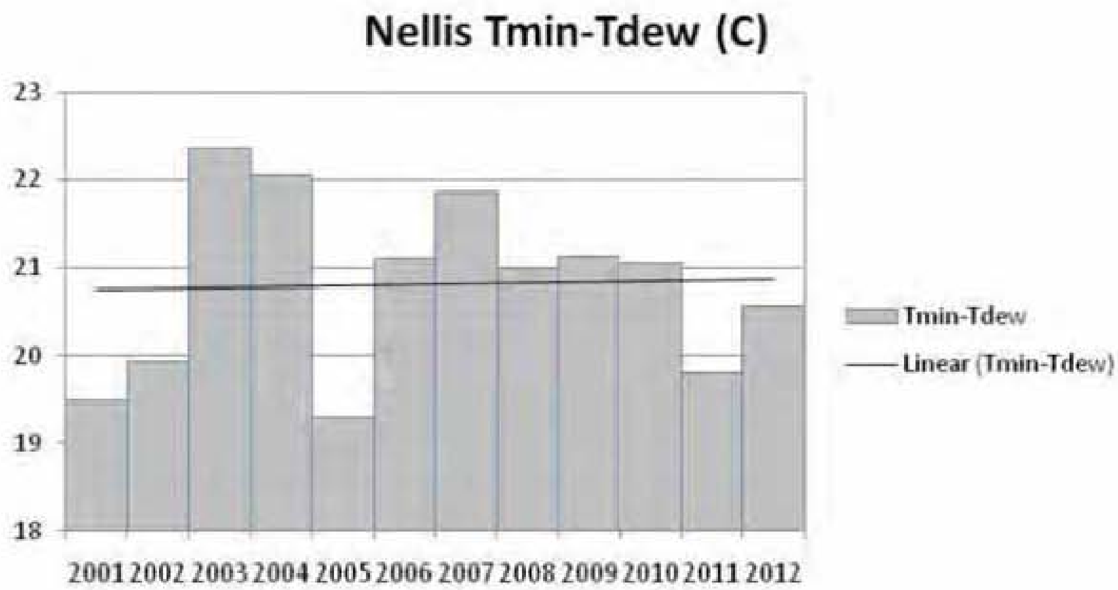

Figure A9. Nellis AFB warm season (May-September) average daily minimum temperature minus dewpoint temperature (i.e. dewpoint depression).

Table A2. Muddy River Springs METRIC *ET* from 2006-2012.

Warm Springs Area METRIC ET (ft)

Month	2006	2007	2008	2009	2010	2011	2012
1	0.11	0.09	0.09	0.10	0.08	0.08	0.11
2	0.12	0.10	0.10	0.10	0.11	0.06	0.13
3	0.20	0.21	0.19	0.23	0.29	0.09	0.18
4	0.38	0.31	0.35	0.26	0.42	0.28	0.30
5	0.54	0.39	0.40	0.46	0.58	0.39	0.47
6	0.54	0.45	0.45	0.48	0.66	0.50	0.53
7	0.59	0.46	0.50	0.57	0.51	0.51	0.44
8	0.51	0.43	0.51	0.56	0.38	0.51	0.44
9	0.41	0.39	0.39	0.44	0.31	0.33	0.39
10	0.22	0.21	0.26	0.26	0.14	0.22	0.28
11	0.10	0.12	0.14	0.13	0.09	0.11	0.13
12	0.09	0.08	0.07	0.09	0.06	0.10	0.08
Seasonal (ft)	3.61	3.08	3.28	3.48	3.48	3.00	3.29
Annual (ft)	3.80	3.24	3.44	3.67	3.62	3.18	3.48
Mean Seasonal (ft)	3.32						
Mean Annual (ft)	3.49						
Seasonal Slope (ft/yr)	-0.03						
Annual Slope (ft/yr)	-0.03						
Warm Springs Area (acres)	797						
2006-2012 Seasonal Change (ft)	-0.23						
2006-2012 Seasonal Change (ac-ft)	-181						
2006-2012 Annual Change (ft)	-0.23						
2006-2012 Annual Change (ac-ft)	-181						

Table A3. Overton CEMP alfalfa reference *ET* (ET_r) for estimating of METRIC *ET* and NDVI *ET*.

Alfalfa Reference ET (ft)

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	0.21	0.25	0.25	0.24	0.17	0.27	0.25	0.23	0.25	0.19	0.22	0.25
2	0.27	0.38	0.29	0.26	0.26	0.35	0.29	0.30	0.25	0.22	0.29	0.33
3	0.39	0.52	0.49	0.62	0.52	0.45	0.53	0.55	0.56	0.50	0.44	0.57
4	0.73	0.76	0.78	0.71	0.65	0.73	0.70	0.82	0.72	0.65	0.70	0.71
5	1.04	1.00	0.93	1.00	0.90	1.00	0.96	0.91	0.93	0.90	0.85	1.01
6	1.14	1.13	1.14	1.04	1.05	1.02	1.02	1.01	0.94	1.02	1.04	1.10
7	1.14	1.08	1.05	1.04	0.97	0.94	0.99	0.98	1.00	1.03	0.91	0.91
8	0.92	1.05	0.86	0.94	0.80	0.95	0.90	0.88	0.90	0.95	0.87	0.78
9	0.73	0.71	0.77	0.76	0.75	0.68	0.71	0.63	0.75	0.61	0.57	0.59
10	0.48	0.46	0.58	0.46	0.50	0.40	0.46	0.45	0.54	0.40	0.39	0.43
11	0.29	0.35	0.23	0.24	0.27	0.25	0.28	0.26	0.29	0.29	0.23	0.24
12	0.17	0.17	0.18	0.20	0.22	0.21	0.17	0.15	0.19	0.14	0.21	0.18
Seasonal (ft)	7.12	7.43	7.13	7.06	6.67	6.76	6.84	6.79	6.88	6.59	6.29	6.66
Annual (ft)	7.51	7.85	7.56	7.51	7.06	7.24	7.26	7.17	7.32	6.92	6.72	7.09

2001-2012 Mean Seasonal (ft)	6.85
2001-2012 Mean Annual (ft)	7.27
2006-2012 Mean Seasonal (ft)	6.69
2006-2012 Mean Annual (ft)	7.10
2001-2012 Seasonal Slope (ft/yr)	-0.068
2001-2012 Annual Slope (ft/yr)	-0.069
2006-2012 Seasonal Slope (ft/yr)	-0.057
2006-2012 Annual Slope (ft/yr)	-0.064
2001-2012 Seasonal Change (ft)	-0.82
2006-2012 Seasonal Change (ft)	-0.40
2001-2012 Annual Change (ft)	-0.83
2006-2012 Annual Change (ft)	-0.45

Table A4. Muddy River Springs METRIC fraction of alfalfa reference ET (ET_rF) from 2006-2012. Values with * indicate that NDVI was used to estimate ET_rF using function described in text.

METRIC ETrF

Month	2006	2007	2008	2009	2010	2011	2012
1	0.39*	0.36*	0.37*	0.38*	0.40*	0.39*	0.42*
2	0.34	0.33	0.33*	0.39*	0.49	0.20	0.38*
3	0.45	0.40	0.35	0.41*	0.57	0.22	0.32
4	0.52	0.45	0.42	0.37	0.64	0.40	0.42
5	0.54	0.41	0.45	0.50	0.64	0.46	0.46
6	0.53	0.44	0.44	0.51	0.65	0.48	0.48
7	0.63	0.47	0.51	0.56	0.50	0.57	0.48
8	0.53	0.48	0.58	0.62	0.40	0.59	0.57
9	0.60	0.55	0.61	0.59	0.50	0.57	0.66
10	0.55	0.47	0.58	0.48	0.36	0.55	0.64
11	0.39	0.41	0.54	0.44	0.30	0.45	0.56
12	0.34*	0.38*	0.38*	0.38*	0.45*	0.45*	0.45*
Seasonal	0.51	0.44	0.48	0.49	0.50	0.45	0.50
Annual	0.48	0.43	0.46	0.47	0.49	0.44	0.49
Mean Seasonal	0.48						
Mean Annual	0.47						
Seasonal Slope	0.0005						
Annual Slope	0.0026						
Seasonal Change	0.003						
Annual Change	0.018						

Table A5. Muddy River Springs PRISM Precipitation from 2001-2012.

Warm Springs Area PRISM Precipitation (ft)

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	0.123	0.001	0.004	0.010	0.192	0.016	0.013	0.069	0.025	0.187	0.002	0.003
2	0.122	0.000	0.154	0.156	0.215	0.001	0.025	0.050	0.107	0.115	0.073	0.018
3	0.073	0.006	0.072	0.016	0.046	0.092	0.004	0.006	0.000	0.053	0.026	0.023
4	0.016	0.000	0.041	0.083	0.044	0.007	0.010	0.000	0.014	0.009	0.010	0.037
5	0.001	0.000	0.002	0.001	0.004	0.001	0.000	0.017	0.001	0.002	0.021	0.000
6	0.000	0.000	0.000	0.002	0.009	0.010	0.000	0.000	0.002	0.000	0.000	0.000
7	0.013	0.014	0.012	0.009	0.033	0.069	0.052	0.034	0.021	0.003	0.043	0.007
8	0.033	0.000	0.056	0.027	0.039	0.000	0.039	0.021	0.002	0.047	0.004	0.142
9	0.000	0.019	0.009	0.009	0.004	0.015	0.075	0.005	0.005	0.002	0.048	0.068
10	0.000	0.029	0.001	0.119	0.104	0.121	0.000	0.020	0.002	0.108	0.095	0.063
11	0.023	0.015	0.044	0.171	0.007	0.000	0.090	0.055	0.004	0.014	0.030	0.000
12	0.022	0.013	0.065	0.176	0.005	0.016	0.039	0.089	0.054	0.292	0.018	0.085
Seasonal (ft)	0.281	0.084	0.389	0.593	0.505	0.315	0.294	0.208	0.158	0.353	0.351	0.358
Annual (ft)	0.426	0.097	0.458	0.779	0.701	0.346	0.346	0.366	0.238	0.832	0.371	0.446

2001-2012 Mean Seasonal (ft)	0.32
2001-2012 Mean Annual (ft)	0.45
2006-2012 Mean Seasonal (ft)	0.29
2006-2012 Mean Annual (ft)	0.42
2001-2012 Seasonal Slope (ft/yr)	0.000
2001-2012 Annual Slope (ft/yr)	0.006
2006-2012 Seasonal Slope (ft/yr)	0.014
2006-2012 Annual Slope (ft/yr)	0.029
Warm Springs Area (acres)	797
2001-2012 Seasonal Change (ft)	0.00
2001-2012 Seasonal Change (ac-ft)	-3
2006-2012 Seasonal Change (ft)	0.10

2006-2012 Seasonal Change (ac-ft)	78
2001-2012 Annual Change (ft)	0.07
2001-2012 Annual Change (ac-ft)	53
2006-2012 Annual Change (ft)	0.20
2006-2012 Annual Change (ac-ft)	162

Table A6. Muddy River Springs METRIC ET minus PRISM precipitation from 2006-2012.

Warm Springs Area METRIC ET minus PRISM Precipitation (ft)

Month	2006	2007	2008	2009	2010	2011	2012
1	0.09	0.07	0.02	0.07	-0.11	0.08	0.10
2	0.12	0.07	0.05	-0.01	-0.01	-0.02	0.11
3	0.11	0.21	0.18	0.22	0.24	0.07	0.16
4	0.37	0.31	0.35	0.25	0.41	0.28	0.26
5	0.54	0.39	0.39	0.46	0.57	0.37	0.47
6	0.53	0.45	0.45	0.48	0.66	0.50	0.53
7	0.52	0.41	0.46	0.55	0.51	0.47	0.43
8	0.51	0.39	0.49	0.56	0.33	0.51	0.30
9	0.40	0.32	0.38	0.43	0.30	0.28	0.33
10	0.10	0.21	0.24	0.26	0.03	0.12	0.21
11	0.10	0.03	0.09	0.13	0.07	0.08	0.13
12	0.07	0.04	-0.02	0.03	-0.23	0.08	-0.01
Seasonal (ft)	3.29	2.78	3.07	3.33	3.13	2.65	2.93
Annual (ft)	3.45	2.90	3.07	3.43	2.79	2.81	3.03
Mean Seasonal (ft)	3.03						
Mean Annual (ft)	3.07						
Seasonal Slope (ft/yr)	-0.046						
Annual Slope (ft/yr)	-0.062						
Warm Springs Area (acres)	797						
2006-2012 Seasonal Change (ft)	-0.32						
2006-2012 Seasonal Change (ac-ft)	-258						
2006-2012 Annual Change (ft)	-0.43						
2006-2012 Annual Change (ac-ft)	-344						

Table A7. Muddy River Springs ETrF of METRIC ET minus PRISM precipitation (METRIC ET-PPT)/ETr from 2006-2012.

METRIC ETrF of ET minus PRISM Precipitation

Month	2006	2007	2008	2009	2010	2011	2012
1	0.33	0.30	0.07	0.28	-0.59	0.38	0.41
2	0.34	0.24	0.16	-0.03	-0.03	-0.06	0.33
3	0.24	0.39	0.34	0.40	0.47	0.16	0.28
4	0.51	0.43	0.42	0.35	0.62	0.39	0.37
5	0.54	0.41	0.43	0.50	0.64	0.43	0.46
6	0.52	0.44	0.44	0.51	0.65	0.48	0.48
7	0.56	0.41	0.47	0.54	0.49	0.52	0.47
8	0.53	0.43	0.55	0.62	0.35	0.59	0.39
9	0.58	0.45	0.60	0.58	0.50	0.48	0.55
10	0.25	0.47	0.54	0.48	0.09	0.30	0.50
11	0.39	0.09	0.33	0.43	0.25	0.33	0.56
12	0.34	0.23	-0.15	0.18	-1.67	0.36	-0.03
Seasonal	0.45	0.38	0.43	0.44	0.40	0.36	0.44
Annual	0.43	0.36	0.35	0.40	0.15	0.36	0.40
Mean Seasonal	0.41						
Mean Annual	0.35						
Seasonal Slope	-0.003						
Annual Slope	-0.010						
Seasonal Change	-0.02						
Annual Change	-0.07						

Table A8. Muddy River Springs NDVI ET from 2001-2012.

Warm Springs Area NDVI Estimated ET (ft)

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	0.09	0.10	0.09	0.09	0.08	0.11	0.09	0.09	0.10	0.08	0.08	0.11
2	0.10	0.15	0.11	0.09	0.14	0.14	0.10	0.10	0.10	0.10	0.09	0.13
3	0.19	0.21	0.19	0.26	0.36	0.18	0.21	0.21	0.23	0.22	0.16	0.22
4	0.45	0.37	0.38	0.42	0.48	0.34	0.36	0.39	0.34	0.36	0.30	0.31
5	0.72	0.55	0.54	0.60	0.67	0.58	0.55	0.50	0.55	0.54	0.43	0.52
6	0.77	0.65	0.64	0.66	0.79	0.61	0.60	0.60	0.60	0.64	0.58	0.59
7	0.74	0.63	0.60	0.66	0.68	0.56	0.56	0.60	0.66	0.43	0.53	0.49
8	0.58	0.61	0.51	0.60	0.61	0.57	0.56	0.56	0.57	0.46	0.52	0.43
9	0.46	0.44	0.45	0.49	0.57	0.40	0.44	0.40	0.47	0.35	0.33	0.34
10	0.30	0.27	0.34	0.29	0.34	0.23	0.26	0.27	0.31	0.21	0.22	0.26
11	0.16	0.17	0.12	0.13	0.16	0.12	0.15	0.14	0.16	0.15	0.12	0.13
12	0.08	0.07	0.07	0.10	0.11	0.09	0.08	0.07	0.09	0.06	0.10	0.08
Seasonal (ft)	4.47	4.05	3.87	4.19	4.81	3.74	3.78	3.77	3.98	3.47	3.28	3.42
Annual (ft)	4.64	4.23	4.04	4.38	5.00	3.93	3.94	3.93	4.17	3.60	3.46	3.60
2001-2012 Mean Seasonal (ft)	3.90											
2001-2012 Mean Annual (ft)	4.08											
2006-2012 Mean Seasonal (ft)	3.63											
2006-2012 Mean Annual (ft)	3.80											
2001-2012 Seasonal Slope (ft/yr)	-0.089											
2001-2012 Annual Slope (ft/yr)	-0.090											
2006-2012 Seasonal Slope (ft/yr)	-0.081											
2006-2012 Annual Slope (ft/yr)	-0.081											
Warm Springs Area (acres)	797											
2001-2012 Seasonal Change (ft)	-1.07											
2001-2012 Seasonal Change (ac-ft)	-851											
2006-2012 Seasonal Change (ft)	-0.56											

2006-2012 Seasonal Change (ac-ft)	-450
2001-2012 Annual Change (ft)	-1.07
2001-2012 Annual Change (ac-ft)	-856
2006-2012 Annual Change (ft)	-0.57
2006-2012 Annual Change (ac-ft)	-451

Table A9. Muddy River Springs NDVI ET minus PRISM Precipitation from 2001-2012.

Warm Springs Area NDVI Estimated ET minus PRISM Precipitation (ft)

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	-0.04	0.10	0.09	0.08	-0.11	0.09	0.07	0.02	0.07	-0.11	0.08	0.10
2	-0.02	0.15	-0.05	-0.06	-0.07	0.14	0.07	0.05	-0.01	-0.02	0.02	0.11
3	0.12	0.20	0.12	0.25	0.31	0.09	0.21	0.20	0.22	0.17	0.13	0.19
4	0.43	0.37	0.34	0.34	0.43	0.34	0.35	0.39	0.33	0.35	0.29	0.28
5	0.72	0.55	0.53	0.60	0.67	0.58	0.55	0.49	0.55	0.54	0.41	0.52
6	0.77	0.65	0.64	0.66	0.78	0.60	0.60	0.60	0.60	0.64	0.58	0.59
7	0.73	0.62	0.59	0.65	0.65	0.49	0.51	0.57	0.64	0.42	0.48	0.48
8	0.55	0.61	0.45	0.57	0.57	0.57	0.52	0.54	0.57	0.41	0.51	0.28
9	0.45	0.42	0.44	0.48	0.57	0.39	0.36	0.39	0.46	0.35	0.28	0.28
10	0.30	0.24	0.33	0.17	0.24	0.11	0.26	0.25	0.31	0.11	0.13	0.19
11	0.14	0.16	0.08	-0.04	0.16	0.12	0.06	0.09	0.15	0.13	0.09	0.13
12	0.06	0.06	0.01	-0.08	0.10	0.07	0.04	-0.02	0.03	-0.23	0.08	-0.01
Seasonal (ft)	4.19	3.97	3.48	3.60	4.31	3.42	3.48	3.57	3.82	3.11	2.93	3.06
Annual (ft)	4.21	4.13	3.58	3.60	4.30	3.58	3.59	3.56	3.93	2.77	3.09	3.16
2001-2012 Mean Seasonal (ft)	3.58											
2001-2012 Mean Annual (ft)	3.63											
2006-2012 Mean Seasonal (ft)	3.34											
2006-2012 Mean Annual (ft)	3.38											
2001-2012 Seasonal Slope (ft/yr)	-0.089											
2001-2012 Annual Slope (ft/yr)	-0.095											
2006-2012 Seasonal Slope (ft/yr)	-0.095											
2006-2012 Annual Slope (ft/yr)	-0.110											
Warm Springs Area (acres)	797											
2001-2012 Seasonal Change (ft)	-1.06											
2001-2012 Seasonal Change (ac-ft)	-849											
2006-2012 Seasonal Change (ft)	-0.66											

2006-2012 Seasonal Change (ac-ft)	-528
2001-2012 Annual Change (ft)	-1.14
2001-2012 Annual Change (ac-ft)	-910
2006-2012 Annual Change (ft)	-0.77
2006-2012 Annual Change (ac-ft)	-613

Table A10. Muddy River Springs ETrF of NDVI ET minus PRISM precipitation (NDVI ET-PPT)/ETr) from 2001-2012.

NDVI ETrF of ET minus PRISM Precipitation

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	-0.17	0.42	0.36	0.32	-0.66	0.33	0.30	0.07	0.28	-0.59	0.38	0.41
2	-0.07	0.39	-0.17	-0.24	-0.27	0.39	0.26	0.16	-0.03	-0.07	0.07	0.33
3	0.30	0.40	0.25	0.40	0.60	0.20	0.39	0.38	0.40	0.33	0.29	0.34
4	0.60	0.49	0.44	0.47	0.66	0.46	0.50	0.48	0.46	0.54	0.41	0.39
5	0.69	0.55	0.57	0.60	0.74	0.58	0.57	0.54	0.59	0.60	0.48	0.52
6	0.68	0.57	0.56	0.63	0.74	0.59	0.58	0.59	0.64	0.63	0.56	0.54
7	0.64	0.57	0.56	0.63	0.67	0.52	0.51	0.58	0.63	0.41	0.54	0.53
8	0.59	0.58	0.52	0.61	0.71	0.60	0.57	0.61	0.63	0.43	0.59	0.36
9	0.62	0.59	0.57	0.63	0.76	0.57	0.51	0.62	0.62	0.58	0.49	0.46
10	0.62	0.53	0.57	0.37	0.48	0.27	0.58	0.55	0.57	0.27	0.32	0.45
11	0.48	0.46	0.32	-0.18	0.58	0.49	0.20	0.32	0.52	0.44	0.37	0.54
12	0.36	0.34	0.05	-0.39	0.48	0.34	0.23	-0.15	0.18	-1.67	0.36	-0.03
Seasonal	0.52	0.51	0.42	0.39	0.57	0.47	0.47	0.48	0.50	0.42	0.41	0.45
Annual	0.45	0.49	0.38	0.32	0.46	0.45	0.43	0.40	0.46	0.16	0.41	0.40
Mean Seasonal	0.47											
Mean Annual	0.40											
Seasonal Slope	-0.005											
Annual Slope	-0.008											
Seasonal Change	-0.06											
Annual Change	-0.10											

Technical Memorandum

Comments on Carbonate Order 1169 Pump Test Data and the Groundwater Flow System in Coyote Springs and Muddy River Springs Valley, Nevada

June 25, 2013

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Prepared For: Great Basin Water Network, Baker, NV.

Purpose and Summary

The purpose of this memorandum is to provide an analysis of the pump test completed as required by the Nevada State Order 1169, or the carbonate aquifer order. The analysis is of data published on the Nevada State Engineer web page and the U.S. Geological Survey National Water Information System web page. The data includes pumping rates, groundwater levels, and spring discharge rates. Also, the groundwater model of flow in the southern White River Flow System (Tetra Tech, 2012a and b) was briefly reviewed for predictions related to pumping from Coyote Springs and Muddy River Springs Valley.

A brief summary of the findings is that the groundwater level in the carbonate aquifer in the Muddy River Springs basin began to decrease in the late 1990s in response to increased carbonate pumping from the Arrow Canyon Well. Groundwater levels in the basin fill aquifer also began to decline in the late 1990s even though substantial basin fill pumping has been occurring since the 1980s. This suggests that decreased groundwater inflow to the basin fill from the carbonate may be causing some of the drawdown in the fill.

A wet year in 2005 contributed to a partial recovery of the carbonate groundwater levels, but the decline resumed and accelerated in the late 2000s. The decline of the carbonate groundwater level near Moapa Springs corresponded with a decrease in spring discharge from the Warm Springs and the Pederson Springs at the Moapa Springs complex. The rate of groundwater level decline increased almost at the same time as the pumping for the Order 1169 pump test commenced in late 2010. This suggests that pumping in the carbonate aquifer of Coyote Springs Valley has a cumulative effect with the pumping in Muddy River Springs Valley. The discharge at the Pederson Springs is less than half of its long-term average and the discharge from the Warm Springs dropped to 3.3 cfs, or just 0.1 cfs higher than the rate which would trigger consultation among the agencies under the Fish and Wildlife Service's (FWS) Memorandum of Understanding (MOU).

