SCOTT LAKE
NV Bar No. 15765
Center for Biological Diversity
P.O. Box 6205
Reno, NV 89513
(802) 299-7495
slake@biologicaldiversity.org

Electronically Filed
Jun 02 2022 04:33 p.m.
Elizabeth A. Brown
Clerk of Supreme Court

IN THE SUPREME COURT OF THE STATE OF NEVADA

ADAM SULLIVAN, P.E., NEVADA STATE ENGINEER, DIVISION OF WATER RESOURCES, DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES; LAS VEGAS VALLEY WATER DISTRICT; SOUTHERN NEVADA WATER AUTHORITY; and CENTER FOR BIOLOGICAL DIVERSITY, Appellants, vs. LINCOLN VALLEY WATER DISTRICT; VIDLER WATER COMPANY, INC.; COYOTE SPRINGS INVESTMENT, LLC; NEVADA COGENERATION ASSOCIATES NOS 1 AND 2; APEX HOLDING COMPANY, LLC; DRY LAKE WATER LLC; GEORGIA-PACIFIC GYPSUM, LLC; REPUBLIC ENVIRONMENTAL TECHNOLOGIES, INC.; MUDDY VALLEY IRRIGATION COMPANY; SIERRA PACIFIC POWER COMPANY, d/b/a NV ENERGY; NEVADA POWER COMPANY, d/b/a	**Supreme Court No. 84739**

NV ENERGY; THE CHURCH OF JESUS CHRIST OF LATTER-DAY SAINTS; MOAPA VALLEY WATER DISTRICT; WESTERN ELITE ENVIRONMENTAL, INC.; BEDROC LIMITED, LLC; and CITY OF NORTH LAS VEGAS,

Respondents.

CENTER FOR BIOLOGICAL DIVERSITY; SOUTHERN NEVADA WATER AUTHORITY; LAS VEGAS VALLEY WATER DISTRICT; MUDDY VALLEY IRRIGATION COMPANY; COYOTE SPRINGS INVESTMENT, LLC; LINCOLN COUNTY WATER DISTRICT; APEX HOLDING COMPANY, LLC; DRY LAKE WATER, LLC; NEVADA COGENERATION ASSOCIATES NOS. 1 AND 2; GEORGIA-PACIFIC GYPSUM, LLC; REPUBLIC ENVIRONMENTAL TECHNOLOGIES, INC; and VIDLER WATER COMPANY, INC.;

Appellants,

vs.

NEVADA STATE ENGINEER; THE CHURCH OF JESUS CHRIST OF LATTER-DAY SAINTS; SIERRA PACIFIC POWER COMPANY d/b/a NV ENERGY AND NEVADA POWER COMPANY d/b/a NV ENERGY; MOAPA VALLEY WATER DISTRICT; CITY OF NORTH LAS VEGAS; WESTERN

Supreme Court No. 84742

ELITE ENVIRONMENTAL, INC.; and BEDROC LIMITED, LLC, Respondents.	
SOUTHERN NEVADA WATER AUTHORITY, Appellant, vs. COYOTE SPRINGS INVESTMENT, LLC; APEX HOLDING COMPANY, LLC; NEVADA COGENERATION ASSOCIATES NOS. 1 AND 2; GEORGIA-PACIFIC GYPSUM, LLC; DRY LAKE WATER, LLC; REPUBLIC ENVIRONMENTAL TECHNOLOGIES, INC.; LINCOLN COUNTY WATER DISTRICT; VIDLER WATER COMPANY, INC.; MUDDY VALLEY IRRIGATION COMPANY; THE CENTER FOR BIOLOGICAL DIVERSITY; SIERRA PACIFIC POWER COMPANY d/b/a NV ENERGY AND NEVADA POWER COMPANY d/b/a NV ENERGY; MOAPA VALLEY WATER DISTRICT; THE CHURCH OF JESUS CHRIST OF LATTER-DAY SAINTS; CITY OF NORTH LAS VEGAS; WESTERN ELITE ENVIRONMENTAL, INC.; BEDROC LIMITED, LLC, and ADAM SULLIVAN, P.E. NEVADA STATE ENGINEER, Respondents.	**Supreme Court No. 84741**

MUDDY VALLEY IRRIGATION COMPANY, Appellant, vs. ADAM SULLIVAN, P.E., NEVADA STATE ENGINEER, DIVISION OF WATER RESOURCES, DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES; LAS VEGAS VALLEY WATER DISTRICT; SOUTHERN NEVADA WATER AUTHORITY; COYOTE SPRINGS INVESTMENT, LLC; APEX HOLDING COMPANY, LLC; DRY LAKE WATER, LLC; CENTER FOR BIOLOGICAL DIVERSITY; NEVADA COGENERATION ASSOCIATES NOS. 1 AND 2; GEORGIA-PACIFIC GYPSUM, LLC; REPUBLIC ENVIRONMENTAL TECHNOLOGIES, INC.; LINCOLN COUNTY WATER DISTRICT; VIDLER WATER COMPANY, INC.; SIERRA PACIFIC POWER COMPANY, d/b/a NV ENERGY AND NEVADA POWER COMPANY, d/b/a NV ENERGY; MOAPA VALLEY WATER DISTRICT; THE CHURCH OF JESUS CHRIST OF LATTER-DAY SAINTS; CITY OF NORTH LAS VEGAS; WESTERN ELITE ENVIRONMENTAL, INC.; AND BEDROC LIMITED, LLC, Respondents.	**Supreme Court No. 84809**

VOLUME THREE OF EXHIBITS IN SUPPORT OF EMERGENCY MOTION FOR STAY UNDER NRAP 27(E) AND JOINDER

Appellant, the Center for Biological Diversity, by and through counsel, submits Volume Three of its exhibits in support of its Emergency Motion for Stay Under NRAP 27(e) and Joinder pursuant to NRAP 8(a)(2).

Affirmation: The undersigned do hereby affirm that the preceding document and/or attachments do not contain the social security number of any person.

Dated this 2nd day of June, 2022.

/s/ Scott Lake
SCOTT LAKE, NV Bar No. 15765
CENTER FOR BIOLOGICAL DIVERSITY
P.O. Box 6205
Reno, NV 89513
slake@biologicaldiversity.org

CERTIFICATE OF SERVICE

I certify that I am an employee of the Center for Biological Diversity, and that on this 2nd day of June, 2022 I served a true and correct copy of the foregoing by electronic service to the participants in this case who are registered with the Nevada Supreme Court's efiling system to this matter.

/s/ Scott Lake
Scott Lake

INDEX OF EXHIBITS/EXCERPTS OF RECORD

Exhibit No.	Description	Number of Pages
1	Findings of Fact, Conclusions of Law, and Order Granting Petitions for Judicial Review (April 19, 2022).	40
2	Nevada State Engineer Order 1309 (June 15, 2020) (SE ROA 2-69)	66
3	Nevada State Engineer Interim Order 1303 (Jan. 11, 2019) (SE ROA 70-88)	19
4	Nevada State Engineer Order 1169 (March 8, 2002) (SE ROA 659-669)	11
5	Nevada State Engineer Ruling 6254 (Jan. 29, 2014) (SE ROA 726-754)	29
6	Muddy River Decree (March 12, 1920) (SE ROA 33770-33816)	47
7	Dr. Tom Myers, Technical Memorandum Submitted in Response to State Engineer Interim Order 1303 (June 1, 2019) (SE ROA 33490-34516)	27
8	Dr. Tom Myers, Rebuttal Report Submitted in Response to Stakeholder Reports and State Engineer Interim Order 1303 (August 16, 2019) (SE ROA 34517-34546)	30
9	Application No. 46777 to Appropriate the Public Waters of the State of Nevada (March 31, 1983) (SE ROA 47837-47840)	4
10	Nevada State Engineer’s Ruling 4542, Conditionally Granting Application No. 46777 (June 19, 1997) (SE ROA 48114-48130)	17
11	Memorandum of Agreement Among Southern Nevada Water Authority, U.S. Fish and Wildlife Service, Coyote Springs Investment LLC, the Moapa Band of Paiute Indians, and the Moapa Valley Water District (April 20, 2006) (SE ROA 9921-9946)	26
12	Stetson Engineers, Inc., Evaluation of Basin Hydrogeology and Assessment of the Sustainable Yield of the Lower White River Flow System, Southeastern Nevada, Prepared for Coyote Springs	113

	Investment, LLC (July 3, 2019) (SE ROA 35600-35712)	
13	F. Eugene Rush, Index of Hydrographic Areas (Sept. 1968)[1]	43
14	Decision, *White Pine County et al. v. King*, No. CV1204049, (7th Jud. Dist. Ct. 2013).	23

---

[1] This technical report published by the Nevada Division of Water Resources and the U.S. Geological Survey was not designated by the State Engineer as part of the Record on Appeal, but was introduced in briefing by Appellant Coyote Springs Investment, LLC, and appears to have been implicitly relied upon by the District Court. *See* Order at 24-26.

EXHIBIT 12

Order 1303 Report

Evaluation of Basin Hydrogeology and Assessment of Sustainable Yield in the Lower White River Flow System, Southeastern Nevada

July 3, 2019

Prepared for:

Coyote Springs Investment, LLC

REGISTERED PROFESSIONAL ENGINEER
STEPHEN B. REICH
No. C58713
Exp. 12/20
CIVIL
STATE OF CALIFORNIA

PROFESSIONAL GEOLOGIST
STEPHEN B. REICH
No. 9712
EXP. 9/19
STATE OF CALIFORNIA

CERTIFIED HYDROGEOLOGIST
JEAN M. MORAN
No. 755
EXP. 9/19
STATE OF CALIFORNIA

Prepared by:

Stetson Engineers Inc.
785 Grand Ave
Suite 202,
Carlsbad, CA 92008

STETSON
ENGINEERS INC.

(This page intentionally left blank.)

TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

APPENDICES

TABLE OF ACRONYMS

AFY	Acre-feet per year
amsl	Above mean sea level
CBD	Center for Biological Diversity
CCRFCD	Clark County Regional Flood Control District
CDM	Cumulative departure from mean
COOP	National Weather Service Cooperative
CSAMT	Controlled Source Audio-frequency Magnetotellurics
CS Nevada	Coyote Springs Nevada, LLC
CSI	Coyote Springs Investment, LLC
CY	Calendar Year
CSV	Coyote Spring Valley
DOI	U.S. Department of the Interior
DRI	Desert Research Institute
ET	Evapotranspiration
GBWN	Great Basin Water Network
GIS	Geographic Information System
gpm	Gallons per minute
LWRFS	Lower White River Flow System
MBOP	Moapa Band of Paiute Indians
MRSA	Muddy River Springs Area
MVWD	Moapa Valley Water District
mya	Million years ago
NHD	National Hydrography Dataset
NRCS	National Resources Conservation Service
NSE	Nevada State Engineer
Ωm	Ohm-meters
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RAWS	Remote Automated Weather Station
SNOTEL	Snow Telemetry
SNWA	Southern Nevada Water Authority
USGS	United States Geological Survey
WRCC	Western Regional Climate Center

1.0 INTRODUCTION

The purpose of this report is to address the Nevada State Engineer's (NSE) request in Interim Order 1303 (Order 1303) to provide a report regarding the water resources in the Coyote Spring Valley, Muddy River Springs Area, California Wash, Hidden Valley, Garnet Valley, and a portion of the Black Mountains Area (alternatively, The Joint Administrative Unit). Specifically, Order 1303 requests that interested stakeholders address:

a. The geographic boundary of the hydrologically connected groundwater and surface water systems comprising of the Lower White River Flow System;

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

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

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

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

The following report addresses the issues raised in Order 1303 and provides recommendations on how to provide long-term management for sustainability in the Lower White River Flow System (LWRFS).

2.0 ORDER 1169 AQUIFER TEST AND POST-TEST RESPONSE

After reviewing aquifer test reports resulting from Order 1169 (March 8, 2002) and Order 1169A (December 21, 2012), the NSE issued Ruling #6255 on January 29, 2014. NSE's Order 1169 placed new applications for appropriation of water from Coyote Spring Valley, Black Mountains Area, Garnet Valley, Hidden Valley, Muddy River Springs Area, and Lower Moapa Valley (collectively termed Order 1169 Basins) in abeyance until the aquifer test was completed. NSE Order 1169A stated that the aquifer test was completed as of December 31, 2012, and the parties had until June 28, 2013 to file reports based on the test data.[1] Subsequently, aquifer test reports were submitted by Southern Nevada Water Authority (SNWA), Coyote Springs Investment, LLC (CSI), U.S. Department of Interior (DOI), Moapa Band of Paiute Indians (MBOP), Moapa Valley Water District (MVWD), Great Basin Water Network (GBWN), and the Center for Biological Diversity (CBD).

The NSE issued Ruling 6255, which upheld the protests to applications for new appropriations in Order 1169 Basins, denying new applications based on the grounds that there is no unappropriated water, and that new appropriations would conflict with existing water rights. Ruling 6255 also addressed perennial yield and found that the scientific literature supported that the Coyote Spring Valley, Muddy River Springs Area, Hidden Valley, Garnet Valley and California Wash basins should be jointly managed.[2] Ruling 6255 did not determine the perennial yield of Coyote Spring Valley, but instead indicated that the total supply to the Order 1169 Basins is likely less than 50,000 acre-feet per year (AFY).[3]

2.1 SUMMARY ASSESSMENT OF ORDER 1169 TEST REPORTS

The information contained in the Order 1169 aquifer test reports by SNWA, CSI, DOI, MBOP, MVWD, GBWN, and CBD did not adequately present all the existing information to allow for the NSE to make an informed decision regarding the availability and sufficiency of water in what would become the Joint Administrative Unit. These reports were not unanimous in whether water was captured from storage or recharge, the effects of climate, or the impacts of geologic structure, among other differences.

The SNWA Study Report (SNWA, 2013) observed that there is a lack of pumping responses north of the Kane Springs Fault, in an area nortb of the MX-5 pumping site. Observations by SNWA in their June 2013 Order 1169 Test Report also noted the presence of flow barriers in the Coyote

---

[1] Order 1169A also rescinded provision 8 of Order 1169 that required an update to Exhibit No. 54 from the July 2001 hearing.

[2] Ruling 6255, para V, page 26.

[3] Ibid.

Spring Valley: "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."[4] SNWA's analysis of Muddy River streamflow at the Moapa gage also found that "nearby carbonate pumping" was not influencing senior Muddy River surface-water rights.[5]

The MBOP Order 1169 Study (MBOP, 2013) observed that declines in groundwater levels during the test period were affected by local and regional climate, atmospheric pressure, tides, and crustal loading phenomena. Additionally, the MBOP Study concluded that the pumping response from groundwater pumped at MX-5 is dominated by boundary conditions, not groundwater storage.[6]

The DOI Study (DOI, 2013) observed that water captured during the test was likely from groundwater storage, and only a fraction was from natural discharge,[7] but their conclusion was based on an average 1.4-foot decline over the entire study area due to pumping without consideration of climate variability. The DOI report specifically stated: "Likewise, no corrections have been made for longer-term (regional) trends in groundwater levels given continued uncertainties concerning the availability of a 'reference' well that can be used to make such corrections."[8] Contrary to their assumption, the records[9] indicate that long-term seasonal variations due to recharge and anthropogenic impacts, including those from local carbonate and alluvial pumping, affect surface water resources of the Muddy River.

The GBWN Study (GBWN, 2013) observed that "groundwater levels for all wells have been decreasing since the mid-1990s 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."[10] Data provided in their report indicates that groundwater levels in the carbonate aquifer[11] and spring discharge at the Pederson Spring Complex[12] increased following the 2005 wet year event. While the GBWN Study notes that "After 2005 the region primarily returned to drought conditions. The late 1990s were among the wettest years since 1980,"[13] it does not differentiate the impacts caused by Order 1169 pumping, other pumping in the five-basin area, and climatic conditions. Additional

---

[4] SNWA June 2013 Order 1169 Report, page 36.
[5] Ibid, Page 45.
[6] MBOP Order 1169 Study, page 32.
[7] DOI Order 1169 Study, Page 31.
[8] Ibid, page 9.
[9] As presented and explained in this report.
[10] GBWN, 2013. Section: Muddy River Springs Area
[11] Ibid, Figure 13
[12] Ibid, Figure 17
[13] Ibid, Section: Discussion of Pumpage, Groundwater Levels and Spring Discharges.

groundwater, spring, and climatic data would be required to assess how the carbonate aquifer and springs respond to prolonged wet and dry cycles.

Important factors that affect the availability of water in the Joint Administrative Unit area, which have become apparent since the submission of the Order 1169 Aquifer Test Reports in June of 2013, include: (1) the impact of long-term climatic cycles on regional groundwater levels; (2) regional geology and groundwater flow; (3) local structural and sedimentary geology; and (4) the effect of nearby pumping on springs in the Muddy River Springs Area. These factors, as well as others, affect the determination of available water, as well as the availability of water to meet the demands of decreed Muddy River water rights and the Moapa dace.

2.2 HYDROLOGIC VARIABILITY AND CLIMATE

The sustainable yield of a basin can be described as "the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from the groundwater supply without causing an undesirable result."[14] The long-term conditions of a basin can be described by the regional climate that affects the recharge, and by groundwater conditions within that basin. The regional climate of the LWRFS is best described by multiple precipitation stations that reflect conditions of both the mountain blocks and valley floors.

Two precipitation records were reviewed to establish the long-term climatic conditions in the LWRFS. A longer 123-year record summarizing the Extreme Southern region of Nevada for the period 1895 to 2017[15] was available from the Western Regional Climate Center (WRCC) (Figure 1, top graph). A shorter 52-year period precipitation record from 1966 to 2017 was available for the Pahranagat Wildlife Refuge (National Weather Service Cooperative station number 265880), located up-gradient from the LWRFS (Figure 1, bottom graph). Wet and dry cycles in the LWRFS may be identified from cumulative departure from mean (CDM) curves that show long-term precipitation trends referenced to average conditions.

The CDM curve for the Extreme Southern region of Nevada shows that relative wet periods occurred from the early-1900s to the early-1920s, the mid-1930s to the early-1940s, and the mid- to late-1970s to the early-1980s. An extended dry period occurred from the mid-1940s to mid- to late-1970s, and a shorter dry period occurred from the mid-2000s to the present. The CDM curve for precipitation at the Pahranagat Wildlife Refuge shows similar patterns of wet and dry cycles over the 1966 to 2017 period. A wet period occurred in early 1980s, from 2004 to 2005, and again from 2013

---

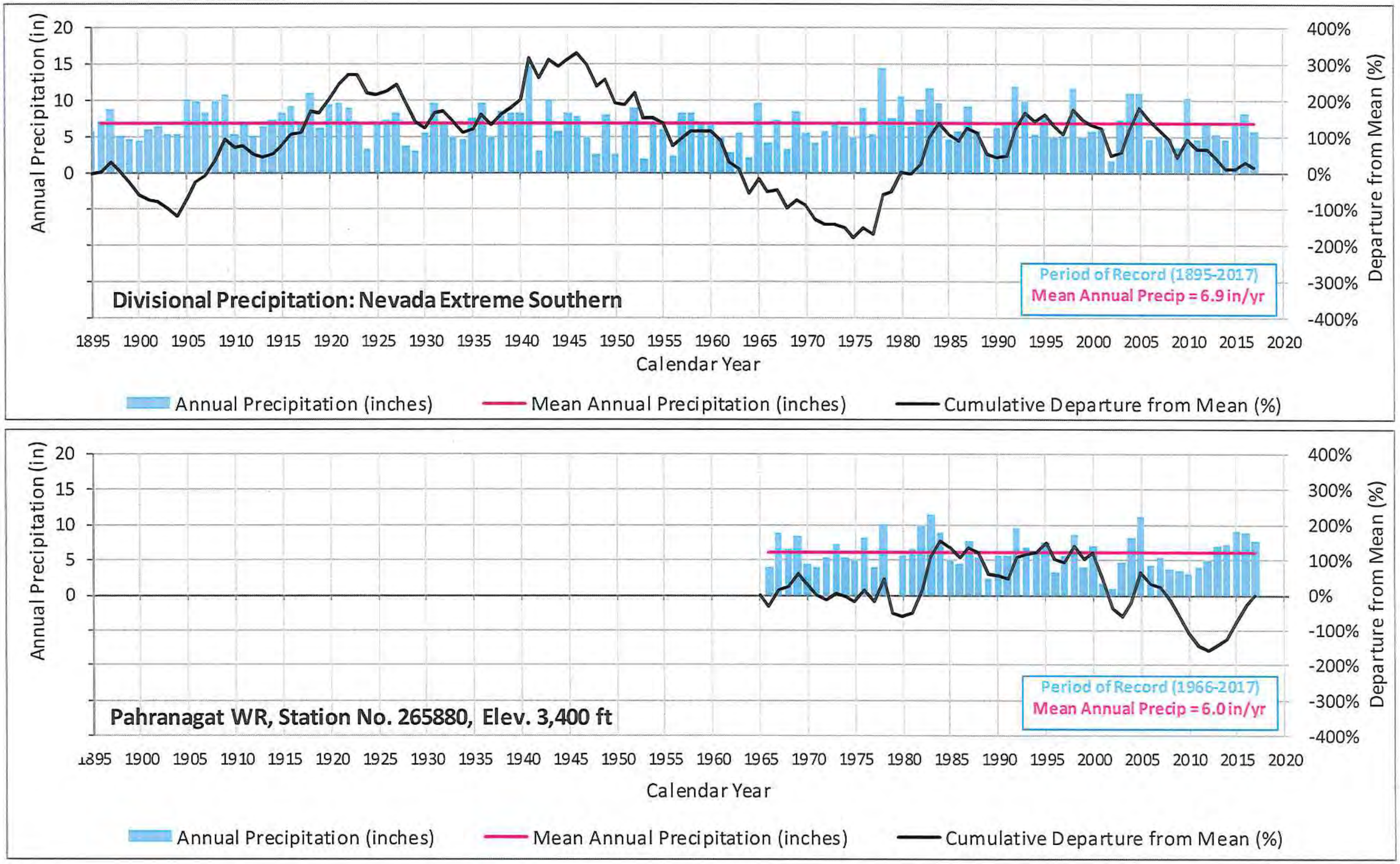
[14] California Code of Regulations §10721
[15] WRCC https://wrcc.dri.edu/cgi-bin/divplot2_form.pl?2604

to 2017. Beginning in 2000, an extended dry period occurred through 2012, except for above average rainfall in 2004 and 2005. The end of the extended dry period in 2012 corresponds with the end of the Order 1169 aquifer test.

A CDM curve may also be used to describe a balanced hydrologic cycle, which occurs when the beginning and end of the cycle show a similar value for cumulative departure. For example, the 36-year period from 1982 through 2017, at both rainfall records, begins and ends on the zero value for cumulative departure, indicating that this 36-year period has the same conditions, on average, as the longer-term periods on each graph. 1982 through 2017 reflects a balanced hydrologic cycle, containing wet periods in the early 1980s and mid-2000s, an average period from 1992 through 2000, and a dry period from 2006 through 2012. For short-term planning, a 14-year balanced hydrologic period may be identified from 2003 through 2016. The data for the Extreme Southern region of Nevada shows a wetting cycle in 2004-2005 and an extended dry period from 2006 through 2017. The Pahranagat Wildlife Refuge precipitation record for 14-year period is characterized by the 2004-2005 wet cycle and a dry cycle from 2006 through 2012.

Investigation and analysis of long-term hydrologic cycles that include extended wet and dry periods are required to assess the occurrence, movement, and availability of groundwater in the LWRFS. Wet hydrologic conditions reset the balance of available groundwater and allow managers to meet targets based on varying demands over the multiple year periods based on a balanced hydrologic period. The Order 1169 aquifer test that was conducted in 2011 and 2012 occurred at the end of an extended dry period when all water resources throughout the LWRFS were negatively affected.

FIGURE 1



PRECIPITATION DATA FOR THE LOWER WHITE RIVER FLOW SYSTEM

2.3 REVIEW OF 2013 SERIESSEE ANALYSIS

Order 1303 relies on Ruling 6254, which cited modeling analysis by the DOI that identified a regional-wide carbonate aquifer water-level decline, estimated to be 1 to 1.6 feet in 1,100 square miles of the LWRFS[16] during the Order 1169 aquifer test. Ruling 6254 cited the DOI's Order 1169 Aquifer Test report (DOI, 2013), which used SeriesSEE modeling to discern and partition the effects of pumping at MX-5 on other locations. Review of the DOI Order 1169 Report and attached appendices show that it does not represent an adequate basis for establishing an "Administrative Unit" for the entire LWRFS. The documented SeriesSEE modeling does not include local and regional recharge, changes in the alluvial aquifer, climatic variability, or boundary effects that could affect the model's conclusions when the full dynamics are accounted for in the LWRFS.

The DOI report relied upon by the State Engineer in Order 1303 is based on modeling results that support a region-wide drawdown based on a simple Theis solution. The calibration process, hydrogeologic parameters used for modeling, and supporting pump test data are not documented and do not allow for third-party verification. Both regional and local recharge that affect the availability of water is not accounted for in DOI's evaluation. Furthermore, available data from 2013 through 2017 have not been used to verify the results of the 2013 model. Based on the lack of documentation and third-party repeatability, the DOI report should not be the primary document relied upon to support region-wide water level drawdown and the need for Order 1303.

In order to evaluate the results from the 2013 DOI model, a Theis solution was utilized to assess relative impacts to the Pederson Spring Complex from pumping in both the Coyote Spring Valley and Muddy River Springs Area. Previously published data[17] was relied upon to analytically model groundwater level drawdown in the Muddy River Springs Area from two pumping centers located at MX-5 and Arrow Canyon wells. The analytical model AquiferWin32© was used to simulate drawdown caused by pumping at the two locations. All pumping in the Coyote Spring Valley was simulated as occurring at the MX-5 well location in the eastern portion of Coyote Spring Valley. Since MX-5 is the closest well to the Pederson Spring area (compared to other production wells in Coyote Spring Valley), this provides a more conservative assumption for the analysis. The MX-5 location is approximately 11.5 miles west of the Pederson Spring location at a heading of 300°. A single pumping rate of 5,217 AFY, or 3,232 gallons per minute (gpm), was selected to represent pumping at this location. This is the average of calendar year (CY) 2011 and CY 2013 production rates, as reported in SNWA (2013).

---

[16] Order 1303, Page 4.

[17] Reported transmissivity by SNWA (2007, Table E-1) averages 279,249 ft^2/day for Coyote Spring Valley and Muddy River Springs Area wells. Measured transmissivity at CSI-4 of 130,000 ft^2/day based on 670 feet of saturated aquifer completed in a fractured zone of the carbonate aquifer.

A midpoint location between the two Arrow Canyon wells was used to simulate carbonate pumping in the Muddy River Springs Area. This location is 2.5 miles from the Pederson Spring location, at a heading of approximately 320°. The volume of pumping was estimated to be 3,000 AFY, or 1,859 gpm. This is similar to an estimate of historical pumping shown in some of the figures in SNWA (2013) for the Muddy River Springs Area. Simulated drawdown due to (1) pumping in Coyote Spring Valley, (2) pumping in Arrow Canyon, and (3) pumping from both well locations are shown in Figure 2.

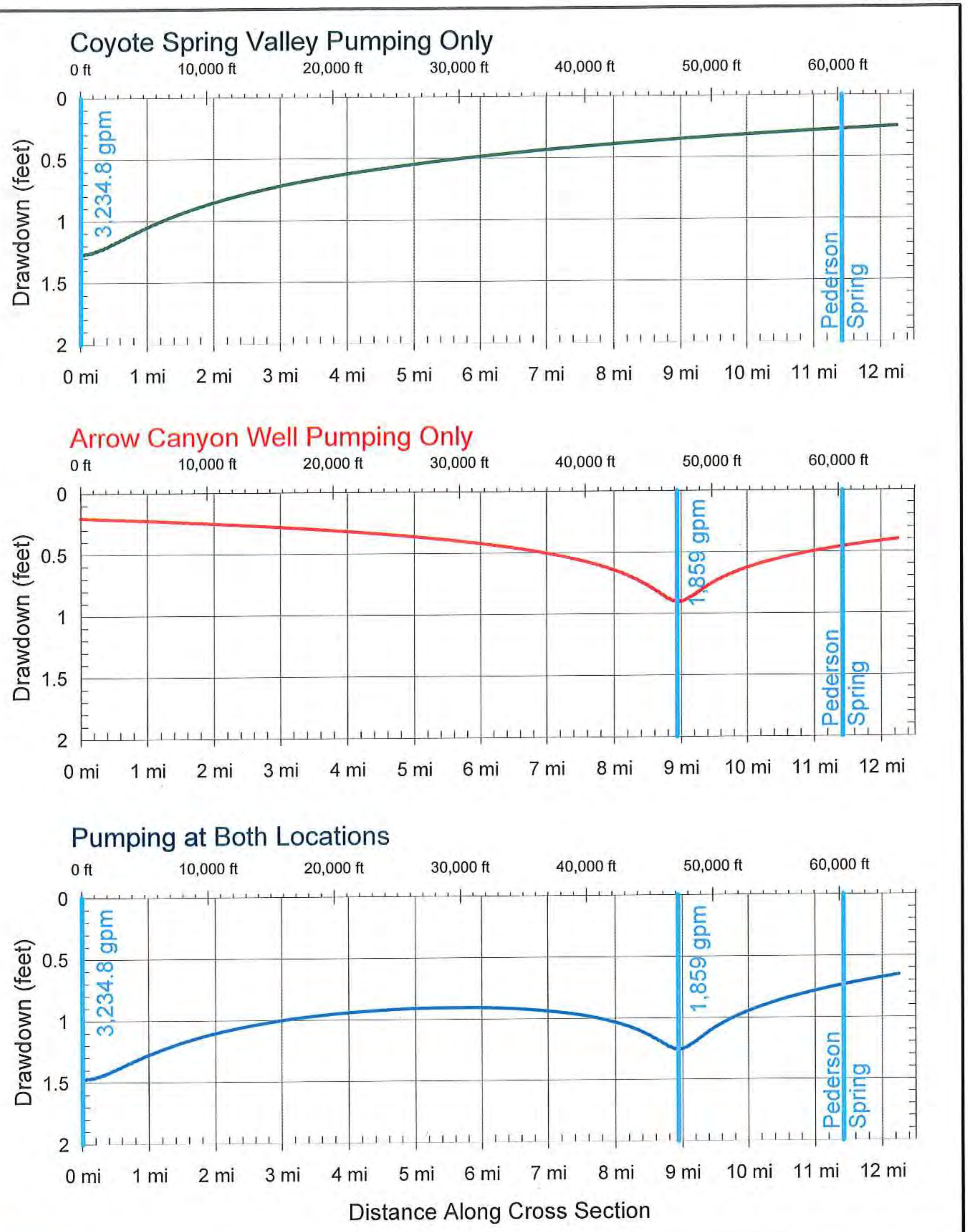
Simulated groundwater level drawdown at the Pederson Spring Complex due to pumping 5,217 AFY in Coyote Spring Valley is estimated to be 0.28 feet (see green line in upper graph of Figure 2) after two years. Simulated groundwater level drawdown at the Pederson Spring Complex due to pumping 3,000 AFY at the Arrow Canyon Wells is estimated to be 0.46 feet (see red line in middle graph of Figure 2) after two years. Finally, simulated groundwater level drawdown at the Pederson Spring Complex due to pumping a combined 8,217 AFY at the Coyote Spring Valley and Arrow Canyon Wells is estimated to be 0.74 feet (see blue line in lower graph of Figure 2) after two years. Results of this analysis indicate that pumping in Coyote Spring Valley during the Order 1169 Aquifer Test has a 38% impact on groundwater level decline at the Pederson Spring Complex after two years when climate and other diversions in the LWRFS are ignored.

The results of this analysis provide an example of the difference in impacts to groundwater levels at the Pederson Spring Complex due to pumping in Coyote Spring Valley versus Arrow Canyon. The analysis was based on Theis equation analytical model that assumed:

1. Groundwater pumping occurs at a constant average rate through the year based upon historical groundwater production;
2. Groundwater pumping is generalized to occur at two locations;
3. An existing general flow gradient of a 1 foot drop every 2 miles;
4. A homogeneous aquifer;
5. The aquifer was assumed to be of infinite extent, and no additional influences to the resulting cone of depression were considered beyond the specified gradient. This includes no recharge or surface inflows from precipitation, agriculture return flows, streamflow, or other sources;
6. No boundary effects.

This evaluation was performed to develop a relative impact analysis of pumping in Coyote Spring Valley and MRSA to groundwater levels at the Pederson Spring Complex. The results are different than those presented in the 2013 DOI report. Our results show a greater influence on monitoring well EH-4 water levels from pumping at Arrow Canyon wells, which are closer to the spring complex, than from pumping at MX-5 in Coyote Spring Valley, which is farther from the springs. The DOI SeriesSEE model simulates the greatest impact at EH-4 from pumping in Coyote Spring Valley.

FIGURE 2



STETSON
ENGINEERS INC.

**SIMULATED DRAWDOWN
AT PEDERSON SPRING COMPLEX
DUE TO PUMPING IN COYOTE SPRING VALLEY,
ARROW CANYON, AND BOTH LOCATIONS.**

AquiferWin WinFlow
Time = 730 days
T = 279,259 ft^2/day
S = 0.03

2.4 CALCULATED DRAWDOWN AT AN OBSERVATION POINT USING THE THEIS SOLUTION

The Theis solution was used to estimate the impact of two pumping wells on drawdown at an observation point based on varying values of transmissivity. While the solution does not account for recharge, groundwater gradients, or boundary effects, it provides an analysis of relative impact to drawdown at an observation point from two pumping wells located at different distances from the observation point. The location of the pumping wells and observation point are consistent with MX-5, Arrow Canyon wells, and the Pederson Spring Complex shown in Figure 2. The pumping rate at the well 11.5 miles from the observation point was 3,232 gpm, while the pumping rate at the second well located 2.5 miles from the observation well was 1,859 gpm. Each well pumped continuously for three years so drawdown at the observation point could be assessed based on both transmissivity and time. The values of transmissivity that were investigated spanned three orders of magnitude, including 28,000 ft^2/day (209,440 gpd/ft), 280,000 ft^2/day (2,094,400 gpd/ft), and 2,800,000 ft^2/day (20,944,000 gpd/ft). The storage coefficient (storativity) was held constant at 0.03 (dimensionless).

Given a transmissivity value of 28,000 ft^2/day, drawdown at the observation point after 1 year is 1.65 feet due to the well pumping 2.5 miles away and 0.03 feet due to the well 11.5 miles away (Table 1). When transmissivity is increased by an order of magnitude, to 280,000 ft^2/day, drawdown at the observation point after 1 year is 0.46 feet due to the well pumping 2.5 miles away and 0.28 feet from the well 11.5 miles away. Finally, when transmissivity is increased to 2,800,000 ft2/day, drawdown at the observation point is 0.07 feet from the nearby well and 0.07 feet from the distal well.

TABLE 1. THEIS SOLUTION FOR DRAWDOWN AT AN OBSERVATION POINT DUE TO TWO PUMPING WELLS

Transmissivity	Drawdown (feet) at Observation Point After: 1-Year of Pumping	2-Years of Pumping	3-Years of Pumping
11.5 miles from Pederson Spring (Q=3,232 gpm)			
28,000 ft^2/day	0.03	0.22	0.46
280,000 ft^2/day	0.17	0.28	0.34
2,800,000 ft^2/day	0.05	0.07	0.07
2.5 miles from Pederson Spring (Q=1,859 gpm)			
28,000 ft^2/day	1.65	2.29	2.68
280,000 ft^2/day	0.39	0.46	0.50
2,800,000 ft^2/day	0.06	0.07	0.07

The Theis solution also shows the impact to drawdown due to pumping over time. Generally, the cone of depression expands at a faster rate given a lower value of transmissivity. The increase in drawdown at the observation point due to constant pumping for three years at the nearby well is 62% (1.65 feet to 2.68 feet) when transmissivity is 28,000 ft^2/day and 16% (0.06 feet to 0.07 feet) when transmissivity is 2,800,000 ft^2/day. Similarly, the increase in drawdown at the observation point due to constant pumping for three years at the distal well is 14300% (0.03 feet to 0.46 feet) when transmissivity is 28,000 ft^2/day and 40% (0.05 feet to 0.07 feet) when transmissivity is 2,800,000 ft^2/day. The Theis solution shows that the cone of depression propagates at a slower rate when transmissivity is high, and at a faster rate when transmissivity is low.

The Theis solution provides insight to the post-Order 1169 aquifer test data collected in the Muddy River Springs Area. The bulk transmissivity value between Coyote Spring Valley and Muddy River Springs Area is at least 280,000 ft^2/day, and possibly much greater. Transmissivity in the carbonate aquifer in Muddy River Springs Area and Coyote Spring Valley was reported to be 312,040 ft^2/day (Arrow Canyon), 365,840 ft^2/day (EH-4), 321,310 ft^2/day (MX-5), and 117,847 ft^2/day (MX-4) by SNWA (2007, Table E-1). A value that would be appropriate to estimate the impact of pumping in Coyote Spring Valley to groundwater levels in Muddy River Springs Area would be the average of reported transmissivity for these four wells of 279,259 ft^2/day. Additionally, a simple solution of Darcy's flow equation based on the groundwater level elevation difference between monitoring wells UMVM-1 and EH-5b, a flow corridor 1.6 miles wide and 4,000 feet deep, and a flow of 37,000 AFY would result in a transmissivity value greater than 279,259 ft^2/day.

The calculated drawdown at an observation point located 11.5 miles from a well pumping 5,217 AFY (3,232 gpm) for two years, based on the average transmissivity of 279,259 ft^2/day and a storativity value of 0.03, is 0.28 feet. While this analysis does not account for groundwater gradients, recharge, and boundary effects,[18] it provides a relative impact analysis for a well pumping in Coyote Spring Valley on an observation point in the Muddy River Springs Area.

Based on the above analysis, it is unlikely that impacts at the Pederson Spring Complex due to pumping in Coyote Spring Valley occurred immediately after Order 1169 pumping began, as previously indicated in the June 2013 Order 1169 aquifer test reports.[19] The groundwater level in EH-4 provides an appropriate representation of the groundwater-level at the Pederson Spring Complex since only flow is measured at the springs. The 1.51-foot decline in EH-4 groundwater level, from 1,816.57 ft above mean sea level (amsl) in May 2006 to 1,815.06 ft amsl in April 2011,[20] is likely attributable to climate, total diversions in Muddy River Springs Area ( ), and other

---

[18] The Theis solution assumes isotropic and homogeneous conditions.

[19] See DOI (2013) page 3.

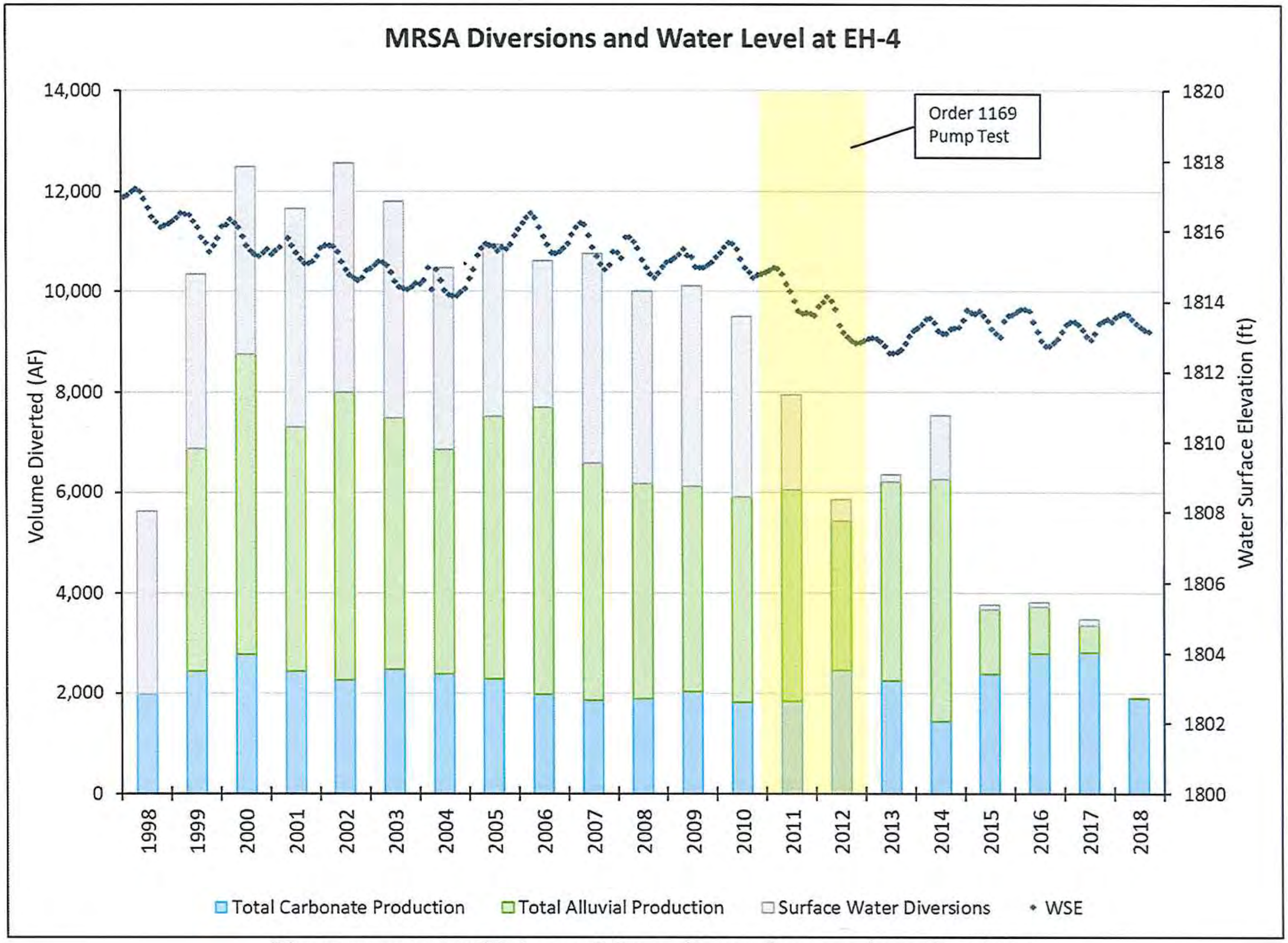
[20] Spring-time groundwater levels in EH-4 reflect annual maximum values and are used for comparison.

nearby pumping prior to the Order 1169 aquifer test. The continued 2.05-foot decline from April 2011 to April 2013 reflects the combined impact from climate and other pumping during the Order 1169 aquifer test on carbonate groundwater levels in the Muddy River Springs Area. The explanation provided by SNWA (2018) is more plausible explanation of observed impacts near the springs, indicating that Muddy River Springs Area alluvial and carbonate pumping impacts the Muddy River streamflow, alluvial aquifer, and springs.