Pumpage from Coyote Springs Valley during the Order 1169 pump test occurred at rates that are much less than half of the underground water rights already granted in Coyote Springs Valley. About a third of the total current underground water rights in Muddy Springs Valley were pumped at the same time. Pumping just this small proportion of existing underground water rights has caused significant drawdown in the carbonate aquifer of the Muddy River Springs basin and in the southeast portion of the Coyote Springs Valley. The drawdown is significant because it almost caused discharge from the Moapa Springs to decrease to a critical point. Continued pumping at those rates would have lowered the groundwater table further and caused the discharge from the springs to decrease further. It is apparent from the Order 1169 pump test data and from the predictions using the groundwater model that full pumpage of even existing groundwater rights in these two valleys will cause the spring discharge to decrease to rates far insufficient for maintenance of the endangered species dependent on the Moapa Springs as outlined by the FWS. Granting of any additional underground water rights will cause the spring discharge to drop even further below required rates, and may eventually dry the discharge from some or all of the springs, destroying endangered species habitat and harming downstream water rights on the Muddy River.

Introduction

Figure 1 shows the monitoring wells in the Coyote Springs and Muddy River Springs area. They extend from well north in Coyote Springs Valley southeast to and through the Muddy Springs area and south into Garnet Valley. Both production and monitoring wells have been constructed in fill and carbonate aquifers so it should be possible to consider hydraulic connections between the aquifers.

Figure 2 shows the groundwater levels as recorded in July 2011 in the project area basins. The general trend is for water levels to be higher in the north and to drop to a range between about 1814 and 1821 ft amsl near the southeast portion of Coyote Springs Valley and the Muddy River Springs area. The water level in CE-VF-1 (Figure 2), screened in basin fill, is notable because it is about 50 feet higher than the level (not shown) in CE-VF-2, a nearby carbonate well. The very small variation between Coyote Springs Valley and the Muddy River Springs area is also notable because the very small difference in water levels indicates a very small gradient. These water levels will be interpreted with more detail below.

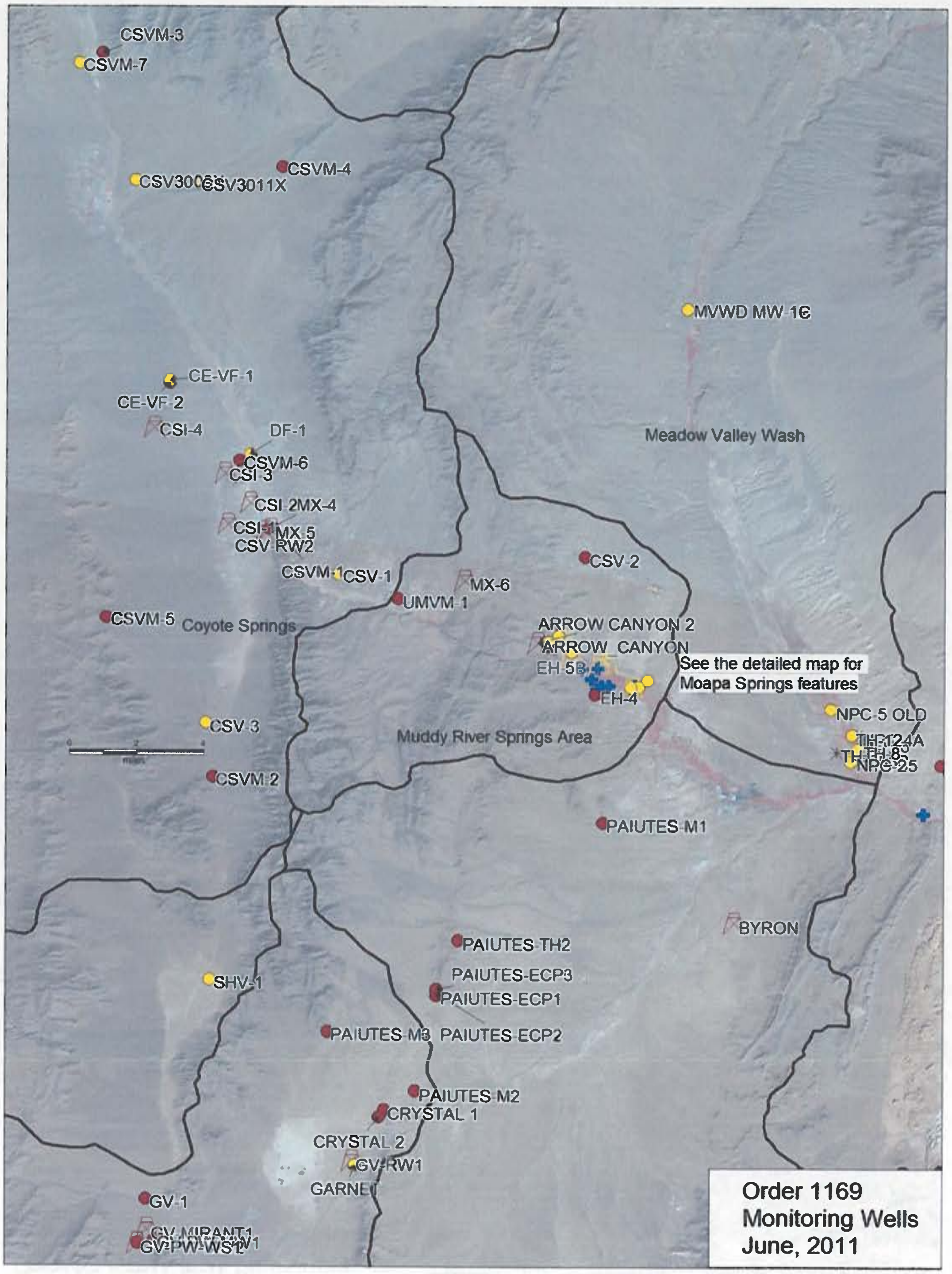

Figure 1: Coyote Springs and Muddy River Springs Area, showing monitoring and production wells. See Figure 2 for a legend explaining the symbols for the wells and Figure 3 for the details of the area around Moapa Springs.

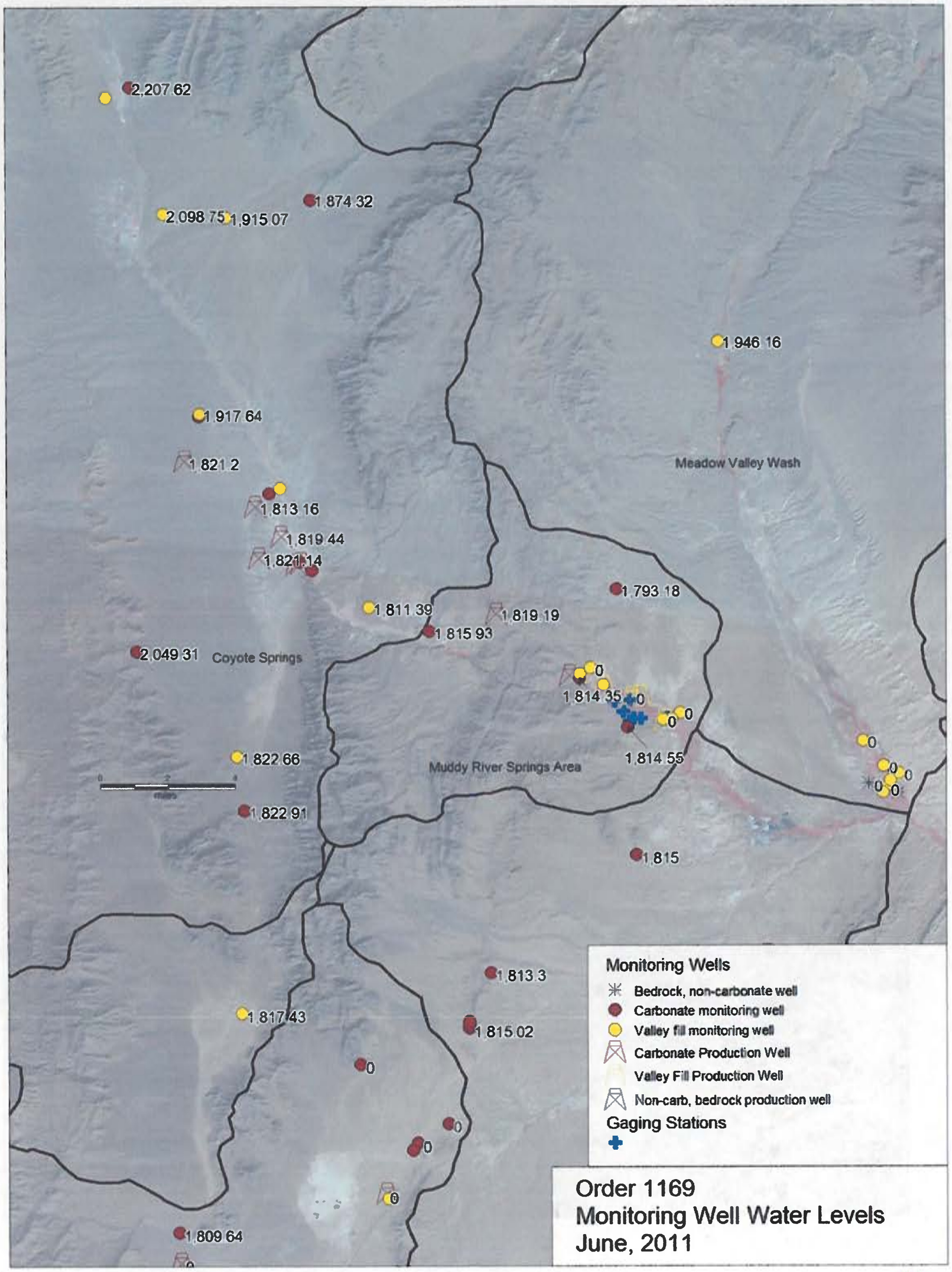

Figure 2: Groundwater levels from July 2011 for miscellaneous wells in the Coyote Springs and Muddy Rivers Springs area.

Figure 3 shows the springs and monitoring wells near the Moapa Springs. It also shows the wells around the Arrow Canyon Well about 1 mile northwest of the springs. Because it is a Landsat image, the red on the map is an infrared image showing the location of riparian vegetation in the area. The springs in the area have created a substantial riparian wetland zone downstream of the Moapa Springs.

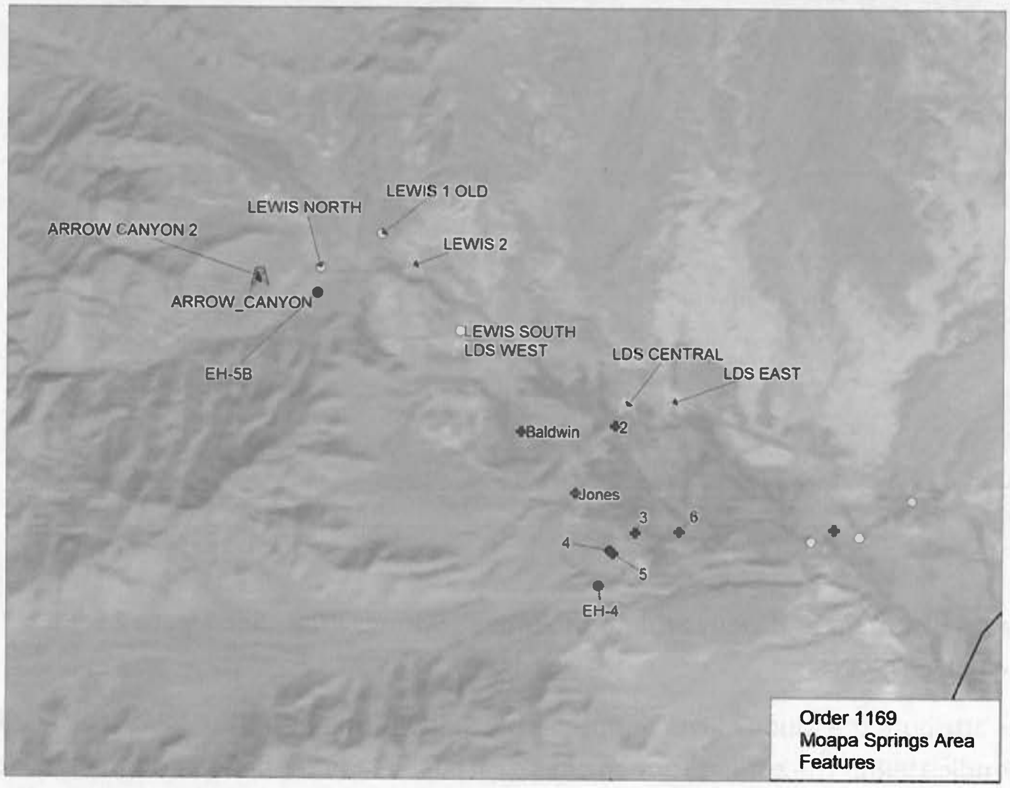

Figure 3: Detail of springs and wells around the Moapa Springs area. See Figure 2 for a legend explaining symbols. The map shows the location of monitored springs with their elevation. Only the continuous-recording stations have been analyzed in this memorandum. 2 – Muddy Springs at L.D.S. Farm near Moapa, NV (09415900); 3 – Warm Springs West near Moapa, NV (09415920); 4 – Pederson Spring near Moapa, NV (09415910); 5 - Pederson East Springs near Moapa, NV (09415908), 6 – Warm Springs Confluence at Iverson Flume near Moapa, NV (09415927)

Figure 4 shows the wells in the southeastern portion of Coyote Springs Valley. Many of the production and monitoring wells in this area are completed in the carbonate aquifer. The map shows that the ridges north and south of the well cluster are offset by about a mile, which may coincide with a significant flow pathway between valleys (Figure 5).

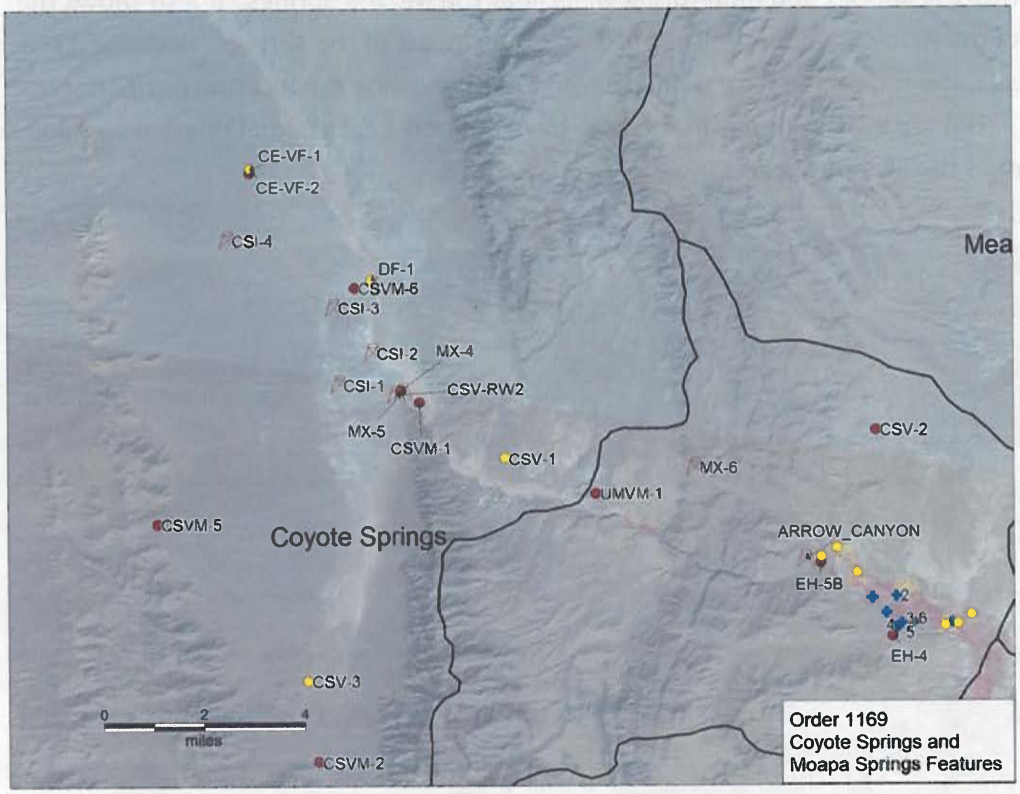

Figure 4: Detail of springs and wells around the Moapa Springs area. See Figure 2 for a legend explaining symbols.

Most studies attribute the Muddy River Springs as being the terminus of the WRFS (Eakin 1966, Harrill and Prudic 1998). The springs formed where carbonate aquifer flow encounters the low permeability Muddy Creek formation at a normal fault (Figure 5). About 20 springs in a 1.2 mile radius area discharge water ranging in temperature from 26 to 32°C (Mayer and Congdon 2008). The total spring discharge is about 36,000 af/y (Eakin 1964, Order 1169).

The flow estimate is from the long-term gage, Muddy River at Moapa (99416000). River flow at this gage is much larger than the sum of the measured discharges from the springs. Eakin (1964) presents a series of measurements, collected in 1963, which include the discernable spring orifices and river flows. That the river flows, including that at the gage, exceed the measured spring flows indicates that a substantial amount of flow, considered to be discharge from the Muddy River Springs, is actually seeps into the river. Johnson and Mifflin (2006), using data from earlier proprietary studies, suggest inflow from the carbonate to the alluvial aquifer equals 34 cfs and that the large springs discharge a total of 17 cfs through "carbonate-cemented conduits through the alluvial gravels (Johnson and Mifflin 2006, page 25). Eakin (1964) notes that the groundwater level from just east of the Arrow Canyon (west of Warm

Springs West) to the White Narrows is just ten feet or so below the ground surface. The natural discharge in this region therefore includes substantial evapotranspiration through riparian vegetation, estimated by Johnson and Mifflin (2006) to equal 4 cfs.

Most of the interbasin flow in the carbonate province occurs through carbonate rocks, but much of the groundwater storage occurs in the basin fill aquifer because of the high primary porosity. Carbonate aquifer flow is primarily through fractures caused by faulting and conduits caused by flow through the fractures dissolving carbonate rock. Primary porosity in carbonate rock is low, but the secondary porosity and conductivity, in the fracture and conduit zones, causes extremely productive zones (Dettinger et al., 1995). Wells constructed in one of these zones may produce high quantities of water with seemingly little head drop, as has been observed at various locations through the southern portion of the study areas (Mayer and Congdon, 2008, Nevada State Engineer Ruling 4542, Bunch and Harrill, 1984). Groundwater flow and storage in Coyote Springs and Muddy River Springs valleys is a good example of this.

Carbonate Aquifer Order 1169

The Nevada State Engineer issued the Carbonate Aquifer Order 1169 in 2002 to place into abeyance all applications for groundwater in six basins in southeast Nevada (Table 1) underlain by the carbonate aquifer until additional information had been collected regarding the effects of pumping from that aquifer in these basins. All six basins are in the southern portion of the White River Flow System (WRFS), which generally discharges to the Colorado River. Basically, the existing water rights in the area (Table 1) already were approximately equivalent to the known discharges from the WRFS. Order 1169 was the State Engineer's response to applications heard in a hearing held in July/August 2001.

Table 1: Tabulation of basins and current water rights in basins affected by Order 1169.

Basin	#	Total UG Rights in Order 1169
Coyote Spring	210	16,300
Black Mountain	215	10,216
Garnet Valley	216	3,380
Hidden Valley	217	2,200
Muddy River Springs	219	14,756
Lower Moapa Valley	220	5,813

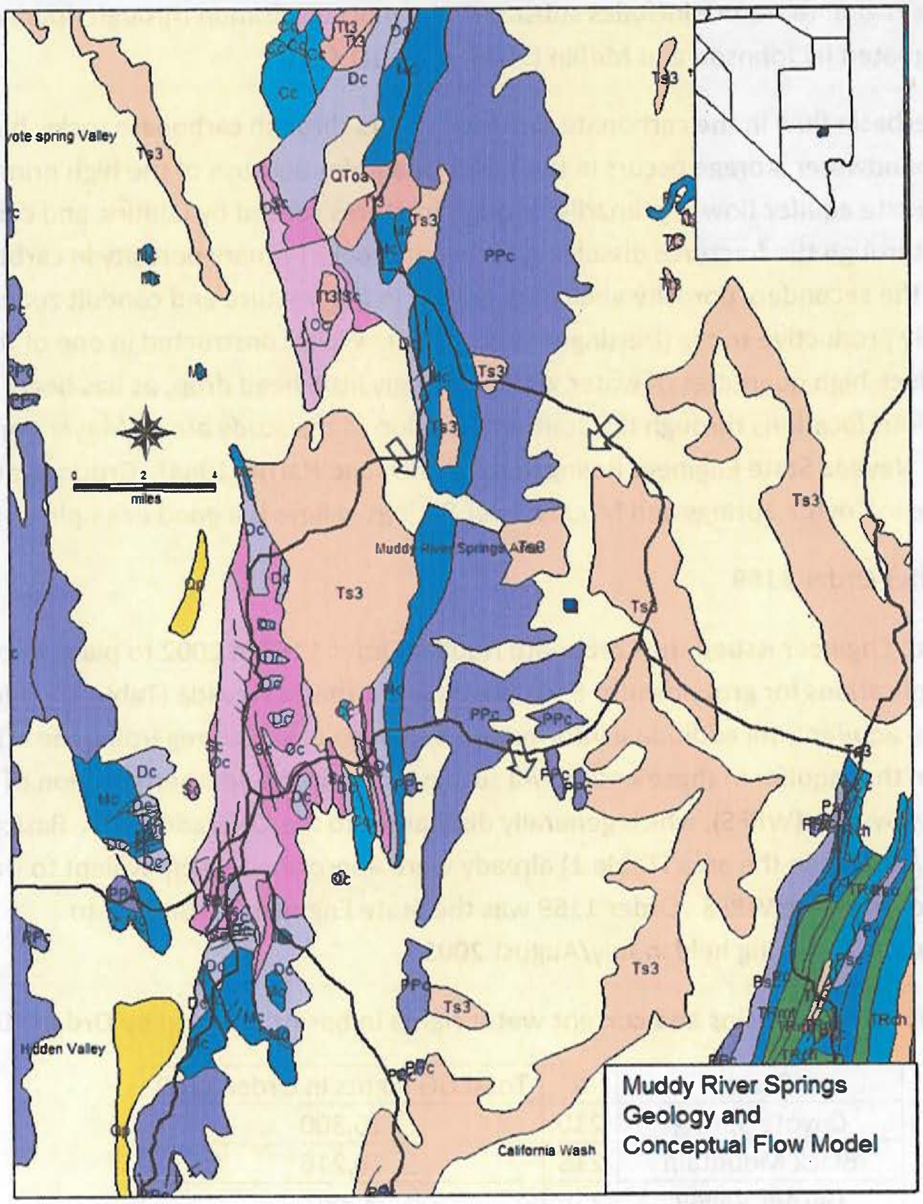

Figure 5: Geology and conceptual flow model of the aquifer system near the Muddy River Springs. Ts3 is volcanic rock, PPc, Mc, and Dc is carbonate rock. The formations west of the Muddy River Springs are the Arrow Canyon Range. The map show faults, but not near the Muddy River Springs because the fault did not appear on the surface. Source: Stewart and Carlson (1978), Stewart (1980).

Order 1169 required that a study that "must cover a 5-year minimum period during which at least 50% of the water rights currently permitted in the Coyote Springs Valley groundwater basin are pumped for a least 2 consecutive years" (Order 1169, p 6). The State Engineer recognized that the required pumping was not commencing and ordered the 2-year pump test to commence in October 2010 (Order 1169ao); it actually commenced November 15, 2010 and the NSE declared it complete as of December 31, 2012 (Order 1169ao). From May 2005 through March 2013, the total pumpage from Coyote Springs Valley has been 22,300 af (Figure 6). Over an almost 7 ½ year period which included the mandated pump test, the total pumpage from Coyote Spring Valley was just 18% of the total water right that would have been allowed to be pumped during that period, which is about 122,250 af.