Total alluvial pumping, carbonate pumping, and surface water diversions in the Muddy River Springs Area are compared to groundwater levels at EH-4 in . As depicted by the EH-4 hydrograph, groundwater levels have not recovered to pre-Order 1169 levels, which could be due to local Muddy River Springs Area production and climatic variability. Because alluvial and carbonate pumping in the Muddy River Springs Area has a direct impact on senior decreed rights on the Muddy River, the relationship between total diversions in the Muddy River Springs Area and surface flow is an important concept to include in sustainable management.

The recovery of carbonate aquifer groundwater levels in EH-4 due to increased recharge is most pronounced in 2005, following the wet years of 2004 and 2005. Following these wet years, the region experienced a long-term dry condition beginning in 2006 and lasting though the end of the Order 1169 aquifer test in 2012. The dry hydrologic conditions during this period are reflected in the decline in EH-4 groundwater-levels from 2006 through 2013. Likely due to slightly above normal rainfall at the Pahranagat Wildlife Refuge from 2013 through 2017, EH-4 groundwater levels only showed a modest recovery of 0.77 feet by April 2018. The most pronounced impact to EH-4 groundwater levels is due to the reduction in total diversions from the Muddy River Springs Area. The long decline in EH-4 groundwater levels from 1998 through 2004 and from 2006 through 2013 can likely be attributed to total diversions in the Muddy River Springs Area. When total diversions are reduced in 2014, groundwater levels cease to decline.

FIGURE 3


MRSA Diversions and Water Level at EH-4

HYDROGRAPH OF EH-4 WITH MUDDY RIVER SPRINGS AREA DIVERSIONS

The Theis analysis and review of water levels and production in the Muddy River Springs Area indicate that factors other than pumping in Coyote Spring Valley are affecting spring discharge at the Pederson Spring Complex. First, the rate of interbasin groundwater flow between Coyote Spring Valley and Muddy River Springs Area dictates that transmissivity must be at least 280,000 ft^2/day in order to achieve to achieve a rate of 37,000 AFY.[21] The high value of transmissivity results in a minimal impact to EH-4 groundwater levels due to Order 1169 pumping as shown by the results in Table 1.

Second, the Theis solution indicates that drawdown in the Muddy River Springs Area due to pumping in Coyote Spring Valley would expand in magnitude over a period of two years. The Theis analysis and post-Order 1169 data show that groundwater levels in the Muddy River Springs Area are more responsive to changes in local production and hydrologic conditions, than they are pumping impacts from Coyote Spring Valley.

Third, the impact from nearby carbonate pumping at the Arrow Canyon wells would be much greater than the impact from Coyote Spring Valley pumping over a short two-year period. Therefore, factors such as Muddy River Springs Area stream diversions, alluvial pumping, carbonate pumping, and regional climate have a greater impact on spring flow in the Muddy River Springs Area than does pumping in Coyote Spring Valley.

---

[21] See Section 5. Thomas et al. (2001).

3.0 GEOGRAPHIC BOUNDARY OF THE LOWER WHITE RIVER FLOW SYSTEM

The purpose of this section is to describe the regional and local carbonate rock aquifer that contains developable water resources in eastern Nevada and western Utah. In general, groundwater moves parallel to faults, in a north-to-south direction, from the Upper White River Basin south toward Lake Mead. Local recharge from rainfall and snowmelt supports water development in each basin and may contribute to regional groundwater flow. Discharge from the aquifer occurs as a result of groundwater production, discharge to streams and springs, interbasin groundwater flow, and loss to evapotranspiration (ET). The mechanisms that control groundwater flow throughout the entire carbonate rock province include structural geologic features, hydrogeologic properties, and natural and anthropogenic stresses.

3.1 LWRFS BOUNDARY

The boundary of the LWRFS includes Coyote Spring Valley, Muddy River Springs Area, California Wash, Hidden Valley, Garnet Valley, and a portion of the Black Mountains Area as defined in Order 1303 (Figure 4). The upper boundary of the LWRFS is consistent with the boundary identified in Order 1303. Specifically, the Pahranagat, Delamar, and Kane Springs Valleys are not included since these areas are tributary to the LWRFS and are distinctly separated by fault and structural boundaries.[22] The Lower Meadow Valley Wash is also tributary to the LWRFS, and is not included due to the depth to the carbonate aquifer and lack of existing or planned development. The water resources in these four basins can be administered individually, or in combination with other tributary basins.

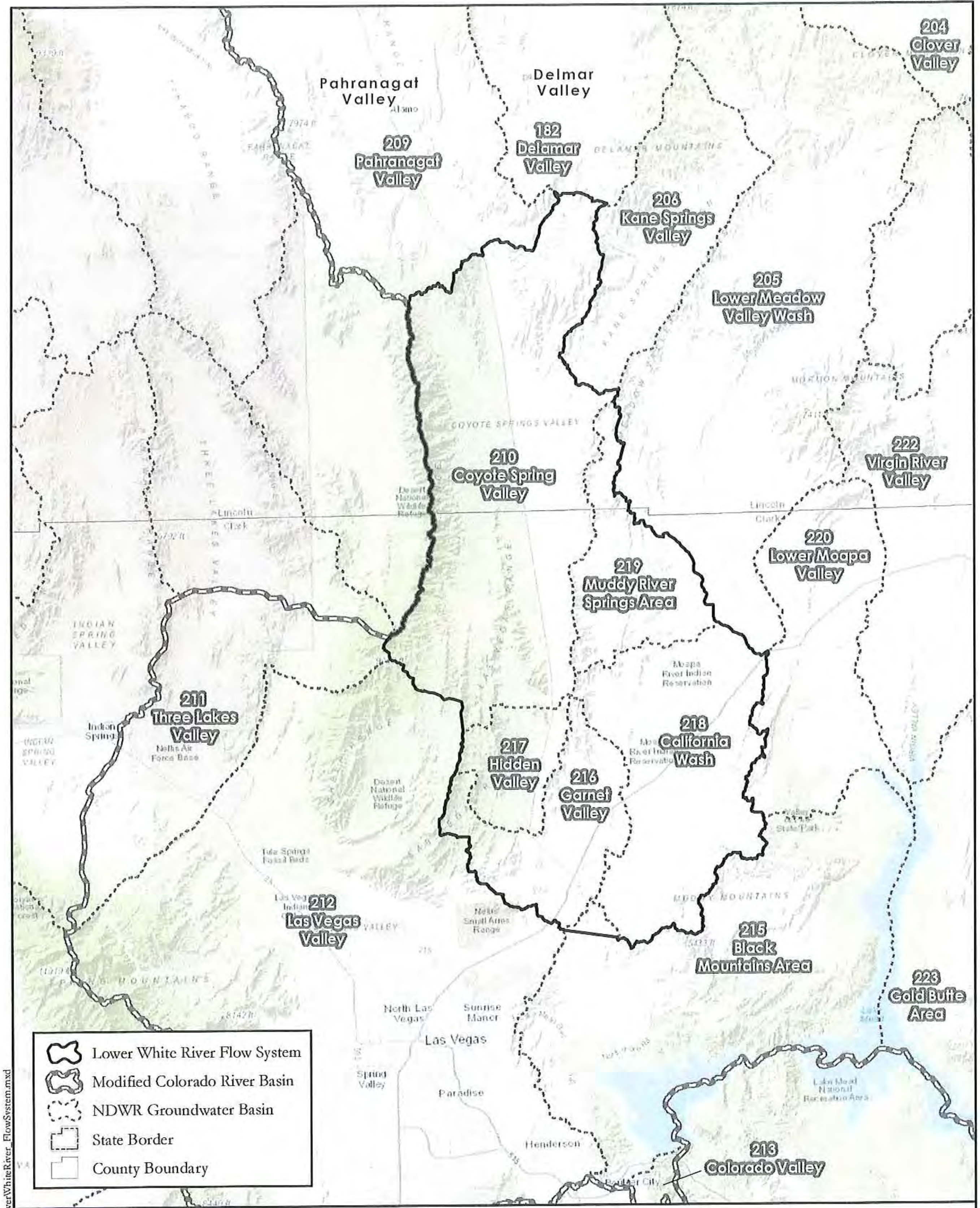
Regional groundwater flow in the southeastern Nevada is generally in a north-to-south direction along normal faults and fractures within the carbonate aquifer. Although watershed and basin boundaries topographically define drainage patterns, they do not necessarily[23] impact the regional groundwater flow pattern. Faults and structural features are the first step in assessing groundwater resources in the carbonate rock aquifer (Rowley et al., 2017). Although water resources in the LWRFS are largely controlled by regional flow patterns, the boundary of the LWRFS, as identified by Order 1303, may be used for administration and sustainability planning.

---

[22] See Order 1169 Aquifer Test Reports.

[23] Basins defined by structural geologic boundaries or local lithology may affect regional groundwater flow.

FIGURE 4



STETSON ENGINEERS INC.

MODIFIED LOWER WHITE RIVER FLOW SYSTEM

Source: Modified from Rowley, et al; 2017

N

0 6.5 13 Miles

Document Path: I:\n2674\LowerWhiteRiver_FlowSystem.mxd

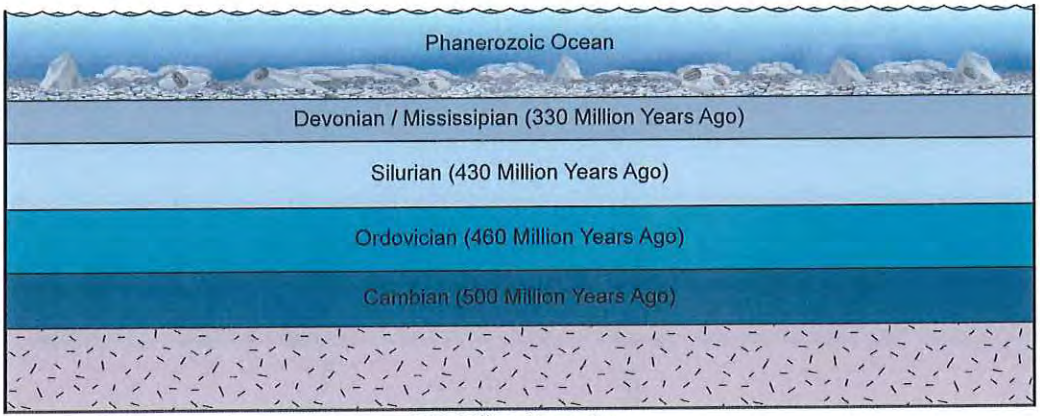
3.2 GEOLOGIC HISTORY

The geologic history of the eastern part of Nevada is characterized by rocks ranging from Precambrian sedimentary rocks to widespread Quaternary alluvial deposits (United States Geological Survey (USGS), 2007). The geologic evolution of the study area since the end of Precambrian (650 million year ago (mya)) time may be subdivided into three general phases: (1) marine sediments deposited along a passive continental margin; (2) late Devonian to Eocene compressive deformation; and (3) middle to late Cenozoic extension, faulting, volcanism, and continental sedimentation (Levy and Christie-Blick, 1989). This sequence of sedimentation, compressive deformation, and extensional faulting establish the geologic framework that controls groundwater flow throughout eastern Nevada. Thus, any water-resource assessment of the area must consider the complex geologic structure and geologic history, as well as the distribution of the diverse rock types and geologic environments.

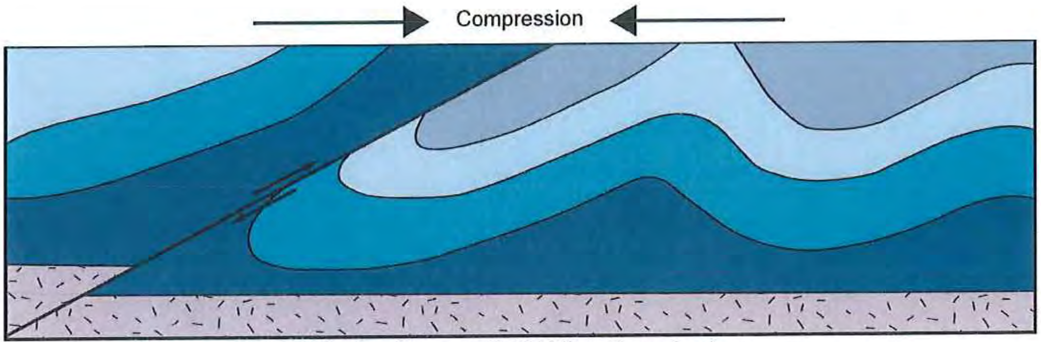
Many studies have been performed by USGS, Desert Research Institute (DRI), SNWA, and others that describe the geologic history and framework in detail. The purpose of this section is to illustrate that the historical sequence of deposition and tectonic activity shows how geologic units and structure control the occurrence and movement of groundwater. The marine sediments that were deposited between 540 mya and 250 mya generally include carbonates, shales, and quartzites that form the aquifers which are the subject of this report. The formation of these sediments represents the transgression and regression of the sea over a broad continental shelf and is depicted in the upper cross-section of Figure 5.

Beginning at the end of the Devonian period (400 mya), compressional forces associated with the Antler Orogeny began to affect the northwest portion of eastern Nevada (Rowley et al., 2017). Later, around the Jurassic to early tertiary period (200 mya – 60 mya), structural compression associated with the Sevier Orogeny resulted in north- to north-northeast striking folds and thrust faults that are evident today throughout eastern and southeastern Nevada (Rowley et al., 2017). Finally, Basin and Range extension beginning about 20 mya formed the north striking basins and mountain ranges that characterize the Basin and Range province. The cross-sections shown in Figure 5 provide a generalized depiction of deposition, compressional folding, extensional faulting, and mountain building occurring from about 500 mya to the present.

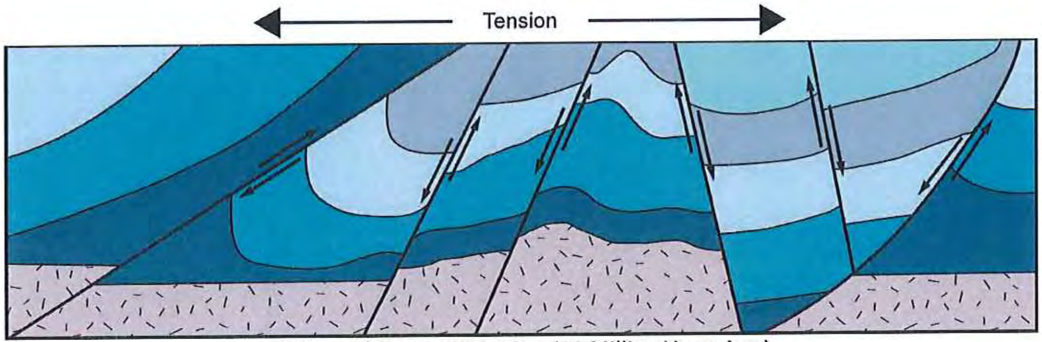
FIGURE 5



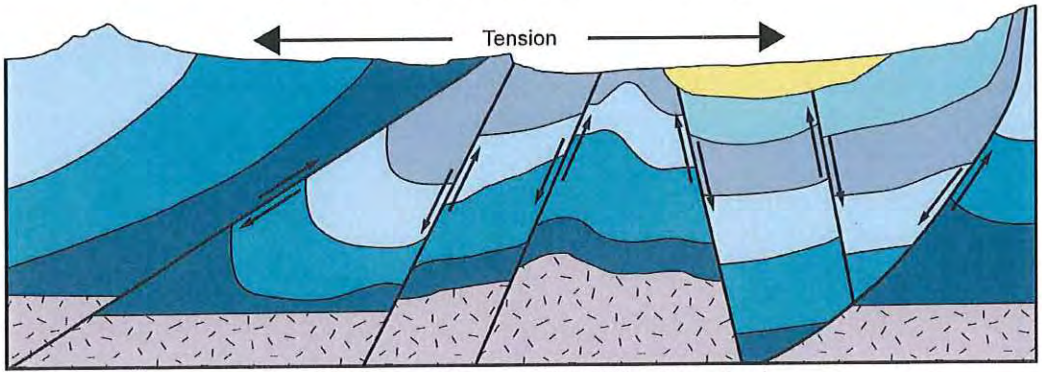
500 Million Years Ago



Sevier Orogeny (140 Million Years Ago)



Basin and Range Extension (20 Million Years Ago)



Basin and Range Extension (10 Million Years Ago)

STETSON
ENGINEERS INC.

Conceptual Formation of Carbonate Aquifer in the Lower White River Flow System

C:\WorkFolder2674/GeologicLayersTimeline_8x11_2a.ai

The Sheep Range mountains, which are composed of carbonate rocks, form the western edge of the Coyote Spring Valley. This range represents the leading edge of the Gass Peak thrust fault that was associated with the Sevier Orogeny (200 mya – 60 mya) (Rowley et al., 2017). The eastern boundary of Coyote Spring Valley is bounded by the Arrow Canyon Range to the south and the Meadow Valley Range to the north, both of which were formed due to normal faulting associated with Basin and Range extension. Additional normal faults associated with Basin and Range extension are present between the two ranges (Rowley et al., 2017). A generalized geologic depiction of Coyote Spring Valley based on Rowley et al. (2017) is shown in Figure 6. The prominent geologic features of Coyote Spring Valley include the north- to north-northeast trending faults and the thick sequence of carbonate rocks.

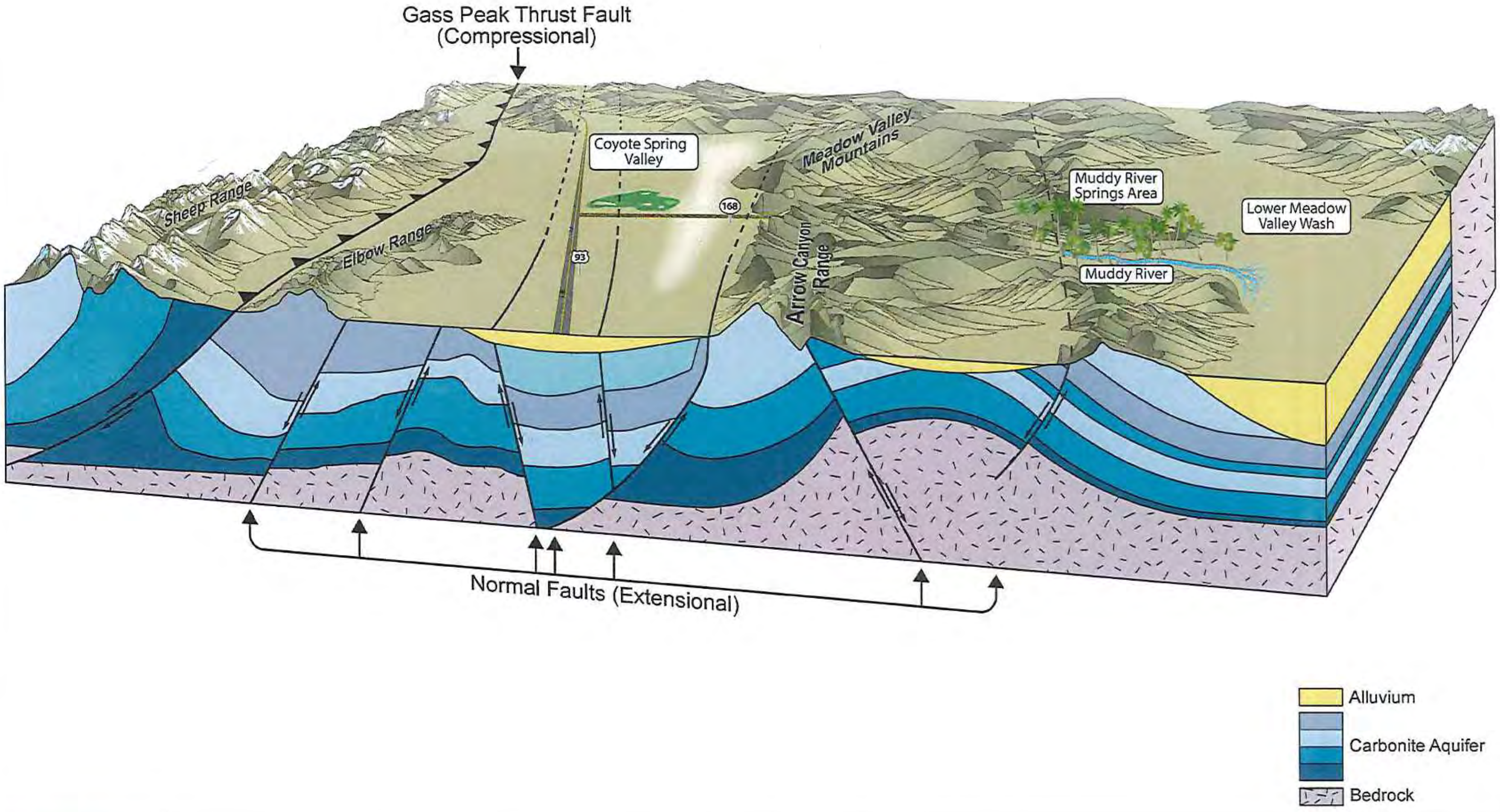
3.3 IMPACT OF STRUCTURAL FEATURES AND FAULTS ON GROUNDWATER FLOW

Based on the most recent study by Rowley et al., (2017), "Basin and Range extension controls groundwater flow," and groundwater flow generally occurs along rock fractures associated with normal faults (extensional), while flow across faults is retarded. Rowley et al. (2017) further explain that extensional faulting is more important to groundwater flow, since these types of faults tend to stay open compared to compressional faults (i.e. Gass Peak Thrust), which do not result in open fractures for groundwater flow. Thus, identifying the locations of normal faults is a primary target for describing groundwater flow in the carbonate rock province.

There are numerous north- to north-northeast trending extensional normal faults within Coyote Spring Valley and the entire LWRFS that act to control the occurrence and movement of groundwater. While some of these faults tend to convey groundwater parallel to the fault, they also act to impede water flow perpendicular to the strike of the fault. The impact of these faults is described in the various sections below, which detail the relative connection between pumping wells, observation wells, and springs throughout the study area.

FIGURE 6

C:\\WorkFolder2674/CoyoteValleyImage_3a.ai



STETSON ENGINEERS INC.

Conceptual Geologic Cross-Section of Coyote Spring Valley and Muddy River Springs Area

3.4 MODIFIED NSE COLORADO RIVER BASIN SYSTEM

The NSE's Designated Groundwater Basins of Nevada Map (Nevada Division of Water Resources, 2017) identifies 27 basins in southeastern Nevada as the Colorado River Basin (Basins 198 to 224). Included in these 27 basins are the six basins of the proposed LWRFS, including: Coyote Spring Valley (210), Black Mountain Area (215), Garnet Valley (216), Hidden Valley (217), California Wash (218), and Muddy River Springs Area (219). However, Cave Valley, (180), Dry Lake Valley (181), and Delamar Valley (182) are not included in the NSE's designation of the Colorado River Basin, although they contribute to interbasin groundwater flow into the LWRFS and the larger Colorado River Basin. Based on deuterium and oxygen-18 data analyses, Thomas and Mihevc (2011) suggest that interbasin groundwater flow occurs from Cave Valley into southeastern White River Valley (207) and northeastern Pahroc Valley (208). Furthermore, Thomas and Mihevc (2011) also suggest that interbasin groundwater flow occurs from Dry Lake Valley into Delamar Valley, eventually discharging into Coyote Spring Valley.[24] Thus, based on this prior analysis, and for purposes of this report, the Colorado River Basin boundary referenced in this report has been modified from the NSE's boundary to include Cave Valley, Dry Lake Valley, and Delamar Valley.

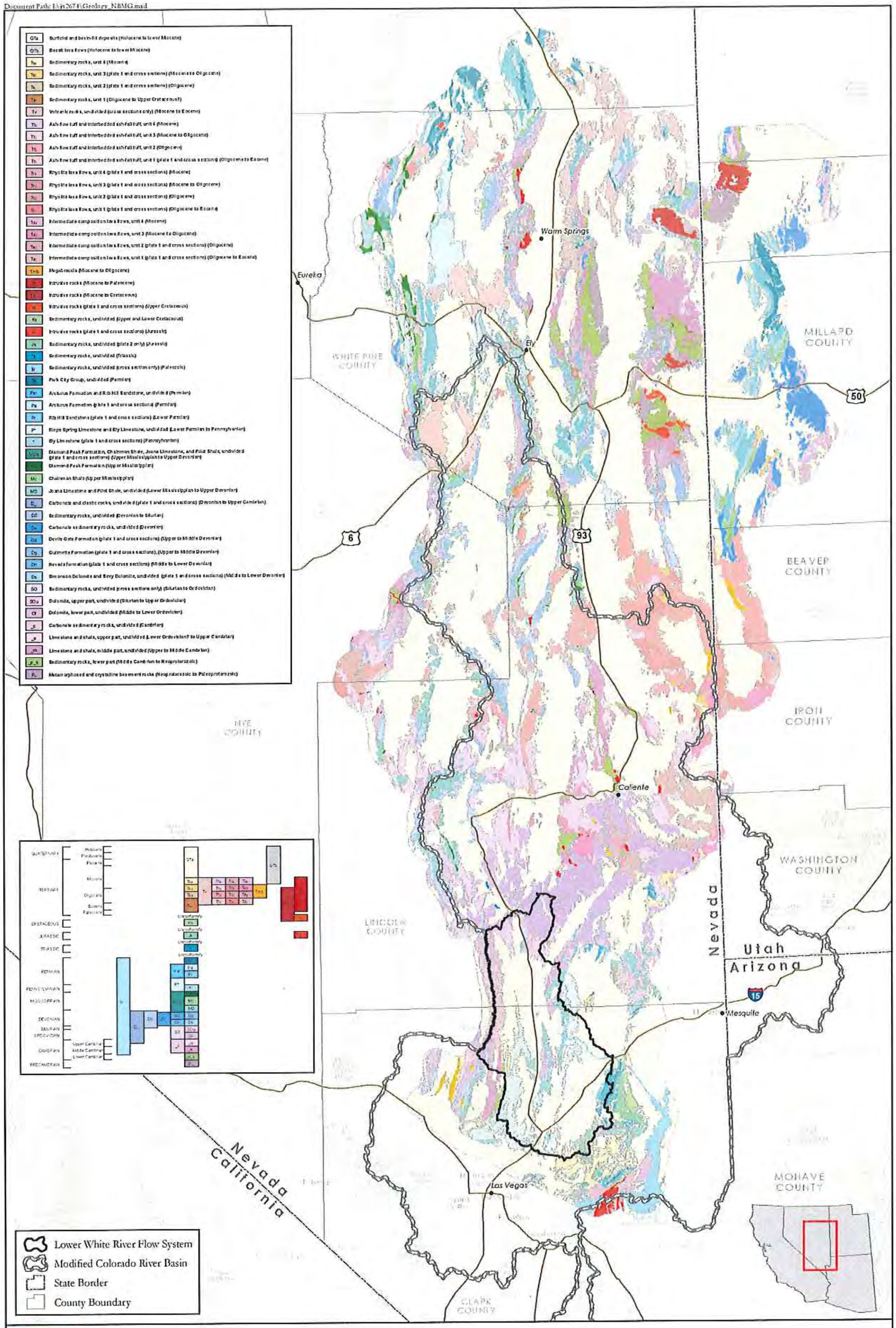
3.5 REGIONAL AND LOCAL GEOLOGIC MAPS

The most recent geologic map of eastern Nevada developed by Rowley et. al (2017) is presented in Figure 7. The extent of the map reaches southern Elko, eastern Nye, White Pine, Lincoln, and Clark Counties. Generalized geologic maps of the Colorado River Basin system and the LWRFS are shown in Figure 8 and Figure 9, respectively. The drainage basins included in the modified Colorado River Basin system have been adjusted from the NSE's inventory of basins for this area to account for interbasin groundwater flow from basins outside the NSE's surface boundary delineation, as discussed in Section 3.4. Additionally, individual geologic units have been generalized into basement, carbonate, volcanic, or basin fill units in order to better depict the aquifers that are the subject of this investigation (see Appendix A).

---

[24] Thomas and Mihevc (2011) indicate that a portion of the interbasin flow from Delamar may flow to Pahranagat Valley.

Document Path: I:\p2674\Geology_NBMG.mxd



STETSON ENGINEERS INC.

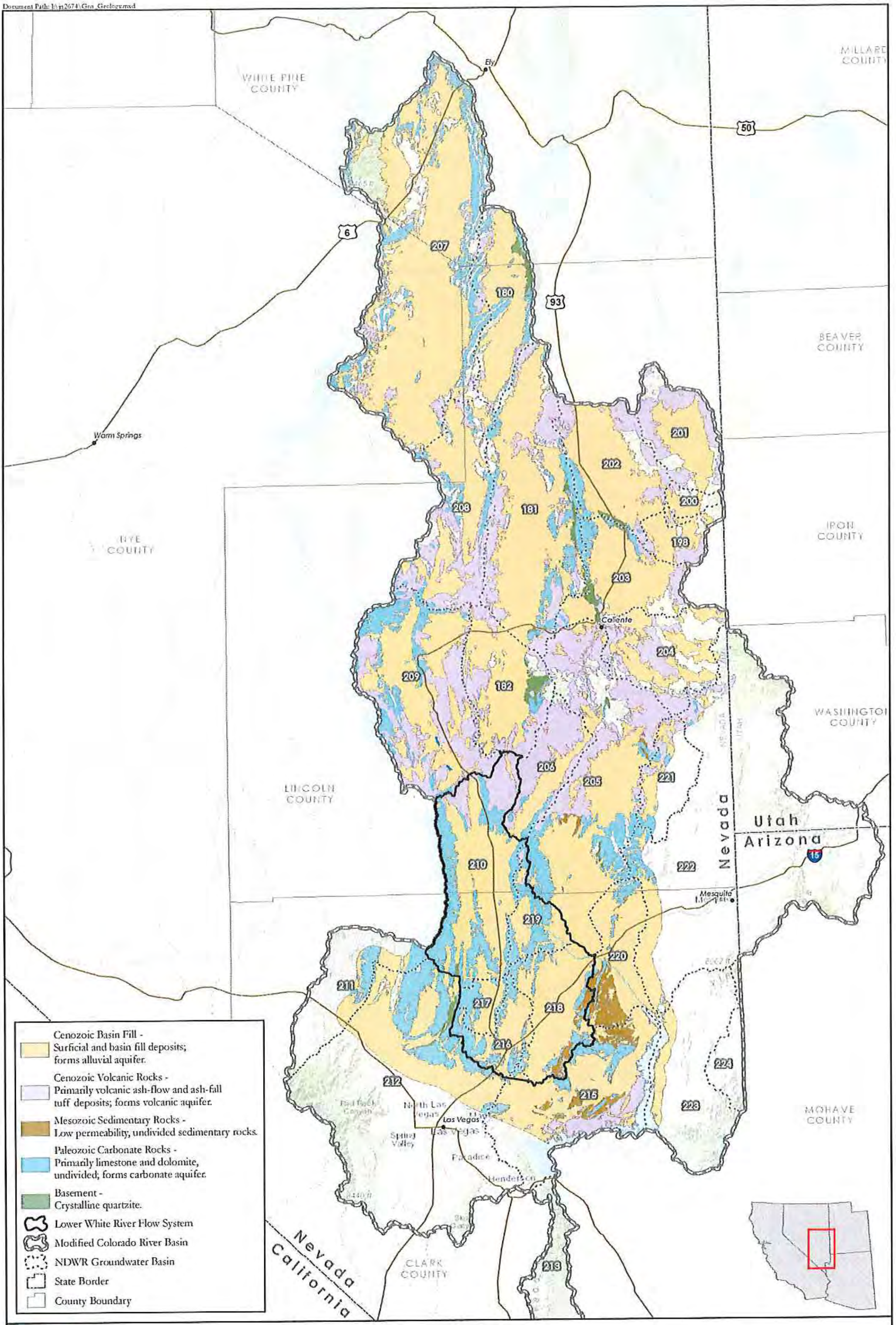
REGIONAL GEOLOGIC MAP
COLORADO RIVER BASIN, NEVADA

Source: Modified from Rowley, et al; 2017

0 10 20 Miles

N

FIGURE



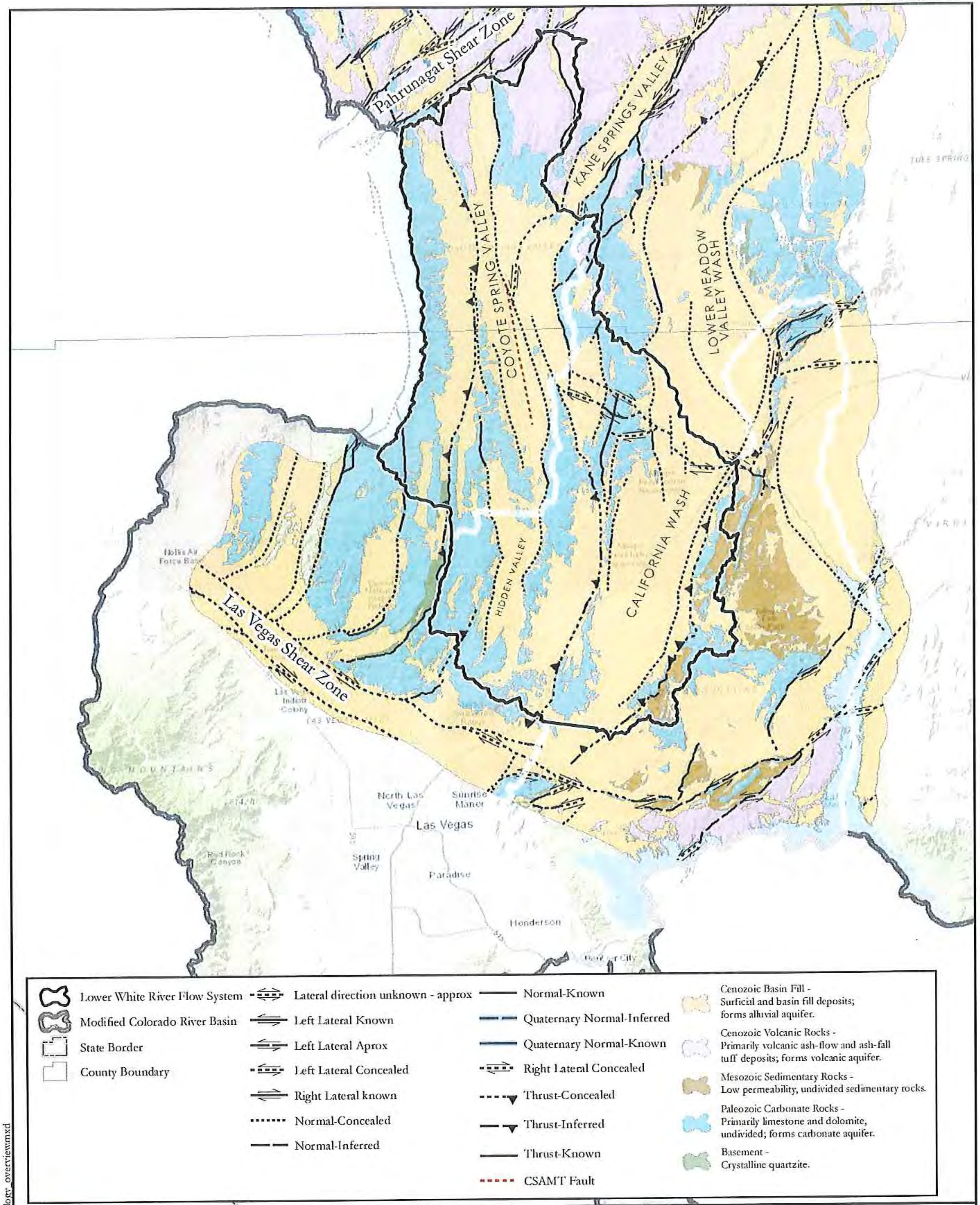
STETSON ENGINEERS INC.

GENERALIZED REGIONAL GEOLOGIC MAP
COLORADO RIVER BASIN, NEVADA

Source: Modified from Rowley, et al; 2017

FIGURE 8

FIGURE 9



Document Path: I:\in2674\Geology_overview.mxd

STETSON ENGINEERS INC.

REGIONAL GEOLOGY
COYOTE SPRING VALLEY

Source: Modified from Rowley, et al; 2017

3.6 APRIL 2019 GEOPHYSICAL INVESTIGATION

Major faults within Coyote Spring Valley are based on Rowley et al. (2017) and a Controlled Source Audio-frequency Magnetotellurics (CSAMT) survey performed at the request of Coyote Springs Nevada, LLC (CS Nevada) during April 2019. A CSAMT survey transmits electrical signals into the ground through a 3,000- to 5,000-foot-long wire, grounded at each end to control the electrical source. Electrical responses are then gathered at a receiver site located up to six miles away from the transmitter. These signals are then processed to determine the electrical resistivity of the geologic formations below the receiver site. By making measurements at numerous receiving stations along a line, a cross section of the earth's electrical resistivity properties can be produced, providing information about subsurface faults, fractures, geologic structures, mineralization, and groundwater. CS Nevada employed the CSAMT technique to assess the locations of normal (extensional) faults and structural blocks in Coyote Spring Valley to assess the preferred paths of groundwater flow. The location of the April 2019 CSAMT cross-section survey Lines A, B, and C are shown in Figure 10.

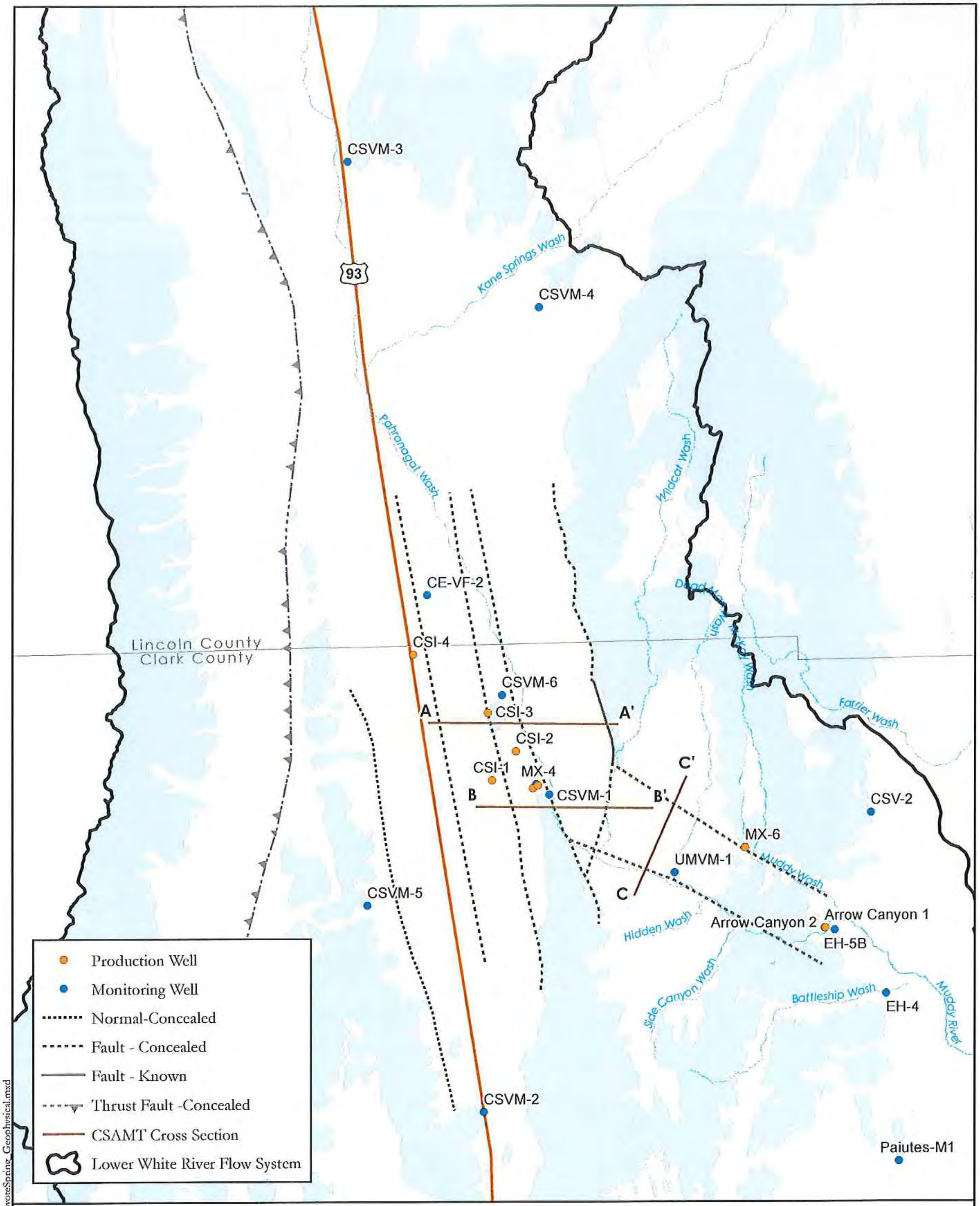
Review of the April 2019 CSAMT cross-section Lines A and B (Figure 11 and Figure 12, respectively) shows a prominent carbonate block (blue color), bounded on either side by normal (extensional) faults. The carbonate block occurs between stations 8,900 and 11,500 on Line A, and between stations 9,000 and 12,000 on Line B. While these normal faults were mapped by Rowley et al. (2017), their location and relationship to the carbonate outcrop in Coyote Spring Valley provides evidence that there are two separate north-south flow paths. One flow path on the west side supports regional groundwater flow toward Hidden Valley, while the eastern flow path supports regional groundwater flow toward Muddy River Springs Area and California Wash.

The resistivity of unsaturated limestone to range from 50 ohm-meters (Ωm) to 10^7 Ωm and unsaturated dolomite to range from 350 Ωm to 5,000 Ωm (Telford et. al, 1976, Appendix B). Saturated limestone is reported to be 600 Ωm with 11% water content; and saturated dolomite is reported to be 530 Ωm with 2% water content[25]. Unsaturated alluvium and sands are reported to range from 10 Ωm to 800 Ωm. The green color at the surface (approximately 100 Ωm) of Lines A and B likely represents unsaturated alluvium and sands; while the deeper layers immediately below the unsaturated alluvium, shown as brown to yellow (8 Ωm to 20 Ωm), likely represent saturated alluvium. The darker red colors ranging from 1 Ωm to 5 Ωm represent saturated basin fill and carbonate rocks. The dark blue color (600 Ωm to 10,000 Ωm) in Lines A and B represent unsaturated limestone that was confirmed by surface mapping, while the lighter blues and greens within the solid blue carbonate block may likely represent areas of saturated fractured limestone within the carbonate block.