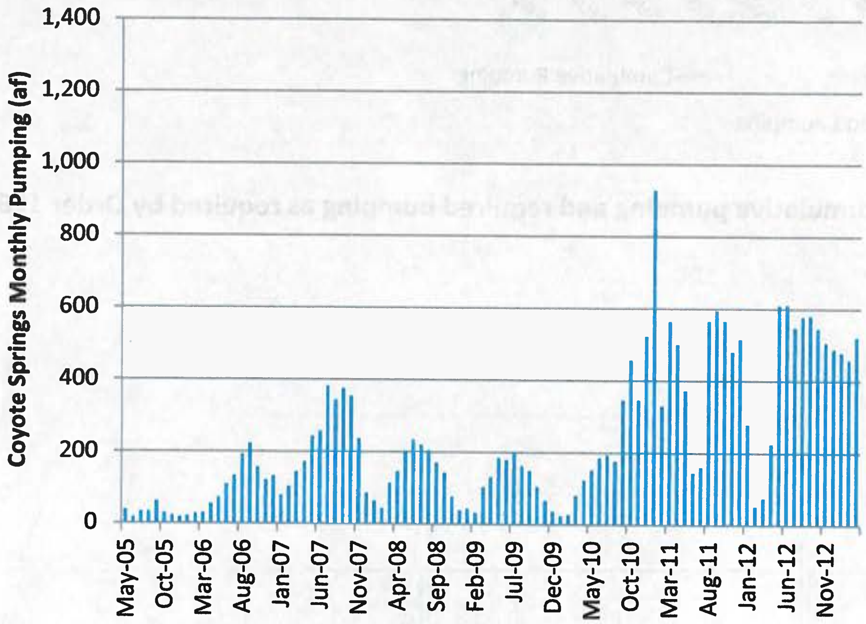

Figure 6: Monthly total pumping from Coyote Spring Valley.

During the period November 2010 through October 2012, there were 10,701 af pumped from Coyote Spring Valley, which is significantly less than the required 16,100 af or 8050 af/y for two years (Figure 7).

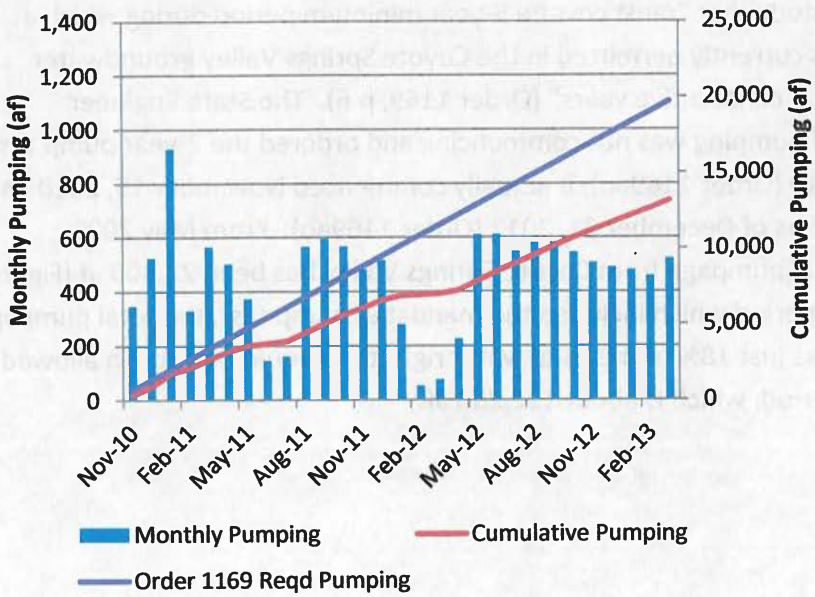

Figure 7: Monthly and cumulative pumping and required pumping as required by Order 1169.

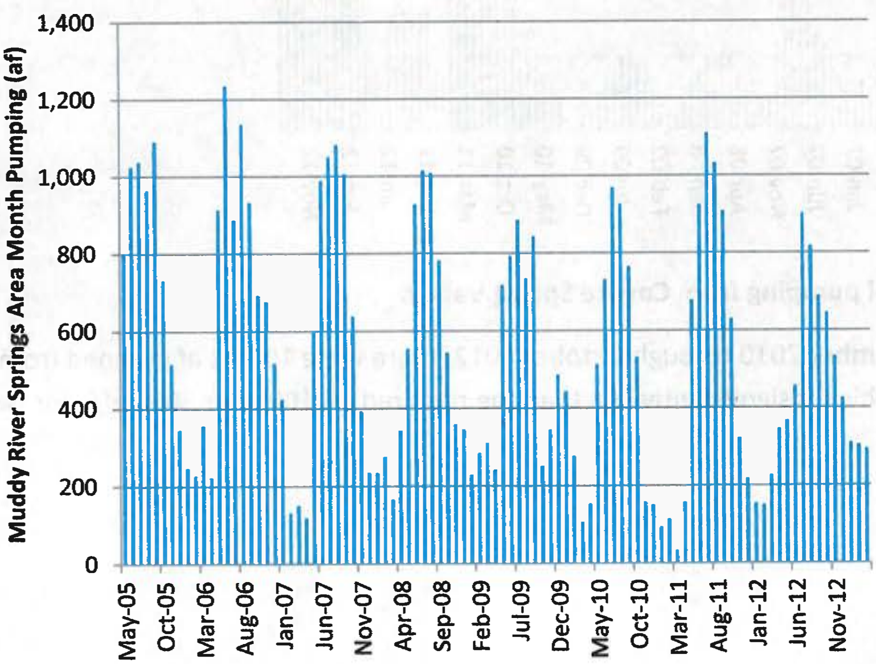

Figure 8: Monthly total pumping from the Muddy Springs Area.

Water Level Response

This memorandum considers the changes in water levels for two primary areas in the south end of the WRFS, Coyote Springs Valley and Muddy Springs Valley.

Coyote Springs Valley

The general slope of groundwater levels is from greater than 2200 ft amsl to about 1815 ft amsl near the point where the Muddy River Wash exits the valley and flows toward Arrow Canyon (Figure 1). Groundwater levels throughout the valley have been relatively stable when considered at a coarse scale since 1997 (Figure 9). Most of the wells have groundwater levels less than 1950 ft amsl with a cluster ranging from 1810 to 1835 ft amsl since 1997 (Figure 10). Those lower water level wells had decreasing groundwater levels from about 1998 until 2003 after which wet conditions allowed the groundwater level to mostly recover. Since 2005 they have been decreasing with an increase in the rate of water level decrease since pumping for the Order 1169 pump test commenced in 2010 (Figure 10). Several wells, including MX-5 and CSI-3 experience up-to-ten foot decreases due to intermittent pumping; in fact, MX-5 is the primary pumping well in Coyote Springs Valley.

The wells with higher groundwater levels, above 2000 ft amsl, are in the northern portion of the valley away from much of the pumping. Interestingly, water levels there have increased a few feet since the early 2000s (Figure 11). This indicates that stress from pumping in Coyote Springs Valley has not reached north to this area. The wells in Figure 11, CSVM-3 and -7, carbonate and basin fill wells, respectively, both have increasing water levels but the basin fill well (CSVM-7) is at least 40 feet higher than the carbonate well (CSVM-3). Similar observations hold for all of the wells in the north end of the valley.

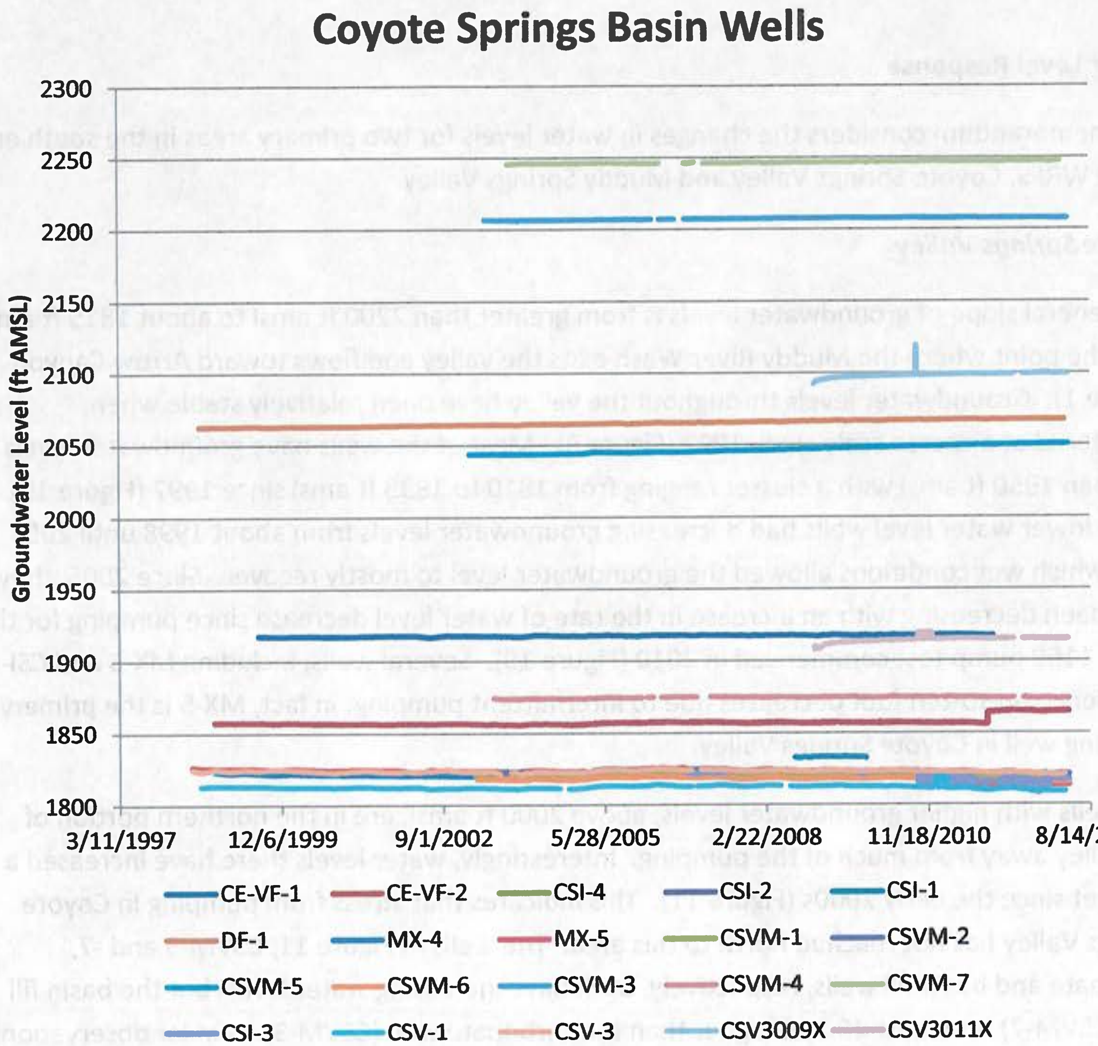

Figure 9: Groundwater level for monitoring and production wells in Coyote Springs Valley. See Figures 1 and 4 for their location, type, and completion.

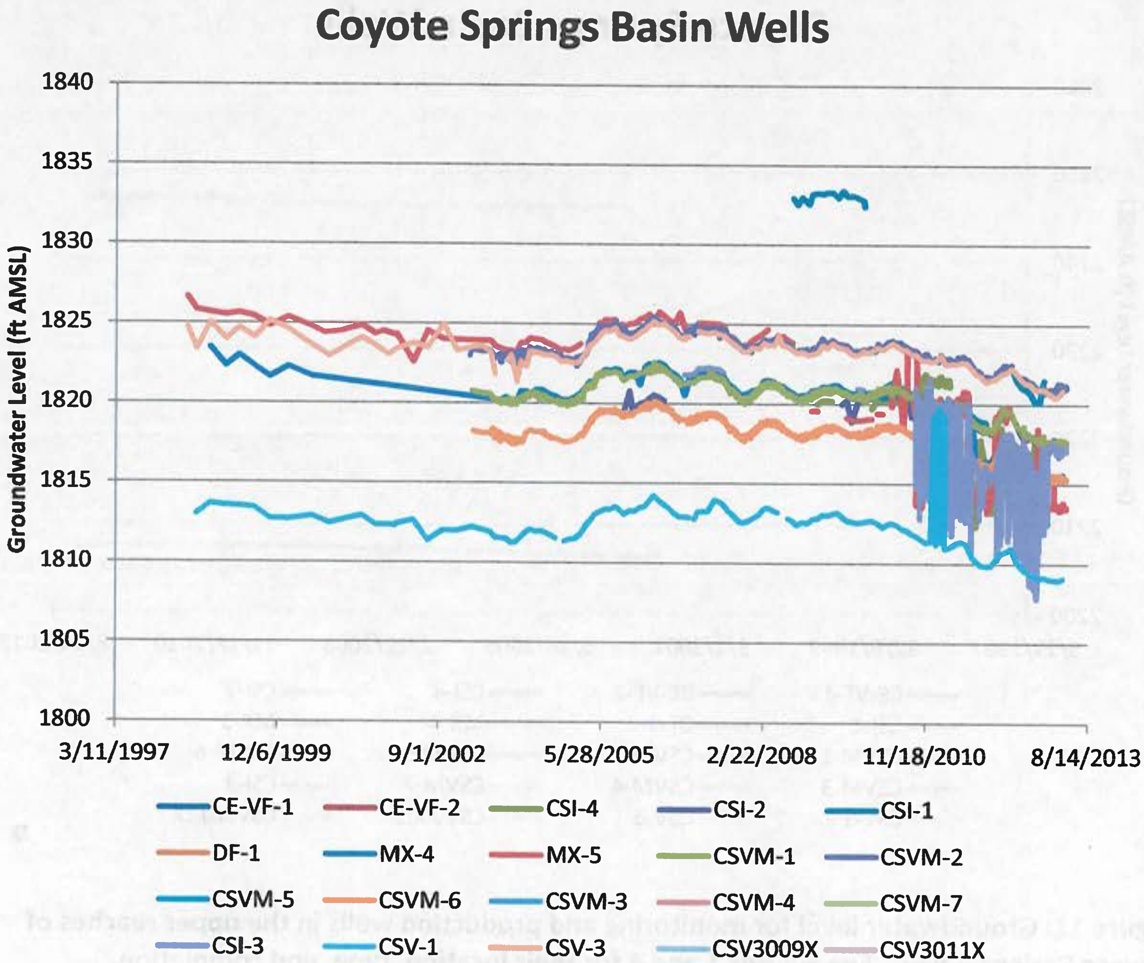

Figure 10: Groundwater level for monitoring and production wells in Coyote Springs Valley near the southeast portion where the valley flows into Muddy Springs Valley.. See Figures 1 and 4 for their location, type, and completion.

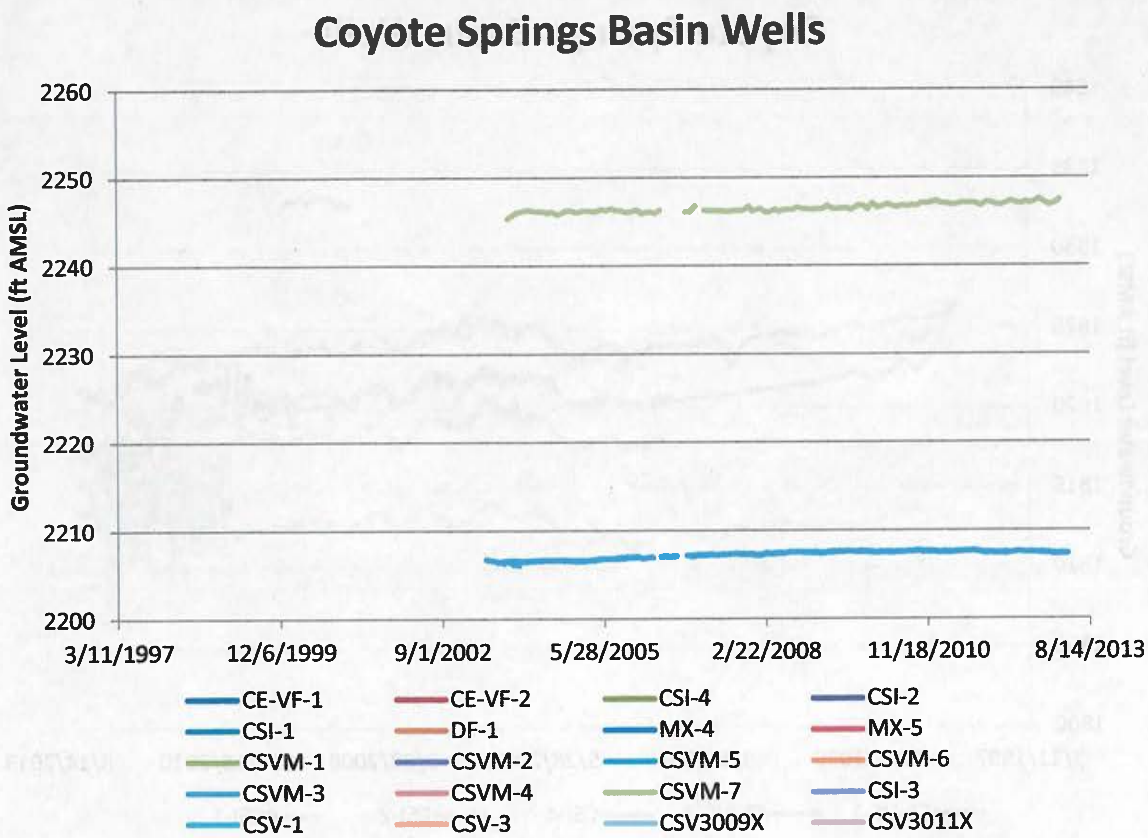

Figure 11: Groundwater level for monitoring and production wells in the upper reaches of Coyote Springs Valley. See Figures 1 and 4 for their location, type, and completion.

Muddy River Springs Area

Muddy River Springs Area and the Moapa Springs are downgradient of Coyote Springs Valley along the Muddy River wash that drains through Arrow Canyon. There are monitoring wells in both the basin fill and carbonate aquifers within the area. Groundwater levels have either remained steady or have decreased at wells within the area (Figure 12). However, groundwater levels at wells close to Moapa Springs have been mostly decreasing since about 1998. Carbonate wells EH-4 and EH-5B have been decreasing since the early 1990s, but they partly recovered in 2005 due to a wet year after which their decrease began again. The rate of water level decrease increased in 2010. Similar observations can be made for well CSV02, another carbonate well north of the springs (Figure 13). Well Lewis North and Boehmer are basin fill wells that have begun to decrease in the mid 1990s; however, the groundwater levels in these fill wells continues to decrease during the pump test, but not at an increased rate (Figure 13). Groundwater levels at the Abbot well, also completed in fill at the downstream end of the valley, decreased about ten feet beginning in the mid 1990s to present with very little recovery around 2005, suggesting the wet conditions did not affect it.

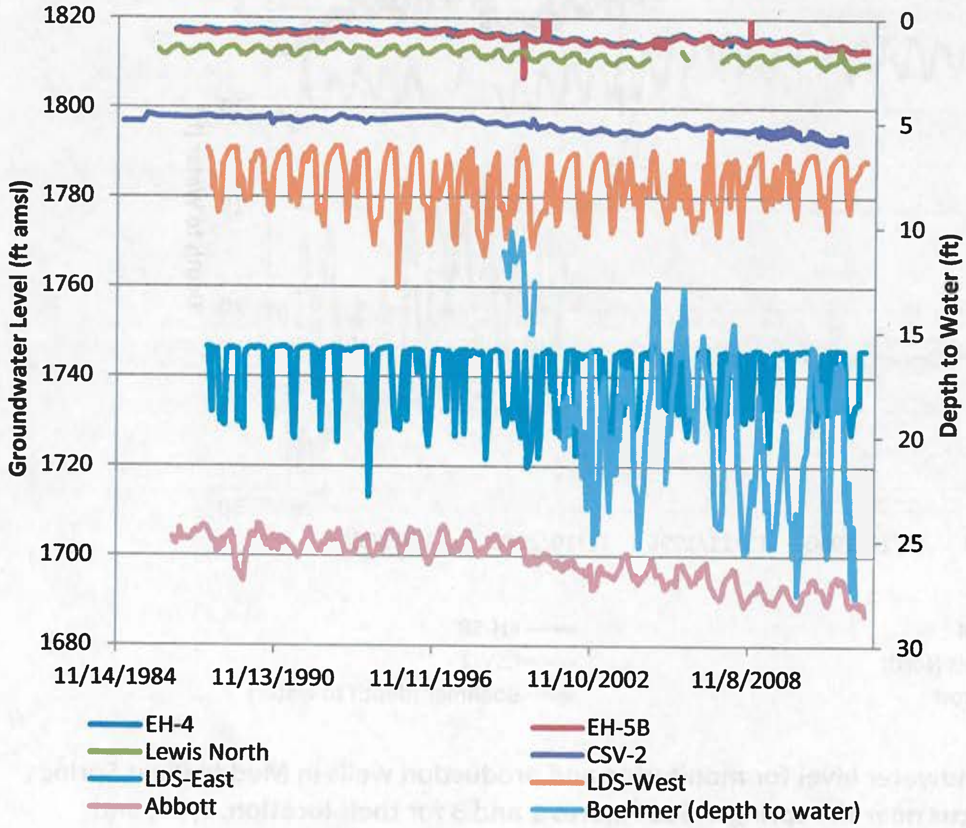

Figure 12: Groundwater level for monitoring and production wells in Muddy River Springs Valley. See Figures 1 and 3 for their location, type, and completion.

The summary for the Muddy River Springs Area is that groundwater levels for all wells have been decreasing since the mid 1990 with some recovery due to wet conditions from 2004 to 2005. During the 2010 to 2012 pump test period the rate of decline in carbonate wells increased.

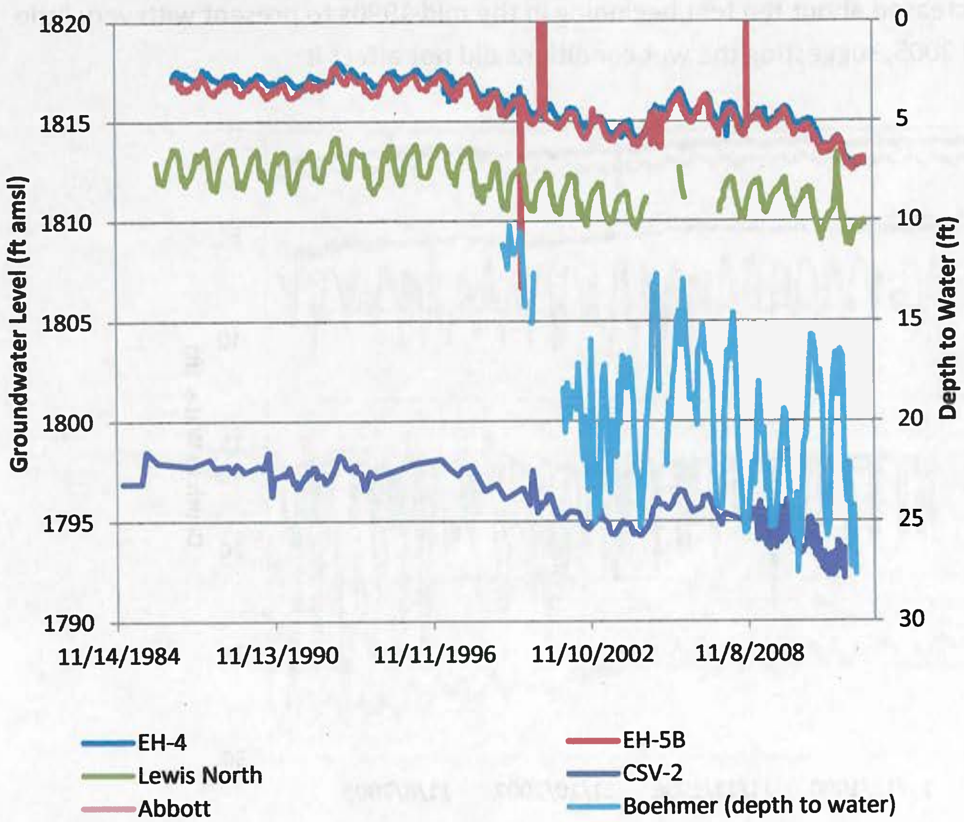

Figure 13: Groundwater level for monitoring and production wells in Muddy River Springs Valley with a focus near the springs. See Figures 1 and 3 for their location, type, and completion.