---

[25] The actual resistivity of these sediments in Coyote Spring Valley will vary from reported book values due to temperature and chemical composition of the water.

FIGURE 10



Document Path: E:\in2674\CoyoteSpring_Geophysical.mxd

STETSON
ENGINEERS INC.

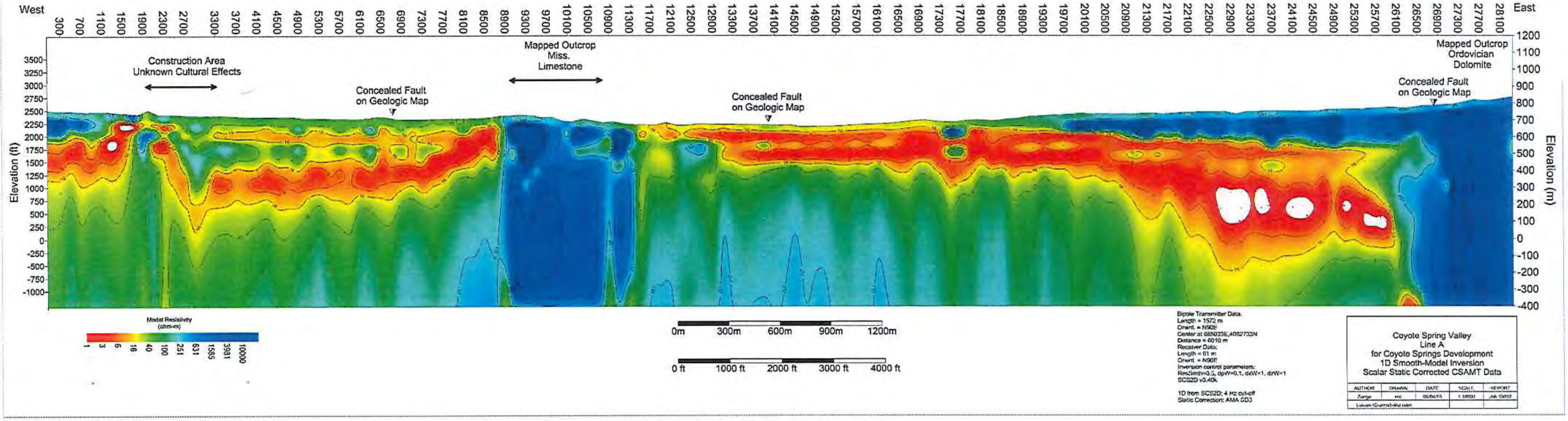
FAULTS LOCATED BY APRIL 2019 CSAMT SURVEY
COYOTE SPRING VALLEY, NEVADA

Source: Modified from Rowley, et al; 2017
(See previous figure for geology legend)

N

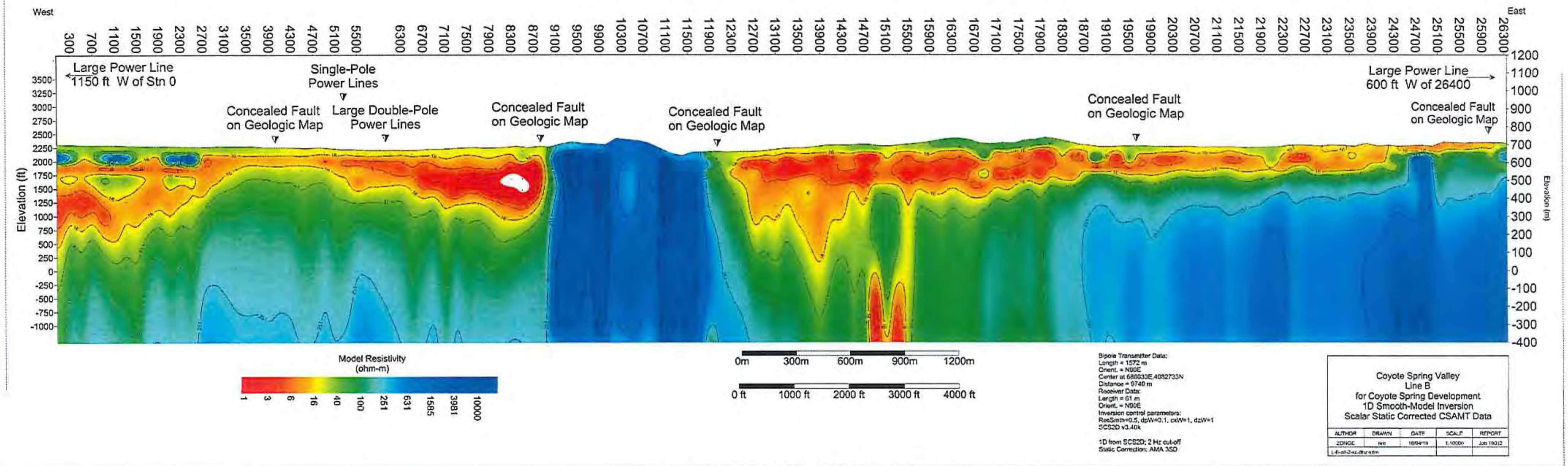
0 2 4 Miles

FIGURE 11



APRIL 2019 CSAMT RESULTS
RESISTIVITY CROSS-SECTION LINE A

FIGURE 12



APRIL 2019 CSAMT RESULTS
RESISTIVITY CROSS-SECTION LINE B

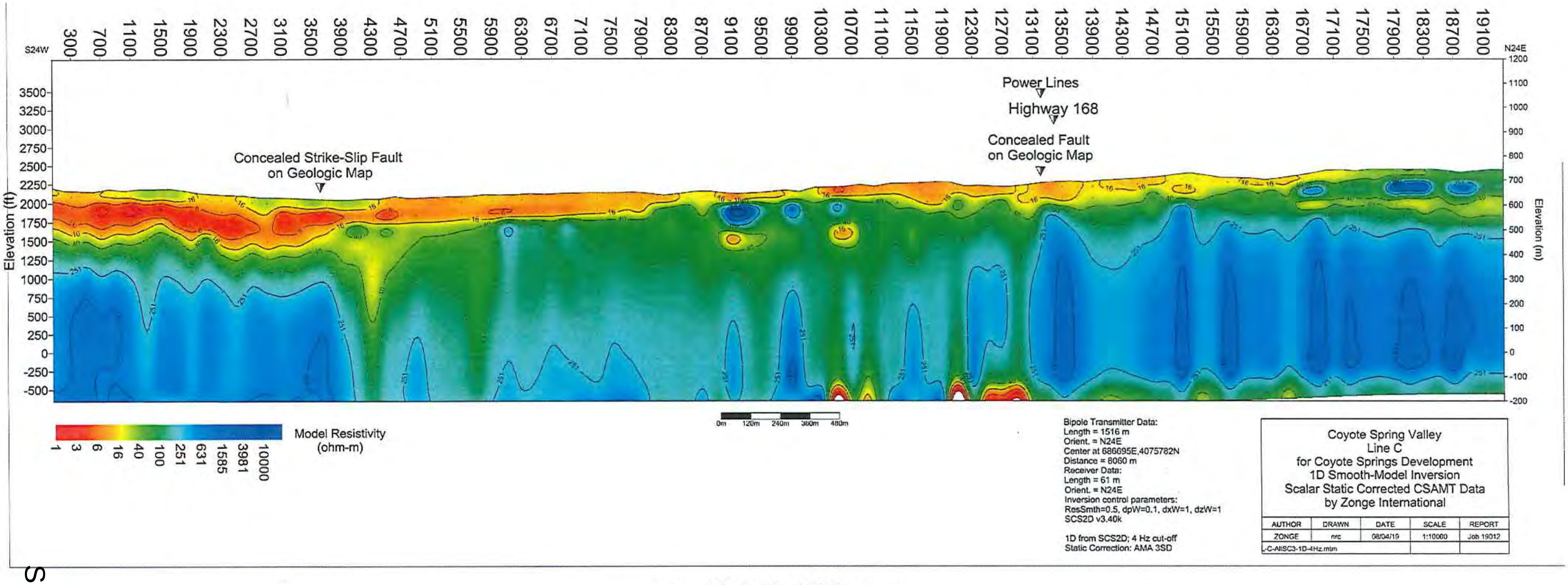
Production wells MX-5 and CSI-2 are located on the eastern side of the carbonate block, while production wells CSI-1, -3, and -4 are located on the western side of the block. The carbonate block effectively isolates the groundwater production wells on the east side of the carbonate block from those on the west side of the carbonate block. The carbonate block also results in a division of groundwater inflow to Coyote Spring Valley from Pahranagat, Delamar, and Kane Springs Valley. Interbasin groundwater outflow from Coyote Spring Valley is to both the Muddy River Springs Area and Hidden and Garnet Valleys. Furthermore, the carbonate block and normal faults isolate local recharge from the Sheep Range to the zone west of the carbonate block, such that it eliminates or limits contributions of local recharge to interbasin groundwater flow to the Muddy River Springs Area.

A previously unmapped fault (shown in red in Figure 9), located at station 1900, is evident at the western end of Line A by the offset in low resistivity (red color) values. The presence of this fault is further supported by the transmissivity values measured at CSI-4 to be 130,000 ft^2/day in a well that penetrated 670 feet of carbonate aquifer (Johnson, 2006). The transmissivity at this well was an order of magnitude higher than values measured in CSI-1, -2, and -3, indicating that CSI-4 was likely located in or near highly fractured carbonate associated with extensional faulting.

Results from Line C (Figure 13), located immediately southeast of CSVM-1, identify the previously mapped sub-parallel faults between Coyote Spring Valley and the Muddy River Springs Area. The geophysical data suggest that the area between the faults is highly fractured, supporting the previous interpretation of an area of high transmissivity.

The preliminary results of combining the generalized geologic map, known faults, and faults identified through tbe April 2019 CSAMT survey are shown in Figure 9. While the locations of faults mapped by Rowley et al. (2017) have not been adjusted based on the April 2019 CSAMT survey, the new fault mapped at the west end of Line A has been added. As previously discussed, groundwater generally moves parallel to normal (extensional) faults in the north-to-south direction. Groundwater flow in the west-to-east direction is impeded by the normal faults, except in areas where cross faults create a preferred pathway for groundwater flow. The Pahranagat Wash from Coyote Spring Valley to Muddy River Springs Area represents one of these areas where faulting between the two basins has resulted an area of high transmissivity for groundwater flow, thus creating a preferred flow path from the east side of Coyote Spring Valley to the Muddy River Springs Area.

FIGURE 13



Bipole Transmitter Data:
Length = 1516 m
Orient. = N24E
Center at 686695E,4075782N
Distance = 8060 m
Receiver Data:
Length = 61 m
Orient. = N24E
Inversion control parameters:
ResSmth=0.5, dpW=0.1, dxW=1, dzW=1
SCS2D v3.40k

1D from SCS2D; 4 Hz cut-off
Static Correction: AMA 3SD

Coyote Spring Valley
Line C
for Coyote Springs Development
1D Smooth-Model Inversion
Scalar Static Corrected CSAMT Data
by Zonge International

AUTHOR	DRAWN	DATE	SCALE	REPORT
ZONGE	nrc	06/04/19	1:10000	Job 19012
L-C-AllSC3-1D-4Hz.mlm				

APRIL 2019 CSAMT RESULTS
RESISTIVITY CROSS-SECTION LINE C

4.0 LWRFS AND COYOTE SPRING VALLEY WATER BUDGETS

Groundwater flow through the carbonate aquifer in the LWRFS originates from both regional and local recharge sources. The regional source of groundwater flow is interbasin flow that originates approximately 200 miles to the north, at the head of the White River Flow System (Eakin, 1966). Additional precipitation and recharge falling in Nevada's central eastern mountains recharges the regional carbonate aquifer that flows north-to-south, towards Las Vegas and Lake Mead. Local recharge occurs within many of the individual basins, along the bounding mountain ranges that define each basin's geographic boundary. Local recharge contributes to and supports groundwater production and evapotranspiration within a basin, as well as regional interbasin groundwater flow between adjacent basins.

4.1 LOCAL RECHARGE FROM THE SHEEP RANGE

Local recharge to Coyote Spring Valley from the Sheep Range, which has been estimated in literature to range from 1,900 AFY to 14,000 AFY[26], may be considered the perennial yield of Coyote Spring Valley. Eakin (1964) estimated recharge in Coyote Spring and Kane Springs Valleys to be a combined 2,600 AFY. An isotopic study by the USGS (Thomas et al., 1996) estimated the Sheep Range's contribution to local recharge of 14,000 AFY. Thomas et al. (2001) assessed local and regional flow in southeastern Nevada using a deuterium mass-balanced model and estimated local recharge in Coyote Spring Valley to be 4,000 AFY. Lopes and Evetts (2004) reported 2,100 AFY of natural recharge in Coyote Spring Valley. The reported values demonstrate that there is some uncertainty in the volume of recharge to Coyote Spring Valley. Published estimates of local recharge from the Arrow Canyon Range and Meadow Valley Mountains on the eastern side of Coyote Spring Valley are not available.

Several recharge models may be used to estimate recharge in Nevada groundwater basins. The recharge models are described below, and were applied to recharge zones in the Sheep Range using geographic information system (GIS) techniques and several data sources.

4.1.1 Description of Recharge Models in Nevada

Recharge to groundwater basins in Nevada is often estimated using a recharge model developed by Maxey and Eakin (1949). The method applies a series of recharge coefficients to corresponding precipitation zones. Each defined precipitation zone, with a particular range of average annual precipitation, is assumed to yield the percentage of that precipitation which reaches

---

[26] Studies estimating recharge to Coyote Spring Valley include: 1,900 AFY by Nevada Division of Water Resources (1971); 5,000 to 6,000 AFY by Kirk and Campana (1990); 4,000 AFY by Thomas et al. (2001); and 14,000 AFY by Thomas et al. (1996).

the groundwater aquifer. Table 2 gives the precipitation bands and coefficients for the Maxey-Eakin method.

TABLE 2. PRECIPITATION ZONES AND RECHARGE COEFFICIENTS FROM MAXEY AND EAKIN (1949)

Precipitation Zone (in/year)	Recharge Coefficient
< 8	0.00
8-12	0.03
12-15	0.07
15-20	0.15
> 20	0.25

The Maxey-Eakin method was originally applied using a precipitation map of Nevada prepared by Hardman (1936). The exact methods used to prepare the Hardman precipitation map are not known, but the delineation of precipitation zones likely relied upon altitude data and precipitation measurements collected at weather stations in Nevada. Precipitation is highly dependent upon altitude.

Eakin (1964, 1966) later studied the White River Area, including Coyote Spring Valley, using these methods. As described in these studies, altitude-precipitation relationships were defined, wherein particular altitudes were associated with a range of precipitation values. Table 3 gives the altitude zones and corresponding precipitation and recharge coefficients.

TABLE 3. PRECIPITATION ZONES, ALTITUDE ZONES, AND RECHARGE COEFFICIENTS FROM EAKIN (1966)

Precipitation Zone (in/year)	Altitude Zone (ft)	Assumed Average Annual Precipitation (in)	Recharge Coefficient
< 8	below 6,000	variable	0.00
8-12	6,000 to 7,000	10	0.03
12-15	7,000 to 8,000	13.5	0.07
15-20	8,000 to 9,000	17.5	0.15
> 20	more than 9,000	25	0.25

The Maxey-Eakin method has been evaluated in several studies (Watson et al. 1976; Dettinger, 1989; Avon and Durbin, 1994; and others). Similar models have been proposed in recent years: Nichols (2000) developed a set of recharge coefficients based on estimates of groundwater evapotranspiration in 15 valleys in eastern Nevada. Similar to the Maxey-Eakin method, the Nichols recharge coefficients were developed for several precipitation zones. Epstein (2004) evaluated both the Maxey-Eakin method and Nichols method and developed a new model using algorithmic optimization (Epstein, 2004; Epstein et al. 2010). The precipitation zones and coefficients developed by Nichols (2000) and Epstein (2004) are given in Table 4 and Table 5, respectively.

TABLE 4. PRECIPITATION ZONES AND RECHARGE COEFFICIENTS FROM NICHOLS (2000)

Precipitation Zone (in/year)	Recharge Coefficient
less than 8	0.000
8 to less than 12	0.008
12 to less than 16	0.130
16 to less than 20	0.144
20 to less than 34	0.158
equal or greater than 34	0.626

TABLE 5. PRECIPITATION ZONES AND RECHARGE COEFFICIENTS FROM EPSTEIN (2004)

Precipitation Zone (in)	Recharge Coefficient
0 to less than 10	0.019
10 to less than 20	0.049
20 to less than 30	0.195
greater than 30	0.629

The Nichols method uses similar precipitation bands to the Maxey-Eakin method, with the exception that a division is defined at 16 inches per year rather than 15 inches per year. Nichols also added a precipitation zone for annual precipitation greater than 20 inches per year. The Epstein method uses only four precipitation zones, with divisions at 10, 20, and 30 inches per year. The lower bound for occurrence of recharge is 0 inches per year, in contrast to 8 inches per year in the Maxey-Eakin and Nichols methods.

All of the recharge models described above are dependent upon the spatial distribution of precipitation. Until the 1990s, the only statewide precipitation map of Nevada was the Hardman map, a hand-drawn map originally prepared in 1936 and updated through the 1960s (e.g. Hardman, 1962 as cited in Lamke and Moore, 1965). In the 1990s, a research group at Oregon State University began producing computer-generated maps of average annual precipitation for the United States (Daly et al., 1994; Daly et al., 1997, Daly et al., 2001). These maps use a method called Parameter-elevation Regressions on Independent Slopes Model (PRISM) to estimate average annual precipitation on a spatial grid. The first two PRISM data sets were produced based on climate normals for 1961-1990 and 1971-2000 with a resolution of 4 kilometers. The third and most recent PRISM data set (PRISM Climate Group, 2015) is based on climate normals for 1981-2010 and has 800-meter resolution. The 30-year climate normal period from 1981-2010 has similar average annual precipitation to the long-term record in southern Nevada,[27] indicating that the recent PRISM data set is representative of long-term averages in this region.

4.1.2. Application of Recharge Models to Coyote Spring Valley

The recharge models described above were applied to the Sheep Range along the west side of Coyote Spring Valley. The contiguous area that drains to Hidden Valley to the south of Coyote Spring Valley was also included for completeness. Recharge zones for Kane Springs Valley, the Arrow Canyon Range and Meadow Valley were not included in this study. Historical estimates of recharge are not available for the Arrow Canyon Range and Meadow Valley, and it is not known whether they contribute significant recharge.

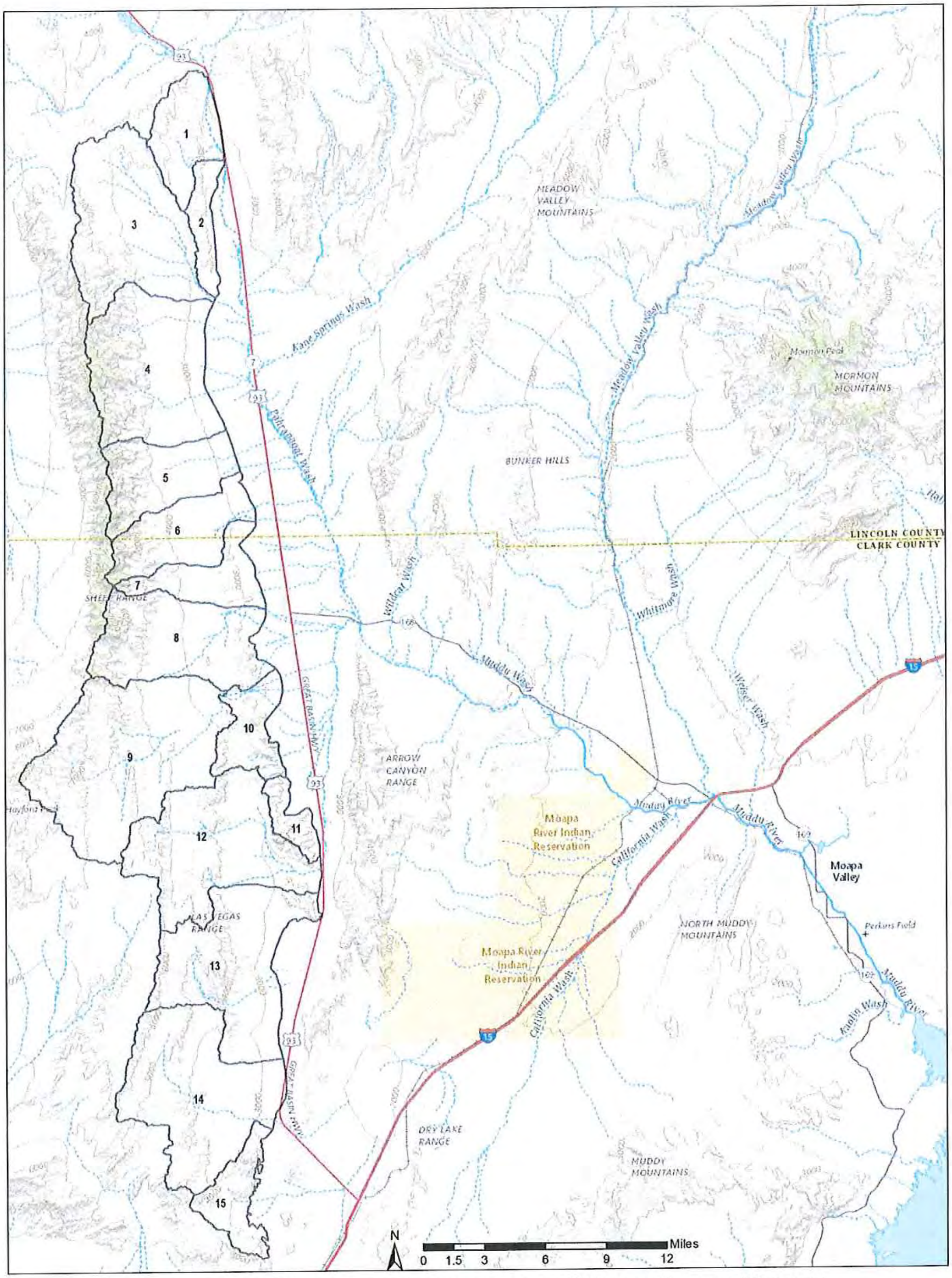
Fifteen general recharge zones were delineated (Figure 14); zones 1 through 12 are part of Coyote Spring Valley (Nevada hydrographic area No. 210) and Zones 13 through 15 are part of Hidden Valley (Nevada hydrographic area No. 217). GIS tools were used to delineate the recharge zones based on hydrography and elevation. The recharge zones were delineated from the ridge of the Sheep Range, which has elevations as high as 9,653 ft amsl, east toward the toe of the mountain slopes, at approximately 2,700 feet amsl. The recharge zones were based upon the sub-basin delineations that are part of the National Hydrography Dataset (NHD) (USGS, 2016). The total area delineated in Figure 14 is 409 square miles. The area and range of elevations within each recharge zone is given in Table 6.

Several recharge models were applied to the recharge zones shown in Figure 14 to understand the range of values for recharge in Coyote Spring Valley and Hidden Valley. All of the recharge models used here are dependent upon the spatial distribution of precipitation. The spatial distribution of precipitation rates may be defined based on altitude (e.g. Eakin, 1964; Eakin, 1966; SNWA, 2006), or the spatial distribution may be taken directly from a precipitation map. Both of these approaches are used here and compared.

---

[27] Long-term average annual precipitation for Nevada Extreme Southern Division 04 is 6.9 inches per year for 1895-2018 and 6.9 inches per year for 1981-2010. Data from: https://www.esrl.noaa.gov/psd/data/timeseries/

FIGURE 14



LOCATION OF RECHARGE ZONES WEST OF COYOTE SPRING VALLEY
RECHARGE ZONES NUMBERED 1 THROUGH 15; BASEMAP: USGS NATIONAL MAP (2019)

TABLE 6. AREA AND ELEVATION FOR RECHARGE ZONES

Hydrographic Area	Recharge Zone & Name		Area		Elevation[a] (ft)		
			(sq mi)	(acres)	Min	Avg	Max
COYOTE SPRING VALLEY (210)	1	Evergreen Flat	15.4	9,841	2,802	3,568	5,093
	2	Pahranagat Wash A	7.1	4,575	2,752	3,070	3,981
	3	Coyote Spring Valley A	42.0	26,901	2,793	4,178	7,487
	4	Coyote Spring Valley B	41.3	26,416	2,762	4,156	7,663
	5	Cherry Spring	20.5	13,137	2,761	4,287	7,728
	6	Grapevine Spring	19.5	12,500	2,760	4,121	8,293
	7	Pahranagat Wash B	13.4	8,565	2,761	3,630	8,127
	8	Perkins Spring	32.6	20,840	2,735	4,496	8,337
	9	Sawmill Wash	59.0	37,770	3,509	5,904	9,653
	10	Las Vegas Range A	11.7	7,504	2,711	3,367	4,609
	11	Las Vegas Range B	5.5	3,530	2,681	3,229	4,653
	12	Wamp Spring	42.8	27,385	2,782	4,242	7,298
HIDDEN VALLEY (217)	13	Hidden Valley A	40.7	26,030	2,763	3,944	7,081
	14	Hidden Valley B	45.9	29,389	2,778	4,248	7,127
	15	Dry Lake	11.3	7,219	2,725	3,280	4,696
		Total	408.8	261,601			

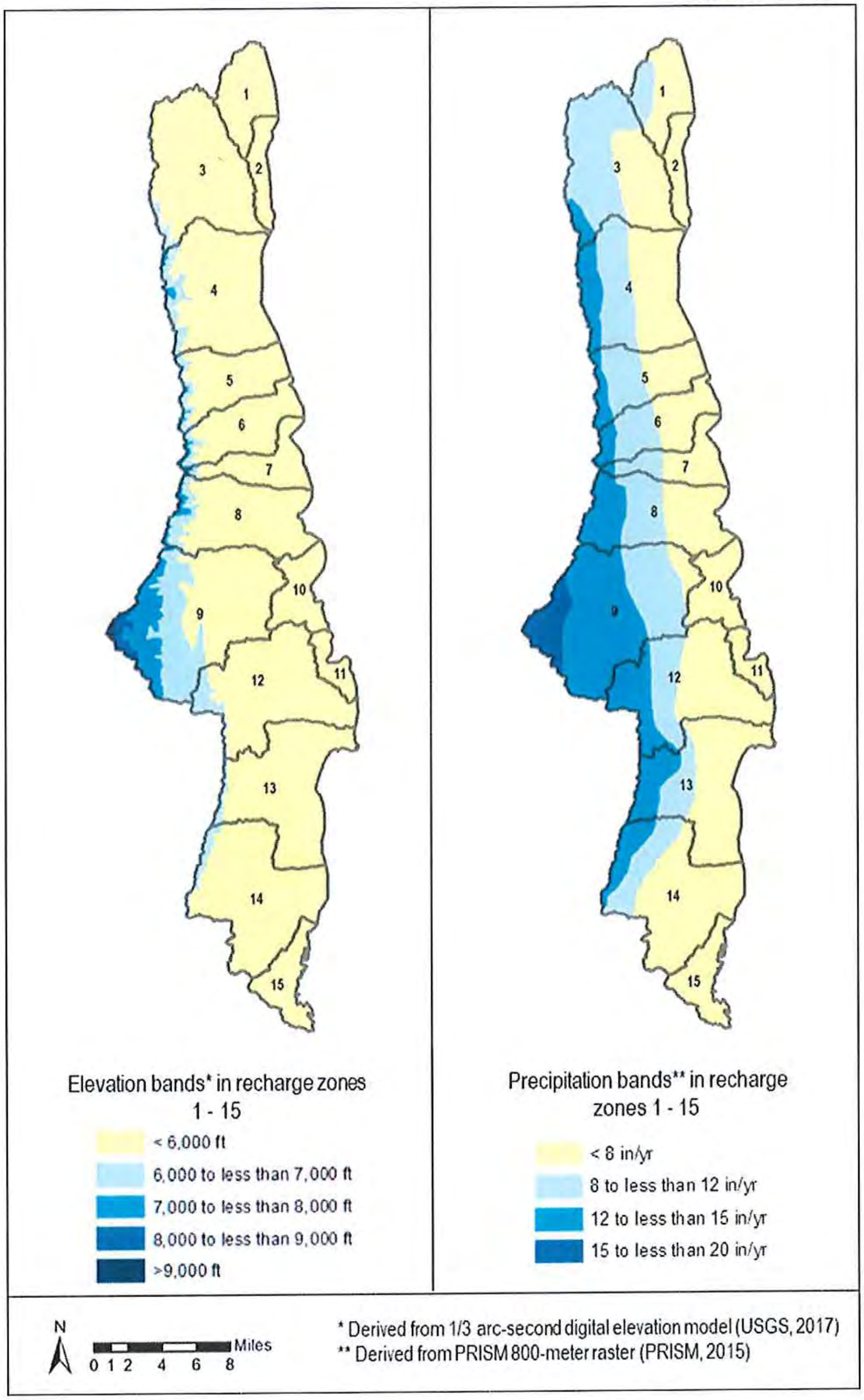
Notes.

a. Elevation estimated from one-third arc-second digital elevation model (USGS, 2017)

The recharge areas were first divided into elevation bands using the altitude divisions defined by Eakin (1966) and given in Table 3. A digital elevation model from the USGS (2017) was used to delineate each elevation band. The delineated elevation bands are shown in the left panel of Figure 15. In this recharge model, only areas at greater than 6,000 ft amsl contribute to recharge. The blue bands in each panel represent areas of recharge, whereas the yellow bands represent areas of no recharge.

The recharge areas were also divided into precipitation bands using the 800-meter-resolution raster of average annual precipitation from PRISM (2015). As shown on the right panel of Figure 15, the PRISM raster shows that the Sheep Range has many areas where the elevation is less than 6,000 ft amsl but precipitation averages more than 8 inches per year. The two panels in Figure 15 show the importance of accurately understanding the spatial distribution of precipitation: the model assumptions on the right panel (precipitation-based bands) include a larger contributing area for recharge compared to the model assumptions on the left (elevation bands).

FIGURE 15



* Derived from 1/3 arc-second digital elevation model (USGS, 2017)
** Derived from PRISM 800-meter raster (PRISM, 2015)

ELEVATION AND PRECIPITATION BANDS USED TO ESTIMATE RECHARGE

Recharge was estimated using the elevation-based and precipitation-based bands. The elevation-based bands in the left panel of Figure 15 were used with the altitude relationships and Maxey-Eakin coefficients given in Table 3. For this calculation, the average annual precipitation was taken from the assumed value presented by Eakin (1966), rather than from a precipitation map. The total recharge for zones 1 through 15 estimated using this method is 1,600 AFY. Appendix Table D-1 gives detailed calculations for this method. The value of 1,600 AFY computed here is less than the value of 2,600 AFY previously computed by Eakin (1964). This is expected since Eakin included Kane Springs Valley and this analysis excludes it. Moreover, because Eakin and this analysis use different sources for elevation, there are also differences in the area for each elevation band.[28]

Precipitation bands were delineated using the PRISM raster and the appropriate precipitation divisions for the Maxey-Eakin, Nichols, or Epstein methods. In all of these methods, the average annual precipitation was computed for each recharge zone and each precipitation band using the PRISM raster data in GIS software. The annual recharge volumes using each of those methods are 6,700 AFY, 8,600 AFY, and 6,400 AFY, respectively. A summary of the recharge calculations is shown in Table 7; Appendix Tables D-2 through D-4 contain detailed calculations. Recharge estimates that rely upon the PRISM precipitation data are higher than those computed with elevation. The PRISM data set used here is the third version and has been refined and become more scientifically sophisticated over time. The PRISM model accounts for different facets of topography, not just elevation, and can therefore provide precipitation estimates for the windward and leeward slopes of a range. In this way, using the PRISM data set offers a potentially improved way to estimate recharge contributions. However, the PRISM data set has not been specifically evaluated for accuracy within the Sheep Range.

Precipitation data in the Sheep Range, especially above 6,000 ft amsl, are limited. Stetson reviewed precipitation data from the National Weather Service Cooperative (COOP), Remote Automated Weather Station (RAWS), Snow Telemetry (SNOTEL), Natural Resources Conservation Service (NRCS), and Clark County Regional Flood Control District (CCRFCD) weather networks. Only two stations, the Wamp Springs RAWS station (6,027 ft amsl) and Hayford Peak NRCS station (9,870 ft amsl), are in or near the Sheep Range at an elevation above 6,000 ft. However, both of these stations are located to the west of the Sheep Range ridge, west of the recharge areas in Figure 14. Data at these stations may not be directly representative of precipitation in areas east of the ridge which contribute recharge to Coyote Spring Valley. Other stations, such as the Elbow Canyon

---

[28] The "Area by Elevation Band" values computed in Table D-1 are less than the zone areas reported in Table 5 of Eakin (1964); some of this difference is certainly due to the inclusion of Kane Springs Valley in Eakin's analysis, and some of the difference appears to be due to differences in source topography.

CCRFCD station, and the Pahranagat and Desert Wildlife Refuge COOP stations, are at elevations less than 4,000 ft amsl and are not in close proximity to the mountain recharge areas.

TABLE 7. SUMMARY OF RECHARGE CALCULATIONS FOR THE SHEEP RANGE

	Delineation of bands from:	**Elevation (USGS, 2017)**	**Precipitation Raster (PRISM, 2015)**		
	Precipitation rate/volume from:	**Eakin (1966)**	**Precipitation Raster (PRISM, 2015)**		
Hydro-graphic Area	**Source of Runoff Coefficients:**	**Maxey & Eakin (1949)[a]**	**Maxey & Eakin (1949)[b]**	**Nichols (2001)[c]**	**Epstein (2004)[d]**
	Recharge Zone and Name	**Estimated Recharge (AFY)**			
COYOTE SPRING VALLEY (210)	1 Evergreen Flat	0	60	10	110
	2 Pahranagat Wash A	0	0	0	40
	3 Coyote Spring Valley A	30	480	300	590
	4 Coyote Spring Valley B	100	550	650	630
	5 Cherry Spring	60	280	310	340
	6 Grapevine Spring	50	230	250	290
	7 Pahranagat Wash B	10	80	60	140
	8 Perkins Spring	120	610	880	600
	9 Sawmill Wash	1,170	2,830	3,920	1,760
	10 Las Vegas Range A	0	0	0	80
	11 Las Vegas Range B	0	0	0	30
	12 Wamp Spring	50	660	980	680
HIDDEN VALLEY (217)	13 Hidden Valley A	20	470	690	520
	14 Hidden Valley B	30	400	530	540
	15 Dry Lake	0	0	0	60
	Total	1,640	6,700	8,600	6,400
	Range of Estimates:	1,600 AFY to 8,600 AFY			

Notes.
a. See supporting calculations in Appendix Table F-1
b. See supporting calculations in Appendix Table F-2
c. See supporting calculations in Appendix Table F-3
d. See supporting calculations in Appendix Table F-4

The range of annual recharge to Coyote Spring and Hidden Valleys computed in this analysis is 1,640 AFY to 8,600 AFY. This falls within the range of values reported in literature (see Appendix C values for Coyote Spring Valley and Hidden Valley). While previous testimony[29] in front of the NSE has identified that the "Maxey-Eakin recharge coefficients are married to the Hardman map and cannot be used otherwise," they have been included in our analysis to show the

---

[29] Ruling 5712, page 11.

difference in recharge estimates due to the application of 1962 rainfall rates used in the Hardman map (1,640 AFY) and the raster precipitation data (PRISIM, 2015) (6,400 to 8,600 AFY).

The results of our analysis indicate that recharge to Coyote Spring Valley ranged from 1,590 AFY to 7,380 AFY when contributions to Hidden Valley were excluded. If the Maxey-Eakin related methods investigated in our analysis are ignored since they rely on older precipitation maps and use runoff coefficients that should not be applied to newer rainfall maps, then the range of recharge to Coyote Spring Valley is between 5,280 AFY and 7,380 AFY. We suggest that the lower value of 5,280 AFY should be used for sustainability planning until additional rainfall data is collected to support a higher value.

The range of values presented here highlights the need for direct precipitation measurements within the Sheep Range recharge areas. High-altitude stations would help to better understand the spatial patterns of precipitation and the applicability of the recharge models and methods described here. However, in lieu of better local precipitation data, which may take many years to collect, the recharge calculations here demonstrate that a value of 5,280 AFY, as used in the groundwater budget in Section 4.3, is an appropriate estimate for recharge to Coyote Spring Valley from the Sheep Range.

4.2 LWRFS BOUNDARY WATER BUDGET

Numerous studies have been performed to assess the quantity of local and regional groundwater flow in each of Nevada's basins. SNWA (2007) assessed local and regional flow in southeastern Nevada and found regional inflow to Coyote Spring Valley was 50,700 AFY, of which Pahranagat Valley contributes 22,440 AFY, Delamar Valley contributes 24,070 AFY,[30] and Kane Springs Valley contributes 4,190 AFY. Interbasin groundwater recharge from Lower Meadow Valley Wash into the LWRFS was estimated by SNWA (2007) to be 9,200 AFY. Local recharge into the LWRFS was estimated to be 2,310 AFY, with 2,130 AFY from the Sheep Range into Coyote Spring Valley, 40 AFY into Muddy River Springs Area, 40 AFY into Hidden Valley, 100 AFY into Garnet Valley, and 0 AFY into both California Wash and Black Mountains Area. These local recharge estimates are low in comparison to other estimates for the area.[31] Total recharge to the LWRFS boundary based on SNWA (2007) is estimated to be 62,210 AFY (Table 8).

Pre-development outflow from the LWRFS was estimated based on reported values by SNWA (2007). Groundwater flow out of California Wash to Lower Moapa Valley and Black

---

[30] Thomas and Mihevc (2011), estimated outflow from Delamar Valley to be 24,900 AFY.

[31] Thomas et al. (2001) estimated total local recharge in the LWRFS to be 6,800 AFY based on a deuterium mass-balance model. See Appendix C for range of estimates from literature review. Local Recharge from Coyote Spring Valley was estimated in Section 4.1 to be 5,280 AFY.

Mountains Area was estimated to be 51,700 AFY, of which 2,000 AF flows toward the Black Mountains Area. Evapotranspiration from California Wash, Black Mountains Area, Muddy River Springs Area, and Coyote Spring Valley was estimated to be 11,930 AFY. Surface flow from spring discharge to the Muddy River and other springs in the LWRFS is included in the groundwater outflow estimates. Based on groundwater outflow, evapotranspiration, and surface flow, the discharge from the LWRFS is estimated to be 63,630 AFY. The water budget for the LWRFS based on SNWA (2007) is shown graphically in Figure 16.

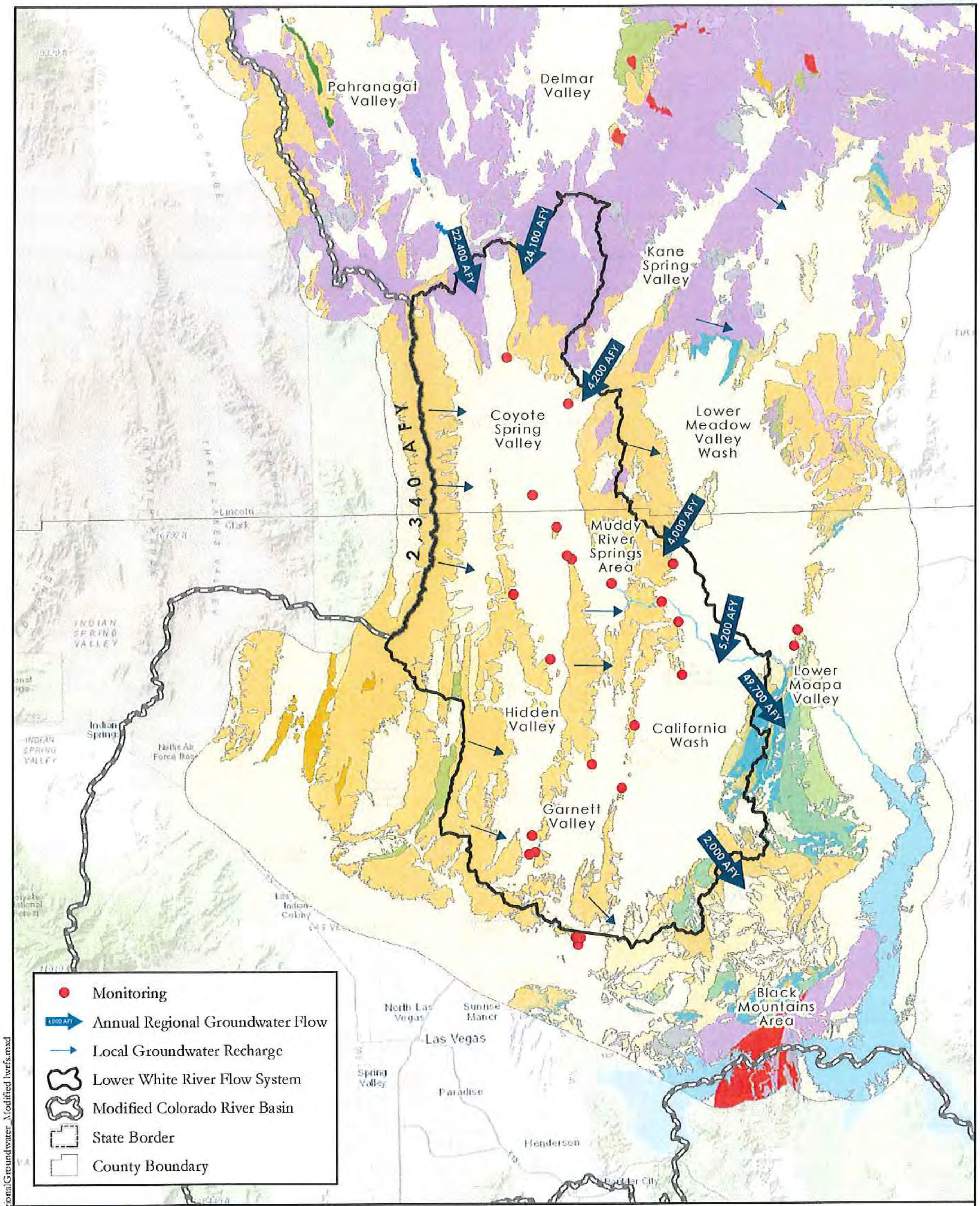
TABLE 8. PRE-DEVELOPMENT WATER BUDGET FOR THE LWRFS BASED ON SNWA (2007) CAVE, DRY LAKE, AND DELAMAR HYDROGEOLOGIC REPORT

Flux Term	Annual Flux (AFY)
Inflow	
Groundwater	
Pahranagat Valley	22,400
Delamar Valley	24,100
Kane Springs Valley	4,200
L. Meadow Valley Wash to MRSA	4,000
L. Meadow Valley Wash to Cal. Wash	5,200
Local Recharge[a]	2,310
Total Inflow	62,210
Outflow	
Groundwater	
Cal Wash to Lower Moapa Valley[b]	49,700
Black Mountain Area toward Lake Mead	2,000
Evapotranspiration	
California Wash	4,510
Muddy River Springs Area	5,990
Black Mountains Area	1,430
Surface Water[b]	Incl.
Total Outflow	63,630

Notes: (a) 2,130 AFY (CSV) + 40 AFY (MRSA) + 40 AF (Hidden) + 100 AFY (Garnet) + 30 AFY (Lower Moapa)

(b) California Wash to Lower Moapa Valley occurs as spring discharge from MRSA springs and subsurface outflow.

FIGURE 16



N

0 6.5 13 Miles

STETSON ENGINEERS INC.

REGIONAL GROUNDWATER FLOW AND LOCAL RECHARGE IN THE LWRFS

Source: SNWA, 2007

Document Path: I:\jn2674\RegionalGroundwater_Modified lwrfs.mxd

The term "Pre-Development" has been used in this report to establish a water budget that does not account for existing alluvial and carbonate groundwater pumping or surface diversions. Thomas et al. (2001, 2011) based the deuterium mixing model on "pre-development" ET rates and relied on water samples collected over many decades in eastern Nevada. While samples may be impacted by pumping, the intent of the water budget analysis is to show recharge and discharge estimates based on the best available data. It is acknowledged that pumping and water development in eastern Nevada prior to the collection of water samples may influence the water budget.

The flux values developed by SNWA (2007) produce a non-unique solution, since a "proportionate decrease or increase in both recharge and ET rates, or a different combination of groundwater sources and mixing, can produce the same results" (Thomas et al., 2001). Therefore, a literature review of available recharge and discharge estimates was performed to assess the reasonableness of the terms, and is provided in Appendix C. Groundwater inflow to the LWRFS ranged from a minimum of 20,400 AFY to 85,500 AFY, averaging 51,923 AFY. NSE Ruling 6255[32] estimated a total of 47,000 AFY to the LWRFS that included: 39,000 AFY from Pahranagat, Delamar, and Kane Springs Valleys; and 8,000 AFY from Lower Meadow Valley Wash to Muddy River Springs Area. Local recharge in the LWRFS ranged from a minimum of 1,996 AFY to 17,818 AFY, averaging 5,475 AFY. Groundwater outflow ranged from 0 AFY to 53,711 AFY, averaging 24,852 AFY. Evapotranspiration from the LWRFS ranged from 1,000 AFY to 15,080 AFY, averaging 10,652 AFY.

The water budget provided in Table 8 and shown in Figure 16 presents an initial budget that may be used for groundwater sustainability in the LWRFS. The proposed budget accounts for local recharge, surface water flow, and groundwater flow that supports senior decreed water rights on the Muddy River in Muddy River Springs Area, California Wash, and Lower Moapa Valley. Ruling 6254 states that the perennial yield of a groundwater basin is defined as the maximum amount of groundwater that can be withdrawn each year over the long-term without depleting the groundwater reservoir and that it is ultimately limited to the maximum amount of natural discharge that can be used for beneficial use. While the perennial yield may be limited to the natural recharge to a groundwater basin, it is typically less in order to prevent adverse conditions such as water quality degradation, storage depletion, diminishing yield of wells, increased pumping costs, and land subsidence.

The amount of water available for appropriation from Nevada's basins has previously been based on the capture of evapotranspiration and groundwater outflow. Under sustainable management conditions for the Lower White River Flow System, factors such as climate, geology,

---

[32] NSE 6255, page 25.

and point of diversion will affect the total quantity that can be pumped based on an acceptable level of impact to resources. This report recommends and supports that an initial estimate of groundwater available for appropriation should be based on capturing all evapotranspiration and groundwater outflow from the LWRFS. The SNWA (2007) estimate of 51,700 AFY of subsurface outflow includes discharge from the springs in the Muddy River Springs Area. Therefore, for the purpose of estimating subsurface outflow from California Wash, 32,000 AFY of surface discharge is subtracted from the 51,700 AFY to yield 19,700 AFY of subsurface outflow. Additionally, the amount of evapotranspiration for the LWRFS is estimated to be 11,930 AFY; resulting in the total evapotranspiration and groundwater outflow of 30,630 AFY. Operating under sustainable management techniques that include monitoring, management, and mitigation will allow existing water rights holders to exercise their rights in priority and assess impacts over time and allow the NSE and stakeholders to assess and protect resources as pumping increases toward the maximum value of 30,630 AFY. Because existing production in the LWRFS is much less than 30,630 AFY, resources of the Muddy River will be protected as a reasonable lowering of the groundwater table occurs.[33]

4.3 COYOTE SPRING VALLEY WATER BUDGET

Numerous studies have been performed to assess the quantity of local and regional groundwater flow in each of Nevada's basins. Reported estimates of local recharge to Coyote Spring Valley from the west bounding Sheep Range ranges from 1,900 AFY to 14,000 AFY. SNWA (2007) assessed local and regional flow in southeastern Nevada and found regional inflow to Coyote Spring Valley was 50,700 AFY, of which Pahranagat Valley contributes 22,440 AFY, Delamar Valley contributes 24,070 AFY,[34] and Kane Springs Valley contributes 4,190 AFY. SNWA (2007) estimated local recharge to be 2,130 AFY. A comparison with other estimates reveals that this value may be low. A local recharge of 5,280 AFY, as estimated in Section 4.1, is more reasonable based on recent studies and updated rainfall patterns (PRISM, 2015). Published estimates of additional recharge that may occur on the east side of Coyote Spring Valley from the Arrow Canyon Range and Meadow Valley Mountains are not available.

Pre-development outflow from Coyote Spring Valley was estimated based SNWA (2007). Groundwater flow out of Coyote Spring Valley was split between 37,800 AFY of flow to Muddy River Springs Area, and 17,180 AFY of flow to Hidden and Garnet Valleys. Estimated evapotranspiration in Coyote Spring Valley is 1,000 AFY, based on Thomas et al. (2001). Groundwater flow to the Muddy River Springs Area was also supported by 32,000 AFY of flow from Lower Meadow Valley Wash to Lower Moapa. Groundwater flow out of Hidden and Garnet

---

[33] NRS 534.110(4)

[34] Thomas and Mihevc (2011), estimated outflow from Delamar Valley to be 24,900 AFY.

Valleys was toward the Black Mountains Area (Thomas et al., 2001). The regional groundwater flow and local recharge in the vicinity of Coyote Spring Valley is shown graphically in Figure 17 and described in Table 9.

Groundwater outflow from Coyote Spring Valley towards Hidden and Garnet Valleys eventually discharges toward the Black Mountains Area and the Las Vegas Shear Zone, the latter of which is a prominent northwest-southeast trending feature that marks the end of the regional carbonate aquifer. In addition to local recharge and groundwater flow from California Wash, groundwater discharge from the Black Mountains Area may occur as evapotranspiration, spring discharge, or seepage along the northern boundary of Lake Mead and Las Vegas.

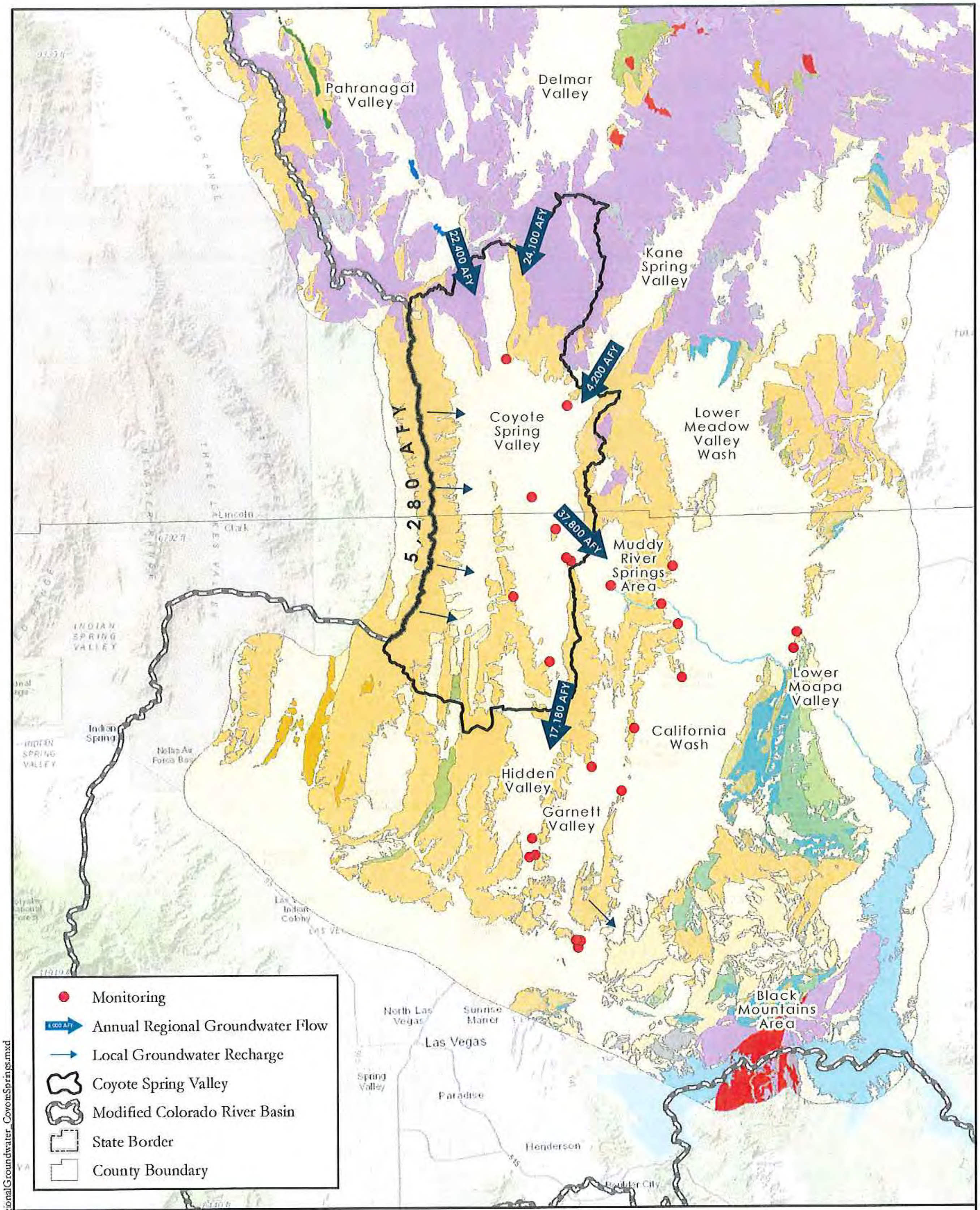
TABLE 9. PRE-DEVELOPMENT WATER BUDGET FOR THE COYOTE SPRING VALLEY BASED ON DEUTERIUM MASS-BALANCED MODEL (MODIFIED FROM SNWA, 2007)

Flux Term	Annual Flux (AFY)
Inflow	
Pahranagat Valley	22,400
Delamar Valley	24,100
Kane Springs Valley	4,200
Local Recharge from Sheep Range[a]	5,280
Local Recharge from east side of CSV[b]	Unknown
Total Inflow	55,980
Outflow	
Muddy River Springs Area(a)	37,800
Hidden/Garnet Valley	17,180
Evapotranspiration	1,000
Total Outflow	55,980

Notes: a) Local recharge has been modified from SNWA (2007) to include the updated recharge estimate from the Sheep Range based on 2015 PRISM data. Additional recharge from the Sheep Range flows toward Hidden and Garnet Valleys.

b) Published estimates of local recharge to Coyote Spring Valley that may occur from Arrow Canyon Range and Meadow Valley Mountains are not available.

FIGURE 17



Document Path: J:\jn2674\RegionalGroundwater_CoyoteSprings.mxd

STETSON ENGINEERS INC.

REGIONAL GROUNDWATER FLOW AND LOCAL RECHARGE IN THE COYOTE SPRING VALLEY

Source: Modified from SNWA, 2007

N

0 6.5 13 Miles

5.0 GROUNDWATER-LEVEL RESPONSES

This section of the report provides observations of groundwater and surface water level responses in the Coyote Spring Valley and Muddy River Springs Area due to pumping and natural climatic variability.

5.1 GROUNDWATER LEVEL RESPONSES

Groundwater-levels in the carbonate aquifer respond to changes in recharge and discharge fluxes that are due to long-term and short-term natural climatic variability and anthropogenic stresses. Long-term time periods characterized by wetter than normal climatic conditions will result in an increase in groundwater levels if discharge rates remain constant. When discharge rates from the aquifer vary and recharge remains constant, groundwater levels will increase when discharge is reduced and decrease when discharge increases. Short-term annual groundwater pumping is also reflected in the groundwater levels; as pumping rates increase during high summer demand, groundwater levels decrease. Review of groundwater level responses in monitoring wells located in both Muddy River Springs Area and the Coyote Spring Valley can be analyzed for impacts due to both long-term climatic variability and short-term changes in pumping rates.

Groundwater levels in the Muddy River Springs Area monitoring well EH-4 show a seasonal response to Muddy River Springs Area carbonate groundwater pumping; minimum groundwater levels occur in summer when pumping is at a maximum, while maximum levels occur in the winter/spring when pumping is curtailed (bottom pane, Figure 18). When groundwater levels in EH-4 are compared to carbonate pumping in Coyote Spring Valley (top pane, Figure 18), there is no variation in the seasonal response pre-2005 and post-2005, when pumping in Coyote Spring Valley was initiated. What is most evident from the water level graph is the long-term climatic impact of drying from 1998 through 2004, wetting in 2004 and 2005, drying from 2006 through 2013, and stable water levels from 2013 through 2018.

Monitoring wells CSVM-1 (Figure 19), CSVM-6, and MX-4 (Appendix E)[35] show a response during the Order 1169 aquifer test (upper pane, Figure 19), as well as a response to pumping in Muddy River Springs Area (lower pane, Figure 19). Similar to groundwater level responses in EH-4, a pumping signature from carbonate pumping in Muddy River Springs Area appears in CSVM-1, CSVM-6, and MX-4 prior to 2005 when groundwater pumping in Coyote Spring Valley began. The groundwater level data suggest hydraulic communication between Muddy River Springs Area and the eastern portion of Coyote Spring Valley. Also similar to EH-4, the long-

---

[35] See Appendix E supporting groundwater level graphs for: CE-VF-2, CSVM-1, CSVM-2, CSVM-3, CSVM-4, CSVM-5, CSVM-6, MX-4, EH-4, EH-5B, UMVM-1, and CSV-2.

term climatic variability from 1998 through 2018 results in increase and decreases in long-term trends of the groundwater level.

Coyote Spring Valley monitoring wells CSVM-2, -3, -4, -5 (Figure 20), and CE-VF-2 (Appendix E) do not show a response to pumping that occurred in either Muddy River Springs Area or the eastern portion of Coyote Spring Valley. There was no response in these monitoring wells from pumping at MX-5 during the Order 1169 aquifer test due to barriers to flow created by normal (extensional) faults that impede groundwater flow in the east-west direction, discussed in the above sections of this report. These monitoring wells are isolated from the eastern portion of Coyote Spring Valley by the normal faults and a structural carbonate block that act as barriers to flow, as evidenced by the lack of water level response. The April 2019 CSAMT survey provides evidence to groundwater flow barriers and substantiates the observations made by SNWA in 2013. Normal faulting associated with the carbonate structural block act as a barrier to groundwater flow in the west to east direction.

Based on these observations, pumping in the western portion of Coyote Spring Valley would not impact groundwater levels on the eastern side of the valley.[36] Production wells CSI-1, -3, and -4, which are on the same side of the structural block as CSVM-2, -3, -4, -5, and CE-VF-2 monitoring wells, are effectively isolated from groundwater resources in the eastern portion of Coyote Spring Valley. Therefore, groundwater pumping in CSI-1, -3, and -4 will not likely cause impact to groundwater resources in the Muddy River Springs Area. Normal faults, as suggested by Rowley et al. (2017) and identified by the April 2019 CSAMT survey, act as barriers to groundwater flow in the west to east direction across the structural carbonate block bounded by the normal faults.

---

[36] Information provided by MBOP at the April 22, 2019 pre-HRT meeting in Las Vegas discussed lack of water level response in CSI-3 during Order 1169 pumping.

Basin 219 - Muddy River Springs Area

EH-4

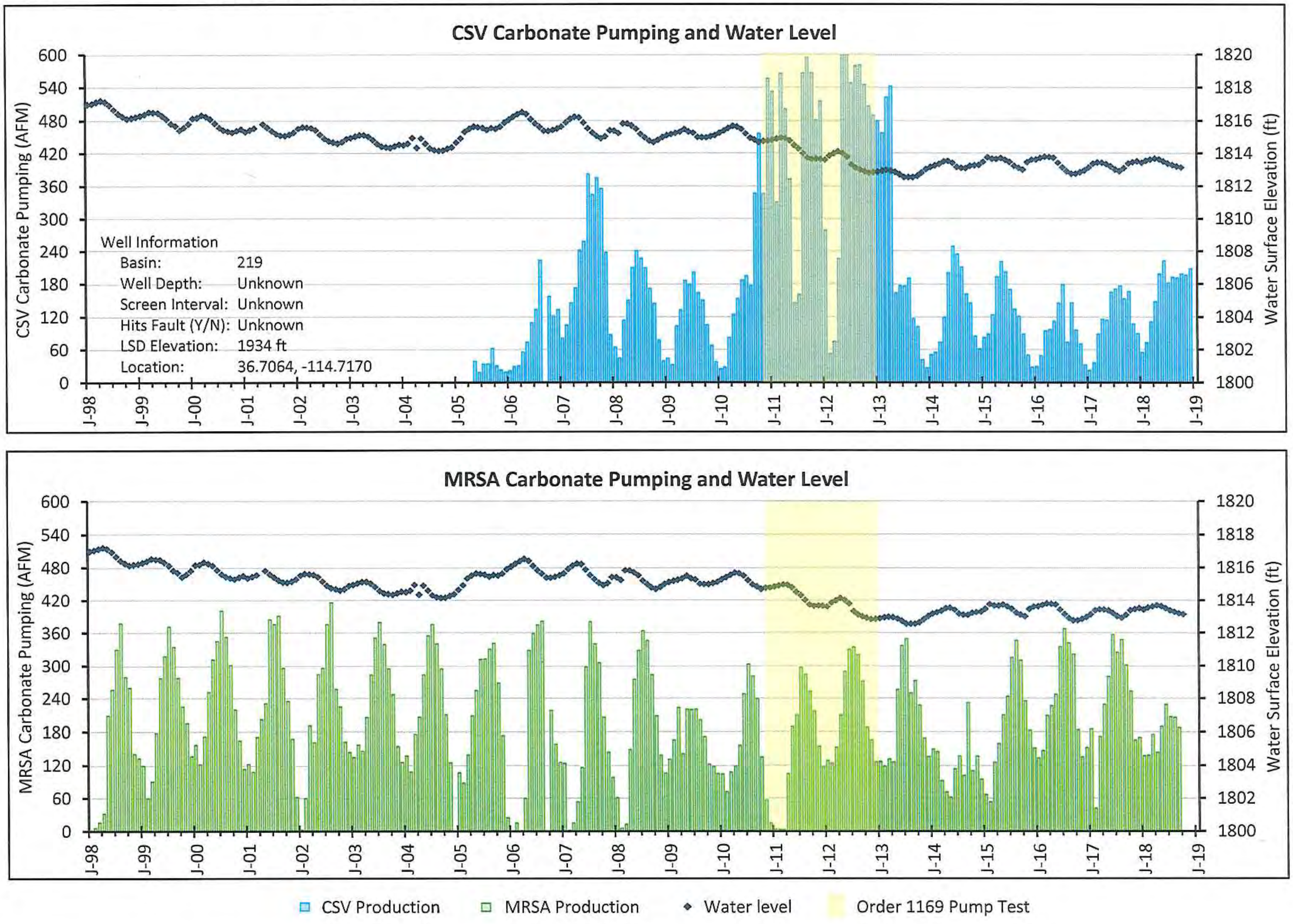


FIGURE 18

Basin 210 - Coyote Spring Valley

CSVM-1

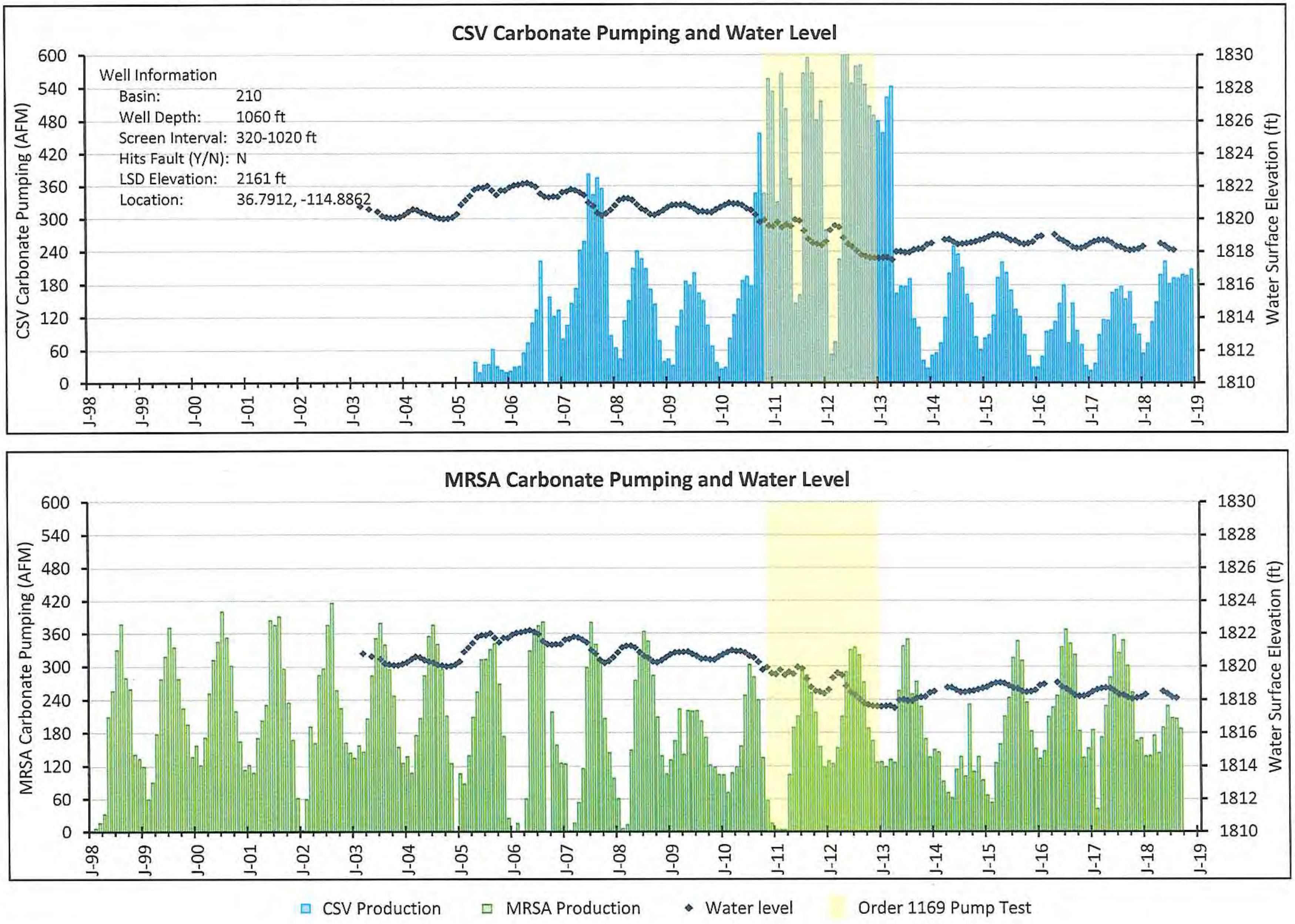


FIGURE 19

Basin 210 - Coyote Spring Valley

CSVM-5

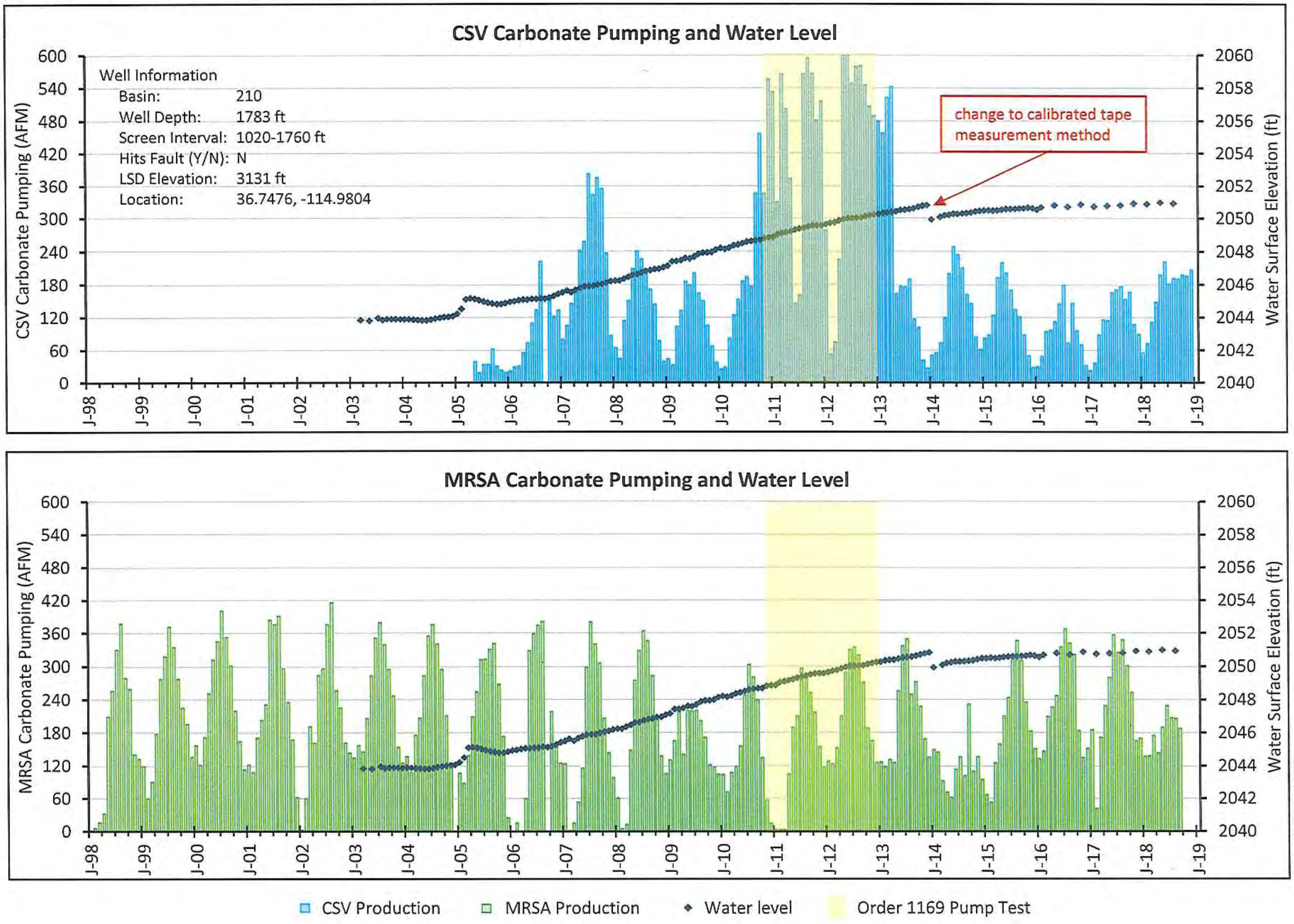


FIGURE 20

5.2 SURFACE WATER FLOW RESPONSE

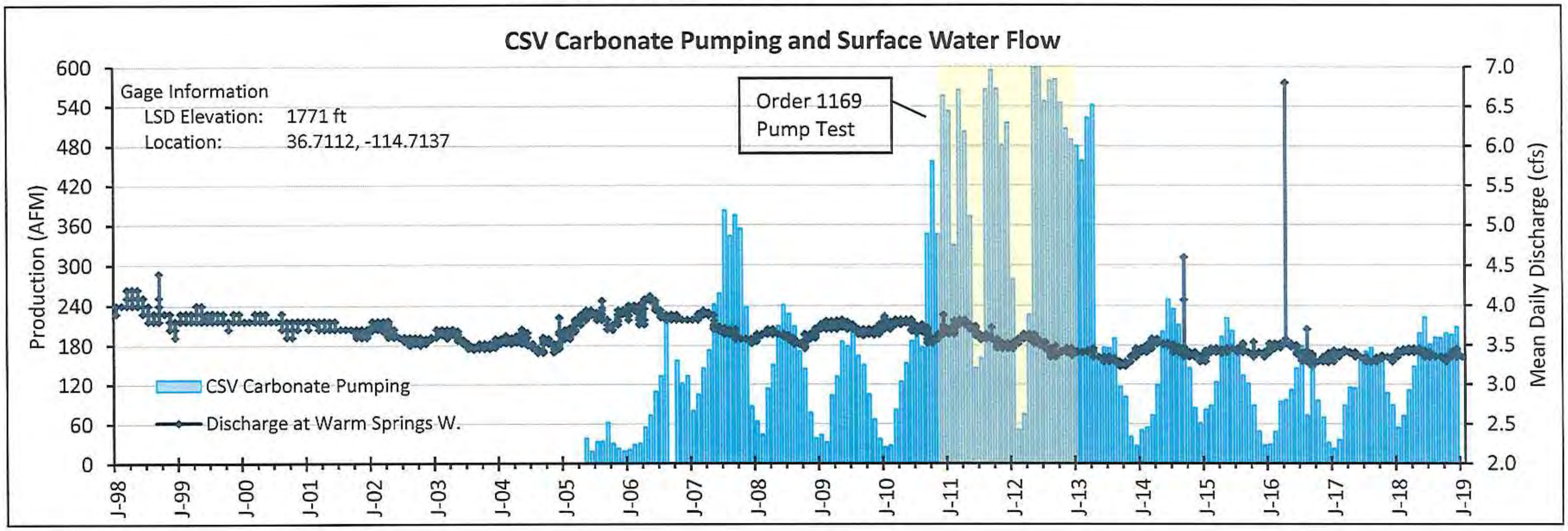
Observations of surface flow records at Warm Spring West near Moapa gage (USGS # 09415920) in the Muddy River Springs Area show that the gage reflects carbonate groundwater levels in EH-4 (Figure 21). Surface flow responds to both wet climatic conditions and extended dry periods as exhibited by the declining surface flow during the 2006-2013 extended dry period following the 2004/2005 wet years. The seasonal signature between highs during winter and spring and lows during summer and fall is also evident in this hydrograph. Further evidence that pumping in Coyote Spring Valley has little, if any, impact on carbonate groundwater levels in the Muddy River Springs Area is shown by the comparison of surface flow to records of groundwater pumping from CSI-2. Located on the eastern side of the carbonate block in Coyote Spring Valley, CSI-2 pumped an equivalent annual rate 2,200 AFY during the last three quarters of 2018. The flow at Warm Springs West continued to show its seasonal variation with no upward or downward trend in surface flow during this period.

Other records of surface flow are compared to groundwater pumping in both Coyote Spring Valley and Muddy River Springs Area in Appendix E. The Muddy River near Moapa gage (USGS # 09416000) shows that surface flow has been increasing steadily since 2001, coincident with a reduction in total diversions from the Muddy River Springs Area as previously shown in . Additionally, surface flow at this gage did not subside or decline during the Order 1169 aquifer test, suggesting that factors other than pumping in Coyote Spring Valley have a larger effect on total streamflow originating from the Muddy River Springs Area. The flow data at the Muddy River near Moapa gage show that senior decreed water rights, resources that support the survival of the Moapa dace,[37] and groundwater resources for appropriation can be managed in a sustainable manner.

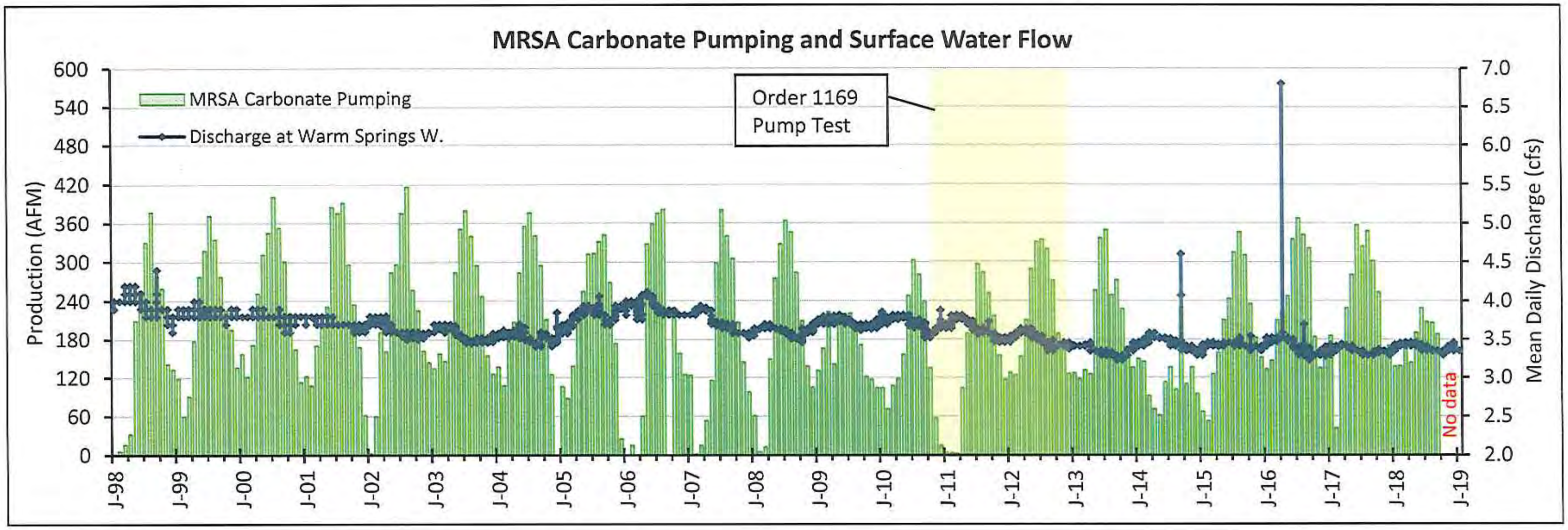
---

[37] The population of Moapa dace increased from low of 462 in August 2008 and February 2009, to a high of 2,182 in August 2015. Data show February 2005 count as 1,296 and the August 2017 count to be 1,533. https://www.fws.gov/uploadedFiles/MoapaDace2017%20508%20checked.pdf

Warm Springs West (USGS 09415920)



CSV Carbonate Pumping and Surface Water Flow



MRSA Carbonate Pumping and Surface Water Flow

FIGURE 21

6.0 SUMMARY AND CONCLUSIONS

The occurrence and movement of water in the LWRFS cannot be explained by an arbitrary boundary based on surface drainage divides. Interbasin groundwater flow into the LWRFS occurs from Pahranagat Valley, Delamar Valley, Kane Springs Valley, and the Lower Meadow Valley Wash. Interbasin groundwater outflow from California Wash into the Lower Moapa Valley occurs due to interbasin groundwater inflow and local recharge within the LWRFS. Together, these sources of local and regional groundwater flow support streams, springs, and evapotranspiration in Muddy River Springs Area, California Wash, and the Black Mountains Area basins. Assessment of impacts to decreed rights on the Muddy River, spring flow, and Moapa dace habitat must account for inflow from the entire carbonate rock aquifer and not just the portion within Coyote Spring Valley. Based on the importance of assessing the impacts of groundwater pumping on senior rights of the Muddy River and springs in the Muddy River Springs Area, the water budget presented in this report for the LWRFS should be adopted by the NSE for determining long-term sustainability in the region.

6.1 WATER AVAILABLE FOR SUSTAINABLE DEVELOPMENT

The role of the NSE is to develop a water budget and inventory of all water in each basin that is available for appropriation to beneficial use in the public's interest.[38] Typically, the amount of water available for appropriation could be calculated based on capture of evapotranspiration and groundwater outflow. The purpose of this section of the report is to establish an estimate for quantifying the amount of groundwater and surface water that may be put to a beneficial use in a sustainable manner.

SNWA (2007) suggests that approximately 11,930 AFY of evapotranspiration occurs within the LWRFS and an additional 51,700 AFY of subsurface outflow, spring flow, and surface flow occurs toward the Lower Moapa Valley and Black Mountains Area. The proposed water budget of the LWRFS further indicates that regional groundwater inflow and local recharge within the LWRFS boundary totals 62,240 AFY. These sources of the interbasin groundwater flow and local recharge supports springs and rising groundwater in the Muddy River Springs Area and California Wash, which in turn supports senior decreed water rights along the Muddy River. After accounting for 32,000 AFY of surface flow of the Muddy River, the total evapotranspiration and groundwater outflow from the LWRFS is 30,630 AFY.

The flow patterns of regional and local groundwater in the LWRFS boundary are neither simple nor straightforward. The April 2019 CSAMT data indicate that regional groundwater recharge to Coyote Spring Valley flows in a north-to-south direction along preferred western and

---

[38] See NRS 532.167 and NRS 534.020

eastern flow paths, separated by a relatively impermeable carbonate block. Outflow from Coyote Spring Valley to Hidden Valley, Garnett Valley, and the Black Mountains Area eventually discharges toward the Las Vegas Shear Zone and California Wash. Interbasin groundwater flow from Lower Meadow Valley Wash support springs, evapotranspiration, and surface flows in both the Muddy River Springs Area, California Wash, and eventually the Lower Moapa Valley.

Estimated drawdown using the Theis solution indicates that impacts from carbonate wells pumping in the Muddy River Springs Area has a greater impact on groundwater levels in EH-4 than pumping in Coyote Spring Valley. Furthermore, SNWA (2018) suggests that groundwater production from the Muddy River Springs Area alluvial aquifer depletes Muddy River streamflow on a 1:1 basis; and that Muddy River Springs Area carbonate production wells capture water that would otherwise replenish the alluvial aquifer. Review of groundwater levels (EH-4) and Muddy River Springs Area total surface and groundwater production supports SNWA's conclusion since a reduction in total diversions since 2013 have resulted in stable carbonate groundwater levels and an increase in Muddy River flows.

Hydrologic conditions for the extreme southern Nevada have been in a below normal trend since 2006, while hydrologic conditions in Pahranagat Valley have been slightly above normal since 2013. Based on the below normal hydrologic conditions in extreme southern Nevada, groundwater levels in EH-4 may have continued to decrease without a reduction in Muddy River Springs Area diversions and groundwater production. The degree of impact from slightly wetter than normal hydrologic conditions in Pahranagat Valley to groundwater levels in the Muddy River Springs Area require further investigation. Because regional interbasin groundwater recharge occurs from the upgradient basins, climate variability in these basins may largely dictate groundwater levels in the LWRFS.

6.2 ORDER 1303 ISSUES

The purpose of this report is to address the NSE's request in Order 1303 to address water resources in the Coyote Spring Valley, Muddy River Springs Area, California Wash, Hidden Valley, Garnet Valley, and a portion of the Black Mountains Area (Joint Administrative Unit). Based on the data and analyses provided in this report, this section addresses specific issues.

Order 1303 Issue 1: The geographic boundary of the hydrologically connected groundwater and surface water systems comprising of the Lower White River Flow System

The LWRFS should be used by the NSE to sustainably manage the surface and groundwater resources. Interbasin groundwater recharge from Pahranagat Valley, Delamar Valley, Kane Springs Valley, and Lower Meadow Valley Wash add to and support regional groundwater flow within the

LWRFS boundary. Although these four basins contribute to the resources within the LWRFS, each of them should be administered separately and not be included in the LWRFS due to geologic characteristics that separate them from the proposed Administrative Unit. The total pre-development inflow to LWRFS is estimated to be 62,210 AFY, while the total predevelopment outflow is estimated to be 63,630 AFY.

Order 1303 Issue 2: The information obtained from the Order 1169 aquifer test and subsequent to the aquifer test and Muddy River headwater spring flow as it relates to aquifer recovery since the completion of the aquifer test.

Hydrologic data for extreme southern Nevada indicates that the area has been in long-term below normal hydrologic condition since 2006. Rainfall data from Pahranagat Valley indicates below normal hydrologic conditions existed from 2006 through the end of 2012, but the upgradient basin has been experiencing above normal hydrologic conditions from 2013 through 2017. The hydrologic conditions play an important role in sustainably managing resources in the LWRFS. The period 1982 through 2017 reflects a balanced hydrologic cycle, containing wet periods in the early 1980s and mid-2000s, an average period from 1992 through 2000, and a dry period from 2006 through 2012 (Stetson, 2018). Because interbasin groundwater inflow to the LWRFS impacts groundwater levels in the LWRFS, the Pahranagat Wildlife Refuge rainfall data could be used to describe relative wet and dry cycled. The precipitation and groundwater level data for both extremen southern Nevada and the Pahranagat Wildlife Refuge show that the Order 1169 aquifer test occurred during a prolonged dry period that began in 2006.

A simple Theis solution to estimate impacts to groundwater levels in Muddy River Springs Area, due to pumping in Coyote Spring Valley, may not provide an absolute solution of groundwater level drawdown, but it does provide a relative comparison. Pumping from the carbonate aquifer in Coyote Spring Valley has less impact on groundwater levels in EH-4 than nearby carbonate pumping in the Muddy River Springs Area. The impact to groundwater levels is constrained by the value of transmissivity used to estimate drawdown; smaller values of transmissivity has a greater impact on drawdown when compared to higher values. In order to solve Darcy's equation for total flux from Coyote Spring Valley to Muddy River Springs Area, high values of hydraulic permeability are required to solve the equation. High values of hydraulic permeability result in high values of transmissivity (greater than 280,000 ft^2/day). Therefore, while there is a hydraulic connection between Muddy River Springs Area and Coyote Spring Valley, the high value of transmissivity minimizes the impact of the distal pumping on carbonate groundwater levels.