Spring Response

The most important feature in the area is the Moapa Springs, which is the upstream end of the perennial Muddy River. The average flow in that river, prior to any development, was about 36,000 af/y. Flows on the Muddy River below LDS Farm have many diversions, so the best way to monitor flows from the springs is to consider direct measurements. The cumulative flow from many of the gages began to decline in 1996. Even with a minor increase in 2007, the flows have decreased from the mid 8 cfs range to close to 7 cfs (Figure 14); prior to 1996, the records are unreliable due to an unmeasured diversion. Little change in flow rate appears to have occurred since 2009 or during the pump test period (Figure 14).

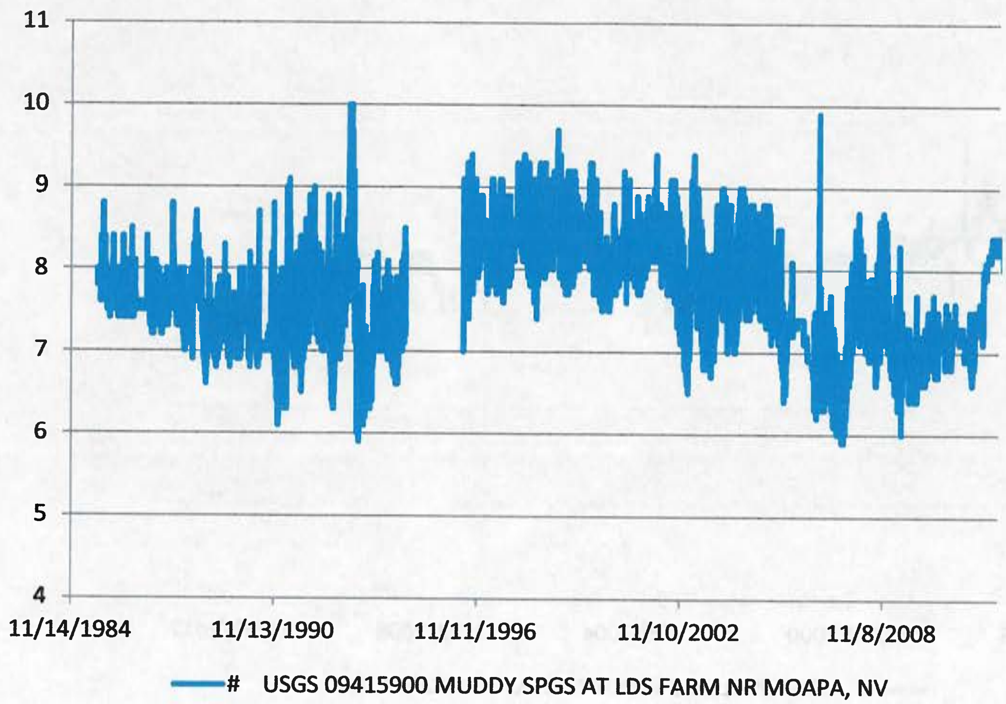

Figure 14: Flow rate downstream of many of the Moapa Springs.

The gage Warm Springs near Moapa is considered a trigger gage because it is at this gage that the Fish and Wildlife Service agreed to monitor the effects of pumping during the pump test (FWS, 2006). The highest trigger point, the flow rate at which the parties to the agreement agreed to meet to determine next steps, is 3.2 cfs. The flow at the gage has been decreasing since about 2009 (Figure 15) and most obviously during the pump test period (Figure 16). For a long period during 2012 and early 2013, the flow remained near 3.3 cfs, or just 0.1 cfs higher that the trigger point. This is the lowest flow recorded at this point since 1996 (Figure 15).

The reduction in discharge from the small Pederson Springs coincides with the low flows at the Warm Springs. The Pederson Springs flows springs had been relatively constant with seasonal fluctuation from 1996 through 2009 (Figure 17), but beginning with the pump test, their flow rates have decreased by more than 50 % (Figure 18); the flows at Pederson Springs near Moapa are less than a third of their value in early 2010 and show no sign of recovery as of April 2013.

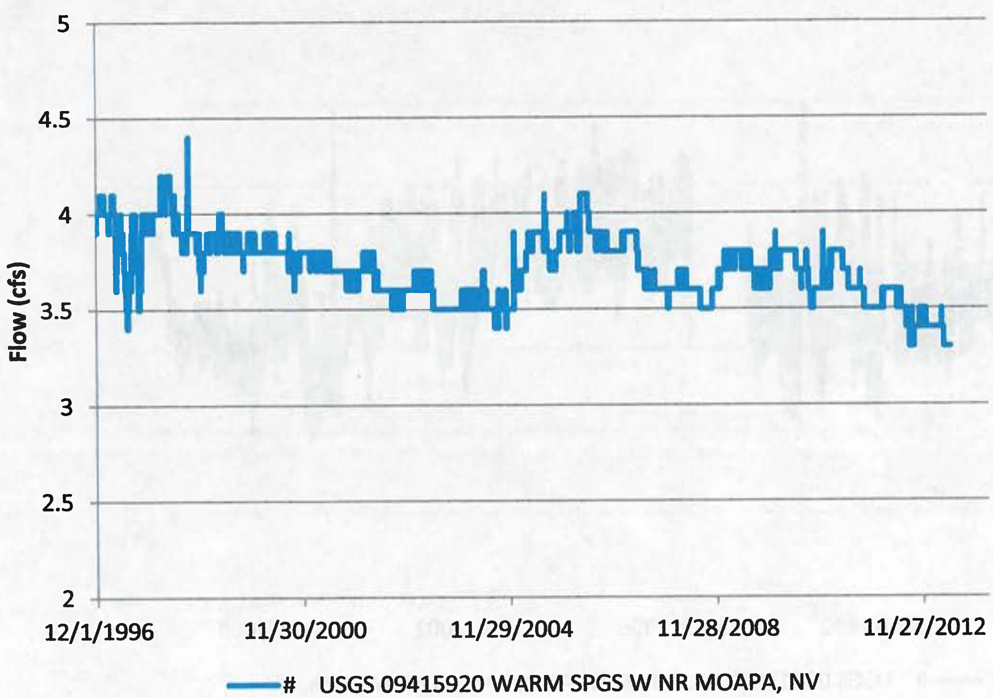

Figure 15: Flow rate at the trigger spring.

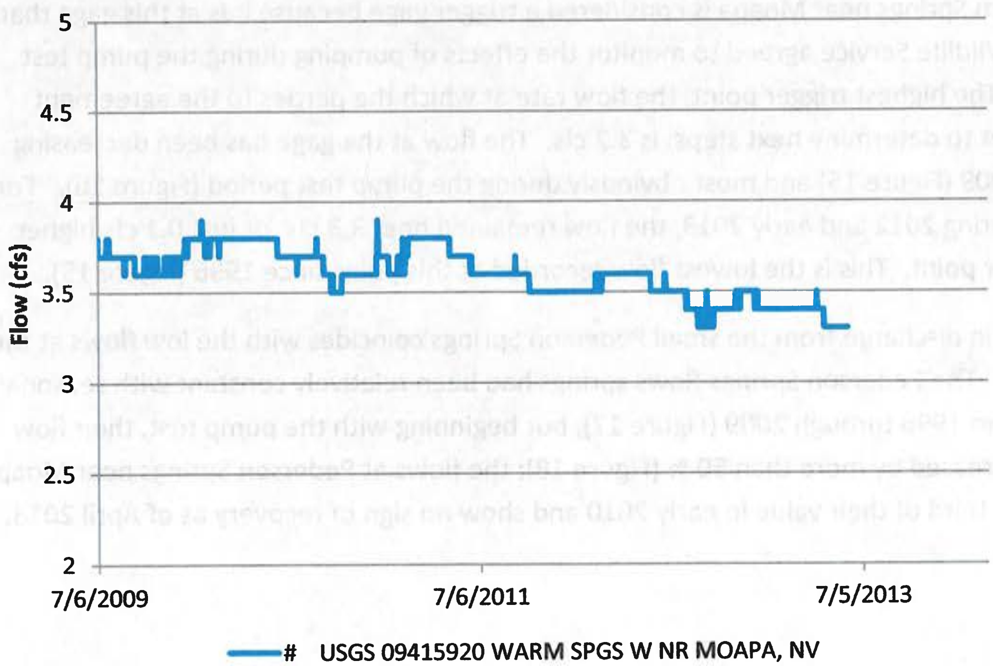

Figure 16: Flow rate at the trigger spring during the Order 1169 pump test.

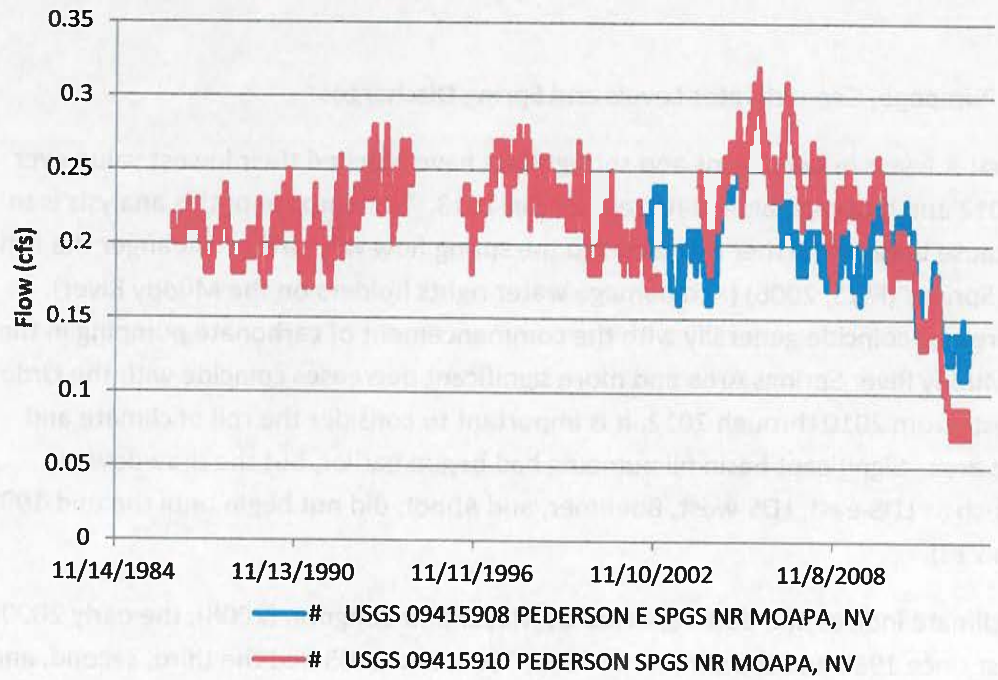

Figure 17: Flow rate at the Pederson Springs near Moapa, NV.

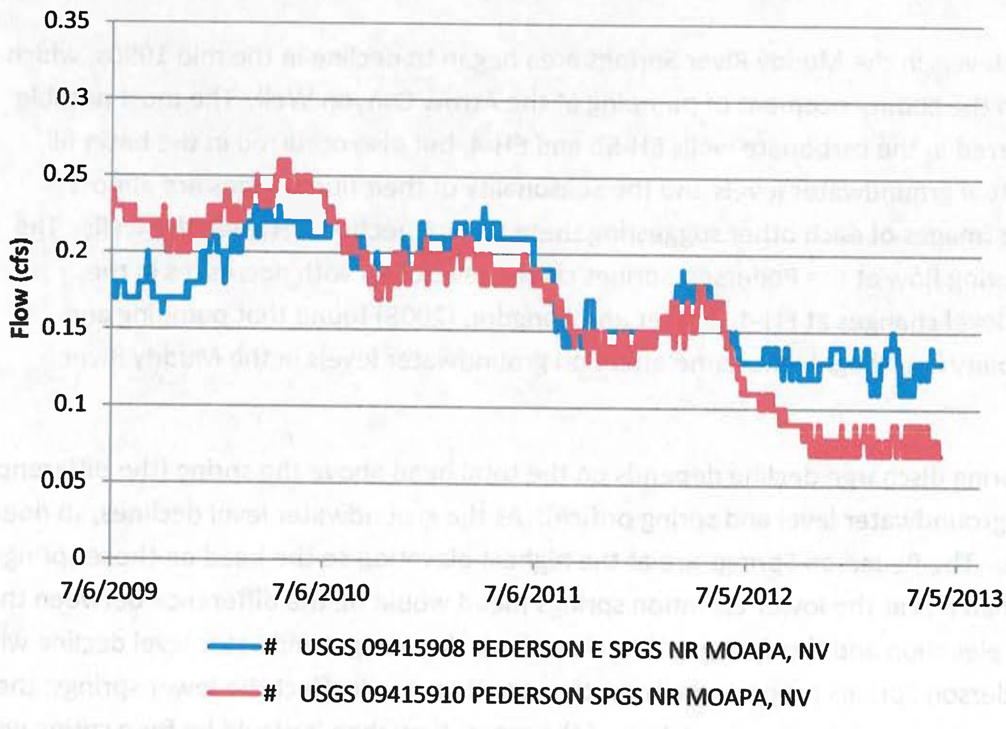

Figure 18: Flow rate at the Pederson Springs near Moapa, NV during the Order 1169 pump test.

Discussion of Pumpage, Groundwater Levels and Spring Discharges

Both groundwater levels in two basins and spring flows have reached their lowest value ever recorded in 2012 and have had almost no recovery in 2013. The purpose of this analysis is to consider the cause because further decreases to the spring flow will further endanger the fishes at the Moapa Springs (FWS, 2006) (and damage water rights holders on the Muddy River). While the decreases coincide generally with the commencement of carbonate pumping in the 1990s in the Muddy River Springs Area and more significant decreases coincide with the Order 1169 pump tests from 2010 through 2012, it is important to consider the roll of climate and drought in the area. Significant basin fill pumping had begun earlier, but the drawdown in those wells, such as LDS-east, LDS-west, Boehmer, and Abbot, did not begin until the mid-1990s (Figures 12 and 13).

According to climate indices and data reported by Mayer and Congdon (2008), the early 2000s were the driest since 1980 and the winters of 1992, 1993, and 2005 had the third, second, and highest precipitation totals since 1985. After 2005 the region primarily returned to drought conditions. The late 1990s were among the wettest years since 1980 (Mayer and Congdon 2008).

Groundwater levels in the Muddy River Springs area began to decline in the mid 1990s, which coincides with the commencement of pumping at the Arrow Canyon Well. The most notable declines occurred in the carbonate wells EH-5b and EH-4, but also occurred in the basin fill wells. The actual groundwater levels and the seasonality of their fluctuations are almost perfect mirror images of each other suggesting there is a connection between the wells. The decrease in spring flow at the Pederson Springs correlates closely with decreases in the groundwater level changes at EH-4. Mayer and Congdon (2008) found that pumping and climate variability had roughly the same effect on groundwater levels in the Muddy River Springs area.

The rate of spring discharge decline depends on the total head above the spring (the difference between the groundwater level and spring orifice). As the groundwater level declines, so does the discharge. The Pederson Springs are at the highest elevation so the head on those springs is likely less than it is at the lower elevation springs (head would be the difference between the groundwater elevation and the spring orifice elevation). A given groundwater level decline will affect the Pederson Springs proportionally much more than it will affect the lower springs; the spring discharge is a much larger proportion of the actual flow than it would be for a spring with more head on it.

The spring monitored for compliance with the stipulated agreement has a lower elevation and therefore presumably has more head. Well EH-4 has dropped from about 1817 to 1813 ft amsl since the mid-1990s during a period the discharge from the Warm Springs has dropped from about 3.9 to 3.3 cfs. If the relationship is linear, the spring would go dry if the groundwater level dropped 26 feet to about 1793 ft amsl. The datum for the spring is 1771 which suggests the water level would actually have to drop further than 26 feet and that the relationship between discharge and groundwater level at EH-4 is not exactly linear. This could be due to the fact that the monitored flow is the cumulative flow from springs above the measuring point. Well EH-4 is constructed in the carbonate aquifer and the spring discharges from the carbonate aquifer, so the well must be on the direct pathway to the spring.

The Arrow Canyon wells are completed in the carbonate aquifer and have been pumped since 1988 but much more extensively since 1998. Since 2000, there has been 28,735 af pumped from those wells (Figure 19). It was a significant portion of the total amount pumped in Muddy River Springs area (Figure 8 and Figure 19), although most of the pumpage other than from Arrow Canyon wells was from basin fill wells. Until the Order 1169 pump test, it was the largest withdrawal from the carbonate aquifer.

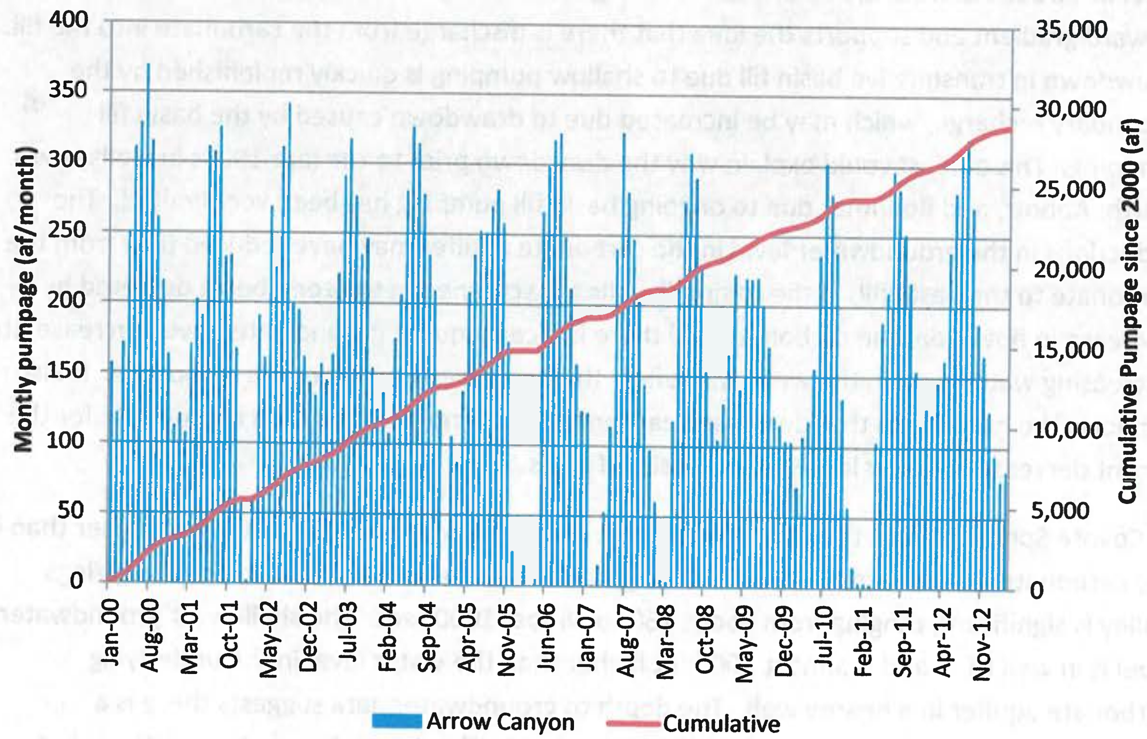

Figure 19: Monthly and cumulative pumping from the carbonate Arrow Canyon Well.

The Order 1169 pump test, although it did not even meet the pumping requirements specified in Order 1169, more than doubled the pumpage from the carbonate aquifer. Groundwater levels in the EH-5b and EH-4 wells declined more rapidly beginning almost coincidentally with the pump test (Figure 13). This suggests the pumping in Coyote Springs Valley has an additive effect with the pumping at Arrow Canyon, the pumping rate of which did not apparently decrease very much during the pump test (Figure 19), on the drawdown in the carbonate aquifer. Because of the linkage between the spring discharge and the groundwater level at EH-4 (and EH-5b), the Order 1169 pumping along with the Arrow Canyon pumping has caused most of the observed decrease in spring flow at the Moapa Springs. The drought has added to the effects, but without the pumping the declines would not have been that significant as can be observed considering the water levels in the early 1990s after an earlier period of significant drought.

The response of the basin fill wells is not indicative of the basin fill pumping, which in the Muddy River Springs area is substantial. Groundwater in the basin fill is likely secondary recharge of the water discharging from the various springs and discharge from the underlying carbonate aquifer into the basin fill, as suggested by Johnson and Mifflin (2006). That the water level in carbonate wells EH-5b and EH-4 are higher than the levels in the fill indicates there is an upward gradient and supports the idea that there is discharge from the carbonate into the fill. Drawdown in transmissive basin fill due to shallow pumping is quickly replenished by the secondary recharge, which may be increased due to drawdown caused by the basin fill pumping. This at least could explain why the drawdown prior to the late 1990s in wells Lewis North, Abbott, and Boehmer due to ongoing basin fill pumping has been very limited. The reductions in the groundwater level in the carbonate aquifer may have reduced flow from the carbonate to the basin fill. If the basin fill wells are screened in the zone being depleted by a decrease in flow from the carbonate and there is a consequent groundwater level decrease, the decreasing water level in the wells will reflect the decreased flow from the carbonate. It also supports the hypothesis that decreased carbonate discharge into the fill is responsible for the recent decrease in water levels in the basin fill wells.

In Coyote Springs Valley, the groundwater level in the fill was from 25 to 200 feet higher than in the carbonate in most areas. The depth to groundwater in both aquifers in Coyote Springs Valley is significant, ranging from about 160 to almost 1000 feet. The shallowest groundwater level is in well DE-1 and is almost 200 feet higher than the water level in the underlying carbonate aquifer in a nearby well. The depth to groundwater data suggests there is a downward gradient from the basin fill to carbonate aquifer, but it does not prove there is a hydraulic connection. The carbonate pumping did not apparently affect water levels in the basin fill, but due to the thickness of the fill aquifer it is possible that the groundwater levels throughout the fill would not change at one time and that the carbonate pumping actually causes a drawdown at depth and increases the gradient within the fill. The data as presented proves nothing about the connection. Due to the aridity of the basin, very little distributed recharge would be expected within the fill.

Groundwater Model of the Lower White River System

The National Park Service, Fish and Wildlife Service, and others have commissioned a groundwater model of the Lower WRFS (Tetra Tech 2012a and b). The purpose of the model is to estimate the future effects of developing all of the water rights in the basin.

Scenario 1 considers long-term pumping at the rates as occurred from 2009 through 2011 in the 13 basins, which means it considered part of the Order 1169 pump test. It shows the discharge rate from the Warm Springs decreasing to about 3 cfs after 1000 years. After about 50 years, it has reduced to about 3.7 cfs from an initial 3.9 cfs. This minor flow reduction occurred even though the reported drawdown is 1 to 2 and 2 to 5 feet after 10 and 50 years, respectively. These results suggest that the model underestimates the effect of pumping in Coyote Springs Valley. It also may reflect that the reported drawdown is not from the same layer as the simulated spring (reviewing the details of how the spring is simulated are beyond the scope of this memorandum).

Scenario 2 considers pumping all existing rights in the 13 basins, which includes pumping 16,100 af/y from Coyote Springs Valley. It also increases the pumping in the Muddy Springs area to 13,688 af/y from the 5964 af/y simulated in Scenario 1, so it is not possible to assign effects shown at the springs to pumping in either of the valleys. In this scenario, flow at the Warms Springs decreases to 3.0 cfs within 50 years, 2.0 cfs within 190 years, and essentially dries in 1000 years. Other springs have similar reductions, including the Pederson Springs which are dry within 50 years. The predicted drawdown after 50 and 200 years is 10 to 20 and 20 to 50 feet, respectively, which essentially verifies relation between drawdown and decreased discharge observed above.