Pumping from carbonate wells in the Muddy River Springs Area affects the amount of recharge from the carbonate aquifer to the alluvial aquifer (SNWA, 2018). Pumping from the alluvial fill aquifer and surface diversions in the Muddy River Springs Area affects the flow of the Muddy River. Therefore, surface diversions, carbonate pumping, and alluvial pumping in the Muddy River Springs Area affects springs and surface flow that support the Moapa dace and senior decreed water rights. Future goals and objectives for sustainable management should consider location and geologic structure as key factors when establishing triggers and thresholds.

Varying hydrologic conditions, interbasin groundwater inflow from Coyote Spring Valley and Lower Meadow Valley Wash, surface water diversions, and groundwater pumping in the Muddy River Springs area impacts spring and surface water flow along the Muddy River. The data collected since the end of 2012 at EH-4 do not show a continued decline in carbonate groundwater levels that would likely be expected to occur following a two-year prolonged pump test at MX-5. Rather, the data show that as total diversions in the Muddy River Springs Area have declined, groundwater levels have remained stable. As the region experiences future wet cycle comparable to 2004/2005 or the mid-1980s, carbonate groundwater levels at EH-4 will likely show recovery if recent Muddy River Springs Area surface and groundwater production remain constant.

Order 1303 Issue 3: The long-term annual quantity of groundwater that may be pumped from the Lower White River Flow System, including the relationships between the location of pumping on discharge to the Muddy River Springs and the capture of Muddy River flow.

As previously stated above, the amount of water available for appropriation can be calculated based on capture of evapotranspiration and groundwater outflow. The water budget for the LWRFS indicates that pre-development evapotranspiration is 11,930 AFY and outflow toward the Lower Moapa Valley is 51,700 AFY. These values provide a basis for initiating long-term sustainable management in the region. Subsurface outflow from California Wash is estimated by subtracting 32,000 AFY of surface discharge from the 51,700 AFY to yield 19,700 AFY. The amount of evapotranspiration for the LWRFS is estimated to be 11,930 AFY; resulting in the total evapotranspiration and groundwater outflow of 30,630 AFY. Operating under sustainable management techniques that include monitoring, management, and mitigation will allow existing water rights holders to exercise their rights in priority and assess impacts over time and allow the NSE and stakeholders to assess and protect resources as pumping increases toward the maximum value of 30,630 AFY. This initial estimate of sustainable yield allows for senior rights along the Muddy River to be exercised.

Spring flow and surface flow in the Muddy River Springs Area is affected by groundwater and surface water development based on its relative upgradient or downgradient location, local recharge, regional recharge, and boundary conditions. The April 2019 CSAMT survey and groundwater level responses in Coyote Spring Valley show that pumping on the west side of Coyote Spring Valley has no measurable impact on flow to the Muddy River Springs Area. The results from the Theis solution and observations of flow in the Warm Spring West gage since 2013 also show minimal or no impact in the Muddy River Springs Area due to pumping on the eastern side of Coyote Spring Valley. While there is no direct measurement of outflow or evapotranspiration from Coyote Spring Valley, the balanced water budget shown in Table 9 indicates up to 5,280 AFY can be produced from the western side of Coyote Spring Valley without impact to the Muddy River Springs Area.

Order 1303 Issue 4: The effects of movement of water rights between alluvial wells and carbonate wells on deliveries to senior decreed rights to the Muddy River.

Groundwater pumping from the carbonate aquifer affects the flow from the carbonate aquifer to the alluvial basin, which then affects the flow from the alluvial basin to the Muddy River. All groundwater pumping, regardless of which aquifer it is pumped from, will eventually affect the flow of the Muddy River or subflow out of the LWRFS. Two factors that must be addressed are the well's location and the delay between pumping and impact.

The location of the well with respect to the entire Muddy River, not just the portion of the river in the Muddy River Springs Area, should be addressed when considering impacts to senior decreed water rights. Regional groundwater flow from California Wash and Lower Meadow Valley Wash supports Muddy River streamflow, not just discharge in the Muddy River Springs Area. The Muddy River may act as both a losing and gaining river as it flows from Moapa through Glendale and eventually toward Overton and Lake Mead. Extractions may have a 1:1 impact on streamflow or they may act to reduce subsurface groundwater flow out of the LWRFS boundary.

Groundwater pumping from the carbonate aquifer will have a delayed response on surface flow of the Muddy River depending on its location. Groundwater pumping from the alluvial aquifer will likely have a relatively immediate impact on streamflow, when compared to carbonate aquifer pumping. Under sustainable management conditions, future adaptive techniques may be available to affect short-term changes such that a reduction in alluvial pumping may immediately impact available water supplies. But, in order to manage the LWRFS over a long-term sustainable period, groundwater pumping from the alluvial and carbonate aquifers should be considered equally. The movement of water rights between alluvial wells and carbonate wells will only serve to shift the timing and location of impacts and not the amount of the impact.

6.3 SUMMARY OF CONCLUSIONS

Groundwater in the carbonate aquifer of southeastern Nevada generally follows a north-south direction along normal faults and structural boundaries. Basin and Range aged related fault zones create preferred pathways for groundwater flow since they formed through extensional faulting creating open spaces and fractures for groundwater flow. Within the LWRFS, these normal faults extend north-to-south through Coyote Spring Valley from Pahranagat and Delamar Valleys toward the Hidden Valley. Recent April 2019 CSAMT survey data show preferred pathways for groundwater flow occur through Coyote Spring Valley toward Hidden Valley and the Muddy River Springs Area through a sub-parallel fault system. The LWRFS contains a series of parallel and sub-parallel north-south trending faults that is bounded in the north west by the Pahranagat Shear Zone and the south by the Las Vegas Shear Zone and Lake Mead. The following results and conclusions provide the basis for structuring any final order arising from Order 1303:

a. Groundwater flow in the carbonate rock aquifer cannot be defined by topographic boundaries that control the flow of surface water. The LWRFS should account for inflow from Lower Meadow Valley Wash to sustainably manage the resources.

b. The carbonate aquifer beneath the entire modified Colorado River Flow System boundary, not just that portion below Coyote Spring Valley, contributes to groundwater resources in Hidden Valley, Garnett Valley, Muddy River Springs Area, California Wash, and the Black Mountains Area. Contributions from Lower Meadow Valley Wash must be accounted for when assessing water resources in the LWRFS.

c. Identification of faults and structural features are the first step in assessing groundwater resources in the carbonate rock aquifer.

d. Normal (extensional) faults create preferred pathways for groundwater flow, in a direction parallel to the fault, throughout the regional carbonate aquifer. They also can act as a barrier to flow in the perpendicular direction to the strike of the fault.

e. The April 2019 CSAMT survey identified normal (extensional) faults in Coyote Spring Valley the control the movement of groundwater. Interbasin groundwater flow occurs toward both Muddy River Springs Area and Hidden and Garnet Valleys.

f. Normal (extensional) faults in the Coyote Spring Valley define a carbonate structural carbonate block that creates preferred flow paths that separate groundwater flow to Muddy River Springs Area from flow towards Hidden and Garnet Valleys.

g. Regional and local groundwater recharge to LWRFS is estimated to be 62,240 AFY. Total outflow, including subsurface outflow and evapotranspiration is 63,630 AFY.

h. Regional interbasin groundwater recharge to Coyote Spring Valley is estimated to be 50,700 AFY. Total groundwater flow is approximately 55,980 AFY, including 5,280 AFY local recharge.

i. Regional groundwater outflow from Coyote Spring Valley to Muddy River Springs Area and Hidden and Garnet Valleys under pre-development conditions is estimated to be 55,980 AFY,

j. Groundwater levels in monitoring wells located west of the structural block in Coyote Spring Valley are not affected by groundwater pumping in Muddy River Springs Area or pumping from MX-5 and CSI-2.

k. Development of locally derived groundwater from wells on the west side of the structural block in the Coyote Spring Valley will not affect decreed water rights on the Muddy River, springs in the Muddy River Springs Area, or habitat that supports the Moapa dace

l. Local recharge in Coyote Spring Valley from the Sheep Range is contained west of a structural carbonate block that limits its contribution to the Muddy River Springs Area.

m. An initial long-term *adequate and sustainable* supply of groundwater in the LWRFS is 30,630 AFY, based the total estimated evapotranspiration and subsurface outflow. Because existing groundwater pumping is much less than the initial estimate, adaptive management techniques can be used to adjust this value in the future based on hydrologic conditions and groundwater development.

n. Up to 5,280 AFY of local recharge may be pumped from the Coyote Spring Valley each year over the long-term without directly affecting the regional groundwater discharge in the Muddy River Springs Area.

7.0 REFERENCES

Avon, L. and Durbin, T.J., 1994. Evaluation of the Maxey-Eakin method for estimating recharge to ground-water basins in Nevada. *Journal of the American Water Resources Association*, *30*(1), pp.99-111.

Daly, C., R.P. Neilson, and D.L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. *J. Appl. Meteor.*, 33, 140-158.

Daly, C., G. Taylor, and W. Gibson. 1997. The PRISM approach to mapping precipitation and temperature. *10th AMS Conf. on Applied Climatology*, Reno, NV, 10-12.

Daly, C., G.H. Taylor, W. P. Gibson, T.W. Parzybok, G. L. Johnson, P. Pasteris. 2001. High-quality spatial climate data sets for the United States and beyond. *Transactions of the American Society of Agricultural Engineers*, 43: 1957-1962.

Dettinger, Michael D, 1989. Reconnaissance estimates of natural recharge to desert basins in Nevada, USA, by using chloride balance calculations. *Journal of Hydrology*, 106 (1989) 55-78.

Eakin, T.E., 1964. Ground-water appraisal of Coyote Spring and Kane Spring Valleys and Muddy River Springs Area: Lincoln and Clark Counties, Nevada. Department of Conservation and Natural Resources.

Eakin, T.E., 1966. A Regional Interbasin Ground-water System in the White River Areas, southeastern Nevada. Water Resources Research, *Water Resources Research,* 2: 251-271.

Epstein, Brian Jeffery, 2004. Development and uncertainty analysis of empirical recharge prediction models for Nevada's desert basins. University of Nevada, Reno thesis dissertation.

Epstein, Brian Jeffery, et. al., 2010. Development and uncertainty analysis of empirical recharge prediction models for Nevada's desert basins. *Journal of the Nevada Water Resources Association*, 1 (2010) 1-22.

Great Basin Water Network, 2013, Technical Memorandum Comments on Carbonate Order 1169 Pump Test Data and the Groundwater Flow System in Coyote Spring and Muddy River Springs Valley, Nevada. Prepared by Tom Myers, Ph.D., June 12, 2013.

Hardman, G., 1936. Nevada precipitation and acreages of land by rainfall zones. University of Nevada Experimental Station, Reno, Nevada.

Hardman, George, 1962. Precipitation map of Nevada. Nevada Department of Conservation and Natural Resources.

Johnson, M.E., 2006. Drilling and Development of CSI Well No. 4 for Coyote Springs Investment LLC, Coyote Spring Valley, Clark County, Nevada.

Kirk, S.T. and Campana, M.E., 1990. A Deuterium-calibrated groundwater flow model of a regional carbonate-alluvial system: Desert Research Institue, Reno, Nevada. *Journal of Hydrology v. 119.* pp. 357-388.

Lamke, Robert D., Moore, Donald O., 1965. Interim inventory of surface water resources of Nevada. Water Resources Bulletin No. 30.

Levy M, Christie-Blick N., 1989. Pre-Mesozoic Palinspastic Reconstruction of the Eastern Great Basin (Western United States). Science 1989 Sep 29;245(4925):1454-62.

Lopes, T.J. and Evetts, D.M., 2004. Ground-water pumpage and artificial recharge estimates for calendar year 2000 and average annual natural recharge and interbasin flow by hydrographic area, Nevada. US Department of the Interior, US Geological Survey.

Maxey, G.B. and Eakin, T.E., 1949. Ground water in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada. Water Resources Bulletin No. 8.

Moapa Band of Paiutes, June 2013. Summary of Order 1169 Testing Impacts, per Order 1169A. Prepared by Cady Johnson and Martin Mifflin.

Nevada Division of Water Resources, 2017. Designated Groundwater Basins of Nevada: Office of the State Engineer, Carson City, Nevada. Map.

Nevada Division of Water Resources, 1971. Nevada's Water Resources, prepared by Nevada State Engineer. Water for Nevada Report No. 3.

Nichols, W.D., 2000. Regional ground-water evapotranspiration and ground-water budgets, Great Basin, Nevada. U.S. Geological Survey Professional Paper No. 1628.

PRISM Climate Group, Oregon State University. 2015. 30-year normal precipitation: Annual; Period: 1981-2010. Resolution: 800 meters. http://prism.oregonstate.edu

Rowley, P.D., Dixon, G. L., Mankinen, E.A., Pari, K.T., Mcphee D. K., et al., 2017. Geology and Geophysics of White Pine and Lincoln Counties, Nevada, and Adjacent Parts of Nevada and

Utah: The Geologic Framework of Regional Groundwater Flow Systems. Nevada Bureau of Mines and Geology Report 56.

Southern Nevada Water Authority, 2018. Assessment of Water Resource Conditions in the Lower White River Flow System: Southern Nevada Water Authority, Las Vegas, Nevada, Doc. No. WRD-ED-0051, 116 p.

Southern Nevada Water Authority, June 2013. Nevada State Engineer Order 1169 and 1169A Study Report.

Southern Nevada Water Authority, June 2007. Water-Resources Assessment and Hydrogeologic Report for Cave, Dry Lake, and Delamar Valleys. Presentation to the Office of the Nevada State Engineer.

Southern Nevada Water Authority, June 2006. Derivation of a spatial distribution of areal recharge from estimates based on estimates reported in reconnaissance investigation reports for the Spring Valley Area. Presentation to the Office of the Nevada State Engineer Volume 2.

Stetson Engineers, December 13, 2018. Technical Memorandum to Nevada State Engineer from Stetson Engineers

Telford, W.M, Geldart, L.P., Sheriff, R.E., Keys, D.A., 1976. Applied Geophysics. Cambridge University Press.

Thomas, J.M., Welch, A.H. and Dettinger, M.D., 1996. Geochemistry and isotope hydrology of representative aquifers in the Great Basin region of Nevada, Utah, and adjacent states. U.S. Geological Survey Professional Paper 1409-C.

Thomas, J.M., Calhoun, S.C., Apambire, W.B., May 2001. A deuterium Mass-balance Interpretation of Groundwater Sources and Flows in Southern Nevada. DRI, Publication No. 41169.

Thomas, J.M., Mihevc., T.M, 2011. Evaluation of Groundwater Origins, Flow Paths, and Ages in East-Central and Southeastern Nevada. DRI, Publication No. 41253

U.S. Department of the Interior (DOI), June 2013. Test Impacts and Availability of Water Pursuant to Applications Pending Under Order 1169, U.S. Fish and Wildlife

U.S. Geological Survey, 2019. USGS National Map Data Collection: U.S. Geological Survey. https://viewer.nationalmap.gov/basic/

U.S. Geological Survey, 2017. 1/3rd arc-second digital elevation models (DEMs) - USGS National Map 3DEP Downloadable Data Collection: U.S. Geological Survey. https://viewer.nationalmap.gov/basic/

U.S. Geological Survey, 2016. Watershed boundary data Set for HUC 15010012 - USGS National Map. Downloadable Data Collection: U.S. Geological Survey. https://viewer.nationalmap.gov/basic/

U.S. Geological Survey, 2007. Water Resources of the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and adjacent Areas in Nevada and Utah. Scientific Investigations Report 2007–5261

U.S. Geological Survey, 1989. Basic Ground-Water Hydrology. U.S. Geological Survey Water Supply Page 2220.

Watson, P., Sinclair, P. and Waggoner, R., 1976. Quantitative evaluation of a method for estimating recharge to the desert basins of Nevada. *Journal of Hydrology*, 31(3-4), pp.335-357.

Appendix A

General Grouping of Geologic Layers

STETSON
ENGINEERS INC.

DRAFT NOTE TO FILE

785 Grand Avenue, Suite 202 • Carlsbad, California • 92008
Phone: (760) 730-0701 FAX: (415) 457-1638 Web site: www.stetsonengineers.com

TO: File
DATE: April 26, 2019
FROM: Nichole Weedman
JOB NO: 2674-002
RE: Grouping of Geologic Units in the Lower White River Flow System, Nevada.

1.0. GEOLOGIC UNITS

Rawley et al. (2017) mapped twenty-two geologic units within the Lower White River Flow System (LWRFS). These units range in age from Cambrian to Quaternary, and compose the three aquifers observed in the Lower White River Flow System: the carbonate aquifer (oldest), the volcanic aquifer and the alluvial aquifer (youngest). Due to density of individual geologic units, units were grouped based on water-bearing properties, rock type, and age. Description of units grouped can be found in Table 1.

2.0. PALEOZOIC BASEMENT AND CARBONATE ROCKS

Paleozoic rock units found in the LWRFS were grouped as 1) Basement or 2) Paleozoic Carbonate Rocks based largely on rock type and presence within the carbonate rock aquifer.

Middle Cambrian to late Proterozoic (CpCs)

- This rock unit was grouped as Paleozoic Basement Rock. CpCs is composed largely of metamorphic quartzite with minor limestone and shale. Based upon rock type and Rowley, et al.'s (2017) definition of the lower aquifer, it can be inferred that this geologic unit is not part of the carbonate rock aquifer. CpCs was classified as Paleozoic Basement.

Upper to Middle Cambrian (Cm)

- Cm was grouped with the Paleozoic Carbonate Rock unit. Rowley, et al. (2017) defined this unit as "a thick limestone sequence that marks the base of the lower carbonate rock aquifer." Inclusion within the carbonate rock aquifer was the reason this unit was grouped as Paleozoic Carbonate Rock.

TABLE 1. LOWER WHITE RIVER FLOW SYSTEM

Era	NV Bureau of Mines Units (Rowley, et al., 2017)	Grouped Units[1]
Cenozoic	QTa	Basin Fill
	QTB	Volcanic
	Ts4	Basin Fill
	Tt4	Volcanic
	Tt3	Volcanic
	Tt2	Volcanic
	Ta5	Volcanic
	Ti	Volcanic
Mesozoic	Ks	Sedimentary
	Js	Sedimentary
	^s	Sedimentary
Paleozoic	Pp	Carbonate
	Par	Carbonate
	P*	Carbonate
	MD	Carbonate
	Du	Carbonate
	Ds	Carbonate
	Ol	Carbonate
	Cc	Carbonate
	Cu	Carbonate
	Cm	Carbonate
	CpCs	Basement

---

[1] Units were grouped as of Paleozoic Basement, Paleozoic Carbonate Rocks, Mesozoic Sedimentary Rocks, Cenozoic Volcanic Rocks, or Cenozoic Basin Fill

Lower Ordovician? to Upper Cambrian (Cu)

- This unit was grouped as Paleozoic Carbonate Rock based on rock type (undivided limestone and shale) and map contacts. Cu was in contact with numerous other rock units grouped as Paleozoic Carbonate Rocks, and was observed in the surrounding ranges.

Cambrian (Cc)

- Cc was grouped as Paleozoic Carbonate Rock based on the rock type (undivided carbonate sedimentary rock).

Middle to Lower Ordovician (Ol)

- Ol was grouped as Paleozoic Carbonate Rock. Although this unit is composed largely of quartzite, two dolomite formations (Laketown and Ely Springs) are present in the LWRFS allowing this unit to be grouped with the Paleozoic Carbonate Rock unit.

Middle to Lower Devonian (Ds)

- Ds was grouped as Paleozoic Carbonate Rock due to rock type (undivided dolomite).

Devonian (Du)

- Like Ds, this geologic unit was grouped as Paleozoic Carbonate Rock based on its rock type (undivided carbonate sedimentary rocks).

Lower Mississippian to Upper Devonian (MD)

- This unit was grouped as Paleozoic Carbonate Rock based on rock type. In the LWRFS MD is composed primarily of limestone.

Lower Permian to Pennsylvanian (P*)

- P* was grouped with Paleozoic Carbonate Rock based on rock type (limestone).

Lower Permian (Par)

- Par was included with Paleozoic Carbonate Rock although it is not carbonate. Par is an undivided sandstone unit within the carbonate rock aquifer (Rowley, et al., 2017). Due to its inclusion within the carbonate aquifer, Par was grouped with carbonate rocks.

Upper and Lower Permian (Pp)

- This unit was included with Paleozoic Carbonate Rock based on rock type as well as the unit's water-bearing properties. This unit is composed of limestone and marks the top of the carbonate aquifer (Rowley et al., 2017).

3.0. MESOZOIC SEDIMENTARY ROCKS

Mesozoic sedimentary rocks found in the LWRFS were grouped as a separate unit. This decision was made based on the unit's age and low-permeability. Mesozoic Sedimentary Rocks found in the LWRFS include Triassic (TRs), Jurassic (Ji), and Upper and Lower Cretaceous (Ks). These units are composed of clastic, fluvial deposits.

4.0. CENOZOIC VOLCANIC AND BASIN FILL ROCK UNITS

Cenozoic rock units observed in the LWRFS were grouped as Cenozoic Volcanic Rocks or Cenozoic Basin Fill. The grouping of units was based on rock type as well as water-bearing properties. Volcanic Rocks observed in the LWRFS are the result of surrounding caldera complexes and compose the volcanic rock aquifer. The remaining basin fill observed in the LWRFS formed as a result of fluvial deposits, and compose the alluvial aquifer.

Miocene to Paleocene (Ti)

- Ti was grouped as Cenozoic Volcanic Rock based on rock type and map contacts. Ti is an intrusive pluton formed from the intrusion of magma into another rock body. This rock unit was grouped with Cenozoic Volcanic Rocks because plutonic and volcanic rocks form through similar processes, however plutonic rocks cool underground whereas volcanic rocks cool above ground.

Miocene (Ta4)

- Ta4 was grouped as Cenozoic Volcanic Rock based on rock type. This unit is composed of lava flows.

Oligocene (Tt2), Miocene to Oligocene (Tt3), and Miocene (Tt4)

- Tt2, Tt3, and Tt4 were grouped as Cenozoic Volcanic Rock based on rock type. All three units are poorly to densely welded ash-flow tuffs with interbedded ash-fall tuffs.

Miocene (Ts4)

- Ts4 was grouped a Cenozoic Basin Fill based on Rowley, et al.'s (2017) definition of Ts4 as "a basal basin-fill sedimentary unit."

Holocene to lower Miocene (QTb)

- QTb is the final unit observed in the LWRFS grouped as Cenozoic Volcanic Rock. Rowley, et al. (2017) stated QTb is "The mafic end of the bimodal volcanic sequence."

Holocene to lower Miocene (QTa)

- QTa was grouped as the final Cenozoic Basin Fill unit observed in the LWRFS. This unit was formed through fluvial processes and forms the alluvial aquifer.

5.0. REFERENCES

Rowley, P.D., Dixon, G.L., Mankinen, E.A., Pari, K.T., McPhee, D.K., McKee, E.H., Burns, A.G., Watrus, J.M., Ekren, E.B., Patrick, W.G., and Brandt, J.M., 2017, Geology and geophysics of White Pine and Lincoln Counties, Nevada, and adjacent parts of Nevada and Utah: The geologic framework of regional groundwater flow systems: Nevada Bureau of Mines and Geology Report 56.

Appendix B

Hydrologic and Physical Properties of Rocks

Telford, W.M, Geldart, L.P., Sheriff, R.E., Keys, D.A., 1976. Applied Geophysics. Cambridge University Press. pp 454-455.

Ore	Other minerals	Gangue	$\rho(\Omega m)$
Graphitic slate			0·13
Graphite, massive			10^{-4}–5×10^{-3}
MoS_2			2×10^2–4×10^3
MnO_2 colloidal ore			1·6
Cu_2S			3×10^{-2}
$CuFeS_2$			10^{-4}–1
$CuFeS_2$ 80%	10% FeS	10%	0·66
$CuFeS_2$ 90%	2% FeS	8% SiO_2	0·65
$FeCr_2O_4$			10^3
$FeCr_2O_4$ 95%		5% Serp.	$1{\cdot}2 \times 10^4$

Tables 5.4 and 5.5 list typical values for rocks and unconsolidated formations. The ranges here are quite similar to water, which obviously is the controlling factor in many rocks.

Table 5.4. *Resistivities of igneous and metamorphic rocks*

Rock type	Resistivity range (Ωm)
Granite	3×10^2–10^6
Granite porphyry	$4{\cdot}5 \times 10^3$ (wet)–$1{\cdot}3 \times 10^6$ (dry)
Feldspar porphyry	4×10^3 (wet)
Albite	3×10^2 (wet)–$3{\cdot}3 \times 10^3$ (dry)
Syenite	10^2–10^6
Diorite	10^4–10^5
Diorite porphyry	$1{\cdot}9 \times 10^3$ (wet)–$2{\cdot}8 \times 10^4$ (dry)
Porphyrite	10–5×10^4 (wet)–$3{\cdot}3 \times 10^3$ (dry)
Carbonatized porphyry	$2{\cdot}5 \times 10^3$ (wet)–6×10^4 (dry)
Quartz porphyry	3×10^2–9×10^5
Quartz diorite	2×10^4–2×10^6 (wet)–$1{\cdot}8 \times 10^5$ (dry)
Porphyry (various)	60–10^4
Dacite	2×10^4 (wet)
Andesite	$4{\cdot}5 \times 10^4$ (wet)–$1{\cdot}7 \times 10^2$ (dry)
Diabase porphyry	10^3 (wet)–$1{\cdot}7 \times 10^5$ (dry)
Diabase (various)	20–5×10^7
Lavas	10^2–5×10^4
Gabbro	10^3–10^6
Basalt	10–$1{\cdot}3 \times 10^7$ (dry)
Olivine norite	10^3–6×10^4 (wet)
Peridotite	3×10^3 (wet)–$6{\cdot}5 \times 10^3$ (dry)
Hornfels	8×10^3 (wet)–6×10^7 (dry)
Schists (calcareous and mica)	20–10^4
Tuffs	2×10^3 (wet)–10^5 (dry)
Graphite schist	10–10^2
Slates (various)	6×10^2–4×10^7
Gneiss (various)	$6{\cdot}8 \times 10^4$ (wet)–3×10^6 (dry)
Marble	10^2–$2{\cdot}5 \times 10^8$ (dry)
Skarn	$2{\cdot}5 \times 10^2$ (wet)–$2{\cdot}5 \times 10^8$ (dry)
Quartzites (various)	10–2×10^8

Table 5.5. *Resistivities of sediments*

Rock type	Resistivity range (Ωm)
Consolidated shales	20–2×10^3
Argillites	10–8×10^2
Conglomerates	2×10^3–10^4
Sandstones	1–$6{\cdot}4 \times 10^8$
Limestones	50–10^7
Dolomite	$3{\cdot}5 \times 10^2$–5×10^3
Unconsolidated wet clay	20
Marls	3–70
Clays	1–100
Alluvium and sands	10–800
Oil sands	4–800

Very roughly, igneous rocks have the highest resistivity, sediments the lowest, with metamorphic rocks intermediate. However, there is considerable overlapping, as in other physical properties. In addition, the resistivities of particular rock types vary directly with age and lithology, since the porosity of the rock and salinity of the contained water are affected by both. For example, the resistivity range of Precambrian volcanics is 200–5000 Ωm, while for Quaternary rocks of the same kind it is 10–200 Ωm.

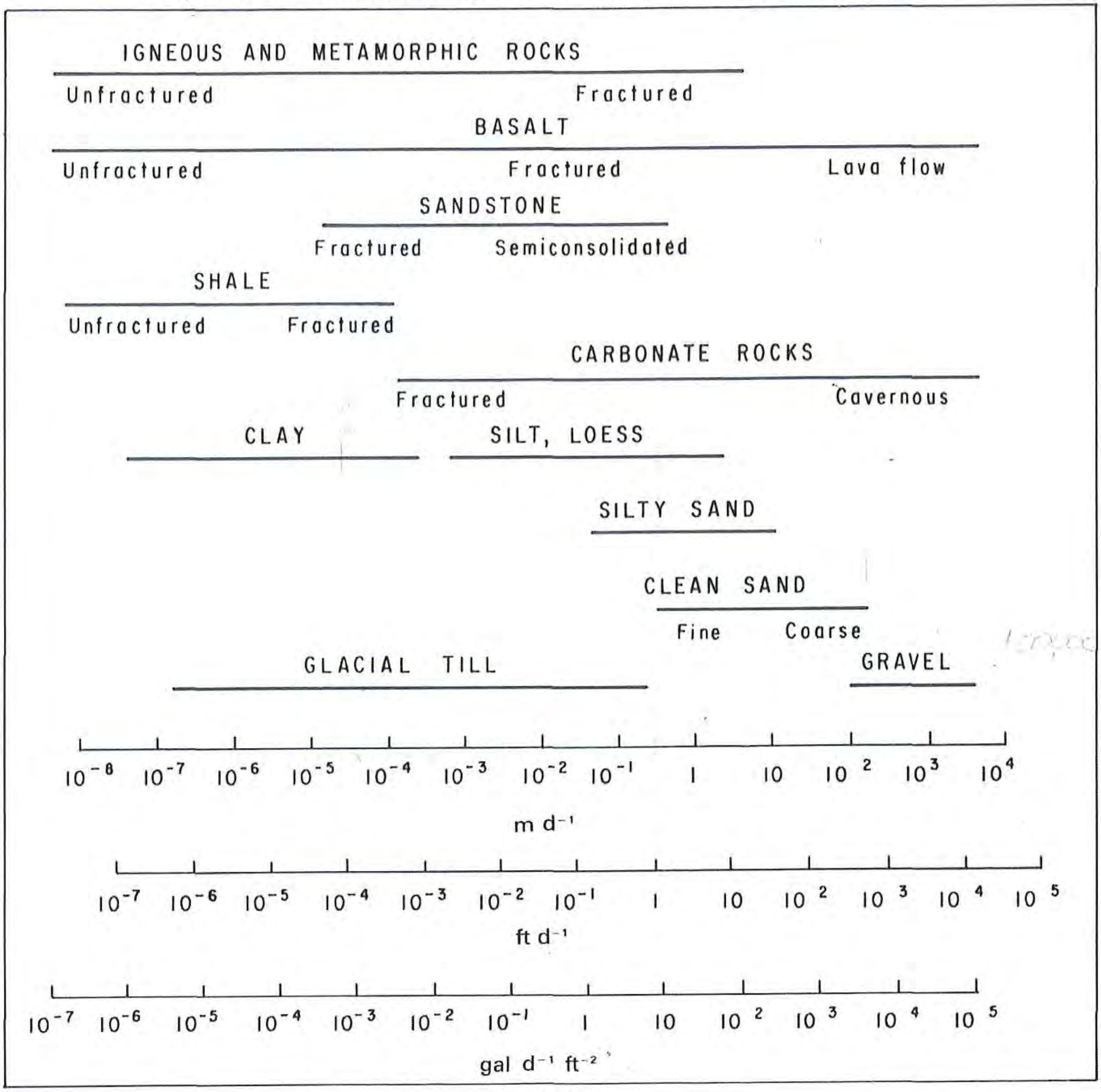
The effect of water content on the bulk resistivity of rocks has been frequently mentioned and is evident from table 5.4. Further data are listed in table 5.6, where samples with variable amounts of water are shown. In all cases a small change in the percentage of water effects the resistivity enormously.

Table 5.6. *Variation of rock resistivity with water content*

Rock	% H_2O	$\rho(\Omega m)$	Rock	% H_2O	$\rho(\Omega m)$
Siltstone	0·54	$1{\cdot}5 \times 10^4$	Pyrophyllite	0·76	6×10^6
Siltstone	0·44	$8{\cdot}4 \times 10^6$	Pyrophyllite	0·72	5×10^7
Siltstone	0·38	$5{\cdot}6 \times 10^8$	Pyrophyllite	0·7	2×10^8
Coarse grain SS	0·39	$9{\cdot}6 \times 10^5$	Pyrophyllite	0	10^{11}
Coarse grain SS	0·18	10^8	Granite	0·31	$4{\cdot}4 \times 10^3$
Medium grain SS	1·0	$4{\cdot}2 \times 10^3$	Granite	0·19	$1{\cdot}8 \times 10^6$
Medium grain SS	1·67	$3{\cdot}2 \times 10^6$	Granite	0·06	$1{\cdot}3 \times 10^8$
Medium grain SS	0·1	$1{\cdot}4 \times 10^8$	Granite	0	10^{10}
Graywacke SS	1·16	$4{\cdot}7 \times 10^3$	Diorite	0·02	$5{\cdot}8 \times 10^5$
Graywacke SS	0·45	$5{\cdot}8 \times 10^4$	Diorite	0	6×10^6
Arkosic SS	1·26	10^3	Basalt	0·95	4×10^4
Arkosic SS	1·0	$1{\cdot}4 \times 10^3$	Basalt	0·49	9×10^5
Organic limestone	11	$0{\cdot}6 \times 10^3$	Basalt	0·26	3×10^7
Dolomite	2	$5{\cdot}3 \times 10^3$	Basalt	0	$1{\cdot}3 \times 10^8$
Dolomite	1·3	6×10^3	Olivine-pyrox.	0·028	2×10^4
Dolomite	0·96	8×10^3	Olivine-pyrox.	0·014	4×10^5
Peridotite	0·1	3×10^3	Olivine-pyrox.	0	$5{\cdot}6 \times 10^7$
Peridotite	0·03	2×10^4			
Peridotite	0·016	10^6			
Peridotite	0	$1{\cdot}8 \times 10^7$			

U.S. Geological Survey, 1989. Basic Ground-Water Hydrology. U.S. Geological Survey Water Supply Page 2220. pp. 13, 36, 37.

Hydraulic Conductivity of Selected Rocks



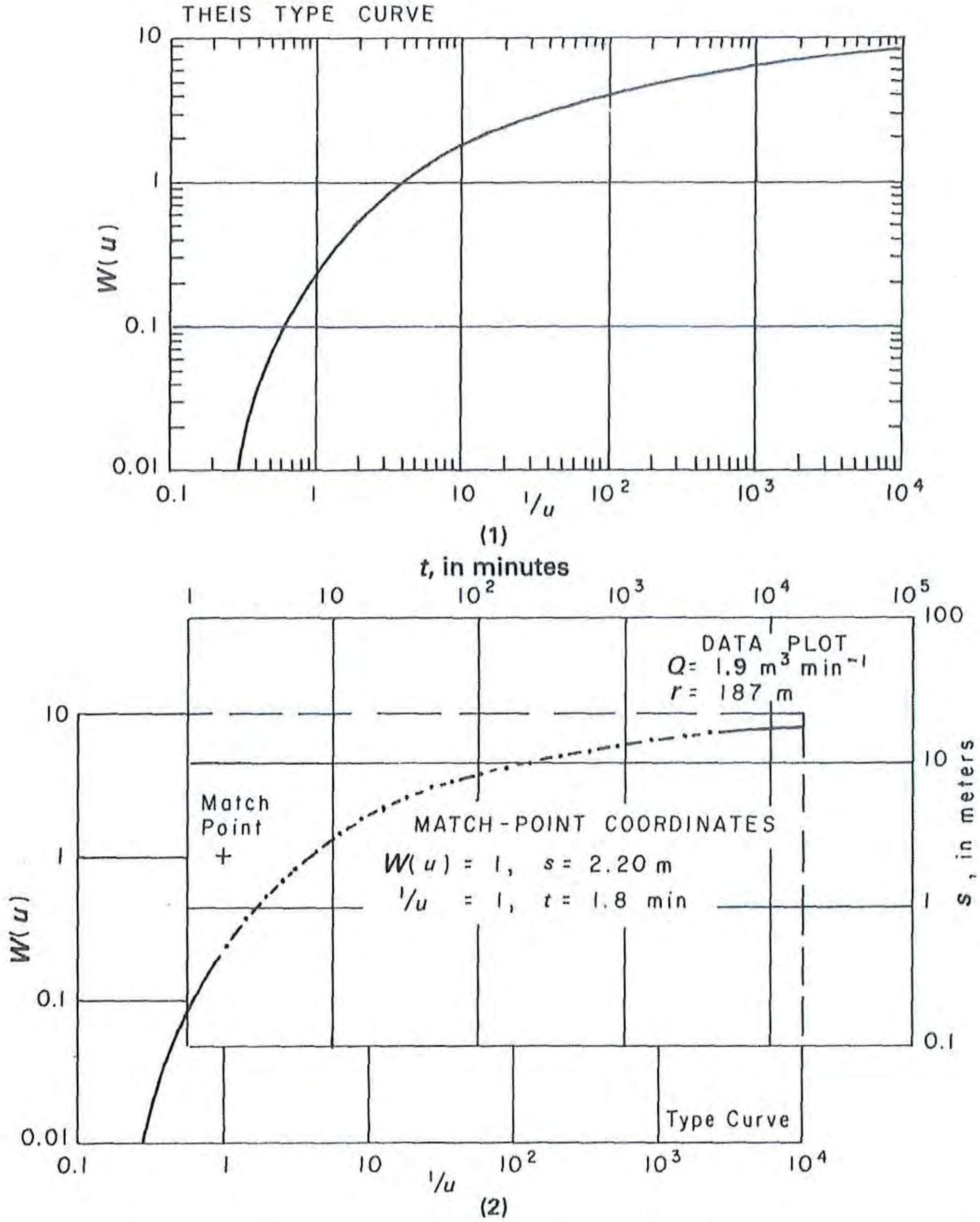
(2)

that area is said to be *homogeneous*. If, on the other hand, the hydraulic conductivity differs from one part of the area to another, the aquifer is said to be *heterogeneous*.

Hydraulic conductivity may also be different in different directions at any place in an aquifer. If the hydraulic conductivity is essentially the same in all directions, the aquifer is said to be *isotropic*. If it is different in different directions, the aquifer is said to be *anisotropic*.

Although it is convenient in many mathematical analyses of ground-water flow to assume that aquifers are both homogeneous and isotropic, such aquifers are rare, if they exist at all. The condition most commonly encountered is for hydraulic conductivity in most rocks and especially in unconsolidated deposits and in flat-lying consolidated sedimentary rocks to be larger in the horizontal direction than it is in the vertical direction.

ANALYSIS OF AQUIFER-TEST DATA



In 1935, C. V. Theis of the New Mexico Water Resources District of the U.S. Geological Survey developed the first equation to include time of pumping as a factor that could be used to analyze the effect of withdrawals from a well. Thus, the *Theis equation* permitted, for the first time, determination of the hydraulic characteristics of an aquifer before the development of new steady-state conditions resulting from pumping. The importance of this capability may be realized from the fact that, under most conditions, a new steady state cannot be developed or that, if it can, many months or years may be required.

Theis assumed in the development of the equation that:

1. The transmissivity of the aquifer tapped by the pumping well is constant during the test to the limits of the cone of depression.
2. The water withdrawn from the aquifer is derived entirely from storage and is discharged instantaneously with the decline in head.
3. The discharging well penetrates the entire thickness of the aquifer, and its diameter is small in comparison with the pumping rate, so that storage in the well is negligible.

These assumptions are most nearly met by confined aquifers at sites remote from their boundaries. However, if certain precautions are observed, the equation can also be used to analyze tests of unconfined aquifers.

The forms of the Theis equation used to determine the transmissivity and storage coefficient are

$$T = \frac{Q\,W(u)}{4\pi s} \tag{1}$$

$$S = \frac{4Ttu}{r^2} \tag{2}$$

where T is transmissivity, S is the storage coefficient, Q is the pumping rate, s is drawdown, t is time, r is the distance from the pumping well to the observation well, $W(u)$ is the well function of u, which equals

$$-0.577216 - \log_e u + u - \frac{u^2}{2\times 2!} + \frac{u^3}{3\times 3!} - \frac{u^4}{4\times 4!} + \ldots$$

and $u = (r^2S)/(4Tt)$.

The form of the Theis equation is such that it cannot be solved directly. To overcome this problem, Theis devised a convenient graphic method of solution that involves the use of a type curve (1). To apply this method, a data plot of drawdown versus time (or drawdown versus t/r^2) is matched to the type curve of $W(u)$ versus $1/u$ (2). At some convenient point on the overlapping part of the sheets containing the data plot and type curve, values of s, t (or t/r^2), $W(u)$, and $1/u$ are noted (2). These values are then substituted in equations 1 and 2, which are solved for T and S, respectively.

A Theis type curve of $W(u)$ versus $1/u$ can be prepared from the values given in the table contained in the preceding section, "Aquifer Tests." The data points are plotted on logarithmic graph paper—that is, graph paper having logarithmic divisions in both the x and y directions.

The dimensional units of transmissivity (T) are L^2t^{-1}, where L is length and t is time in days. Thus, if Q in equation 1 is in cubic meters per day and s is in meters, T will be in square meters per day. Similarly, if, in equation 2, T is in square meters per day, t is in days, and r is in meters, S will be dimensionless.

Traditionally, in the United States, T has been expressed in units of gallons per day per foot. The common practice now is to report transmissivity in units of square meters per day or square feet per day. If Q is measured in gallons per minute, as is still normally the case, and drawdown is measured in feet, as is also normally the case, equation 1 is modified to obtain T in square feet per day as follows:

$$T = \frac{Q\,W(u)}{4\pi s} = \frac{\text{gal}}{\text{min}} \times \frac{1{,}440\ \text{min}}{\text{d}} \times \frac{\text{ft}^3}{7.48\ \text{gal}} \times \frac{1}{\text{ft}} \times \frac{W(u)}{4\pi}$$

or

$$T(\text{in ft}^2\ \text{d}^{-1}) = \frac{15.3Q\,W(u)}{s}$$

(when Q is in gallons per minute and s is in feet). To convert square feet per day to square meters per day, divide by 10.76.

The storage coefficient is dimensionless. Therefore, if T is in square feet per day, t is in minutes, and r is in feet, then, by equation 2,

$$S = \frac{4Ttu}{r^2} = \frac{4}{1} \times \frac{\text{ft}^2}{\text{d}} \times \frac{\text{min}}{\text{ft}^2} \times \frac{\text{d}}{1{,}440\ \text{min}}$$

or

$$S = \frac{Ttu}{360\,r^2}$$

(when T is in square feet per day, t is in minutes, and r is in feet).

Analysis of aquifer-test data using the Theis equation involves plotting both the type curve and the test data on logarithmic graph paper. If the aquifer and the conditions of the test satisfy Theis's assumptions, the type curve has the same shape as the cone of depression along any line radiating away from the pumping well and the drawdown graph at any point in the cone of depression.

Use of the Theis equation for unconfined aquifers involves two considerations. First, if the aquifer is relatively fine grained, water is released slowly over a period of hours or days, not instantaneously with the decline in head. Therefore, the value of S determined from a short-period test may be too small.