The impacts from pumping Scenario 2 are due to pumping only the existing water rights in the basin. It would have been useful to simulate pumping only the amount from Coyote Springs Basin to more carefully examine the simulated connection between that valley and the springs. The effects of pumping Scenarios 3 through 7 are immense, with up to hundreds of feet of drawdown and springs going completely dry.

The effects of pumping from the carbonate aquifer on the spring flow may have been significantly underestimated because the model simulates drawdown expanding in many directions from the areas of pumping. In general, for Scenario 2, drawdown up to 100 feet covers much of the southwestern third of the model domain. The drawdown parallels the west boundary due to model boundary effects. Tetra Tech (2012b, p 62) claims this is due to "high transmissivity and low storativity of the carbonate aquifer". The reality may actually be that the model simulates the aquifer as a homogenous porous media across which the effects spread evenly in all directions. The aquifer due to its highly transmissive pathways would actually be very horizontally anisotropic which means that high transmissivity would occur only in one direction. It is also likely that the high transmissivity pathways end at the springs, due to a fault and termination of the carbonate rock which causes groundwater to surface in the springs.

Because of the horizontal anisotropy, it is likely that the volume from which groundwater can be removed from storage is much less than simulated in the model. It is therefore likely that the extent of the highly transmissive aquifer zone will be reached much sooner than simulated and that water levels in the Muddy Springs Area and the spring discharge will decrease more quickly than predicted by the model. The apparent additive effect of the Coyote Spring and Arrow Canyon pumping is substantial evidence that pumping from the carbonate aquifer in this area directly lowers the water table and is directly drawn from the Moapa Springs.

Conclusion

The purpose of the Order 1169 pump test was to stress the aquifer to determine whether to grant the water right applications that have been held in abeyance and to provide information as to what to do with all of the additional applications that have been filed since 1989. This memorandum did not summarize the applications but a brief compilation of the total amounts are provided in Tetra Tech (2012b).

Pumpage from Coyote Springs Valley during the Order 1169 pump test occurred at rates that are much less than half of the underground water rights already granted in Coyote Springs Valley. About a third of the total current underground water rights in Muddy Springs Valley were pumped at the same time. Just this small amount of pumping, in comparison with the total permits in the valleys, has caused significant drawdown in the carbonate aquifer of the Muddy River Springs basin. The drawdown is significant because it almost caused discharge from the Moapa Springs to decrease to a critical point. Continued pumping at those rates would have lowered the groundwater table in the carbonate aquifer further and caused the discharge from the springs to decrease further. It is apparent from the Order 1169 pump test data and from the predictions made using the groundwater model (Tetra Tech, 2012b) that full pumpage of even existing groundwater rights in these two valleys will cause the spring discharge to decrease to rates far insufficient for maintenance of the endangered species dependent on the Moapa Springs. Granting future water rights in these valleys will cause the spring discharge to drop even further below required rates, and may eventually dry the discharge from some or all of the springs, destroying endangered species habitat and harming downstream water rights on the Muddy River.

The pump test has provided no data with which to consider water rights in the other valleys subject to the Order. Considering that there is little recharge to the basin fill and that the carbonate aquifer likely has highly conductive but limited transmissive zones, similar effects due to pumping from these valleys could be expected. There has been insufficient pumping from the carbonate aquifer in these valleys to know what discharge would be affected.

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GREAT BASIN WATER NETWORK

PO Box 75
Baker, NV 89311

June 25, 2013

Jason King, State Engineer
Nevada Division of Water Resources
901 South Stewart St. #2002
Carson City, NV 89701

Dear Mr. King:

We appreciate the invitation by Deputy State Engineer Rick Felling at the February 2013 NWRA conference in Reno to submit comments on the pump test results from implementing Order #1169 in Coyote Spring Valley and 5 other basins in southeastern Nevada.

Based on the results of Dr. Tom Myers' review and analysis of the pump test results, it seems clear that even pumping less than 50% of existing groundwater rights in Coyote Springs Valley caused a decrease in spring flows to critical levels for the endangered Moapa Dace in the Muddy River Springs basin, and appeared certain to cause serious adverse impacts on senior water rights in downgradient basins had the test pumping continued. In view of this stark demonstration of the regional groundwater system's limits, we urge the State Engineer to deny all pending applications in Coyote Springs Valley and in the rest of the 6 basins comprising the lower portion of the White River Flow System (WRFS) in southeastern Nevada. We also urge the State Engineer to take administrative actions in Coyote Springs and, where appropriate in the other 5 basins, to reduce existing water permits to sustainable levels.

Dr. Myers' review of the pump test and other data clearly shows the link between groundwater pumping in these valleys and spring discharges. It also supports the conclusion that full pumping of existing underground water rights will unacceptably decrease spring discharges in the Muddy River Springs basin. GBWN believes that any additional pumping of the WRFS, including pumping in Cave, Dry Lake and Delamar basins, will exacerbate the problem of decreasing spring flows and eventually dry up of springs in the downgradient basins.

Even before the full completion of Order #1169's five-year pump test period, and without pumping an amount of groundwater close to the intended 50% of the existing water rights in Coyote Spring Valley for at least 2 consecutive years, the pump test results show clear decreases in spring discharges at Moapa Warm Springs to within 0.1 cfs of the trigger point of 3.2 cfs set in the MOU agreed to by the US Fish and Wildlife Service. Spring flows lower than 3.2 cfs were recognized as insufficient to maintain the endangered Moapa Dace.

Thank you for considering our comments and Dr. Myers' attached Technical Memorandum: "Comments on Carbonate Order 1169 Pump Test Data and the Groundwater Flow System in Coyote Springs and Muddy River Springs Valleys, Nevada."

Sincerely,

Abby Johnson /s/

Abby Johnson, Chair
Great Basin Water Network

Attachment - Dr. Myers's TM

STATE ENGINEERS OFFICE
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COYOTE SPRINGS LAND

3100 State Route 168 • P.O. Box 37010
Coyote Springs, Nevada 89037
Telephone: (702) 422-1400 • Facsimile: (702) 422-1419

Writers Phone Number: (775) 321-5940

June 14, 2013

<u>Via US First Class Mail, Certified Return Receipt Requested</u>
Mr. Jason King, P.E.
State Engineer
Division of Water Resources
901 South Stewart Street, Suite 2002
Carson City, Nevada 89701

Re: REPORT OF COYOTE SPRINGS INVESTMENT LLC PURSUANT TO NEVADA STATE ENGINEER ORDER 1169A

Dear Mr. King:

Please accept this letter as the Report (the "CSI Report") of Coyote Springs Investment LLC ("CSI") pursuant to Order 1169A issued by your office on December 21, 2012. We understand Southern Nevada Water Authority ("SNWA") will issue a parallel Report pursuant to Orders 1169 and 1169A.

Together, CSI and the Clark County – Coyote Springs Water Resources General Improvement District ("GID"), own 4600 acre-feet-per-year (afy) of water rights appropriated within the Coyote Spring Valley, for the benefit of the Coyote Springs master planned community. These water rights are evidenced by Permit numbers, 70429, 70430, 74094, 74095 and 82051-T (the "CSI Permits"). The GID owns 2000 afy, and CSI owns 2600 afy of which 460 afy is held for the benefit of dedication to U.S. Fish & Wildlife Service and preservation of the Moapa dace.

In addition to the CSI-Permits, CSI holds various applications for additional water rights in the Coyote Spring Valley (Basin 210) which are identified by your office as Application Numbers: 63272 – 63276, inclusive, 63867 – 63876, inclusive, and 64186 – 64192, inclusive (collectively, the "CSI-Applications"). SNWA also holds various applications for additional water rights in, among others, the Coyote Spring Valley which will be referred to herein as the "SNWA-Applications".

As a result of the CSI-Applications, the SNWA Applications, and other related third-party applications and actions, on March 8, 2002, your office issued Order 1169, and thereafter, Order 1169A on December 21, 2012. Arising out of obligations set forth in Order 1169, SNWA established an extensive monitoring network in various basins, including, without limitation, the Coyote Spring Valley. Thereafter, in 2002, SNWA entered into an agreement with CSI and Moapa Valley Water District to conduct the Monitoring Requirements associated with Order 1169, among others, the CSI Permits and CSI-Applications in the Coyote Spring Valley. SNWA's monitoring locations are shown on SNWA's Figure 5 attached to this Report which shows all such Monitoring Locations. These Monitoring Locations are described, and data from these Monitoring Locations, are included in SNWA's Annual Monitoring Reports submitted to the Nevada Division of Water Resources since 1999, the most current of which is entitled *"Monitoring Report for Southern Nevada Water Authority and Las Vegas Valley Water District's Groundwater Rights Permits and Applications in Coyote Springs Valley, Hidden Valley and Garnet Valley within Clark and Lincoln County, Nevada – Calendar Year 2012".*

The overall effect of the pumping tests on the Coyote Spring Valley aquifer are evidenced by the responses from CSI's wells and SNWA's MX-5 well which are indicative of a confined to semi-confined aquifer system and demonstrates a shallow pumping cone that extends miles from SNWA's MX-5 well. This and all of the other information gathered during SNWA's monitoring network will be useful for CSI and the GID as it manages the water resources in the Coyote Spring Valley.

CSI believes SNWA's Annual Monitoring Reports support the assertion that the Kane Springs fault acts as a structural barrier to groundwater flowing from north to south in the Coyote Spring Valley. Water levels observed in the monitoring wells located north of the Kane Springs fault do not reflect any pumping impacts. This fault might also serve as a barrier to pumping cones advancing toward Muddy River Springs, from production occurring north of the fault.

CSI is in agreement with the information presented by SNWA in the prior reports and with the information we understand SNWA will provide in response to Order 1169A.

In sum, CSI opines that SNWA's Annual Monitoring Reports support CSI's position that there is additional groundwater available for appropriation in the Coyote Spring Valley. Thus, the CSI-Applications and the SNWA-Applications should be granted in whole, or in part.

Thank you for your consideration.

Respectfully submitted,

Carl D. Savely

Carl D. Savely

3100 State Route 168 • P.O. Box 37010 // Coyote Springs, Nevada 89037

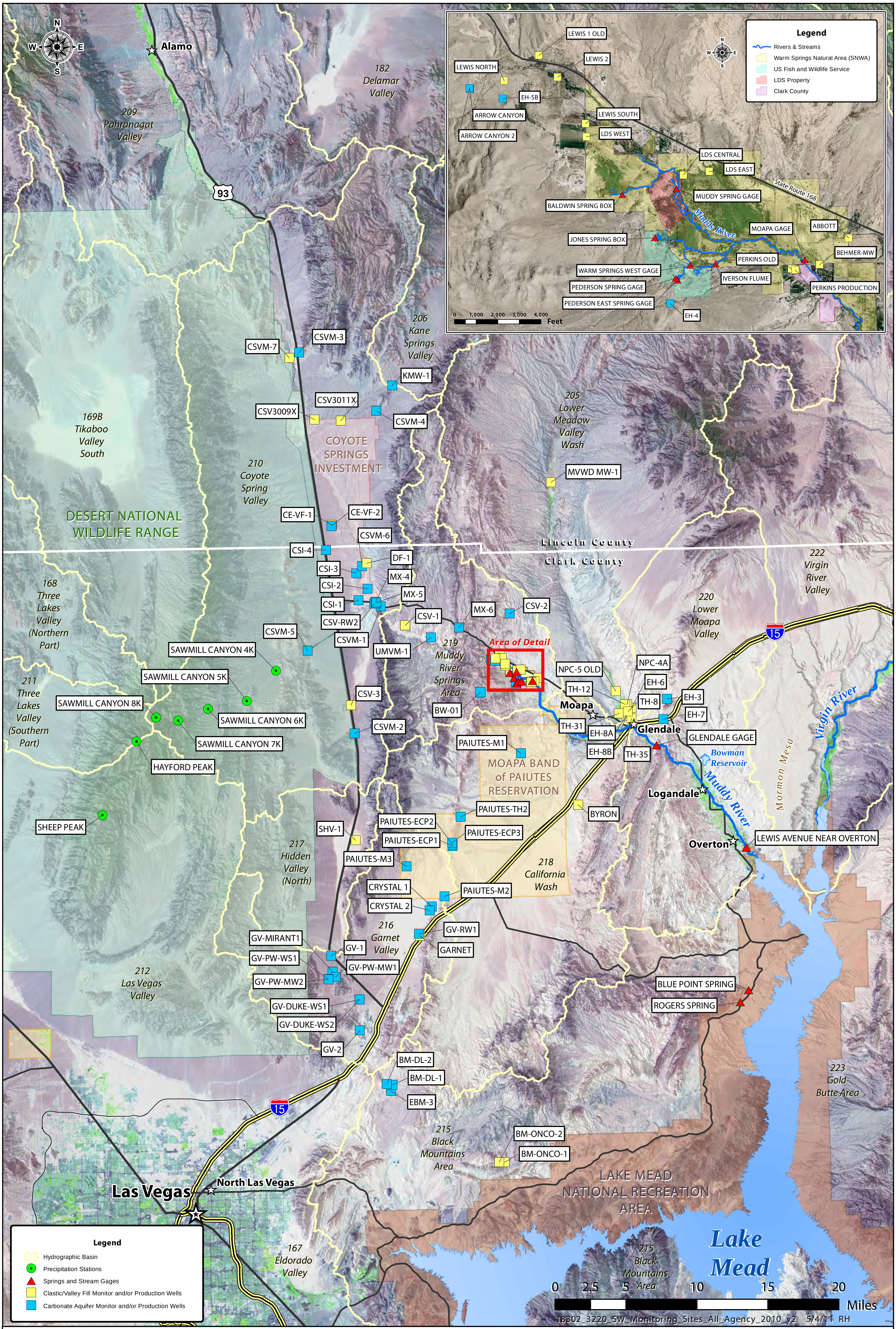

Figure 5
Surface Water, Groundwater, and Weather Stations Monitored by SNWA and Other Entities in the Southern Portion of the White River and Lower Meadow Valley Wash Flow System

SE ROA 10401

Jason King, State Engineer
Nevada Division of Water Resources
901 South Stewart St. #2002
Carson City, NV 89701

June 27, 2013

Regarding Orders 1169 and 1169a

Dear Mr. King:

It was with great interest that the Center for Biological Diversity noted your Order 1169a suspending the called-for pump test in the Coyote Springs Basin of the White River Flow System before it had met the requirements of Order 1169.

As you are likely aware, the Center filed a lawsuit against the U.S. Fish and Wildlife Service regarding the 2006 Muddy River Memorandum of Agreement because we believe the facts show that pumping at the levels permitted under Order 1169 and under the terms of the MOA would lead to significant impacts to Moapa dace habitat and eventual declines and possible extinction of the Moapa dace. Our suit is currently in the 9th Circuit Court of Appeals.

As part of an agreement with the Southern Nevada Water Authority in that litigation, the Center withdrew our request for a preliminary injunction with the understanding that the pump test would go forward and additional monitoring data would be collected and provided to the Center. That monitoring data as well as the data provided to the State Engineer was included in the recent report by Dr. Tom Myers regarding the suspended pump test and Order 1169a (attached hereto submitted by and Great Basin Water Network).
Based on the results of Dr. Tom Myers' review and analysis of the pump test results, it seems clear that even pumping *less than* 50% of existing groundwater rights in Coyote Springs Valley has caused a decrease in spring flows to critical levels for the endangered Moapa dace in the Muddy River Springs basin, and appeared certain to cause serious adverse impacts on senior water rights in down-gradient basins had the test pumping continued and the full pump test been completed.

Dr. Myers' review of the pump test and other data clearly shows the link between groundwater pumping in these valleys and spring discharges. It also supports the conclusion that full pumping of existing underground water rights will unacceptably decrease spring discharges in the Muddy River Springs basin.

Based on the incomplete pump test data, as well as data contained in the BLM's Final Environmental Impact Statement for the SNWA groundwater development project, we contend that there is ample evidence showing that any additional pumping of the White River Flow System, including pumping in Cave, Dry Lake and Delamar basins, will exacerbate the problem of decreasing spring flows and eventually dry up of springs in the down-gradient basins, including those at Muddy Warm Springs, thereby causing take of the Moapa dace, a federally protected species.

In view of this stark demonstration of the regional groundwater system's limits and threat to the Moapa dace and other imperiled fish and springsnail species found in these waters, we urge the State Engineer to deny all pending applications in Coyote Springs Valley and in the rest of the 6 basins comprising the lower portion of the White River Flow System in southeastern Nevada. We also urge the State Engineer to take administrative actions in Coyote Springs and, where appropriate in the other 5 basins, to reduce existing water permits to sustainable levels.

The Center also requests that we be provided with any public materials and documents that arise from your anticipated meeting with pump test participants.

Thank you for your consideration,

Ecologist/Nevada Conservation Advocate

CC: Bill Van Liew, U.S. Park Service
Ted Koch, U.S. Fish and Wildlife Service
Amy Levoie, U.S. Fish and Wildlife Service
Jon Sjoberg, Nevada Department of Conservation
Tom Myers, Ph.D.
John Buse, Legal Director, Center for Biological Diversity
Lisa Belenky, Senior Attorney, Center for Biological Diversity

Technical Memorandum

Comments on Carbonate Order 1169 Pump Test Data and the Groundwater Flow System in Coyote Springs and Muddy River Springs Valley, Nevada

June 12, 2013

Prepared by: Tom Myers, Ph.D., Hydrologic Consultant

Prepared For: Great Basin Water Network, Baker, NV.

Purpose and Summary

The purpose of this memorandum is to provide an analysis of the pump test completed as required by the Nevada State Order 1169, or the carbonate aquifer order. The analysis is of data published on the Nevada State Engineer web page and the U.S. Geological Survey National Water Information System web page. The data includes pumping rates, groundwater levels, and spring discharge rates. Also, the groundwater model of flow in the southern White River Flow System (Tetra Tech, 2012a and b) was briefly reviewed for predictions related to pumping from Coyote Springs and Muddy River Springs Valley.

A brief summary of the findings is that the groundwater level in the carbonate aquifer in the Muddy River Springs basin began to decrease in the late 1990s in response to increased carbonate pumping from the Arrow Canyon Well. Groundwater levels in the basin fill aquifer also began to decline in the late 1990s even though substantial basin fill pumping has been occurring since the 1980s. This suggests that decreased groundwater inflow to the basin fill from the carbonate may be allowing some of the drawdown in the fill.

A wet year in 2005 allowed a partial recovery of the carbonate groundwater levels, but the decline resumed and accelerated in the late 2000s. The decline of the carbonate groundwater level near Moapa Springs correlates with a decrease in spring discharge from the Warm Springs and the Pederson Springs at the Moapa Springs complex. The rate groundwater level decline increased almost immediately as the pumping for the Order 1169 pump test commenced in late 2010, suggesting an additive effect due to pumping in the carbonate aquifer. The discharge at the Pederson Springs is less than half of its long-term average and the discharge from the Warm Springs dropped to 3.3 cfs, or just 0.1 cfs higher than the rate which would trigger consultation among the agencies.

Pumpage from Coyote Springs Valley during the Order 1169 pump test occurred at rates that are much less than half of the underground water rights already granted in Coyote Springs

Valley. About a third of the total current underground water rights in Muddy Springs Valley were pumped at the same time. Just this small amount of pumping has caused significant drawdown in the carbonate aquifer of the Muddy River Springs basin. The drawdown is significant because it almost caused discharge from the Moapa Springs to decrease to a critical point. Continued pumping at those rates would have lowered the groundwater table further and caused the discharge from the springs to decrease further. It is apparent from the Order 1169 pump test data and from the predictions using the groundwater model that full pumpage of even existing groundwater rights in these two valleys will cause the spring discharge to decrease to rates far insufficient for maintenance of the endangered species dependent on the Moapa Springs. Granting of any future water rights will cause the spring discharge to drop even further below required rates, and may eventually dry the discharge from some or all of the springs, destroying endangered species habitat and harming downstream water rights on the Muddy River.

Introduction

Figure 1 shows the monitoring wells in the Coyote Springs and Muddy River Springs area. They extend from well north in Coyote Springs Valley southeast to and through the Muddy Springs area and south into Garnet Valley. Both production and monitoring wells have been constructed in fill and carbonate aquifers so it should be possible to consider hydraulic connections between the aquifers.

Figure 2 shows the groundwater levels as recorded in July 2011 in the project area basins. The general trend is for water levels to be higher in the north and to drop to a range between about 1814 and 1821 ft amsl near the southeast portion of Coyote Springs Valley and the Muddy River Springs area. The water level in CE-VF-1 (Figure 2), screened in basin fill, is notable because it is about 50 feet higher than the level (not shown) in CE-VF-2, a nearby carbonate well. The very small variation between Coyote Springs Valley and the Muddy River Springs area is also notable because the very small difference in water levels indicates a very small gradient. These water levels will be interpreted with more detail below.

Figure 3 shows the springs and monitoring wells near the Moapa Springs. It also shows the wells around the Arrow Canyon Well about 1 mile northwest of the springs. Because it is a Landsat image, the red on the map is an infrared image showing the location of riparian vegetation in the area. The springs in the area have created a substantial riparian wetland zone downstream of the Moapa Springs.

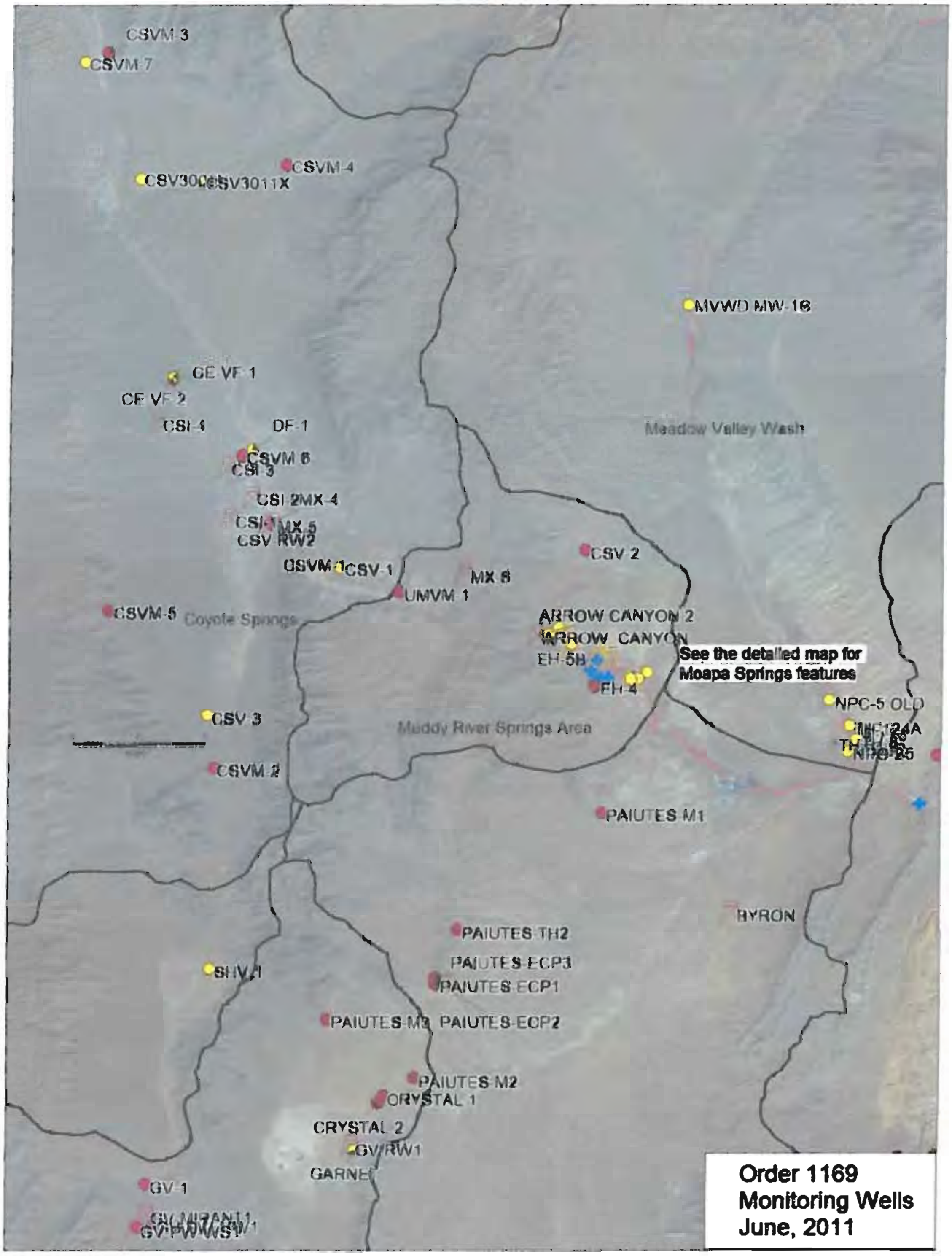

Figure 1: Coyote Springs and Muddy River Springs Area, showing monitoring and production wells. See Figure 2 for a legend explaining the symbols for the wells and Figure 3 for the details of the area around Moapa Springs.

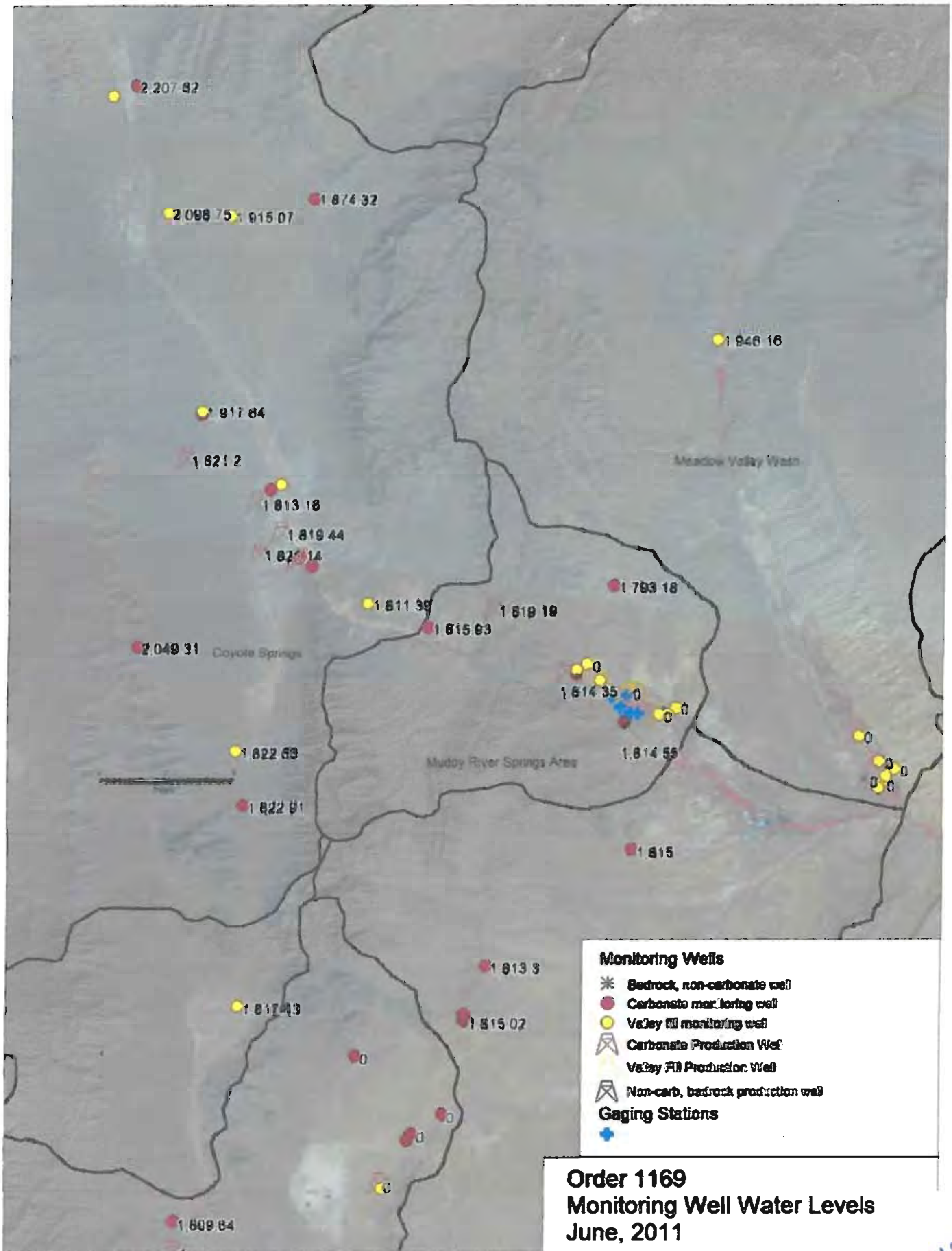

Figure 2: Groundwater levels from July 2011 for miscellaneous wells in the Coyote Springs and Muddy Rivers Springs area.

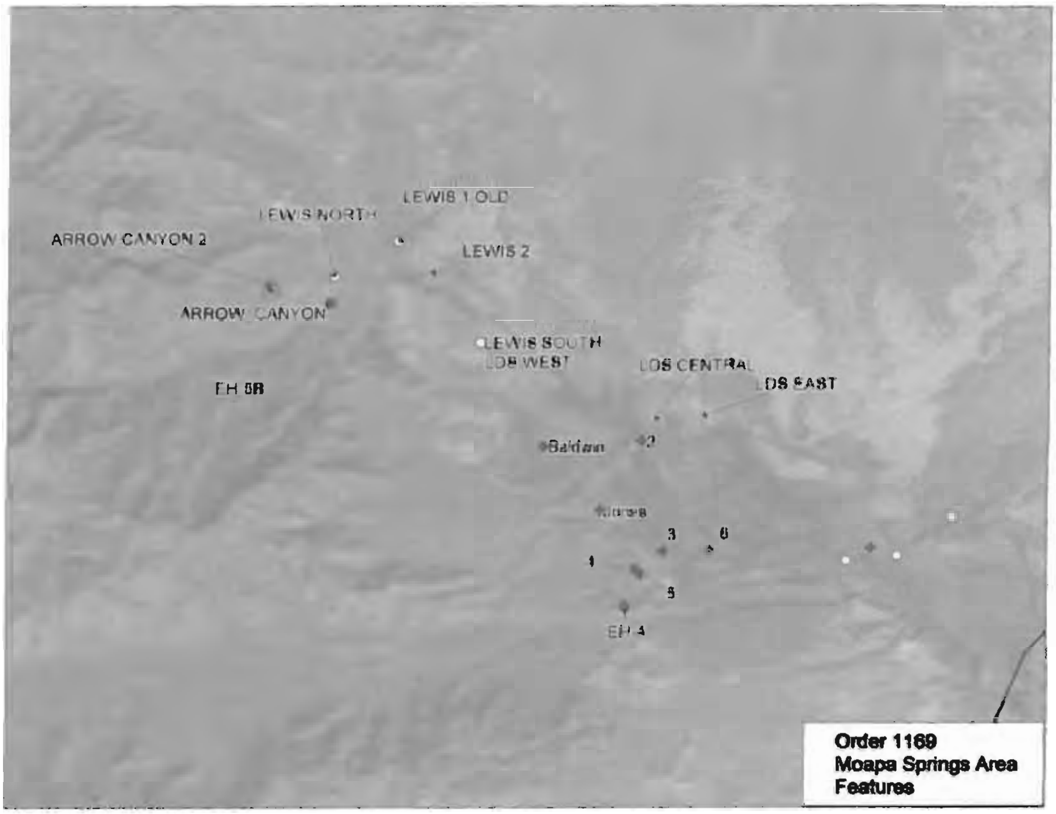

Figure 3: Detail of springs and wells around the Moapa Springs area. See Figure 2 for a legend explaining symbols. The map shows the location of monitored springs with their elevation. Only the continuous-recording stations have been analyzed in this memorandum. 2 – Muddy Springs at L.D.S. Farm near Moapa, NV (09415900); 3 – Warm Springs West near Moapa, NV (09415920); 4 – Pederson Spring near Moapa, NV (09415910); 5 - Pederson East Springs near Moapa, NV (09415908), 6 – Warm Springs Confluence at Iverson Flume near Moapa, NV (09415927)

Figure 4 shows the wells in the southeastern portion of Coyote Springs Valley. Many of the production and monitoring wells in this area are completed in the carbonate aquifer. The map shows that the ridges north and south of the well cluster are offset by about a mile, which may coincide with a significant flow pathway between valleys (Figure 5).

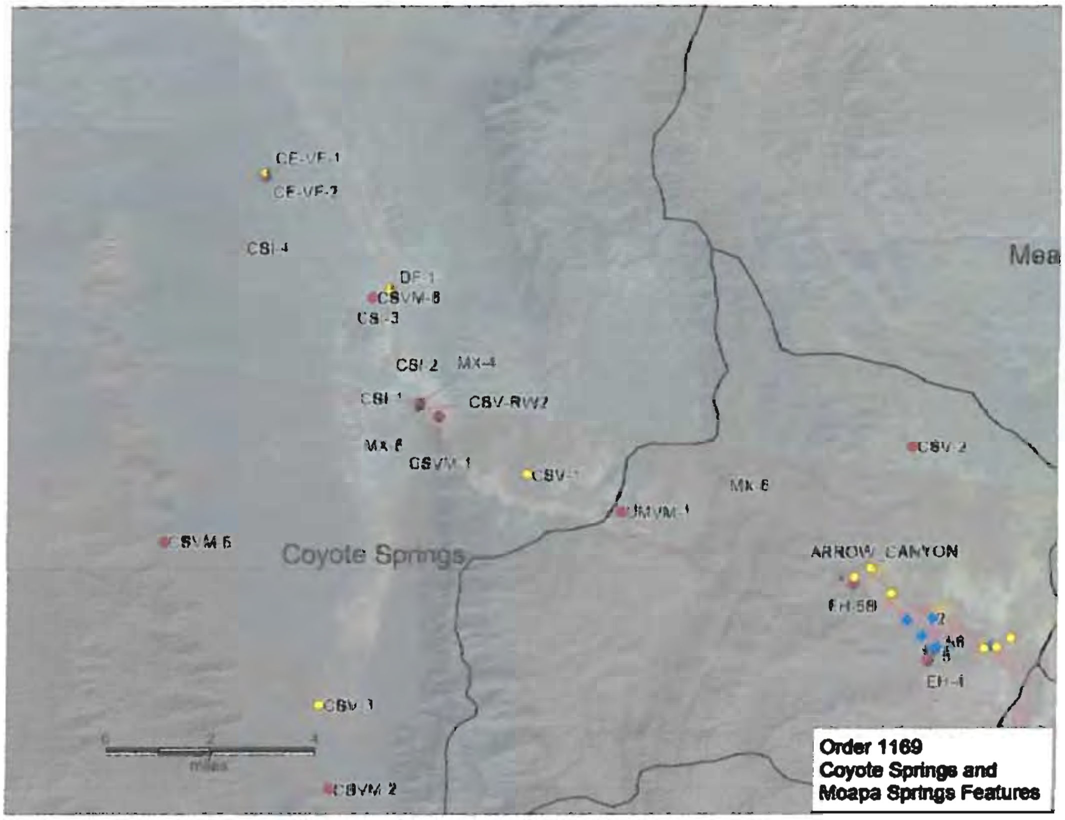

Figure 4: Detail of springs and wells around the Moapa Springs area. See Figure 2 for a legend explaining symbols.

Muddy River Springs are the terminus of the WRFS (Eakin 1966, Harrill and Prudic 1998), although there are some differing opinions that flow passes the springs to reach the Colorado River in Lake Mead. The springs formed where carbonate aquifer flow encounters the low permeability Muddy Creek formation at a normal fault (Figure 5). About 20 springs in a 1.2 mile radius area discharge water ranging in temperature from 26 to 32°C (Mayer and Congdon 2008). The total spring discharge is about 36,000 af/y (Eakin 1964, Order 1169).

The flow estimate is from the long-term gage, Muddy River at Moapa (99416000). River flow at this gage is much larger than the sum of the measured discharges from the springs. Eakin (1964) presents a series of measurements, collected in 1963, which include the discernable spring orifices and river flows. That the river flows, including that at the gage, exceed the measured spring flows indicates that a substantial amount of flow, considered to be discharge from the Muddy River Springs, is actually seeps into the river. Johnson and Mifflin (2006), using data from earlier proprietary studies, suggest inflow from the carbonate to the alluvial aquifer equals 34 cfs and that the large springs discharge a total of 17 cfs through "carbonate-cemented conduits through the alluvial gravels (Johnson and Mifflin 2006, page 25). Eakin

(1964) notes that the groundwater level from just east of the Arrow Canyon (west of Warm Springs West) to the White Narrows is just ten feet or so below the ground surface. The natural discharge in this region therefore includes substantial evapotranspiration through riparian vegetation, estimated by Johnson and Mifflin (2006) to equal 4 cfs.

Most of the interbasin flow in the carbonate province occurs through carbonate rocks, but much of the groundwater storage occurs in the basin fill aquifer because of the high primary porosity. Carbonate aquifer flow is primarily through fractures caused by faulting and conduits caused by flow through the fractures dissolving carbonate rock. Primary porosity in carbonate rock is low, but the secondary porosity and conductivity, in the fracture and conduit zones, causes extremely productive zones (Dettinger et al., 1995). Wells constructed in one of these zones may produce high quantities of water with seemingly little head drop, as has been observed at various locations through the southern portion of the study areas (Mayer and Congdon, 2008, Nevada State Engineer Ruling 4542, Bunch and Harrill, 1984). Groundwater flow and storage in Coyote Springs and Muddy River Springs valleys is a good example of this.

Carbonate Aquifer Order 1169

The Nevada State Engineer issued the Carbonate Aquifer Order 1169 in 2002 to place into abeyance all applications for groundwater in six basins in southeast Nevada (Table 1) underlain by the carbonate aquifer until additional information had been collected regarding the effects of pumping from that aquifer in these basins. All six basins are in the southern portion of the White River Flow System (WRFS), which generally discharges to the Colorado River. Basically, the existing water rights in the area (Table 1) already were approximately equivalent to the known discharges from the WRFS. Order 1169 was the State Engineer's response to applications heard in a hearing held in July/August 2001.

Table 1: Tabulation of basins and current water rights in basins affected by Order 1169.

Basin	#	Total UG Rights in Order 1169
Coyote Spring	210	16,300
Black Mountain	215	10,216
Garnet Valley	216	3,380
Hidden Valley	217	2,200
Muddy River Springs	219	14,756
Lower Moapa Valley	220	5,813

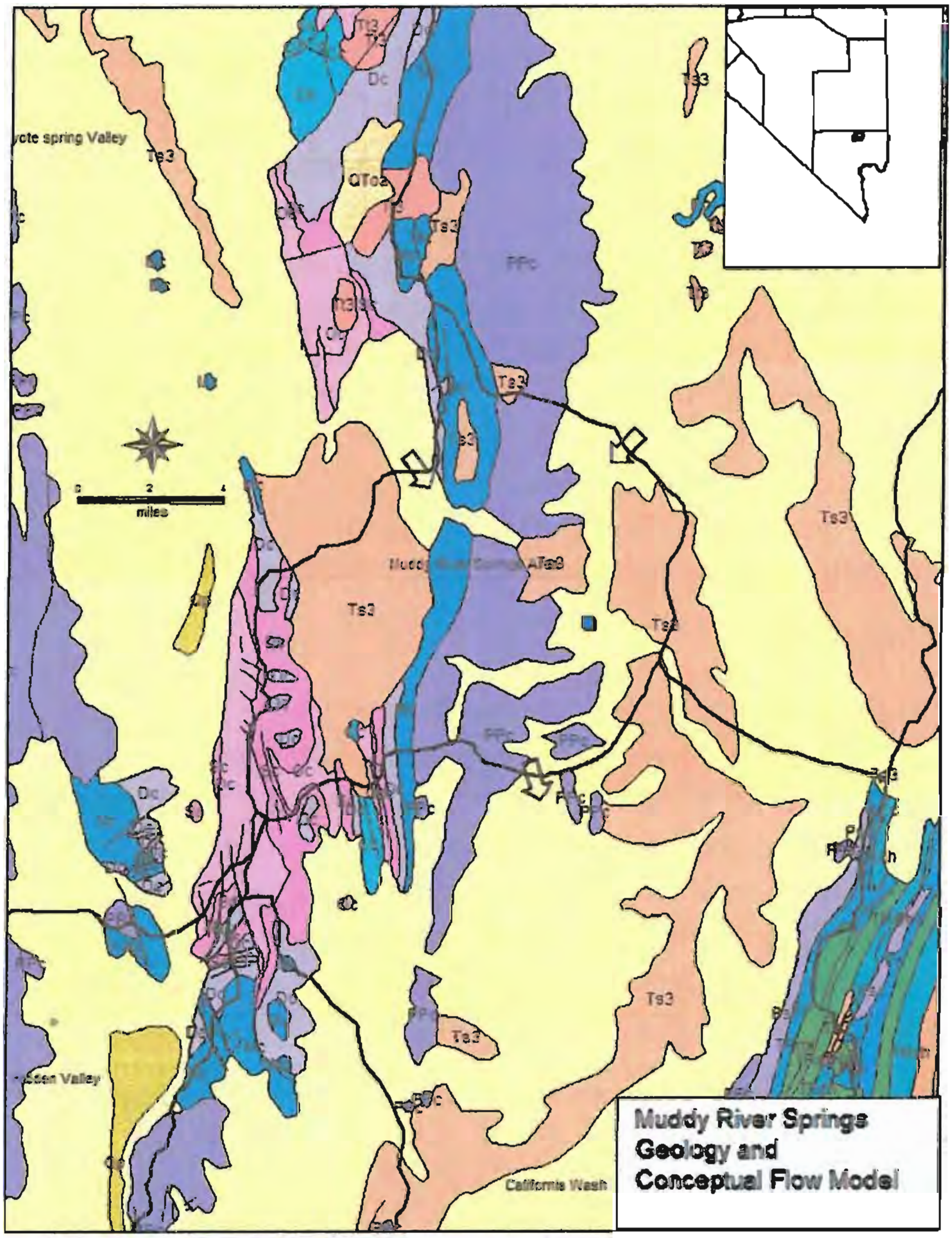

Figure 5: Geology and conceptual flow model of the aquifer system near the Muddy River Springs. Ts3 is volcanic rock, PPc, Mc, and Dc is carbonate rock. The formations west of the Muddy River Springs are the Arrow Canyon Range. The map show faults, but not near the Muddy River Springs because the fault did not appear on the surface. Source: Stewart and Carlson (1978), Stewart (1980).

Order 1169 required that a study that "must cover a 5-year minimum period during which at least 50% of the water rights currently permitted in the Coyote Springs Valley groundwater basin are pumped for a least 2 consecutive years" (Order 1169, p 6). The State Engineer recognized that the required pumping was not commencing and ordered the 2-year pump test to commence in October 2010 (Order 1169ao); it actually commenced November 15, 2010 and the NSE declared it complete as of December 31, 2012 (Order 1169ao). From May 2005 through March 2013, the total pumpage from Coyote Springs Valley has been 22,300 af (Figure 6). Over an almost 7 ½ year period which included the mandated pump test, the total pumpage from Coyote Spring Valley was just 18% of the total water right that would have been allowed to be pumped during that period, which is about 122,250 af.

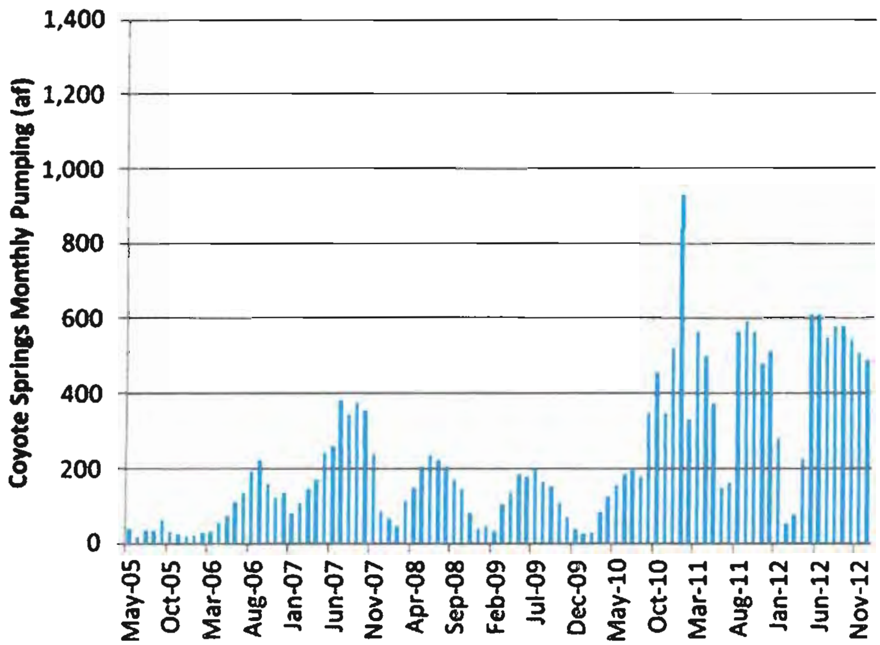

Figure 6: Monthly total pumping from Coyote Spring Valley.

During the period November 2010 through October 2012, there were 10,701 af pumped from Coyote Spring Valley, which is significantly less than the required 16,100 af or 8050 af/y for two years (Figure 7).

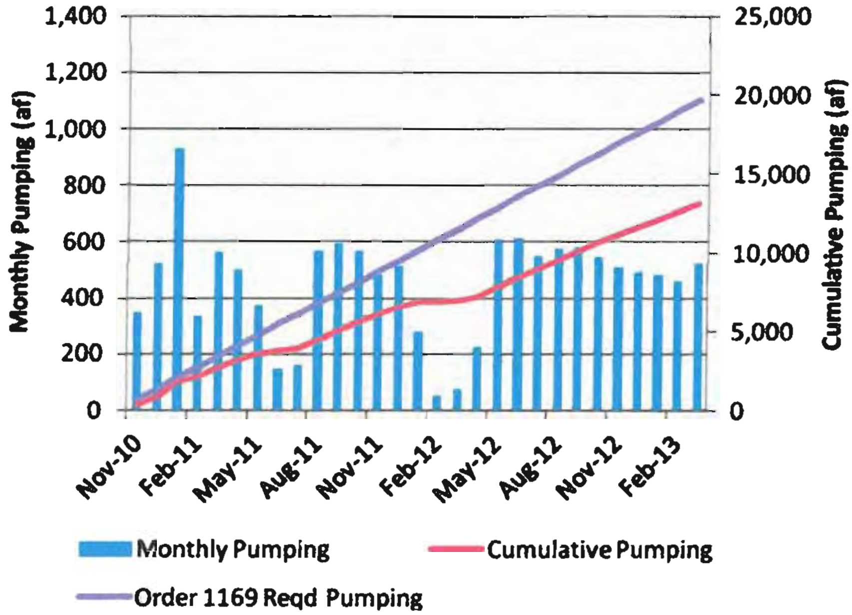

Figure 7: Monthly and cumulative pumping and required pumping as required by Order 1169.