Second, if the pumping rate is large and the observation well is near the pumping well, dewatering of the aquifer may be significant, and the assumption that the transmissivity of the aquifer is constant is not satisfied. The effect of dewatering of the aquifer can be eliminated with the following equation:

$$s' = s - \left(\frac{s^2}{2b}\right) \tag{3}$$

where s is the observed drawdown in the unconfined aquifer, b is the aquifer thickness, and s' is the drawdown that would have occurred if the aquifer had been confined (that is, if no dewatering had occurred).

To determine the transmissivity and storage coefficient of an unconfined aquifer, a data plot consisting of s' versus t (or t/r^2) is matched with the Theis type curve of $W(u)$ versus $1/u$. Both s and b in equation 3 must be in the same units, either feet or meters.

As noted above, Theis assumed in the development of his equation that the discharging well penetrates the entire thickness of the aquifer. However, because it is not always possible, or necessarily desirable, to design a well that fully penetrates the aquifer under development, most discharging wells are open to only a part of the aquifer that they draw from. Such *partial penetration* creates vertical flow in the vicinity of the discharging well that may affect drawdowns in observation wells located relatively close to the discharging well. Drawdowns in observation wells that are open to the same zone as the discharging well will be larger than the drawdowns in wells at the same distance from the discharging well but open to other zones. The possible effect of partial penetration on drawdowns must be considered in the analysis of aquifer-test data. If aquifer-boundary and other conditions permit, the problem can be avoided by locating observation wells beyond the zone in which vertical flow exists.

Appendix C

Estimates of Recharge, Evapotranspiration, and Groundwater Flow in the LWRFS

Appendix C - Estimates of Recharge, ET, and GW Outflow in the LWRFS

LWRFS Local Recharge (AFY)

	Basin						
Source	CSV	MRSA	HV	GV	CW	BMA	**Total[g]**
Recon	2,000	0	400	400	100	100	**2,900**
Eakin 1966[a]	2,600	0	400	400	100	100	**3,500**
NDWR 1971	1,900	100	400	400	100	100	**2,900**
Kirk 1990[b]	5,014	NE	NE	NE	NE	NE	**5,014**
Kirk 1990[c]	6,012	NE	NE	NE	NE	NE	**6,012**
USGS 1996	14,000	NE	NE	NE	NE	NE	**14,000**
DRI 2001	4,000	300	300	400	300	500	**5,300**
LVVWD 2001	4,000	237	339	393	311	438	**5,280**
BCM 2004[d]	5,184	12	188	294	23	54	**5,701**
BCM 2004[e]	5,951	207	571	1,000	652	1,470	**8,381**
Epstein 2004[f]	5,815	509	521	976	1,738	3,178	**9,559**
USGS 2004	2,100	NE	400	400	60	70	**2,960**
DRI 2007	2,300	0	0	100	0	0	**2,400**
SNWA 2007	2,128	38	42	96	0	0	**2,304**
SNWA 2009	2,215	41	45	101	0	0	**2,402**
Min	*1,900*	*0*	*0*	*96*	*0*	*0*	***1,996***
Max	*14,000*	*509*	*571*	*1,000*	*1,738*	*3,178*	***17,818***
Mean	*4,348*	*131*	*301*	*413*	*282*	*501*	***5,475***

Notes:

(a) Eakin (1966) includes KSV in the local recharge estimate for CSV. This is not acknowledged in several studies which cite the 2,600 AF value.

(b) Results of Scenarios 1 and 3

(c) Results of Scenario 2

(d) Mean value of Basin Characterization Model

(e) Time series result of Basin Characterization Model

(f) Based on Bootstrap Brute-Force Model

(g) Total does not include BMA, as most of the area is not included in the LWRFS. BMA values included in table for reference.

Abbreviations:

CSV	Coyote Spring Valley	LMV	Lower Moapa Valley
MRSA	Muddy River Springs Area	PV	Pahranagat Valley
HV	Hidden Valley	DV	Delamar Valley
GV	Garnet Valley	KSV	Kane Springs Valley
CW	California Wash	LMVW	Lower Meadow Valley Wash
BMA	Black Mountains Area	NE	Not estimated

Appendix C - Estimates of Recharge, ET, and GW Outflow in the LWRFS

LWRFS GW Inflow (AFY)

	Basin						
Source	PV to CSV	DV to CSV	KSV to CSV	LMVW to MRSA	LMVW to CW	LMVW to LMV	**Total[a]**
Recon	37,300	0	600	0	12,700	0	**50,600**
NDWR 1971	35,000	0	0	0	7,000	0	**42,000**
DRI 2001	28,000	16,000	6,000	0	0	32,000	**50,000**
LVVWD 2001	28,000	16,000	6,000	0	0	32,000	**50,000**
USGS 2004	NE	900	NE	0	7,000	0	**7,900**
DRI 2007	20,400	25,500	4,500	4,000	5,200	0	**59,600**
SNWA 2007	22,443	24,068	4,189	4,000	5,200	0	**59,900**
SNWA 2011	NE	24,800	NE	NE	NE	NE	**24,800**
Min	*20,400*	*0*	*0*	*0*	*0*	*0*	***20,400***
Max	*37,300*	*25,500*	*6,000*	*4,000*	*12,700*	*32,000*	***85,500***
Mean	*28,524*	*13,409*	*3,548*	*1,143*	*5,300*	*9,143*	***51,923***

Note:

(a) Total does not include inflow to LMV as it is not part of the LWRFS. LMV to Lake Mead values included for reference.

LWRFS ET (AFY)

	Basin						
Source	CSV	MRSA	HV	GV	CW	BMA	**Total[a]**
Recon	500	0	0	0	1,000	0	**1,500**
NDWR 1971	NE	NE	0	0	1,700	1,200	**2,900**
DRI 2001	1,000	5,000	0	0	5,000	2,000	**13,000**
LVVWD 2001	1,000	5,080	0	0	5,760	2,000	**13,840**
DRI 2007	0	6,000	0	0	4,500	1,400	**11,900**
SNWA 2007	0	5,989	0	0	4,505	1,432	**11,926**
DeMeo 2008	NE	4,090	NE	NE	6,080	1,952	**12,122**
SNWA 2009	NE	5,998	NE	NE	4,506	1,432	**11,936**
Min	*0*	*0*	*0*	*0*	*1,000*	*0*	***1,000***
Max	*1,000*	*6,000*	*0*	*0*	*6,080*	*2,000*	***15,080***
Mean	*500*	*4,594*	*0*	*0*	*4,131*	*1,427*	***10,652***

Abbreviations:

CSV	Coyote Spring Valley	LMV	Lower Moapa Valley
MRSA	Muddy River Springs Area	PV	Pahranagat Valley
HV	Hidden Valley	DV	Delamar Valley
GV	Garnet Valley	KSV	Kane Springs Valley
CW	California Wash	LMVW	Lower Meadow Valley Wash
BMA	Black Mountains Area	NE	Not estimated

Appendix C - Estimates of Recharge, ET, and GW Outflow in the LWRFS

LWRFS GW Outflow (AFY)

	Basin				
Source	CW to BMA	CW to LMV	MRSA to LMV	LMV to Lake Mead	**Total[a]**
Recon	0	21,300	0	21,100	**21,300**
NDWR 1971	0	0	0	1,100	**0**
DRI 2001	4,000	8,000	0	26,000	**12,000**
LVVWD 2001	2,300	41,000	0	48,000	**43,300**
USGS 2004	NE	NE	NE	1,100	**0**
DRI 2007	2,000	18,800	0	17,200	**20,800**
SNWA 2007	2,000	49,711	0	24,432	**51,711**
SNWA 2009	NE	NE	NE	10,808	**0**
Min	*0*	*0*	*0*	*1,100*	**0**
Max	*4,000*	*49,711*	*0*	*48,000*	***53,711***
Mean	*1,717*	*23,135*	*0*	*18,718*	***24,852***

Note:

(a) Total does not include outflow from LMV as it is not part of the LWRFS. LMV to Lake Mead values included for reference.

Abbreviations:

CSV	Coyote Spring Valley	LMV	Lower Moapa Valley
MRSA	Muddy River Springs Area	PV	Pahranagat Valley
HV	Hidden Valley	DV	Delamar Valley
GV	Garnet Valley	KSV	Kane Springs Valley
CW	California Wash	LMVW	Lower Meadow Valley Wash
BMA	Black Mountains Area	NE	Not estimated

Appendix C - Estimates of Recharge, ET, and GW Outflow in the LWRFS

Sources

Eakin 1966	Eakin, T. E., 1966, A regional interbasin ground-water system in the White River area, southeastern Nevada: U. S. Geological Survey Water Resources Research, Vol. 2, No. 2, pp 251-271.
NDWR 1971	Nevada Division of Water Resources, 1971. Nevada's Water Resources, prepared by: Nevada State Engineer, Water for Nevada Report No. 3, 97 p.
Kirk 1990	Kirk, S. T., and M. E. Campana, 1990. A deuterium-calibrated groundwater flow model of a regional carbonate-alluvial system: Journal of Hydrology 119, pp 337-388.
USGS 1996	Thomas, J. M., A. H. Welch, and M. D. Dettinger, 1996. Geochemistry and isotope hydrology of representative aquifers in the Great Basin Region of Nevada, Utah, and adjacent states: U. S. Geological Survey Professional Paper 1409-C, 110 p.
DRI 2001	Thomas, J. M., S. C. Calhoun, and W. B. Apambire, 2001, A Deuterium mass-balance interpretation of groundwater sources and flows in southeastern Nevada: prepared for Las Vegas Valley Water District. Desert Research Institute, Nevada, Publication No. 41169, 52 p.
LVVWD 2001	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, Nevada: Las Vegas Valley Water District, Las Vegas, Nevada, 250 p.
BCM 2004	Flint, A. L., L. E. Flint. J. A. Hevesi, and J. M. Blainey, 2004, Fundamental concepts of recharge in the Desert Southwest – A regional modeling perspective: pp.159-184 in Hogan, J. F., Phillips, F. M., and Scanlon, B. R., eds. Ground-water recharge in a desert environment – The southwestern United States: American Geophysical Union, Water and Science Applications Series Vol. 9 294 p.
Epstein 2004	Epstein, B. J., 2004, Development of Uncertainty Analysis of Empirical Recharge Prediction Models for Nevada's Desert Basins, University of Nevada Reno M. S. Thesis, 204p.
USGS 2004	Lopes, T. J., and D. M. Evetts, 2004, Ground-water pumpage and artificial recharge estimates for calendar year 2000 and average annual natural recharge and interbasin flow by hydrographic area, Nevada: U.S. Geological Survey Investigations Report 2004-5239, Carson City, Nevada, 87 p.
DRI 2007	Thomas J. M.and T. M. Mihevic, 2007, Stable Isotope Evaluation of Water Budgets for the White River and Meadow Valley Wash Regional Groundwater Flow Systems in East-Central and Southeastern Nevada, Letter Report, 189 p.
SNWA 2007	Southern Nevada Water Authority, 2007, Water Resources Assessment and Hydrogeologic Report for Cave, Dry Lake and Delamar Valleys, Presentation to the Nevada State Engineer: Southern Nevada Water Authority, Las Vegas, Nevada, 352 p.
SNWA 2009	Southern Nevada Water Authority, 2009, Conceptual model of groundwater flow for the Central Carbonate Rock Province: Clark, Lincoln, and White Pine Counties Groundwater Development Project: Southern Nevada Water Authority, Las Veegas, Nevada, 416 p.
DeMeo 2008	DeMeo, G.A., Smith, J.L., Damar, N.A., and Darnell, J., 2008, Quantifying ground-water and surface-water discharge from evapotranspiration processes in 12 hydrographic areas of the Colorado Regional Ground-Water Flow System, Nevada, Utah, and Arizona: U.S. Geological Survey Scientific Investigations Report 2008-5116, 34 p.
SNWA 2011	Burns A.G. and W. Drici, 2011. Hydrology and water resources of Spring, Cave, Dry Lake, and Delamar valleys, Nevada and vicinity: Presentation to the Office of the Nevada State Engineer: Southern Nevada Water Authority, Las Vegas, Nevada, 313 p.
Recon*	Estimates from the reconnaissance series reports; Cited from secondary source; DRI 2007 (Figure 14)

Appendix D

Supporting Calculations for Coyote Spring Valley Recharge Estimates

Table D-1. Estimate of Recharge using Elevation Bands and Precipitation-Elevation relationship from Eakin, 1966

						Precipitation (in/yr) by band (Eakin, 1964):										Recharge coefficients from Maxey-Eakin (1949):						
						varies	10	13.5	17.5	21						0	0.03	0.07	0.15	0.25	Estimated Annual Recharge (ac-ft)	
						Source: Eakin, 1966																
	Area by Elevation Band (acres)					Average Precipitation by Band (in/yr)					Precipitation Volume (ac-ft)					Recharge by Band (ac-ft/yr)						
Recharge Zone and Name	< 6000 ft	6000-7000 ft	7000-8000 ft	8000-9000 ft	>9000 ft	< 6000 ft	6000-7000 ft	7000-8000 ft	8000-9000 ft	>9000 ft	< 6000 ft	6000-7000 ft	7000-8000 ft	8000-9000 ft	>9000 ft	< 6000 ft	6000-7000 ft	7000-8000 ft	8000-9000 ft	>9000 ft	Total	Rounded
1 Evergreen Flat	9,841	0	0	0	0	–	–	–	–	–	–	–	–	–	–	0	–	–	–	–	0	0
2 Pahranagat Wash A	4,575	0	0	0	0	–	–	–	–	–	–	–	–	–	–	0	–	–	–	–	0	0
3 Coyote Spring Valley A	25,874	973	54	0	0	–	10.0	13.5	–	–	–	808	61	–	–	0	24	4	–	–	28	30
4 Coyote Spring Valley B	23,429	2,456	531	0	0	–	10.0	13.5	–	–	–	2,039	597	–	–	0	61	42	–	–	103	100
5 Cherry Spring	11,522	1,291	325	0	0	–	10.0	13.5	–	–	–	1,071	366	–	–	0	32	26	–	–	58	60
6 Grapevine Spring	11,370	771	329	30	0	–	10.0	13.5	17.5	–	–	640	370	44	–	0	19	26	7	–	52	50
7 Pahranagat Wash B	8,292	215	57	2	0	–	10.0	13.5	17.5	–	–	178	64	3	–	0	5	4	0	–	10	10
8 Perkins Spring	17,977	2,034	797	32	0	–	10.0	13.5	17.5	–	–	1,688	897	46	–	0	51	63	7	–	120	120
9 Sawmill Wash	19,146	10,576	6,405	1,465	177	–	10.0	13.5	17.5	21.0	–	8,778	7,206	2,139	310	0	263	504	321	77	1,166	1,170
10 Las Vegas Range A	7,504	0	0	0	0	–	–	–	–	–	–	–	–	–	–	0	–	–	–	–	0	0
11 Las Vegas Range B	3,530	0	0	0	0	–	–	–	–	–	–	–	–	–	–	0	–	–	–	–	0	0
12 Wamp Spring	25,253	2,132	0	0	0	–	10.0	–	–	–	–	1,769	–	–	–	0	53	–	–	–	53	50
13 Hidden Valley A	25,198	832	0	0	0	–	10.0	–	–	–	–	691	–	–	–	0	21	–	–	–	21	20
14 Hidden Valley B	28,009	1,381	0	0	0	–	10.0	–	–	–	–	1,146	–	–	–	0	34	–	–	–	34	30
15 Dry Lake	7,219	0	0	0	0	–	–	–	–	–	–	–	–	–	–	0	–	–	–	–	0	0
Subtotal by zone	228,737	22,661	8,498	1,529	177						0	18,808	9,560	2,232	310	0	564	669	335	77	1,646	1,640
Total			total, acres		261,601								total, ac-ft		30,910							
			total, sq mi		409																	

Table D-2. Estimate of Recharge using Precipitation Bands and Recharge Coefficients from Maxey and Eakin (1949)

													Recharge coefficients from Maxey-Eakin (1949):					
					Source: PRISM, 2015								0	0.03	0.07	0.15	Estimated Annual	
	Area by Precip Band (acres)				Average Precipitation by Band (in/yr)				Precipitation Volume (ac-ft)				Recharge by Band (ac-ft/yr)				Recharge (ac-ft/yr)	
Recharge Zone and Name	< 8"	8-12"	12-15"	15-20"	< 8"	8-12"	12-15"	15-20"	< 8"	8-12"	12-15"	15-20"	< 8"	8-12"	12-15"	15-20"	Total	Rounded
1 Evergreen Flat	7,317	2,523	0	0	6.6	8.7	--	--	4,000	1,836	--	--	0	55	--	--	55	60
2 Pahranagat Wash A	4,575	0	0	0	6.1	--	--	--	2,331	--	--	--	0.0	--	--	--	0	0
3 Coyote Spring Valley A	10,099	15,326	1,476	0	7.0	9.7	12.5	--	5,865	12,443	1,543	--	0.0	373	108	--	481	480
4 Coyote Spring Valley B	13,033	9,150	4,232	0	6.6	10.0	12.8	--	7,183	7,643	4,522	--	0.0	229	317	--	546	550
5 Cherry Spring	5,922	5,238	1,977	0	6.7	10.4	12.6	--	3,293	4,520	2,072	--	0.0	136	145	--	281	280
6 Grapevine Spring	6,629	4,391	1,480	0	6.6	10.2	13.9	--	3,663	3,721	1,717	--	0.0	112	120	--	232	230
7 Pahranagat Wash B	6,122	2,137	306	0	6.3	9.8	14.2	--	3,202	1,743	362	--	0.0	52	25	--	78	80
8 Perkins Spring	8,860	6,209	5,771	0	6.6	9.9	13.4	--	4,853	5,144	6,448	--	0.0	154	451	--	606	610
9 Sawmill Wash	2,211	9,768	20,761	5,029	7.5	10.0	13.3	15.6	1,382	8,165	22,939	6,558	0.0	245	1606	984	2,834	2,830
10 Las Vegas Range A	7,426	78	0	0	6.3	8.3	--	--	3,921	54	--	--	0.0	2	--	--	2	0
11 Las Vegas Range B	3,530	0	0	0	5.7	--	--	--	1,690	--	--	--	0.0	--	--	--	0	0
12 Wamp Spring	14,325	6,463	6,597	0	6.2	9.9	13.1	--	7,422	5,319	7,176	--	0.0	160	502	--	662	660
13 Hidden Valley A	16,975	4,441	4,614	0	5.9	9.9	13.3	--	8,343	3,649	5,102	--	0.0	109	357	--	467	470
14 Hidden Valley B	20,253	5,681	3,456	0	6.6	9.2	13.3	--	11,137	4,355	3,843	--	0.0	131	269	--	400	400
15 Dry Lake	7,219	0	0	0	5.4	--	--	--	3,259	--	--	--	0.0	--	--	--	0	0
Subtotal by zone	134,495	71,406	50,670	5,029					71,546	58,593	55,724	6,558	0	1,758	3,901	984	6,642	6,650
Total			total, acres	261,601							total, ac-ft	192,421						
			total, sq mi	409							avg, in/yr:	8.8						

Table D-3. Estimate of Recharge using Precipitation Bands and Recharge Coefficients from Nichols (2001)

													Recharge coefficients from Nichols (2000):					
					Source: PRISM, 2015								0	0.008	0.13	0.144	Estimated Annual	
	Area by Precip Band (acres)				Average Precipitation by Band (in/yr)				Precipitation Volume (ac-ft)				Recharge by Band (ac-ft/yr)				Recharge (ac-ft)	
Recharge Zone and Name	< 8"	8-12"	12-16"	16-20"	< 8"	8-12"	12-16"	16-20"	< 8"	8-12"	12-16"	16-20"	< 8"	8-12"	12-16"	16-20"	Total	Rounded
1 Evergreen Flat	7,317	2,523	0	0	6.6	8.7	--	--	4,000	1,836	--	--	0	15	--	--	15	10
2 Pahranagat Wash A	4,575	0	0	0	6.1	--	--	--	2,331	--	--	--	0	--	--	--	0	0
3 Coyote Spring Valley A	10,099	15,326	1,476	0	7.0	9.7	12.5	--	5,865	12,443	1,543	--	0	100	201	--	300	300
4 Coyote Spring Valley B	13,033	9,150	4,232	0	6.6	10.0	12.8	--	7,183	7,643	4,522	--	0	61	588	--	649	650
5 Cherry Spring	5,922	5,238	1,977	0	6.7	10.4	12.6	--	3,293	4,520	2,072	--	0	36	269	--	306	310
6 Grapevine Spring	6,629	4,391	1,480	0	6.6	10.2	13.9	--	3,663	3,721	1,717	--	0	30	223	--	253	250
7 Pahranagat Wash B	6,122	2,137	306	0	6.3	9.8	14.2	--	3,202	1,743	362	--	0	14	47	--	61	60
8 Perkins Spring	8,860	6,209	5,771	0	6.6	9.9	13.4	--	4,853	5,144	6,448	--	0	41	838	--	879	880
9 Sawmill Wash	2,211	9,768	24,708	1,083	7.5	10.0	13.6	16.2	1,382	8,165	28,040	1,459	0	65	3,645	210	3,921	3,920
10 Las Vegas Range A	7,426	78	0	0	6.3	8.3	--	--	3,921	54	--	--	0	0	--	--	0	0
11 Las Vegas Range B	3,530	0	0	0	5.7	--	--	--	1,690	--	--	--	0	--	--	--	0	0
12 Wamp Spring	14,325	6,463	6,597	0	6.2	9.9	13.1	--	7,422	5,319	7,176	--	0	43	933	--	975	980
13 Hidden Valley A	16,975	4,441	4,614	0	5.9	9.9	13.3	--	8,343	3,649	5,102	--	0	29	663	--	692	690
14 Hidden Valley B	20,253	5,681	3,456	0	6.6	9.2	13.3	--	11,137	4,355	3,843	--	0	35	500	--	534	530
15 Dry Lake	7,219	0	0	0	5.4	--	--	--	3,259	--	--	--	0	--	--	--	0	0
Subtotal by zone	134,495	71,406	54,617	1,083					71,546	58,593	60,825	1,459	0	469	7,907	210	8,586	8,580
Total			total, acres	261,601							total, ac-ft	192,424						
			total, sq mi	409							avg, in/yr:	8.8						

Table D-4. Estimate of Recharge using Precipitation Bands and Recharge Coefficients from Epstein (2004)

Recharge Zone and Name		Area by Precip Band (acres)		Source: PRISM, 2015 Average Precipitation by Band (in/yr)		Precipitation Volume (ac-ft)		Recharge coefficients from Epstein (2004): 0.019	0.049	Estimated Annual Recharge (ac-ft)	
								Recharge by Band (ac-ft/yr)			
		< 10"	10-20"	< 10"	10-20"	< 10"	10-20"	< 10"	10-20"	Total	Rounded
1	Evergreen Flat	9,841	0	7.2	--	5,866	--	111	--	111	110
2	Pahranagat Wash A	4,575	0	6.1	--	2,331	--	44	--	44	40
3	Coyote Spring Valley A	19,418	7,483	7.9	11.3	12,836	7,059	244	346	590	590
4	Coyote Spring Valley B	17,582	8,834	7.3	11.8	10,663	8,694	203	426	629	630
5	Cherry Spring	7,940	5,198	7.1	11.7	4,728	5,049	90	247	337	340
6	Grapevine Spring	8,495	4,005	7.1	11.9	5,023	3,974	95	195	290	290
7	Pahranagat Wash B	7,211	1,354	6.6	11.6	3,994	1,304	76	64	140	140
8	Perkins Spring	11,658	9,182	7.0	12.5	6,820	9,530	130	467	597	600
9	Sawmill Wash	7,088	30,681	8.5	13.3	5,012	33,938	95	1,663	1,758	1,760
10	Las Vegas Range A	7,504	0	6.3	--	3,962	--	75	--	75	80
11	Las Vegas Range B	3,530	0	5.7	--	1,690	--	32	--	32	30
12	Wamp Spring	17,846	9,540	6.8	12.5	10,095	9,939	192	487	679	680
13	Hidden Valley A	19,524	6,505	6.2	12.5	10,159	6,753	193	331	524	520
14	Hidden Valley B	24,181	5,209	7.0	12.7	14,005	5,532	266	271	537	540
15	Dry Lake	7,219	0	5.4	--	3,259	--	62	--	62	60
	Subtotal by zone	173,610	87,991			100,444	91,773	1,908	4,497	6,405	6,410
	Total		total, acres 261,601				total, ac-ft 192,217				
			total, sq mi 409				avg, in/yr: 8.8				

Appendix E

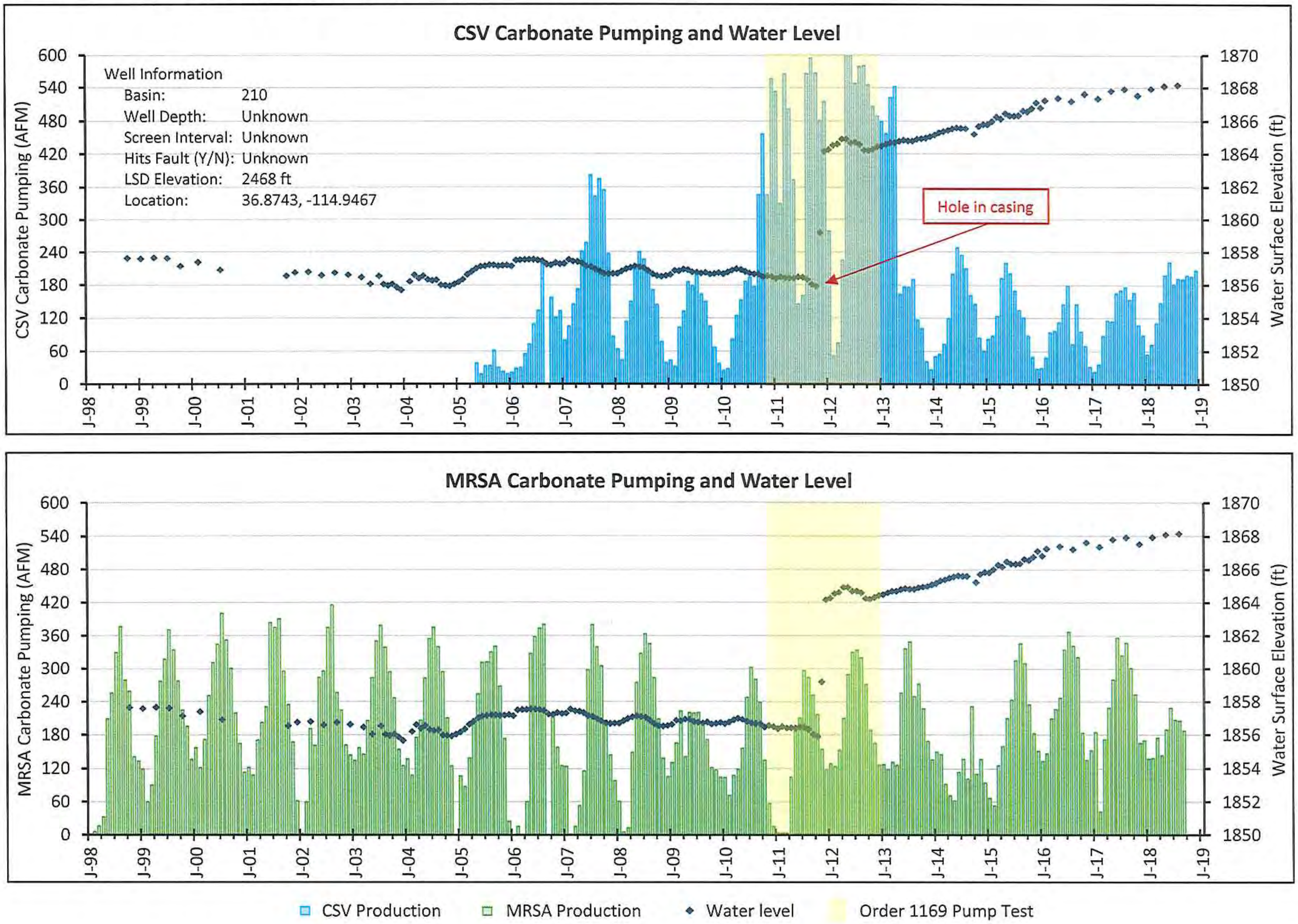
Supporting Groundwater Level and Pumping Graphs

Carbonate Aquifer Monitoring Wells
Coyote Spring Valley and Muddy River Springs Area

				Screened Interval		Hits Fault		Location	
No.	Well Name	Basin	Well Depth	Start Depth	End Depth	(Y/N)	LSD Elevation	Lat	Long
1	CE-VF-2	210					2468 ft	36.8743	-114.9467
2	CSVM-1	210	1060 ft	320 ft	1020 ft	N	2161 ft	36.7912	-114.8862
3A 3B	CSVM-2	210	1425 ft	720 ft	1380 ft	N	2573 ft	36.6618	-114.9231
4	CSVM-3	210	1230 ft	380 ft	1180 ft	N	2651 ft	37.0525	-114.9834
5	CSVM-4	210	1605 ft	800 ft	1580 ft	N	2842 ft	36.9911	-114.8865
6	CSVM-5	210	1783 ft	1020 ft	1760 ft	N	3131 ft	36.7476	-114.9804
7A 7B	CSVM-6	210	1200 ft	420 ft	1160 ft	N	2252 ft	36.8325	-114.9092
8	MX-4	210	669 ft			N	2177 ft	36.7957	-114.8928
9	EH-4	219					1934 ft	36.7064	-114.7170
10	EH-5B	219					1845 ft	36.7329	-114.7426
11	UMVM-1	219	1785 ft	960 ft	1760 ft	N	1785 ft	36.7581	-114.8232
12	CSV-2	219	478 ft				2186 ft	36.7807	-114.7227

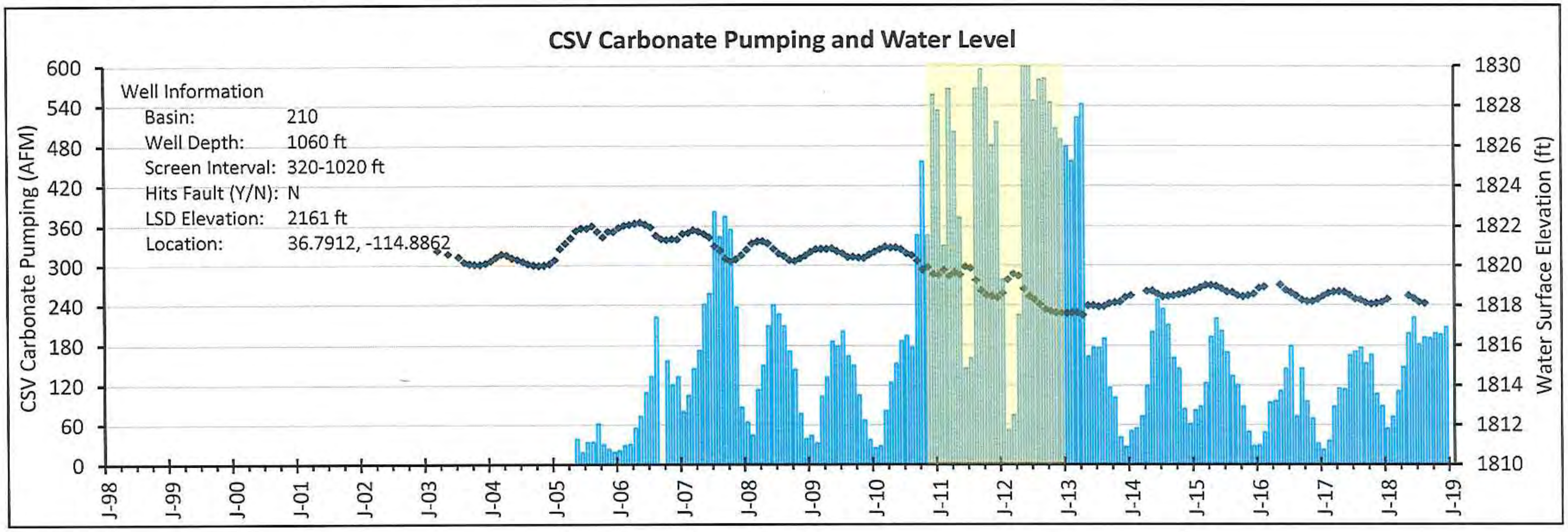
Basin 210 - Coyote Spring Valley

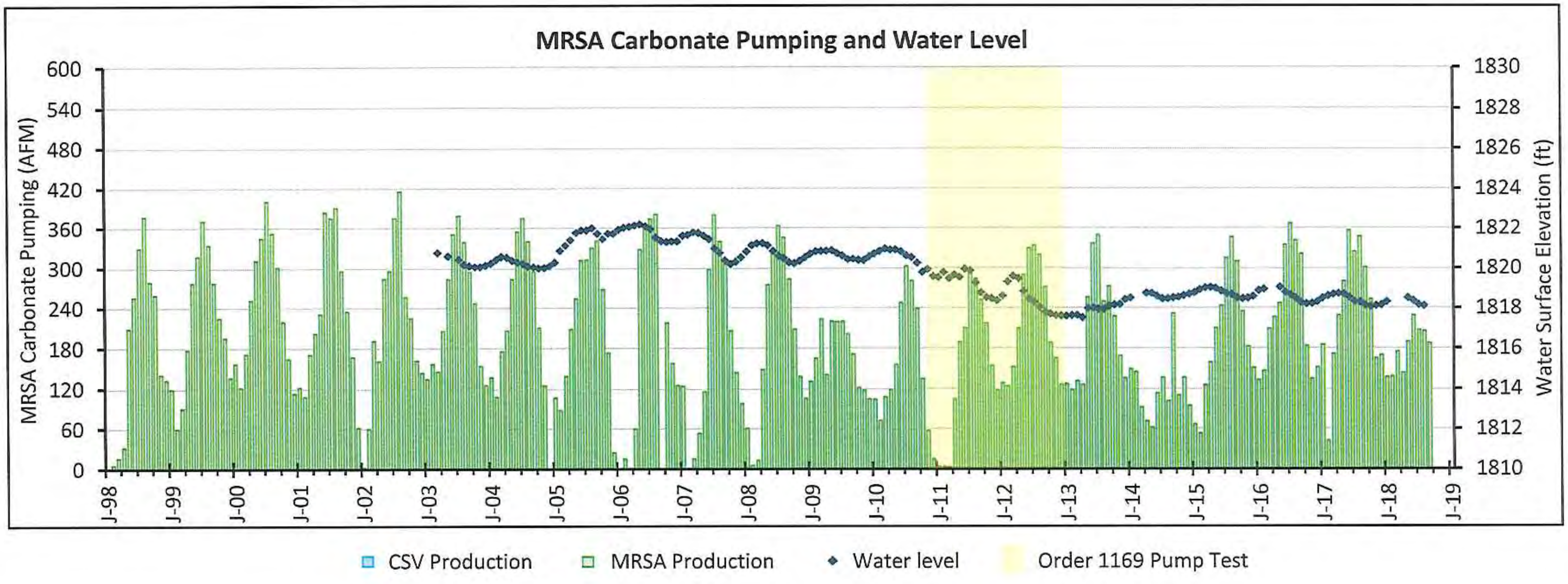
CE-VF-2



Basin 210 - Coyote Spring Valley

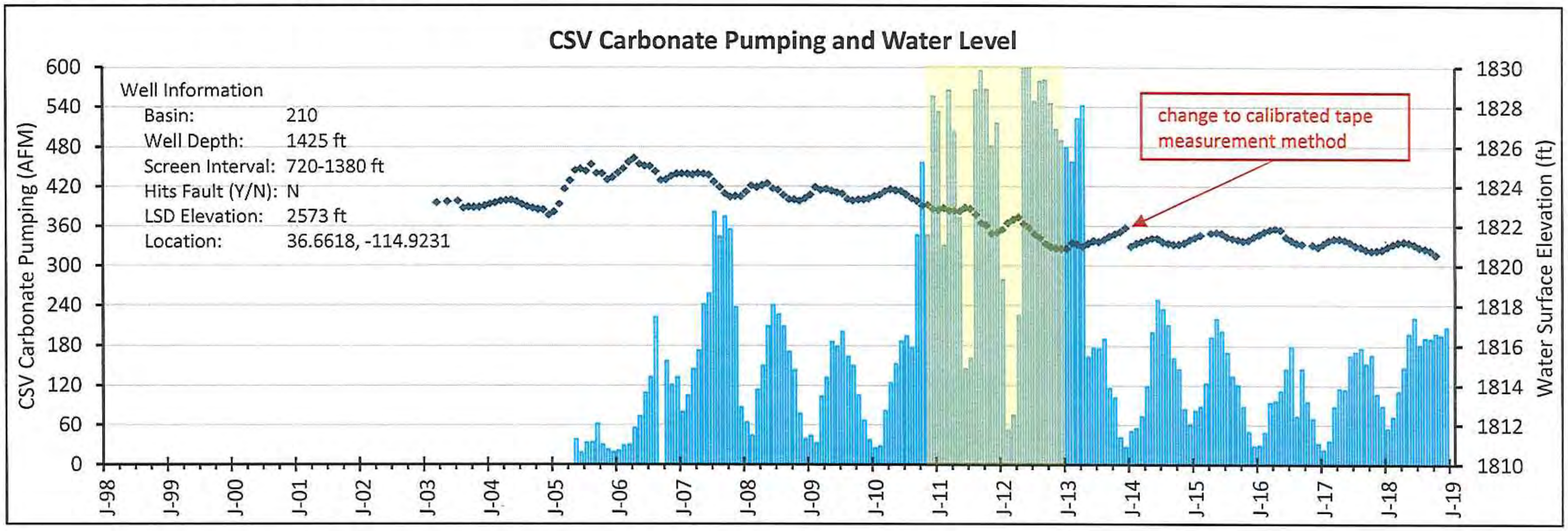
CSVM-1



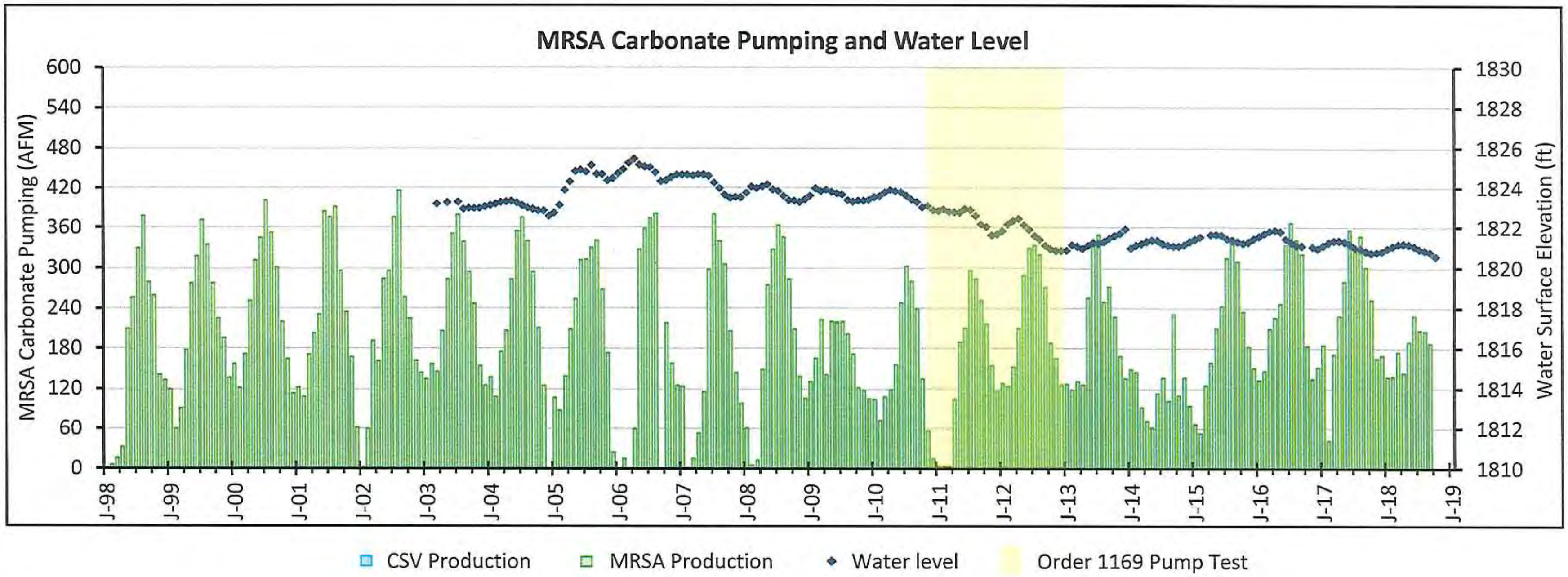


Basin 210 - Coyote Spring Valley

CSVM-2



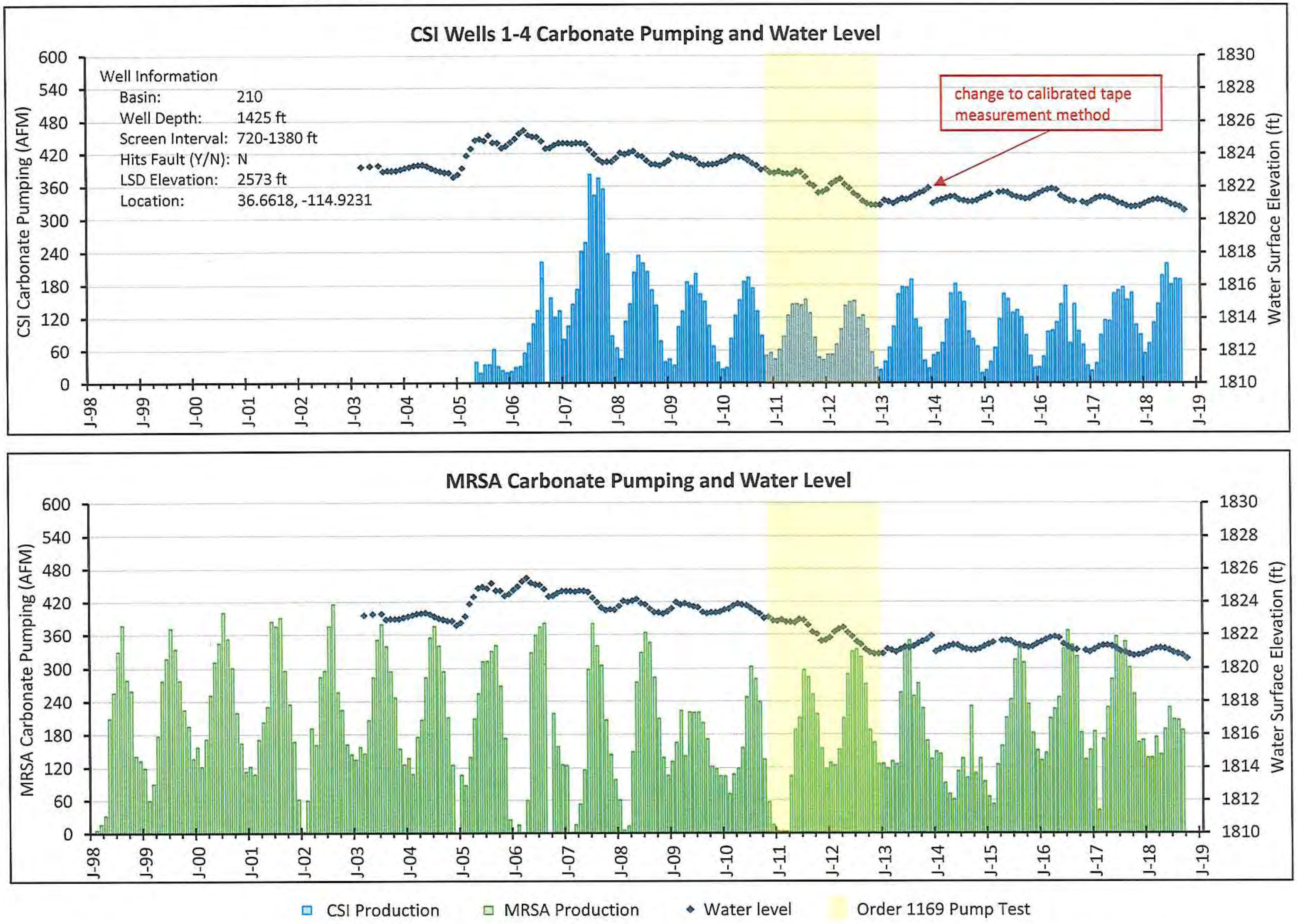
CSV Carbonate Pumping and Water Level



MRSA Carbonate Pumping and Water Level

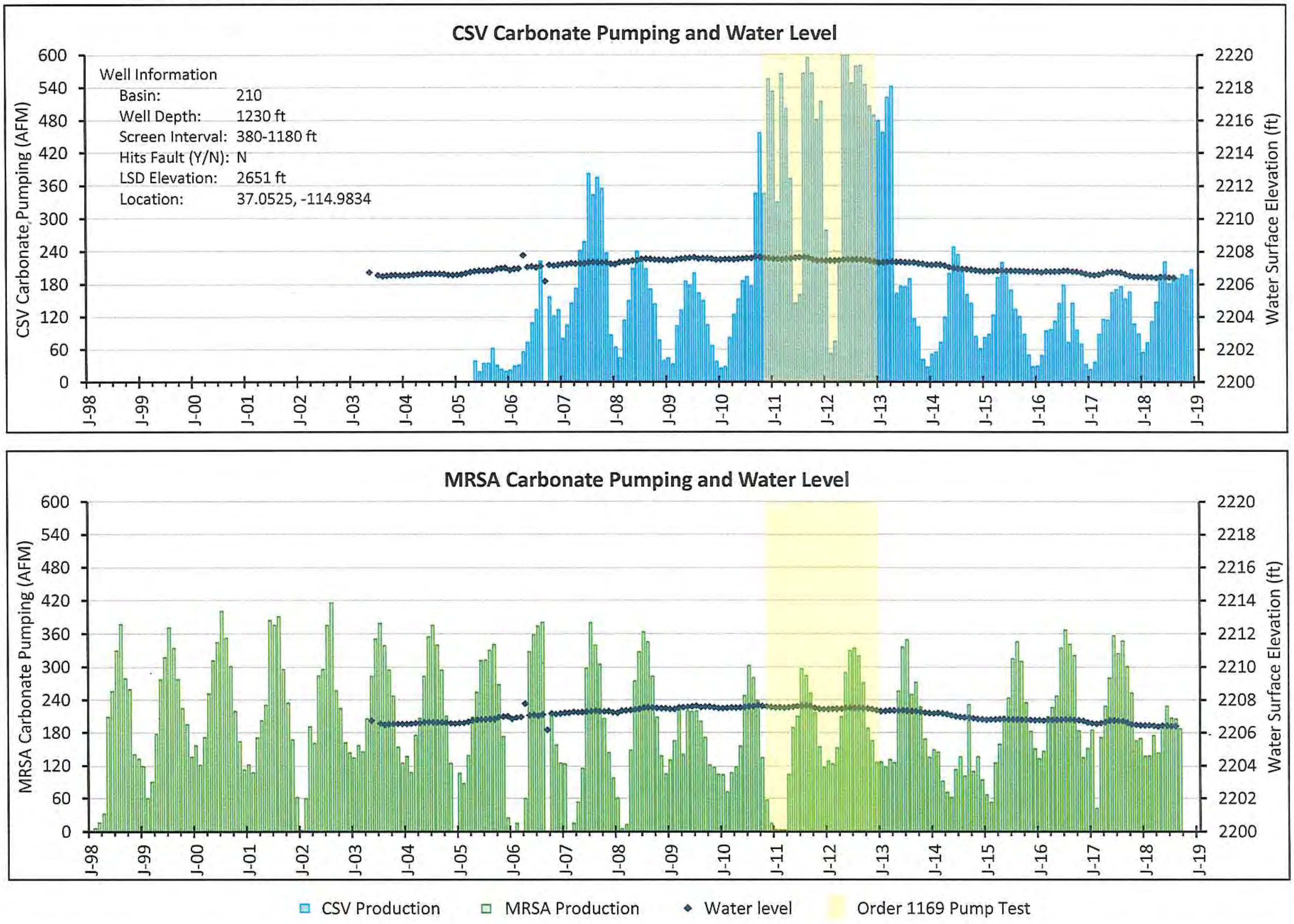
Basin 210 - Coyote Spring Valley

CSVM-2



Basin 210 - Coyote Spring Valley

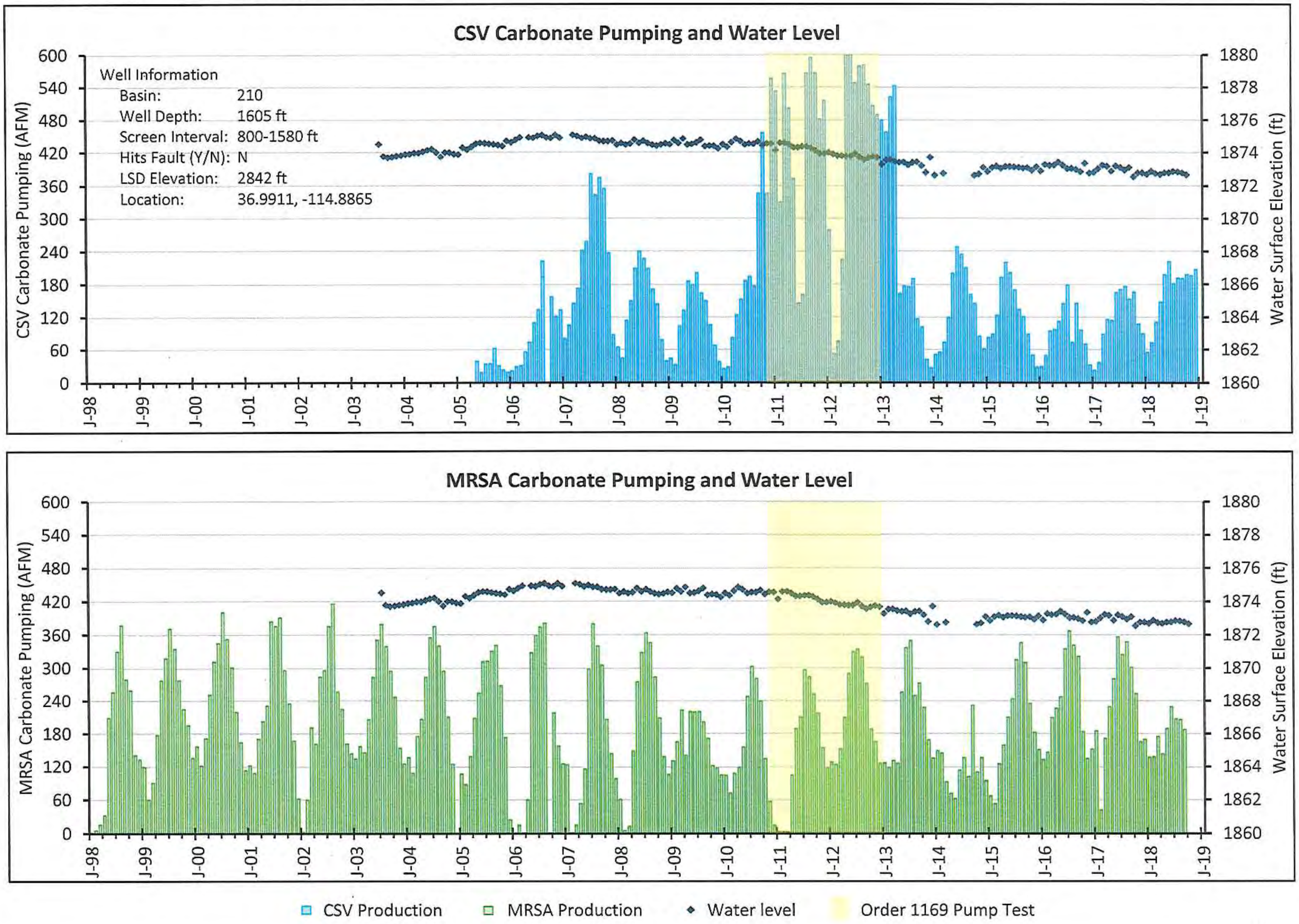
CSVM-3



Well Information
- Basin: 210
- Well Depth: 1230 ft
- Screen Interval: 380-1180 ft
- Hits Fault (Y/N): N
- LSD Elevation: 2651 ft
- Location: 37.0525, -114.9834

Basin 210 - Coyote Spring Valley

CSVM-4



CSV Carbonate Pumping and Water Level

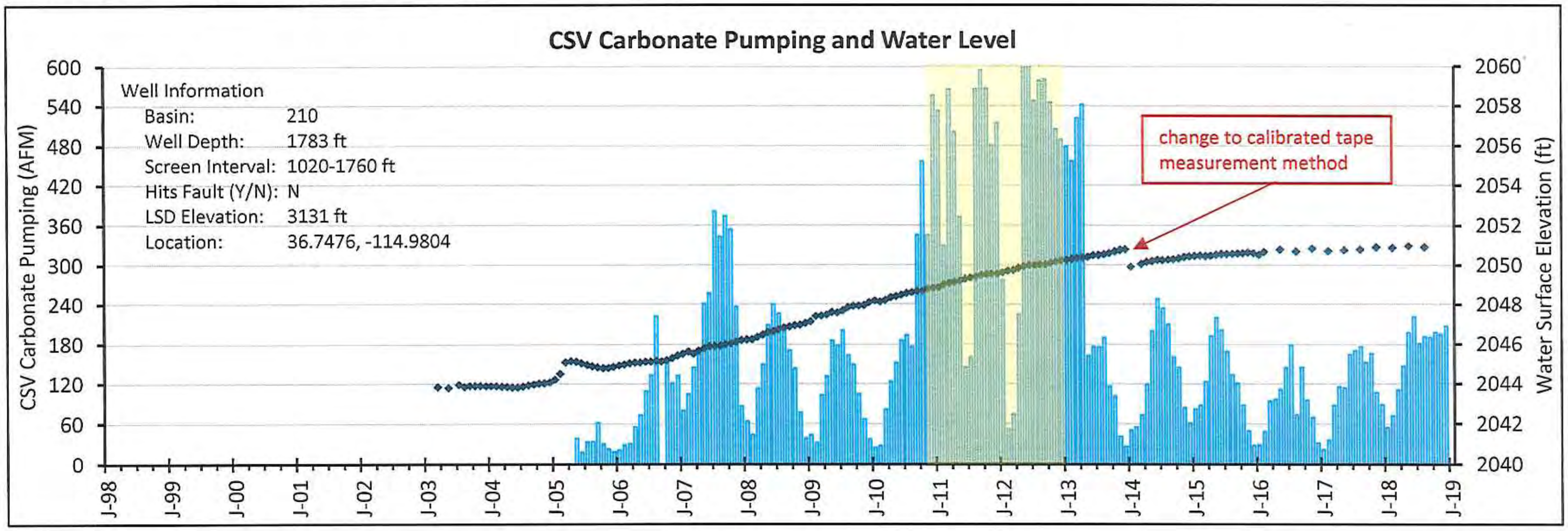
Well Information

Basin:	210
Well Depth:	1605 ft
Screen Interval:	800-1580 ft
Hits Fault (Y/N):	N
LSD Elevation:	2842 ft
Location:	36.9911, -114.8865

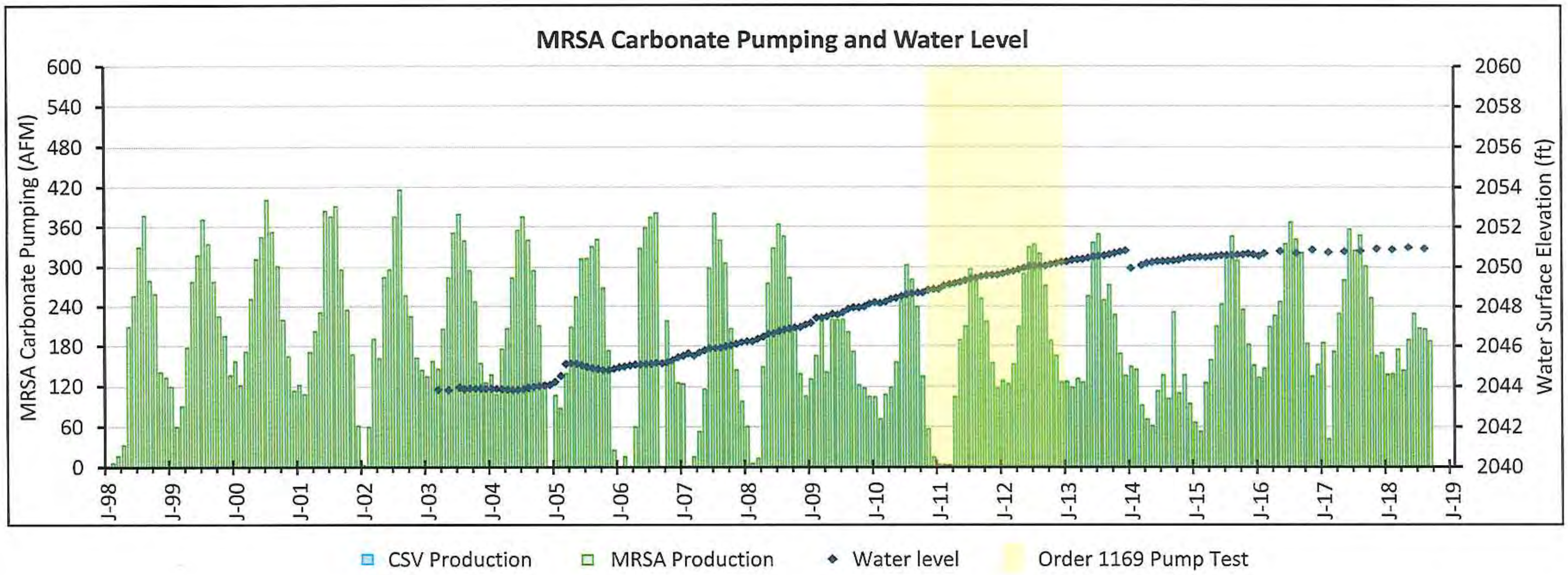
MRSA Carbonate Pumping and Water Level

Basin 210 - Coyote Spring Valley

CSVM-5

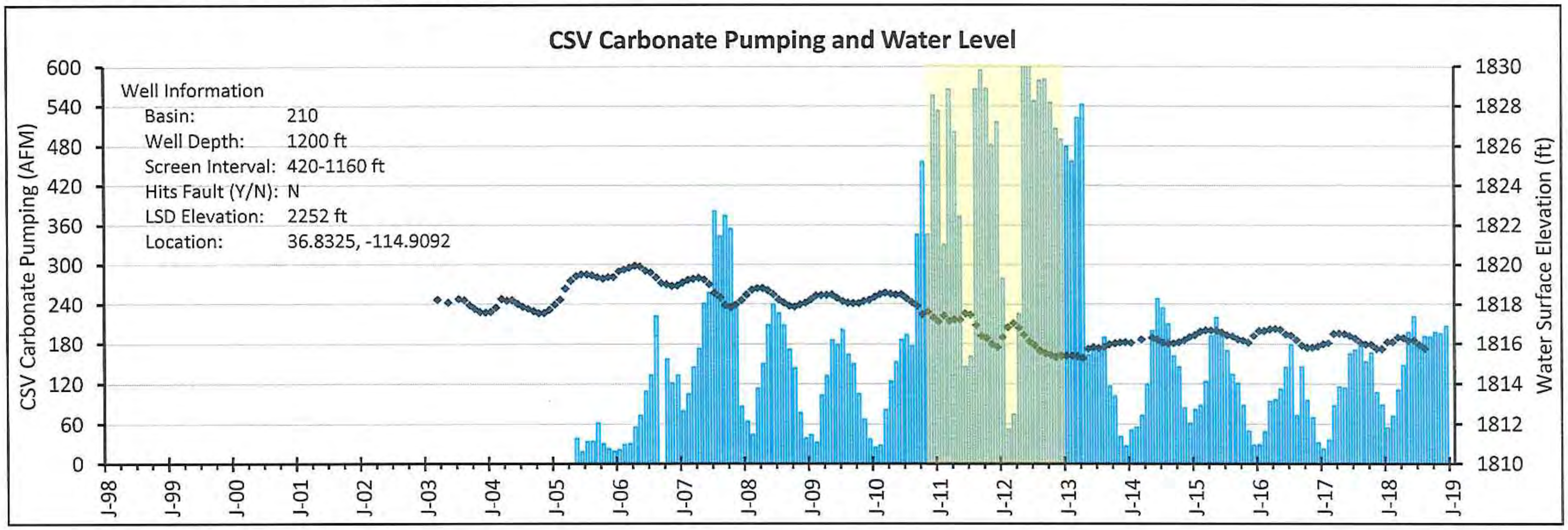

CSV Carbonate Pumping and Water Level

Well Information
Basin: 210
Well Depth: 1783 ft
Screen Interval: 1020-1760 ft
Hits Fault (Y/N): N
LSD Elevation: 3131 ft
Location: 36.7476, -114.9804


MRSA Carbonate Pumping and Water Level

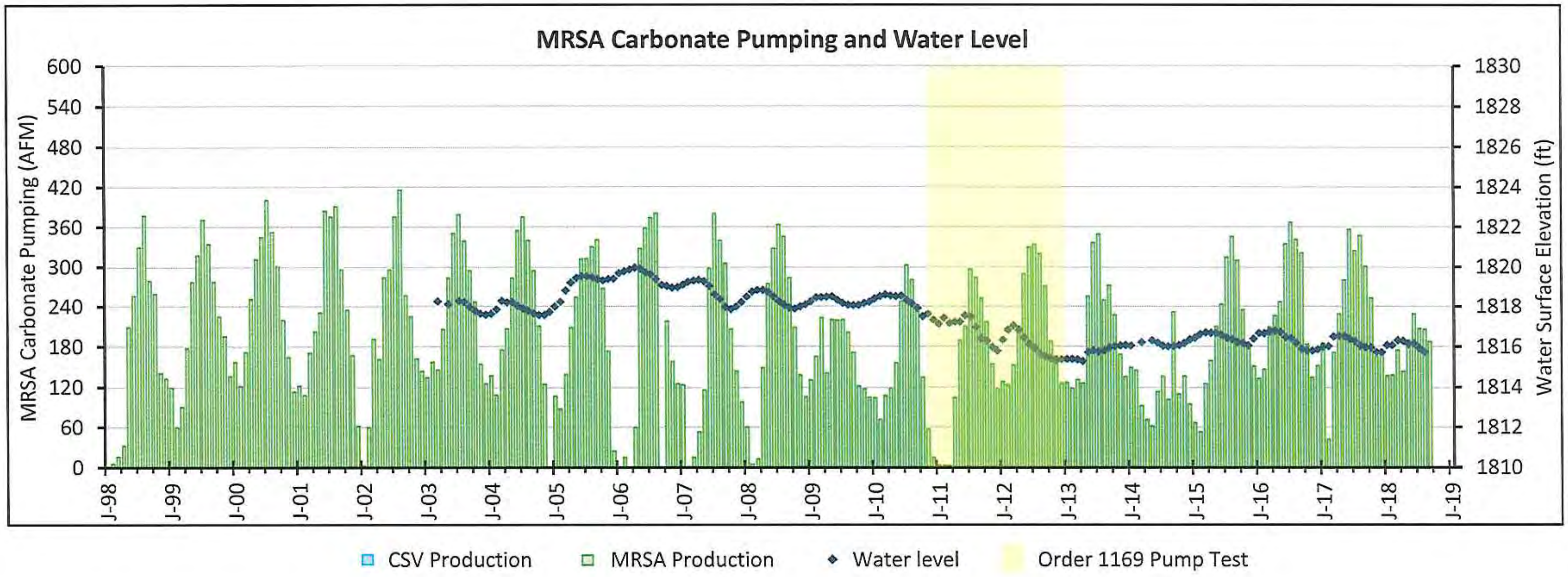
Basin 210 - Coyote Spring Valley

CSVM-6



CSV Carbonate Pumping and Water Level

Well Information
Basin: 210
Well Depth: 1200 ft
Screen Interval: 420-1160 ft
Hits Fault (Y/N): N
LSD Elevation: 2252 ft
Location: 36.8325, -114.9092

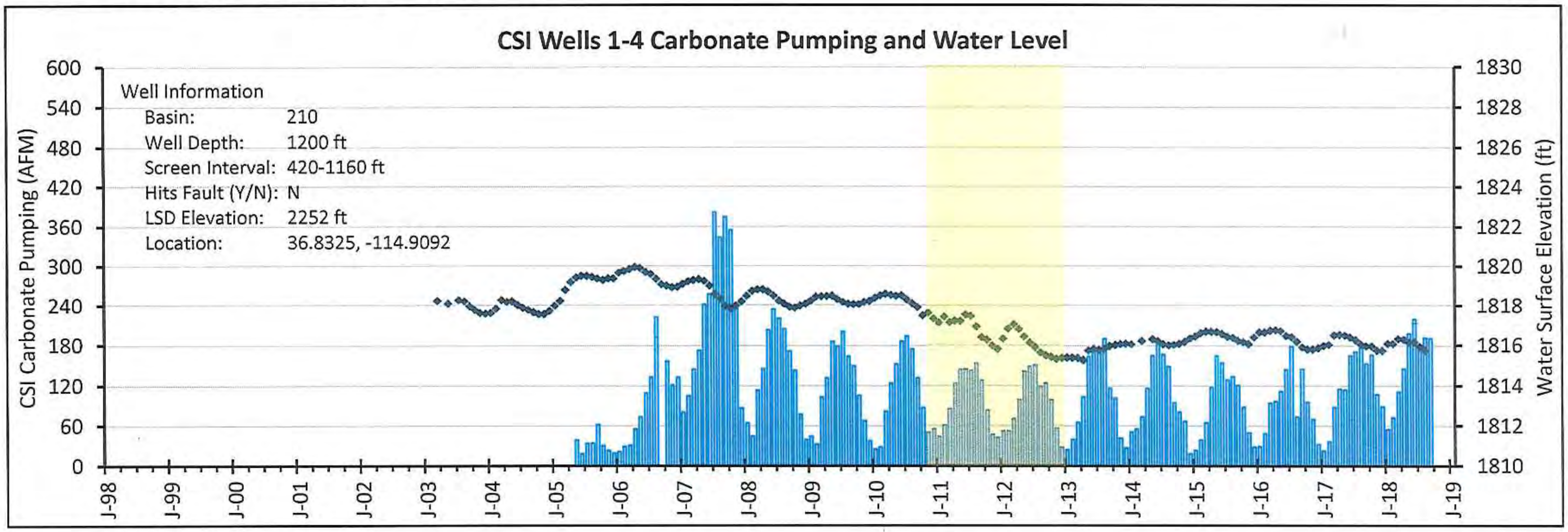


MRSA Carbonate Pumping and Water Level

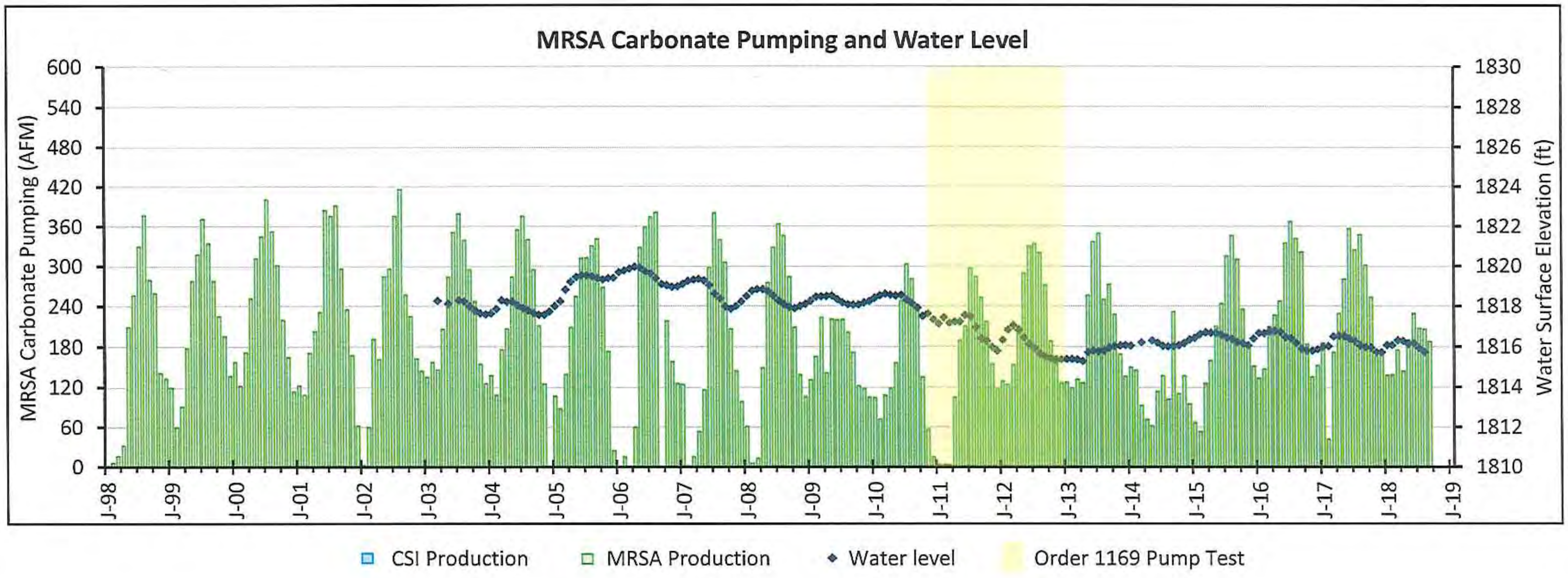
7A

Basin 210 - Coyote Spring Valley

CSVM-6

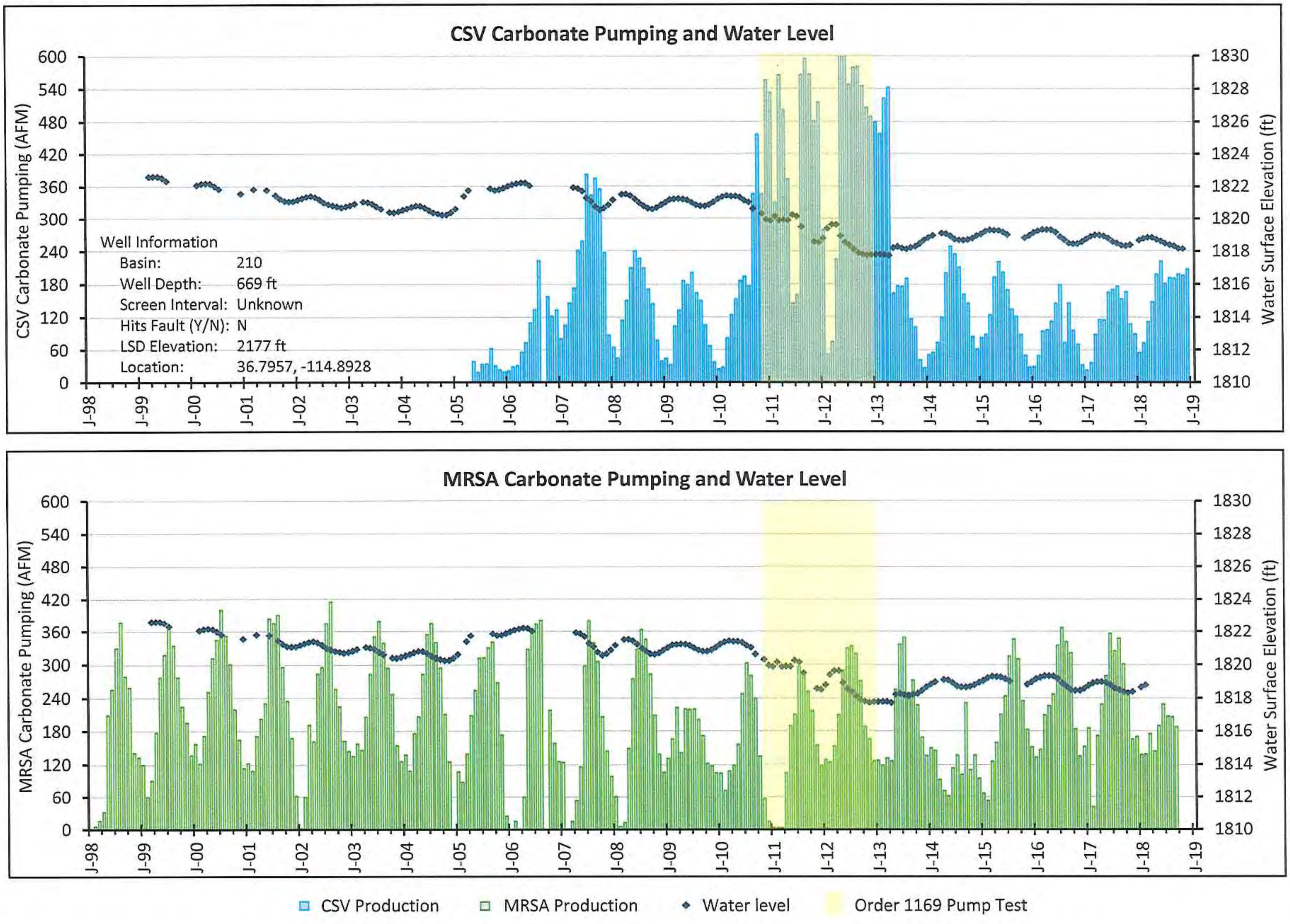

CSI Wells 1-4 Carbonate Pumping and Water Level

Well Information
Basin: 210
Well Depth: 1200 ft
Screen Interval: 420-1160 ft
Hits Fault (Y/N): N
LSD Elevation: 2252 ft
Location: 36.8325, -114.9092


MRSA Carbonate Pumping and Water Level

Basin 210 - Coyote Spring Valley

MX-4



CSV Carbonate Pumping and Water Level

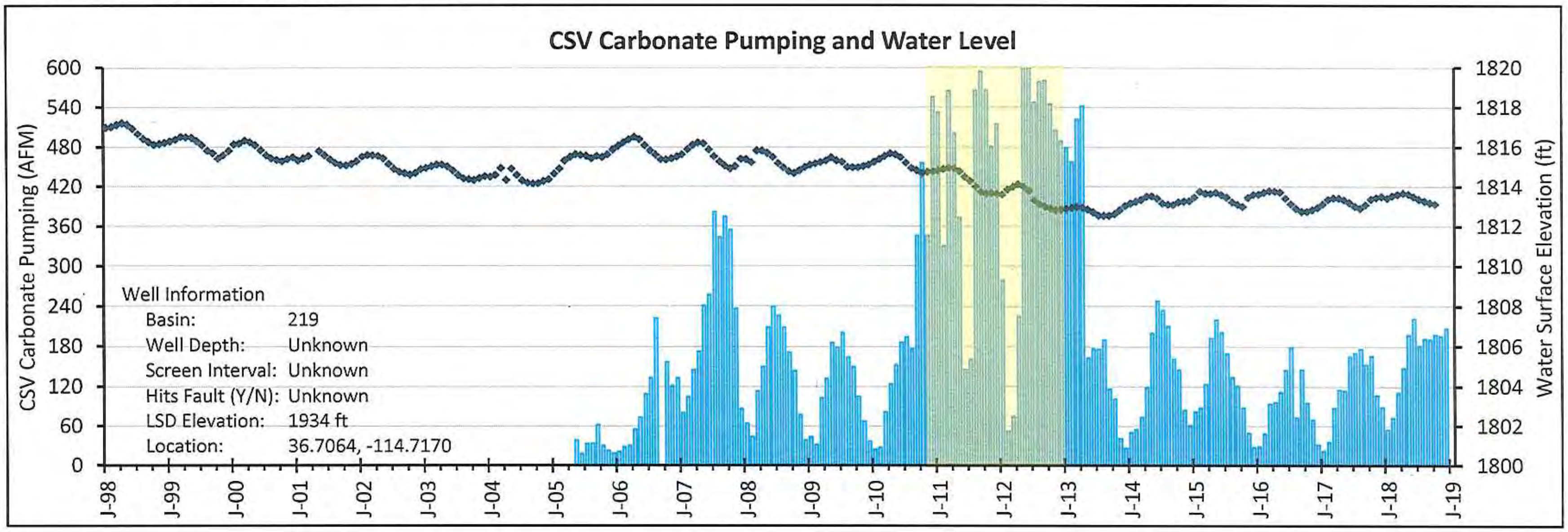
Well Information

Basin: 210
Well Depth: 669 ft
Screen Interval: Unknown
Hits Fault (Y/N): N
LSD Elevation: 2177 ft
Location: 36.7957, -114.8928

MRSA Carbonate Pumping and Water Level

Basin 219 - Muddy River Springs Area

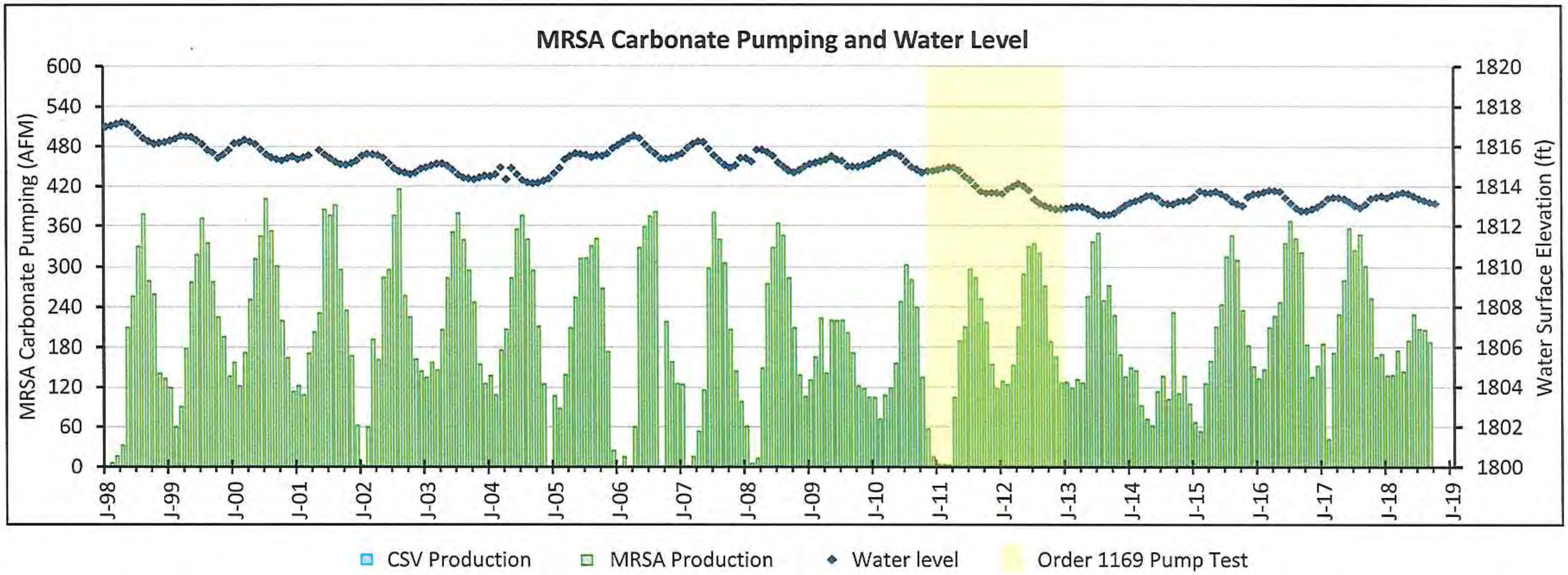
EH-4



CSV Carbonate Pumping and Water Level

Well Information

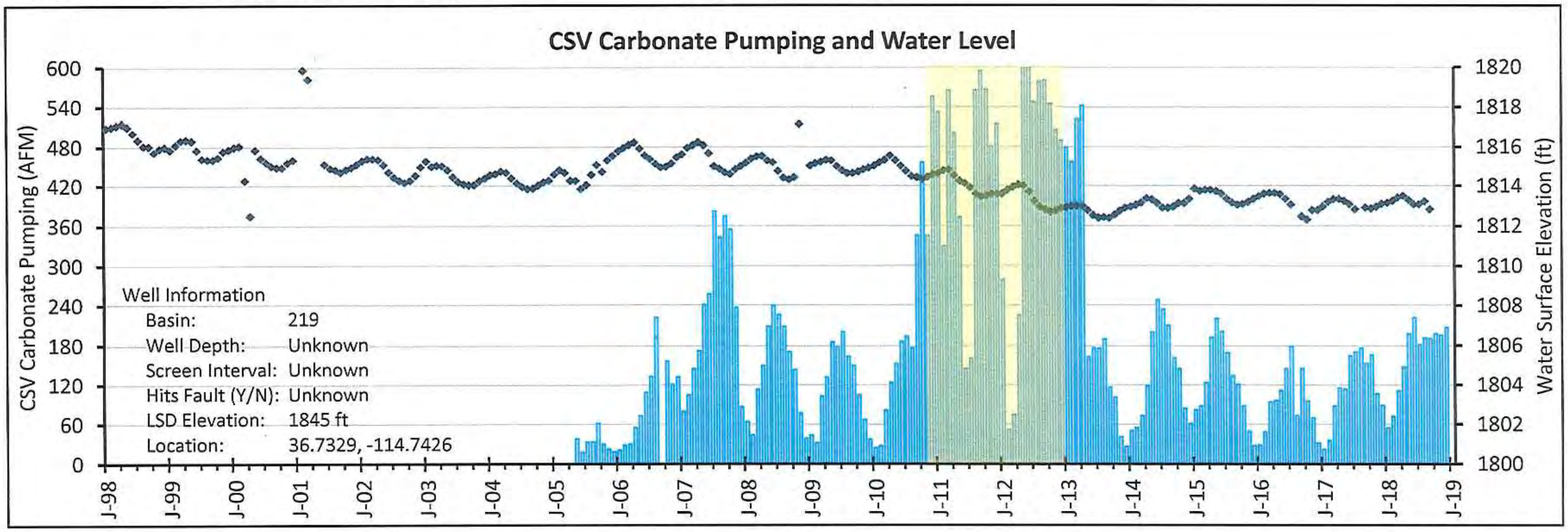
Basin:	219
Well Depth:	Unknown
Screen Interval:	Unknown
Hits Fault (Y/N):	Unknown
LSD Elevation:	1934 ft
Location:	36.7064, -114.7170