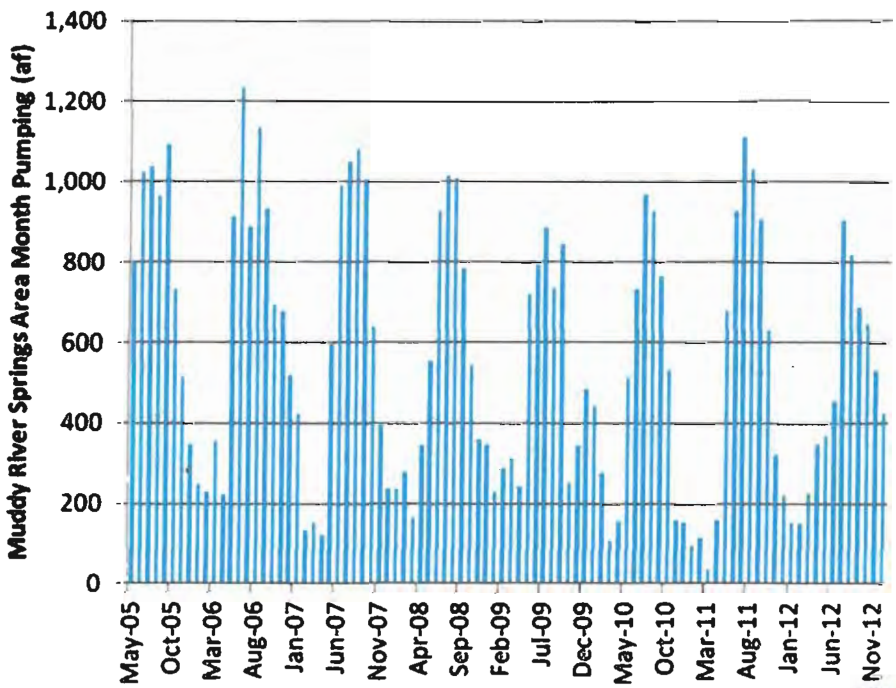

Figure 8: Monthly total pumping from the Muddy Springs Area.

Water Level Response

This memorandum considers the changes in water levels for two primary areas in the south end of the WRFS, Coyote Springs Valley and Muddy Springs Valley.

Coyote Springs Valley

The general slope of groundwater levels is from greater than 2200 ft amsl to about 1815 ft amsl near the point where the Muddy River Wash exits the valley and flows toward Arrow Canyon (Figure 1). Groundwater levels throughout the valley have been relatively stable when considered at a coarse scale since 1997 (Figure 9). Most of the wells have groundwater levels less than 1950 ft amsl with a cluster ranging from 1810 to 1835 ft amsl since 1997 (Figure 10). Those lower water level wells had decreasing groundwater levels from about 1998 until 2003 after which wet conditions allowed the groundwater level to mostly recover. Since 2005 they have been decreasing with an increase in the rate of water level decrease since pumping for the Order 1169 pump test commenced in 2010 (Figure 10). Several wells, including MX-5 and CSI-3 experience up-to-ten foot decreases due to intermittent pumping; in fact, MX-5 is the primary pumping well in Coyote Springs Valley.

The wells with higher groundwater levels, above 2000 ft amsl, are in the northern portion of the valley away from much of the pumping. Interestingly, water levels there have increased a few feet since the early 2000s (Figure 11). This indicates that stress from pumping in Coyote Springs Valley has not reached north to this area. The wells in Figure 11, CSVM-3 and -7, carbonate and basin fill wells, respectively, both have increasing water levels but the basin fill well (CSVM-7) is at least 40 feet higher than the carbonate well (CSVM-3). Similar observations hold for all of the wells in the north end of the valley.

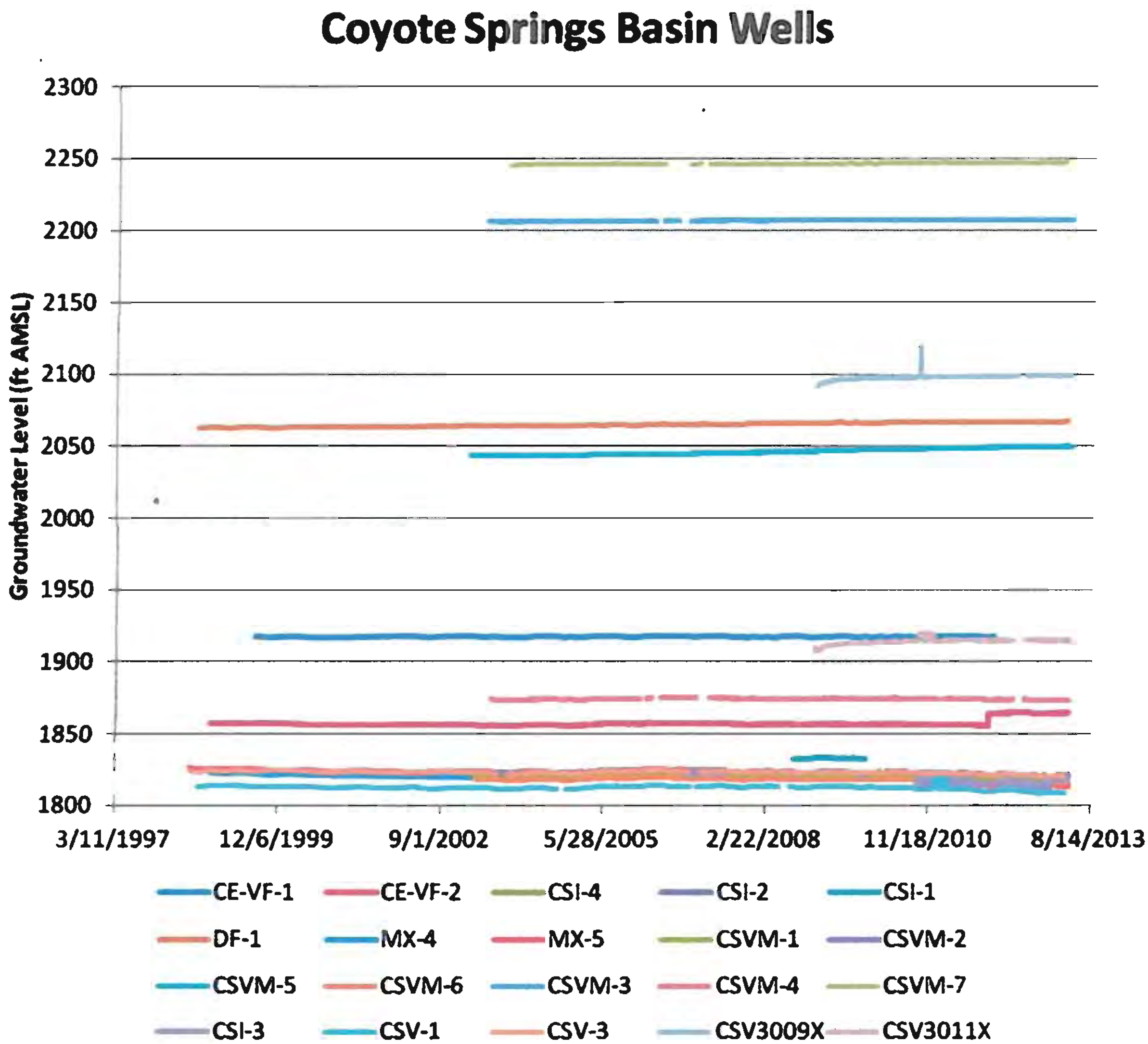

Figure 9: Groundwater level for monitoring and production wells in Coyote Springs Valley. See Figures 1 and 4 for their location, type, and completion.

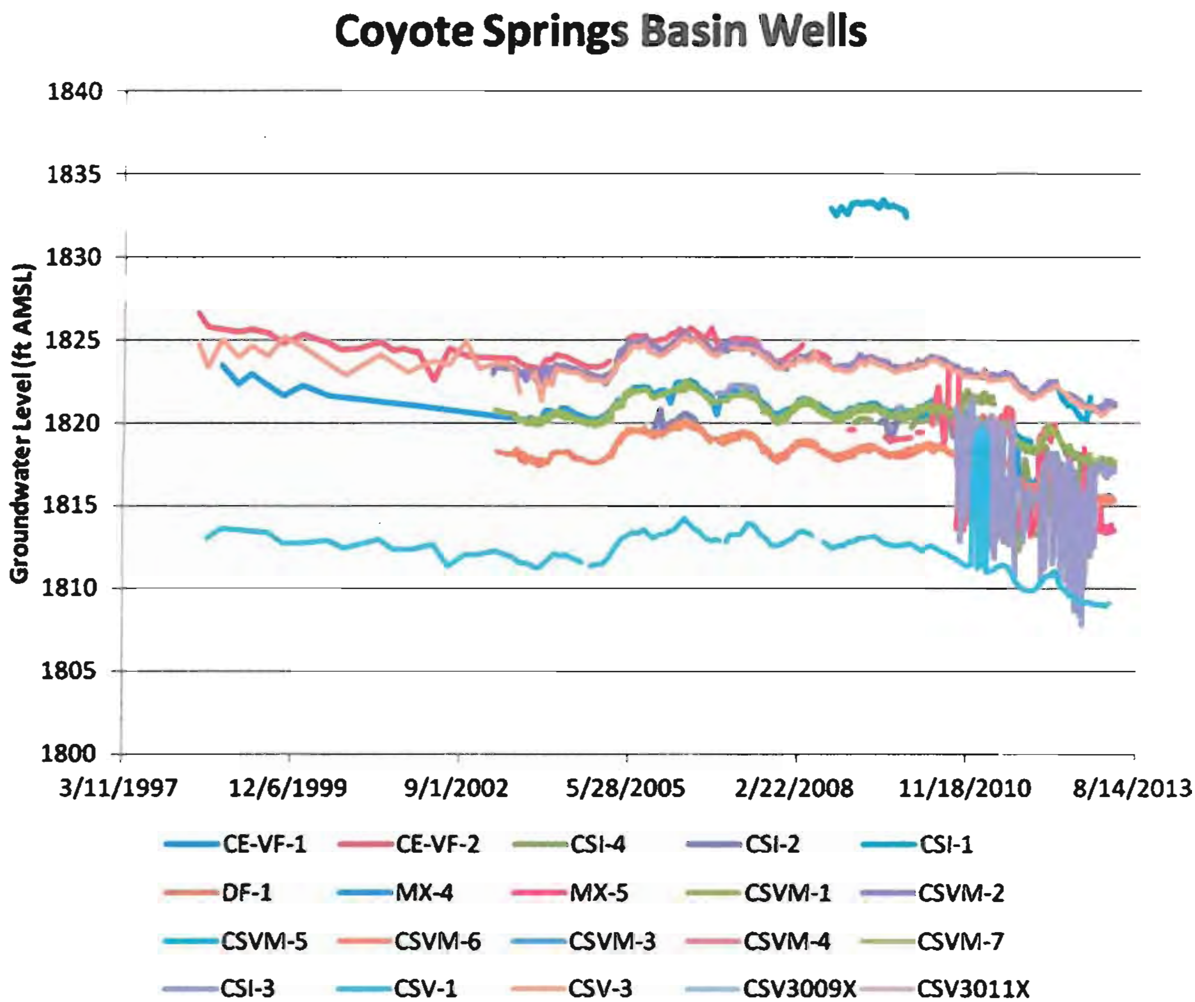

Figure 10: Groundwater level for monitoring and production wells in Coyote Springs Valley near the southeast portion where the valley flows into Muddy Springs Valley.. See Figures 1 and 4 for their location, type, and completion.

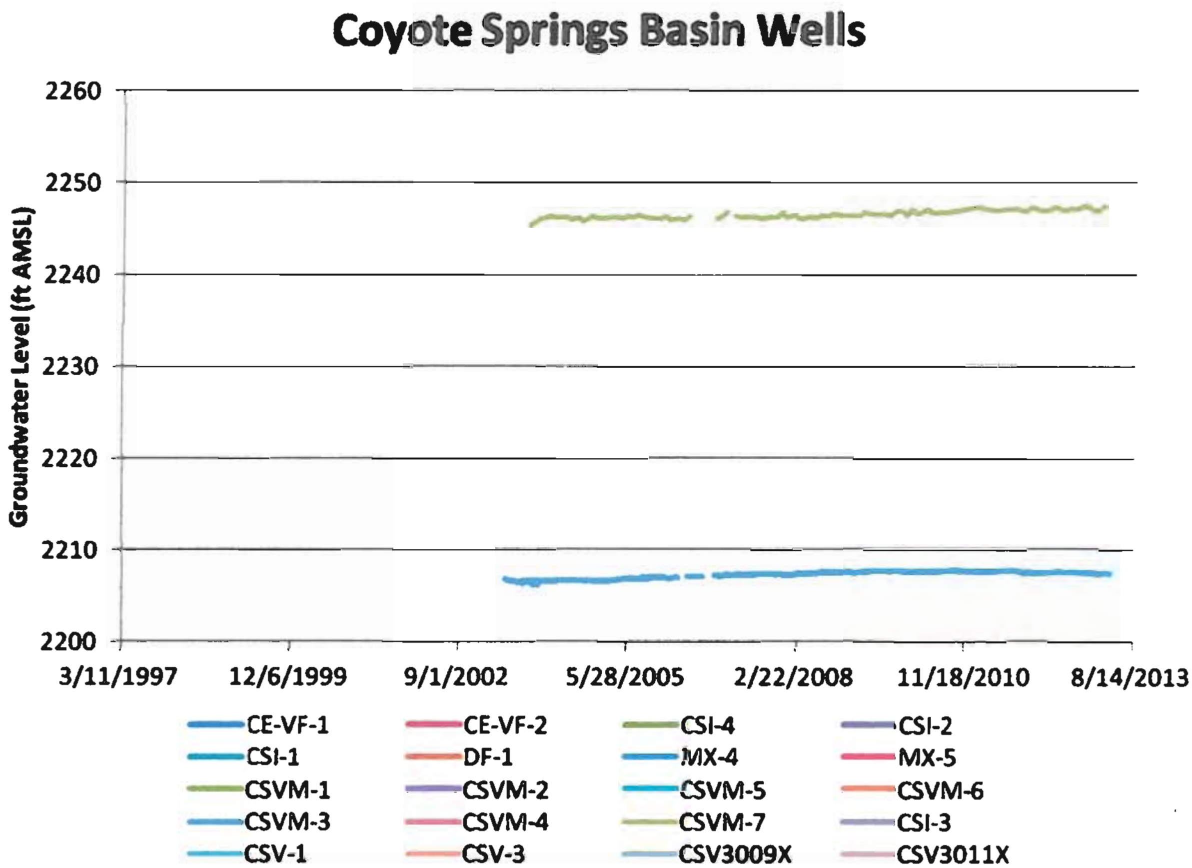

Figure 11: Groundwater level for monitoring and production wells in the upper reaches of Coyote Springs Valley. See Figures 1 and 4 for their location, type, and completion.

Muddy River Springs Area

Muddy River Springs Area and the Moapa Springs are downgradient of Coyote Springs Valley along the Muddy River wash that drains through Arrow Canyon. There are monitoring wells in both the basin fill and carbonate aquifers within the area. Groundwater levels have either remained steady or have decreased at wells within the area (Figure 12). However, groundwater levels at wells close to Moapa Springs have been mostly decreasing since about 1998. Carbonate wells EH-4 and EH-5B have been decreasing since the early 1990s, but they partly recovered in 2005 due to a wet year after which their decrease began again. The rate of water level decrease increased in 2010. Similar observations can be made for well CSV02, another carbonate well north of the springs (Figure 13). Well Lewis North and Boehmer are basin fill wells that have begun to decrease in the mid 1990s; however, the groundwater levels in these fill wells continues to decrease during the pump test, but not at an increased rate (Figure 13). Groundwater levels at the Abbot well, also completed in fill at the downstream end of the valley, decreased about ten feet beginning in the mid 1990s to present with very little recovery around 2005, suggesting the wet conditions did not affect it.

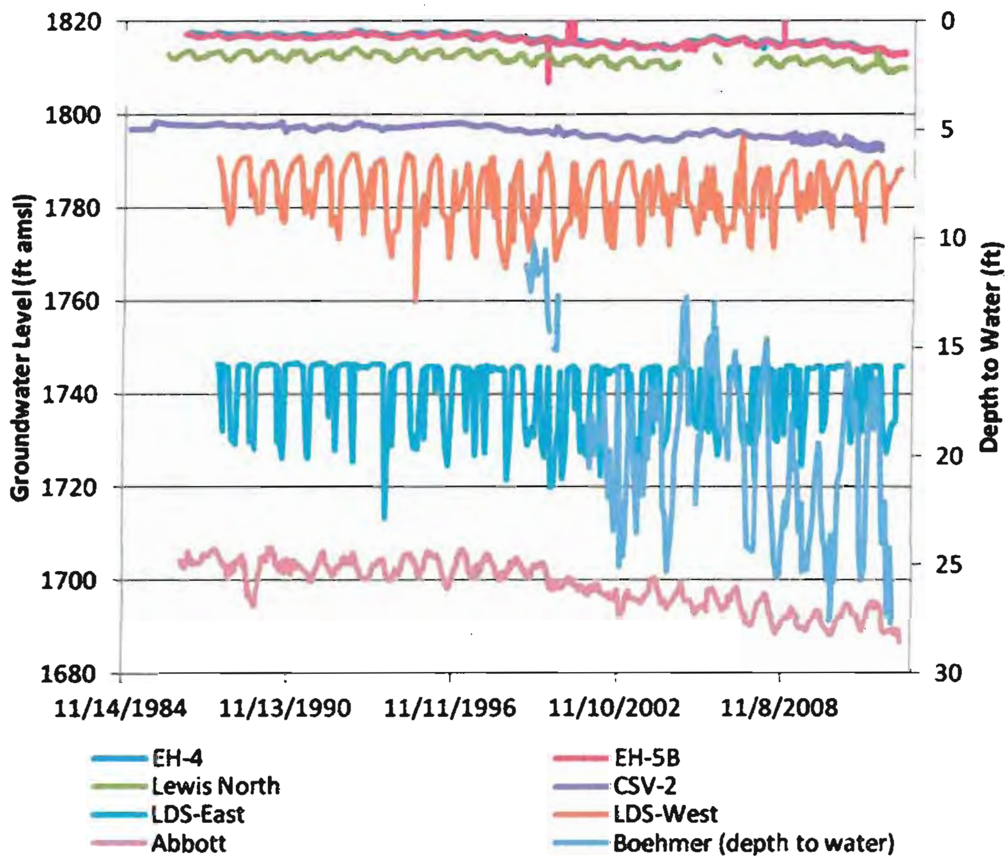

Figure 12: Groundwater level for monitoring and production wells in Muddy River Springs Valley. See Figures 1 and 3 for their location, type, and completion.

The summary for the Muddy River Springs Area is that groundwater levels for all wells have been decreasing since the mid 1990 with some recovery due to wet conditions from 2004 to 2005. During the 2010 to 2012 pump test period the rate of decline in carbonate wells increased.

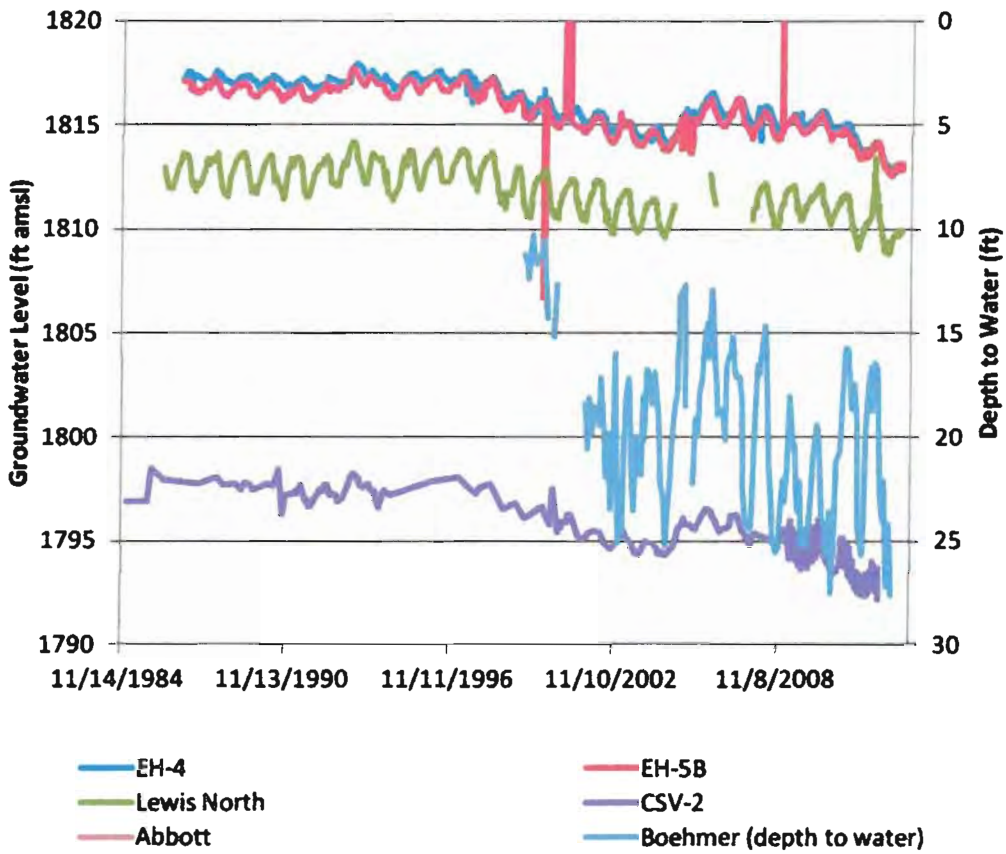

Figure 13: Groundwater level for monitoring and production wells in Muddy River Springs Valley with a focus near the springs. See Figures 1 and 3 for their location, type, and completion.

Spring Response

The most important feature in the area is the Moapa Springs, which is the upstream end of the perennial Muddy River. The average flow in that river, prior to any development, was about 36,000 af/y. Flows on the Muddy River below LDS Farm have many diversions, so the best way to monitor flows from the springs is to consider direct measurements. The cumulative flow from many of the gages began to decline in 1996. Even with a minor increase in 2007, the flows have decreased from the mid 8 cfs range to close to 7 cfs (Figure 14); prior to 1996, the records are unreliable due to an unmeasured diversion. Little change in flow rate appears to have occurred since 2009 or during the pump test period (Figure 14).

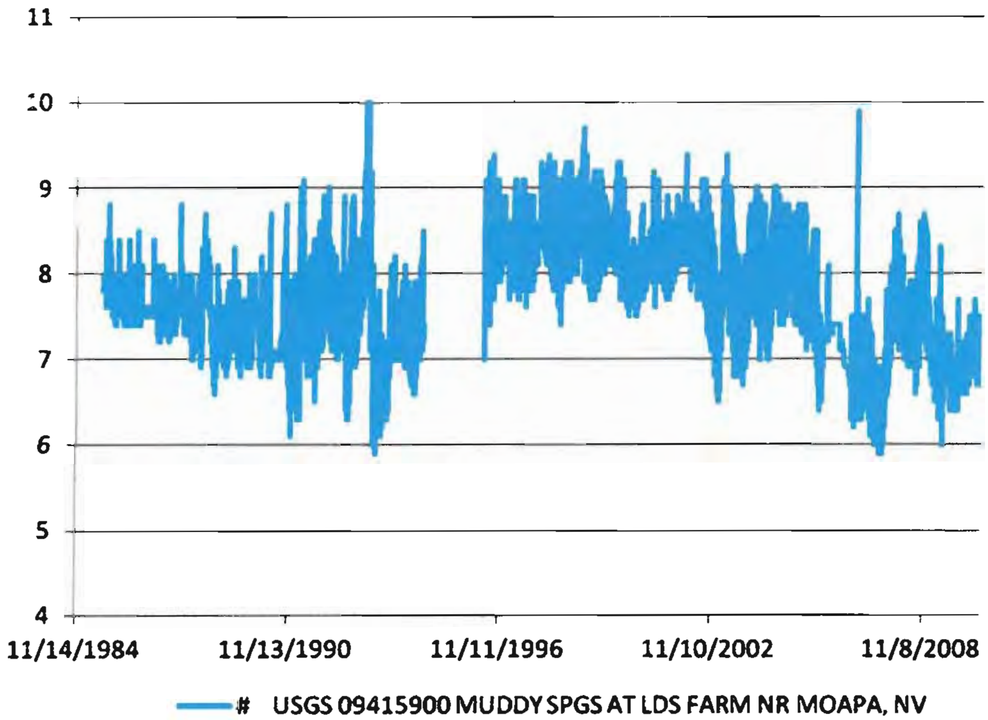

Figure 14: Flow rate downstream of many of the Moapa Springs.

The gage Warm Springs at Moapa is considered a trigger gage it is at this gage that the Fish and Wildlife Service agreed to monitor the effects of pumping during the pump test Fish ad Wildlife Service, 2006). The uppermost trigger point, at which the parties to the agreement agreed to meet to determine next steps, is 3.2 cfs. The flow at the gage has been decreasing since about 2009 (Figure 15) and most obviously during the pump test period (Figure 16). For a long period during 2012 and early 2013, the flow decreased to 3.3 cfs, or just 0.1 cfs higher that the trigger point. This is the lowest flow recorded at this point since 1996 (Figure 15). The small Pederson Springs reflect these low flows, although due to their low flow rate they are not responsible for all of the decrease. Flows at these springs had been relatively constant with seasonal fluctuation from 1996 through 2009 (Figure 17), but beginning with the pump test, their flow rates have decreased by more than 50 % (Figure 18); the flows at Pederson Springs near Moapa are less than a third of their value in early 2010 and show no sign of recovery by April 2013.

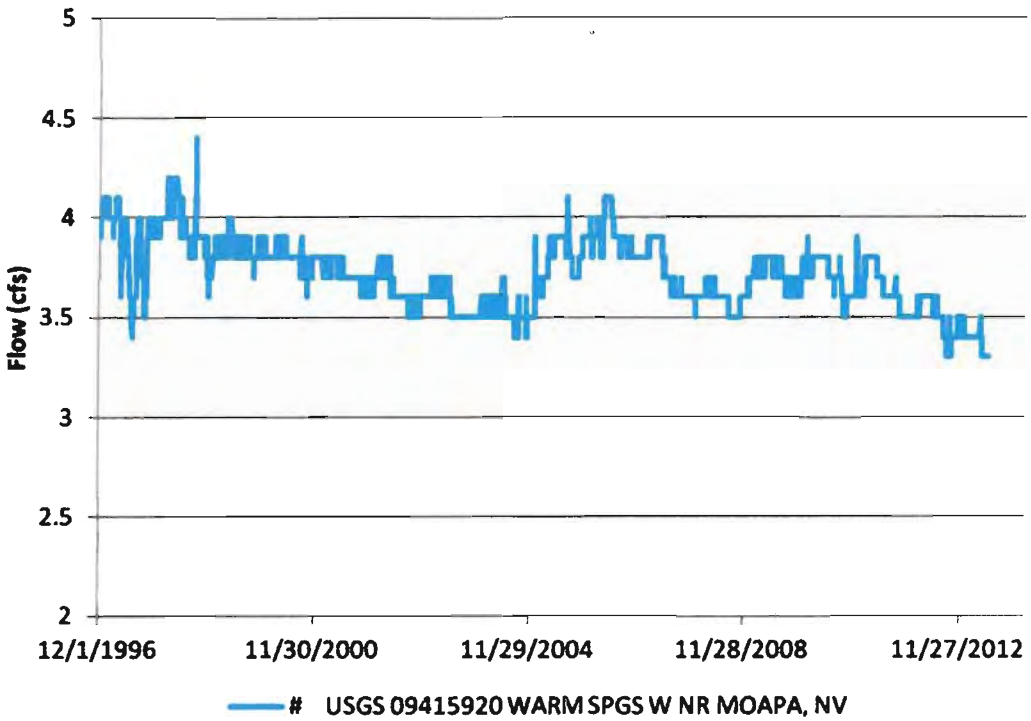

Figure 15: Flow rate at the trigger spring.

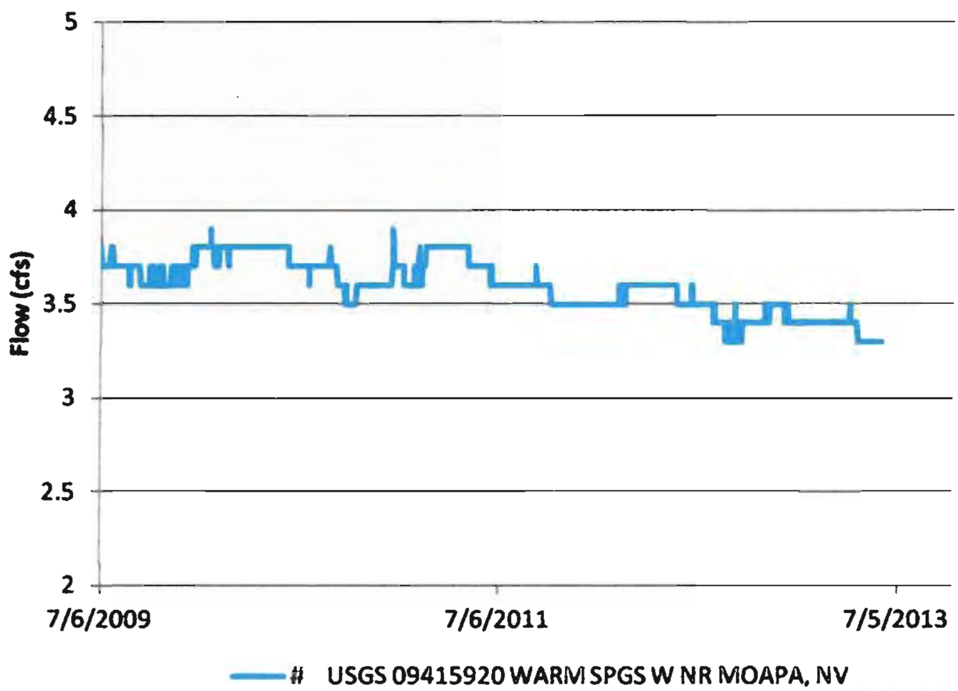

Figure 16: Flow rate at the trigger spring during the Order 1169 pump test.

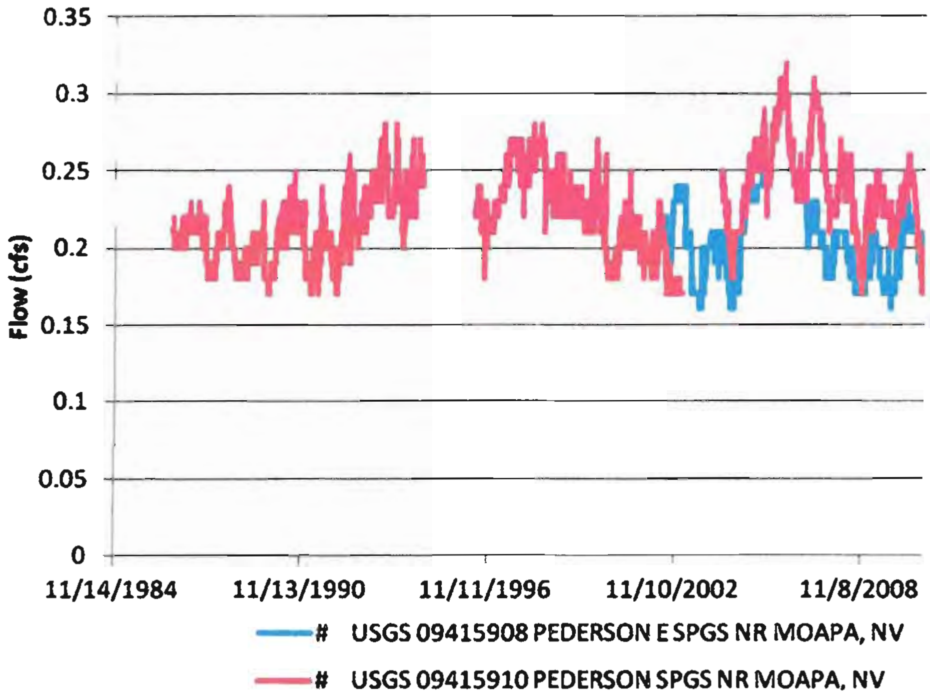

Figure 17: Flow rate at the Pederson Springs near Moapa, NV.

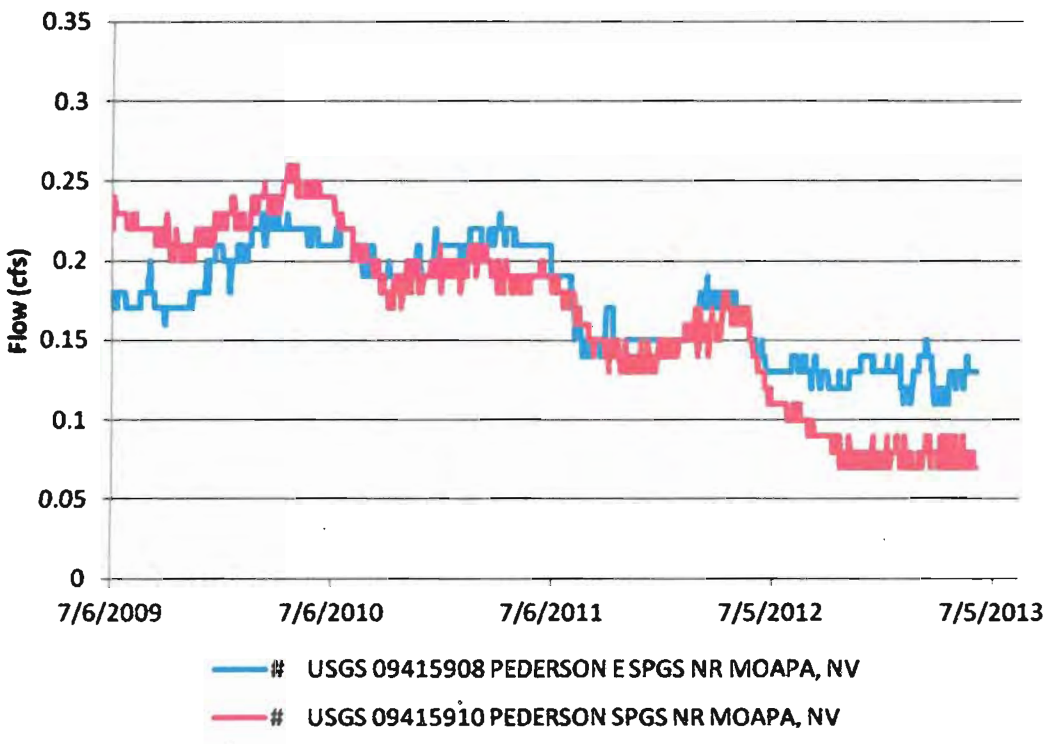

Figure 18: Flow rate at the Pederson Springs near Moapa, NV during the Order 1169 pump test.

Discussion of Pumpage, Groundwater Levels and Spring Discharges

Both groundwater levels in two basins and spring flows have reached their lowest value ever recorded in 2012 with almost no recovery in 2013. The purpose of this analysis is to consider the cause because further decreases to the spring flow will further endanger the fishes at the Moapa Springs (and damage water rights holders on the Muddy River). While the decreases coincide generally with the commencement of carbonate pumping in the 1990s in the Muddy River Springs Area and more significant decreases coincide with the Order 1169 pump tests from 2010 through 2012, it is important to consider the roll of climate and drought in the area. Significant basin fill pumping had begun earlier, but the drawdown in those wells, such as LDS-east, LDS-west, Boehmer, and Abbot, did not begin until the mid-1990s (Figures 12 and 13).

According to climate indices and data reported by Mayer and Congdon (2008), the early 2000s were the driest since 1980 and the winters of 1992, 1993, and 2005 had the third, second, and highest precipitation totals since 1985. After 2005 the region primarily returned to drought conditions. The late 1990s were among the wettest years since 1980 (Mayer and Congdon 2008).

Groundwater levels in the Muddy River Springs area began to decline in the mid 1990s, which coincides with the commencement of pumping at the Arrow Canyon Well. The most notable declines occurred in the carbonate wells EH-5b and EH-4, but also occurred in the basin fill wells. The actual groundwater levels and the seasonality of their fluctuations are almost perfect mirror images of each other suggesting there is a connection between the wells. The decrease in spring flow at the Pederson Springs correlates closely with the groundwater level changes at EH-4. Mayer and Congdon (2008) found that pumping and climate variability had roughly equivalent effects in the Muddy River Springs area. Those effects presumably mean groundwater level and spring discharge, which are linearly related.

As the groundwater level that controls spring discharge declines, the discharge also declines. The rate of spring discharge decline depends on the total head above the spring (the difference between the groundwater level and spring orifice). The Pederson Springs are the highest elevation so the head on those springs is likely less than the lower elevation springs (head would be the difference between the groundwater elevation and the spring orifice elevation). A given groundwater level decline will affect the Pederson Springs proportionally much more than it will affect the lower springs; the spring discharge is a much larger proportion of the actual flow than it would be if for a spring with more head on it.

The Warm Springs used as a trigger for the stipulated agreement are lower and therefore have more head. Well EH-4 has dropped from about 1817 to 1813 ft amsl since the mid-1990s as the discharge from the Warm Springs has dropped from about 3.9 to 3.3 cfs. If the relationship is linear, the spring would go dry if the groundwater level dropped 26 feet to about 1793 ft amsl. The datum for the spring is 1771 which suggests the water level would actually have to drop further and that the relationship between discharge and groundwater level at EH-4 is not exactly linear. The well is constructed in the carbonate aquifer and the spring discharges from the carbonate aquifer, so there well must be on the direct pathway to the spring.

The Arrow Canyon wells are completed in the carbonate aquifer and have been pumped since 1988 but much more extensively since 1998. Since 2000, there has been 28,735 af pumped from those wells (Figure 19). It was a significant portion of the total amount pumped in Muddy River Springs area (Figure 8 and Figure 19), although most of the pumpage other than from Arrow Canyon wells was from basin fill wells. Until the Order 1169 pump test, it was the largest withdrawal from the carbonate aquifer.

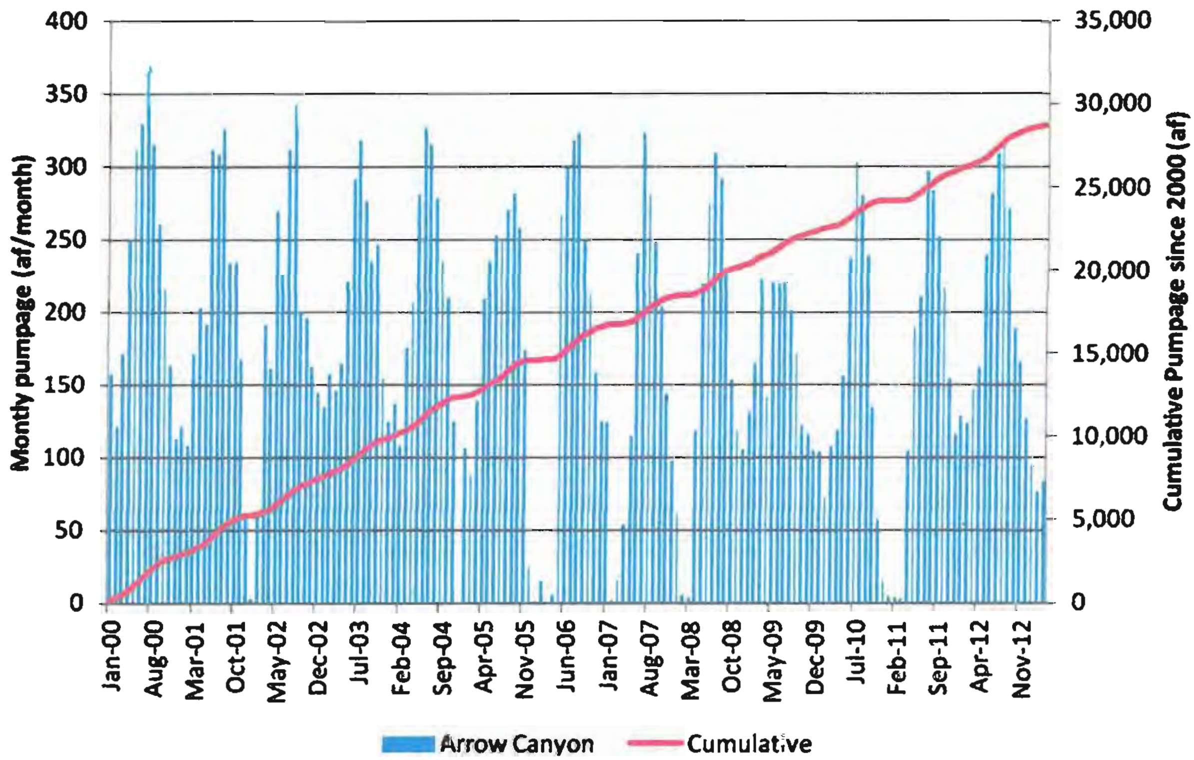

Figure 19: Monthly and cumulative pumping from the carbonate Arrow Canyon Well.

The Order 1169 pump test, although it did not even meet the pumping requirements specified in Order 1169, more than doubled the pumpage from the carbonate aquifer. Groundwater levels in the EH-5b and EH-4 wells declined more rapidly beginning almost coincidentally with the pump test (Figure 13). This suggests the pumping in Coyote Springs Valley has an additive effect with the pumping at Arrow Canyon, the pumping rate of which did not apparently decrease very much during the pump test (Figure 19), on the drawdown in the carbonate aquifer. Because of the linkage between the spring discharge and the groundwater level at EH-4 (and EH-5b), the Order 1169 pumping along with the Arrow Canyon pumping has caused most of the observed decrease in spring flow at the Moapa Springs. The drought has added to the effects, but without the pumping the ultimate decreases would not have been that significant as can be observed considering the water levels in the early 1990s after an earlier period of significant drought.

The response of the basin fill wells is not indicative of the basin fill pumping, which in the Muddy River Springs area is reasonably substantial. Groundwater in the basin fill is likely secondary recharge of the water discharging from the various springs. Drawdown in transmissive basin fill is quickly replenished by the spring flow. This at least could explain why there is no apparent drawdown prior to the late 1990s in wells Lewis North, Abbott, and Boehmer due to the pumping that has been occurring in the basin fill in the area. It is possible that the reductions in the groundwater level in the carbonate aquifer reduced groundwater flow from the carbonate to the basin fill; flow to the basin fill had been noted by Johnson and Mifflin (2006). If the wells are screened to include the zone being depleted by a decrease in flow from the carbonate, it is possible that the deeper levels control the measured water levels in the well rather than being controlled by the actual water table in the basin fill. This would reflect a vertical gradient in the basin fill and that the vertical movement is not fast enough to quickly replenish groundwater at depth. The fact that the carbonate levels in EH-5b and EH-4 are higher than the levels in the fill indicates there is an upward gradient and supports the idea that there is discharge from the carbonate into the fill.

In Coyote Springs Valley, the groundwater level in the fill was from 25 to 200 feet higher than in the carbonate in most areas. The depth to groundwater in both aquifers in Coyote Springs Valley is significant, ranging from about 160 to almost 1000 feet. The shallowest groundwater level is in well DE-1 and is almost 200 feet higher than the water level in the underlying carbonate aquifer in a nearby well. The depth to groundwater data suggests there is a downward gradient, but it does not establish a hydraulic connection. The carbonate pumping did not apparently affect water levels in the basin fill, but due to the thickness of the fill aquifer it is possible that the groundwater levels throughout the fill would not change at one time. The data as presented proves nothing about the connection. Due to the aridity of the basin, very little recharge would be expected within the fill.

Groundwater Model of the Lower White River System

The National Park Service, Fish and Wildlife Service, and others have commissioned a groundwater model of the Lower WRFS (Tetra Tech 2012a and b). The purpose of the model is to estimate the future effects of developing all of the water rights in the basin.

Scenario 1 considers long-term pumping at the rates as occurred from 2009 through 2011 in the 13 basins, which means it considered part of the Order 1169 pump test. It shows the discharge rate from the Warm Springs decreasing to about 3 cfs after 1000 years. After about 50 years, it has reduced to about 3.7 cfs from an initial 3.9 cfs. This minor flow reduction occurred even though the reported drawdown is 1 to 2 and 2 to 5 feet after 10 and 50 years, respectively. These results suggest that the model does not accurately simulate the pump test. It also may reflect that the reported drawdown is not from the same layer as the simulated spring (reviewing the details of how the spring is simulated is beyond the scope of this memorandum).

Scenario 2 considers pumping all existing rights in the 13 basins, which includes pumping 16,100 af/y from Coyote Springs Valley. It also increases the pumping in the Muddy Springs area to 13,688 af/y from the 5964 af/y simulated in Scenario 1, so it is not possible to assign effects shown at the springs to pumping in either of the valleys. In this scenario, flow at the Warms Springs decreases to 3.0 cfs within 50 years, 2.0 cfs within 190 years, and essentially dries in 1000 years. Other springs have similar reductions, including the Pederson Springs which are dry within 50 years. The predicted drawdown after 50 and 200 years is 10 to 20 and 20 to 50 feet, respectively, which essentially verifies relation between drawdown and decreased discharge observed above.

The impacts from pumping Scenario 2 are due to pumping only the existing water rights in the basin. It would have been useful to simulate pumping only the amount from Coyote Springs Basin to more carefully examine the simulated connection between that valley and the springs. The effects of pumping Scenarios 3 through 7 are immense, with up to hundreds of feet of drawdown and springs going completely dry.

It is possible that the effects of pumping from the carbonate aquifer on the spring flow has been significantly underestimated because the model simulates drawdown expanding in many directions from the areas of pumping. In general, for Scenario 2, drawdown up to 100 feet covers much of the southwestern third of the model domain. The drawdown parallels the west boundary due to model boundary effects. Tetra Tech (2012*, p 62) claims this is due to "high transmissivity and low storativity of the carbonate aquifer". The reality may actually be that the model simulates the aquifer as a homogenous porous media across which the effects spread evenly in all directions. The aquifer due to its highly transmissive pathways would actually be very horizontally anisotropic which means that high transmissivity would occur only in one direction. It is also likely that the high transmissivity pathways end at the springs, due to a fault and termination of the carbonate rock which causes groundwater to surface in the springs.

Because of the horizontal anisotropy, it is likely that the volume from which groundwater can be removed from storage is much less than modeled. It is therefore likely that the extent of the highly transmissive aquifer zone will be reached much sooner than simulated and that water levels in the Muddy Springs Area and the spring discharge will decrease more quickly than predicted by the model. The apparent additive effect of the Coyote Spring and Arrow Canyon pumping is substantial evidence that pumping from the carbonate aquifer in this area directly lowers the water table and is directly drawn from the Moapa Springs.

Conclusion

The purpose of the Order 1169 pump test was to stress the aquifer to determine whether to grant the water right applications that have been held in abeyance and to provide information as to what to do with all of the additional applications that have been filed since 1989. This memorandum did not summarize the applications but a brief compilation of the total amounts are provided in Tetra Tech (2012b).

Pumpage from Coyote Springs Valley during the Order 1169 pump test occurred at rates that are much less than half of the underground water rights already granted in Coyote Springs Valley. About a third of the total current underground water rights in Muddy Springs Valley were pumped at the same time. Just this small amount of pumping, in comparison with the total permits in the valleys, has caused significant drawdown in the carbonate aquifer of the Muddy River Springs basin. The drawdown is significant because it almost caused discharge from the Moapa Springs to decrease to a critical point. Continued pumping at those rates would have lowered the groundwater table further and caused the discharge from the springs to decrease further. It is apparent from the Order 1169 pump test data and from the predictions made using the groundwater model (Tetra Tech, 2012b) that full pumpage of even existing groundwater rights in these two valleys will cause the spring discharge to decrease to rates far insufficient for maintenance of the endangered species dependent on the Moapa Springs. Granting of any future water rights will cause the spring discharge to drop even further below required rates, and may eventually dry the discharge from some or all of the springs, destroying endangered species habitat and harming downstream water rights on the Muddy River.

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