MRSA Carbonate Pumping and Water Level

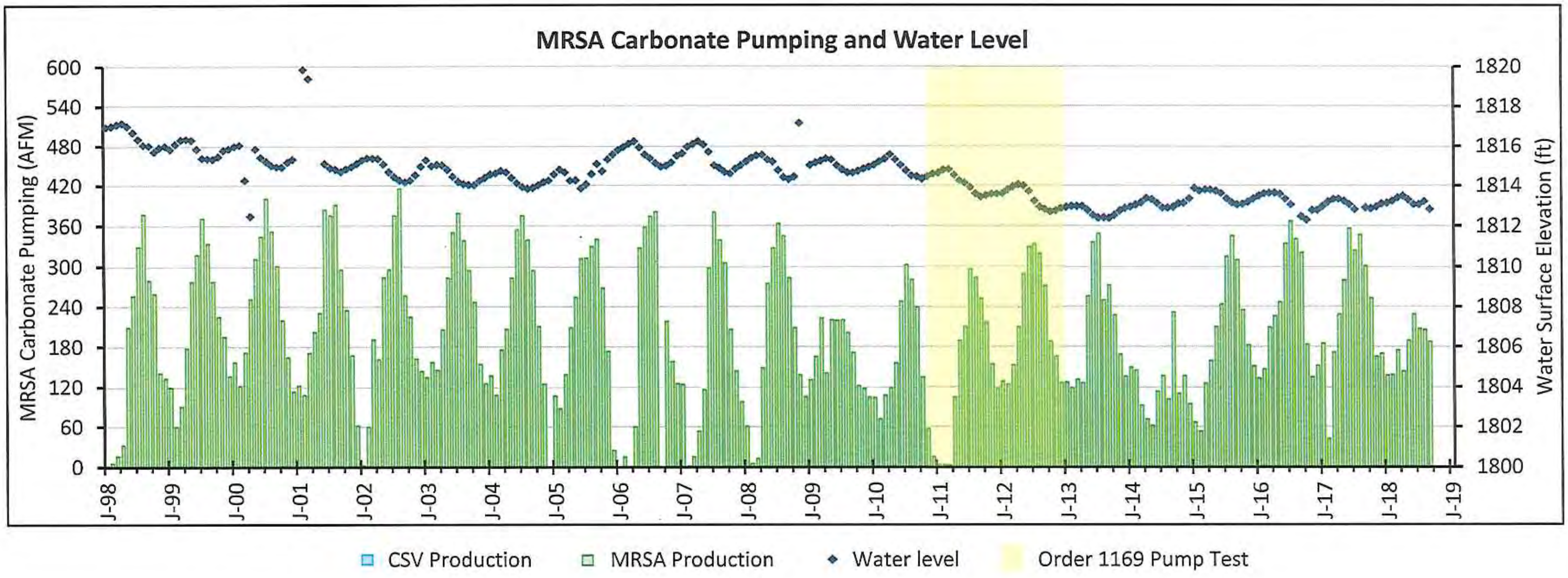
Basin 219 - Muddy River Springs Area

EH-5B


CSV Carbonate Pumping and Water Level

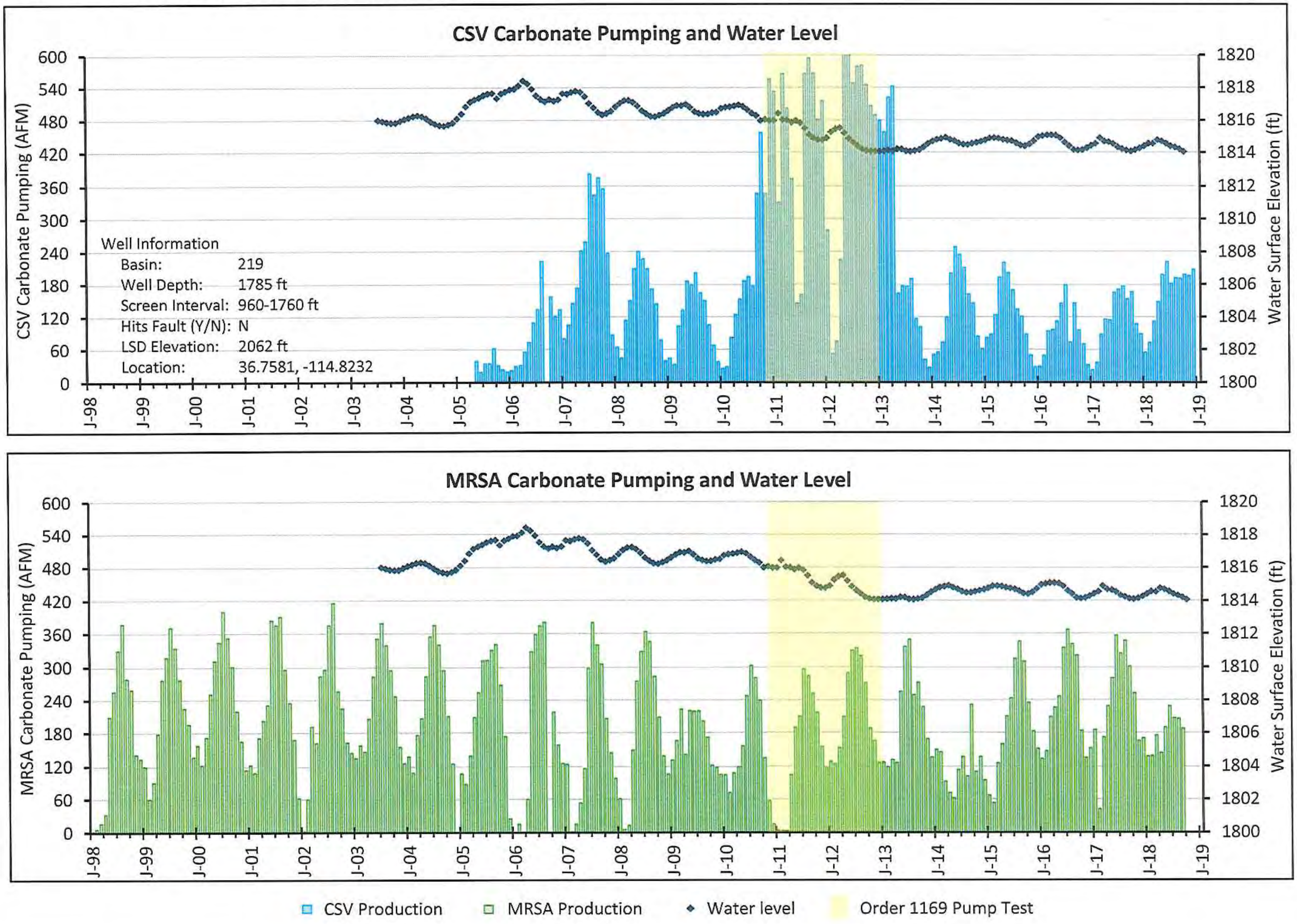
Well Information

Basin:	219
Well Depth:	Unknown
Screen Interval:	Unknown
Hits Fault (Y/N):	Unknown
LSD Elevation:	1845 ft
Location:	36.7329, -114.7426


MRSA Carbonate Pumping and Water Level

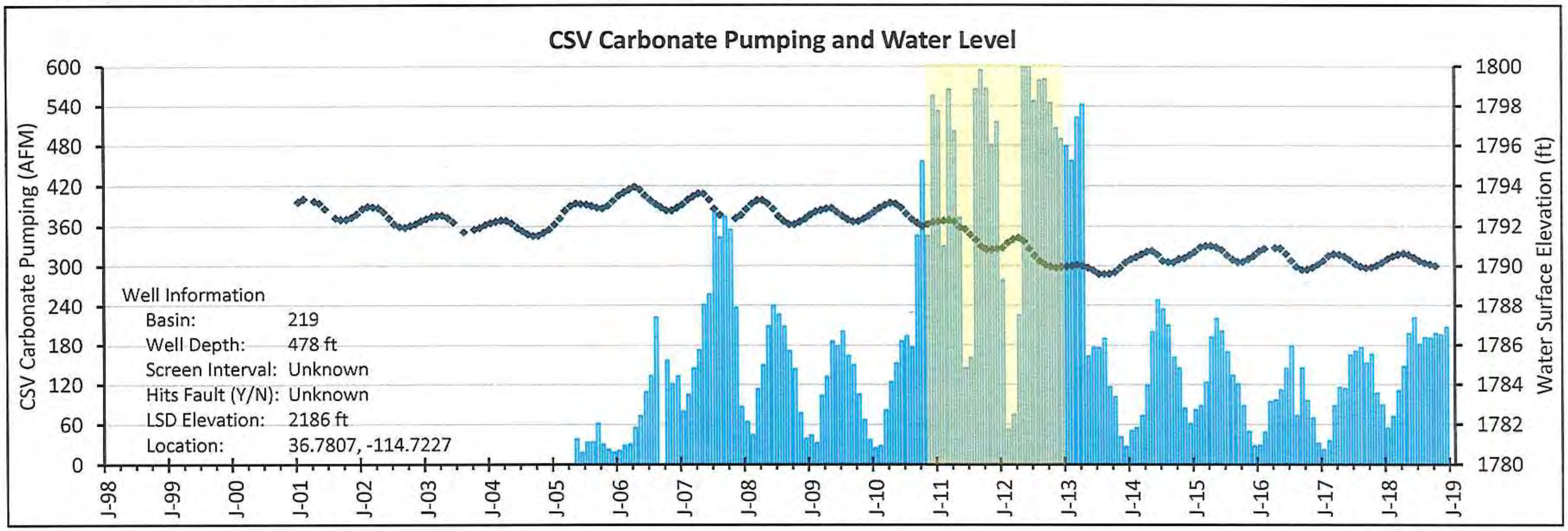
Basin 219 - Muddy River Springs Area

UMVM-1



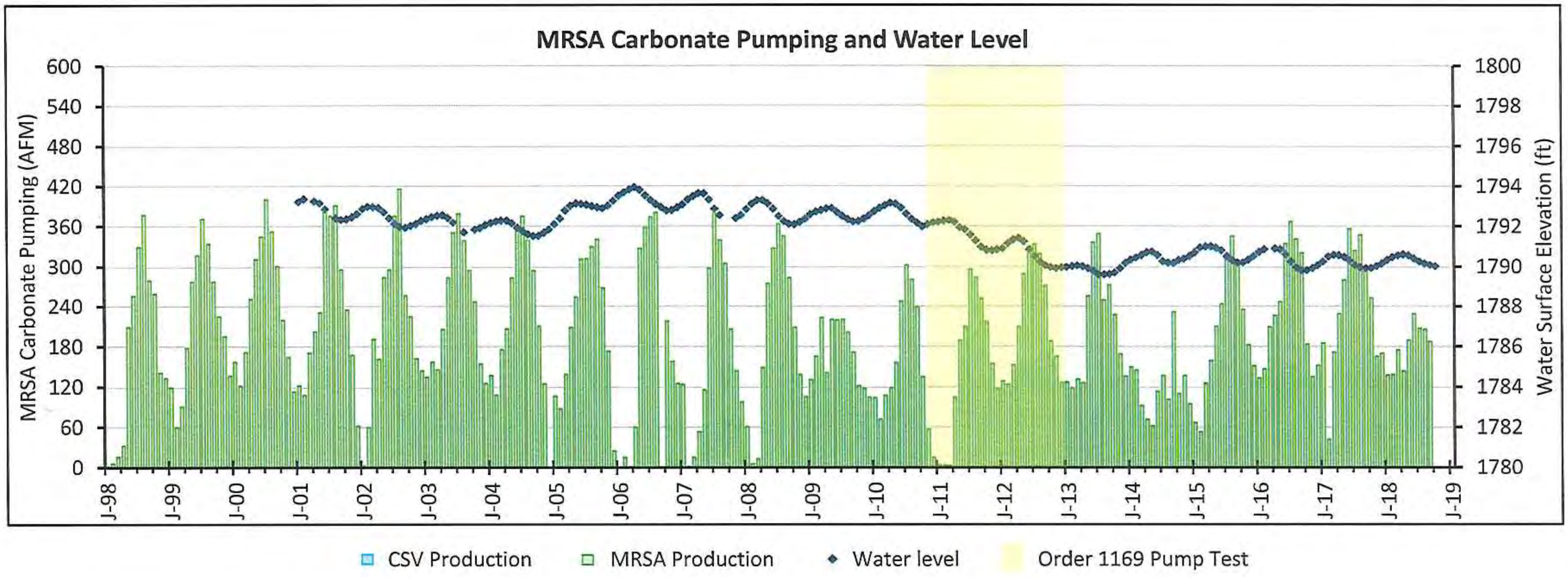
Basin 219 - Muddy River Springs Area

CSV-2



CSV Carbonate Pumping and Water Level

Well Information
Basin: 219
Well Depth: 478 ft
Screen Interval: Unknown
Hits Fault (Y/N): Unknown
LSD Elevation: 2186 ft
Location: 36.7807, -114.7227

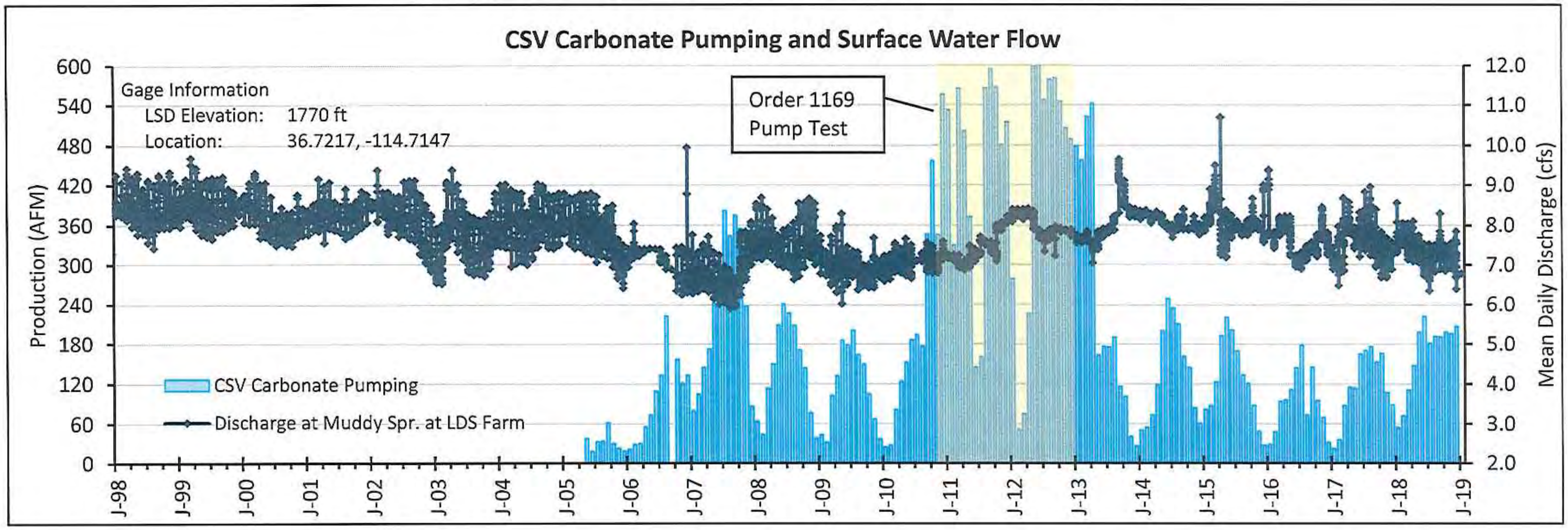


MRSA Carbonate Pumping and Water Level

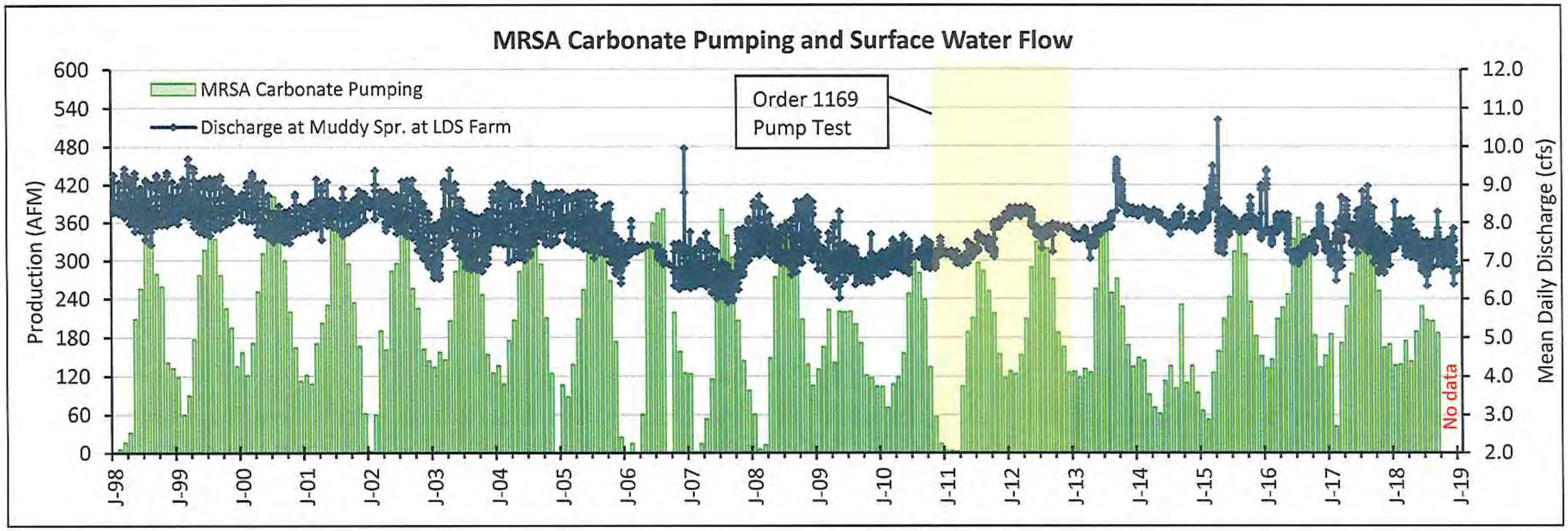
Surface Water Monitoring in Muddy River Springs Area

				Location	
No.	Surface Water Site	USGS Station No.	LSD Elevation	Lat	Long
1	Muddy River Springs at LDS Farm	09415900	1770 ft	36.7217	-114.7147
2	Warm Springs West	09415920	1771 ft	36.7112	-114.7137
3	Pederson Spring	09415910	1811 ft	36.7096	-114.7160
4	Pederson Spring East	09415908	1808 ft	36.7094	-114.7157
5	Muddy River Near Moapa	09416000	1710 ft	36.7111	-114.6944
6	Muddy River Near Glendale	09419000	1460 ft	36.6431	-114.5389

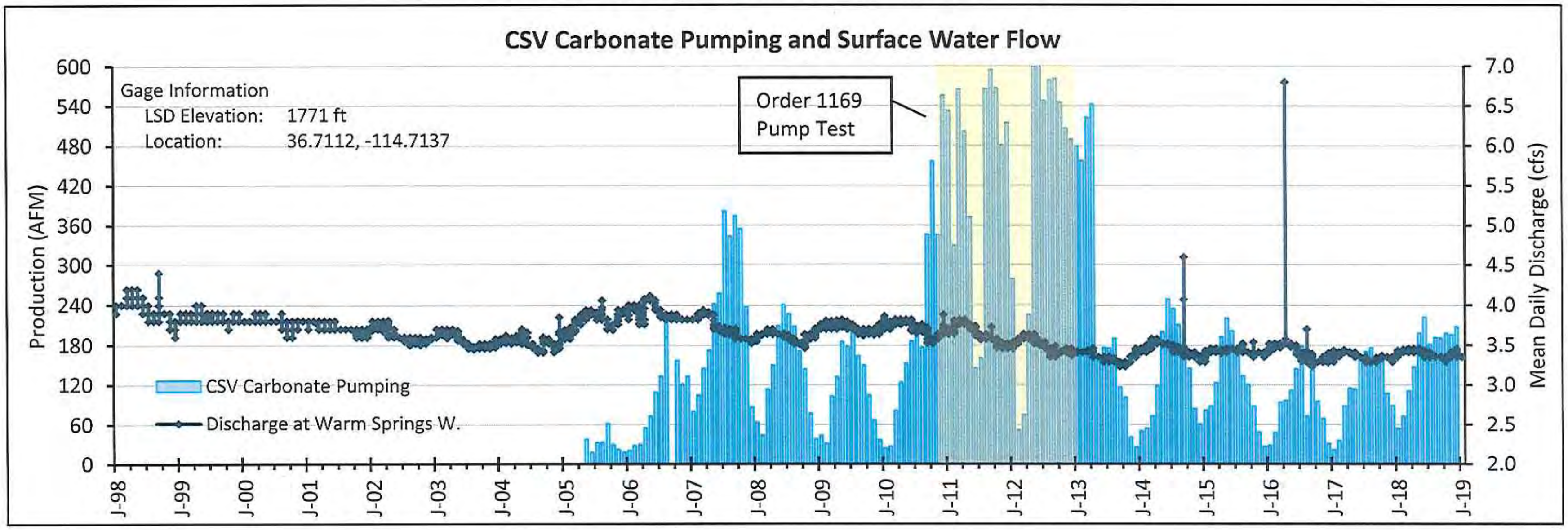
Muddy River Springs at LDS Farm (USGS 09415900)


CSV Carbonate Pumping and Surface Water Flow

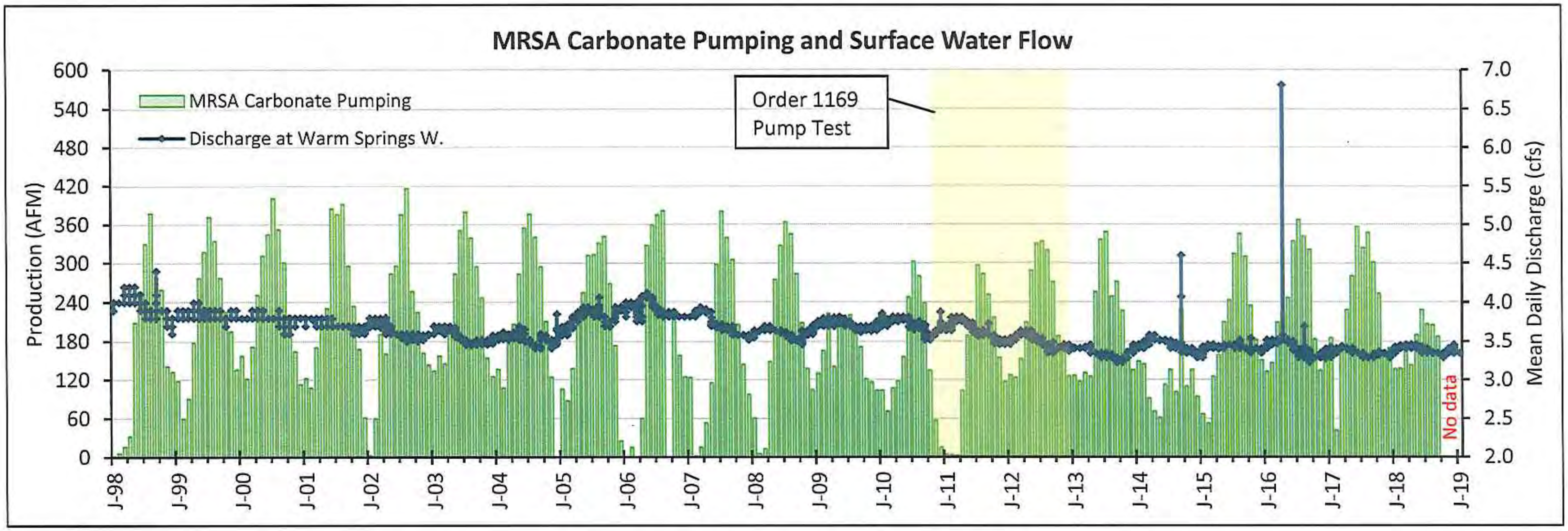
Gage Information
LSD Elevation: 1770 ft
Location: 36.7217, -114.7147


MRSA Carbonate Pumping and Surface Water Flow

Warm Springs West (USGS 09415920)

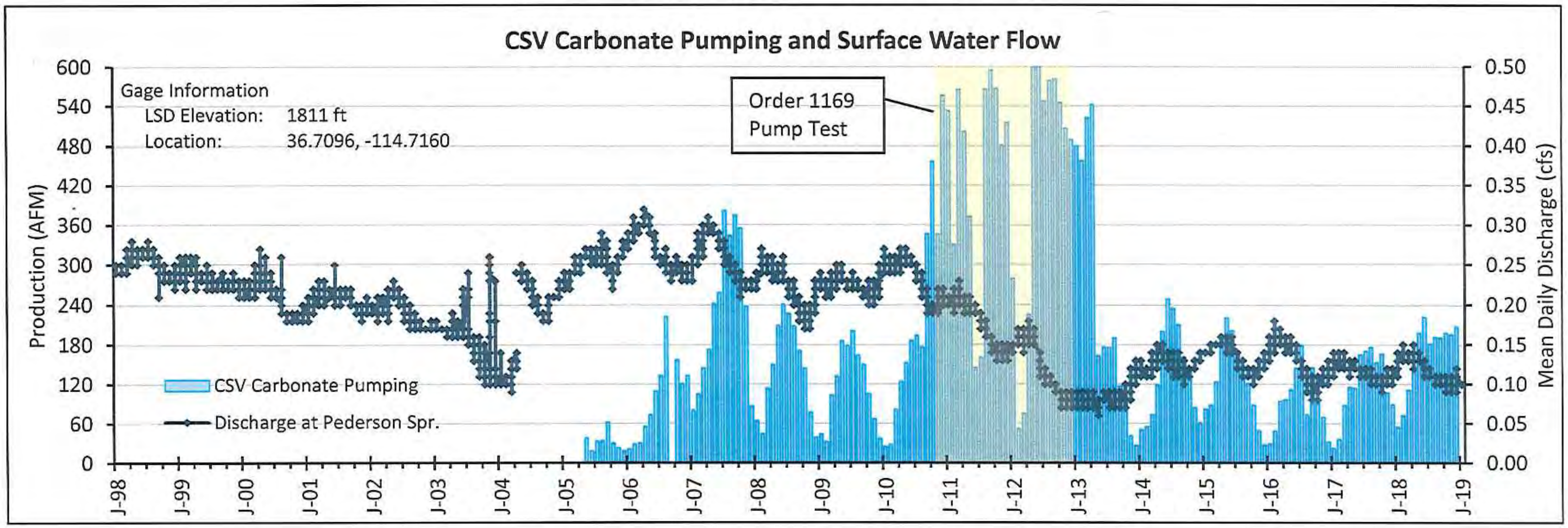


CSV Carbonate Pumping and Surface Water Flow

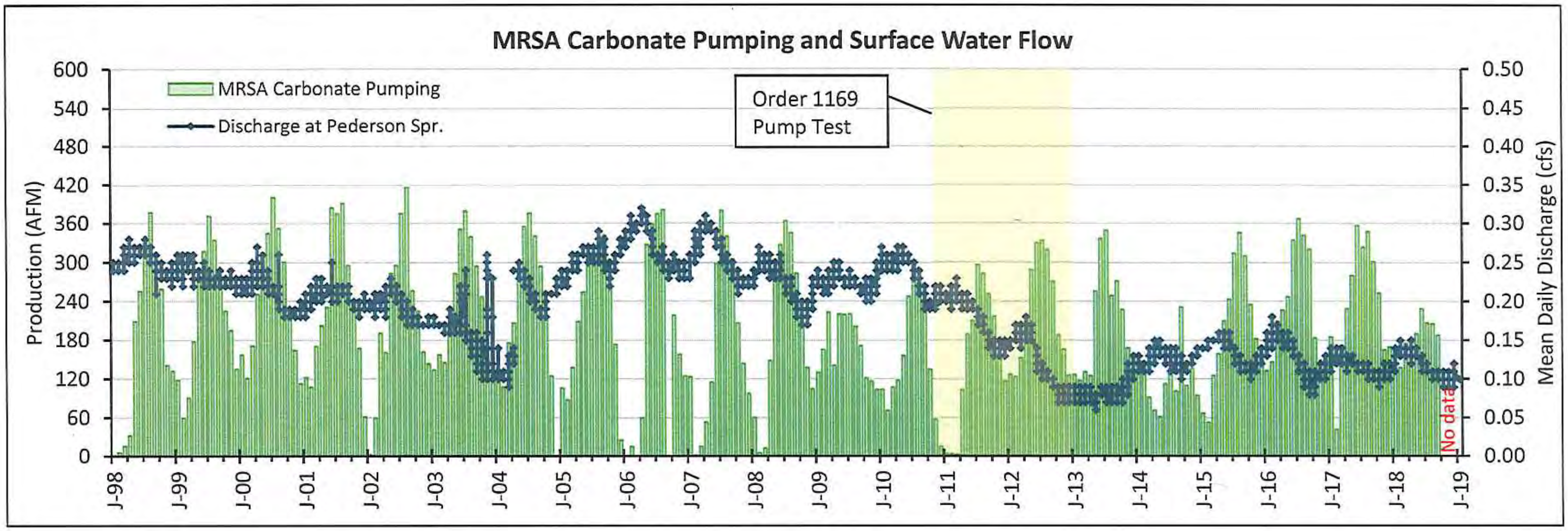


MRSA Carbonate Pumping and Surface Water Flow

Pederson Spring (USGS 09415910)

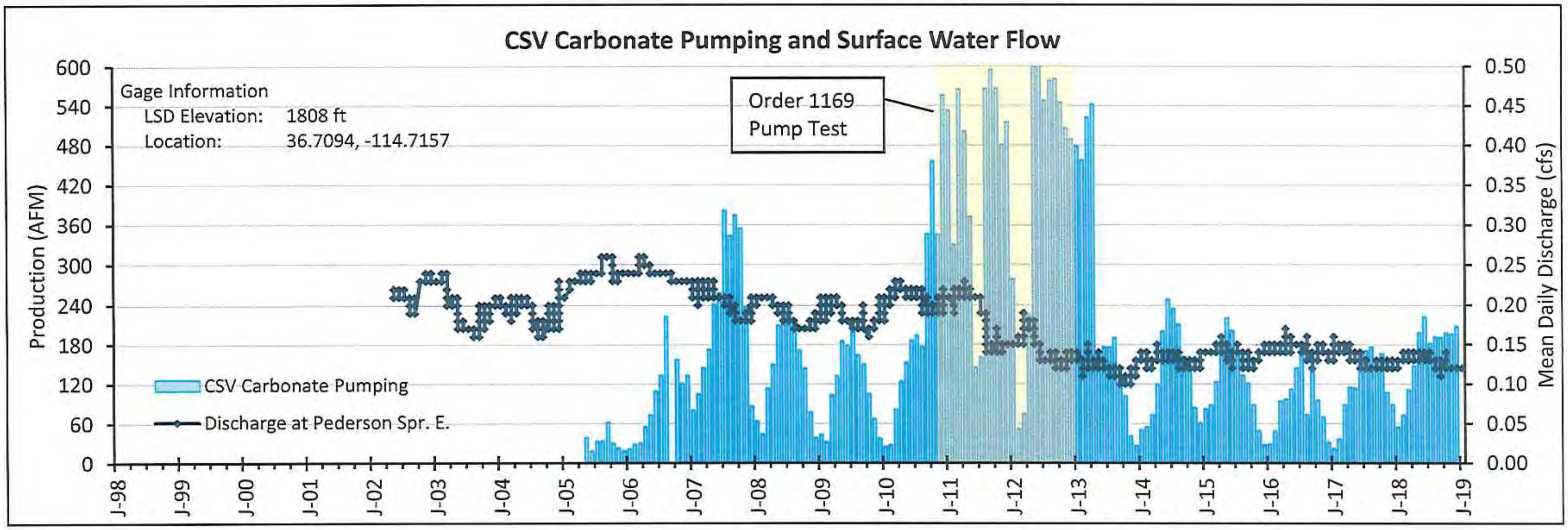


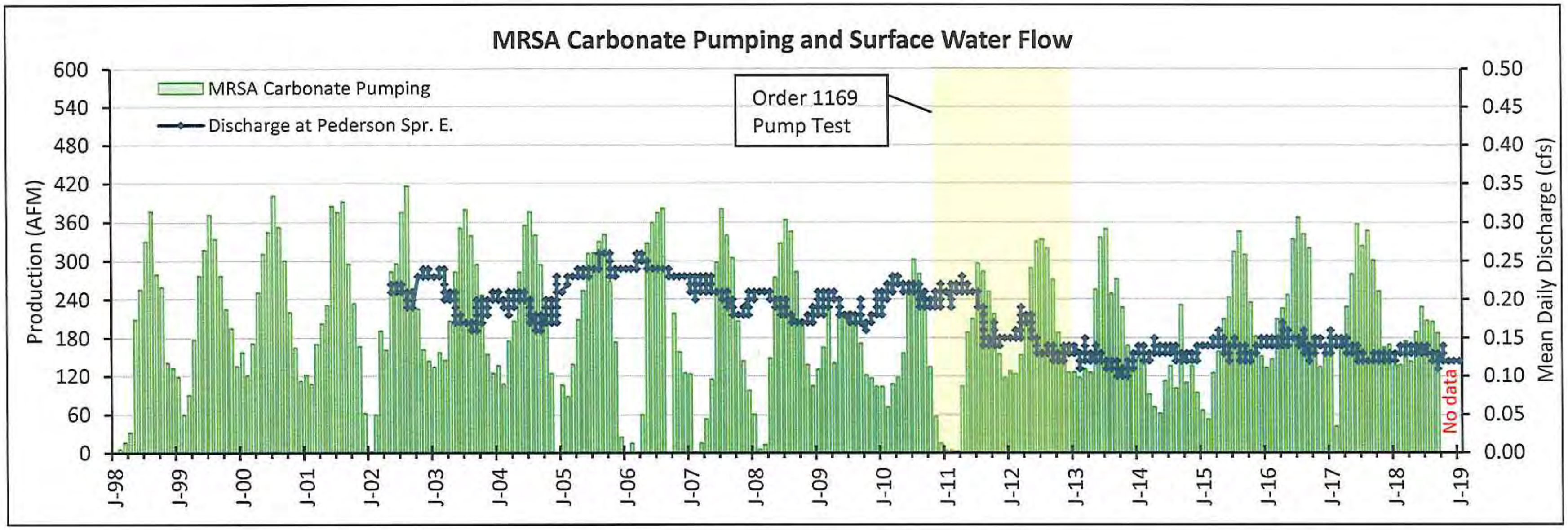
CSV Carbonate Pumping and Surface Water Flow



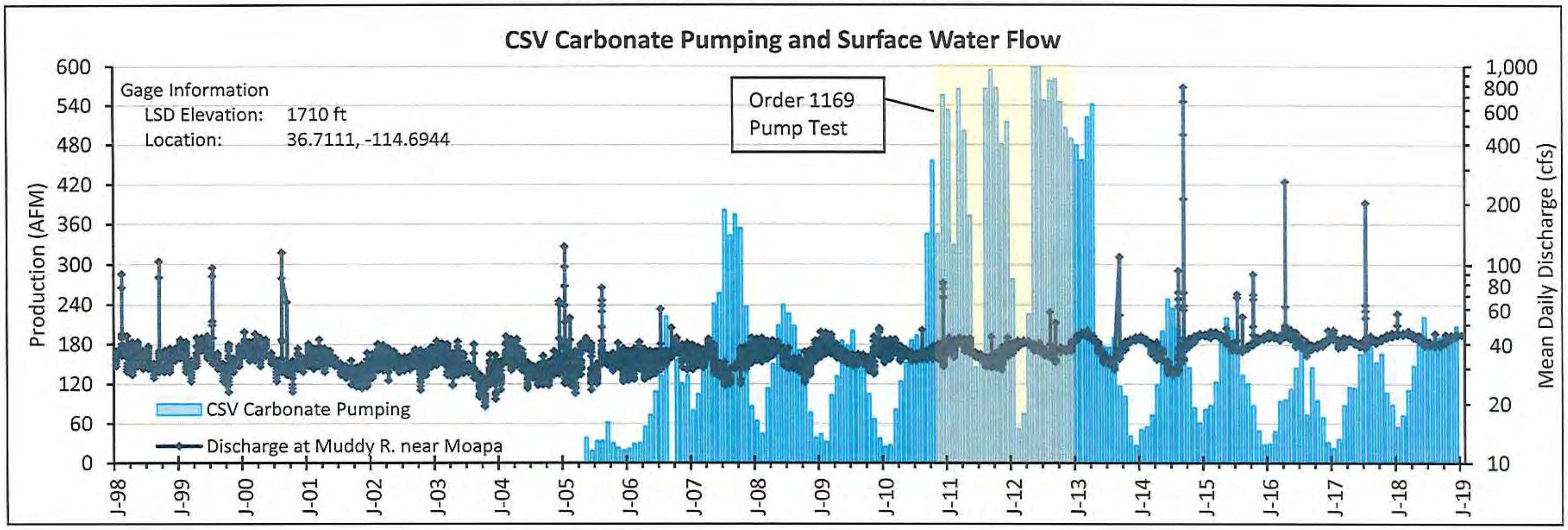
MRSA Carbonate Pumping and Surface Water Flow

Pederson Spring East (USGS 09415908)

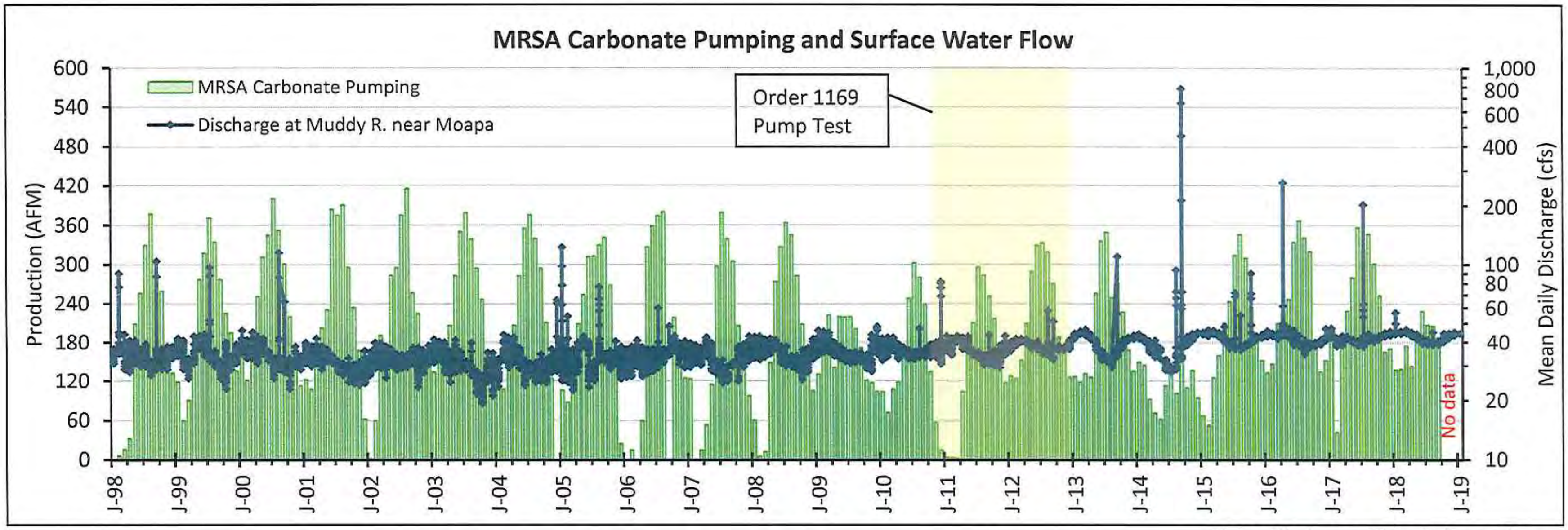




Muddy River near Moapa (USGS 09416000)



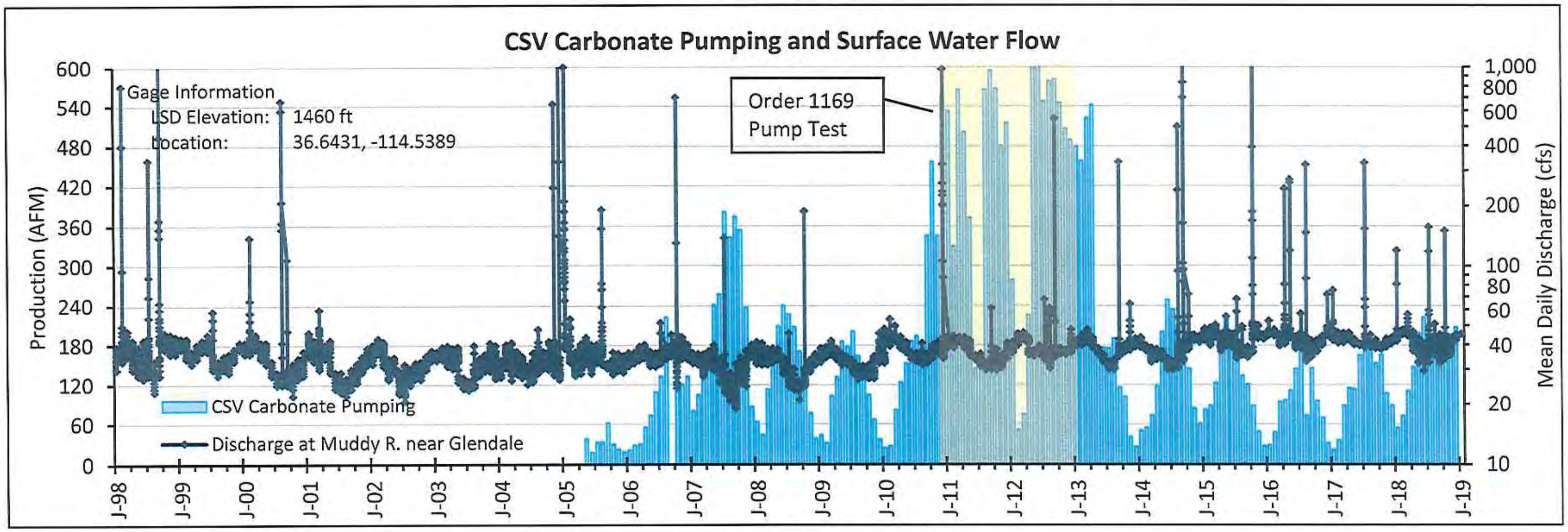
CSV Carbonate Pumping and Surface Water Flow



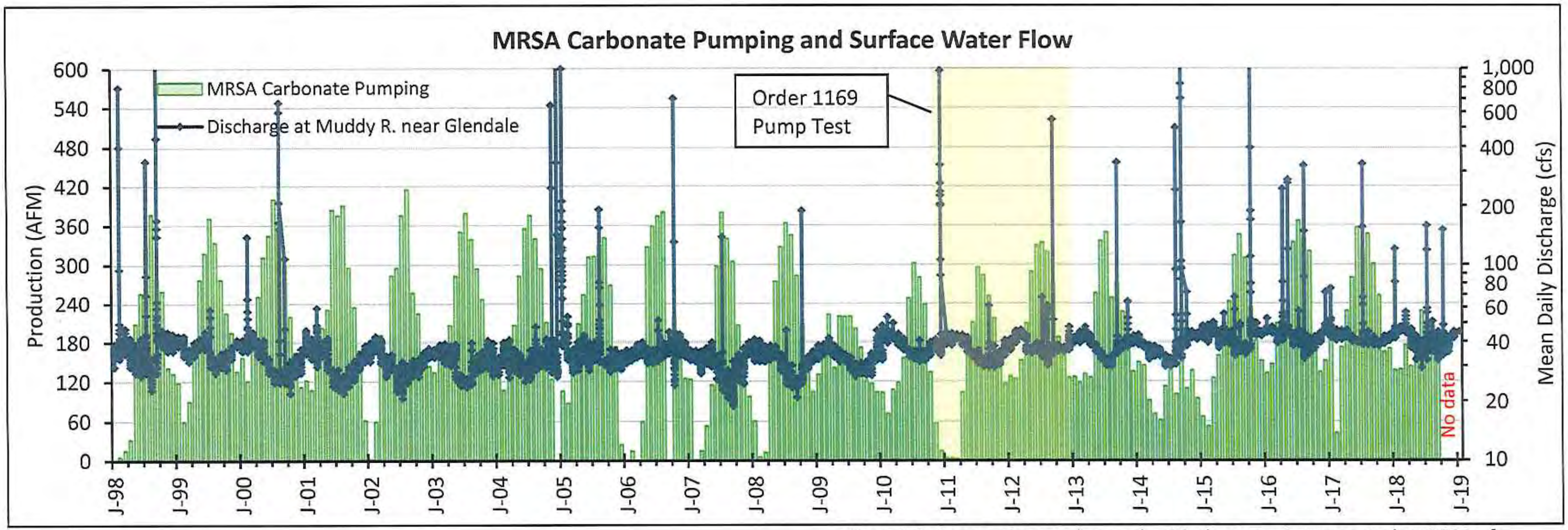
MRSA Carbonate Pumping and Surface Water Flow

Note: Discharge given in log scale.

Muddy River near Glendale (USGS 09419000)



CSV Carbonate Pumping and Surface Water Flow



MRSA Carbonate Pumping and Surface Water Flow

Note: Discharge given in log scale. Discharge axis truncated at 1000 cfs.